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Hydrogeochemistry of Efteni Geothermal Area, Duzce - NW Turkey

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ABSTRACT

Efteni geothermal area is located on the western branch of North Anatolian Fault Zone (NAFZ). The last earthquakes on 17 August (Mw= 7.4) 1999 and 12 November 1999 (Mw =7.2), caused significant changes in geothermal manifestations especially in the north-western Turkey. A joint project has been started in 2003 by HU (Hacettepe University) - TUBITAK (The Scientific and Technical Research Council of Turkey). An observation network has been established by TUBITAK for monitoring possible parameters (T, EC, pH, Rn) to be used as precursors of earthquakes and one of the stations located on Efteni thermal spring, in the study area.

The basement rock is Precambrian metagranite and main lithologic units are lava and volcano sedimentary rocks (Eocene), clay and sandstone alternations (Pliocene) and alluvium (Quaternary). The geothermal reservoirs are consisted of joints and fracture zones in different lithologic units in the area.

Temperatures of the thermal springs range between 22–43ºC, pH and EC values are in the range 6.0 – 10.0 and 300- 7000 µS/cm, respectively. Ion characteristics of the geothermal springs generally are Na>Mg>Ca and HCO_3>Cl >SO_4. The estimated reservoir temperature by silica and cation geothermometers is in the range 50-110 ºC. Isotopic and chemical evaluations show that Efteni and Derdin thermal springs are associated with regional groundwater flow systems whereas Degirmen, Uyuz, and Yanangol springs are characterized by intermediate groundwater flow system in the area.

1. INTRODUCTION

Efteni low-temperature geothermal area is located on the southwest of Duzce province, NW Turkey (Fig. 1). Study area is formed from two morphological units: (i). *Ridge of Almacik block* comprises highlands at the south and (ii). *Duzce plain* is flat at low altitude in the north part of the area. Surface manifestations of relatively low temperatured springs (22-43 ºC) emerge on the active northern branch of North Anatolian Transform Fault (NATF). Efteni thermal spring which has a flow rate of ≈3.5 l/sec and temperature of 42.5 ºC is the main spring of the study area. This spring had shown many remarkable physical and chemical variations (T, EC, turbidity etc.) before 12 November 1999 Duzce Earthquake with magnitude of 7.2 (Simsek and Yildirim, 2000). A new warm spring (Yanangol spring) emerged after the earthquake. TUBITAK has established a groundwater observation and monitoring network to detect precursory changes associated with seismic activities in Northwestern Turkey. Efteni spring is a part of this network and the physical (electrical conductivity (EC), TDS, temperature, pH) and chemical (anions, trace metals) parameters including radon concentration are monitored continuously since 2002. Nevertheless, Efteni geothermal area has not been explored and reservoir rocks and reservoir temperatures have not been verified by explaratory drilling yet. This study presents the determination of the origin of geotermal fluids, reservoir temperature and, recharge area of the thermal springs in the Efteni geothermal area.

2. GEOLOGICAL SETTINGS

Basement rock in the region is Precambrian Yedigoller formation which is mainly comprised from metagranite, amphibolite and gneiss (Aydin et. al., 1987). Paleozoic formations consist of sedimentary and calcareous rocks that overlie on the basement at south of the area (Fig 1). Lower Cretaceous Almacik Ophiolite Mélange is mainly of ultramafic rocks (serpentinite, peridodite, gabbro-amphibolite) and Upper Cretaceous Akveren Formation (clayey limestone) overthrusted to Eocene aged Yigilca (andesite, basalt) and Caycuma (sandstone, mudstone, limestone) formations. Unconsalidated Plioquaternary Karapurcek Formation and Quaternary alluvium unconformably overlie older formations.

