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Hydrogeochemical and Isotopic Survey of Kütahya-Simav Geothermal Field

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ABSTRACT

Simav geothermal field is located in the Simav graben system at Kütahya province in western Anatolia. Geological units are mainly consisting of formations the Menderes Massif. The Kalkan formation and Simav metamorphics consist of migmatite, gneiss and schists of Precambrian - Paleozoic age, and accorded at the basement of the study area. The sequence continues upward with laterally and vertically interbedded, Paleozoic Balikbasi (marble), Saricasu (schist) and Arikaya (crystallized limestone) formations. The Triassic - Jurassic Budagan limestone rest on the above mentioned formation with angular conformity. The Paleocene Egrigöz granite crosscut all the above mentioned units. Detritic and calcareous Kizilbük formation, Civanadag tuff and Akdag volcanic comprising of agglomerate, dacite, rhyodacite and rhyolite are Miocene in age, laterally and vertically interbedded to each other and, overlie the Egrigöz granite unconformably. Coarse detritic Toklargölü formation, Eynal formation and Nasa basalt intercalating both formations occur at the top of the sequence. All of these formations are covered by actual alluvium. Joints and fractures developed in the Nasa basalt (1. reservoir rock), the Budagan limestone (2. reservoir), marble and limestone of the Arikaya and Balikbasi formations form secondary porosity and better permeability. The Eynal formation, Akdag volcanics, Civanadag tuffs, Kizilbük formation and Saricasu formation are impermeable and are cap rocks in character. According to the data obtained from wells drilled for the drinking and irrigation water purposes, ground water flow is toward the desiccated lake. Cold water analysis gave high CO_3+HCO_3, Ca, Mg ion values, and low NH_4, NO_3, Fe, NO_2, Al and Mn ion values. Hot water analysis gave a cation trend of Na+K >Ca>Mg and an anion trend of $HCO_3+CO_3>SO_4>Cl$ .Cold water - hot water interactions and contaminated areas were determined by doing isotherm, resistivity and hydrochemical maps. Based on saturation indices, hot waters are saturated in respect to aragonite, calcite and dolomite and this indicates that rocks at the recharge area and reservoir are calcareous in composition. Isotopic analyses have shown that geothermal water is meteoric in origin and the circulation time of water is longer than 50 years. Reservoir rock temperatures have been calculated as being 148 - 180 ºC through geothermometric applications.

1. INTRODUCTION

In western Anatolia, there are several graben systems related principally to the active tectonism and, in which volcanic activities have been observed. These increase the geothermal potential of Turkey. There are 170 geothermal fields in Turkey, having temperature above 40 °C. One of these important geothermal fields is the Simav geothermal field located in the Simav graben.

Geochemical explorations give lights to find the geothermal potential, to determine the reservoir rock temperatures, to provent any chemical problem that may happen during exploitation and to evaluate the origin of the waters. First geochemical exploration in the field was done by Yenal (1976) on the Nasa and Eynal hot springs. According to the IAH (1979) standards these waters are generally classified as hot water bearing silisic acid, sodium, bicarbonate, and sulphate. First detailed petrographic, geophysical and hydrochemical study was conducted by Yücel et al., (1983). On the Union Oil Company (1982) study, it is concluded that ion abundance of water was as Na>K>Ca, $SO_4>HCO_3>Cl$, that this water does not form crust and, that the possibly of being corrosive is weak. In addition, these researchers were calculated that the reservoir temperature ranges from 160 to 230 °C by means of SiO_2, Na/K and Na-K-Ca geothermometers.

In this study, hydrochemical analyses were realized in field (EC, pH, T, Q etc) and at the laboratories in Hacettepe University and KOSKI. In the Simav drainage basin, there are approximately 85 cold water wells (Ural and Mumcu, 1976), 61 cold water spring, 12 hot water spring and 12 active geothermal water wells (EJ-1, EJ-2, EJ-3, E-2, E-3, E-5, E-6, E-8, C-1, C-2, N-1, N-2, Figure 1). Isotope analyses were conducted by IAEA laboratory in Vienna.

2. GEOLOGY

Metamorphics of the Menderes Massive crops out at the base of the sequence in the study area, and comprises of the Precambrian – Paleozoic Kalkan formation and Simav metamorphics. The Kalkan formation begins with migmatite, amphibolite, granitic migmatite which were cut by aplite vein at the base, and passes into biotite gneisse with marble inter beds and pegmatoid veins, migmatitic gneisse and leptite gneisse. The Simav metamorphics tectonically overlap the Kalkan formation and this form “a cataclastic zone” having many kilometers of extension. In this zone, milonite, milonite schist and cataclasits were determined. The Simav metamorphics comprise of metabasics bearing marble bands and lenses and schist having metabasic and metaultramafic interbeds (Akdeniz and Konak, 1979).

The sequence continues upward by the Paleozoic aged formations which have lateral and vertical transitions. These are the Balıkbası formation comprising of quartz-schist, albite- chlorite- muscovite schist, chlorite – quartz-muscovite schist having marble interbeds, the Sarıcasu formation being composed of quartz phillite and the Arıkaya formation comprising of crystallized limestone.

