Mineral Res Expl. Bull., 131, 21-36, 2005

HYDROGEOLOGICAL, HYDROCHEMICAL AND ISOTOPIC SURVEY OF THE BAYINDIR GEOTHERMAL AREA (İZMİR, WESTERN ANATOLIA, TURKEY)

Metin BULUT* and Şevki FİLİZ**

ABSTRACT. -The Bayındır geothermal system is located to the northern margin of the Küçük Menderes Graben. The reservoir rocks of geothermal system are the calcschists and marbles of the metamorphic formation of Triassic age. The system is controlled by active graben faults. The geothermal field is a low-enthalpy one and the surface temperature of the hot waters is 42-46 °C. According to the chemical geothermometer applications, the temperature of the reservoir is 55-118 °C. The chemical and isotopic data imply that the thermal waters are mixed with meteoric, shallow cycling and cold underground water. The chemical composition of the thermal waters are Ca>Mg>Na>K and HCO_3>SO_4>Cl and the chemical composition of the cold waters are Ca>Mg>Na>K and HCO_3>SO_4>Cl. The Sarıyurt Pb-Zn mineralization which is located in the collecting area is proved to cause no natural or artificial heavy metal pollution in the waters.

Key words: Heavy metal, hydrogeology, hydrochemistry, isotope, Bayındır.

INTRODUCTION

Recently, the effects of the energy use on the natural environment has become a popular issue, because of the increase in the environmental problems all over the world. The most important environmental issue is the air pollution. All the countries try to increase the use of environmental friendly energy sources in order to reduce and control their environmental polluting emissions. The geothermal energy being cheap and environmental friendly is useable in a variety of areas including heating and cooling procedures, industrial and food drying, thermal health tourism, greenhouses, fish farms etc. and therefore becomes more and more important in all over the world.

Turkey's potential is rich in geothermal energy resources. The issues of investigating, improving, operation and protecting the low, medium and high enthalpied geothermal systems are very important for Turkey. The sustainabilities of the known geothermal areas are as important as investigating for the new ones. It should always be taken into consideration that geothermal energy is a renewable one but geothermal systems are fragile and need careful protection to be sustainable; otherwise, they could easily be less profitable or the worst, destroyed. Their chemical compositons are very important from many respects and it is important to protect their compositions.

The Bayındır geothermal system is located in the northern margin of the Küçük Menderes Basin and has a low enthalpy. Up to now, it has been used for health tourism; for the treatment of dermatological and reumathological illneses in particular. However, Bayındır has vast agricultural areas and the use of geothermal energy in the heating of greenhouses is an important issue in the area. In this study, the hydrogeological, hydrogeochemical and isotopic features of the system, the cold surface and underground water interactions and probable natural pollution issues were investigated.

Material and method

The study area is located in about 14 km Northeast of the Bayındır (İzmir) town and covers the Ergenli-Dereköy hot springs in the nothern margin of the Küçük Menderes Graben. It is in the İzmir L19-a3, d2 maps (Figure 1).

* Maden Tetkik ve Arama Genel Müdürlüğü, Ege Bölge Müdürlüğü, 35100 Bornova - İzmir mbulut@mta.gov.tr
** Dokuz Eylül Üniversitesi, Jeoloji Mühendisliği Bölümü, 35100 Bornova - İzmir sevki.filiz@deu.edu.tr

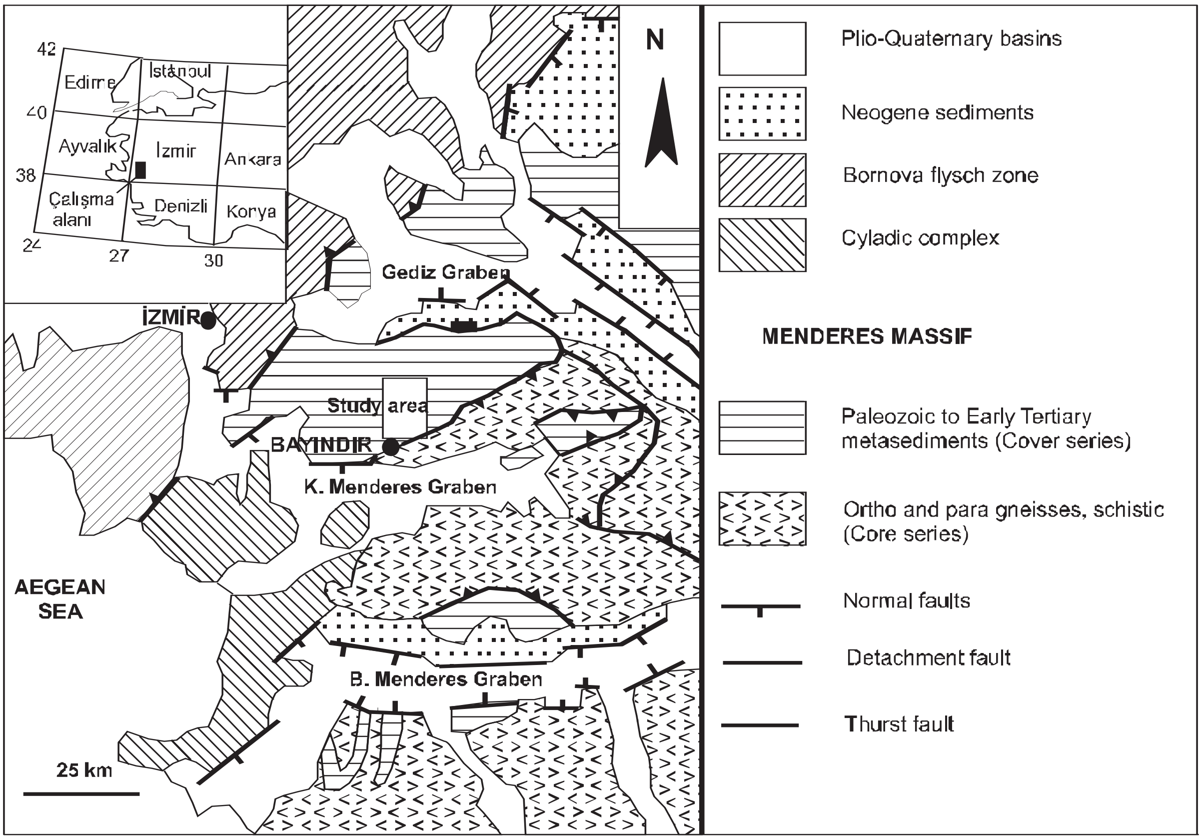

Figure 1- Regional geological map of western Anatolia (modified Rimmele at al., 2003)