Major structural features in the study area are E-W trending Northern segment (Duzce Fault) of North Anatolian Fault which crosses almost the whole northern part of Turkey and its segments. The active tectonics of NAFZ causes major earthquakes. Last activity caused 845 casualties in Duzce province and its vicinity in November 12, 1999. This fault also plays important role on the deformation and morphological evolution of the study area. Strike-slip (right direction) motion of the fault caused the formation of Duzce Plain which is an extensional sedimentary basin with 260 m thickness (Simsek and Dalgic, 1997). Secondary tectonic features are Zekeriya and Yukariderdin faults.

3. HYDROGEOLOGICAL FEATURES

The study area is located in Black Sea Region which is characterized by warm and relatively humid climate. Mean annual temperature and precipitation in the plain area according to the Duzce Meteorological Station (148 m asl) are 13.1 ºC and 840 mm, respectively. In highlands (350-450 m asl) precipitation is over 1100 mm according to the Meteorological Stations located in the Almacik block.

Metagranitic basement, volcanic and ultramafic rocks which crop out mainly at the highlands of the area have low primary permeability. However, active tectonics caused the development of joint and fracture systems and enhancement of secondary permeability to the rocks. Thus main aquifers are comprised from joints and fracture zones. Alluvium in the plain part of the Efteni geothermal area forms main cold groundwater aquifers. Unsal (1991) detemined two confined aquifers in the alluvium and an unconfined aquifer at the top of it.

