Bulletin of MTA (2013) 147: 153-167

Bulletin of the
Mineral Research and Exploration

http://bulletin.mta.gov.tr


BULLETIN OF THE
MINERAL RESEARCH AND EXPLORATION

CONTENTS

A NEW MEDIUM TO HIGH ENTHALPY GEOTHERMAL FIELD IN AEGEAN REGION (AKYAR) MENDERES – SEFERİHİSAR – İZMİR, WESTERN ANATOLIA, TURKEY

Metin BULUT[*,a]

[a] General Directorate of Mineral Research and Exploration, Regional Directorate of Aegean, Bornova, İzmir

Keywords:
Seferihisar, geothermal, hydrogeochemistry, drilling

ABSTRACT

This study was performed considering that low to medium enthalpy geothermal areas are important besides the geothermal fields with high temperature located in Western Anatolia for heating, thermal tourism and agricultural applications. It was also aimed at obtaining fluids at high temperature in areas which were observed at a temperature relatively lower than the surface temperature. The study area is located at a region between the towns of Menderes and Seferihisar to the south-southwest of Izmir. This is a multidisciplinary investigation which obtained fluids and studied the geothermal energy potential of the area. Field studies were finalized carrying out geological prospection and detailed geological prospection, hydrogeological, hydrogeochemical, geophysical and drilling studies which formed a potential for geothermal energy. As a result of these studies, the fluid with a flow rate of 104 tons per hour and a temperature of 141,18^{o}C was obtained in the form of vapor + water with compressor machine. This fluid was obtained at a depth of 1215,50 m in the conducted exploratory drilling around Akyar Tepe. It was seen that the fluid obtained is sodium chloride type water and consists of a mixture of hot spring, surface water and marine water. This, which had been known as the low temperature field was introduced as a medium-high enthalpy geothermal system.

1. Introduction:

Due to the increase of environmental problems in the world because of fossil fuels, the use of renewable energy has become important in recent years as it had positive effects of natural environment. All countries in the world have begun to prefer renewable energy sources such as; environmentally friend biomass, solar, wind and geothermal energy to limit and control the environmental polluting emissions within the framework of Kyoto Protocol in order to reduce the greenhouse effect. The use of geothermal energy which is cheap and environmentally friend has a broad range of application areas such as; the generation of electricity, heating and cooling in urban areas, desiccation in food industry, thermal tourism, greenhouse cultivation and aquaculture farming. These areas steadily increase the importance of geothermal energy in the world.

As it is known; Turkey, especially the Western Anatolia Region, has a great potential in terms of geothermal energy resources. The study area lies in between Seferihisar and Menderes districts of İzmir City in the Western Anatolia. Seferihisar geothermal field has been known for years as a high temperature geothermal area and its temperature at source varies between 49–85ºC. Due to the hot water drillings run in this area, it was observed that temperatures in the well varied between 56–153ºC. The study area is 7 – 14 km away from the Seferihisar geothermal field in plan view. The temperature of available springs

* *Corresponding author: M. BULUT, metinbulut@mta.gov.tr*

ranges between 33–36,5ºC and these were assessed as low enthalpy areas with respect to their surface temperatures.

The investigation, development, management and the preservation of geothermal systems with low, medium and high enthalpy have a great significance in Turkey. For this purpose, the geological prospection, detailed geological and geophysical researches and hydrochemistry studies were performed in June - September 2009 within the framework of "İzmir Güneyi Jeotermal Enerji Aramaları Project" of the General Directorate of Mineral Research and Exploration. As a result of these studies, it was decided to perform a geothermal exploratory drilling around Akyar Tepe (Hill). This investigation was carried out in June – October 2011 at a depth of 1215,50 m. Drilling studies were performed by MR-6000 tower type drill machine. Cut samples were taken at each 2 meters during advance, studied under binocular microscope and their well lithologies were described. Geophysical well logs (thermal, sp, neutron, gamma ray, resistivity and density) had been taken before the well was cased and during the well completion. So, the well development and completion processes have been managed correlating with well lithology. At well completion, 7" diameter sized production boreholes were set into the well, and well bleaching and development processes were carried out. Reservoir parameters were determined by Amereda Test equipment. In-well tests were completed and the well was prepared for production.

Not only the exploration of hot springs but also the development and careful attention of continuous usage of these known and explored energy sources are of big importance. It should always be bared in mind that, if geothermal systems which are the sources of renewable energy are not well protected then these sources will not be productive as same as before and terminate in the near future. Therefore; re-injection studies and controls should be accelerated in geothermal fields. Besides; as thermal springs which are used balneologically are good to human health, the hydrogeochemical preservation of these sources are of great importance.

2. Regional Geology

The study area is located among Seferihisar, Menderes and Gümüldür towns, in south–southeastern parts of the İzmir City. The Cumaovası basin in which the study area lies is one of the basins belonging to Miocene – Quaternary period in western Anatolia. The basin is NE trending and has an approximate width of 5 -17 km and a length of 35 km, which has developed under the control of active strike-slip and normal faults (Uzel and Sözbilir, 2008). It has previously been named as Çubukludağ graben in previous studies (Eşder and Şimşek, 1975) (Figure 1).

Cover units of the Paleozoic Menderes massif form the basement of the study area, but this unit is exposed outside the study area along the İzmir – Gümüldür auto road. Cover units of the massif were passed over at a depth of 850 meters at the drilling. The Menderes Massif in regional scale consists of a core made up of gneissic, high grade metamorphic rocks and cover rocks made up of schist, phyllites, metaquartzite and of recrystallized limestone (Hetzel et al., 1995; Bozkurt and Park, 1994). Despite the age of the unit was determined as Paleozoic – Mesozoic in literature (Şengör et al., 1984; Dora et al., 1990; Güngör, 1998; Yılmaz et al., 2000; Güngör and Erdoğan, 2002), recent studies have indicated that this age reached even up to Eocene (Özer and Sözbilir, 2003). The unit is tectonically overlain by the rocks of İzmir – Ankara Zone (Başarır and Konuk, 1982; Erdoğan, 1990).

The rocks of the İzmir – Ankara Zone are the one of the paleotectonic units in western Anatolia. These are made up of flysch facies rocks consisting of highly deformed sandstone – shale matrix in which olistoidal limestone and serpentine blocks are present. The unit which was defined as İzmir Flysch has formerly been defined as "Bornova Complex" by Erdoğan (1990) and as "Bornova Flyschoidal Zone" by Okay and Siyako (1991). The age of the unit was given as Late Cretaceous – Paleocene according to these two investigations and is unconformably overlain by Neogene deposit (Figures 2 and 3).

Neogene aged units in the study area begin with Bahçecik Formation consisting of the alternation of Lower Miocene conglomerate, millstone, sandstone, lignite and limestone (Eşder, 1988). These units then continue with Middle Miocene aged Yeniköy Formation which is the alternation of red conglomerate, green sandstone, claystone at bottom then grading into clayey limestone towards upper layers (Eşder and Şimşek, 1975; Eşder, 1988, Genç et al., 2001) (Figures 2 and 3).

