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WATER CHEMISTRY AND ISOTOPE STUDIES IN AKSARAY GEOTHERMAL FIELDS (ACIGÖL-ZİGA-ŞAHİNKALESİ), CENTRAL ANATOLIA, TURKEY

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ABSTRACT.- The basement in the study area is comprised of gneisses of Paleozoic Tamadağ formation, marbles of Bozçaldağ formation and Upper Cretaceous Baranadağ granitoid intrusion into the above mentioned rocks. These units have unconformable relations with Lower Eocene Çayraz formation and sedimentary rocks of Upper Eocene - Lower Miocene Mezgit group. All these units are unconformably overlain by Middle Miocene-Quaternary tuffs, ignimbrites with sedimentary intercalations and rocks of Cappadocia Volcanic belt represented by tuffites with sedimentary interbeddings, basaltic lavas, volcanic ashes, pumice, dacitic-rhyodacitic lava domes. The study area contains Ziga and Acıgöl (Narköy) thermal fields which have a temperature of 44-65 °C from wells and hot springs. Hydrothermal alterations surrounding the geothermal area; young volcanic and tectonic activity, and the hot springs are the surface manifestation of the geothermal possibilities in the area. Reservoir rocks of the geothermal system are Paleozoic gneiss, schist and marbles. Cap rocks of the system in the study area are hydrothermally altered tuffs and ignimbrites. According to the classification of IAH (International Association of Hydrogeologists) standards while; all of the cold waters are Ca-Mg-HCO_3 and $CaHCO_3$ type in the region, the hot waters of the Acigöl field are classified as Ca-Na-HCO_3-Cl type and mineralized hot waters, the hot waters in Ziga field are classified as Na-Cl-HCO_3 type and B bearing mineralized hot waters, the hot water of Şahinkalesi field (from well) is classified as non-mineralized thermal water. Deuterium results suggest 1500-1600 m recharging elevation for hot springs and water chemistry and isotope studies imply that recharging area may extend up to the foothills of the Hasandağ. Tritium analyses have revealed that the hot water was recharged from precipitation before nuclear tests experienced before 1952 (i.e. older than 60 years). According to SiO_2 - enthalpy mixing model, 155 °C reservoir temperature and 65% cold water mix were calculated for Acıgöl field. On the basis of chalcedony geothermometer 114-160°C, 69-93 °C and 135°C and on the basis of quartz geothermometer 140-181 °C, 99-121 °C, and 159 °C reservoir temperatures were calculated for Acıgöl, Ziga and Şahinkalesi geothermal fields, respectively.

Keywords: Aksaray geothermal fields, hydrochemistry, geothermometer, mixing model, isotope.

INTRODUCTION

The study area is located in Cappadocia volcanic belt in Central Anatolian region, east of Aksaray (Figure 1) and includes the Acıgöl-Ziga-Şahinkalesi geothermal fields. Its close proximity to Melendiz and Hasandağ stratovolcanoes, high heat flow, and surficial indicators such as widespread hydrothermal alteration zones surrounding the geothermal fields and presence of hot water (44 – 65 °C) imply that the region might have a significant geothermal potential.

Central Anatolia in which the study area is located in the central part of the Anatolian block is delimited by the North Anatolian Fault (NAF) and the East Anatolian Fault (EAF). The Anatolian block fell under N-S compressional effect after the continent-to-continent collision of the Arabian and Anatolian plates towards the end of Late Miocene and consequently two major faults (NAF and EAF) were formed (Figure 1). The Anatolian block, bounded by these two major faults began moving westward (McKenzie, 1972; McKenzie and Yılmaz, 1991; Aydar et al., 1994).

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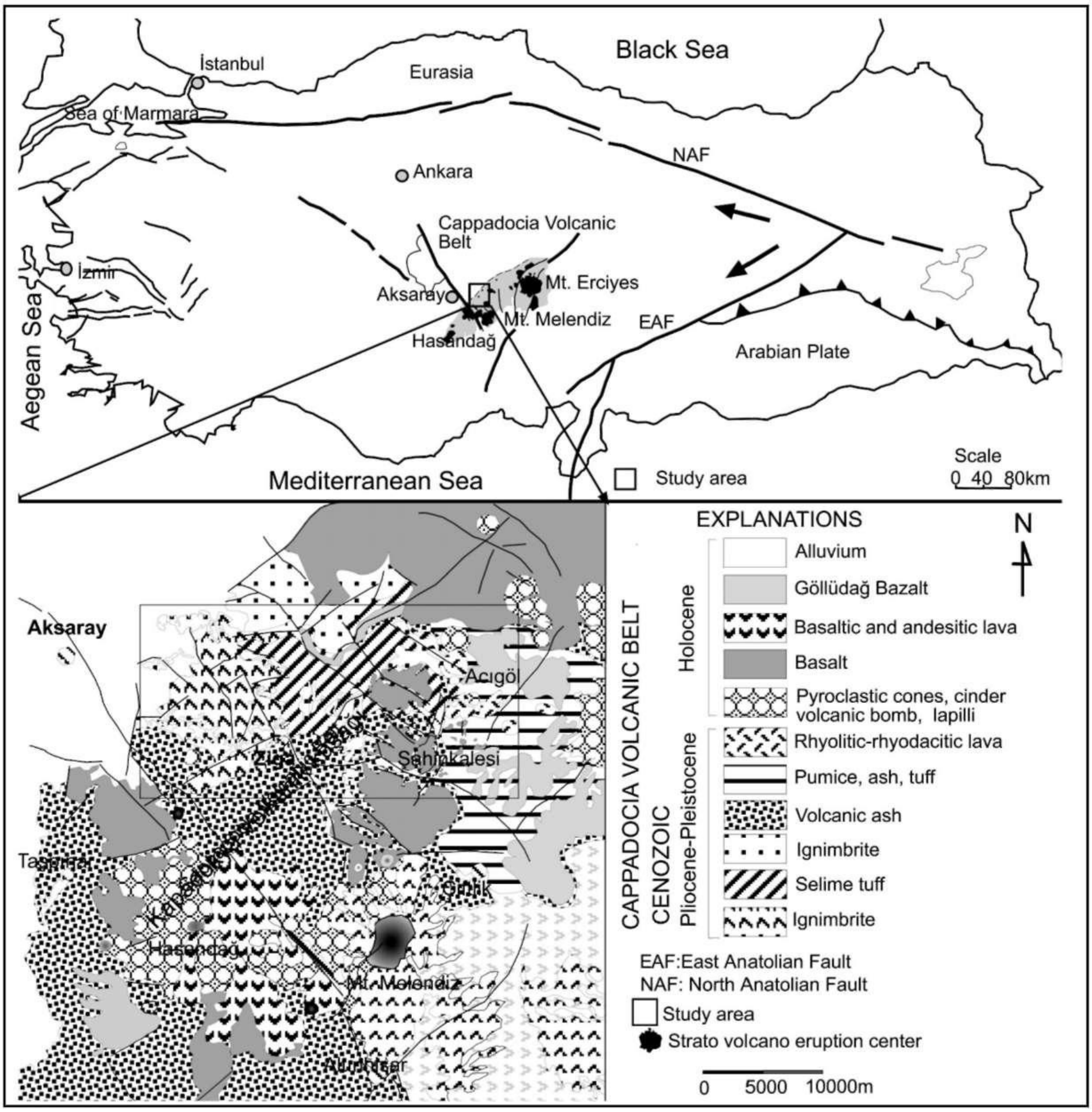

Figure 1- Location map of the study area and tectonic features of the Central Anatolia (after Mc Kenzie,1972, Barka 1992 and Toprak,1998 (upper map); Burçak, 2006 (lower map).

directly related with this movement. This belt which is known as Cappadocian Volcanic Belt includes polygenic ignimbrite vents, two Miocene-Pliocene stratovolcano (Karacadağ and Melendiz) and monogenic vents (basaltic maar, cinder cones, lava domes) and two Quaternary volcanoes (Hasandağ and Erciyes) of stratovolcanoe type (Figure 1). The volcanism which was effective between Late Miocene–Quaternary has been studied by many researchers for its petrographical features, chronological development, ignimbrite emplacement and geochemical characteristics (Lahn, 1945; Beekman, 1966; Pasquare, 1966, 1968; Sür, 1972; Keller, 1974;

petrographical features, chronological development, ignimbrite emplacement and geochemical characteristics (Lahn, 1945; Beekman, 1966; Pasquare, 1966, 1968; Sür, 1972; Keller, 1974; Innocenti et al.,1975; Batum, 1978*a*, *b*; Seymen 1981; Pasquare et al., 1988; Schumacher et al., 1990; Ercan et al., 1990, 1992; Bigazzi et al., 1993; Aydar et al., 1994,1998; Le Pennec et al., 1994; Druit et al., 1995; Dhont et al., 1998; Temel et al., 1998; Toprak, 1998, 2000). Geothermal oriented mapping studies, water chemistry studies (Öktü and Kalkan, 1984, Göçmez, 1994, Burçak et al., 2007), gravity studies in Ziga and Acıgöl fields (Akdoğan, 1989), magnetic studies (Kaynak, 1989) and artificial source magnetotelluric (CSAMT) studies (Kaya and Tokgöz, 1991) were conducted in the study area.

This study aims to define the characteristics of the cold and hot waters in the study area, application of geothermometer to determine the reservoir temperature, to determine the mixture of cold and hot waters, to investigate the height of feeding for hot waters and feeding age. Geological mapping, chemical analyses of cold and hot waters and isotope studies are included in this study.

GEOLOGY

The geological basement in the region is comprised of a Paleozoic sequence and intrusive rocks emplaced in these sequence during the Cretaceous. The lower part of the sequence comprises Tamadağ gneiss and schists whereas the upper part is comprised of Bozçaldağ marbles. The Cretaceous Baranadağ granitoid – gabbroid intrusion has cut and emplaced in the Paleozoic sequence (Seymen, 1981). These rocks which form the basement are defined as "Central Anatolian Crystalline Complex" by Göncüoğlu (1992) and Göncüoğlu et al. (1992). The basement units are unconformably overlain by Çayraz formation which is comprised of Lower Eocene marine limestone and marls, and rocks of Mezgit group which are Upper Eocene – Lower Miocene terrestrial sedimentary rocks with evaporitic intercalations (Ayhan and Papak, 1988). These units are unconformably overlain by the Upper Miocene-Quaternary volcanics of the Cappadocia volcanic belt and by the sedimentary units intercalating these volcanics (Beekman, 1966).

The basement units are represented by the Cretaceous Baranadağ granitoid in the north and northwest of the study area and by Bozçaldağ marbles with coarse calcite crystals around Keltepe in the east. In a narrow area in the east of the Keltepe, they are represented by highly altered gneiss and schists which crop out beneath the marbles (Figures. 2, 3).

