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The Relation of Geothermal Resources with Young Tectonics in the Gediz Graben (West Anatolia, Turkey) and Their Hydrogeochemical Analyses

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ABSTRACT

Paleozoic Menderes metamorphic rocks (gneiss, micaschist and marbles) comprise the basement in the area. The metamorphics are unconformably overlain by a Neogene sedimentary and volcanic rocks. The upper most part is represented by Quaternary alluvium. In Western Anatolia again E-W trending normal faults and NE-SW and NW-SE trending right lateral strike slip faults have been formed as a result of E-W trending compressions. Gediz Graben, like Büyük Menderes Graben, formed during Quaternary. That is why Quaternary volcanics formed along the E-W trending fractures, while the Neogene volcanic products of West Anatolia crop out near the N-S trending fractures and fissures.

In the region, WNW-ESE trending faults have been formed during Upper Quaternary, while E-W and NE-SW trending faults formed during Lower Quaternary and this activity continues presently. In fact, geothermal resources are located at the intersect points of these differently-directed tectonic events. Gediz Graben is also a rift system and the formation of the Quaternary Kula volcanics of the region is related with this rift system. The heating source of the geothermal systems in Gediz Graben is these deepening young faults and Kula Volcanics.

Many hot water resources occur along Gediz Graben starting from Alaşehir-Sarıgöl in the east. The measured reservoir temperature is 215^oC in Alasehir, 155^oC in Salihli, and 85^oC in Urganlı geothermal system. Accordingly, temperatures in Gediz Graben decrease from east to west. The thermal waters of Alaşehir, Salihli and Urganlı geothermal systems are alkaline where carbonate alkalinity>non carbonate alkalinity. They are very soft waters which is rarely found in the nature. According to the classification nearly whole waters' type is sodium-bicarbonated.

1. INTRODUCTION

The Gediz graben is located in western part of Turkey (Figure 1). The Alaşehir, Salihli and Urganlı fields under investigation are next to each other and are within the same geothermal system. The aim of this work is to investigate lithologic, structural and hydrochemical relations between the Alaşehir, Salihli and Urganlı geothermal fields each of which has been studied previously. In the preparation of this manuscript, studies of MTA, universities and private sector were utilized. Studies conducted for each field were synthesized and used for modeling of the Gediz geothermal system.

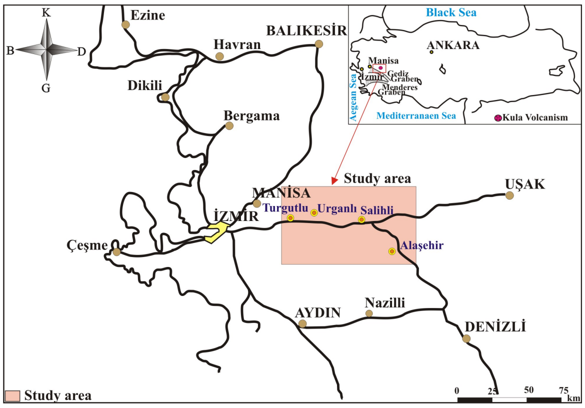

Figure 1: Location map of the study area.

2. GEOLOGY

The Alaşehir-Salihli-Urganlı geothermal fields under investigation are located in the ESE-WNW extending Gediz graben. The generalized stratigraphic section of the Gediz graben is shown in Figure 2. Metamorphites of the Paleozoic Menderes massif comprise the basement. These are overlain at northwest part of the graben by the Mesozoic ophiolithic rocks of allochtonous character (1/500.000 scaled geologic map of M.T.A). Miocene and Pliocene sediments unconformably overlie the older units. Quaternary travertine and alluvium set above the Basement rocks and Neogene deposits with a discordance (Figure 2). The Menderes massif mostly starts with spotted gneiss at the bottom and continues with various types of schists to the top. Gneiss is mostly exposed on the hanging part of the horst at south of Sarıgöl, Alaşehir and Salihli. Schists are generally observed just south of Salihli and Alaşehir and east of Urganlı (Figure 3). Marbles in upper parts of basement rocks are exposed around Salihli and Urganlı. They are called as Azıtepe marbles, Karamanderesi et al. (1984) (Figure 3).

Tertiary deposits overlie the metamorphites of the Menderes massif along the Gediz graben. These deposits, so called Osmaniye group, are well exposed in between Salihli and Alaşehir areas. They contain Miocene conglomerate, sandstone and claystone levels and little amount of fine to thick bedded limestone levels. Pliocene deposits cover a wide area. They are mostly composed of conglomerate, sandstone, claystone and tuff interbedded and their lower parts are variegated while upper sections with lignite layers are white colored (Figure 3). Emre (1996), described the Neogene units around the Salihli-Alaşehir area as Acıdere, Göbekli and Aşartepe formations. Quaternary travertine and old and recent alluviums are at the top, Karamanderesi et al. (1984).

Based on field observations, Alaşehir-Salihli-Urganlı geothermal fields show lithological continuity. They have similar cover and reservoir rocks and heating source.