There are four drillings in the study area and their depths vary between 45 and 80 meters. The flow of the hot water is 13 L/s. It is used in the hot spring resort. The chemical and isotopic data are obtained from the samples derived from the hot and cold water drillings, springs and streams in the study area. The chemical analyses of the samples were done in the laboratories of MTA (Ankara) and Dokuz Eylül Universty; the heavy metal analyses were done in Acme Analytical Laboratiories (Canada), isotopic analyses were done in the isotop laboratory of DSİ (Ankara). The heat and pH measurement were taken in the field. 1000 ml samples were used for the chemical analyses. 50 ml samples were used for the heavy metal analyses and 500 ml samples were used for the isotopic analyses. All the samples were put in polyethylene jars. The sampled hot water locations are shown with B5, B6, B7, B8, K6 and K7 smybols in all of the figures and tables. The rest belong to the cold water samples. The results of the analyses were evaluated in the Aquachem (Calmbach, 1997) and PhreeqCi (Parkhurst and Appelo, 1999) computer programs. The field and laboratory works were carried out between 2002 and 2004.

The Ödemiş meteorology stations is the closest to the study area and according to its records the most rainy month is December with 124 mm rain and the driest month is August with 2.3 mm rain. According to the temperature records, the warmest month is July with 27 °C and the coldest month is January with 7 °C.

GEOLOGY

A vast massive called Menderes Massive crops out in the Western Anatolia (Figure 1). The massive is composed of a Precambrian aged core and Paleozoic and Mesozoic aged cover series (İzdar, 1969, 1971 and 1975).

The rocks forming the core are mainly high methamorphic augen gneisses. The origin of the gneisses are still contraversial. According to some researchers, their original rocks are sedimentary (Schuiling, 1962; Şengör et al., 1984; Satır and Friedrichsen, 1986). Some researchers, however, consider the original rocks as granitic (Konak et al. 1987 and Bozkurt et al., 1995).

The cover rocks were divided into two as schist envelope and marble envelope. The schist envelope is made up of augen, kyanite, staurolite, chlorite and sillimanite schists, quartzites, augen amphybolites and, pelitic and psammitic gneisses with black marble intercalations (Dürr, 1975; Akkök, 1983; Ashword and Evirgen, 1984; Şengör et.al., 1984; Satır and Friedrichsen, 1986; Konak et al., 1987; Bozkurt, 1996; Hetzel et.al., 1988). In this sequence, the degree of methamorphism increases from south to north (Bozkurt, 1996).

The basic volcanism exist in Kula, Kiraz and Söke areas in the Menderes Massive. The rich geothermal resources encountered in the graben zones of the massive indicate that the volcanic activity is continuing (Dora et al., 1992).

The fault systems in the active rift zones in the Menderes Massive provide deep circulation for the meteoric waters. The geothermal gradient is high in these zones and young subvolcanic activities heat the water (Özgür and Pekdeğer, 1995).

The southwestern parts of the Selçuk-Bayındır area is covered by the methamorphics of the Menderes Massive. The metamorphic rocks, here, form an anticlinal extending NE-SW direction and plunging towards SW called Bayındır anticlinal (Figure 2). Along this structure of a very thick methamorphic sequence crops out. This unit is called Bayındır formation and is composed of uniform micaschists, muscovite and biotite schist, micaschists with augen and quartz micaschists and Triassic in age.

The micaschists contain thin marble lenses. The unit is overlain by the Kayaaltı formation which is composed of marble-micaschist alternation in its lower levels and of dolomitic marbles in its upper levels. The contact between the two formations is transitional in both lateral and vertical directions. Erdoğan and Güngör (1992) claim that this transition is a few km thick around of Bayındır.

The Western Anatolia is subjected to a N-S tension and as a result, an extension of 3-6 cm/year occurs. Because of the N-S tension, E-W extending grabens were developed. These grabens are bordered by normal faults. The marginal fault zones of these grabens extend 100 to 150 km as fault zones formed by faults with extension about 8-10 km. These faults are the source of a continuous seismic activity (Yılmaz, 2000). The seismic activities of the Western Anatolia are mainly located in those graben systems. Around Büyük Menderes, Gediz, Simav, Bakırçay, İzmir, Gönen and Edremit areas, 123 hot springs and 36 geothermal areas were defined (MTA, 1980; Şimşek, 2002).

The core and cover rocks of the above summarized rocks of Menderes Massive crops out in the study area. The core is represented by schistose gneisses. The cover rocks are micaschists, quartzschists, chlorite schists and Calcschists. Laterally discontinuous marble lenses are present in the chalk schists. Besides, there are quartzite bands in these rocks. These methamorphic cover rocks are transitional and named as Bayındır formation. The core rocks are thrusted over the cover rocks. The youngest formations in the study area are the talus and the alluviums in the Küçük Menderes Basin. The micaschists are mainly thin to medium bedded and the calc schists and marbles are medium to thick bedded. The dominant schistozity and bedding shows N 75 E / 45 SE. The rocks are densely fractured and the main fracture system shows ENE-WSW and NNE-SSW (Figure 2 and 3).