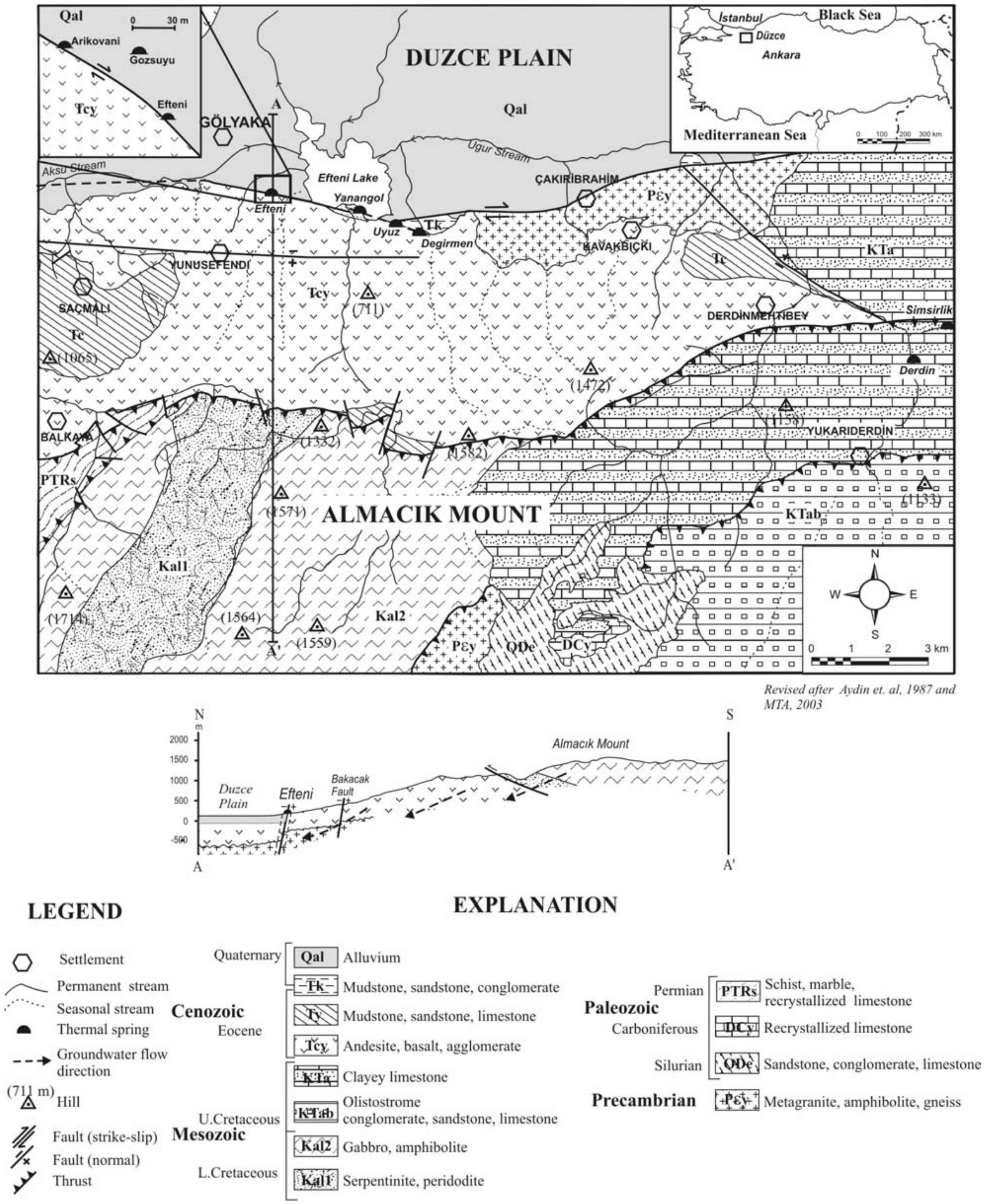

Figure 1: Location and simplified geological map of the study area

4. THERMAL MANIFESTATIONS

4.1. Efteni Spa Springs

Efteni, Gozsuyu and Arikovani springs are the main thermal springs of the geothermal area. All the springs emerge at the contact of Eocene volcanics and alluvium which are formed by Duzce Fault at the southwest of Efteni Lake (Fig. 1). Temperature and EC of the Efteni, Arikovani and Gozsuyu springs are 42.5 ºC, 31 ºC, 28 ºC and 3000 µS/cm, 2500 µS/cm, 2000 µS/cm, respectively Efteni spring has the flow rate of ≈3.5 l/sec whereas others have less than 0.1 l/sec.

4.2. Derdin Spring and Simsirlik Mineral Water

Derdin spring is located 17 km south of Duzce province. It has a temperature of 31 ºC with 4 l/sec flow rate. Its has relatively high EC (7000 µS/cm). The spring emerges at the contact of impervious Akveren formation and intrusive dacitic volcanics. Simsirlik mineral water emerges at approximately 500 m south of Derdin spring in a stream channel with temperature 18 ºC and EC 3200 µS/cm. This is a typical seepage spring which emerges from several outlets with the total flow rate ~0.1 l/sec.

4.3. Degirmen and Uyuz Springs

These springs emerge at the contact of Eocene volcanics and Plioquaternary Karapurcek Formation (Fig. 1). Degirmen spring has a flow rate of 0.5 l/sec and temperature of 25 °C. Uyuz spring is relatively cooler (23 °C) and has lesser flow rate (≈ 0.1 l/sec). Both of the springs have low mineralization (EC≈ 300-400 µS/cm).

4.4. Yanangol Spring

Yanangol spring emerged after 12 November 1999 Duzce Earthquake at the southwestern shore of Efteni Lake. During this study it was found that temperature and EC of the springs vary seasonally which is associated with the level variation of Efteni Lake. In wet season when the level of the lake reaches to maximum height, the temperature and EC values of the Yanangol spring decrease to 15 °C and 900 µS/cm, respectively. In dry season's temperature and EC of the spring increase to 22 °C and EC 1800 µS/cm, respectively. Initial temperature just after the earthquake was measured 25.4 °C and was supposed to be a simple two component mixture of thermal and cold lake waters (MTA, 1999). Also, it is reported that a significant amount of CH_4 and CO_2 are degassing from the spring.