The Çayraz formation which unconformably overlies the basement is represented in the study area by beige colored Nummulites bearing limestones which crop out in a narrow area beneath the Miocene volcanics in west of the Göstük village. The lower contact of the unit can not be observed in the study area. The rocks of Upper Eocene-Lower Miocene Mezgit group which are comprised of blocky conglomerate, sandstone, siltstone and claystone with distinctive evaporite (gypsum and salt) take place in the upper levels. Blocks and pebbles of overlain granitoids, Nummulites bearing limestone and Paleozoic basement are observed in the unit. The unit which crops out in the eastern section of the study area unconformably overlies the granites located in the basement. All these units are unconformably overlain by the Upper Miocene-Quaternary volcanic rocks represented by tuffs, ignimbrites, basalt lavas, volcanic ashes, pumice and dacitic-rhyodacitic lava domes. These units, from bottom to top, are comprised of Göstük tuffite formed by red, earth colored tuff, pebbly tuff and sandstone, and pebblestone lenses; purplish gray, lilac colored Göstük ignimbrite; Karakaya formation which begins with red colored pebblestone and sandstone and end up with claystone, marl and beige colored limestone; weakly consolidated Selime tuff, Gelveri lava which is comprised of dark gray colored, altered andesite; Gelveri ignimbrite with coarse blocks

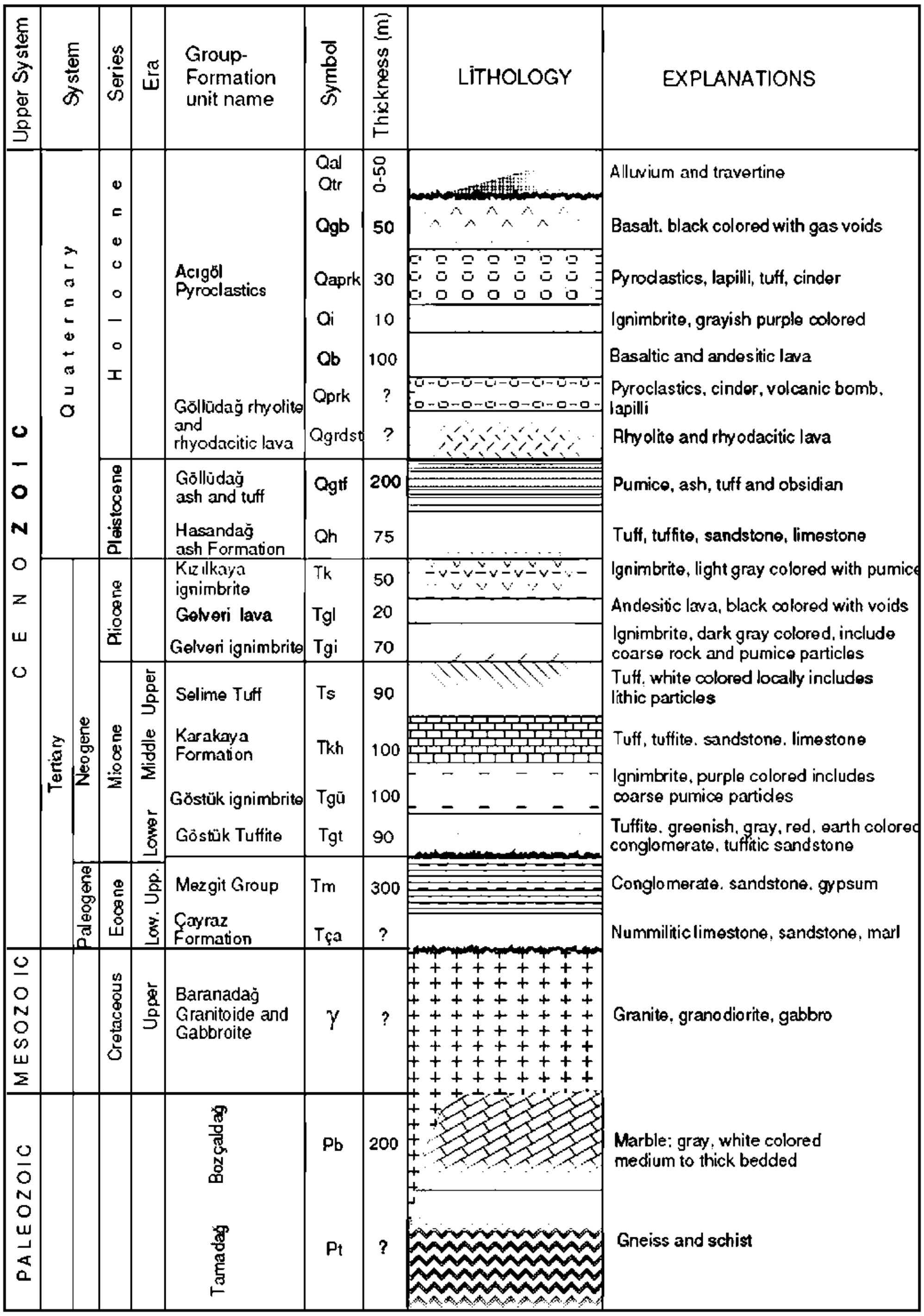

Figure 2- Stratigraphic columnar section of the study area (Beekman, 1966, Ayhan and Papak, 1988, Burçak et al., 2007).

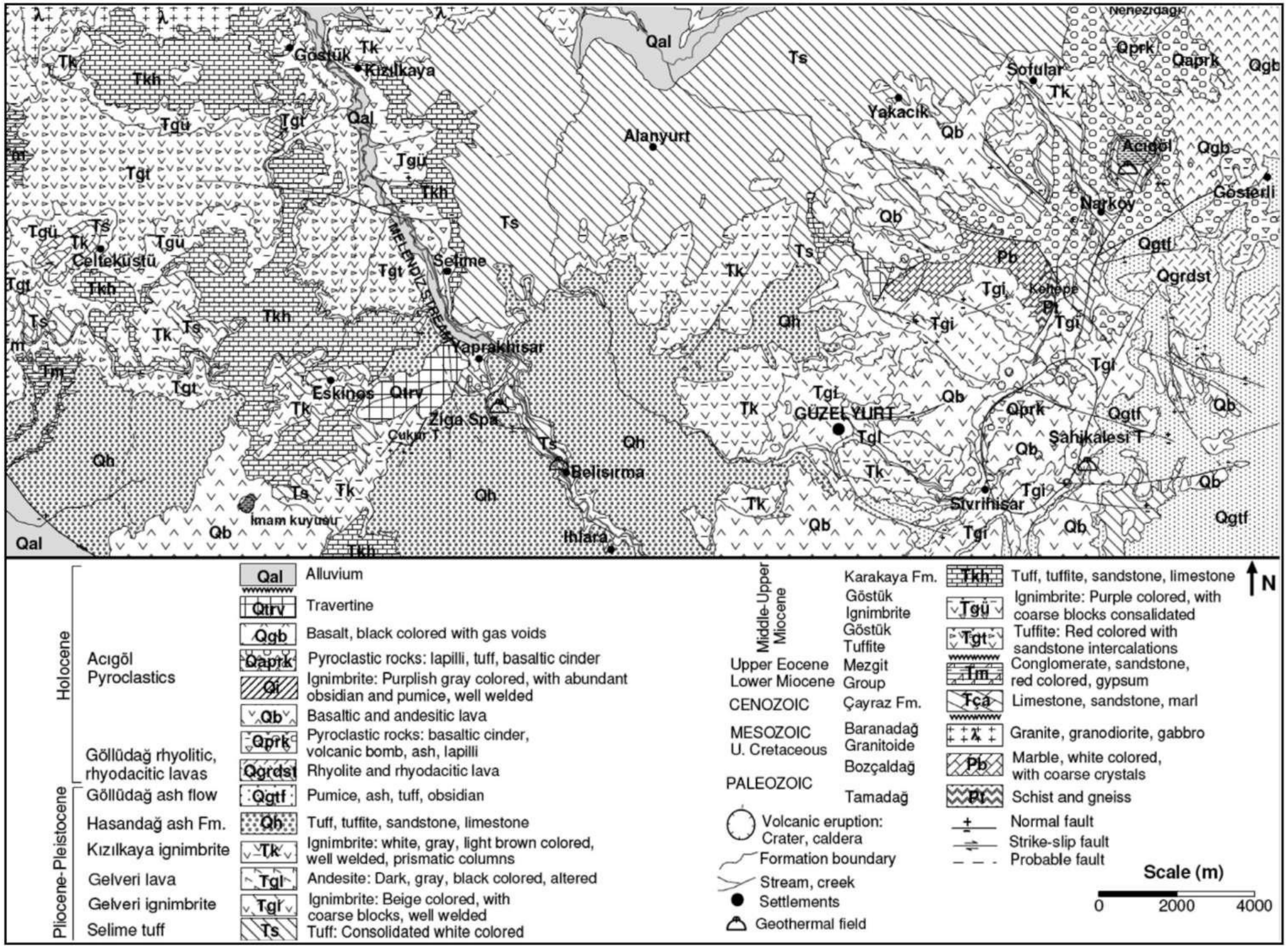

Figure 3- Geological map of the study area (Burçak et al., 2007).

of volcanic rocks, gray colored Kızılkaya ignimbrite; Hasandağı volcanic ash formation; Göllüdağ pyroclastics; dacitic-rhyodacitic lavas; basaltic and andesitic lavas; Acıgöl ignimbrites and pyroclastics; basaltic lavas; traverten and alluvial deposits (Figures 2, 3).

HYDROGEOLOGIC FRAMEWORK AND GEOTHERMAL STUDIES

The main reservoir in the study area for geothermal sources are comprised of the fractured zones of the Paleozoic Tamadağ formation which is includes schist and gneiss. The shallow reservoir is formed by the sandstone, limestone levels and terrestrial deposits of the Çayraz formation and the evaporitic (gypsum and salt) levels included in these rocks. The cover rock of the geothermal system is comprised of hydrothermally altered tuffs and ignimbrites (Burçak et al., 2004, 2005, 2007; Burçak, 2006).

Four gradient drilling wells were opened in the study area. In the ZBG-1 (209 m) and ZBG-2 wells in Ziga area the gradient increase is measured as 0.62 °C/10 m and 0.53 °C/10 m, respectively, which are close twice as the normal geothermal gradient (Ölmez and Gevrek, 1991). In SFG-1 (123 m) and SFG-2 (244.8 m) wells in Acıgöl area the gradient increase values were measured as 3 °C/10 m and 0.5 °C/10 m, respectively (Ölmez and Gevrek, 1991). Particularly, the gradient increase in SFG-1 well (123 m) is approximately tenfold of a normal gradient increase which implies a significant heat source in depth. In SHK-1 well (1697 m) opened in Şahinkale field, the average gradient increase and the well base temperature were measured as 0,75 °C/10 m and 130 °C, respectively (Kara, 2007).

Gravity and magnetic studies conducted in Ziga Acıgöl fields were re-interpreted and consequently it was stated that the high gravity and the low magnetic anomalies were interpreted to imply magmatic intrusions which could have been the heat sources for the geothermal systems (Akdoğan et al., 2002). Conceptual models were put forward for Aksaray geothermal fields by magnetotelluric, hydrothermal alteration, water chemistry and resistivity studies. The geothermal heat source was studied by magnetotelluric methods and it was pointed out that the high resistivity masses intruded in crust, and also the masses with low resistivity of which depth varies between 5-8 km, were interpreted to be magmatic intrusions which have been melted / partially melted or solidified but not yet lost their heat (Burçak et al., 2004, 2005, 2007; Burçak, 2006).