Volcanic rocks made up of tuff, rhyodacitic tuff, rhyolitic tuff, agglomerate, perlite, alkaline rhyolite, trachy andesite, rhyolite, hyalorhyolite, dacites and dacitic tuff known as the Cumaovası volcanites (Eşder and Şimşek, 1975; Özgenç, 1978; Kaya, 1979, 1981; Eşder, 1988; Genç et al., 2001) broadly crops out throughout the region (Figures 2 and 3). The

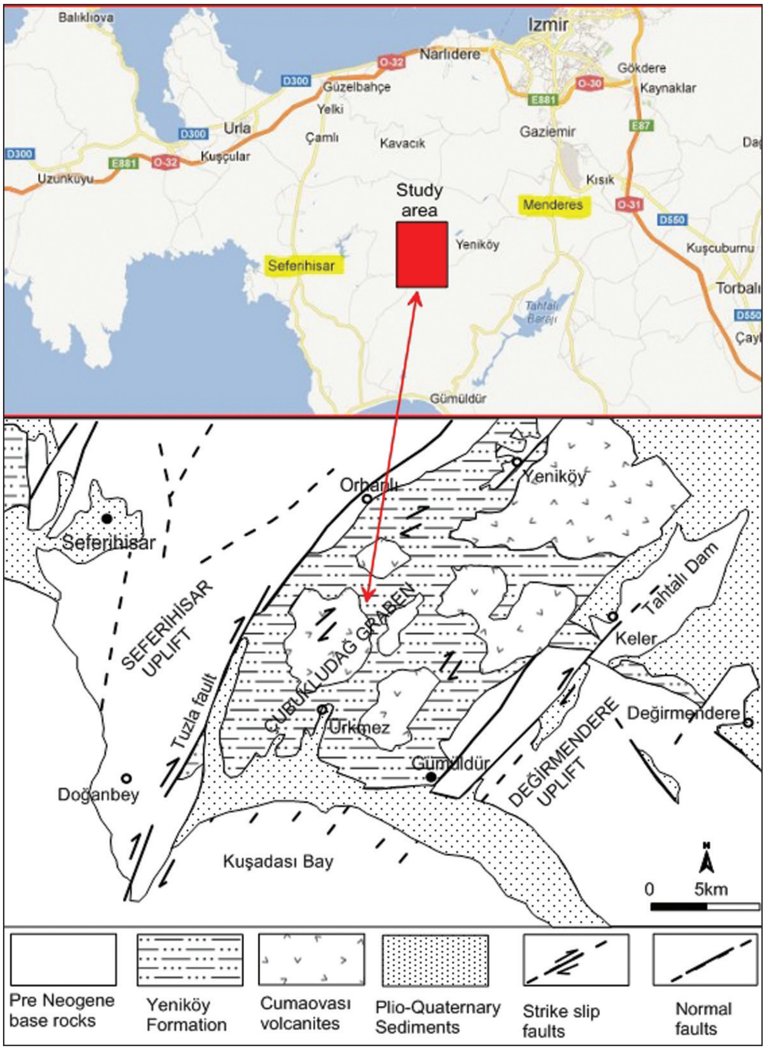

Figure 1- The location of the study area and generalized geological and tectonical maps of its surround (modified from Uzel and Sözbilir, 2008).

age of Cumaovası volcanites were dated as 12,5 my according to Sr, Rb, Sr isotopic ratios (Borsi et al., 1972) and aged as Upper Miocene according to their stratigraphical positions (Genç et al., 2001).

3. Tectonics

The neotectonism of the western Anatolia is represented by tensional tectonism (Şengör; 1979, 1980). Regionally; N-S trending tensional tectonism is a result of the neotectonism which is observed throughout Anatolia. It was stated that, both strike and normal slip active faults were in İzmir and in its close vicinity, and also within the study area located in Aegean region active tectonic belt. It was shown that, normal faults were in E-W direction and strike slip faults were right lateral N-S, NE-SW, NW-SE directions. There was observed intensive seismicity along these active faults in the region and was emphasized that these faults had produced many earthquakes both during historical and prehistorical times (Emre et al. 2005).

NE-SW directing, right lateral Tuzla Fault which is located at NW of the study area forms the most significant tectonical structure. This fault is 42 km long between Doğanbey – Gaziemir towns and exceeds 50 km when its submarine delineation is also considered (Figure 1). However; there are many geothermal activities that developed along this fault zone and are accepted as an active fault system.

4. Drilling Studies

NW-SE directing, oblique, right lateral slip fault that developed along Çamalan River in Akyar area

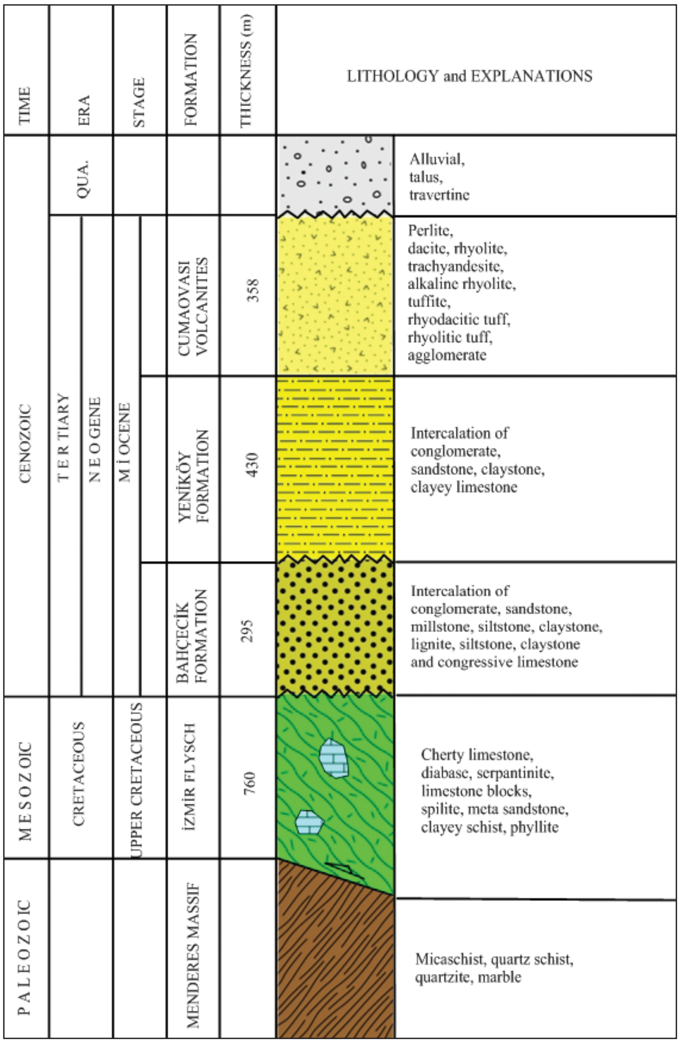

Figure 2- Generalized stratigraphical columnar section of the study area (modified from Eşder, 1988).

and shear faults cutting across this fault approximately in N-S directions indicate a geothermal activity. Geophysical investigations were carried out by deep electrical drilling in Akyar area in order to determine a probable drill location to obtain a fluid, (Bulut et al., 2013).