5. GEOCHEMISTRY

Chemical compositions of thermal water samples taken from the study area are given in Table 1. Ionic characteristics of Efteni, Arikovani and Gozsuyu springs are HCO3>Cl>SO4 - Na>Mg>Ca; Derdin, Simsirlik, Degirmen and Uyuz springs are HCO3>SO4>Cl – Na>Ca>Mg; Yanangol spring is HCO3>Cl>SO4 – Mg>Ca>Na. Triangular (Piper) diagram of thermal and cold water samples is given in Fig. 2. This diagram indicates that Efteni spa springs originated from the same reservoir and lithology of this reservoir is completely different from the reservoir lithology of Derdin and Simsirlik springs. Second important finding in the diagram is the position of Yanangol spring which is close to confined aquifer water samples. This may be interpreted as pointing to the supposition that this spring originated from a confined aquifer. Actually, the chemical composition of the confined aquifer waters in the study area is quite similar to that of Yanangol spring. CH_4 and CO_2 degassing is also observed in drilling wells which are feeding from confined aquifers. Semi-logarithmic diagram (Fig. 3) shows that Efteni spa springs have similar compositions indicating that these springs originate from the same lithological units. Also the low ionic concentration of Arikovani and Gozsuyu springs in comparison to Efteni spring suggests dilution with local groundwater. Extremely low sulphate concentration of Efteni spa springs is probably due to sulphate reduction processes. Ercan et.al., 1994 determined volumetric percentage of gaseous component of Efteni spring, %99 CO_2 and % 0.908 CH_4. According to this volumetric percentages redox potential calculated with PhreeqC geochemical modeling software for C(-4)/C(4) redox pair as -0.19 V which can correspond to sulphate reduction processes.

Semi-logarithmic (Schoeller) diagram also shows that Derdin, Simsirlik, Degirmen and Uyuz springs originate from the same lithological units.

Table 1: Chemical and stable isotopic analyses results of thermal springs of the study area (April, 2003).

Sample	pH	EC (µS/cm)	T (ºC)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Cl (ppm)	SO4 (ppm)	HCO3 (ppm)	B (ppm)	$\delta^{18}O$	$\delta^{2}H$
Efteni	6.3	2900	43.0	174	134	385	13	149	-	1808	6.5	-11.21	-75.61
Gozsuyu	6.5	2000	24.0	95	85	220	8.1	85	0.6	1043	3.0	-10.29	-71.17
Arikovanı	6.2	2400	30.0	105	113	305	10.9	126	0	1367	4.6	-10.70	-71.86
Derdin	6.8	7000	30.0	124	68	1945	48.5	270.8	1220	3654	31.2	-8.30	-70.03
Yanangol	7.1	900	15.0	78	49	53	1.9	5.7	5.8	557	0	-10.77	-72.44
Degirmen	7.9	400	25.0	31	4.5	52.5	0.23	8.7	46.6	173	0	-10.19	-66.98
Uyuz	7.8	350	23.0	28.5	4.5	43.1	0.26	5.9	27.9	170	0	-10.73	-67.89
Simsirlik	6.4	3200	18.0	138	28	657.5	23.3	64.9	421.3	1669	7.8	-	-