WATER CHEMISTRY STUDIES

Water chemistry studies include 34 water samples collected from natural springs and wells (Figure 4, Table 1). The samples were collected between 01-15 September 2004.

Chemical analyses of the water samples were made in Water Analysis Laboratory of the Department of Mineral Analyses and Technology of the MTA. Cation analyses, ICP-MS (Inductively Coupled Plasma–Mass Spectrometer), carbonate and bicarbonate analyses, volumetry and anion analyses were made by using the ion chromatography method. Results of the chemical analyses were shown in table 1.

Analyses of the samples AZ–1, 2, 3, 4, 5, MTA–1 and MTA–2 were made also in Water Laboratories of the MTA. The analyses values were taken from Ölmez and Gevrek (1991).

CHEMICAL CLASSIFICATION OF WATERS

The cold water samples collected in the study area are in Ca-Mg-HCO_3 and $CaHCO_3$ type according to IAH (1978) classification. On the other hand, the hot water samples from Acıgöl and Ziga are mineral thermal waters of Na-Ca-HCO_3-Cl type and B-bearing Na-Cl-HCO_3 type, respectively. The hot water samples from Şahinkale are of Ca-Na-HCO_3.

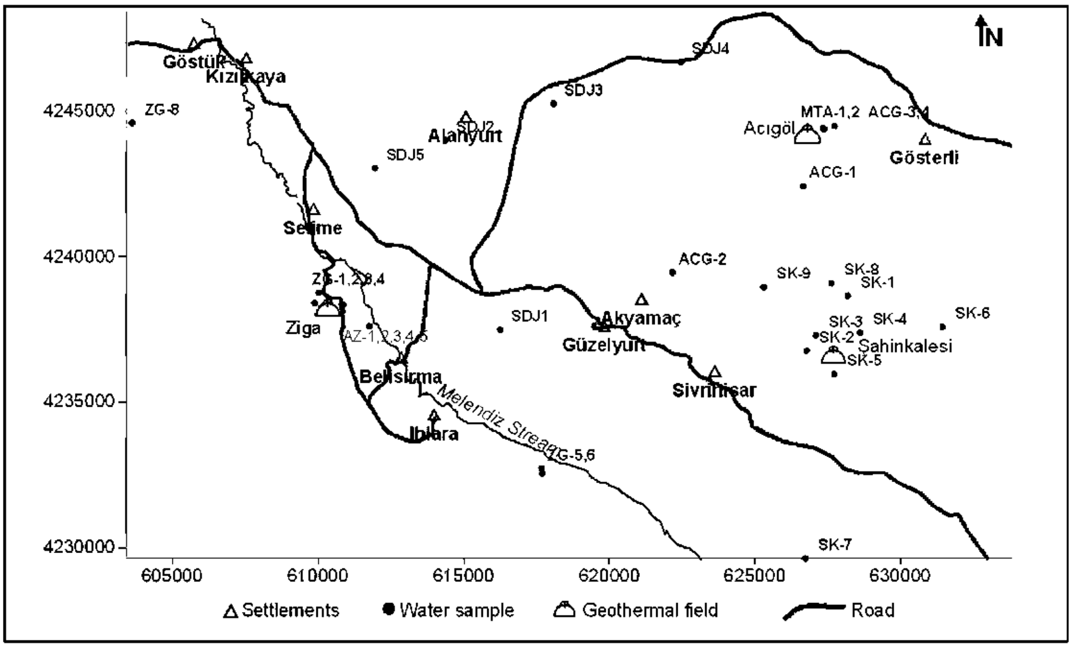

Figure 4- Location map of the water samples.

According to Piper diagram (Figure 5) all of the cold waters in the area and the Şahinkalesi hot waters fall into 1st region cationwise (Ca+Mg>K+Na) and fall into 3rd region anionwise (HCO_3+CO_3> $Cl+SO_4$). For this reason, these are Ca-Mg-HCO_3 type waters and their carbonate hardness is more than 50% (5th region).

Except for the sample collected from the MTA-2, the waters from the Acıgöl area take place in 1st region cationwise (Ca+Mg>N+K), and in 3rd region anionwise (HCO_3+CO_3>$Cl+SO_4$). The MTA-2 sample is located in 4th region since $Cl+SO_4$ is more than HCO_3+CO_3 and in the sample alkali earth elements (Ca+Mg) and alkali elements (Na+K) are equal to each other; therefore this water sample falls into mixed water group (9th region).

The water samples collected from the Ziga area are classified into two groups. The waters in the first group fall into 2nd group cationwise (Na+K>Ca+Mg) and in 4th group cationwise ($Cl+SO_4$ >CO_3+HCO_3). These samples are of type Na-Cl which fall into 7th region and their non-carbonate alkali values are higher than carbonate alkali values. The second group waters in Ziga area (Ilıca hot waters, the samples ZG-5 and 6), fall into 1st region when classified according to their cations (Ca+Mg>K+Na), and into 3rd region according to their anions (HCO_3+CO_3> $Cl+SO_4$). Therefore, these are Ca-HCO_3 type waters of which carbonate hardness is more than 50% (5th region).

According to semi-logarithmic Schoeller diagram (Figure 6), the cold water samples ACG-2, SK-1, SK-8 and SK-9 have the same origin (similar aquifers) based on their parallel cation and anion contents. It can be said that the cold water samples ZG-7 and ZG-8 have different origins due to their higher "Na+K" contents. When the hot waters were investigated, it was seen that the Acıgöl hot waters (MTA-1, MTA-2 and ACG-4) have the same origin. Some water samples with temperatures higher than 20 °C such as the SDJ-6 collected from the Acıgöl area and SK-2 and SDJ-1 from Şahinkalesi area differ from the cold waters based on their Na+K and Cl- enrichment. These waters have characteristics that fall between the cold waters and Acıgöl hot waters.

Table 1– Results of the chemical analysis of the hot and cold water samples collected in the study area

Sample No	Temp. °C	pH	Ca^{+2} (mg/l)	r(Ca) mek/l	Mg^{+2} (mg/l)	r(Mg) mek/l	Na^{+} (mg/l)	r(Na) mek/l	K^{+} (mg/l)	r(K) mek/l	Cl^{-} (mg/l)	r(Cl) mek/l	SO_4^{-2} (mg/l)	$r(SO_4)$ mek/l	HCO_3^{-} (mg/l)	$r(HCO_3)$ mek/l	Ionic balance (%)	B (mg/l)	SiO_2 (mg/l)	TDS (mg/l)
ACG-1	19.6	8.0	30.7	1.5	5.1	0.4	12.2	0.5	5.1	0.1	5.0	0.1	3.4	0.1	162.0	2.7	-4.7	0.7	54.0	278.2
ACG-2	13.8	7.7	45.7	2.3	1.9	0.2	11.9	0.5	1.4	0.0	2.5	0.1	61.0	1.3	93.0	1.5	2.2	0.5	69.0	286.8
ACG-3	43.3	6.7	327.0	16.3	13.9	1.1	175.0	7.6	60.5	1.6	247.0	6.9	80.2	1.7	1275.0	20.9	-5.2	14.0	106.0	2298.6
ACG-4	22.4	6.8	351.0	17.5	53.0	4.3	138.0	8.0	73.1	1.9	255.0	7.2	98.9	2.1	1681.0	27.6	-7.4	13.0	147.0	2810.0
MTA-1*	53.0	7.0	224.0	11.2	44.0	3.6	190.0	8.3	64.0	1.6	300.0	8.5	156.0	3.2	970.0	15.9	-5.6	8.3	202.0	2158.3
MTA-2*	65.0	7.0	92.0	4.6	49.0	4.0	195.0	8.5	66.0	1.7	299.0	8.4	160.0	3.3	537.0	8.8	-4.5	8.3	170.0	1576.3
AZ-1	39.0	6.5	276.0	13.8	46.0	3.8	1175.0	51.1	150.0	3.8	1889.0	53.2	72.0	1.5	1165.0	19.0	-0.8	32.6	47.0	4852.6
AZ-2	37.5	6.5	300.0	15.0	41.0	3.4	1225.0	53.3	156.0	4.0	1907.0	53.8	78.0	1.6	1208.0	19.8	0.3	33.4	47.0	4995.4
AZ-3	51.0	6.9	309.0	15.4	49.0	4.0	1160.0	50.5	158.0	4.0	1900.0	53.6	65.0	1.4	1244.0	20.4	-0.9	32.0	47.0	4964.0
AZ-4	46.0	6.0	300.0	15.0	36.0	3.0	1180.0	51.3	162.0	4.1	1880.0	53.0	71.0	1.5	1208.0	19.8	-0.6	32.6	75.0	4944.6
AZ-5	47.5	6.6	361.0	18.0	39.0	3.2	1212.0	52.7	168.0	4.3	1900.0	53.6	73.0	1.5	1506.0	24.7	-1.0	29.8	91.0	5379.8
ZG-1	50.0	7.1	270.0	13.5	75.6	6.2	946.0	41.1	124.0	3.2	1294.0	36.5	42.6	0.9	1722.0	28.2	-1.3	26.0	45.0	4545.2
ZG-2	44.6	6.6	278.0	13.9	58.4	4.8	1088.0	47.3	164.0	4.2	1434.0	40.4	43.9	0.9	1739.0	28.5	0.3	32.0	62.0	4899.3
ZG-3	32.9	6.5	212.0	10.6	162.0	13.4	830.0	36.1	118.0	3.0	1220.0	34.4	39.9	0.8	2087.0	34.2	-4.8	23.0	48.0	4740.0
ZG-4	43.4	7.1	187.0	9.4	75.8	6.2	1161.0	50.5	174.0	4.4	1558.0	43.9	59.6	1.2	1797.0	29.5	-2.8	40.0	109.0	5161.0
ZG-5	35.9	7.5	31.2	1.6	49.2	1.4	49.2	2.1	17.9	0.5	20.9	0.6	10.1	0.2	290.0	4.8	0.5	1.7	114.0	584.2
ZG-6	29.6	7.4	33.9	1.7	10.6	0.9	51.1	2.2	18.1	0.5	30.9	0.9	1.0	0.0	273.0	4.5	-1.1	0.9	94.0	513.5
ZG-7	16.8	7.7	65.9	3.3	19.4	1.6	12.7	0.6	8.7	0.2	7.5	0.2	6.7	0.1	336.0	5.5	-1.7	0.7	57.0	514.6
ZG-8	14.3	7.8	59.1	3.0	12.2	1.0	11.7	0.5	2.0	0.1	7.1	0.2	11.0	0.2	244.0	4.0	1.1	0.6	52.0	399.7
SDJ-1*	24.4	6.9	43.0	2.2	7.7	0.7	18.1	0.8	10.6	0.3	8.5	0.2	5.3	0.1	232.0	3.8	-3.6	0.7	100.0	425.9
SDJ-2*	24.6	7.4	45.0	2.2	6.0	0.5	47.5	2.1	13.1	0.3	14.6	0.4	16.8	0.4	296.0	4.9	-4.4	1.0	90.0	530.0
SDJ-3*	22.8	7.8	51.4	2.6	6.2	0.5	23.7	1.0	13.5	0.4	7.5	0.2	5.3	0.1	281.0	4.6	-4.9	0.7	84.0	472.6
SDJ-4*	21.0	7.6	42.1	2.1	7.2	0.6	20.2	0.9	16.3	0.4	5.7	0.2	5.8	0.1	250.0	4.1	-4.7	0.6	90.0	437.8
SDJ-5*	22.1	7.6	41.9	2.1	7.6	0.6	21.0	0.9	10.5	0.3	13.5	0.4	11.0	0.2	226.0	3.7	-5.1	0.7	86.0	417.5
SDJ-6*	21.2	7.1	42.7	2.1	3.2	0.3	21.5	0.9	4.1	0.1	10.6	0.3	4.8	0.1	209.0	3.4	-5.2	0.6	88.0	384.5
SK-1*	10.9	7.3	22.0	1.1	1.8	0.2	3.5	0.2	6.6	0.2	2.8	0.1	7.7	0.2	81.0	1.3	0.0	<0.1	52.0	177.5
SK-2*	44.1	7.4	44.0	2.2	7.9	0.7	21.5	0.9	16.5	0.4	3.6	0.1	2.5	0.1	261.0	4.3	-2.7	<0.1	146.0	502.9
SK-3*	26.8	7.2	52.0	2.6	13.2	1.1	17.1	0.7	12.2	0.3	4.6	0.1	4.8	0.1	296.0	4.9	-3.6	<0.1	100.0	499.9
SK-4*	27.2	7.6	36.1	1.8	7.9	0.7	17.5	0.8	11.8	0.3	3.6	0.1	1.8	0.0	226.0	3.7	-4.5	<0.1	124.0	428.6
SK-5*	23.7	7.5	22.0	1.1	8.3	0.7	17.8	0.8	12.9	0.3	3.2	0.1	1.9	0.0	162.0	2.7	1.6	<0.1	118.0	346.1
SK-6*	22.5	8.4	28.5	1.4	3.5	0.3	12.2	0.5	0.8	0.0	5.0	0.1	2.1	0.0	140.0	2.3	-4.6	<0.1	70.0	262.1
SK-7*	28.9	7.7	33.1	1.7	11.1	0.9	42.7	1.9	14.8	0.4	7.9	0.2	4.3	0.1	267.0	4.4	1.3	0.7	87.0	468.6
SK-8	16.9	7.9	26.0	1.3	5.1	0.4	7.7	0.3	3.1	0.1	2.4	0.1	1.7	0.0	134.0	2.2	-3.8	<0.1	77.0	257.0
SK-9	12.0	7.0	12.9	0.7	1.6	0.1	2.9	0.1	1.2	0.0	1.2	0.0	2.1	0.0	58.0	1.0	-4.1	<0.1	30.0	109.9