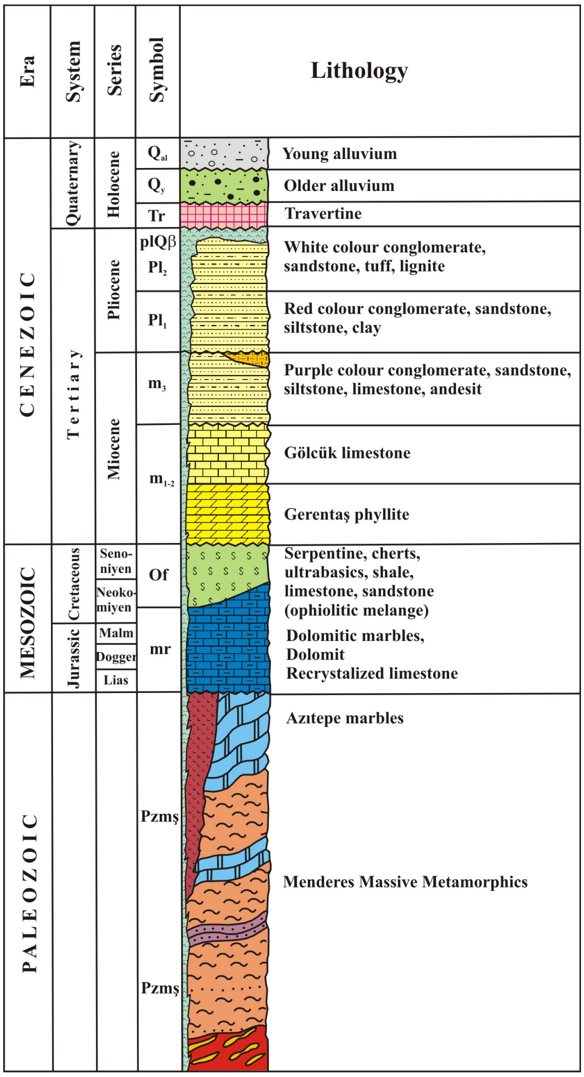

Figure 2: Stratigraphic columnar section for the study area.

3. TECTONISM

The Gediz graben is located in a tectonically active region (Figure 3). Gediz and Büyük Menderes grabens in Turkey are formed by Quaternary E-W compression. NE-SW and NW-SE trending faults in the region are of strike-slip character while E-W trending ones are of normal fault type. According to, Arpat and Şaroğlu (1975), there are several active normal dip-slip faults in the Salihli-Alaşehir graben. The Neotectonic period in western Anatolia was started continent-continent collision in the Miocene, Şaroğlu (1990); Yılmaz (1980).

Until upper Pliocene, deformation was developed as N-S trending compression. In the upper Pliocene, the Anatolian plate moved westwards along the North and Eastern Anatolian transform faults and direction of deformation was E-W in the Quaternary. In the first stage, NE-SW trending left-lateral and NW-SE trending right-lateral faults were formed. In the second stage, trends of tectonic structures were changes to N-S in folds and thrust faults, E-W in normal faults, NE-SW in right-lateral strike-slip faults and NW-SE in left-lateral strike-slip faults, Şaroğlu (1990); Yılmaz (1982).

In association with above-mentioned tectonic events in Neogene, volcanic activity was developed in N-S trending normal faults and extension fractures. In the Quaternary, E-W trending fractures were the eruption centers of volcanic products, like in the Kula basalts. According to Yılmaz and Şengör (1982), the region was uplifted which resulted in formation of a mantle-derived hybrid magma. They conclude that Kula volcanism and grabens are the surface manifestations of this magmatic activity. This is consistent with young tectonic events. Neomagmatism in the Gediz graben was very effective on development of Neogene and Quaternary basins, Şaroğlu (1990); Yılmaz (1982). Basalts in this region of graben tectonism were formed by magma upwelling from hot a spot, Ercan and Öztunalı (1982).

The lower Quaternary is represented by E-W and NE-SW trending faults while the upper Quaternary is characterized by WNW-ESE trending faults and these activities are still continued (Figure 3). There is a close relation between the formation of Gediz graben and geothermal system. Thermal springs are issued at the junctions of Quaternary and pre-Quaternary faults. The Alaşehir, Salihli and Urganlı geothermal fields (Figure 3) in the Gediz graben were formed after the culmination of these tectonic activities. Active faults within the Gediz graben are ideal heat flow conduits for the geothermal energy model. The general trend of these young and active faults is WNW-SSE (Figure 3).

Gravity data, Erden (1965) indicate that the Gediz graben is also a rift system. Young tectonic activities associated with the rift system supply heat to the thermal springs.

As a result, basin formation shows parallelism with young tectonic development in the Alaşehir-Salihli-Urganlı geothermal system (Figure 3). These events were also affected by Neomagmatism time to time. Basin formation, young tectonic activities and Neomagmatism are successive events but they might also be formed concurrently. Faults forming the Gediz graben have slip of as much as 1500 m. Focal depths of these faults might attain a depth of 10-15 km Yılmazer (1988). This indicates that heat from the crust is transferred to the surface and plays an important role in the formation of geothermal system.

The Neogene terrestrial sediments, which are made up of poorly cemented clayey levels, have very low permeability and may act as cap rocks. Sandstone and conglomerate levels of this Neogene unit contain minor aquifers. The circulation of the thermal and mineral waters is closely related to major fault and fractures zone Yılmazer (1984). The heat source of all geothermal system in Gediz graben may probably related to the high thermal gradient caused by graben structure of the area.

