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CHEMICAL AND ISOTOPIC SURVEY OF GEOTHERMAL RESERVOIRS IN WESTERN ANATOLIA, TURKEY

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ABSTRACT

The main high enthalpy geothermal fields of Western Anatolia and their reservoir temperatures are as follows; Denizli-Kizildere (242°C), Aydin-Germencik (232°C) and low enthalpy areas in Söke region. The Kizildere field is situated in the eastern part of the Buyuk Menderes Graben. The power plant with 20 MWe capacity was installed in 1984. Also, a factory started production of CO_2 in 1986 with a capacity of 40,000 ton/year. Besides 20 exploration and production wells, the reinjection well (R1) was drilled to a depth of 2261 m in 1998. The highest reservoir temperature determined for this area is 242°C. The chemical analysis shows the water type is $NaHCO_3$.

Germencik geothermal field is located 100 km west of Kizildere. The temperatures of the first and second reservoirs are found to be 203-217 and 216-232°C. According to the chemical studies the water types in wells are NaCl and the springs are NaCl and NaCl-$NaHCO_3$.

The geothermal waters are of meteoric origin in the region. Kizildere and Germencik waters are partially equilibrated and deep reservoir temperatures estimated by using different geothermometers are 250-260°C and 230-260°C, respectively. There are clear $\delta^{18}O$ shifts from the Mediterranean Meteoric Water Line (MMWL) in Kizildere and Germencik fields. Also, a good relationship is observed between the high temperature and the $\delta^{18}O$ shift, which shows deep circulation and water rock interactions. In Soke region, low temperature, small isotope shift, shallow circulation and mixing with shallow cold water and seawater are documented.

1. INTRODUCTION

This study has been carried out within the framework of the IAEA Coordinated Research Program of the "Research on Isotope Techniques for Exploitation of Geothermal Reservoirs in Western Turkey".

Geothermal activity is thought to be enhanced by tensional forces that resulted from the rigid behavior of Western Anatolia during the Neogene, which has caused the formation of extended coastal grabens. The geothermal areas that were identified and explored naturally lie along these grabens mainly the Buyuk Menderes, Gediz, Simav, Bakircay, Izmir, Gonen and Edremit grabens. A total of 123 hot springs were identified and 36 geothermal areas were located (MTA, 1980, Simsek and Okandan, 1990 Simsek, 1995).

The reservoir and cap rock characteristics which affect the water circulation system and the source and mechanism of heating are still under investigation. Up to now a total of 500 shallow and deep wells have been drilled in the fields (including about 200 shallow gradient wells in the high temperature fields of Kizildere, Seferihisar and Tuzla). As a result of these studies, a pilot electrical power plant (20 MWe) was installed in Denizli-Kizildere field in 1984 and as well, important greenhouse and domestic heating systems have been developed in Turkey. Approximately 50,000 residences and greenhouses of 300,000 m^2 are heated by geothermal energy (350 MWt). Balneological utilization in 190 spa areas reached 285 MWt, and total installed geothermal capacity is 635 MWt. Since the geothermal sources are clean, cheap and renewable, there is an expectation for widespread applications throughout the country in the near future.

The main purpose of geothermal investigations in Turkey is the development of hydrogeological and geothermal models, determination of the energy capacity, utilization possibilities, and disposal areas for reservoir wastewater (reinjection). However, operation-management and maintenance strategies for an optimum utilization require the knowledge of some important hydrogeochemical interactions and behavior of the reservoir. Considering this fact, this project is designed to determine the relations between chemical properties such as acidity, and origin of fluid production and reinjection at Western Anatolia mainly Buyuk Menderes Graben Geothermal Province which includes the Kizildere, Tekkehamam, Germencik, Salavatli geothermal fields as well as the adjacent fields such as Pamukkale and Golemezli (Figure.1). The water from the reservoir fluid in Kizildere, Tekkehamam and Germencik is acidic in character. To establish the relationship between recharge, production and reinjection, similar studies have been performed in several fields such as Lardarello, Italy and Palinpinon, Philippines. The recharge mechanism, geochemistry and hydrodynamic structure of the system and effects on hydrothermal systems need to be investigated and explained very carefully in order to utilize the geothermal field to optimum capacity (Panichi and Gonfiantini, 1982; Arnorsson 1983; Yildirim 1989; Truesdell, 1990; Gerardo, 1995). Without doubt, this will be accomplished by isotope techniques on samples taken from geothermal fluid, a very useful tool in the above mentioned investigations and studies (Simsek et al., 1993). For that reason, sampling points, sampling time and periods were chosen accordingly.