At the location in L17–c2 sheet around Akyar Tepe and Çamalan River (X: 4220830, Y: 499214), a geothermal energy exploratory drilling with a drill number of İSA-2011/10 (İzmir – Seferihisar – Akyar) was performed at a depth of 1215,50 meters, as a result of geological, geophysical and hydrogeochemical investigations carried out. Between 0,00 – 60,00 meters, altered tuff; between 60,00 – 440,00 meters, Yeniköy Formation (sedimentary rocks composed of conglomerate, sandstone and claystone alternation); between 440,00 – 840,00 meters, İzmir Flysch (rocks in flyschoidal facies composed of sandstone cemented with carbonate, clayey limestone, claystone alternation) and 840,00 – 1215,50 meters, Menderes metamorphites (alternation of mica schist, quartz schist, sericitic schist) were cut at the drilling (Figure 4). In drilling investigation, between 1175 – 1185 meters the fault zone were cut and mud circulation could not be resupplied. This zone is the full water loss zone and was determined as the main production zone. Geophysical logs were also taken inside the well and probable well development risks were also checked. As a result, the well was completed at a depth of 1215,50 meters. Core sample was taken at the well bottom making an extra 1,80 meters advance and this sample was detected as mica schist – quartz schist. Casing with a diameter size of 9 5/8” were lowered to a depth of 595,00 meters inside the well and its outer side was cemented. Later on; 7 “ diameter sized,

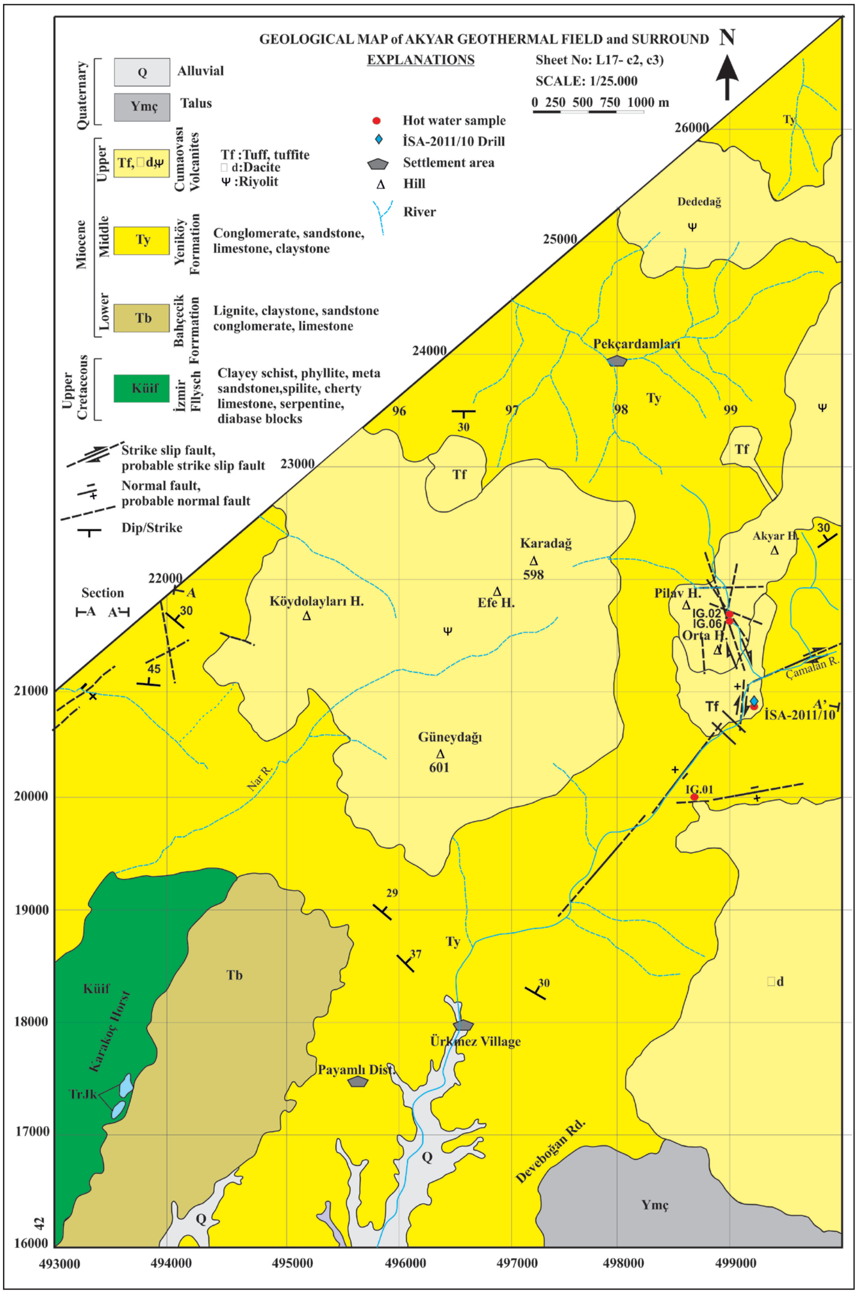

Figure 3- Geological map of the study area (modified from Eşder and Şimşek, 1975; Eşder, 1988).

closed, filtered production wells were placed down to 1215,50 meters (Figure 4).

Static temperature, static pressure, water-loss and injectivity tests were performed by Amerada test equipment in order to determine in-well reservoir parameters in İSA-2011/10 Akyar geothermal exploratory drilling and besides; production test investigations were carried out. It was detected that the main production in the well was at a depth of 1.176 meters and the temperature at this point was measured as 124,04ºC. The temperature at the well bottom was also estimated as 129,28ºC and as 141,18ºC at the depth of 850 meters. The approximate temperature inside the well was measured above 130ºC. The temperature of the fluid production made by compressor on the well (vapor + water) was estimated as 115ºC by digital thermometer in the horizontal production pipe. The fluid temperature and flow rate estimated inside the weir box are 84ºC and

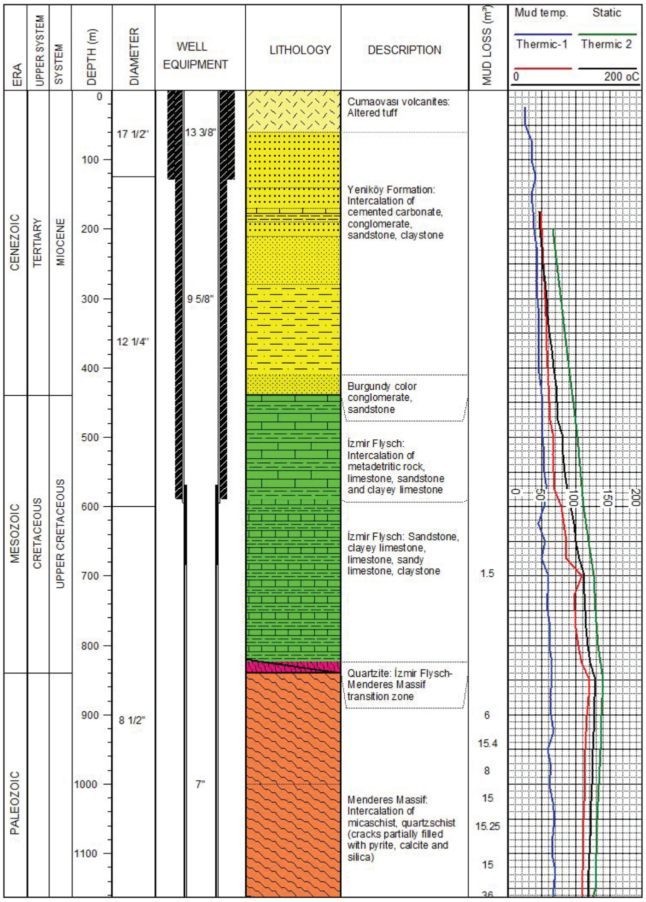

Figure 4- Lithology of the geothermal exploratory drill (from Bulut et al., 2013).

104 tons/h, respectively (Figure 5). Static water level inside the well starting from the level of rotary height was detected as 125,00 meters (Bulut et al., 2013).