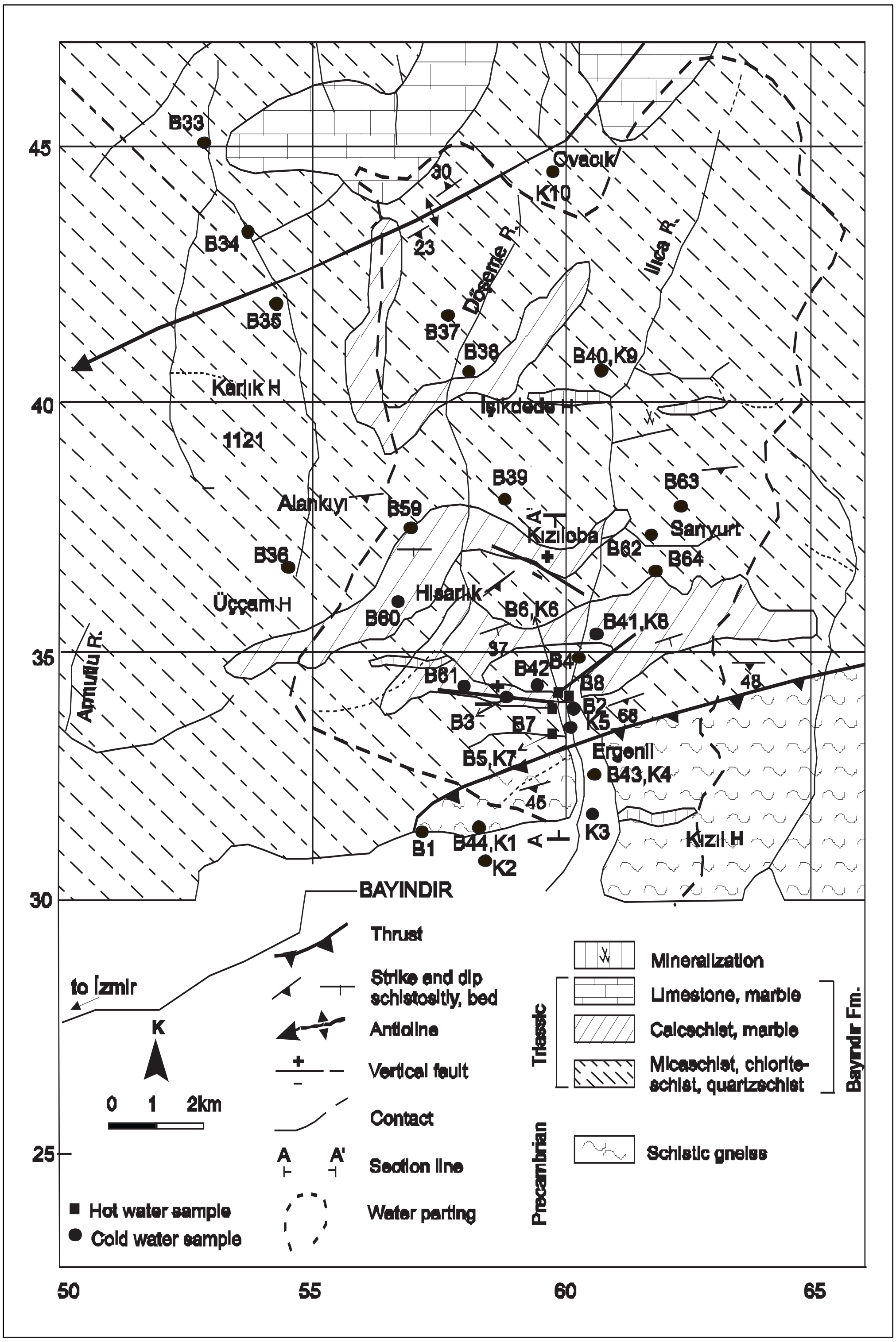

Figure 2- Geological map of the study area and location of samples.

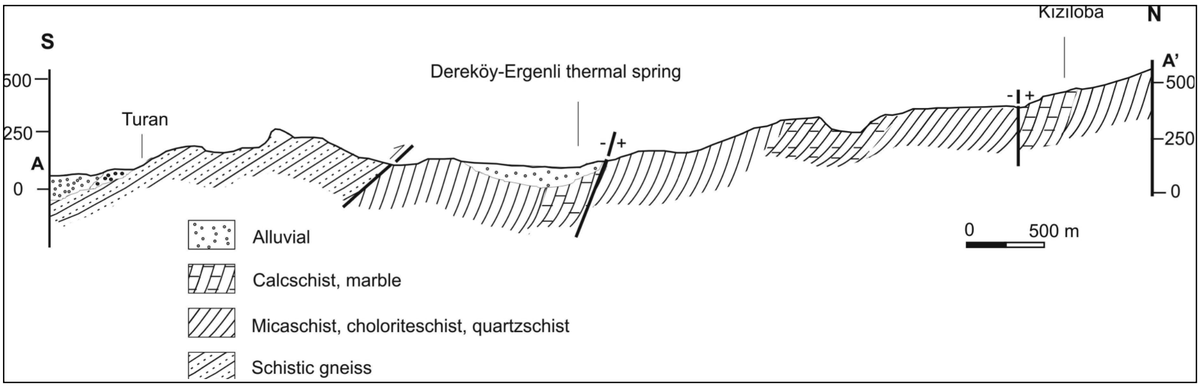

Figure 3- Cross section of the study area N-S (this study)

HYDROGEOLOGICAL AND HYDROGEOCHEMICAL PROPERTIES

The rock units existing in the study area were divided into three as basement, reservoir and cap rocks. The permeabilities of those rocks vary. Permeability is related to the type of the rock, fracture systems, schistosity and bedding. The micaschists are weakly permable or not permeable at all and form the basement rocks. The fractured and faulted calcschists and marbles form the reservoir rocks. Micaschists and quartzschists whic are transitional with the reservoir rocks form the cap rocks (Figure 2).

The watershed area is defined by both geological and morphological structures. In the watershed area, the dip of the dreinage and schistosity are towards south and provides the deep infiltration of the water. A deep drilling might reach to the deep fractured reservoir rocks. The meteoric waters filtered through the deeper parts of the reservoir get heated and then issue using the fault with N80E/75 SE strike and dip which passes through Dereköy (Figure. 3).

The temperature, pH, Ec and chemical analysis results recorded from 1942 up to date by various researchers are given in the table 1. According to those records, the temperature vary between 44 and 48°C, the pH varies between 6.42 and 8.50, Ec varies between 970 and 1299 µS/cm in the Ergenli - Dereköy hot springs. The hot waters are mixing with the meteoric waters before and/or after the heating (Tarcan, 2000).

The chemical analyses of the samples taken from the hot and cold springs, streams and drillings are given on the (Table 2). The hot waters in the study area display Na>Ca>Mg>K and HCO_3>SO_4>Cl chemical composition and are of Na-HCO_3 and Na-Ca-HCO_3 type. The cold waters of the study area display Ca>Mg>Na>K ve HCO_3>SO_4>Cl chemical composition and are mainly of Ca-Mg-HCO_3 type (Figure 4). The cold water springs issue from three kinds of fractured aquifer: Gneiss, calcschists and micaschists-quartzschists aquifers. The waters issueing from the gneisses are in the Ca-Mg-Na-HCO_3-SO_4, the ones issueing from the calcschists and marbles are in the Ca-Mg-HCO_3 and the ones issueing from the micaschists-quartzschists are in the Ca-Mg-HCO_3-SO_4 facies. The streams are of Ca-HCO_3 type.

All the analyzed hot and cold waters are rich in bicarbonate from the anion content point of view. From the viewpoint of cation content, hot waters are sodium and cold waters are calcium dominant. The pH of the cold waters vary between 6.28 - 7.80. According to the French degree of hardness of the samples, majority of the waters are in soft hard water class. The majority of the French degree of hardness of the sampled waters are in the soft- rather hard water class (Figure 5).

Table 1- Chemical analyse of the Fatma hanım hot spring at different time.