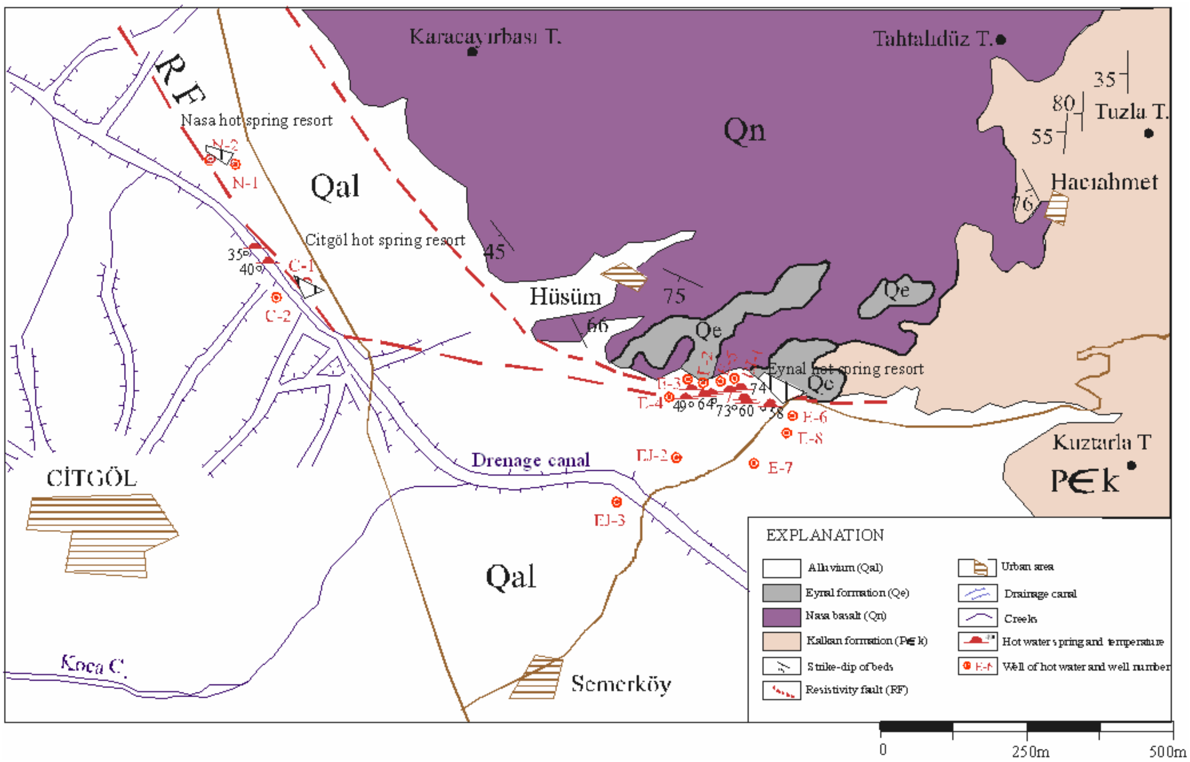

Figure 1: Geological map of the well at its environs.

Rocks which are Upper Triassic – Upper Jurassic in age, dolomitized, laminated, cherty and quartzite bearing crystallized limestone is examined as the Budagan limestone. The Egrigöz granite comprises of granite having granite porphir at its peripheral parts and microgranit cut by aplite and pegmatite veins (Uz, 1991).

The Kızılbük formation is composed of interbedded sandstone tuffite, claystone, and clayey limestone. The Civanadag tuff comprises of riodasit, dasitic and plagiodasitic tuff having sandstone and claystone lenses. Akdag volcanics is made of riyolite, riyodasite, dasite and agglomerate. The Akdag volcanics, the Civanadag tuff and the Kızılbük formation have lateral and vertical transition and are Middle – Upper Miocene in age.

The Toklargölü formation comprising of gravel, sand and clay consolidated in places, the fine grained. Basic Nasa basalt with flow structure come over the above mentioned units. The Eynal formation being composed of loosely consolidated pebble, sand and clay rest over them (Erisen, 1989).

3. HYDROGEOLOGY OF THE LITOLOGY UNITS

Joints and faults resulted from neotectonic activity are caused the developments of secondary porosity and high permeability in limestone and marble. In the study area 4 reservoir rock were determined (Figure 2).

I. Reservoir rock: the Nasa basalt pinching out in quaternary units is the first reservoir rock. The Nasa basalt and the Toklargölü formation covers an area of 84 km^2 in the study area. In Nasa basalt covered by alluvium and Eynal formation, geothermal fluid production is done in C-1, C-2 (abandoned C-3, C-4, C-5) and N-1, N-2 wells. In addition, hot water has been produced from the first reservoir rocks in some of the other boreholes. The highest temperatures in first reservoir rock (105 °C) were measured at 85m of depth in C-1 well.

II. Reservoir rock: the Budagan limestone and the Arıkaya formation having secondary porosity and permeability are the second reservoir rock. These formations crop out in an area of 25 km^2. These formations have longer lateral extension and are located deeper than I. Reservoir rock. Therefore higher temperatures were obtained. Hot water from EJ-1, EJ-2, E-2, E-3, E-4, E-5, E-6, E-7, E-8, and E-9 is drawn from this reservoir. The highest temperature (162.47 °C) was measured from EJ-1 well (Yücel et al., 1983).

III. Reservoir rock: It is possible to consider the presence of third reservoir rock depending on the interbedding of cover and reservoir rocks. The Balıkbası formation crops out in an area of 6 km^2 in the study area. It comprises of secondary porous and permeable marble and underlines the Sarıcasu formation having cover rock characteristics. EJ-1 and EJ-2 wells yield hot water at this reservoir (Yücel et al., 1983).

In the study area tree sealing cap rocks having impermeable characteristics were determined.

I. Cap rock: The Eynal formation over the Nasa basalt contains impermeable clayey level in places. In wells around the Nasa and Citgöl thermal springs, after alluvium, impermeable levels were cut. This points that it has cap rock characteristics. It crops out in an area of 2 km^2 in the study area.

II. Cap rock: The Akdag volcanics, the Civanadag tuff and the Kızılbük formation form a thick cap rock. All these units cover an area of 140 km^2 in the study area. The temperature is raised to 162 °C due to the presence of this cap rock. Whereas a temperature of 105 °C was measured in the reservoir under the I. cap rock.

III. Cap rock: the Sarıcasu formation having lateral and vertical transition with the III. Reservoir rock. It crops out in an area of 19 km in the study area.

Table 1a. The chemical results of waters analyzed in 1995 (From Bayram, 1999).

Sample Name	T (°C)	pH	EC_{25} (µS/cm)	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	Cu	Fe	Zn	Pb	Mn	Ni	Cd	Cr
Ey-1	79	8.16	2646	300	55	60	10	212.1	1166.32	79.76	313.88	0	0.02	0	0.05	0.07	0.03	0.01	0
Ey-2	80	8.7	3370	460	45	40	10	90.9	602.07	81.54	318.92	0	0.45	0.19	0.04	0.05	0.02	0.01	0
Ey-3	67.4	8.79	2520	450	75	25	10	84.9	498.98	83.31	308.85	0	0.15	0.01	0.05	0	0.02	0.01	0
Nasa-1	65.4	6.59	3020	302.5	30	70	15	0	566.69	60.27	254.2	0	0.21	0.13	0.05	0.5	0.02	0.01	0
Nasa-2	45.4	6.79	1800	362.5	30	80	15	0	782.63	65.58	256.36	0	0.05	0.03	0.04	0.43	0.03	0.01	0
Citgol-2	87.7	9.14	2040	360	35	35	5	84.9	403.21	69.13	285.14		0.08	0.18	0	0.02	0.02	0.01	0
Husum	18.1	7.6	535	14.97	9	86	19	18.3	307.44	30.13	22.48								
Akpinar	8.4	7.97	252	2.3	10	48	11	12	160.43	3.55	10.8								
Nadarcam	11.8	7.25	445	4.4	9	68	31	18.3	283.04	8.86	27.69								
Kalkan	16.7	7.47	579	8	8	97	29	18.3	387.35	10.64	28.05								
Ahlatli cs.	14.5	7.65	494	14.3	7	87	14	18.3	270.23	23.04	8.99								
Kınık	13.9	6.15	270	7.1	10	36	6	0	117.12	13.47	8.1								

Table 1b. The chemical results of waters analyzed in 1996 (From Bayram, 1999).