Stratigraphically; the Middle Miocene aged sedimentary rocks forming the Yeniköy formation within conglomerate, sandstone, claystone and clayey limestone facies and the Upper Miocene aged volcanic rocks preferably consisting of rhyolite, rhyodacite, dacitic lava and tuffs and agglomerates which unconformably overlie pre Neogene rocks are in the character of cover rocks (Cumaovası volcanites). Fracture zones within metamorphic units belonging to Paleozoic aged Menderes Massif, fractured, fissured mica schist and quartz schists, tectonic fractures and limestone layers within İzmir Flysch are considered as reservoir rocks in the study area (Figure 6). According to hydrochemical data, the geothermal system fed both by surface and marine waters. Waters entering the system in this manner are heated under the effect of high geothermal gradient that is formed by the crustal thinning and mantle uplift which developed due to graben tectonism in Western Anatolia.

Figure 5- Fluid production in İSA-211/10 geothermal drill.

5. Hydrogeochemical Studies

Looking at the field in terms of geothermal resources, it is seen that the study area is located between the Balçova geothermal field at north and the Seferihisar geothermal field at southwest. There are four low enthalpy springs in the study area as; Ilık Pınar 1 (İG.1), Ilık Pınar 2 (İG.3) and Akyar Pınar (İG.2 and İG6) of which their temperatures are in between 33-36,5ºC. Ilık Pınar springs (İG.1 and İG.3) discharge at a low flow rate (0,5 – 1 l/s), Akyar Pınarı springs (İG.2 and İG.6) discharge as in leaks. Chemical analyses of these hot waters were carried out by the sampling of cold waters (İG-4, İG-5, İG-7, İG-8) and drilling waters (İG-9 and İSA-10) (Figure 7 and Table 1).

In order to assert hot-cold water relationships, the chemical analyses of hot water, cold water and drilling water samples discharging in the form of spring and leakage were performed in MTA hydrogeochemistry laboratories (Table 2).

Among these samples, the cation-anion order of İG-01, İG-02, İG-03, İG-04, İG-08, İG-09 samples are as; rCa+rMg>rNa+rK, $rHCO_3+rCO_3 > rCl+rSO_4$ and are classified as carbonate, bicarbonate type waters. However, the cation-anion order of samples İG-05, İG-06, İG-07, İG-10 are in the form of rNa+rK>rCa+rMg, $rHCO_3+CO_3>Cl+SO_4$ and are classified as sodium and bicarbonate type waters (Table 3).

The cation order of the sample taken from the drill İSA-10 is rNa+rK>rCa+rMg. However; the anion order contrary to other waters is $rCl+rSO_4>rHCO_3+CO_3$ and in are sodium, chloride type waters (Table 3). This situation is interpreted as the drill water was mixed with marine water.

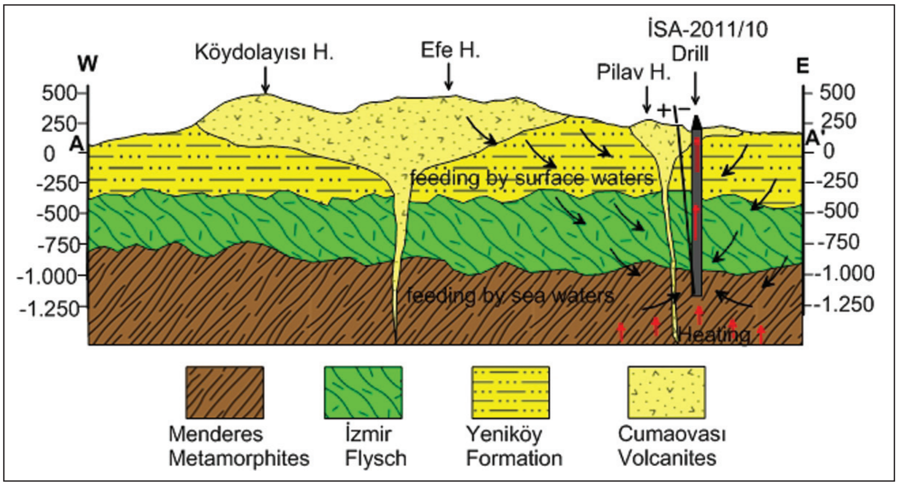

Figure 6- Tectonic model forming the geothermal system.

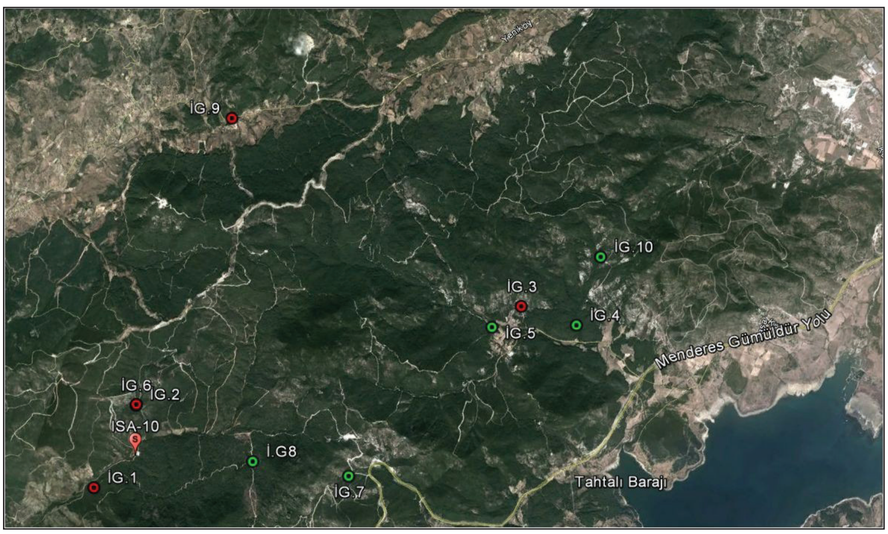

Figure 7- Water sample locations.

Table 1- Water sample coordinates.

Order No	Sample No	Date of sampling	Locality Name	Sampling location				
				Province	District	Village	Sheet No	Coordinate
1	İG-01	8/25/2009	Ilıkpınar	İzmir	Seferihisar	Ürkmez	L17-c2	X: 4220100 Y: 0498650
2	İG-02	8/25/2009	Akyar 1	İzmir	Seferihisar	Ürkmez	L17-c2	X: 4221740 Y: 0498995
3	İG-03	8/25/2009	Ilıkpınar	İzmir	Menderes	Deliömer	L18-d1	X: 4225225 Y: 0505300
4	İG-04	8/26/2009	Suluçay	İzmir	Menderes	Deliömer	L18-d1	X: 4225148 Y: 0506360
5	İG-05	8/26/2009	Bağtepe Pn.	İzmir	Menderes	Deliömer	L18-d1	X: 4224724 Y: 0504881
6	İG-06	8/27/2009	Akyar 2	İzmir	Seferihisar	Ürkmez	L17-c2	X: 4221725 Y: 0498995
7	İG-07	8/31/2009	Çakmak T.	İzmir	Menderes	Deliömer	L18-d1	X: 4221500 Y: 0503075
8	İG-08	9/1/2009	Kovuklu T.	İzmir	Menderes	Deliömer	L18-d1	X: 4221300 Y: 0501325
9	İG-09	9/2/2009	Kuyucak S.	İzmir	Seferihisar	Kuyucak	L17-c2	X: 4227187 Y: 0499335
10	İG-10	9/3/2009	Ali Molla Pn.	İzmir	Menderes	Deliömer	L18-d1	X: 4226457 Y: 0506467
11	İSA-10	10/4/2011	Akyar Drill MTA	İzmir	Seferihisar	Ürkmez	L17-c2	X: 4220830 Y: 0499214

Table 2- Results of water sample analysis.