Date	T (°C)	pH	Ec (μS/cm)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	SiO_2 (mg/l)	Reference
July,1933	44	8.50		231		52	6	17	756			(Reman,1942)
June,1971	45	6.42	1170	206	11.0	50	9	19	734	25	59.8	(Yenal et al., 1975)
March,1985	48	6.70	970	240	9.0	51	6	18	766	26	58	(Erişen et al., 1996)
May,1998	48	6.69	1299	199	9.0	62	6	7	683	19		(Gönen,1988)
Jan,2000	48	6.50	1026	207	9.0	56	5	17	754	13	83.1	(Tarcan,2000)
Apr,2002	44	7.00	970	198	14.5	45.3	5.5	9.5	682	13.5	64.2	(This study)

When the cold and hot waters of the study area compared, as it could be seen in the Schoeller diagram; hot waters are rich in Na ion and, hot and cold waters are similar with respect to their content of other ions (Figure 6). This implies that, either hot and cold waters have the same watershed area and/or they are mixing during the elevation of the hot waters.

The heavy metal content of the hot and cold waters.

There are various kinds of mineralizations in different parts of the study area which is located in the north of Sarıyurt villiage which the most important of those is Sarıyurt Pb-Zn mine (Figure. 2). This mine is known for a long time and was intensely investigated by MTA between 1971-1974. In the context of this investigation many trenches and 72 exploration drillings were done. A probable reserve of 860 000 tonnes of mine with 2.76% Pb and 3.7% Zn grades were determined in the mentioned study (Özcan, 1972).

The micaschists, chloriteschists, calcschists, marbles and quartzites belonging to the cover rocks of Menderes Massive crop out in and arround of the mine. The micaschists contain muscovite, serisite and quartz as main components and may contain calcite. Albite, graphite, zircon and rutile are important accesory minerals. They contain almost no chlorite and biotite and were derived from Fe-poor sandstones with very little clay and some marls. No Pb-Zn mineralization were recorded in the micaschists. The most widespread rocks around the mine are chloriteschists. The chloriteschits contain quartz, albite and serisite besides chlorite. Flogopite, clinozoicite, garnet, rutile and graphite are present as accesory minerals and sometimes are present as abundant as the main minerals. Almost all chloriteschist samples contain Pb-Zn pics. Calcschists and marbles are transitional with chloriteschists. Calcite is the main mineral of calcschists and marbles. Some layers of graphites and thin horizons of mineralizations are

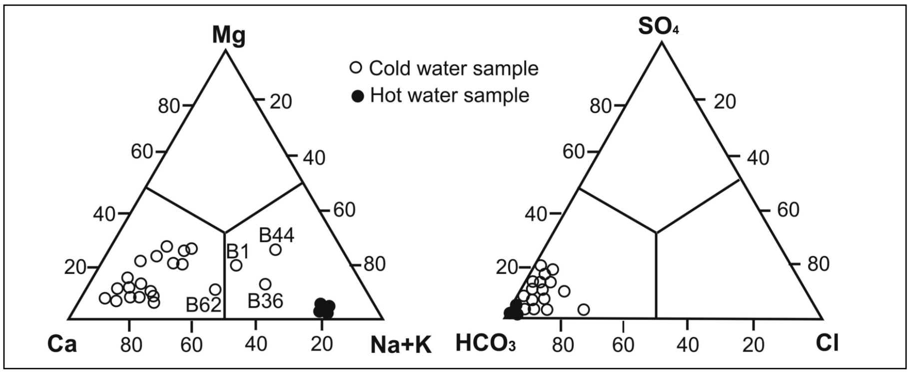

Figure 4- Relative Na+K, Mg, Ca and Cl, SO_4, HCO_3 of waters from the study area.

Table 2- Chemical analyses of the cold and hot sample waters of Bayındır region

Sample No	Sampling lacation	Date	T (°C)	pH	Ec (μS/cm)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Si (mg/l)	Fe (mg/l)	B (mg/l)	Li (mg/l)	Mn (mg/l)	F (mg/l)	Water type
B1	Bayındır çş	Apr,2002	17	7.10	300	20.5	5.60	22.5	12.4	4.8	138	30.4	13.7	<0.03	<0.1	<0.1	<0.03	0.35	Ca-Mg-Na-HCO3-SO_4
B2	Dereköy çş	Apr,2002	19	7.40	430	13.6	3.20	53.1	15.9	7.6	251	9.8	10.5	0.05	<0.1	<0.1	<0.03	0.3	Ca-Mg-HCO_3
B3	Döşeme dere*	Apr,2002	12	7.80	350	8.5	2.10	54.7	6.4	9.5	197	21.3	6.4	<0.03	<0.1	<0.1	<0.03	0.4	Ca-HCO_3
B4	Ilıca dere*	Apr,2002	11	7.70	240	7.9	1.50	32.2	4.7	9.5	120	17.6	6.5	0.12	<0.1	<0.1	<0.03	0.1	Ca-HCO_3
B5	Y.Kayacık**	Apr,2002	44	7.10	890	153	20.20	49.4	7.7	11.4	622	5.8	32.3	0.5	0.4	0.1	<0.03	2.3	Na-Ca-HCO_3
B6	Fatma hanım**	Apr,2002	44	7.00	970	198	14.50	45.3	5.5	9.5	682	13.5	30.0	<0.03	0.7	0.12	<0.03	1.5	Na-HCO_3
B7	Şifa**	Apr,2002	42	7.10	866	161	11.90	48.5	5.8	10	610	14.3	25.2	0.1	0.6	0.1	0.05	3.3	Na-Ca-HCO_3
B8	Vardar**	Apr,2002	46	7.00	950	185	14.00	43.1	5.7	10.5	652	11.4	28.0	0.04	0.7	0.12	0.04	1.5	Na-HCO_3
B33	Kadir Süzün çş	Oct,2003	16	7.07	437	8.0	1.47	73.7	9.4	11	229	25.9	10.1						Ca-HCO_3
B34	Alankıyı dere*	Oct,2003	15	7.67	389	8.9	1.68	64.4	10.3	11	209	13.8	7.3						Ca-Mg-HCO_3
B35	Ayvacık Y çş	Oct,2003	16	7.23	453	8.9	2.52	51.5	23.9	14	224	26.5	8.7						Ca-Mg-HCO_3
B36	Alankıyı Y Şifalı çş	Oct,2003	17	6.28	77.5	7.9	0.59	4.7	2	9	26	0.21	4.6						Ca-HCO_3
B37	Dereköy Y Havuz çş	Oct,2003	16	7.35	570	10.1	2.36	97.1	6	13	337	7.8	13.2						Ca-HCO_3
B38	Karanlık çş	Oct,2003	17	7.54	190	8.7	0.50	17.6	9	15	92.7	0.4	9.6						Ca-Mg-HCO_3-Cl
B39	Çeşmecik çş	Oct,2003	18	6.87	199	8.5	0.50	18.7	9	11	95.2	6.0	9.2						Ca-Mg-HCO_3
B40	Maden çş	Oct,2003	19	7.51	610	11.8	0.84	93.6	20.1	13	285	6.7	11.4						Ca-Mg-HCO_3
B41	Köprübaşı çş	Oct,2003	22	6.69	289	13.1	0.98	29.3	11.2	11	159	0.41	14.1						Ca-Mg-HCO_3
B42	Dereköy +	Oct,2003	22	7.24	537	19.7	1.70	55.0	19.6	18	273	19.6	11.9						Ca-Mg-HCO_3
B43	Ergenli Fayanslı çş	Oct,2003	24	7.31	520	13.0	1.65	60.8	23.0	15	271	27.2	11.9						Ca-Mg-HCO_3
B44	Turan havuz çş	Oct,2003	23	7.48	341	19.3	6.31	16.4	20	14	151	13.5	22.7						Mg-Na-Ca-HCO_3
B59	Kuruçeşme çş	Oct,2003	19	6.85	390	8.9	0.88	70.8	12.6	11	278	4.1	20.0						Ca-Mg-HCO_3
B60	Hisarköy çş	Oct,2003	15	6.48	268	6.6	0.72	41.2	13.1	13	132	28.2	10.0						Ca-Mg-HCO_3
B61	Narlı çş	Oct,2003	21	6.79	305	11.0	0.95	52	9.2	14	188	4.5	20.0						Ca-Mg-HCO_3
B62	Sarıyurt yolu çş	Oct,2003	19	6.38	230	25.2	0.78	30.8	7.3	20	146	3.9	20.0						Ca-Na-HCO_3
B63	Sarıyurt çş	Oct,2003	20	7.12	230	13.0	0.55	42.8	5.1	12	151	2.7	13.0						Ca-HCO_3
B64	Aşağıköydere çş	Oct,2003	22	7.67	392	20.6	1.00	52	12.2	35	166	17.9	16.0						Ca-Mg-Na-HCO_3-Cl