2. GENERAL CHARACTERISTICS OF THE PROJECT AREA

The regional grabens of Western Anatolia of Turkey have formed due to neotectonic activity between the Miocene and the present. East-west alignment of Buyuk Menderes, Kucuk Menderes, Gediz, Bakircay, Edremit, and Simav grabens have formed as a result of the doming uplift and mainly north-south tensional forces. The grabens are generally asymmetric but some are symmetric. A typical step faulting system is seen at the graben flanks. The thickness of the Neogene and Quaternary deposits in the grabens reaches 2500 m. Geological findings and interpretations have been supported by geophysical and geochemical surveys, and drilling data in the grabens.

The basement rocks in the region are Paleozoic metamorphic rocks of the Menderes Massif. These rocks are composed of mainly gneisses, schists, marble, and quartzite units. The Neogene and Quaternary deposits overlie the basement with an angular unconformity.

The Buyuk Menderes Graben that includes the Aydin and Denizli provinces is located south of the Menderes Massif. The length of the graben is 200 km, the width is 5-40 km and it has continuity in the Aegean Sea.

In the region, crustal thinning and magma intrusion has developed in places together with graben formations. Locations suitable for geothermal systems have developed, especially along dislocation or intersection zones of faults. The slip along the northern flank of the faults where the graben is effective is greater than that of the southern flank (approximately a total of 3000 m). Many hot springs and fumaroles are located along these lines. However, there is thermal activity also along the graben faults on the southern flank near Buharkent (Cubukdag□) where the graben is partially symmetric.

The geothermal areas in the region are located especially along the the main graben fault where the basement units are juxtaposed with young sediments and syntetic and antitetic faults that occurred simultaneously with the main fault.

The hard and brittle lithologies have gained secondary permeability due to active graben tectonism in the region. The first geothermal reservoir in Denizli is limestone (Pliocene) and conglomerates (Miocene) in Aydin. On the other hand, the second reservoir, composed of the marble-quartzite unit of the basement, can be used economically (Simsek, 1989).

The geothermal fluids rising along the main faults of the grabens in the fields is collected in the permeable zones and migrates to the middle section of the grabens.

Some important geothermal fields have been discovered as a result of geothermal exploration carried out by MTA along the Buyuk Menderes Graben. These fields and their reservoir temperatures are as follows: Denizli-Kizildere (242 °C) and Aydin-Germencik (232 °C).

The pilot project area is located in Western Anatolia. Aydin and Denizli areas are located in the Buyuk Menderes Massif representing one of the regional grabens, which are situated in this region.

The selection criteria for a project area are:

a) Location of thermal springs and reservoirs (determined by wells) with highest temperatures in the region (20-242 °C).
b) Presence of varying thermal springs and discharge water of the wells in temperature (low and high) at the same field.
c) Presence of metamorphic and sedimentary reservoir rock and caprock in the region.
d) Presence of SO_4, Cl and HCO_3 water in the same area.
e) Presence of acidic reservoir fluids
f) Geothermal exploitation has been realized at Kizildere (Denizli) field. A pilot Power Plant (20 MWe) is generating electricity, CO_2 production (40000 ton/year) is realized at the same field. Also district heating, greenhouse heating, industrial and balneological uses are important applications in the region.
g) Initiation of reinjection drilling in exploited fields.
h) Government and private enterprises consider presence of geothermal fields where investment plans for geothermal energy use.

3. METHODS

Detailed hydrogeochemical studies have been carried out and chemical analyses made in UKAM laboratories. Analyses of the samples (^2H, ^{18}O and ^3H) which were collected from thermal and cold waters in the study area have been made at IAEA.