Sample No	Locality Name	Date of sampling	Temp.	pH	EC	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	SO_4^{--}	SiO_2	Water type
			°C		mS/cm	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	
İG-1	Ilıkpınar	25.08.2009	36,0	6,9	284	25,4	8,05	26,7	2,59	16,6	113	32,5	81,5	$Ca\text{-}HCO_3$
İG-2	Akyar 1	25.08.2009	33,0	7,1	449	23,3	8,16	62,1	6,85	24,6	255	3,3	62,7	$Ca\text{-}HCO_3$
İG-3	Ilıkpınar	25.08.2009	33,0	7,0	379	27,9	10,3	47,2	2,3	22,2	201	15,3	83,8	$Ca\text{-}HCO_3$
İG-4	Suluçay	26.08.2009	17,6	6,9	546	7,34	1,0	112	2,22	15,7	343	13,5	9,1	$Ca\text{-}HCO_3$
İG-5	Bağtepe Pn.	26.08.2009	22,5	6,9	127	18,7	4,81	5,0	1,0	12,8	53	3,3	77,1	$Na\text{-}HCO_3$
İG-6	Akyar 2	27.08.2009	36,5	6,8	326	33,0	15,6	25,6	2,28	26,2	160	36,5	72,9	$Na\text{-}HCO_3$
İG-7	Çakmak T.	31.08.2009	22,5	6,4	116	16,2	4,1	5,2	1,0	14,5	41,4	4,3	61,5	$Na\text{-}HCO_3$
İG-8	Kovuklu T.	01.09.2009	22,0	7,8	366	28,0	6,2	51	1,0	18,4	213	7,2	71,8	$Ca\text{-}HCO_3$
İG-9	Kuyucak S.	02.09.2009	41,0	7,1	800	39,8	4,62	78,9	40,5	26,6	450	66,6	29,5	$Ca\text{-}HCO_3$
İG-10	Ali Molla Pn.	03.09.2009	20,0	6,5	181	21,5	5,54	14,3	1,1	14,2	88,8	4,4	91,3	$Na\text{-}HCO_3$
İSA-10	Akyar S.	04.10.2011	84,0	8,5	5.690	1.154	158	9,2	7,8	1.697	272	203	153	Na-Cl
Sea water		Somay, 2006	x	8,3	58.800	12.720	398,8	476,0	48,1	17.800	156,2	2920,7	x	Na-Cl
Balçova-9		MTA,1993	122	9,0	1.500	440	31	8	4	223	467	169	109	$Na\text{-}HCO_3$
Doğanbey		MTA,1995	78	6,8	12.370	2750	254	235	100	4941	689	375	93	Na-Cl

The percentages of major element analysis values of waters were calculated in terms of milliequivalent based on the classification of Association of International Hydrogeologists (AIH). Samples which have percentages more than 20% were categorized according to the highest anion and cation percentages and by means of ternary diagrams at the same time (Table 3 and Figure 8). When looking at their positions in the diagram it was seen that there was not a distinct accumulation and both hot and cold water samples had similar chemical characteristics. High sodium and chloride content in drill water İSA-10 indicates that this water is affected from marine water.

According to this diagram, it was concluded that the drilling water showed similarity with marine water and Seferihisar geothermal waters but had no relation with Balçova geothermal field located at north.

Schoeller semi logarithmic diagram is a frequently used diagram in hydrogeology in order to easily display ions as cumulative in one diagram and to compare waters from similar and different origins at the same time. According to this diagram, waters with similar origin, aquifer and drainage areas give similar peaks. It is observed that hot and cold water

Table 3- Estimated meq/l and % values of water chemistry samples.

Sample No	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	SO_4^{--}	Water type
	(meq/l); %	(meq/l); %	(meq/l); %	(meq/l); %	(meq/l); %	(meq/l); %	(meq/l); %	
İG-01	1,105; %19	0,206; %4	1,332; %23	0,213; %3	0,468; %8	1,852; %32	0,677; %11	Ca-HCO_3
İG-02	1,013; %10	0,209; %2	3,099; %32	0,564; %6	0,694; %7	4,180; %42	0,069- %1	Ca-HCO_3
İG-03	1,214; %15	0,263; %3	2,355; %29	0,189; %2	0,626; %7	3,200; %40	0,319; %4	Ca-HCO_3
İG-04	0,319; %3	0,025; %0	5,589; %45	0,183; %1	0,443; %4	5,622; %45	0,281; %2	Ca-HCO_3
İG-05	0,813; %31	0,123; %5	0,250; %10	0,082; %3	0,361; %14	0,874; %34	0,069; %3	Na-HCO_3
İG-06	1,435; %21	0,399; %6	1,277; %19	0,188; %3	0,739; %11	2,623; %38	0,135; %2	Na-HCO_3
İG-07	0,705; %30	0,105; %5	0,259; %11	0,082; %4	0,409; %17	0,679; %29	0,090; %4	Na-HCO_3
İG-08	1,218; %15	0,159; %2	2,545; %31	0,082; %1	0,519; %6	3,491; %43	0,150; %2	Ca-HCO_3
İG-09	1,731; %9	0,118; %1	3,937; %21	3,337; %18	0,750; %4	3,376; %40	1,387; %7	Ca-HCO_3
İG-10	0,935; %25	0,142; %4	0,714; %19	0,090; %2	0,401; %10	1,456; %38	0,092; %2	Na-HCO_3
İSA-10	50,196; %44	4,041; %4	0,489; %1	0,642; %1	47,866; %42	4,227; %4	4,458; %4	Na-Cl
Sea water	5533; %47	10,2; %1	23,7; %2	3,95; <%1	502,1; %44	2,5; <%1	60,8; %5	Na-Cl
Balçova-9	19,13; %46	0,79; %2	0,39; %1	0,32; %1	6,29; 15	7,65; %20	3,5; %9	Na-HCO_3
Doğanbey	119; %40	6,49; %2	11,7; %4	8,2; %3	139; %46	11,29; %4	7,8; %3	Na-Cl

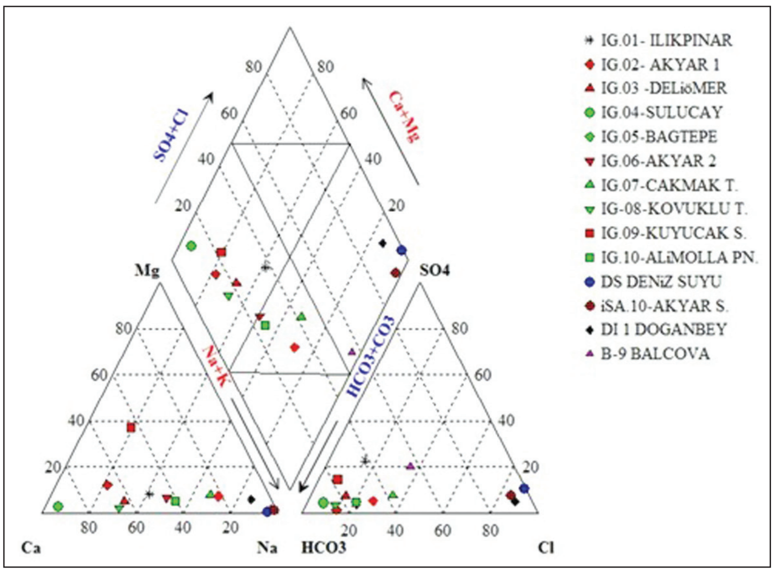

Figure 8- Piper diagram of water samples.

samples taken from the study area give similar peaks (Figure 9). It can be stated that surface waters filter out beneath the surface through fractures and fissures then come up to the surface followed by heating. However, it is probable to say that drill waters are fed by marine waters in addition to surface waters.