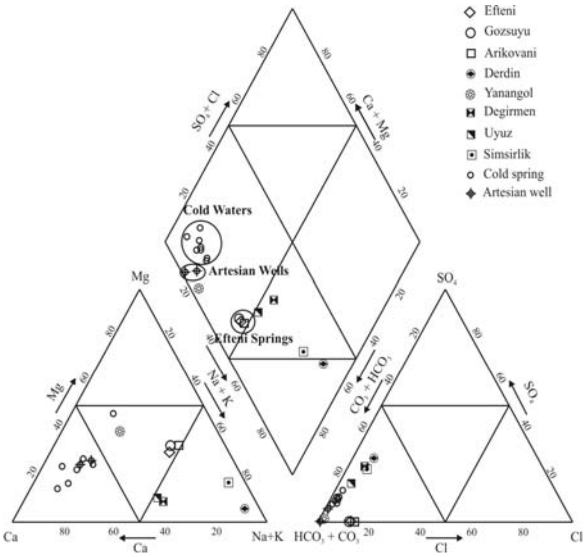

Figure 2: Triangular diagram of the thermal and cold waters of the study area

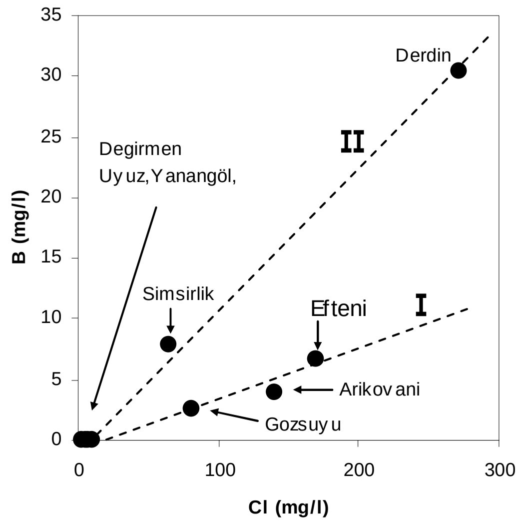

Figure 4: Cl-B diagram

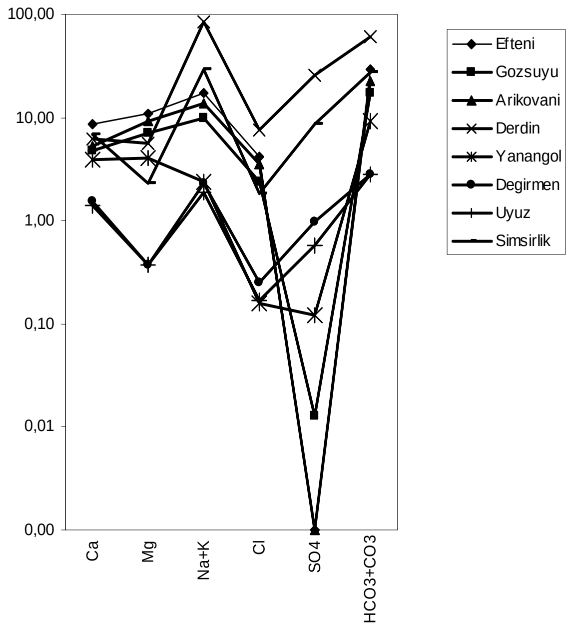

Figure 3: Schoeller diagram of the thermal springs.

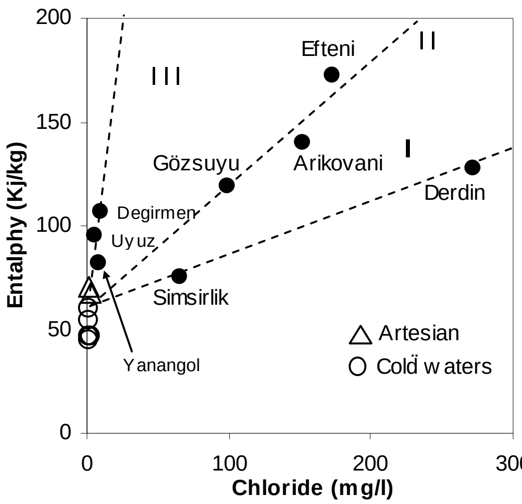

Figure 5: Cl-Enthalpy diagram

5.1. Groundwater Mixing Processes

Geothermal fluids are examined for possible mixing processes through conservative constituents such as Cl, B and Enthalpy. Cl-B diagram (Fig. 4) depicts that there exist two different mixing lines between thermal springs. Efteni spa springs coincide with mixing line (I) whereas Derdin and Simsirlik springs is on the mixing line (II). Thermal water proportions of Arikovani and Gozsuyu springs are roughly determined as 87 and 56%, respectively if Efteni spring is assumed to be a pure member of thermal water component. Similar mixing lines can be observed in Chloride-Enthalpy diagram (Fig. 5). However, Degirmen, Uyuz and Yanangol springs which have lower Cl concentration when compared to other thermal manifestations coincide with a different mixing line.