4. RESULTS OF THE HYDROGEOLOGIC, CHEMICAL AND ISOTOPE SURVEY OF THE PROJECT AREA

Buyuk Menderes Geothermal Province is located in Western Anatolia. Three groups of fields are situated in the project area. These fields are Kizildere (Denizli), Germencik and Soke (Aydin) fields (Figure 1). The area has a typical Mediterranean climate. Winter and spring are the rainy seasons. Average precipitations are 431, 670 and 893 mm/year respectively in 1960-1990 period.

Denizli-Kizildere Geothermal Field

Kizildere Geothermal Field is located 40 km west of Denizli city. This field was discovered by a cooperative project between MTA and UNDP in 1968. It is situated in the eastern part of the Buyuk Menderes Graben (Figure 1). After the geological, geophysical and geochemical studies, 20 deep wells with a depth ranging from 370 m to 1241 m were drilled in the years between 1968-1973. The field has 2 reservoirs; the first reservoir (130-198°C) and the second reservoir (200-212°C) in production. TEAS (the Turkish Electricity Authority) installed the power plant with 20 MWe capacity in the area in 1984. A factory started production of CO_2 in 1986 with a capacity of 40,000 ton/year and in addition, there is 6000 m^2 of greenhouse heating. A feasibility study is proposed to use the remaining fluid (about 140 MWt) as district heating and for the industry around Denizli.

Besides 20 exploration and production wells, the reinjection exploration well (R-1), which reached a depth of 2261 m., was drilled by MTA on behalf of TEAS in 1998 and produced the highest reservoir temperature (242°C) found in the metamorphic basement (quartzite-schist) for the field, and also in Turkey. This third reservoir was assumed to exist in the area by hydrogeological and chemical arguments (Simsek, 1985).

The chemical and isotopic compositions of 12 water samples, taken from R-1 and other wells (KD-6, KD-13, KD-15, KD-21) in the second reservoir and different temperatures in the field (200-210°C) have been analyzed. These chemical analyses show the water type is $NaHCO_3$ for well R-1, the same as other wells in the field (Table 1 and Figure 2). The geothermal waters have chemical composition where Na+K>Ca>Mg and HCO_3+ CO_3>SO_4>Cl and on a Na-K-Mg diagram fall in the region of partially equilibrated fluids (Figure 3). The main geochemical difference between the second and third reservoir fluids are the HCO_3 and CO_2 contents. The noncondensible gas content of R-1 (the third reservoir) is about 3% by weight while in other wells it is approximately 1-1.8%. From ^{13}C analyses, the origin of the

CO_2 gas is mainly from decomposition of carbonate rocks (Filiz, 1984). Also, a contribution of magmatic CO_2 is important.

It is calculated that the geothermal fluid in the deep reservoirs has an acidic character (pH: 5.5-5.9). A close relationship between the data from geothermal wells (maximum 242^o C) and the cation geothermometers (240-260^o C) has been observed.

Stable isotope results are given in Table 2 which indicates that the water samples in the Kizildere field have a meteoric origin. There is a clear $\delta^{18}O$ shift from the MMWL and cold water values (Figure 4). This suggests that water-rock interaction is an important process for geothermal fluids, implying a deep circulation and high temperatures.

Hot spring waters and deep geothermal wells contain waters with almost no tritium, so the age of the thermal fluids in the field are older than 50 years (Figure 5).

Aydin-Germencik Geothermal Field

This area is located on 100 km west of Kizildere in Western Anatolia. Geological, geophysical and geochemical studies were conducted (Simsek, 1984)and after these studies a total of 9 exploration wells with a depth of 285-2398 m were drilled between 1982-1987. The temperatures of the first and second reservoirs are found to be 203-217 °C and 216-232 °C. The average flow rate is 300 ton/hour and the steam ratio varies from 13% to 20%.

The collected data indicate that the field has important geothermal potential. This resource can be used for generation of electricity, district and greenhouse heating, cooling, industry, tourist and balneological centers.