Sample Name	T (°C)	pH	EC_{25} (µS/cm)	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	Cu	Fe	Zn	Pb	Mn	Ni	Cd	Cr
Ey-1	79	8.16	2646	300	57.5	57.5	10	0	556.198	58.493	350.49	0.02	15.03	0.25	0.01	0.11	0	0.01	0.02
Ey-2	64.3	8.47	2060	380.1	42.5	25	7.5	64.71	552.78	63.81	377.82	0.03	0.17	0.03	0	0.02	0	0.01	0
Ey-3	87	7.35	250	2.3	5	39	2	0	125.599	1.773	7.545	0.41	4.97	0.65	0	0.14	0	0.01	0
Nasa-1	56.7	6.13	2100	325	35	60	10	0	604.022	54.548	324.865	0	0.28	0.04	0.01	0.47	0	0	0.02
Nasa-2	50.4	6.62	2230	306.1	45	72.5	12.5	0	669.78	54.94	309.49	0	0.37	0.01	0	0.45	0	0.01	0
Citgol-2	88.5	9.68	2560	342.6	42.5	30	5	64.71	421.205	62.038	352.198	0	3.2	0.02	0	0.04	0	0.01	0.02
Husum	21.4	7.35	680	9.2	4	90	27	0	370.75	5.318	42.224	0	0.12	0.07	0	0.04	0	0.01	0
Akpinar	8.9	7.8	256	2.5	7	42	11	0	173.42	1.773	13.353	0	0.1	0.01	0	0.03	0	0.01	0
Nadarcam	12.9	7.04	489	3.5	8	57	31	0	322.93	3.545	29.07	0	0.08	0.03	0	0.02	0	0	0
Kalkan	18.5	8.7	735	8.1	7	92	26	0	394.73	5.318	37.953	0	0.15	0.02	0	0.02	0	0	0
Ahlatli cs.	16.4	6..9	225	3.8	6	29	4	0	113.64	3.545	7.716	0	0.12	0.05	0	0.01	0	0	0
Kınık	17.3	7.09	540	29.1	12	48	19	0	179.4	58.49	35.732	0	0.12	0.01	0	0.01	0	0.01	0.03

Table 1c. The chemical results of waters analyzed in 1997 (From Bayram, 1999).												
Sample name	T (°C)	pH	EC_{25} (µS/cm)	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	SiO_2
Ey-1	81.2	7.5	1519	510	40	53	5	34.62	744.99	81.53	448.52	69.14
Eynal Spring	96	8.32	2504	520	40	65	7.5	121.17	592.43	77.99	529.53	54.08
Ey-5	90.1	8.77	2808	535	55	127.5	7.5	213.45	445.78	88.62	610.01	119.52
Citgol-2	70.1	7.86	1574	277.5	20	54	7	28.86	416.44	53.17	323.54	63.06
Nasa-1	50.5	6.1	1882	335	25	88	9	0	680.39	56.72	346.26	41.34

4. WATER CHEMISTRY

Analysis of water from many cold water and hot water springs and wells in the study area were compiled (Table 1a, 1b, 1c). Of 69 analyses, 20 are from hot water, 45 from cold water and 4 from creek water. The hydrochemical properties of hot and cold water are given below:

Cold water spring: These springs were observed along the contact between impermeable and permeable units and along the fracture lines. Analysis of cold water springs show that the CO_3+HCO_3, Ca and Mg content is high and that NH_4, NO_3, Fe, NO_2, Al and Mn content is low.

Hot water springs: These springs flow out at the points where the east- west aligned faults was cut by faults aligned differently in the regionally fractured zone. Development of hydraulic channel along the faults facilitates the formation of hot water springs. 12 hot water springs having a temperature range between 35 and 74 °C are spread around the Eynal and Citgöl.

- The Eynal hot water springs: There are many low yielded hot water springs which are very close to each other and, are located in an area west of the Eynal Kaplıca and south of wells. The Ayak Banyosu and Eski Hamam springs waters were analyzed as representing these springs having a temperature between 49 – 74 °C.

- The Ayak Banyosu hot water spring: It is located 100m to south of the Eynal hot spring resort hotel. Its temperature is 54 °C and the anion and cation range is as follow Na>K>Ca and HCO_3>CO_3>Cl.

- The Eski Hamam hot water spring: The temperature of this spring is 65 °C. It is located at the central part of the Eynal Kaplıca. Its anion and cation range is as follow Na>K>Ca and HCO_3>SO_4>CO_3.

- The Citgöl hot water springs: They are located at 500m to south of the Citgöl Kaplıca. There are 2 springs having 35 C and 40 C of water temperatures. The presence of travertine in a small area within the canal points that there were much hot water springs upto near past. These springs were probably exhausted after hot water withdrawn from the drilled wells.

According to the measurement done on the cold-water and hot-water springs in the field, the water electricity conductivity contour curves have maximum closures at the points where there are hot water springs and creeks around the Eynal and Citgöl Kaplıca (Figure 3a).

The chloride contour lines spreads from the fault which provide the hot water springs toward the south and southeast (Figure 3b). This points that the surfacial spreading of elevating hot water is diluted by cold water.

On the bicarbonate contour map, lines were become condense around the Eynal and Citgöl hot spring. Besides, the bicarbonate lines are parallel to the tectonic trend (Figure 3c).

The sulphate contour lines present high closures in Eynal and Citgöl (Figure 3d). Spreading toward the southwest where no water was drown points the dilution of high sulphatous hot water by mixing with cold water. Sodium contour lines show similar behavior with sulphate contour lines (Figure 3e).

Waters in the area are generally rich in calcium (Figure 3f). The calcium contour lines present high anomalies around creeks and hot water springs.

The ammonium contour lines are crowded around creeks and channels (Figure 3g). The onitrate contour lines are condensed at the center of the plain where the groundwater flows are realized (Figure 3h).

4.1. Evaluation of the Water Analysis Results with Diagrams

The main anions and cations in 69 hot water, cold water and hot water wells are compared on the Schoeller diagram (Schoeller, 1962; Figure 4). As it can be seen on the diagram the rCa and rMg content of hot water is low relative to the cold water and the rNa+rK, rCl, rSO_4 and $rHCO_3$+CO_3 is high. The lines connecting the ions in the cold water and hot water is parallel to each other. This points that they have the same origin. But the parallel of lines in intermittent area is lost. This points that hot water is mixed with cold water in the flowing path. On the Piper diagram (Piper, 1953; Figure 5), It has been seen that cold water is classified as Ca+Mg>Na+K carbonate and sulphate water that weak acid root is larger then the strong acid root (HCO_3+CO_3>Cl+SO_4, that the hardness of carbonate is bigger than that of noncarbonated and, that more than %50 of carbonate hardness is $CaCO_3$ and $MgCO_3$ bearing water. In addition, mixed waters in which none of the ions is larger than %50 are present in the study area.