(MTA–1*: Samples collected from the wells)

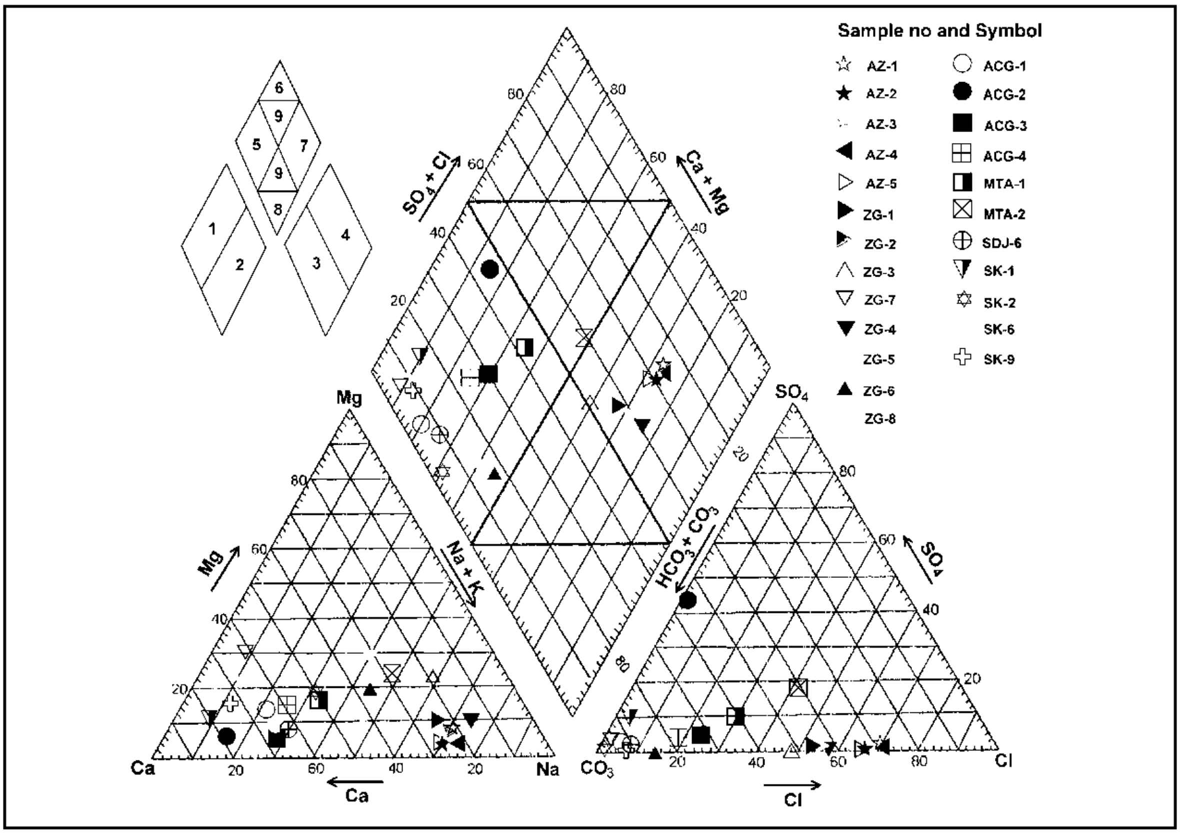

Figure 5- Piper diagram of hot and cold waters collected from Acıgöl-Ziga and Şahinkalesi areas.

The waters collected from the Ziga area are classified into two groups, too. The close cation and anion contents of the waters in the group I (AZ-1, AZ-2, AZ-4, ZG-1, ZG-3) make us think their origins are the same. The most prominent feature of this group is that the dominant cation is Na^{+}+K^{+} and the dominant anion is Cl^{-}. In the group II (ZG-5 and ZG-6) in Ziga area the dominat cation is Na^{+}+K^{+} and the dominant anion is HCO_3^{-}.

GEOTHERMOMETER APPLICATIONS

SILICA GEOTHERMOMETERS

In reservoir calculations silica geothermometers were applied. When the silica and temperature distribution of the waters collected from the study area are examined, it was observed that the silica content and temperature are conformable (Figures 7 and 8).

Reservoir temperatures in Acıgöl area were calculated as 114-160 °C according to chalcedony thermometer and as 140-181 °C according to silica thermometer (Tables 2, 3, 4); whereas in Ziga area the respective measurements are 69-93 °C and 99-121 °C (Tables 5, 6). In Şahinkalesi area, the reservoir temperatures were calculated as 135 °C and 159 °C according to chalcedony and silica termometers, respectively (Table 7).

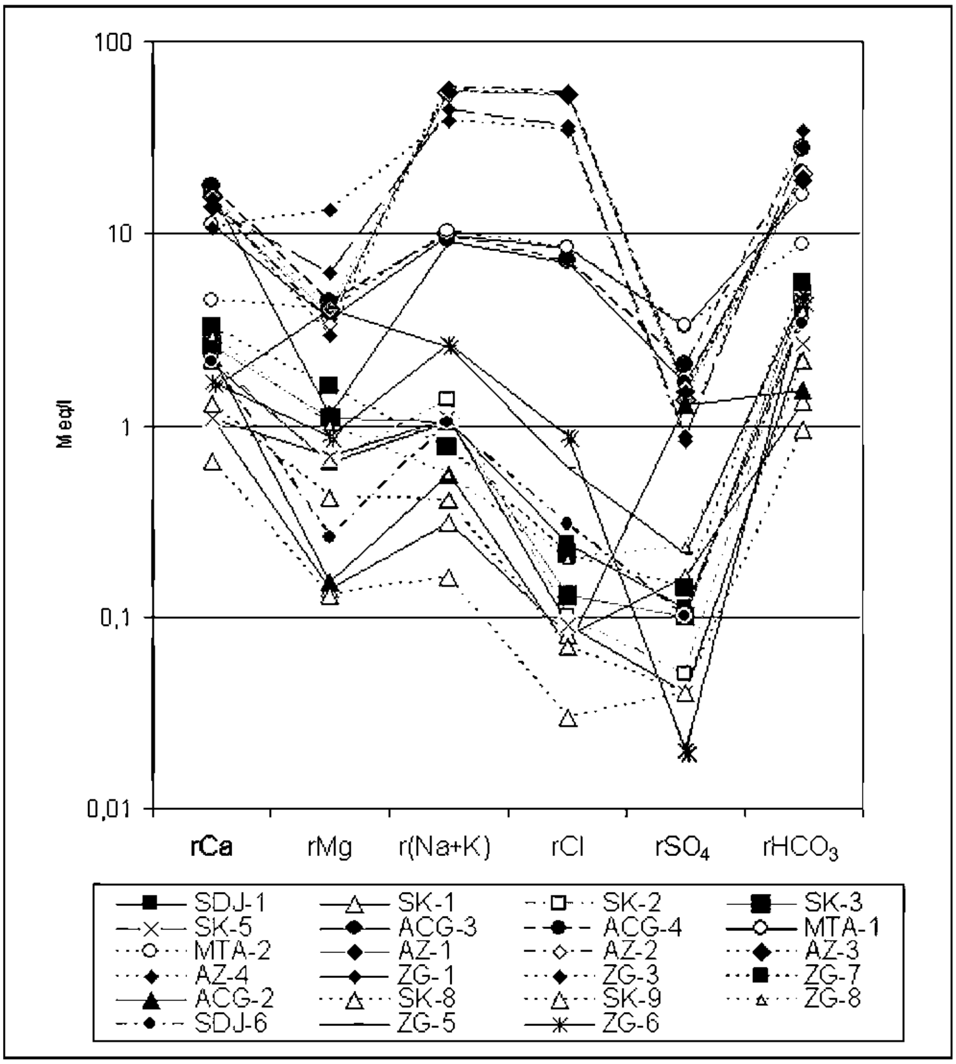

Figure 6- Schoeller diagram of the cold and hot waters from Aksaray Acıgöl-Ziga and Şahinkalesi areas.

CATION GEOTHERMOMETERS

According to Giggenbach (1988) cation maturity diagram, with respect to cations, the waters collected in the study area are raw waters with no water-rock balance (Figure 9). For this reason, cation geothermometers were not used to calculate reservoir temperature.

MIXTURE MODELING

On silica-enthalpy diagram (Figure 10), when SiO_2 (mg/l) content of the sample waters are marked corresponding to enthalpy, it is observed that the water samples are aligned on a line representing the mixture line. When a perpendicular line is drawn to mixture line (in case steam loss is involved, from 420 KJ/kg enthalpy value which corresponds to 100 °C where the water boils) and from the interception point of the lines, when a line parallel to entalphy axis is drawn, the enthalpy value of the intersection point of this line and the quartz steam loss curve is the enthalpy value (650 KJ/Kg) corresponding to the reservoir temperature, which is 155 °C.