çş; cold water spring, +; cold water well, **; hot water well, *; stream

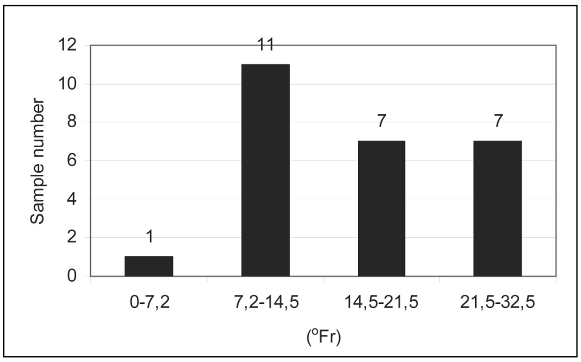

Figure 5- The classification of the sampled waters of the study are according to their degree of hardness [(°Fr= 5x (rCa+rMg)].

present in the chalschists. The quartzites are present as vertically and laterally discontinuous masses in the other rocks (Köktürk, 1978).

The main minerals recorded in the mineralisation are pyrrhotite, pyrite, sphalerite, galena, calcopyrite, magnetite and ilmenite. The elements found in those minerals are Ag, As, Ba, Bi, Cd, Co, Cu, Cr, Fe, Mn, Mo, Nb, Ni, Pb, Sb, Se, Sr, Ti, V, Zn and Zr (Köktürk, 1978). In order to determine if there is a natural or artificial heavy metal pollutions in the waters of the study area, the heavy metal analyses were performed and

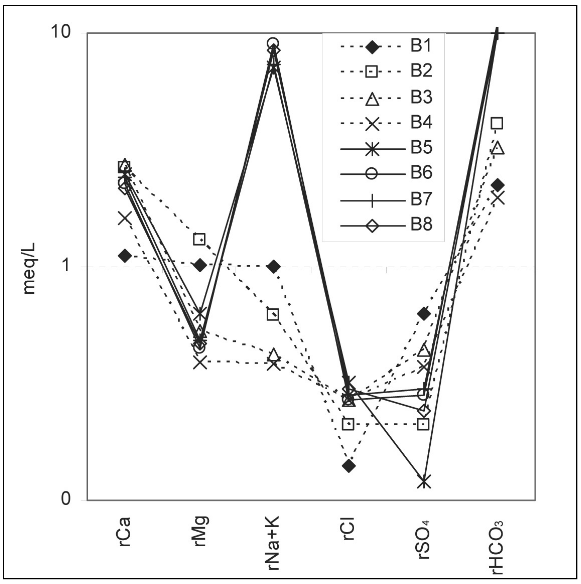

Figure 6-The Schoeller diagram of the waters in the study area.

the results are given in the table 3. The samples belonging the cold waters are below the limits for the drinking water determined by the Turkish Institute of Standarts (TSE 266, 1997) and World Health Organization (WHO, 1975) with respect to their toxic element (As, Cd, Cr, Hg, Ni, Pb, Sb, Se) contents and undesired heavy metal (Ag, Ba, Cu, Fe, Mn, Zn) contents (Table 3). K1 cold spring issuing from the gneisses is rich in Pb content. The spring K9 issuing in the mine is rich in S and the drillings in the alluvium are slightly rich in Zn content comparing with the other samples taken from the study area (Figure 7).

The heavy metal analyses of the hot waters show that there is a richening in the contents of As, Ba, Cu, Fe, Li, Mn and Sr (Figure 7). However, the values of those contents are below the limits of Turkish Standarts Institute (TSE 266, 1997) and World Health Organization (WHO, 1975). Only Fe content of the K7 is over the limits. The borate pollution is an important issue in the geothermal systems of Aegean Region and is between 0.33 and 0.70 ppm in the study area and does not seem to be a problem neither for environmental issues nor the agricultural issues (Table 2 and 3).

Saturation index

It is crucial to know and take measures against the probable problems such as corrosion and incrustation in the pipes and pumps used in the production and usage of the hot waters.

The saturation indices of anhydrite, aragonite, dolomite, gypsum, chalcedony, calcite and quartz were calculated for some of the samples taken from the study area and the results are given in the figure 8. All of the evaluated samples of hot and cold waters are undersaturated in anhydrite, gypsum, aragonite and dolomite. However, B5 is oversaturated in aragonite and dolomite. These samples are oversaturated in quartz and chalcedony. Sample B1 is undersaturated in calcite and the other samples are close to equilibrium line in calcite contents.