The chemical and isotopic compositions of some 7 water samples which were taken from hot springs and deep wells (OB-1, OB-2, OB-8, OB-9) have been analyzed (Table 1 and 2). This chemical analysis shows the water type is NaCl for the deep wells, shallow wells and hot springs in the field. The geothermal water samples have a chemical composition where Na+K>Ca>Mg and $Cl>HCO_3+CO_3>SO_4$ or $HCO_3+CO_3>Cl>SO_4$ for shallow well and hot spring waters.

As illustrated in the Na-K-Mg diagram, most of the well discharge waters are partially equilibrated fluids (Figure 3). It is calculated that the geothermal fluids in the deep reservoirs have an acidic character (pH: 4.9-5.5). A close relationship was obtained between the measured temperatures from geothermal wells and the chemical geothermometers to give temperatures of 230-260^{o}C.

The results of stable isotope results are given in Table 2 and indicate that the geothermal waters originated from meteoric waters.

There is a clear $\delta^{18}O$ shift from the MMWL and cold-low temperature Soke region waters. This suggest that water-rock interaction is an important process for most of chloride hot spring and deep geothermal well waters at Germencik reservoirs.

Aydin-Söke Geothermal Area

This area is situated between Germencik geothermal area and the Aegean Sea. Hot springs are located on the northern flank of the main faults of the B. Menderes graben and north side of the Gumusdag horst. The temperature range is 20.6-27.5^{o}C for the springs and 41.7 ^{o}C for the well (Davutlar well). The chemical and isotopic compositions have been measured on 7 water samples collected from 3 hot water springs, 2 cold water springs, 1 shallow well and sea water.

The main lithologic formations are karstic marble and schists of Paleozoic age. According to hydrogeological studies, water samples collected from karstic springs have Ca>Mg>Na+K and $HCO_3+CO_3>Cl>SO_4$ (Sazlikoy and Priene springs). There is mixing with karstic water and seawater from inland to the Aegean Sea and the water composition changes to a Na+K>Mg>Ca and $Cl>SO_4>HCO_3+CO_3$ character.

The Na-K-Mg diagram is shown in Figure 3. The position of all the data points indicates that the thermal systems of the Söke region are immature waters.

The stable isotope results are given in Table 2. Isotopic values of cold waters are very close to the MMWL equation δ2H=8xδ18O+22. Slight deviations from the line show that there is an effect of evaporation on the cold waters and they originate from shallow circulation and a low temperature system (Figure 4 and 5).

The isotopic composition of the thermal waters in the Soke areas shows that they are of meteoric origin. Seawater mixing with this water occurs in the west part of Söke, particularly near the coast. Seawater flow into the West Soke area is along the main E-W graben fault lines.

5. CONCLUSIONS

The geothermal waters are of meteoric origin and have accumulated their heat during circulation in the fault systems. Only west Söke region shows mixing with seawater. The Na-K-Mg diagram indicates that the geothermal systems of the Kizildere and Germencik fields contain partially equilibrated fluids.

Deep reservoir temperatures estimated by different chemical geothermometers for the two major fields of Kizildere and Germencik are 240-260^{o}C and 230-260^{o}C, respectively. The results of new exploratory wells show that the geothermometer estimates are reliable for Kizildere (242^o C) and Germencik (232^o C) fields. Geothermal fluids from the deep reservoirs in Kizildere and Germencik fields are slightly acidic with pH: 5.5-5.9 and pH: 4.9 -5.5, respectively.

The absence of tritium in Kizildere and Germencik geothermal waters indicates that the residence time of recharge waters in the geothermal system is more than 50 years while at the Söke region thermal waters appear to be young in age.

There is a clear $\delta^{18}O$ shift from MMWL in both Kizildere and Germencik high temperature fields. A good correlation between high temperature and $\delta^{18}O$ shift is noticed, which implies a deep circulation and water-rock interaction. In the Söke region however, low temperature, low shift, shallow circulation and mixing with shallow cold water and seawater is observed.

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Table1: The Chemical Analysis Results of The Cold-Hot Waters of Kizildere, Germencik and Söke Regions (July 1998).