On the Wilcox diagram (Wilcox, 1955), the waters in the study area are determined to be drinkable. On the diagram the sodium percent is calculated by the formula of %Na= rNa/(r+rK+rCa+rMg) where ion concentration are in meq/L. On the diagram most of the cold waters are placed in the very good-good and good-usable area, whereas hot water are placed in "doubtful-usable", "doubtful-inconvenient" and "inconvenient" areas (Figure 6).

On the USA Saltiness Laboratory diagram (Richards, 1954), the sodium absorption ratio was calculated by the formula of SAR= rNa/SQR ((rCa+rMg)/2), where ion concentrations are in meq/l. According to the interpretation of Türkmen (1974) on the USA saltiness laboratories diagram, the EC values of cold water in the study area are variable and, are classified as low (C1), intermediate (C2) and high (C3) salty water. Accordingly, waters falling in the C1 and C2 area can be used in any kind of irrigation. But water in C3 area (11, 19, 20, 21, 25, 26, 30, 36 as 37 numbered springs) can be used only in the irrigation of special plants which are resistant to salty water (Figure 7).

Besides, cold water can be used as irrigation water (S1) without creating a sodium danger. Since the hot water are classified as highly (C3) and very highly (C4) salty water. Plants which are thought to be irrigated with this water must be resistant to salty water and the water which fall in S2 and S3 have sodium danger can be used in irrigation after they are treated with organic and chemical materials. The 42, 43, 54, 56 and 66 numbered hot waters are never suitable for irrigation.

4.2. Evaluating the Isotopic Analysis results

In the geothermal studies, the natural isotopes of water such as δO^{18}, δ^2H are used in determining the drainage basin and the origins of springs, the water- reservoir rock relations, the temperatures of reservoir rocks, the relative age of water, the rate of water circulation and the degree of mixing cold water with hot water. For these purposes, samples collected from cold water and hot water springs and hot water wells in the study area.

The analysis results of tritium (δ^3H) deuterium (δ^2H) and oxygen-18 ($\delta^{18}O$) isotopes are given on the Table 2.

Table 2: Isotope analysis results.

Sample name	Date	$\delta^{18}O$ (™)	δ^2H (™)	3H (TU)	Tritium Error
E – 7 (51°C*)	26.8.1997	-9,34	-65,3	0,78	0,28
Eynal spring (96°C*)	26.8.1997	-8,94	-62,1	0,83	0,28
E – 1 (142°C^x)	26.8.1997	-9,08	-60,9	0,36	0,27
Citgöl – 2 (105°C$^+$)	26.8.1997	-9,23	-55,9	0,64	0,28
Nasa – 2 (50°C*)	26.8.1997	-9,62	-66,7	1,44	0,28
Nadarcam Cs.(12°C*)	26.8.1997	-9,19	-57,1	10,57	0,46

*: Off-spring temperature, ^{x}: Well temperature at 65.8m of depth, $^+$: Well temperature at 46m of depth.

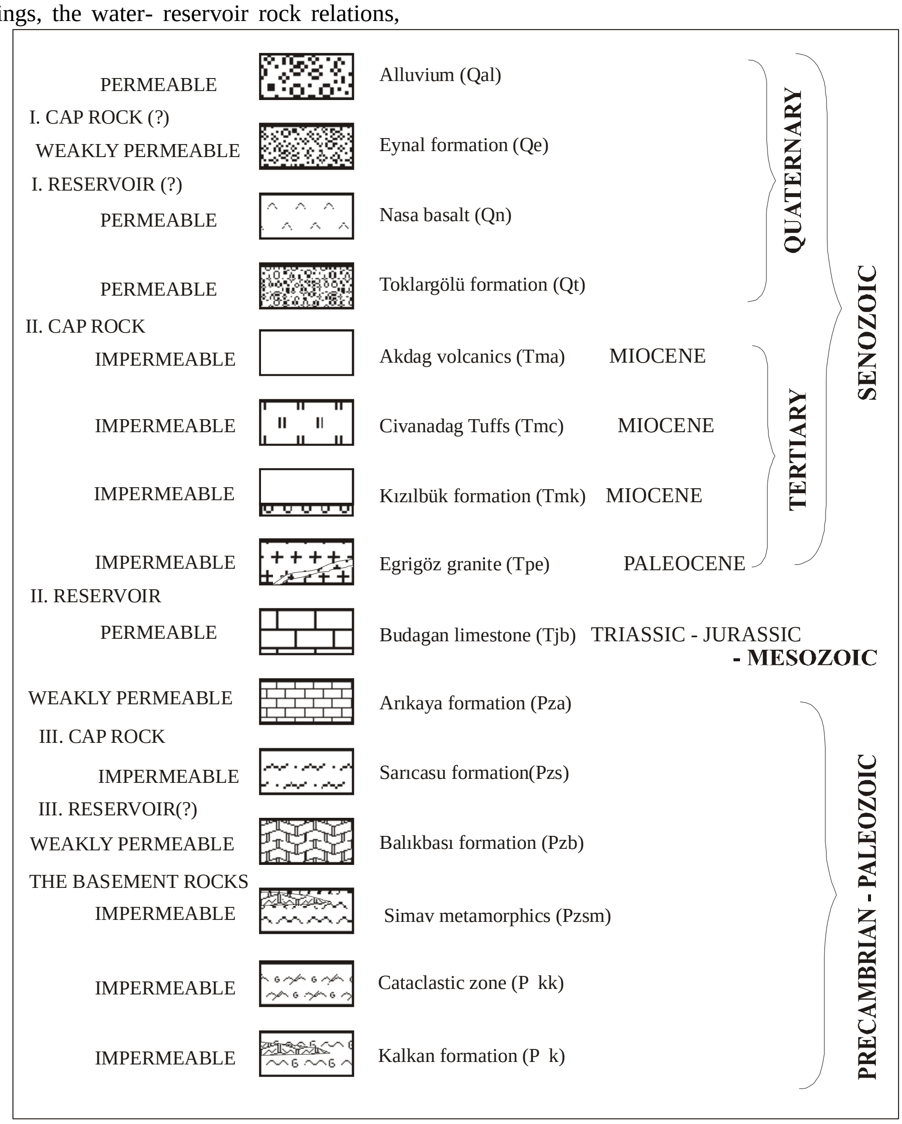

Figure 2: Hydrogeological characteristic of units.