5.2. Geothermometry Applications

Reservoir temperature of Efteni geothermal area estimated by geothermometric equations proposed several authors. Cation geothermometers gave very wide temperature ranges (30 – 250 °C) and position of thermal waters in Na-K-Mg diagram proposed by Giggenbach, 1988, indicates that the chemical equilibrium has not yet been attained. For that reason silica geothermometers are assumed to be more applicable. Reservoir temperature were calculated as 110-115 ºC based on chalcedony geothermometers of Fournier, 1977 and Arnnórsson et.al, 1983 for Efteni spring. According to the mineral equilibrium approach (Pang and Reed, 1998) mineral saturation curves calculated for Efteni spring, intersect at SI=0 for the temperature interval 90-110 ºC for aluminous mineral assemblage (albite, microcline, illite, epidote), chalcedony and quartz (Fig. 6). In the same approach same mineral saturation curves are dispersed and do not converge. The intersection of mineral saturation curves in Q/K graph gives an opinion regarding the lithology of reservoir rocks. Aluminous mineral assemblages in Q/K graph indicate that lithology of reservoir rock/rocks of Efteni geothermal area are of magmatic or volcanic origin.

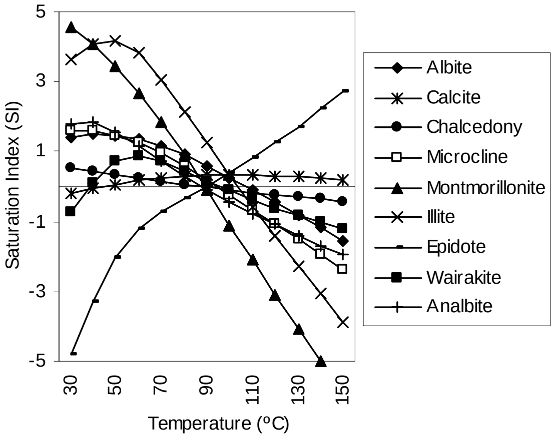

Figure 7: Mineral saturation curves of Efteni spring.

6. ISOTOPIC STUDIES

Stable isotopic ^{18}O and ^{2}H analyses (Table 1) were carried out to determine the origin of thermal waters and the recharge area of geothermal reservoirs. Local Meteoric water line (LMWL) was obtained with isotopic composition of cold water samples (Fig. 8). The equation of LMWL is same to that of Eisenlohr (1997) for Marmara Region (NW Turkey):

$$\delta D = 8 * {}^{18}O + 15$$

Nevertheless, some water samples present between LMWL and Eastern Mediterranean MWL (Gat and Carmi, 1970). Deuterium excess of LMWL represents a climatic transition zone between the Eastern Mediterranean and Central Anatolia ($\delta D = 8 * {}^{18}O + 10$) Climatic Regions for the study area. Except for Derdin spring, thermal waters of the study area are closed to LMWL and this suggests that geothermal waters are meteoric in origin. Clear ^{18}O shift from LMWL due to isotope exchange by progressive water-rock interaction observed only in Derdin spring. Although the reservoir temperature of Efteni spring was computed higher than that of Derdin spring, geothermal shift is not clearly observed in this spring.

Recharge areas of thermal springs are estimated via stable isotopic composition-altitude relationship between snow sample (1260 m. asl) and Bestekneler spring (1651 m asl) which has the highest elevation among all of the springs in the study area (Fig. 9). Regression equations computed from $\delta^{18}O$ and $\delta^{2}H$ against altitude are:

Altitude (m) = $-425 * \delta^{18}O - 3317.3$ and

Altitude (m) = $-39.178 * \delta^{2}H - 1469.9$

Also this equation resulted in an apparent altitude effect for $\delta^{18}O$ -0.24‰ and for $\delta^{2}H$ -2.55‰ per 100 m increase in altitude. Average recharge elevations of thermal sprigs computed from above mentioned equations are given in Table 2. Average recharge area altitudes calculated from ^{18}O-Altitude and ^{2}H-Altitude relationships reveal that thermal springs are recharged mainly from the highland parts of the Almacik mount with peak elevation ranging between 1500-1800 m.