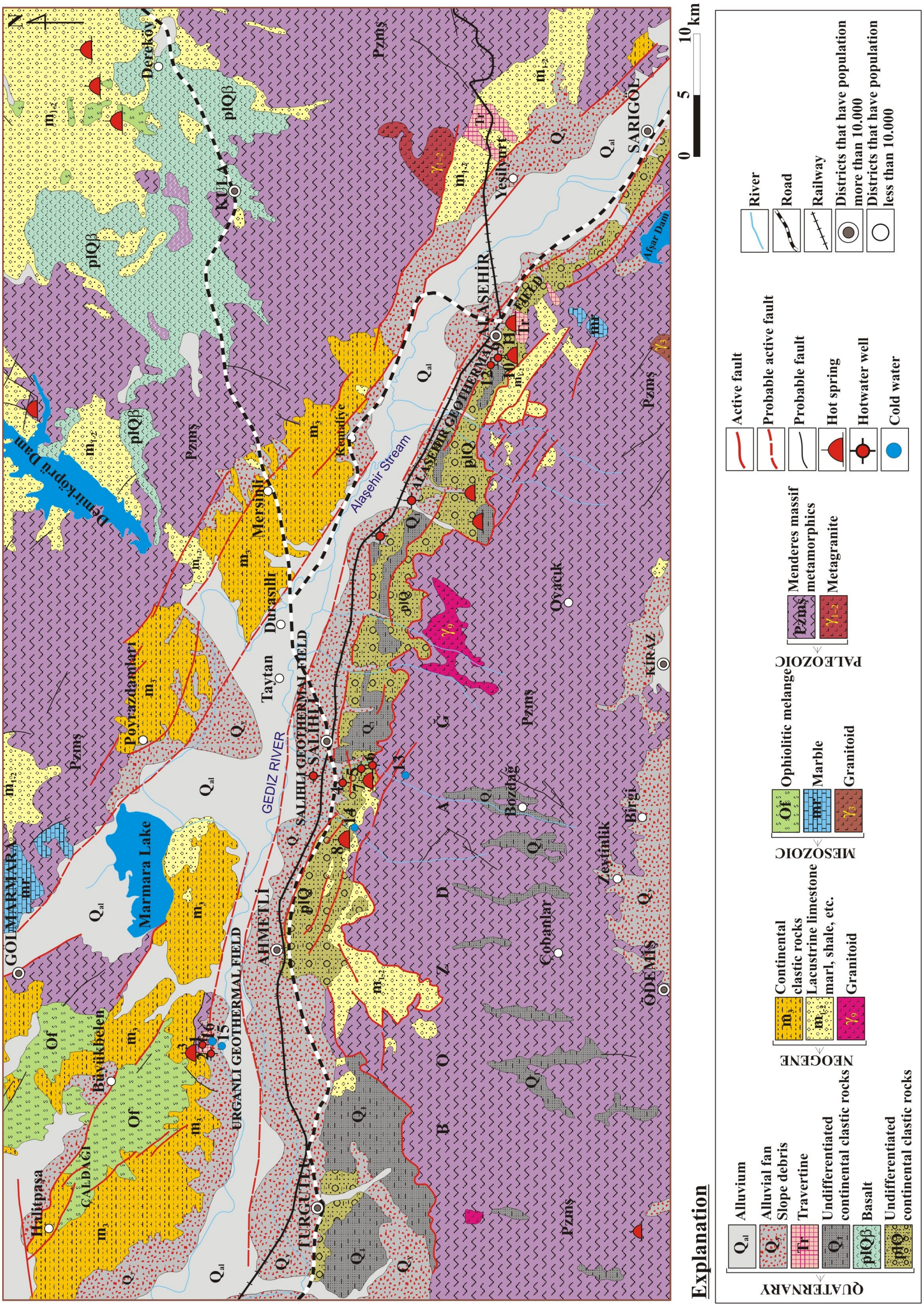

Figure 3: The geological map of the study area (after M.T.A, 2002).

4. BACKGROUND ON THE INVESTIGATED GEOTHERMAL FIELDS

Major thermal and mineral water sites of the Gediz graben are Turgutlu (Urganlı), Salihli and Alaşehir. Table 1 summarizes the number of wells drilled, maximum and minimum drilled depths, measured down hole temperature ranges, total discharge rate, aquifer and cap rocks, present use, and references for Turgutlu, Salihli and Alaşehir geothermal systems. The permeability within the Menderes Masif rocks are highly fractured and karstified and act as an aquifer for both thermal and cold waters. Also fractured gneiss and quartz-schist units of the Menderes Massif act as aquifers for thermal and mineralized waters for Gediz Graben geothermal systems. The Neogene terrestrial sediments, which are made up of poorly cemented clayey levels, have very low permeability and may act as cap rocks. Sandstone and conglomerate levels of this Neogene unit contain minor aquifers. The circulation of the thermal and mineral waters is closely related to major fault and fractures zone, Karamanderesi and Yılmazer (1984).

The heat source of all geothermal system in Gediz Graben may probably related to the Kula volcanism (Figure 3). In addition, tectonic activities in association with volcanism transfer the magma heat to the surface and therefore, geothermal gradient in these fields is high.

Turgutlu geothermal field is located along the northern rim of Gediz Graben. Exploration of Urganlı geothermal field began in 2001, and to date, 10 deep wells have been drilled. The wells produce from a reservoir with a maximum temperature of 83°C, Yılmazer et al. (2008); MTA (2005). Temperatures of thermal water springs and wells range from 50 to 75ºC with flowrate of 0.5-2 l/s and 62-83°C with flowrate of 2 to 40 l/s respectively, Vural (2009).U-1 well drilled by MTA in 2002 with a deep of 460 m. The temperature of the this well is 62°C and has 20 l/s of artesian well. This well was used for feding of the green house plants with CO_2 which was the first application in Turkey, Tarcan et al. (2005). Today are not used any more. Unfortunately U-1 well has been constantly discharging with uncontrol into the environment. Salihli and Alaşehir geothermal field are located along the southern boundary fault of the Gediz Graben which is more active than the northern fault. Salihli geothermal field is situated to the SE of Manisa at a distance of a bout 48 km to the city. Salihli is also known for its mercury mineralization of hydrothermal origin where small mining operations, including underground mining, have been carried out intermittently for several years. The field is currently under reconsideration as a prospect foe epithermal Au-Sb mineralization, Larsen and Erler (1993). In the Salihli geothermal field hot springs are concentrated in the Kurşunlu, Kükürtlü and Sart areas. Kurşunlu and Sart thermal springs are located to the southwest of Salihli, at a distance of 6 km and 11 km, respectively, from the city center. Kurşunlu is the most important geothermal field in the area. Thermal waters in the Kurşunlu area are used for balneological purposes and thermal well waters in the Salihli are utilized for central heating.