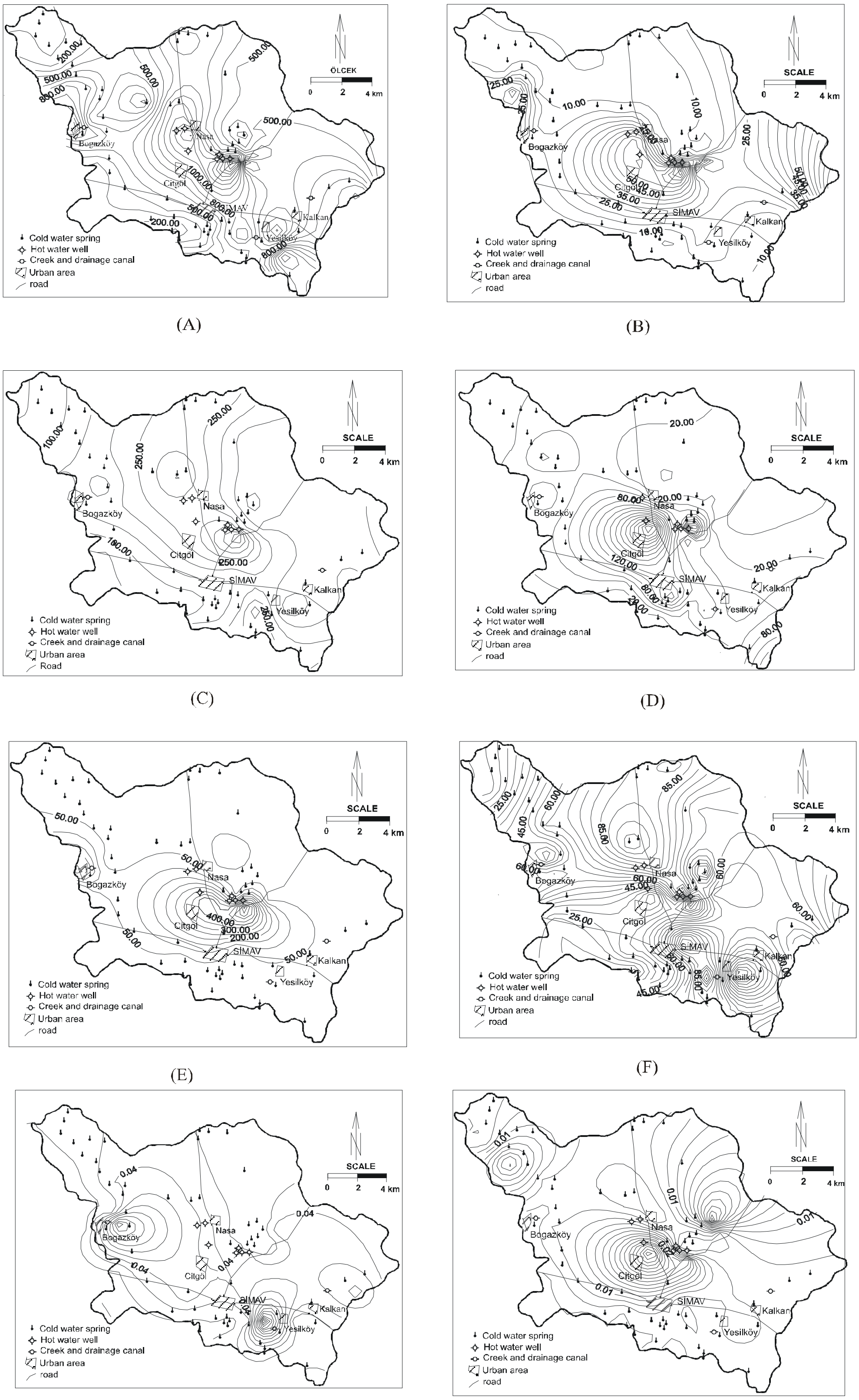

Figure 3: The iso-ion map of the study area (in mg/l). a) Electricity conductivity contour lines, b) Chloride contour lines c) Bicarbonate contour lines d) Sulphate contour lines e) Sodium contour lines f) Calcium contour lines g) Amonium contour lines h) Nitrate contour lines