Cl-SO_4-HCO_3 ternary diagram is used in order to determine whether waters are deep or shallow circulating. Samples taken are $HCO_3/Cl>4$ and all these samples plot out at HCO_3 corner showing that these are shallow circulating waters and were subjected to an effect of mixing process at the same time when assessed in this diagram (Figure 10). According to this diagram, it is seen that water sample belonging to Akyar drill (İSA-10) takes place in the category of saturated water. This water is admixed with marine water and is in saturated water category because of its high chloride content.

6. Saturation Indexes

It is an important issue to predict chemical precipitations that might occur along pipes and pumps during the production and usage of hot waters through drilling wells. The precipitation of calcite and dolomite minerals namely the "coating" can be considered as the first precipitation type. The solubility of calcite and dolomite in waters increases with respect to the amount of CO_2 gas in water. The results of mineral

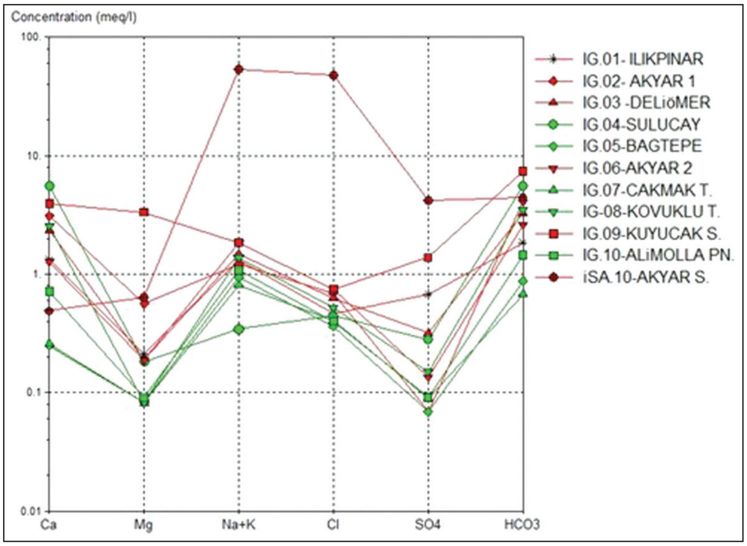

Figure 9- Schoeller diagram of water samples.

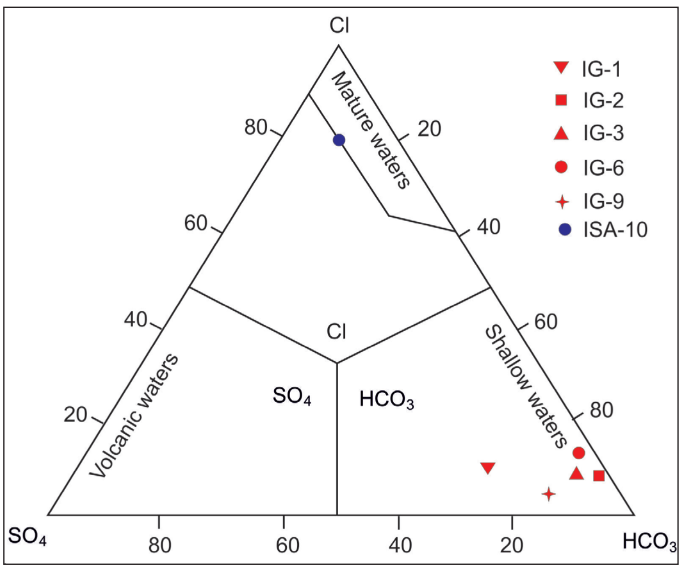

Figure 10- Cl-SO_4-HCO_3 diagram of water samples.

saturation index calculated by thermodynamic methods are interpreted as shown below;

If;

SI (log Q/K) = 0; then water is in equilibrium with mineral.

SI (log Q/K) > 0; then water is saturated with the related mineral.

SI (log Q/K) < 0; then water is not saturated with the related mineral.

For this reason, the saturation of water samples of which their chemical analysis were carried out against calcite, dolomite and some other minerals were calculated and shown graphically (Table 4 and Figure 11). It was observed that, hot and cold water samples except the drilling water number İSA-10 were not saturated mainly with minerals such as; anhydrate, aragonite, calcite, dolomite and gypsum and water could easily dissolve these minerals. It was also detected that these samples were saturated with minerals such as; chalcedony and quartz, and these minerals could precipitate in water. It was determined that, drilling water number İSA-10 was not saturated for anhydrate, chalcedony and gypsum, and hot water could dissolve these minerals. However; it was also seen that this drilling water was saturated for aragonite, dolomite and quartz minerals and these minerals could easily dissolve out in water.

7. Geothermometer Applications

It is significant to predict the temperature of reservoir rock before the application of deep drillings in geothermal systems. For this purpose, chemical geothermometer applications are used. There are

Table 4- Saturation indexes of water samples for some minerals.

Sample No	T (°C)	Anhydrite	Aragonite	Calcite	Chalcedony	Dolomite	Gypsum	Quartz
İG-01	36,0	-2,52	-1,02	-0,88	0,56	-2,33	-2,36	0,96
İG-02	33,0	-3,27	-0,18	-0,14	0,48	-0,6	-3,08	0,88
İG-03	33,0	-2,67	-0,48	-0,34	0,61	-1,57	-2,49	1,01
İG-04	17,6	-2,51	-0,25	-0,1	-0,18	-1,65	-2,27	0,27
İG-05	22,5	-4,18	-2,19	-2,05	0,69	-4,48	-3,95	1,12
İG-06	36,5	-3,24	-0,97	-0,84	0,51	-2,66	-3,07	0,9
İG-07	22,7	-4,04	-2,78	-2,63	0,59	-5,66	-3,81	1,02
İG-08	22,0	-3,01	0,21	0,36	0,66	-0,68	-2,78	1,1
İG-09	41,0	-1,98	0,19	0,32	0,06	0,84	-1,85	0,45
İG-10	20,0	-3,65	-1,98	-1,83	0,79	-4,49	-3,42	1,24
İSA-10	84,0	-1,24	1,01	1,09	-0,17	1,17	-2,27	0,05

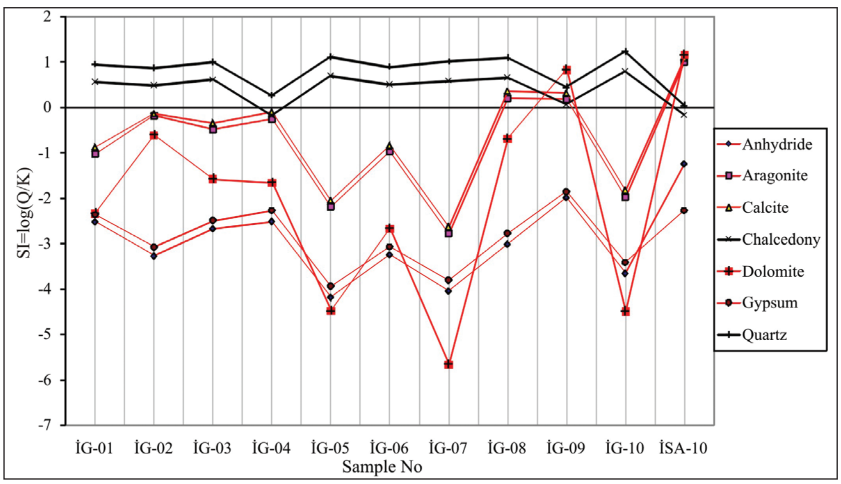

Figure 11- Saturation diagram of water samples for some minerals.