The Major faults in the field trend dominantly E-W and NW-SW while N-S and NE-SW trending faults also exist on a smaller scale. A total of 25 wells were drilled in the field. The maximum and minimum drilled depth in the area are between 40 and 1189 m with discharge rate between 5 and 40 l/s. In 1997 a well (SC-1) drilled in the Salihli-Caferbeyli geothermal system has a maximum temperature of 155°C at 1189 m, Karamanderesi (1997). However, a low discharge rate of 2 l/s, suggesting low permeability, has deterred economic use of this well, MTA (1996). Alaşehir geothermal field is located in the Gediz graben. As a result of drilling of 7 wells with a depth of 450–1507 m, thermal water with a discharge of 8-12 l/s and with a temperature of 56–215ºC was produced.

A deep well (KG-1) in Kavaklıdere-Göbekli was drilled by MTA in 2002. The KG-1 (no 9) well with a depth of 1447 m and discharge a 12 l/s artesian flow, Karahan et al. (2002). The temperature of this well is 182°C. In addition the Ak-2 well (no 12) is the deepest well drilled in Alaşehir with a depth of 1507 m and discharge rate of 12 l/s artesian flow. The temperature of this well at the bottom hole is 215 °C the third high temperature well in Turkey, Karahan et al. (2002).

Table 1: Well informations for Urganlı, Salihli and Alaşehir geothermal systems.

Geothermal System	NWD	MMDD	TDR (l/s)	Reservoir Rocks	Cap Rocks	Present Use	Well Temperature	References
Urganlı Geothermal System	10	280-605	2-40	Paleozoik to Mesozoik Menderes masif marble, schist and quartizite	Neogene interclated siltstone claystone, sandstone, conglomerate	Spa, Green house heating	62-83°C (well head)	Yılmazer et all, 2008; Vural, 2009
Salihli Geothermal System	25	40-1189	5-40	Paleozoik to Mesozoik Menderes masif marble, schist and quartizite	Neogene interclated siltstone claystone, sandstone, conglomerate	Spa, Green house heating and District heating	57-155 °C (bottom hole)	Karamenderesi, 1997b; Tarcan et all.2000
Alaşehir Geothermal System	7	450-1507	8-12	Paleozoik to Mesozoik Menderes masif marble, schist and quartizite	Neogene interclated siltstone claystone, sandstone, conglomerate	Out of use	56-215 °C (bottom hole)	Tarcan et all.2000; Karahan et all., 2003

NMD: number of well drilled (m), MMDD: Maximum and minimum drilled depth (m), TDR:Total discharge rate (l/s)

Table 2: Description of shortcuts for Urganlı-Salihli-Alaşehir thermal waters.

Sample Location	Sample No	Sample Name	References
Urganlı thermal waters	1	EU-8 well	Vural, S., (2009)
	2	U-1 well	MTA, (2005)
	3	Ana kaynak	Tarcan, G., (1995)
Salihli thermal waters	4	SC-1 well	Karamanderesi, İ.H., (1990)
	5	K-3 well	MTA, (2005)
	6	Kurşunlu MTA well	Yılmazer, S., (1984)
	7	Kükürtlü hot spring	MTA, (2005)
	8	Sart spa	MTA, (2005)
Alaşehir thermal waters	9	KG-1 well	MTA, (2005)
	10	Horzumsazdere spa	Yılmazer, S., (1984)
	11	Sarıkız mineralized water	MTA, (2005)
	12	AK-2 well	Karahan, Ç., (2005)
Cold waters	13	Salihli cold water	Salihli Municipality
	14	Sart cold water	Salihli Municipality
	15	Gediz River (Urganlı)	Vural, S., (2009)
	16	Seraiçi cold well (Urganlı)	Vural, S., (2009)

Table 3: Results of chemical analysis for the thermal waters (mg/l). Sample numbers are as in Table 2 corresponding to the locality number.

Sample Number	Date	T (°C)	pH	Ca	Mg	Na	K	Cl	SO_4	HCO_3	CO_3	SiO_2	F	B	EC (µS/cm)	TDS (mg/lt)	Water type
Urganlı Thermal Waters																	
1	2008	83	6.89	83.21	21.4	438.04	41.5	56.5	2.85	1550	-	42.02	3.85	10.67	4981	3188	Na-HCO3
2	2001	62	7.3	16.7	35.8	509	41.8	76	5.9	1603	<10	31	6	13.4	2310	1478	Na-HCO3
3	1992	62	6.61	32	22	529	50	73	54	1514	-	68.45	3.5	11	2200	1408	Na-HCO3
Salihli Thermal Waters																	
4	1990	87	7.8	42	6.1	680	70	115	34	1983	<1	214	3.1	67	2700	1728	Na-HCO3
5	1992	96	8.38	10	12.1	355	42	64	98	945	30	128	1.4	40	1400	896	Na-HCO3
6	1984	86	7.25	54	25	320	40	64	98	1031	-	167	1.7	30	-	1076	Na-HCO3
7	1993	40	7.1	292	5	98	8	31	274	1019	10	30	0.1	7.59	1880	1203	Ca-HCO3,SO4
8	1993	50	7.6	29	20	198	24	37	40	531	54	72	0.6	16	907	580	Na-HCO3
Alaşehir Thermal Waters																	
9	2002	95	8.6	5.4	1	1520	86.2	170	26.8	2723	698	174	3.9	116	5260	3366	Na-HCO3
10	1984	32.5	6.7	128	75	690	58	161	12	2471	-	133	1.1	98	-	2257	Na-HCO3
11	1993	27	8	39	154	240	13	58	200	1049	78	27	0.6	17.4	1558	997	Mg-Na-HCO3
12	2005	98	8.2	12.3	<1	810	99.8	162	119	2127	<10	242	-	131	3180	2035	Na-Mg-HCO3
Cold Waters																	
13	2005	-	-	118.2	13.5	12.81	1.7	9.6	62.9	305	4	17.5	0.44	-	-	528	Ca-HCO3
14	2005	15	7.11	9	6.1	15	1.2	6	2	81	-	-	-	<0.2	178	120	Na-Mg-HCO3
15	2008	10.1	7.77	77.17	38.47	120.44	12.3	69.38	166.9	505.2	-	14.85	0.22	1.65	899	575	Na-Ca-HCO3,SO4
16	2008	15.8	7.67	84.79	36.68	76.65	4.32	20.59	40.71	597.3	-	22.25	0.16	0.83	828	530	Ca-Na-HCO3,SO4