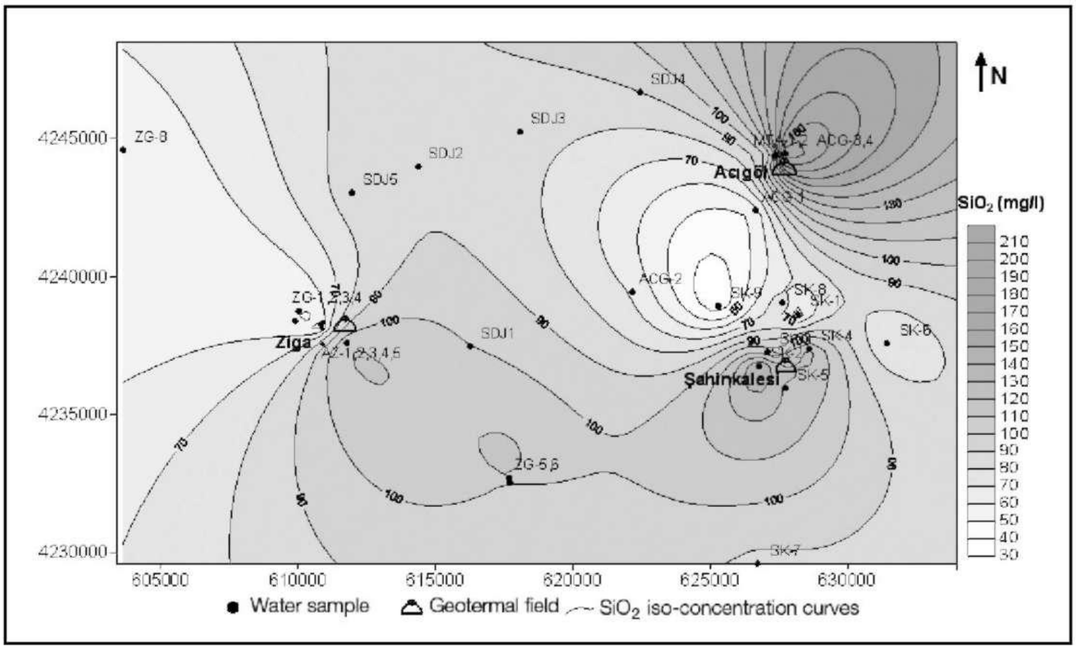

Figure 7- SiO_2 distribution map of the samples collected in study area.

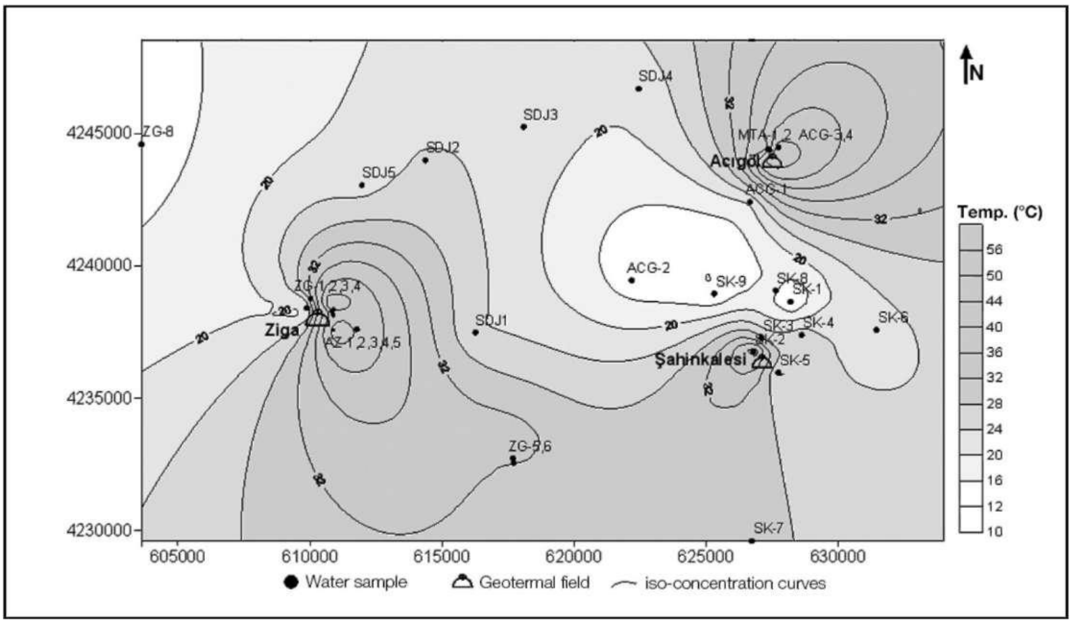

Figure 8- Temperature distribution map of the samples collected in the study area.

Table 2- Geothermometer calculations in Acıgöl area (sample no. ACG-3).

Sample No: ACG-3	Location: Aksaray -Acıgöl	Water Type: Ca-Na-HCO_3-Cl	
Temperature (°C): 43,3			
Thermometer	Calculated Temp. (°C)	Reference Interval	
Chalcedony	114	Fournier 1977	0-250
Quartz	140	Fournier 1977	0-250
Quartz (steam loss)	135	Fournier 1977	0-250

Table 3- Geothermometer calculations in Acıgöl area (sample no. MTA-1).

Sample No: MTA-1	Location: Aksaray-Narköy	Water Type: Ca-Na-HCO_3-Cl	
Temperature (°C) : 53,0			
Thermometer	Calculated Temp. (°C)	Reference Interval	
Chalcedony	160	Fournier 1977	0-250
Quartz	181	Fournier 1977	0-250
Quartz (steam loss)	169	Fournier 1977	0-250

Table 4- Geothermometer calculations in Acıgöl area (sample no. MTA-2).

Sample No: MTA-2	Aksaray-Acıgöl-Narköy	Water Type:Na-Ca-HCO_3-Cl	
Temperature (°C): 65.0			
Thermometer	Calculated Temp. (°C)	Reference Interval	
Chalcedony	147	Fournier 1977	0-250
Quartz	169	Fournier 1977	0-250
Quartz (steam loss)	159	Fournier 1977	0-250

Table 5- Geothermometer calculations in Ziga area (sample no. AZ-3).

Sample No: AZ-3	Ziga-Aksaray	Water Type: Na-Cl-HCO_3	
Temperature (°C): 51.0			
Thermometer	Calculated Temp. (°C)	Reference Interval	
Chalcedony	69	Fournier 1977	0-250
Quartz	99	Fournier 1977	0-250
Quartz (steam loss)	100	Fournier 1977	0-250

Table 6- Geothermometer calculations in Ziga area (sample no. AZ-4).

Sample No: AZ-4	Aksaray Ziga	Water Type: Na-Cl-HCO_3	
Temperature °C: 46.0			
Thermometer	Calculated Temp. (°C)	Reference Interval	
Chalcedony	93	Fournier 1977	0-250
Quartz	121	Fournier 1977	0-250
Quartz (steam loss)	119	Fournier 1977	0-250

Table 7- Geothermometer calculations in Şahinkalesi area (sample no. SK-2).

Sample No: SK-2	Aksaray - Şahinkalesi	Water Type: Ca-Na-HCO_3	
Temperature (°C): 44.1			
Thermometer	Calculated Temp. (°C)	Reference Interval	
Chalcedony	135	Fournier 1977	0-250
Quartz	159	Fournier 1977	0-250
Quartz (steam loss)	151	Fournier 1977	0-250

The value calculated from the silica-enthalpy diagram (650 KJ/Kg) is taken as the enthalpy value of the original water. This value is marked as the enthalpy value of the original water (Figure 11) and when the mixture calculation for the sample from MTA-2 well (272 KJ/Kg) –which falls on the mixture line and is the closest value to the original enthalpy value- was made (assuming that the water mixed has an enthalpy value of 16 °C ~ 67 KJ/Kg), the mixture ratio of the cold water is calculated as 65% for MTA-2 sample. According to Cl^-Enthalpy diagram, while the water samples from Acıgöl fall on the mixture line, the water samples from Şahinkalesi are observed to be of steam heated water type with their very low Cl^- content. It was assumed that, on the other hand, water samples from Ziga, with their similar entalphy values but higher Cl^- contents, represent Cl^- enrichment related to evaporites or cooling by adiabatic way losing steam.

When the equi-Cl^- distribution of the waters (Figure 12) and graph of chemical composition-temperature (Figure 13) are examined, it was observed that the water samples from Ziga area (AZ–1, AZ–2, AZ–3, AZ–4, ZG–1 and ZG–3), different from that of Acıgöl and Şahinkalesi samples, do not have the highest temperature although their Na^+ and Cl^- content have the highest value. The Cl^- enrichment in Ziga waters might be related to solubilization of evaporites, however, as related to steam loss the concentration of Cl^- (and Na^+) might have increased.

HYDROLOGICAL ISOTOPE STUDIES

Isotope analyses were made on 11 samples (Table 8). Oxygene-18 ($\delta^{18}O$) and Deuterium (δ^2D) analyses were conducted in TÜBİTAK Marmara Research Center (MAM) Laboratories and Tritium analyses were made in Isotope Laboratories of Department of Technical Research and Quality Control of General Directorate of DSİ (State Hydraulic Works).