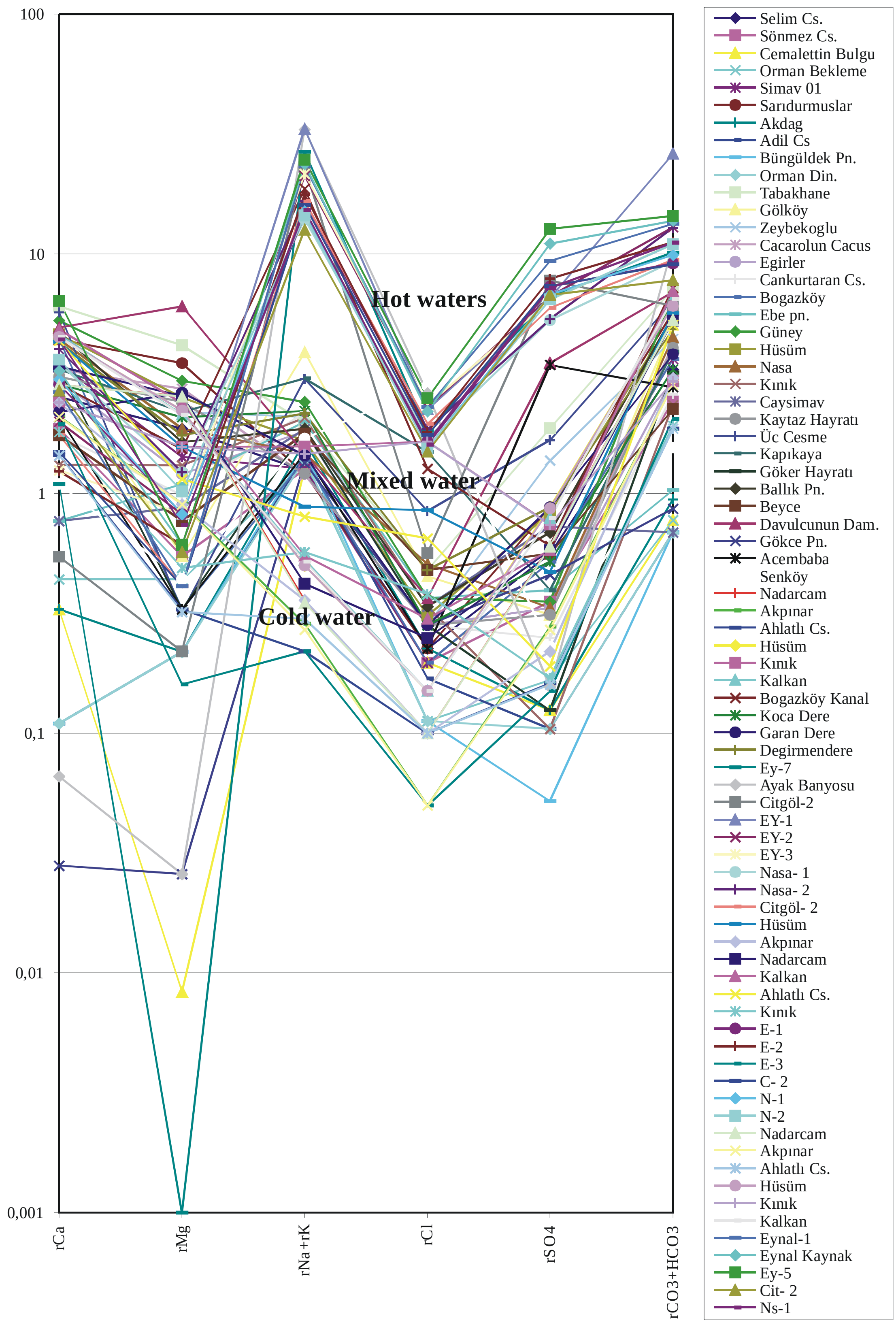

Figure 4: Schoeller diagram for waters in the Simav district.

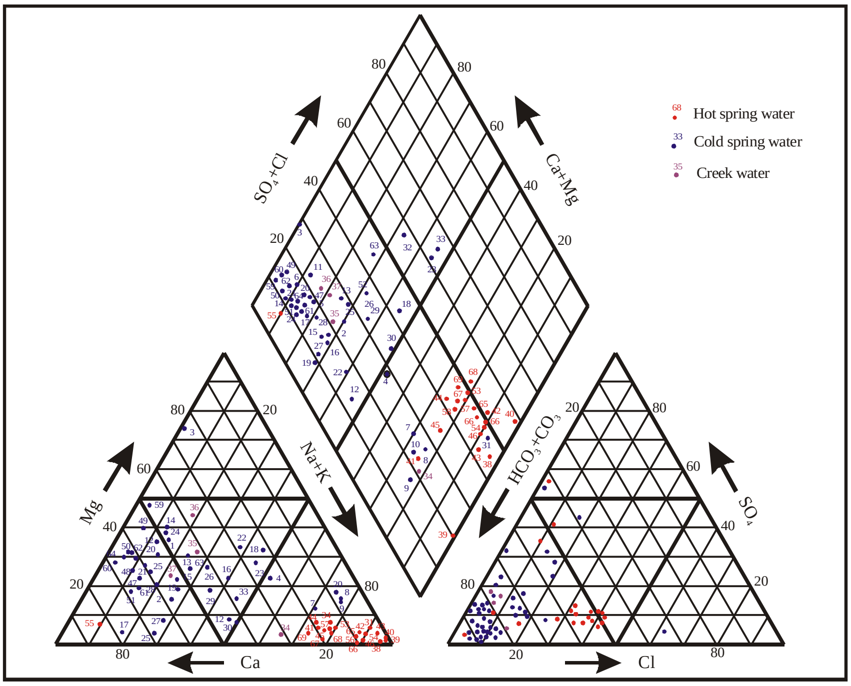

Figure 5. Piper diagram which idendifies types of the waters in the Simav District

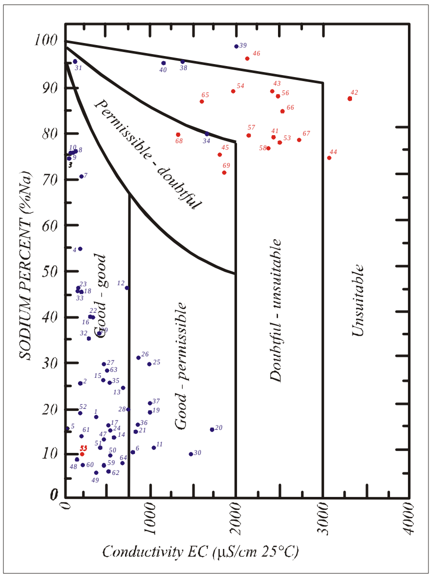

Figure 6. Wilcox diagram for waters in the Simav district.

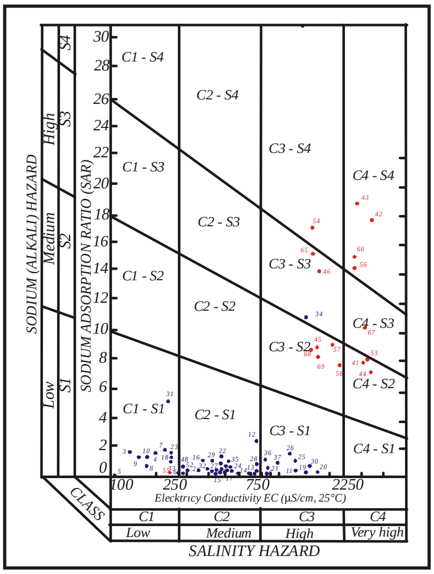

Figure 7. USA salinity laboratory diagram for waters in the Simav district.

The equation of the relation between O18 and 2H in precipitation is linear and this relation for Central Anatolia Region is as follow $\delta^2H = 8\delta^{18}O+10$ (Onhon et al., 1979). Nir (1967) determined the relation for precipitation water in the eastern Mediterranean basin has linearly with equation $\delta^2H = 8\delta^{18}O+22$ (Filiz, 1986).

The $\delta^{18}O$ - δ^3H relation of the water in the study area has close similarities with these lines (Figure 8). This close similarities point that waters are meteoric origin. In addition an enrichment of $\delta^{18}O$ is observed with increasing the temperature of the hot water (Figure 8).

As it can be seen on the Cl – ^3H relationships, the low content of Tritium (^3H) point that the Eynal spring and water in wells were more deeply circulated than other hot waters and, are meteoric origin (Figure 9). After extracting the error ratio for tritium, it has been seen that the circulation of geothermal water takes more than 50 years. Also as it can be seen in ^3H – Temperature (°C) relation (Figure 10) the tritium content drops with increasing temperature.

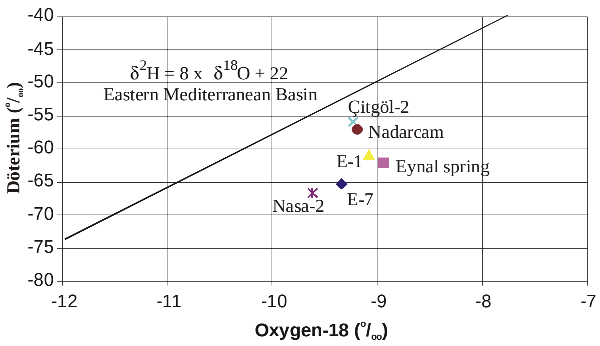

Figure 8. Deuterium (δ^2H ‰) – Oxygen 18 (δ^{18}O ‰) relation.