Table 4: Geothermometer results for thermal waters.

Sample Location	Urganlı Thermal Waters			Salihli Thermal Waters					Alaşehir Thermal Waters				
Sample Number	1	2	3	4	5	6	7	8	9	10	11	12	
Sample Temperature (°C)	83	62	64	87	96	86	40	50	95	32.5	27	98	
Geothermometers	Temperature (°C)												References
SiO_2 (Quartz-no steam loss)	94	81	117	185	151	168	79	120	171	154	75	193	Fournier, 1977
SiO_2 (Quartz-max. steam loss)	96	84	116	172	145	158	83	118	161	147	79	179	Fournier, 1977
SiO_2 (Quartz-no steam loss)	82	68	107	180	144	162	67	109	165	146	62	189	Arnorsson, 1983
SiO_2 (Quartz-max. steam loss)	94	83	114	171	144	158	82	117	160	146	78	179	Arnorsson, 1983
SiO_2 (Chalcedony-no steam loss)	63	49	88	164	126	145	48	91	148	129	44	174	Fournier 1973
SiO_2 (Chalcedony-max. steam loss)	68	55	90	155	123	139	54	93	142	125	50	164	Fournier, 1973
SiO_2 (Chalcedony-no steam loss)	65	52	89	158	124	141	51	91	143	126	47	167	Arnorsson, 1983
SiO_2 (Chalcedony-max. steam loss)	70	58	91	151	121	136	57	93	139	124	53	159	Arnorsson, 1983
Na/K	182	168	194	191	207	213	167	210	134	170	130	211	Truesdell, 1976
Na/K	221	209	231	229	241	247	209	244	180	211	177	245	Fournier, 1979
Na/K	189	173	201	198	215	222	173	218	138	176	134	220	Tonani, 1980
Na/K	211	201	220	218	229	234	200	231	175	202	172	233	Arnorsson et al, 1983
Na/K	199	188	208	206	218	223	187	220	161	190	157	222	Nieva and Nieva, 1987
Na/K	228	217	237	235	246	251	217	248	191	219	188	250	Giggenbach et al.,1988
Na/K	197	185	207	204	217	223	185	220	158	187	154	221	Arnorsson et al, 1998
Na/K	178	162	190	187	204	212	161	208	126	164	122	210	Fournier & Truesdell 1973
K-Mg	93	87	113	126	101	90	70	80	164	85	44	171	Giggenbach et al., 1983
Na-K-Ca (Beta 1/3)	182	192	194	202	211	196	140	191	202	180	150	229	Fournier, 1979

5. HYDROCHEMICAL EVALUATION

Total 16 chemical analytical results of waters from earlier studies were selected and used to comment on hydrogeology and geochemistry. Three thermal water samples from Turgutlu, 5 samples from Salihli and 4 samples from Alaşehir geothermal field. Also 2 cold water samples from Turgutlu and 2 from Salihli field (Table 2 and 3).

The pH values for thermal waters are between 6.61 (no 3) and 8.6 (no 9), but those for cold spring range from 7.11 (no 14) to 7.77 (no 16). The TDS (Total dissolved solids) content of thermal waters range from 580 (no 8) to 3366 mg/l (no 9) .The cold waters attain a maximum TDS value of 575 (no 15) mg/l. Electrical conductivities range from 907 (no 8) to 5260 (no 9) µS/cm for thermal waters and 178 to 899 µS/cm for cold waters (Table 3).

The dominant anion of thermal waters of Turgutlu, Salihli and Alaşehir is HCO_3 varying from 523 (no 8) to 2723 (no 9) mg/l. They also show high concentrations of Na with maximum value of 1520 (no 9) mg/l. The cold waters attain a maximum HCO_3 value of 597.3 mg/l. Thermal springs and the water from boreholes in these fields are similar in origin. This suggests that the ground water comes from the local precipitation and has passed through similar rock types, i.e. aquifer (Figure 4). These thermal and mineralized waters are Na, HCO_3, B, SiO_2, CO_2 bearing, IAH (1979).