Tritium concentrations of cold water samples are close to tritium concentration of recent precipitations (≈10 TU). Low tritium content of Efteni spring shows that the thermal aquifer is recharged by groundwater having relatively long residence time (>55 years) which represents a deep circulation groundwater flow system in the study area. Derdin spring has relatively high tritium concentration (~ 2 TU) with respect to Efteni spring, suggests this spring is influenced by young groundwaters in shallow depths.

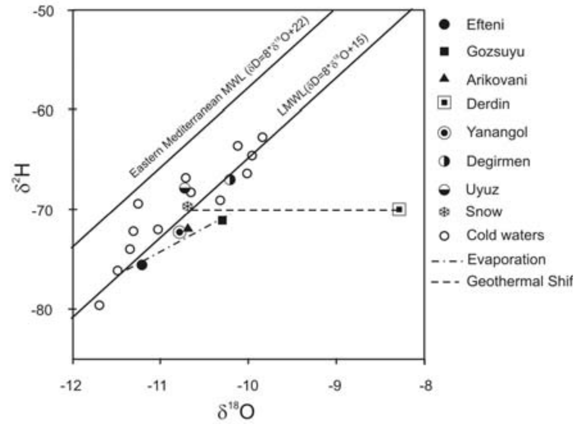

Figure 8: 10. $\delta^{2}H$ vs $\delta^{18}O$ diagram of the thermal and cold waters of the study area.

Table 2: Average recharge altitudes of the thermal springs.

Spring	Discharge Elevation	Average Recharge Altitude	
		^{18}O	^{2}H
Efteni	132	1319	1462
Gozsuyu	130	1181	1297
Arikovani	127	1288	1347
Derdin	410	255	1267
Degirmen	183	1069	1180
Uyuz	160	1122	1169
Yanangol	115	1377	1431

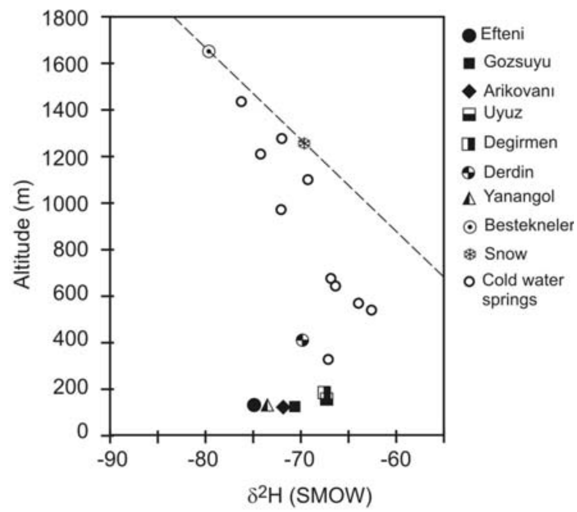

Figure 9: $\delta^{2}H$ vs altitude relationship of the thermal and cold water springs of the study area.