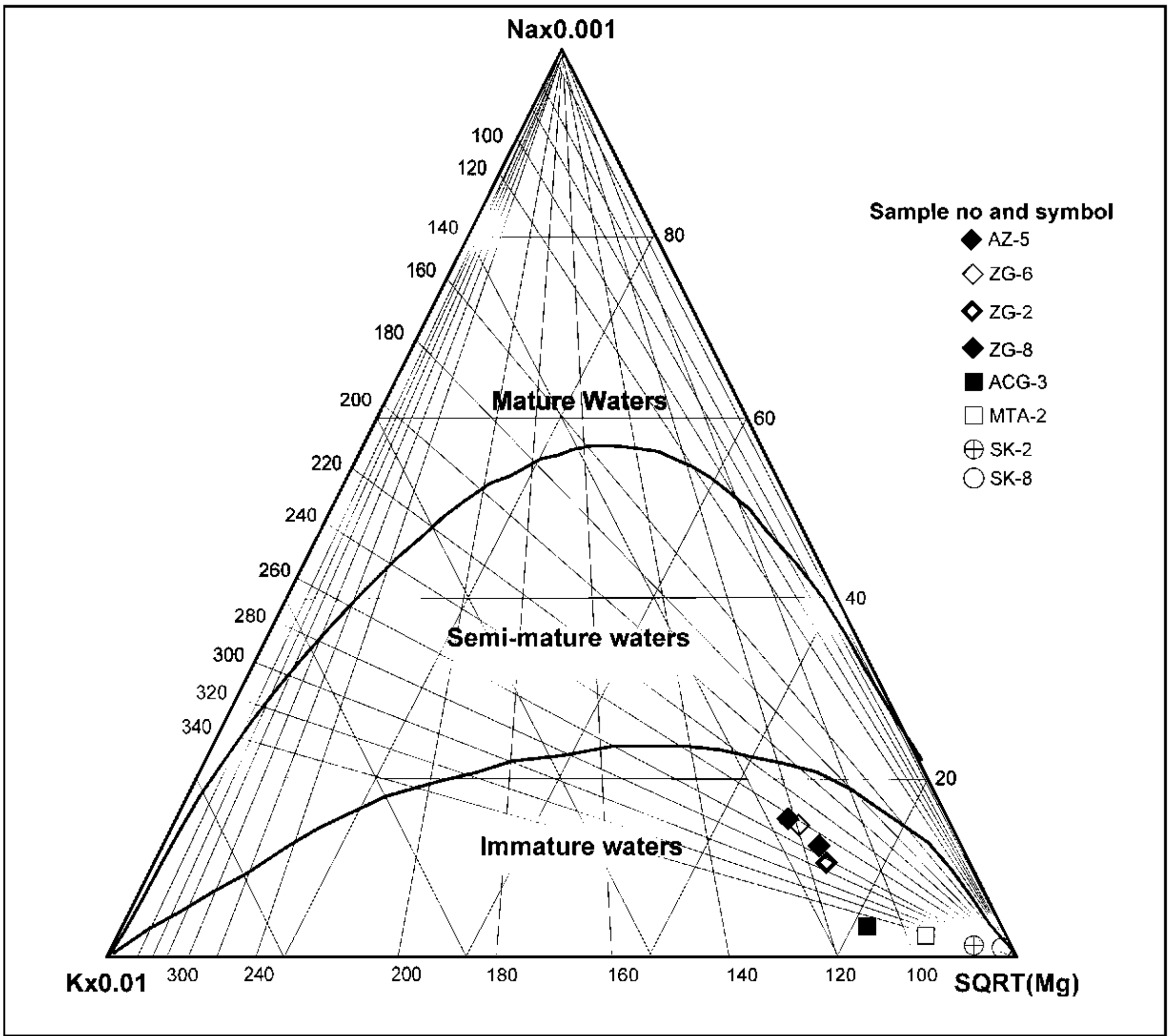

Figure 9- Maturity diagram of the cold and hot waters of Aksaray Acıgöl-Ziga and Şahinkalesi areas (Giggenbach, 1988).

RELATION BETWEEN OXYGENE18 - DEUTERIUM

In calculation of recharging elevation only the cold water samples were considered since they were only fed by precipitation and discharge in short time interval. When the deuterium (δ D) data were marked corresponding to the topographic elevations where the cold water samples were collected;

$$D= - 0.024.h - 42,358 \qquad (1)$$

$$h = \frac{D + 42,358}{-0,024} \qquad (2) \qquad (2)$$

(1) The line is defined as height inclination line (Figure 14). In the equation D and h Express the deuterium value and height (m), respectively. When we take the value h from this equation and put the value of deuterium in the obtained equation (2), the recharging elevation of the

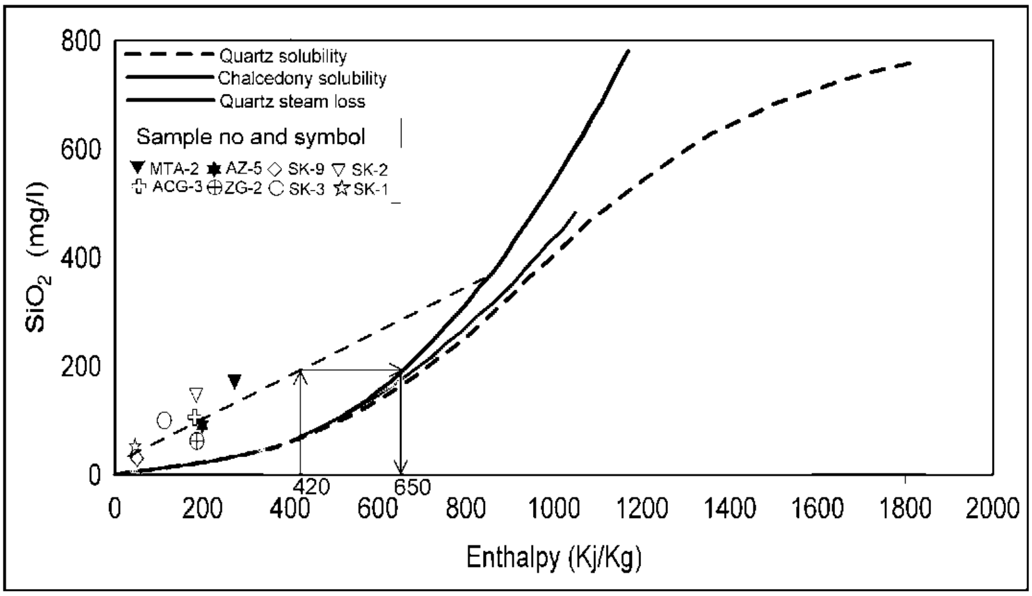

Figure 10- SiO_2-enthalpy mixture modeling of water samples collected in the study area.

Acıgöl and Ziga hot waters are calculated as 1500 and 1600 m, respectively. These height data indicate that the feeding area might extend up to the skirts of Hasandağ (Figure 15). The sample HD-1 directly falls on the line formed by 4 cold water samples. It was excluded from the line considering any possible analysis error.

In $\delta^{18}O$ - $\delta^{2}D$ graph, it was observed that some underground waters are enriched in isotopes in direction of arrow due to evaporation effect developed after feeding (Figure 16). The maximum evaporation is observed at the sample no. ACG-4 located at the tip of the arrow which was collected from a hot water spring with low discharge rate. The samples no. SK–5, ZG–1 and ZG–3 (which are located in the octagonal) were shifted to right from the local meteoric line and enriched in $\delta^{18}O$. This enrichment can be explained by deep-seated circulation of the waters and having longer interaction with the rocks. On the other hand, although the sample MTA-2 is the hottest sample, it does not show any deviation from the meteoric line. This can imply no long time rock-water interaction.

TRITIUM STUDIES

According to results of tritium analyses, the underground waters in the area are classified in three groups (Figure 17). The tritium value of the samples in the first group is TU>5 and these waters are modern waters of 5-10 years that formed by recent precipitations. The same value for the second group varies between 0-2 TU and accordingly these waters are younger than 60 years, that formed before the nuclear tests (pre-1952). All the hot water samples collected in the study area fall into this group. The other waters which fall into the third group, with 2-5 TU tritium content, are the "sub-modern" waters affected both from the precipitation waters before and after 1952.

In $\delta^{18}O$ versus tritium graph of underground waters, data of the circulation time and height of recharging of the area were dealt. According to this, related to decrease of tritium ratio in underground waters, the circulation time in Şahinkalesi, Ziga and Acıgöl, in the order, is observed to increase (Figure 18).

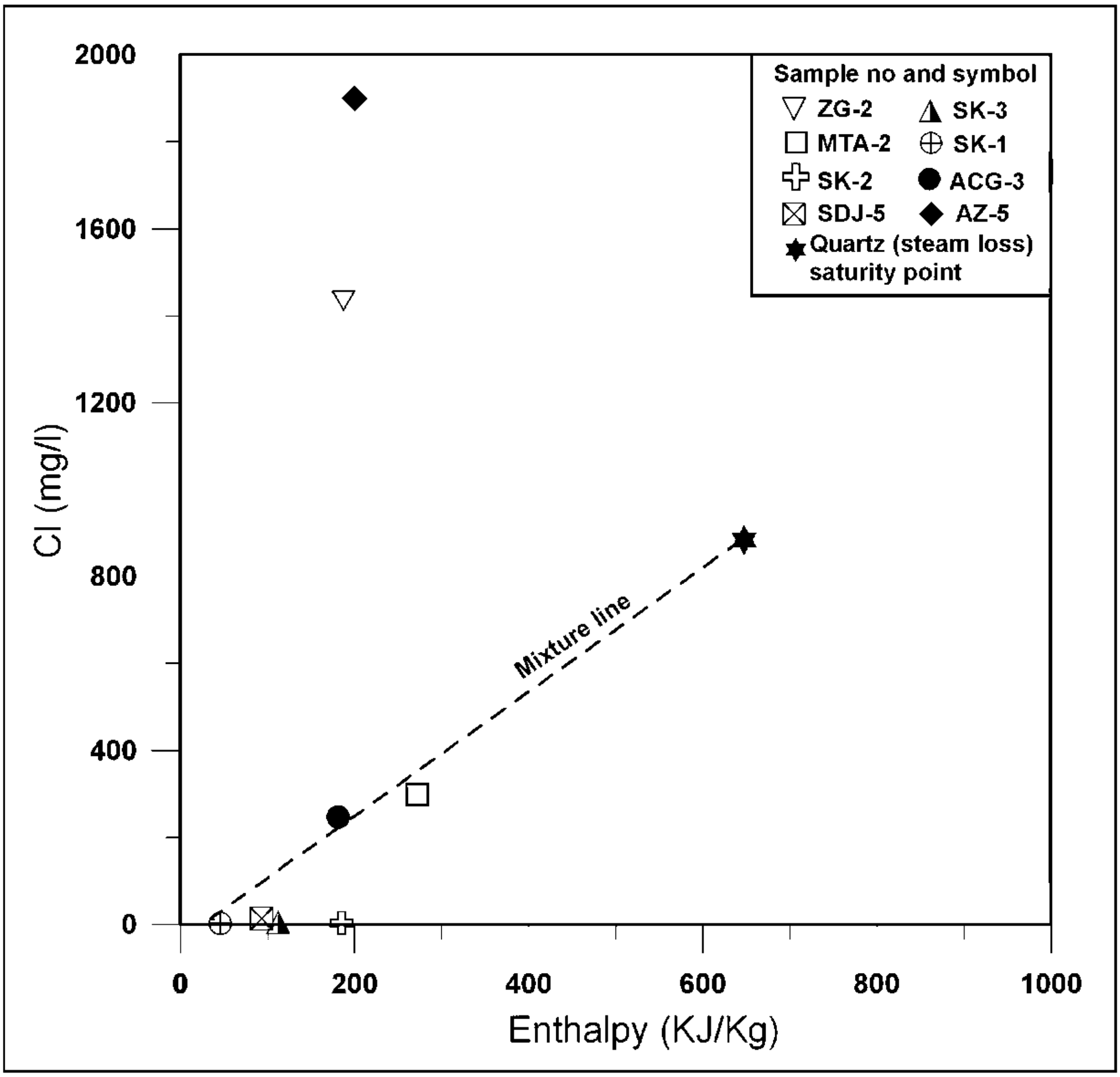

Figure 11- Cl-enthalpy diagram of the water samples collected in the study area.