Piper (1944) diagram, indicate that thermal waters of Alaşehir, Salihli and Urganlı geothermal systems are alkaline where carbonate alkalinity>non carbonate alkalinity. They are very soft waters which is rarely found in the nature (Figure 5)

Thermal waters of Salihli no 7 (Kükürtlü hot spring) and no 11 (Sarıkız mineralized water) of Alaşehir are Ca-HCO_3-SO_4 and Mg Na-HCO_3 waters respectively (Table 3). Na-HCO_3 waters are comment in geothermal systems associated with metamorphic rocks which is consistent with the general lithology of the Menderes Masif (Table 3) and the high CO_2 content that is typical of the thermal water of Gediz Graben. The origin of the high dissolved CO_2 according to $\delta^{13}C$ and He isotopic data is magmatic, Vural (2009); Ercan et al. (1994); Filiz (1982). The Na-HCO_3 chemical composition is therefore a combination of high CO_2 flux and extensive water rock interactions with metamorphic rocks, Vengosh et al. (2002); Vural et al. (2008). Cold waters with carbonate hardness of more than %50 plot into the field no. 5 (Figure 5) which indicates calcite dissolution. These waters are of Ca-HCO_3 and $MgCO_3$ type and represent for shallow-circulating ground waters with low TDS and EC.

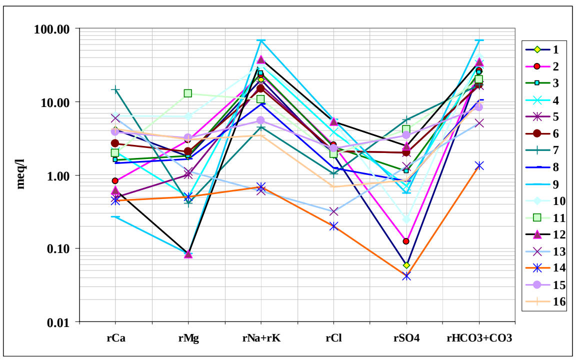

Figure 4: Schoeller diagram of the study area.

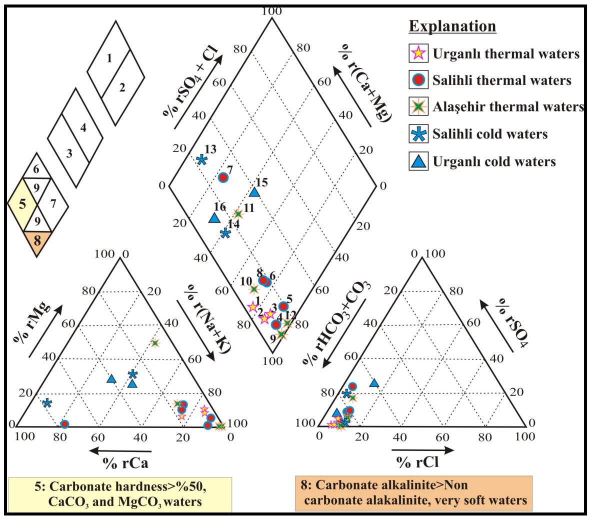

Figure 5: Piper Diagram.

The change in Ca/Mg ratios of waters from Turgutlu, Salihli and Alaşehir vary in a wide range. This is attributed to precipitation/dissolution of Ca and Mg-bearing minerals (probably carbonates). The geothermal water in Turgutlu, Salihli and Alaşehir geothermal fields has concentration ratios of Na/Cl, Ca/Mg and HCO_3/Cl that all exceed a value of 1. It also has high B and silica. This is strong evidence that the water has been in contact with acidic rocks.

All thermal waters (Turgutlu, Salihli and Alaşehir) in Gediz Graben is enriched in B. Boron concentration is 7.59-116 mg/l in thermal waters and 0.699 mg/l in cold waters. As shown in Table 3, B contents of waters from selected points reach peak values of 116 mg/l in KG-1 well water and 98 mg/l in Horzumsazdere spa in Alaşehir. High boron content is attributed to deep water circulation or deeply seated magma body. Vengosh et al. (2002) indicate that, isotopic composition ($\delta^{11}B$) of Boron in Gediz Graben is either leaching of B from rocks or B $(OH)_3$ degassing flux from deep sources. The relative distribution of Cl and B in the spring and well waters from Gediz Graben is thought to reflect their abundance in the rocks with which the water has reacted rather than the maturity of the system. The concentrations of boron and Cl generally increase with water temperature. The Cl/B ratio in geothermal water decreases with increased temperature and approach that of rock. The reason is that with high water temperature, the leaching of Cl and B from the rock becomes faster, and because of the low Cl content in the limestone (Figure 6).Water rock interaction is the most important source for boron.

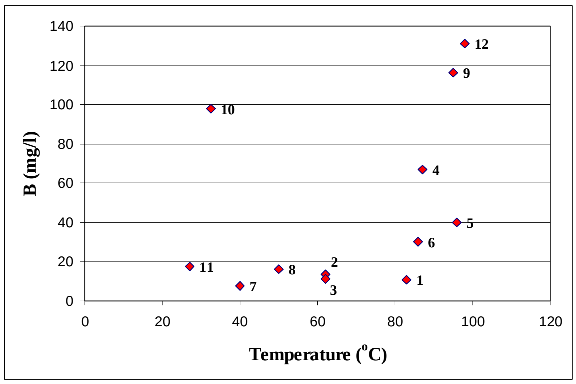

Figure 6: Plot of Boron versus temperature.

SiO_2 concentration in Turgutlu, Salihli and Alaşehir geothermal areas is high. There values range 27 (no 11) to 214 (no 4) mg/l. Silica addition to waters may be accomplished by alteration of volcanic glass and silicate minerals or dissolution of quartz in alkaline conditions Şahinci (1991).

Isotope results (^{18}O and ^{2}H) indicate that Turgutlu, Salihli and Alaşehir geothermal areas are of meteoric origin, Vural et al. (2008); Filiz (1982), but shifted in O^{18}, indicating deep circulation and water rock interactions in Salihli-Kurşunlu and they recharge area of the whole geothermal systems in these area are large. The increase in O^{18} values is attributed to the fact that the aquifer temperatures of the Salihli geothermal area are higher than those of other geothermal field in Gediz graben, Tarcan et al. (2005).