Region	Sample No	*Sampling Location	T (°C)	pH	EC (μS/cm)	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	CO_3 (ppm)	HCO_3 (ppm)	Cl (ppm)	SO_4 (ppm)	B (ppm)
KİZİLDERE	30	KD13 HW	79,50	7,62	11000	1125,00	132,50	20,00	1,00	19,56	2214,48	102,80	637,03	11,75
	31	KD6A HW	83,80	8,18	10000	955,00	132,50	122,50	1,50	32,61	2055,33	102,80	617,91	8,30
	32	R1 HW	76,70	8,18	12500	1595,00	127,50	25,00	1,50	45,66	3222,20	147,12	747,95	19,10
	33	Tekkehamam HS	67,80	7,07	9000	905,00	92,50	45,00	4,50	218,70	820,94	88,62	988,84	9,72
	34	Tekkeköy CS	28,90	8,37	1300	32,50	17,50	125,00	65,00	56,07	302,13	21,27	290,91	1,70
	MRBK	Menderes RW	14,10	8,45	900	51,70	11,00	91,00	46,00	72,90	199,53	63,81	141,15	1,40
	MRAK	Menderes RW	19,10	8,18	1200	72,40	35,00	135,00	70,00	56,07	239,42	67,35	415,21	1,59
GERMENCİK	40	Bozköy HS	59,50	6,83	10000	1505,00	90,00	90,00	17,50	285,99	1818,59	1152,12	46,30	20,49
	41	Bozköy-Confined HS	55,00	7,30	10000	1320,00	100,00	167,50	67,50	489,12	1611,13	1063,50	3,66	10,85
	42	Gümüsköy HW	38,70	6,96	5000	705,00	62,50	152,50	30,00	56,07	729,74	957,15	37,50	2,99
	43	ÖB2 HW	47,50	6,71	9000	1445,00	135,00	30,00	1,00	0,00	1419,53	1559,80	33,30	31,32
	44	ÖB9 HW	88,60	8,20	14200	1440,00	140,00	85,00	10,00	336,45	860,83	1542,07	43,62	27,83
	45	ÖB8 HW	48,50	7,08	8800	1410,00	122,50	62,50	1,50	0,00	1396,72	1488,90	96,02	29,00
	46	ÖB1 HW	30,00	7,21	6500	1440,00	60,00	50,00	1,00	0,00	1140,21	1595,25	125,85	31,06
SÖKE	47	Tuzburgazi HS	20,60	6,68	39500	9230,00	360,00	640,00	437,50	39,24	267,97	15598,00	1577,87	3,83
	48	Karina HS	26,60	7,03	45000	11725,00	480,00	715,00	462,50	22,44	119,74	19852,00	1858,98	5,12
	49	Sea Water	27,50	8,33	46000	12110,00	485,00	505,00	477,50	56,07	62,71	20029,20	1786,32	5,89
	50	Yuvaci CS	19,50	7,85	2200	360,00	20,00	120,00	47,50	44,85	153,90	638,10	212,51	1,67
	51	Prien CS	21,40	7,54	750	29,00	15,00	93,00	40,00	50,46	267,97	42,54	92,19	1,62
	52	Davutlar HW	41,70	6,28	12000	1650,00	110,00	462,50	80,00	112,14	1185,78	2747,37	58,73	2,22
	53	Sazliköy HS	26,80	7,56	1130	37,30	7,00	152,00	44,00	112,14	437,86	49,63	22,59	1,74

* :Abbreviations; **HW** (hot water well), **HS** (hot water spring), **CS** (cold water spring), **RW** (river water)