DISCUSSIONS

In Deuterium-height graph, the sample HD-1 does not fall on the line formed by 4 cold water samples. The height inclination was formed according to four water samples taken from four different heights (1291 m, 1418 m, 1478 m and 1712 m). The HD-1 sample which do not fall on the line is taken from 1310 m, however, another sample representing this elevation (ZG-7) has different deuterium value than HD-1 has. For this reason, assuming that an analysis error might have occurred, this point has been excluded from the line. We think, on the other hand, that it is possible to calculate the recharging ele

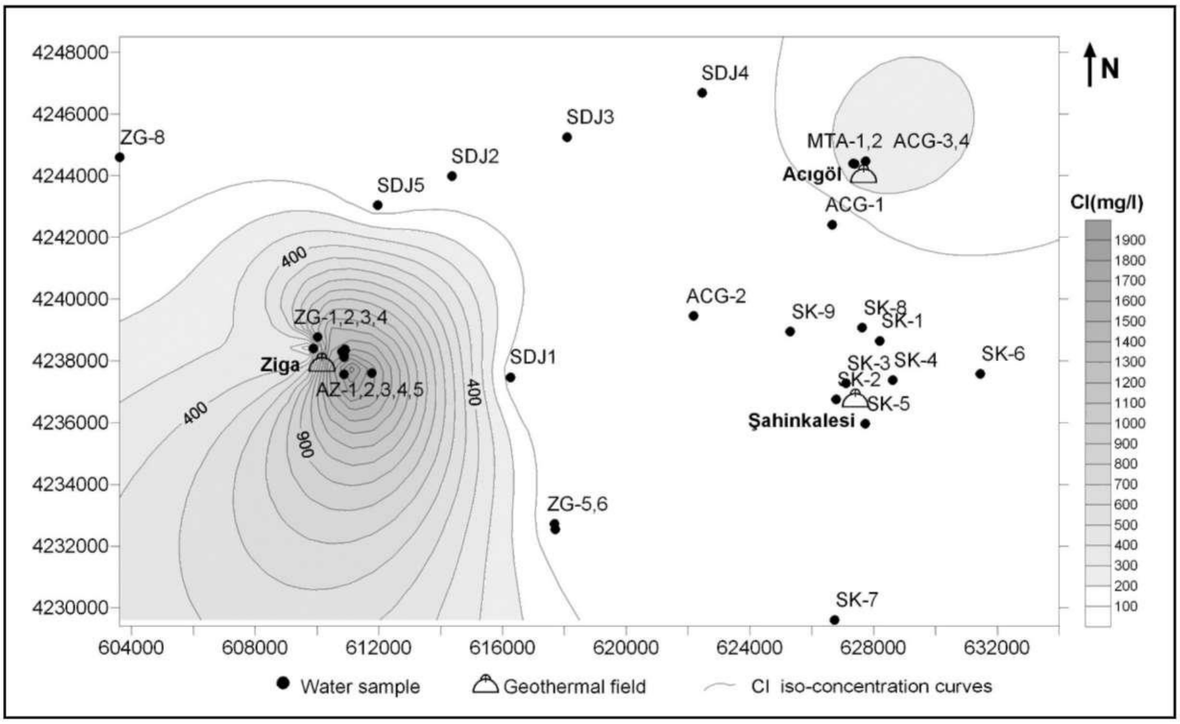

Figure 12- Cl⁻ distribution of the water samples collected in the study area.

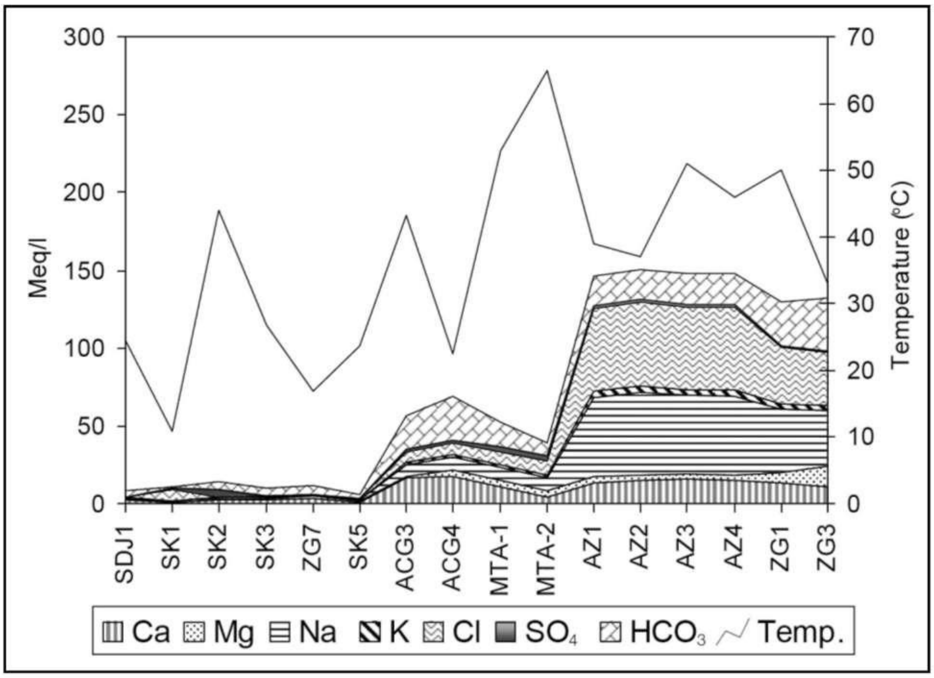

Figure 13- Relation between the variation of chemical composition of the waters and temperature.

Table 8– Isotope analysis results of the water samples collected in the study area [*δ ^{18}O and δ D results of the sample HD-1 were taken from Afşin and Baş (1997)].

Sample no	Location	Coordinates			Ec (µS/cm)	pH-25°C	Temp.	Date	Date	δ D	$\delta^{18}O$	Tritium	
		Y	X	Z		°C		O^{18}-δ D	(TU)	%o	%o	(TU)	Error
ZG-1	Ziga well (235m)	610891	4238377 ±1.95	1268	7002	7.13	45	01.10. 2003	29.09. 2004	-79.69	-11.55	1.35	
ZG-3	Y.hisar Spring	610017	4238766	1280	5980	6.53	32.9	01.10. 2003	29.09. 2004	-80.46	-11.61	0.3	2.00
ZG-7	Y.hisar Spring	609883	4238408	1291	553	7.66	16.8	01.10. 2003	29.09. 2004	-73.33	-10.63	4.45	2.05
ACG-1	Narköy Spring	627334	4242417	1478	227	8	19.6	01.10. 2003	29.09. 2004	-78.1	-11.77	3.2	2.00
MTA-2	Narköy well (300m)	627384	4244387	1371	2900	6.69	65	01.10. 2003	29.09. 2004	-76.39	-11.5	0	1.95
ACG-4	Narköy Spring	627355	4244410	1370	3120	6.8	22.4	01.10. 2003	29.09. 2004	-65.6	-9.41	1.4	1.95
SK-1	Bozköy Spring	628192	4238649	1712	1319	7.3	10.9	01.10. 2003	29.09. 2004	-83.43	-12.6	7.75	2.05
SK-2	Bozköy well (300m)	626779	4236759	1769	402	7.4	44.1	01.10. 2003	29.09. 2004	-77.62	-11.61	0.8	1.95
SK-5	Bozköy well (200m)	627725	4235964	1705	301	7.54	23.7	01.10. 2003	-	-78.73	-11.66	-	-
HD-1*	H.dere Spring	605967	4228496	1310	258	6.79	10.7	26.04. 1996	29.09. 2004	-98.53	-11.62	5.65	2.00
SDJ-1	G.yurt well (200m)	616259	4237478	1418	375	6.8	18.8	01.10. 2003	29.09. 2004	-74.82	-10.7	2.1	±2.05

vation accurately by collecting more samples from different elevations.

CONCLUSIONS

The basement in the study area is represented by gneisses of the Paleozoic Tamadağ formation and marbles of Bozçaldağ formation and the Upper Cretaceous Baranadağ granitic intrusion intruded in these rocks. These units have unconformable relations with Lower Eocene Çayraz formation and Upper Cretaceous-Lower Miocene sedimentary deposits of Mezgit group. All these rock units were unconformably overlain by Cappadocia volcanic belt represented by Middle Miocene-Quaternary tuffs and ignimbrites and interbedded sedimentary levels, basalt lava, volcanic ash, pumice, dacitic-rhyo dacitic lava domes.

The main reservoir of the geothermal system in the study area is formed by the fractured zones of Paleozoic schists and gneisses and the marbles at higher levels. The shallow reservoir is formed by sandstone, limestone levels and terrestrial deposits and the evaporitic levels included in these rocks. The cover rock of the geothermal system is comprised of extensively hydrothermally altered tuffs and ignimbrites.

According to water chemistry studies, the cold waters in the study area are of Ca-Mg-HCO_3 and $CaHCO_3$ type. The geothermal fields are located in three different areas; the hot waters in Acigöl field are classified as Ca-Na-HCO_3-Cl type and mineralized hot waters, the hot waters in Ziga field are classified as Na-Cl-HCO_3 type and B bearing mineralized hot wa-

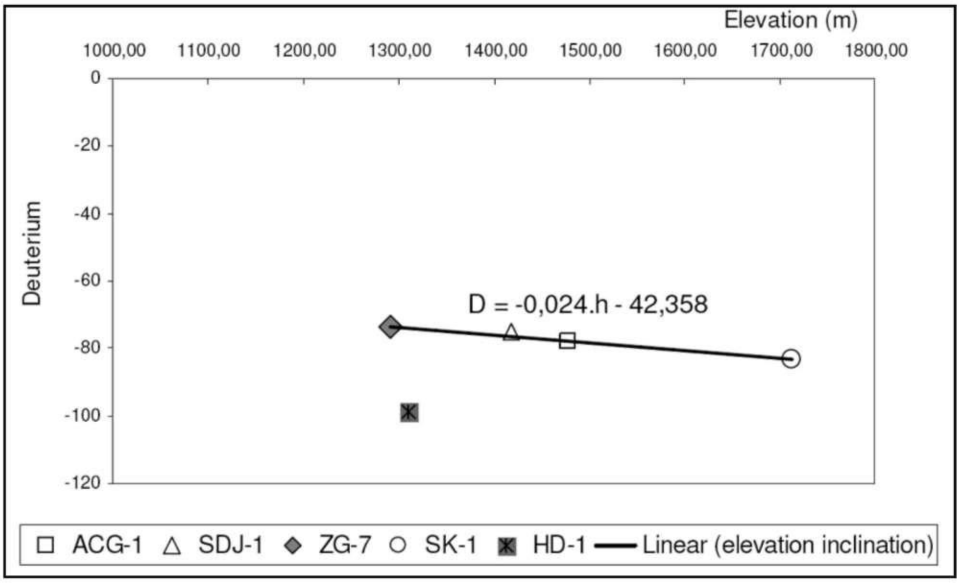

Figure 14- δ D – Height graph of the water samples collected in the study area.