AquaChem computer program, Calmbach (1997), was used to compute the saturation index of various carbonate, sulfate, silica and silicate minerals at the outlet temperatures of the waters. The results show that thermal and cold waters of Gediz Graben are oversaturated with respect to calcite, dolomite, aragonite and quartz. Therefore they have a significant calcite scaling potential. None of them is oversaturated or in equilibrium with anhydrite, gypsum and fluorite. This may imply the SO_4 concentration of the waters is controlled by steady state dissolution process, Grasby et al. (2000).

5.1 Chemical Geothermometers

In order to determine reservoir temperatures of the Gediz geothermal waters, chemical geothermometers were applied, and the results are shown in Table 4. Some Geothermometer calculations, which give unreliable results (i.e., temperatures lower than the measured surface temperatures or much higher than possible), have not been shown in Table 4. Among the silica geothermometers, the quartz geothermometers and chalcedony geothermometers yield reservoir temperatures of 68-117°C and 49-91°C in Urganlı, 67-185°C and 48-167°C in Salihli and 62-193°C with 44-174°C in Alaşehir respectively. Compared with quartz geothermometers, the chalcedony geothermometers of Fournier (1973) and Arnorsson et al. (1983) display relatively lower reservoir temperatures. Since chalcedony, rather than quartz, controls silica saturation at temperatures less than 180ºC, Fournier (1991). SiO_2 content of fluids which is relatively high in Salihli (30-214 mg/l) and Alasehir (27-242 mg/l) in comparison to Urganlı geothermal field. (31-68.45mg/l) suggesting that thermal waters rise to the surface without equilibration, due to their rapid circulation. These waters may also precipitate silica or mix with dilute cold waters reroute to surface.

Different reservoir temperatures calculated for the study area are attributed to varying silica and cation concentrations which are affected by chemical processes such as mixing and evaporation and the use of different constants in geothermometers developed by various workers.

Although the temperature of water from the Alaşehir thermal water (sample no 9 and 12) is the highest, reservoir temperatures (particularly from the silica geothermometers) of other waters with lower temperatures yield higher results. This may be due to conductive cooling which results in removal of SiO_2 from the fluid.

The reservoir temperatures computed from the Na/K cation geothermometers for each field waters are generally higher than those of silica geothermometers.

It is obvious that Na-K geothermometers applied to Turgutlu and Salihli fields give anomalously high temperature. This is because at low temperatures Na/K ratio of waters is governed by leaching rather than chemical equilibrium.

In order to eliminate the possible effects of Ca concentrations on the Na-K geothermometer, the Na-K-Ca geothermometer of Fournier and Truesdell (1973) was used.

The reservoir temperature calculated from this geothermometer yields temperature estimates lower than those of the Na-K geothermometers but still higher than those of the quartz and chalcedony geothermometers suggesting that these estimates reflect the high Ca/Na ratio of the leachate (as the solubility of Ca increases with decreasing temperature), rather than the equilibrium conditions at depth. K-Mg geothermometer gives low temperatures even lower than silica geothermometers. This is probably due to the increasing solubility of Mg with decreasing temperature and its leaching from rocks during the ascent of waters to the surface; the Mg contents higher than those at reservoir conditions thus result in underestimated temperatures as the geothermometry equation is based on the use of $K/\sqrt{Mg}$ ratios. In other words, since Mg reflects equilibrium at shallower levels, K-Mg geothermometers is not a good indicator of deep temperatures. The applicability of cation geothermometers was evaluated on the Na-K-Mg diagram proposed by Giggenbach (1988). Turgutlu, Salihli and Alaşehir (except no 9 and 12) geothermal springs, well waters and cold water plot in the area of the immature waters therefore these thermal waters do not attained equilibrium, the evaluation of equilibrium temperatures is not applicable and the results obtained by the cation geothermometers should be taken into account as doubtful and the interpretation of the temperature predictions of such waters should be made cautiously, Giggenbach, (1988). No 9 and 12 of Alaşehir thermal waters are plots in area of partial equilibrium. These waters give reservoir temperatures of 210°C and 265°C.

The fact that the highest reservoir temperature is obtained from Gediz field may suggest that the waters in Alaşehir are less effected by the secondary processes (e.g. mixing and boiling) which is in fact reflected in the ternary diagram (Figure 7) of Giggenbach (1988).

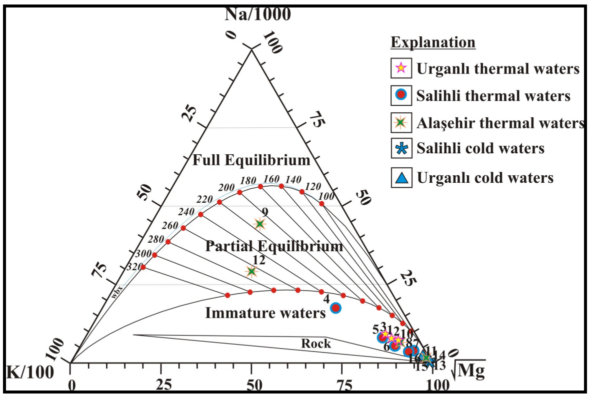

Figure 7: Giggenbach diagram.

Comparing the results with the measured reservoir temperature155°C at the bottom in SC-1 well (no 4) in the Salihli, 182°C at the bottom in KG-1 well (no 9) and 215°C at the bottom in Ak-2 well (no 12) in Alaşehir field. The reservoir temperature is 85^{o}C in Urganlı geothermal field.