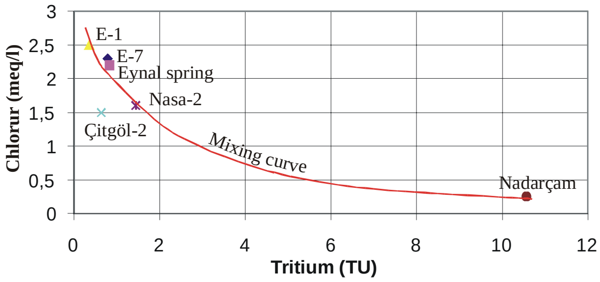

Figure 9. Chloride (Cl, meq/l) – tritium (^{3}H, TU) relation.

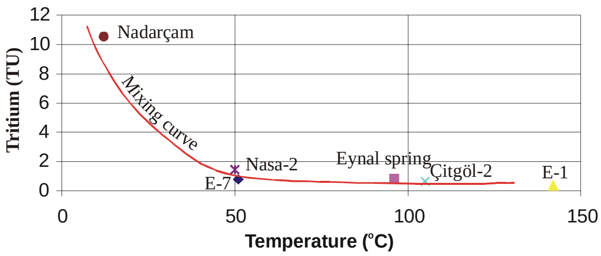

Figure 10. Tritium (^{3}H, TU) – Temperature (°C) relation.

5. GEOTHERMOMETER EVALUATIONS

In the study area, cation and SiO_2 geothermometers are used. The geothermometer equations given in Balmes (1994) and Idris (1998) are as follow;

t°=856/(0,857+(log(Na/K)/log(10)))-273,15 (1)

t° =883/(0,78+(log(Na/K)/log(10)))-273,15 (2)

t° =933/(0,993+(log(Na/K)/log(10)))-273,15 (3)

t° =1319/(1,699+(log(Na/K)/log(10)))-273,15 (4)

t° =1217/(1,483+(log(Na/K)/log(10)))-273,15 (5)

t° =1178/(1,47+(log(Na/K)/log(10)))-273,15 (6)

t° =1390/(1,75+(log(Na/K)/log(10)))-273,15 (7)

t°=4410/(14+(log(K/(Mg^0,5))/log(10)))-273,15 (8)

t° =1096,7/(2,37-(log(Na/Ca^0,5)/log(10)))-273,15 (9)

t° =1930/(2,92-(log(K/Ca^0,5)/log(10)))-273,15 (10)

t° = 1533,5/(5,765-log(SiO_2)/log(10)))-273,15 (11)

t°=
1647/((log(Na/K)/log(10))+α*((log(Ca^0,5)/Na)/log(10))
+2,06))-273,15 (12)

(log(Ca^0,5)/Na)/log(10) < 0 ⇒ α = 1/3 (12a)

(log(Ca^0,5)/Na)/log(10) > 0 ⇒ α = 4/3 (12b)

In order to apply the Na-K geothermometer, the Log (Ca^0.5/Na) must be smaller than 0.5 (Simsek et al., 1997). All the water samples given on Table 3 have Log (Ca^0.5/Na)>0.5. Hot waters in the study area numbered as 38 and 40 fall in the "balanced water" on the Na-K-Mg triangular diagram (Figure 11). Waters falling in the "unbalanced water" area do not give good results in applying of Na-K geothermometer (Giggebbach, 1988). The majority of the waters in the study area is classified as "unbalanced (immature) water" (Figure 11). Na-K-Ca geothermometer applied the high Mg-bearing water gives better results than the Na-K geothermometer (Sahinci 1991). The Mg temperature corrections were done by using temperatures and R values on the graphics prepared by Fournier (1981) in calculating the Na-K-Ca geothermometer values.

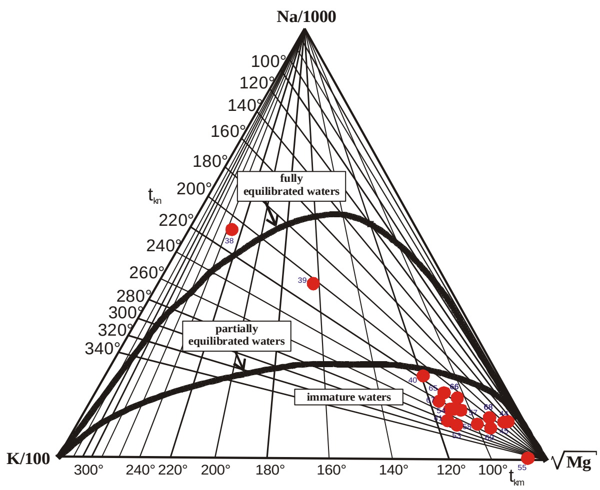

Figure 11. Triangular diagram of Na-K-Mg based on mineral-rock equilibrium (Giggenbach 1991).

Table 3: Estimated reservoir temperatures of the thermal waters calculated by chemical geothermometers.