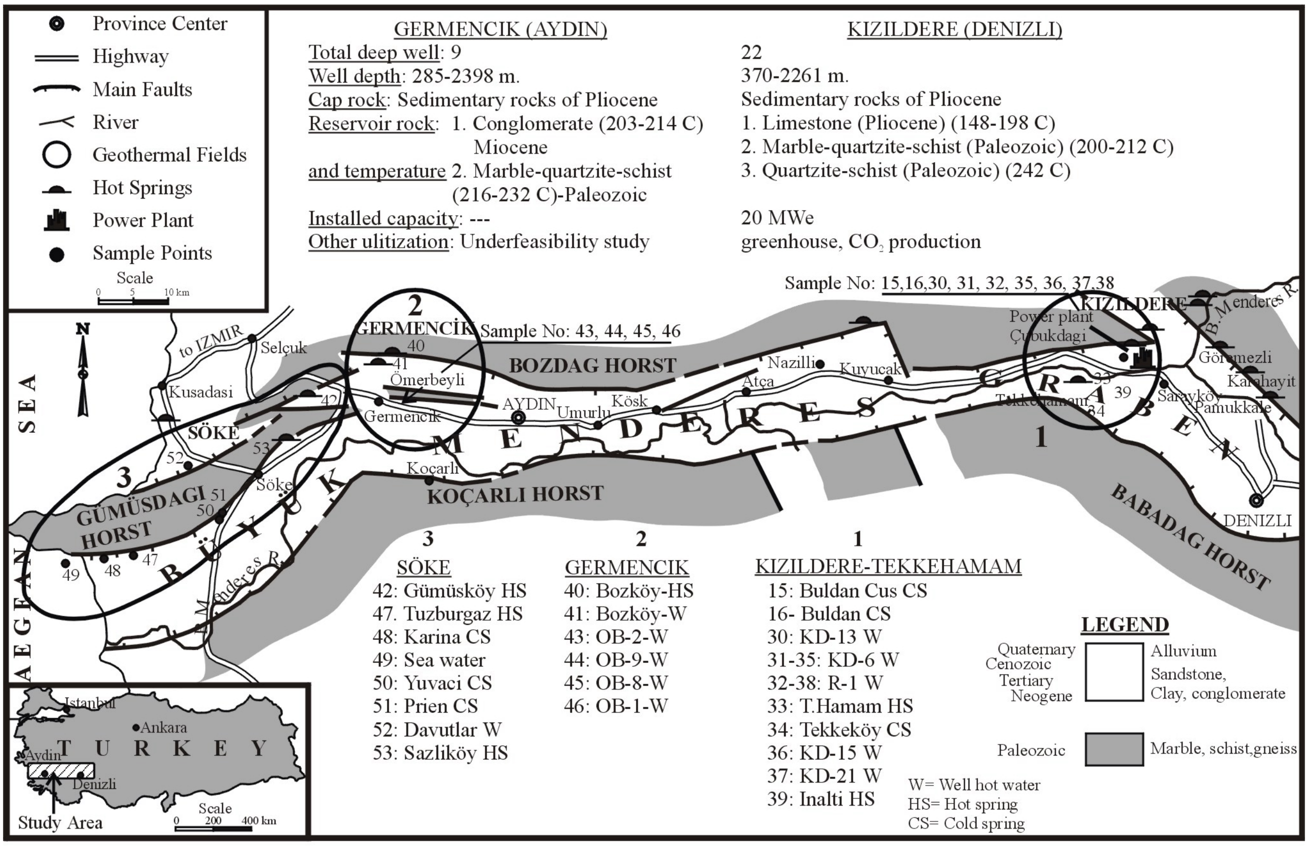

Figure 1: Main geothermal fields and sampling points of the study area.

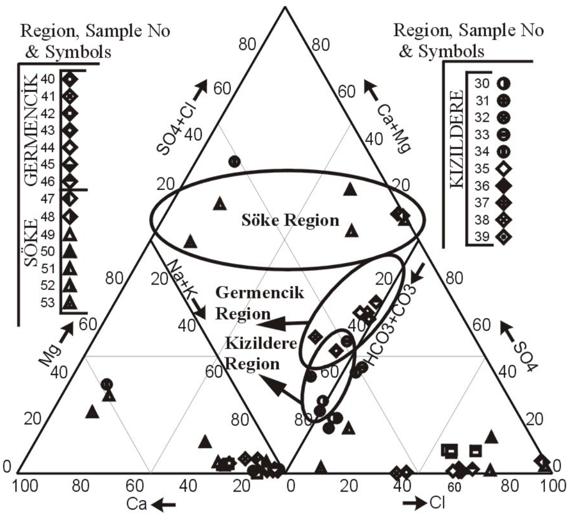

Figure 2: Triangular diagram of the thermal waters in the study areas.