6. CONCEPTUAL MODEL OF THE GEOTHERMAL SYSTEMS AT THE GEDIZ GRABEN

According to results of this study, springs recharging the geothermal systems have a meteoric origin. Rainwater percolates downward along fractures and faults of Menderes Masif and are heated by a magma chamber possibly seated at a depth of 10-12 km, and then rise to the surface along the ESE-WNW trending faults and fractures which act as hydrothermal conduit for thermal waters. Temperature of springs is between 27°C and 62°C while temperature of artesian water of Alaşehir well Ak-2 (no 12) is up to 96°C. Due to their secondary porosity and permeability, Paleozoic schist, marbles and limestones below the Neogene units found in wells opened around the geothermal areas are believed to be possible reservoir rocks. Neogene terrestrial sediments of 2000 m thickness with an impermeable character are the cap rocks of the reservoir. The heat source of all geothermal system in Gediz Graben may probably related to the Kula volcanic (Figure 8). In addition, tectonic activities in association with volcanism transfer the magma heat to the surface and therefore, geothermal gradient in these fields is high. The chemistry of thermal waters is explained in the following (Figure 8).

During the penetration of rainwater, it is enriched in earth alkali elements and while the filtration continues, its temperatures increases and water makes a base exchange with Na and K ions and thus, chemical composition of waters is changed. During this exchange, Ca and Mg whose solubility decreases with temperature are removed from water or precipitated as carbonate minerals along the fractures or they are replaced by other ions in the minerals. Meanwhile, concentration of Cl increases which behaves in a conservative manner. As a result, composition of fluid changes to Na-Ca-HCO_3 character. Steam that is separated due to heat flow from. the heat source at depth mixes with CO_2 and H_2S gases and forms HCO_3 and SO_4. SiO_2 concentration increases with temperature. The circulation of the thermal and mineral waters is closely related to major fault and fractures zone Although the expected type of thermal and mineralized waters in the geothermal field (Turgutlu, Salihli and Alaşehir) is initially Na-HCO_3, mixing during the Upflow zone, and re-equilibrium processes causes Na-HCO_3 type waters to turn into various types as shown in Table 3.

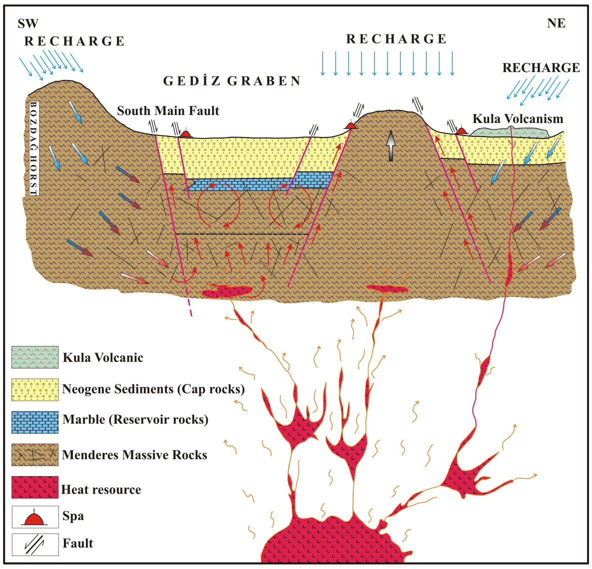

Figure 8: Conceptual model of the geothermal systems at the Gediz graben.

7. RESULTS

This study which was conducted on geothermal waters in the Gediz Graben in western Anatolia, Turkey, yielded the following results and suggestions: Rocks of Paleozoic Menderes Massif comprise the basement in the Gediz Graben and its surrounding. They are overlain by Neogene and Quaternary deposits. The Neotectonic period that formed the Gediz graben system was started in the upper Miocene and gained its present position at the end of Quaternary. The region is still tectonically active. The Gediz Graben in an active tectonic belt is also noticeable with its geothermal springs. The Alaşehir geothermal system in southern part of graben has a reservoir temperature of 215°C. The heat source of geothermal systems in the Gediz Graben is associated with young tectonic events and the rift system within the Gediz Graben system. The Alaşehir-Salihli-Urganlı geothermal fields show lithologic continuity. The lithologies of cap, reservoir and heating rocks in these fields are the same and, the geothermal systems in these areas are formed by the same tectonic regime that extends from Alaşehir to Urganlı.

Chemical characteristics of Turgutlu, Salihli and Alaşehir thermal waters nearly whole waters' type is sodium-bicarbonated and have higher boron and silica concentrations. They also represented by higher total ion concentrations and EC values. Na bearing waters have high temperatures. B contents of thermal waters reach peak values of 116 mg/l in KG-1 well water and 98 mg/l in Horzumsazdere spa in Alaşehir. All of thermal waters (Turgutlu, Salihli and Alaşehir) in Gediz Graben have a meteoric origin, rainwater percolates downward along fractures and faults, is heated at depth, and then rises to the surface along major fractures and faults which act as hydrothermal conduit. The heat source of all geothermal system in Gediz Graben may probably related to the Kula volcanism. In addition, tectonic activities in association with volcanism transfer the magma heat to the surface and therefore, geothermal gradient in these fields is high. The measured reservoir temperature is 215°C in Alasehir, 155°C in Salihli, and 85°C in Urganlı geothermal system. Accordingly, temperatures in Gediz Graben decrease from east to west. On the basis of mineral equilibrium calculations performed at the discharge temperatures of the Gediz Graben thermal waters, carbonate and silica minerals show equilibrium saturation. Although most of the are sulfate enriched, all waters were undersaturated with anhydrite and gypsum and this may indicate that the SO_4 concentration of the waters is controlled by steady state dissolution process.

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