Table 3- The heavy metal analyses of the hot and cold waters in the study area (August,2003) and the elements in the Sarıyurt mine.

Örnek no		K.1	K.2	K.3	K.4	K.5	K.6	K.7	K.8	K.9	K.10	a	aa	b	bb
Ag	(μg/L)	0.07	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	0	10		50
As	(μg/L)	<.05	1.6	3.3	3.7	3.9	2.9	6.4	2.7	5.3	2.4	0	50		50
Ba	(μg/L)	40.3	55.7	123.2	9.3	11.5	128.3	185.6	4.0	2.6	6.2	100	300		1000
Bi	(μg/L)	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05				
Cd	(μg/L)	0.17	0.16	<.05	0.2	0.14	<.05	0.17	0.21	0.18	0.23	0	5		10
Co	(μg/L)	0.06	0.02	0.06	<.02	<.02	<.02	0.06	0.03	<.02	0.04				
Cu	(μg/L)	2.5	1.6	2.1	2.7	4	3.8	4.7	3.1	2.1	1.8	100	3000	1000	
Cr	(μg/L)	<.5	<.5	10.6	0.6	0.9	10.4	0.6	<.5	<.5	<.5	0	50		50
Fe	(μg/L)	24	<10	<10	64	96	<10	721	14	<10	45	50	200	300	
Mn	(μg/L)	2.15	0.41	0.62	0.29	0.21	35.4	29.2	0.31	0.49	3.14	20	50	50	
Mo	(μg/L)	0.7	1.6	0.8	0.2	0.2	<.1	<.1	<.1	0.4	<.1				
Nb	(μg/L)	<.01	<.01	0.03	<.01	<.01	0.01	<.01	<.01	<.01	<.01				
Ni	(μg/L)	0.8	0.4	1.1	0.4	<.2	0.3	0.6	0.6	0.7	0.5	0	50		
Pb	(μg/L)	0.6	0.2	<.1	0.2	0.1	<.1	0.2	0.2	0.3	0.3	0	50		50
Sb	(μg/L)	<.05	<.05	0.06	0.08	<.05	<.05	0.1	0.09	0.06	0.09	0	10		10
Se	(μg/L)	1.4	1.3	0.8	0.6	0.6	<.5	0.6	0.5	1.2	<.5	0	10		10
Sr	(μg/L)	105	161	332	434	402	1112	1174	192	452	216				
Ti	(μg/L)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10				
V	(μg/L)	3.7	4.8	2.7	2.4	1.8	3.7	6.2	2.3	1.9	1.9				
Zn	(μg/L)	5.6	34.8	6.7	18	6.5	0.8	3.1	2.4	2.5	4.9	100	5000	5000	
Zr	(μg/L)	0.02	<.02	0.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02				
B	(μg/L)	<20	25	<20	<20	<20	653	330	<20	<20	<20	1000	2000	1000	
Hg	(μg/L)	<.1	<.1	0.1	0.5	<.1	<.1	<.1	<.1	<.1	<.1	0	1		2
Li	(μg/L)	10.1	6.5	13.5	3.6	5.3	118	92	8	3.9	1				
S	mg/L	11	11	13	13	10	6	3	3	23	2				

Sarıyurt mine[c]

		ore zone	pyrr-hotine	pyrite	spha-lerite	gale-nite	magne-tite
Ag	(ppm)		30	20	30	100	
As	(ppm)			200			
Ba	(ppm)		10			10	
Bi	(ppm)	500			40	40	
Cd	(ppm)		500	40	0.2(%)		
Co	(ppm)			100			
Cu	(ppm)	1000	260	100	500	1000	20
Cr	(ppm)						40
Fe	(%)	15.5			11		
Mn	(ppm)	5000	100	200	0.15(%)	1.5(%)	0.5(%)
Mo	(ppm)						60
Nb	(ppm)	350			20	20	
Ni	(ppm)	100	20	100	10	40	10
Pb	(ppm)	8000					
Sb	(ppm)	500			700	1000	
Se	(ppm)			100			
Sr	(ppm)	500	10		100	1000	
Ti	(ppm)	2000	10		25	1500	0.1(%)
V	(ppm)						20
Zn	(ppm)	5.7(%)					20
Zr	(ppm)	100			20-100	20-100	

	Lokasyon
K.1	Turan çş
K.2	Turan alüvyon*
K.3	Sadıker çş
K.4	Ergenli çş
K.5	M.Hilmi çş
K.6	Fatmahanım**
K.7	Y.Kayacık**
K.8	Köprübaşı çş
K.9	Maden çş
K.10	M.Atalay*

**; hot water drilling, *; cold water drilling, çş; cold water spring
a; adviced concentration (μg/l) (mg/l), aa; maximum value (μg/l);TSE 266 (1997) standarts
b; adviced concentration (μg/l), bb; maximum allowable concentration (μg/l); WHO (1975) standarts
[c] ; chemical analyse results are after Köktürk (1978)