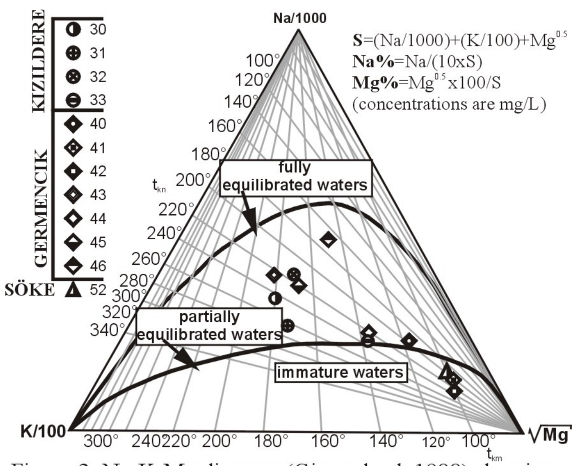

Figure 3: Na-K-Mg diagram (Giggenbach 1988) showing Kizildere and Germencik (high enthalpy fields) fluids located partially equilibrated water zone. Söke waters (low enthalpy field) located immature waters.

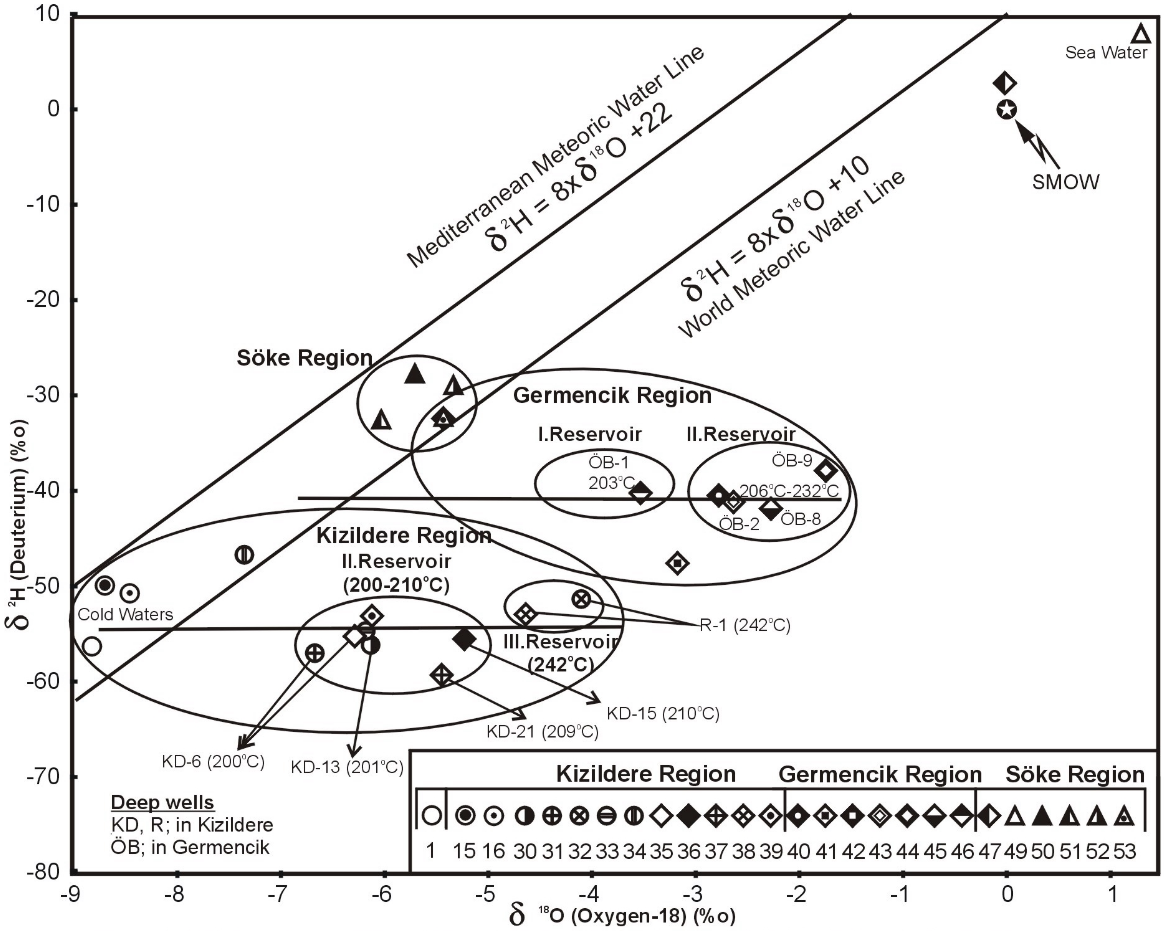

Figure 4: Stable isotope compositions of the geothermal reservoir fluids in the study areas.

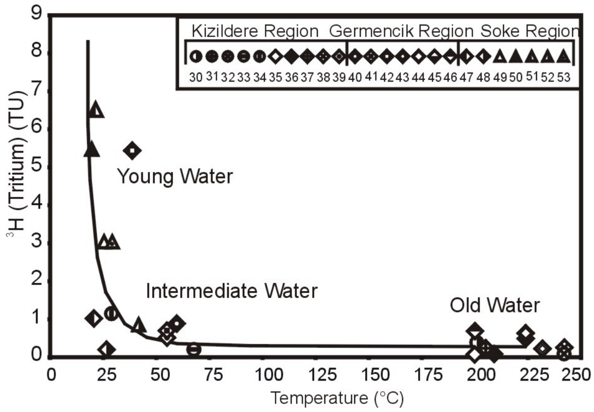

Figure 5: ^3H (Tritium) and Temperature (°C) diagram of thermal and cold waters in the study area.

Table 2. Environmental Isotope (^{18}O, ^2H and ^3H) Data of The Cold-Hot Waters of Kizildere, Germencik and Söke Regions.

Region	Sample No	Sampling date: July 1998 Sampling Location*	$\delta^{18}O$(%)	δ^2H(%)	^3H(TU)	(TU) Error
KIZILDERE	15	Buldan Çus CW	-8,49	-50,00	5,96	0,45
	16	Buldan CW	-8,44	-50,50	0,46	0,32
	30	KD13 HW	-4,64	-34,10	0,09	0,28
	31	KD6A HW	-6,13	-56,20	0,39	±0,34