	Sample Name	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	SiO_2 (mg/l)	Truesdell and Fornier (1976)	(2) Tonani (1980)	(25- 250)	(250- 350)	Fournier (1979)	Nieva and Nieva (1987)	Giggenbach et al. (1983)	Giggenbach (1988)	Tonani (1980)	Tonani (1980)	Tonani (1980)	(1974)
	Geothermometer						Na-K							Na-Mg	Na-Ca	K-Ca	Na-K-Ca	SiO_2
Analysis in 1995	EY-1	300.0	55.0	60.00	10.0		263.95	309.01	266.23	268.37	275.1	260.6	285.8	16.21	1129.3	659.8	216.44	
	EY-2	460.0	45.0	40.00	10.0		185.45	220.27	192.76	213.83	215.1	201.9	230.5	17.88	1884.5	660.2	191.37	
	EY-3	450.0	75.0	25.00	10.0		250.35	293.55	253.63	259.32	265.0	250.8	276.6	13.68	2364.6	833.5	228.46	
	Nasa- 1	302.5	30.0	70.00	15.0		186.92	221.92	194.14	214.90	216.2	203.0	231.6	23.04	1077.7	542.7	178.86	
	Nasa- 2	362.5	30.0	80.00	15.0		168.27	201.02	176.45	201.11	201.2	188.4	217.6	23.04	1165.6	532.8	171.63	
	Citgöl- 2	360.0	35.0	35.00	5.00		184.79	219.53	192.13	213.34	214.5	201.4	230.0	17.09	1599.2	625.3	187.66	
Analysis in 1996	EY-1	300.0	57.5	57.50	10.0		270.53	316.52	272.32	272.69	279.9	265.3	290.1	15.85	1146.1	672.8	219.71	
	EY-2	380.1	42.5	25.00	7.50		200.17	236.81	206.66	224.49	226.7	213.3	241.3	17.16	1969.2	696.4	199.96	
	EY-3	2.30	5.00	39.00	2.00		1373.77	1721.17	1149.6	695.45	789.0	766.7	710.7	29.97	118.00	366.6	28.61	
	Citgöl- 2	342.6	42.5	30.00	5.00		212.28	250.45	218.06	233.11	236.1	222.5	250.1	15.48	1638.2	677.5	202.26	
	Nasa-1	325.0	35.0	60.00	10.0		195.94	232.05	202.67	221.45	223.4	210.0	238.2	19.99	1194.6	578.9	186.45	
	Nasa-2	306.1	45.0	72.50	12.5		233.46	274.40	237.90	247.85	252.4	238.4	265.0	18.81	1073.6	605.3	201.39	
Analysis in 1997	EY-1	510.0	40.0	53.00	5.00	69.14	163.03	195.16	171.45	197.16	197.0	184.2	213.6	15.98	1817.5	612.1	178.45	117.23
	Eynal spring	520.0	40.0	65.00	7.50	54.08	161.16	193.07	169.67	195.75	195.4	182.7	212.1	17.66	1683.6	594.5	175.93	106.90
	Ey-5	535.0	55.0	127.5	7.50	119.5	190.81	226.29	197.83	217.73	219.3	206.1	234.5	15.03	1306.2	591.3	186.12	142.37
	Citgöl- 2	277.5	20.0	54.00	7.00	63.06	155.01	186.21	163.80	191.09	190.4	177.8	207.4	23.25	1109.9	503.4	163.35	113.29
	Nasa-1	335.0	25.0	88.00	9.00	41.34	158.28	189.86	166.92	193.57	193.1	180.4	209.9	22.41	1068.8	500.6	164.16	96.22

Table 4: Gas analysis results (From Bayram, 1999).

Sample Name	Naşa (dissolved)	E-7 Well (vapour)	E-5 Well (vapour)	E-1 Well (vapour)	Eynal spring (vapour)
T (°C)	50.5	86	90.1	96	81.2
pH	6.10	8.50	8.77	7.50	8.32
EC(µS/cm)	1882	1574	2808	1519	2504
H_2	0	0	2.25	0	0
O_2	8.57	8.1	6.01	8.58	7.76
N_2	24.57	23.39	18.25	25.17	23.89
CH_4	0	0	0	0	0
CO_2	66.86	68.5	73.49	66.25	68.35
C_2H_4	0	0	0	0	0
C_2H_4	0	0	0	0	0

The average reservoir rock temperature is calculated as 262.59 °C using the Na-K geothermometer and 181.2 °C using the Na-K-Ca geothermometer.

According to the total 218 ppm SiO_2 content, SiO_2 geothermometer gives 174 °C of temperature. But the average Na-Ca geothermometer is 142.23 °C and K-Ca geothermometer is 207.11 °C (Table 3).

As it can be seen on the Giggenbach diagram. Na-K geothermometer calculation applied to the wells numbered as 38 and 39 and spring water give more reliable results.

6. CONCLUSIONS

Geothermal fluids in the reservoir rocks are related with each other and these relations are realized by faults. Hot water spreading from reservoir rocks to cold water region change the composition of water in these areas and the concentration of Na, K, NH_4, HCO_3, Cl and SiO_2 in cold water increases, whereas the concentrations of Ca and Mg drops.

The analysis results of gas collected from hot water springs and wells, point that there is a little mixing of air if we consider the ratio and balance of oxygen and nitrogen in the air (Table 4). Therefore the main component is CO_2.

The $\delta^{18}O$ - $\delta^{3}H$ relation of the water and Tritium (^{3}H) point that the Eynal spring and water in wells were more deeply circulated than other hot waters and, are meteoric origin and the circulation of geothermal water takes more than 50 years.

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7. REFERENCES

Akdeniz, N. and Konak, N.: Simav- Emet- Tavsanli- Dursunbey- Demirci Yorelerinin Jeolojisi, MTA rapor No: 6547, Ankara (1979).

Arnorsson, S.: Chemical Equilibria in Icelandic Geothermal Systems, Implications for Chemical Geothermal Investigations, Geothermics, 12, 119-128 (1983).

Balmes, C., P.: The Geochemistry of The Mahanagdong Sector, Tongonan Geothermal Field, Philippines, The United Nations University, Geothermal Training Programme, Reports 1994, Number 2, p. 31-52,Orkustofnun, Grensasvegur 9, IS-108 Reykjavik, Iceland (1994).

Bayram, F.: Simav jeotermal Alanının Hidrojeoloji İncelemesi, S.Ü. Fen Bilimleri Enstitüsü Doktora Tezi, 156 s (1999).

Erisen, B.: Simav Grabeninin (Turkiye-Kutahya) Jeotermal Enerji Potansiyeli, Jeomorfoloji Dergisi, 17, 43- 51 (1989).

Erisen, B. ve Yıdırım, N.: Simav - Citgöl (Kütahya) jeotermal alanı Citgöl-1 sondajı kuyu bitirme raporu, MTA rapor (1986).

Filiz, S.: Suyun yası ve izledigi yolun arastırılması, Ege Üniv. Cevre’86 Sempozyumu, s 19, İzmir (1986).

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

Fournier, R.O.: A Revised Equation for the Na/K Geothermometer, Geoth. Res. Council, Transactions, 3, 221-224 (1979).

Fournier, R.O.: Application of water geochemistry to geothermal system, Principles and case histories, L. Rybach and J.L.P. Muftler eds., p 109-143, Wiley New York (1981).

Giggenbach, W.F., Gonfiantini, R., Jangi, B.L. and Truesdell, A.H.: Isotopic and Chemical Composition of Parbatia Valley Geothermal Discharges, NW-Himalaya, India, Geothermics, 12, 199-222 (1983).

Giggenbach, W.F.: Geothermal Solute Equilibria, Derivation of Na-K-Mg-Ca Geoindicators, Geochim. Cosmochim. Acta, 52, 2749-2765 (1988).

Giggenbach, W.F.: Collection and analysis of geothermal and volcanic water and gas discharge, in application of geochemistry in geothermal reservoir development (Ed. By F. D’Amore), p 119-144, Unitar, Rome (1991).

IAH’a (International Association of Hydrogeologists):. Map of Mineral And Thermal Water of Europe, scale 1:500 000, International Association of Hydrogeologists, London (1979)