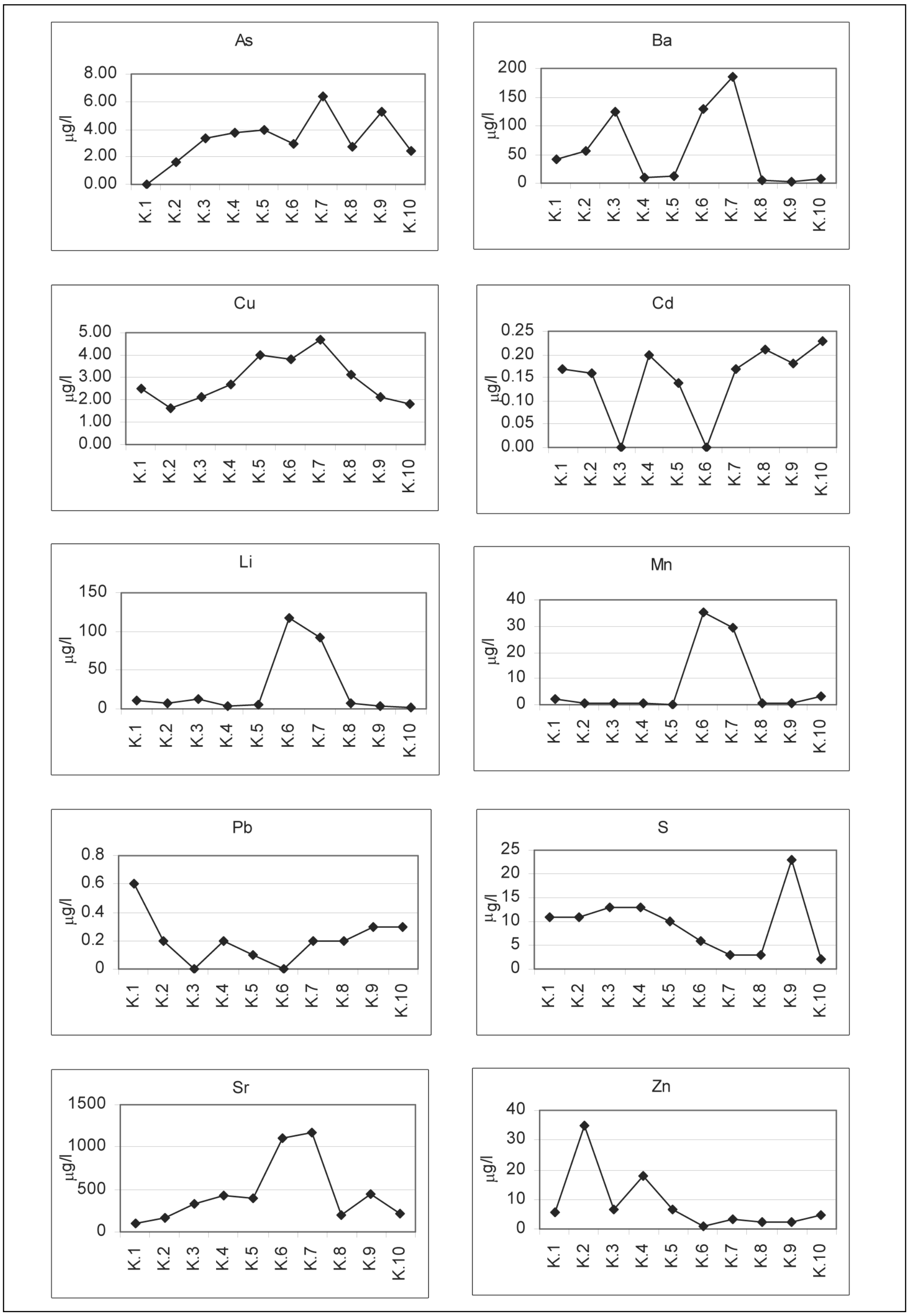

Figure 7- Diagram of heavy metal analyes.

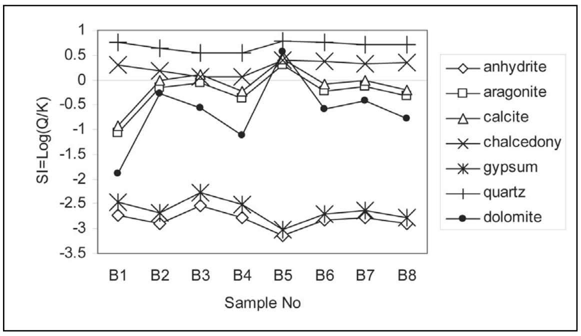

Figure 8- Mineral saturation index diagram of waters at outlet conditions.

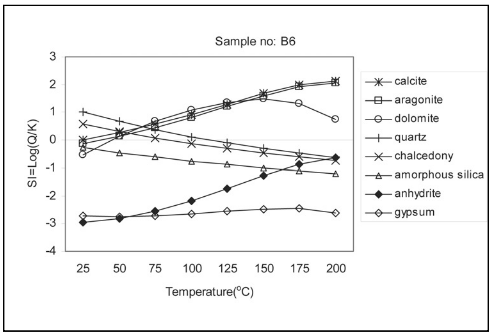

Figure 9- Mineral equilibrium diagrams of the sample B6.

The solubilities of the alteration minerals existing in the water as solutions develop as a function of temperature. Therefore, different kinds of minerals would be in equilibrium in the systems with different temperatures. The saturations of certain minerals are used to estimate the temperatures of the reservoirs. Thermodynamical equilibrium is a kind of approach for geothermometer applications. It is based on the changing saturation index values of the alteration minerals in different temperatures. If a group of mineral have equilibrium or almost equilibrium, it could be inferred that the hot liquid is saturated in those and therefore, the temperature could be considered as the temperature of the reservoir (Reed and Spycher, 1984).

The changing saturation index values according to the temperature of the sample B6 taken from Fatma hanım hot spring are given in figure 9. The overall evaluation of the saturation indexes of the minerals shows that quartz and chalcedony are in almost equilibrium between 90 °C and 100 °C (SI=0) and therefore the temperature of the reservoir could be as high as 100 °C.

Geothermometer applications

It is an important issue to predict the temperature of the reservoir before performing deep drillings in the geothermal systems. Because it is expensive and time consuming to measure it directly, geothermometer applications which are more economical, are used. There are many ways suggested for this procedure. Na-K-Mg (Giggenbach, 1988) triangular diagram is used to predict the temperature of reservoirs and the relationship of equilibrium of the water and host rock, according to the cation geothermometer values of the hot water. All the hot water of Bayındır hot springs are in the immature water (water with no water-rock equilibrium) area in the graphic. Therefore, the temperature of the reservoir calculated from the cation geothermometer is contraversial (Figure 10).

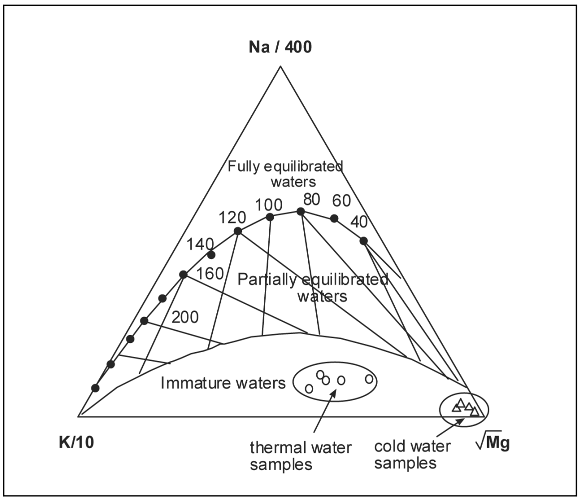

Figure 10- Distribution of waters from study area in the Na-K-Mg triangular diagram (Giggenbach, 1988; Gigenbach and Corales, 1992).

Some of the results obtained from geothermometer calculations are below the surface temperature. The cation geothermometer calculation results vary between 45 and 226 °C. This situation is originated from the immature nature of the water and do not reflect the true reservoir temperature. Silica geothermometer calculations indicate a temperature between 55 and 118 °C and seem more reliable (Table 4).