	32	R1 HW	-6,67	-57,00	0,16	±0,33
	33	Tekkehamam HS	-4,10	-51,30	0,09	±0,33
	34	Tekkeköy CS	-6,18	-54,70	0,21	±0,35
	35	KD6 HW	-7,35	-46,70	1,15	±0,35
	36	KD15 HW	-5,23	-55,50	0,10	±0,34
	37	KD21 HW	-5,45	-59,30	0,24	±0,33
	38	R1 HW	-4,64	-52,90	0,26	±0,33
	39	Inalti HS	-6,13	-53,50	0,52	±0,33
GERMENCIK	40	Bozköy HS	-2,78	-40,45	0,89	±0,34
	41	Bozköy-Confined HS	-3,18	-47,60	0,70	±0,34
	42	Gümüsköy HW	-5,43	-32,40	5,44	±0,41
	43	ÖB2 HW	-2,64	-41,20	0,23	±0,33
	44	ÖB9 HW	-1,74	-37,90	0,64	±0,33
	45	ÖB8 HW	-2,27	-41,90	0,50	±0,33
	46	ÖB1 HW	-3,53	-40,20	0,69	±0,33
SÖKE	47	Tuzburgazi HS	-0,02	2,70	1,02	0,35
	49	Sea Water	1,58	9,50	3,03	0,36
	50	Yuvaci CS	-5,71	-27,90	5,45	0,40
	51	Prien-Pinar Rest. CS	-6,02	-32,70	6,50	0,42
	52	Davutlar-Thermal HW	-5,34	-29,10	0,84	0,33
	53	Sazliköy HS	-5,97	-32,50	3,03	0,36

* Abbreviations: **HW** (hot water well), **HS** (hot water spring), **CS** (cold water spring)