several formula developed on this issue. One of them is Na-K-Mg (Giggenbach, 1988) ternary diagram. It is used to determine reservoir rock temperatures according to cation geothermometers of hot waters and to study mineral equilibrium relationships between the water and rock. The curve separating immature waters from partly mature waters is where the maturity index equals to 2 (MI=2,0) and is formed by connecting points that have equal chemical features. Samples taken from the investigation area have MI<2 and waters fall into immature water category (water – rock equilibrium not provided). In this case, results of reservoir rock temperature calculated according to cation geothermometers are suspicious. The drilling water takes place in which the rock-water equilibrium is partly balanced. It is also necessary to consider reservoir rock temperatures calculated by cation geothermometers in future studies (Figure 12).

It was seen that reservoir rock temperatures calculated by silica geothermometers could vary between 48 and 127ºC. It was understood that the temperature of reservoir rock could even increase up to 162ºC according to silica geothermometers which were applied to the sample taken from the drilling (Table 5).

8. Results and Discussion

The Akyar geothermal field which has geographically very irregular topography has been thought as an area which has a lower temperature compared to its surround. This field can be assessed as a medium to high enthalpy geothermal system based on geological, geophysical, hydrogeochemical results and drilling investigations within the scope of Geothermal Energy Explorations of the General Directorate of MTA. The maximum temperature and flow rate of the fluid (vapor + water) inside the well were obtained as 141,8ºC and 104 tons/h, respectively. The fluid is sodium chloride type water and the system is fed by the mixture of surface and marine water. Investigations made so far are the beginning stage to determine the potential of a geothermal system and these should be improved more. The electrical conductivity values of hot and cold water samples taken from the study area vary between 116-800 µs/cm, and dominant cation and anion in waters are Na, Ca and HCO_3, respectively. According to AIH classification, both hot and cold water springs fall into mineral poor water types as; sodium, bicarbonated and calcium. The electrical conductivity value of Akyar İSA-10 drill water sample is 5,690 µs/cm, and the dominant cation and anion are; Na and Cl, respectively. It falls into hot and mineralized water region with sodium and chloride. pH value for this drilled water is 8,5. However; pH values of hot and cold springs vary between 6,9-7,8. This situation indicates a probable mixing of the drilled water with marine water.

Based on previous studies made so far in the region, the general lithostratigraphic succession and tectonical characteristics of the area were investigated. Accordingly; the well lithology and geophysical measurements carried out inside the İSA-

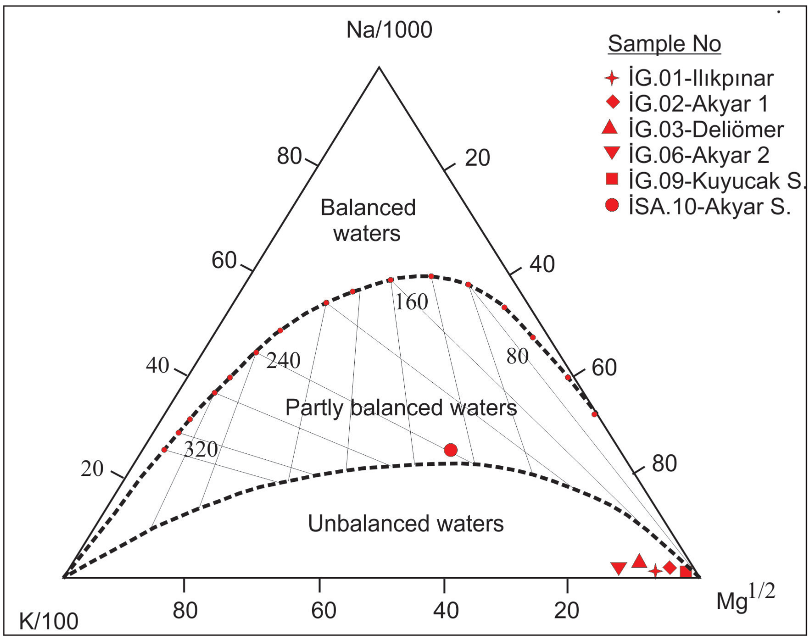

Figure 12- Giggenbach diagram of hot water samples.

Table 5- Reservoir rock temperatures calculated in hot water samples.

Sample No	İG-01	İG-02	İG-03	İG-06	İG-09	İSA-10
Measured temperature (°C)	36	33	33	36	41	84
Thermometer	Calculated temperature					
Amorphous silica[a]	x	x	x	x	x	x
Crystobalite alpha[a]	75	62	77	70	x	112
Crystobalite beta[a]	x	x	x	x	x	x
Chalcedony[a]	98	84	100	92	48	139
Quartz[a]	126	113	127	120	79	162
Quartz (vapor loss)[a]	123	112	125	118	83	154
K/Mg [b]	x	40	x	x	65	x
Na/K[c]	375	399	413	485	202	224
Na/K[d]	358	379	391	451	204	224
Na/K[e]	379	395	404	448	252	270
Na/K[f]	341	355	362	400	230	245
Na-K-Ca[f]	208	204	213	240	152	247
Na-K-Ca-Mg corrected[f]	135	120	175	165	x	152
x ; Temperatures calculated are below the outlet temperatures.						
[a]; Fournier and Potter 1977, [b]; Giggenbach at al., 1988, [c];Fournier and Truesdell, 1973						
[d];Truesdell 1976, [e];Fournier and Potter 1979, [f]; Fournier 1979						

2011/10 geothermal exploratory drill were correlated. As a result, the thickness of the İzmir Flysch which was tectonically deposited over Menderes Massif was estimated as 400 m. This unit is unconformably overlain by the Middle Miocene aged Yeniköy formation and the thickness of this sedimentary unit is 380 m.

Stratigraphically; the Middle Miocene aged sedimentary rocks forming the Yeniköy formation within conglomerate, sandstone, claystone and clayey limestone facies and the Upper Miocene aged volcanic rocks consisting of rhyolite, rhyodacite, dacitic lava and tuffs, and agglomerates which unconformably overlie pre Neogene rocks are in the character of mantle rocks (Cumaovasi volcanites). Fracture zones within metamorphic units belonging to Paleozoic aged Menderes Massif and fractured, fissured mica schist and quartz schists, and tectonic fractures and limestone layers within İzmir Flysch are considered as reservoir rocks in the study area (Figure 6). According to hydrochemistry, the geothermal system is fed by both from surface and marine waters. Waters entering the system in this manner are heated under the effect of high geothermal gradient that is formed by the crustal thinning and mantle elevation due to graben tectonism in Western Anatolia.

The Seferihisar Geothermal Field which is located at the southwest of the area (Cumali hot springs, Tuzla Field, Karakoç hot spring, Doğanbey springs) has been a significant well known geothermal field for years. Geological, geophysical and drilling investigations in these areas have been performed for many years and temperatures inside the well were detected up to 153ºC. The well temperature of the Balçova geothermal field which is located at the north of the study area was detected around 142ºC as a result of geological, geophysical and drilling investigations carried out. The study area which lies in between these two geothermal fields is located within Çubukludağ Graben. As a result of geological, geophysical and geothermal drilling investigations performed, 104 tons/h flow rate and 141,8ºC maximum in-well static temperature were measured and these values indicate that the field is a prominent area.