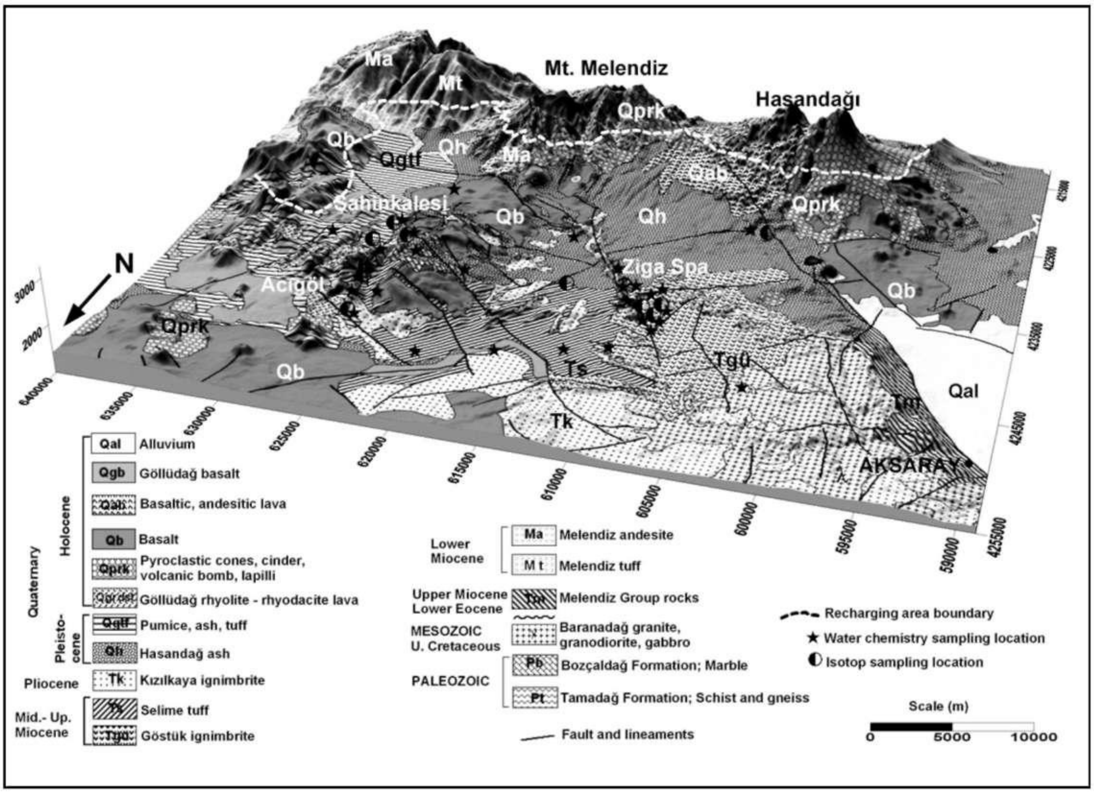

Figure 15- 3D geological map of the study area and the surrounding regions (Burçak, 2006).

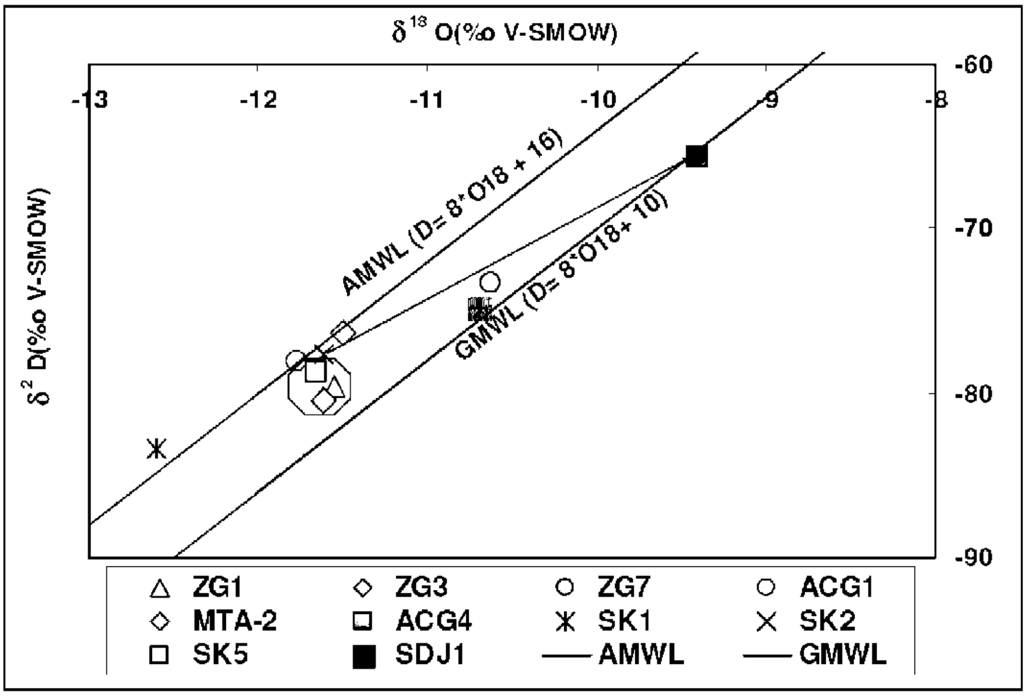

Figure 16-$\delta^{18}O$- $\delta^{2}D$ relation of the water samples collected from the study area [(GMWL: Global Meteoric Water Line (Craig, 1961); AMWL: Antalya Meteoric Water Line (Sayın and Eyüpoğlu, 2005)].

ters, the hot water in Şahinkalesi field (from well) is classified as thermal waters of Ca- Na-HCO_3.

According to deuterium analyses, the recharging height of the waters in these three areas vary between 1500-1600 m. When this recharging height is considered, the recharging area might reach up to the skirts of Hasandağ. On $\delta^{18}O$-deuterium graph, some hot water samples collected in the study area are observed to deflect from the local meteoric line and enriched in $\delta^{18}O$. According to results of tritium analyses, the samples collected in the study area were grouped into three. With "0" tritium content, the hot waters represent the group I which have been fed by the precipitations before 1952. The cold water samples with high tritium values (TU>5) are the modern waters of 5-10 years that form the group II. The samples of which tritium values are between 2-5 form the group III and represent the sub-modern waters which have been fed by the pre- and post-1952 nuclear test precipitations.

According to SiO_2 enthalpy mixture model, the reservoir temperature in Acıgöl area is calculated as 155 °C and the cold water mixture ratio is calculated as 65% (in MTA-2 sampling point). Chalcedony and quartz geothermometer was applied to the waters. The reservoir temperatures in Acıgöl, Ziga and Şahinkalesi areas were calculated respectively as 114-160 °C; 69-93 °C; 135 °C based on the chalcedony thermometer and as 140-181 °C; 99-121 °C ve 159 °C according to quartz thermometer.

In SHK-1 well (depth: 1697 m) opened by the MTA in Şahinkalesi area the average gradient increase and well bottom temperature were measured as 0.75 °C/10 m and 130 °C, respectively. The temperature value measured in the well approximately is the same as that found by geothermometer (chalcedony and quartz) calculations. The temperature values reached in this area implies that it is a suitable area for hot dry rock studies.

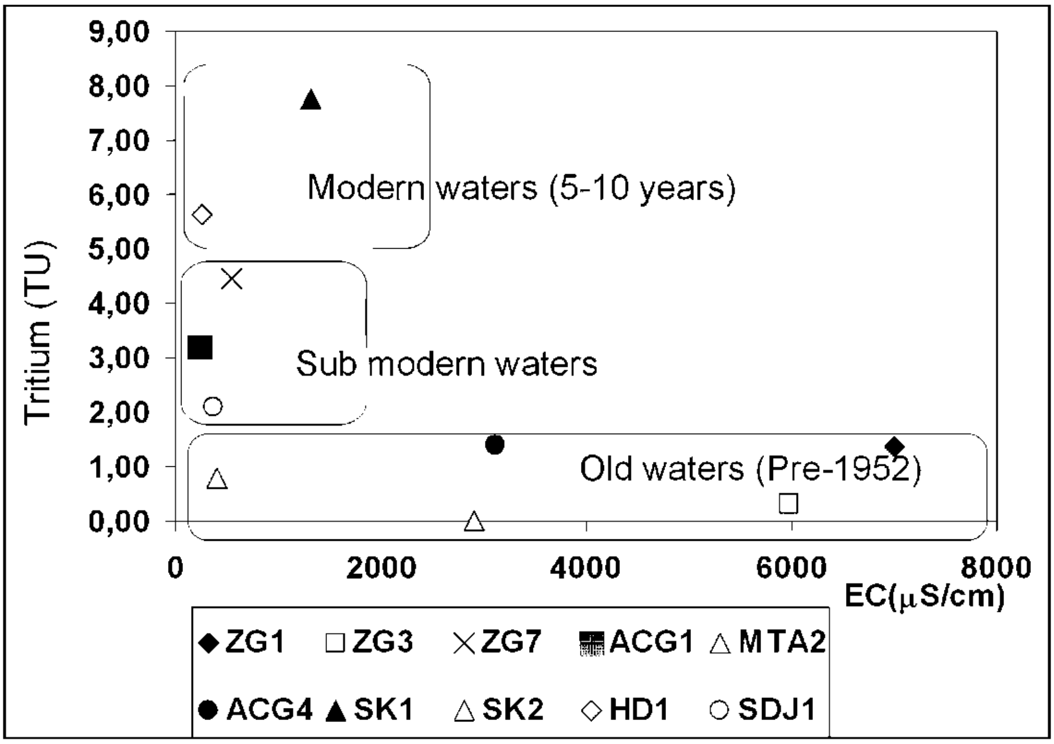

Figure 17- Tritium-EC graph of the waters collected in the study area.

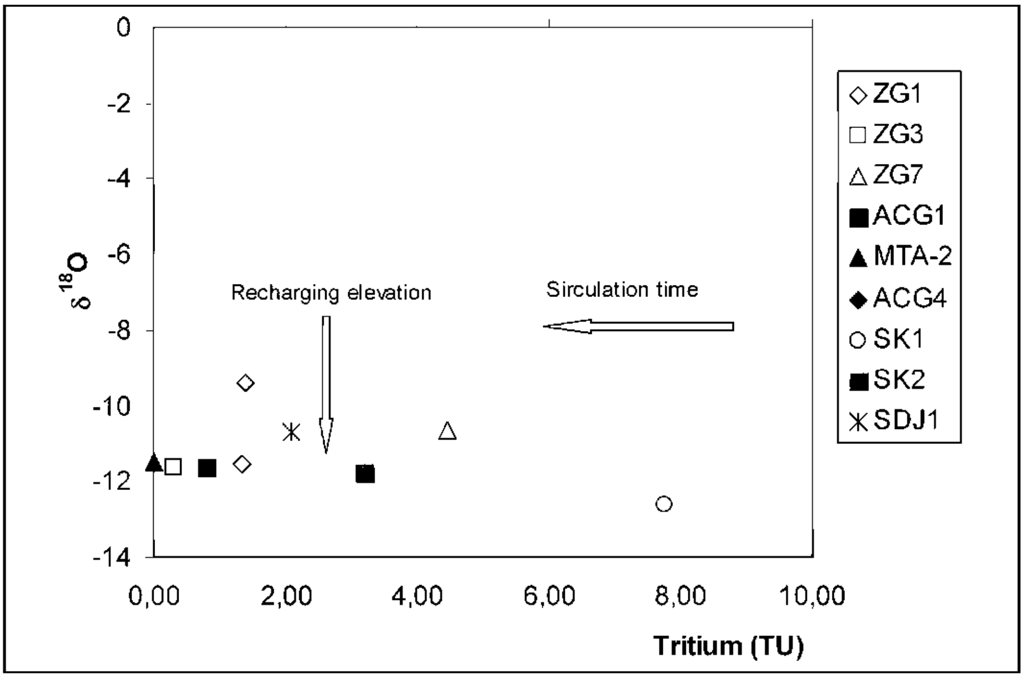

Figure 18- $\delta^{18}O$ tritium relation of the water samples collected in the study area.

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