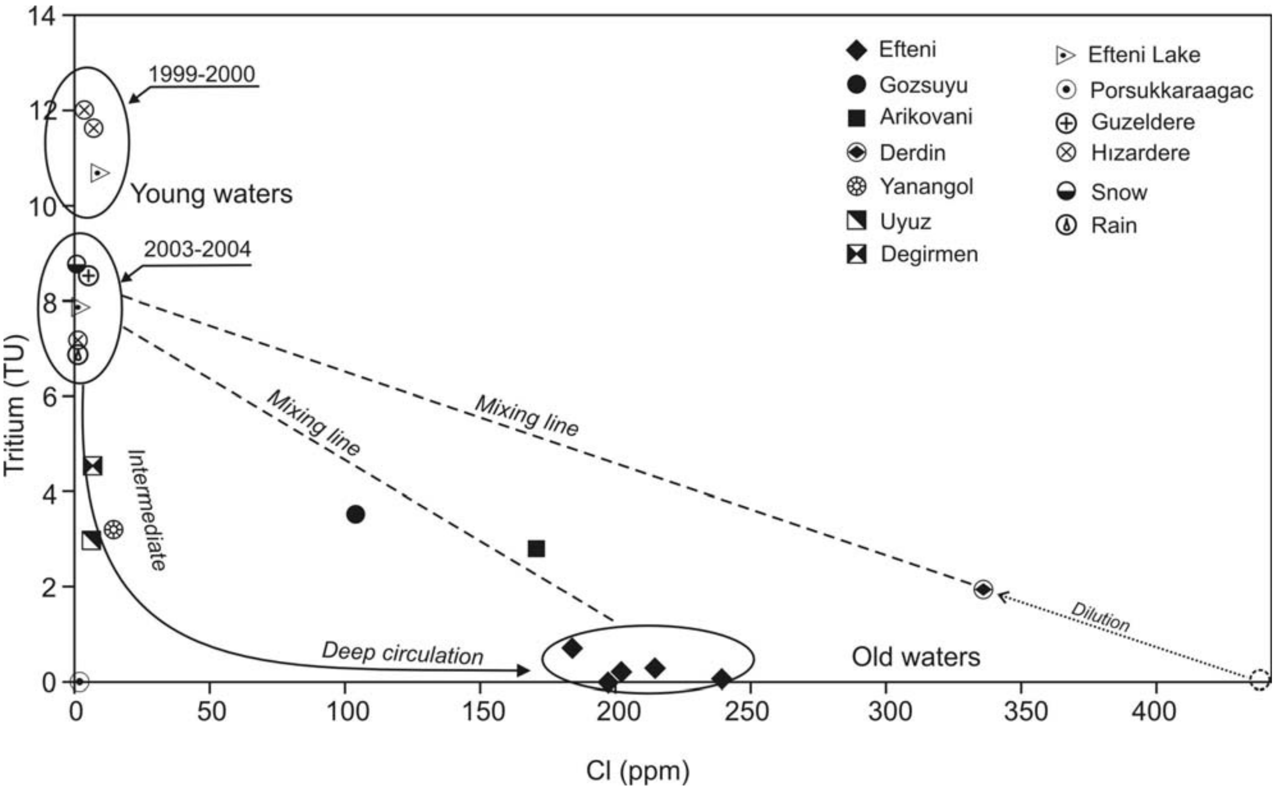

Fig. 10: Tritium – Cl diagram of the thermal and cold waters of the area.

Chloride-Tritium graph (Fig. 10) indicates that Yanangol spring does not represent a simple two component mixture between thermal and cold waters. Relatively low tritium and high chloride concentration of the spring denotes the presence of intermediate groundwater flow system in the area.

7. CONCLUSIONS

In this study, aquifer lithologies and reservoir temperatures were estimated via hydrochemical techniques. Hard and brittle lithologies have acquired secondary permeability through active tectonism thus main aquifers are comprised from joints and fracture zones. That Efteni and Derdin springs show different chemical and isotopical features suggests the existence of two distinct thermal aquifers in the study area. The geothermal waters are mainly Na-HCO3 type waters. Reservoir temperatures were estimated via geothermometry applications as 50-110 ºC. Stable isotopic composition shows that the geothermal waters are mainly of meteoric origin. Clear ^{18}O shift of Derdin spring from LMWL is probably due to ^{18}O isotope exchange by water-rock interaction. Average recharge area altitudes of thermal springs calculated from ^{18}O-Altitude and ^{2}H relationships reveal that the thermal springs are recharged mainly from the highland parts of the Almacik mount. Absence of tritium in the Efteni spring indicates that the residence time of the water recharging the geothermal system is more than 55 years which represents a deep circulation groundwater flow system in the study area. Chloride-Enthalpy and Chloride-Tritium diagrams for possible mixing processes depict that Yanangol spring does not represent a thermal aquifer origin or simple two component mixture; it may be warmed up due to high geothermal gradient.

8. ACKNOWLEDGEMENTS

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