Acknowledgement

This study was made within geothermal projects of the General Directorate of Mineral Research and Exploration (MTA) 2009-33-13-04.2 prospection and 2011-33-13-04.1 drilling). The author thanks to all staffs of MTA who have participated in field studies.

Received: 22.12.2012
Accepted: 20.06.2013
Published: December 2013

References

Başarır, E., Konuk, Y.T. 1982. Gümüldür yöresinin kristalin temeli ve allokton birimleri. *Türkiye Jeoloji Kurumu Bülteni* 24, 1–6.

Bozkurt, E., Park, R.G. 1994. Southern Menderes Massif: an incipient metamorphic core complex in western Anatolia, Turkey. *Journal of Geological Society* 151, 213-216.

Borsi, S., Ferrara, G., Innocenti, F., Mazzuoli, R. 1972. Geochronology and Petrology of Recent Volcanics in the Eastern Aegean sea (West Anatolia and Leovos Island). *Bulletin of Volcanology* 36, 473–496.

Bulut, M., Büyükboyacı, Ü., Dünya H. 2013. Akyar-Ilıkpınar (Seferihisar-Menderes-İzmir) ruhsat sahalarının jeotermal etüt (Jeoloji-Jeofizik) ve Akyar İSA-2011/10 jeotermal arama sondajı kuyu bitirme raporu. *Maden Tetkik Arama Genel Müdürlüğü*,109, (unpublished) Ankara.

Dora, O., Kun, N., Candan, O. 1990. Metamorphic history and geotectonic evolution of the Menderes massif. *International Earth Sciences Congress on Aegean Regions*, İzmir-Turkey, Proceedings, 102–115.

Emre Ö., Özalp S., Doğan A., Özaksoy V., Yıldırım C., Göktaş F. 2005. İzmir yakın çevresinin diri fayları ve deprem potansiyelleri. *Maden Tetkik Arama Genel Müdürlüğü Rapor No*: 10754, 80, (unpublished) Ankara.

Erdoğan, B. 1990. İzmir-Ankara Zonu'nun, İzmir ile Seferihisar Arasındaki Bölgede Stratigrafik Özellikleri ve Tektonik Evrimi. *Türkiye Petrol Jeologları Dergisi Bülteni* 2/1, 1–20.

Eşder, T. 1988. Gümüldür-Cumaovası (İzmir) alanının jeolojisi ve jeotermal enerji olanaklarının araştırılması. PhD Thesis, İstanbul Üniversitesi. Fen Bilimleri Enstitüsü, Jeoloji Mühendisliği Bölümü Anabilim Dalı, 401 p. (unpublished).

Eşder, T, Şimşek, Ş. 1975. İzmir (Seferihisar) alanı, Çubukludağ grabeni ile dolaylarının jeolojisi ve jeotermal olanakları. *Maden Tetkik ve Arama Enstitüsü Raporu*, 190, (unpublished), İzmir.

Fournier, R. O. 1977. Chemical geothermometers and mixing models for geothermal system. Geohthermics, 5, 41-50.

Fournier, R. O. 1979. A revised equation for the Na/K geothermometer. *Geothermal Res. Council Trans.*, 3, 221-224.

Fournier, R. O., Truesdell, A.H. 1973. An Empirical Na-K-Ca Geothermometer for Natural Waters. *Geochimica et Cosmochimica Acta*, 37, 1255-1275.

Fournier, R. O., Potter, R. W. 1979. Magnesium correction to the Na-K-Ca chemical geothermometer. *Geochimica et Cosmochimica Acta*, 43, 1543-1550.

Genç, S.C., Altunkaynak, Ş., Karacık, Z., Yılmaz, Y. 2001. The Çubukludağ graben, Karaburun peninsula: it's tectonic significance in the Neogene geological evolution of the western Anatolia. *Geodinamica Acta* 14, 45–55.

Giggenbach, W. F. 1988. Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators. *Geochimica et Cosmochimica Acta*, 52, 2749-2765.

Güngör, T. 1998. Stratigraphy and Tectonic Evolution of the Menderes Massif in the Söke-Selçuk Region. Doktora Tezi, Dokuz Eylül University.

Güngör, T., Erdoğan, B. 2002. Tectonic significance of mafic volcanic rocks in a Mesozoic sequence of the Menderes Massif, West Turkey. *International Journal of Earth Science* 91, 386–397.

Hetzel, R., Ring, U., Akal, C., Troesch, M. 1995. Miocene NNE-directed extensional unroofing in the Menderes Massif, southwestern Turkey. *Journal of Geological Society* 152, 639–654.

Kaya, O. 1979. Ortadoğu Ege çöküntüsünün Neojen stratigrafisi ve tektoniği. *Türkiye Jeoloji Kurumu Bülteni* 7/22, 35–58.

Kaya, O. 1981. Miocene reference section for the coastal parts of West Anatolia. *Newsletters on Stratigraphy* 10, 164–191 pp.

MTA, 2005. Türkiye Jeotermal Kaynakları Envanteri, Ankara.

Okay, A.İ., Siyako, M. 1991. The New Position of the İzmir-Ankara Neo-Tethyan Suture Between İzmir and Balıkesir. *Proceedings of the Ozan Sungurlu Symposium*, Ankara, 333–355.

Özer, S., Sözbilir, H. 2003. Presence and tectonic significance of Cretaceous rudist species in the so-called Permo-Carboniferous Göktepe Formation, central Menderes Massif, western Turkey. *International Journal of Earth Sciences* 92, 397–404.

Özgenç, İ. 1978. Cumaovası (İzmir) asit volkanitlerde saptanan iki ekstrüzyon aşaması arasındaki göreceli yaş ilişkisi. *Türkiye Jeoloji Kurumu Bülteni*, 21/1, 31–34.

Somay, M. 2006. Hydrogeology of Küçük Menderes River coastal wetland. Dokuz Eylül Üniversitesi Fen Bilimleri Enstitüsü Doktora Tezi, 222. (unpublished).

Şengör, A.M.C. 1979. The North Anatolian Transform Fault: its age, offset and tectonic significance. *Journal of the Geological Society of London*, 136, 269–282.

Şengör, A.M.C. 1980. Türkiye'nin neotektoniğinin esasları, *Türkiye Jeoloji Kurumu yayını*, 40.

Şengör, A.M.C., Satır, M., Akkök, R. 1984. The timing of tectonic events in the Menderes Massif, western Turkey: implication for tectonic evolution and evidence for Pan-African basement in Turkey. *Tectonics* 3, 693–707.

Truesdell, A.H. 1976. Summary of section III geochemical techniques in exploration. Proceedings of second United Nations Symposium on the development and use of geothermal resources. 1975, San Francisco, 1, 53-89 pp.

Uzel, B., Sözbilir, H. 2008. A First record of strike-slip basin in western Anatolia and its tectonic implication: The Cumaovası basin as an example. *Turkish Journal of Earth Sciences* 17, 559–591.

Yılmaz, Y., Genç, S.C., Gürer, O.F., Bozcu M., Yılmaz K., Karacık Z., Altunkaynak Ş., Elmas A. 2000. When did the western Anatolian grabens begin to develop Bozkurt E., Winchester J.A., Piper J.D.A. (Eds.), Tectonics and magmatism in Turkey and the surrounding area, *Geological Society of London*, Special Publication 173, 353–384.