The isotopic features of the water

Filiz (1982) considers the Bayındır hot springs worthwhile to be investigated in detail in his work, which reveals the main geothermal systems of Aegean Region with respect to their ^{18}O, ^{2}H, ^{3}H, ^{13}C isotopic contents. In this context, the $\delta^{18}O$ and $\delta^{2}H$ values of the hot and cold water samples of the study area are given by using the Mediterranean Meteoric Water Line $\delta^{2}H=8\ \delta^{18}O+22$ (Gatt and Carmi, 1970) and World Meteoric Water Line $\delta^{2}H=8\ \delta^{18}O+10$ (Craig, 1961) graphs (Figure 11). The locations of the waters in the $\delta^{18}O$ and $\delta^{2}H$ graphic indicate that they are of meteoric origin and have the same watershed area. The tritium analyses of the samples show that they were effected by the precipitation and were relatively fed by the precipitations of the last fifty years (Table 5).

Table 4-Calculated aqufier temperatures

Sample no	BO5	BO6	BO7	BO8
Measured (t °C)	44	44	42	46
Thermometer	Calc Temp (°C)			
Amorphous Silica[a]	x	x	x	x
Cristobalite Alpha[a]	67	68	55	60
Cristobalite Beta[a]	x	x	x	x
Chalcedony[a]	89	85	76	81
Quartz[a]	118	114	105	110
Quartz steam loss[a]	116	113	106	110
K/Mg[b]	x	x	x	x
Mg/Li[c]	x	46	x	45
Na/Li[c]	128	125	126	128
Na/Li Cl<10000 mg/L[d]	x	x	x	x
Na/K[e]	219	150	151	154
Na/K[f]	220	157	157	160
Na/K[a]	266	209	210	212
Na/K[h]	242	192	192	194
Na-K-Ca[h]	186	160	157	161
Na-K-Ca Mg corrected[h]	100	107	105	102

x;Tempratures calculated below outlet temperatures
[a]; Fournier 1977, [b]; Giggenbach 1983, [c];Kharaka and Mariner(1989).
[d]; Fouillac and Michard (1981), [e] ;Fournier and Trusdell (1973).
[f]; Truesdell 1976, [g];Fournier and Potter 1979, [h]; Fournier 1979*a*

Table 5- Isotopic compositions of the waters.

Sample no	Location	Date	$\delta^{18}O$(%)	$\delta^{2}H$(%)	^{3}H(TU)	(TU)Eror ±
K6**	Fatma hanım	August,2003	-7,76	-41,21	9,95	2,00
K9*	Maden çş	August,2003	-7,45	-41,34	9,45	1,85
**; hot water well, *; cold water spring						

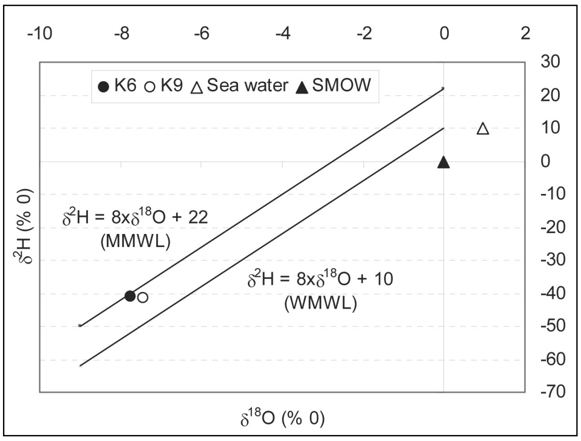

Figure 11- Stable isotopic compositions of the waters. (MMWL; Mediterranean Meteoric Water Line, WMWL; World Meteoric Water Line)

DISCUSSION AND CONCLUSIONS

The Bayındır geothermal system is a shallow circulation, low enthalpied one. The reservoir rocks are the calcschists and marbles in the system. The theoretical calculations indicate reservoir temperatures between 55 and 118 °C. The hot water of the study area are the type of mainly Na-HCO_3 and Na-Ca-HCO_3; cold waters are mainly Ca-Mg-HCO_3 and the streams are mainly Ca-HCO_3 types of water. Isotopic data indicate that hot water is of meteoric origin and effected by the relatively young precipitations. There is no signs of borate pollution in the hot water of this geothermal system. The metallic mineralisations present in the study area cause no heavy metal pollution. All the water analysed from the study area posses heavy metal concentration values below the Turkish Standarts Institute and the World Health Organization standarts.

ACKNOWLEDGMENTS

This study is a part of the PhD thesis which is being prepared in the Applied Geology section of the Geological Engineering Department of the Graduate School of Natural and Applied Sciences of Dokuz Eylül University: The authors acknowledge the partial finacal support of Dokuz Eylül Univertiy Research Fund (Project number; 03.KB.FEN.048) and the contributions of General Directorate of MTA (Project number; 13-D4). The authors are grateful to Prof. Dr. Nilgün Güleç and Prof. Dr. Şakir Şimşek who revised the manuscrpt with great care and to Dr. Nuray Önoğlu for her efforts in editing the English version of the manuscript.

Manuscript received October 22, 2004

REFERENCES

Akkök, R. 1983. Structural and metamorphic evolution of the northern part of the Menderes massif: new data from the Derbent area and their implication for the tectonics of the massif. Jornual of Geology, 91, 342- 350.

Ashworth, J.R. and Evirgen, M.M. 1984. Garnet and associated minerals in the southern margin of the Menderes Massif, southwest Turkey. Geogical Magazine, 121, 323-337.

Bozkurt, 1996. Metamorphism of Paleozoic schists in the Southern Menderes Massif: field, petrographic, textural and microstructural evidence. Turkish Journal of Earth Sciences, 5, 105-121.

Bozkurt, Winchester, J.A. and Park, R.G. 1995. Geochemistry and tectonic significance of Augen Gneisses from the Southern Menderes Massif (west Turkey). Geological Magazine, 132, 287-301.

Calmbach, L. 1997. AquaChem Computer Code-Version 3.7.42, Waterloo, Ontario, Canada N2L 3L3.

Craig, H. 1961. Isotopic variations in meteoric waters. Science, 133, 1702-1703.

Dora, O., Ö., Kun, N. and Candan, O. 1992. Menderes Masifinin metamorfik tarihçesi ve jeotektonik konumu. Türkiye Jeoloji Bülteni, 35, 1-14

Dürr, S. 1975. Uber alter und geotektonische stellung des Menderes - Kristallins/SW-Anatolien und seine aequivalente in der mittleren Aegaeis. PhD Thesis, University of Marburg, Germany, 107p.

Erdoğan, B. and Güngör, T. 1992. Menderes Masifinin kuzey kanadının stratigrafisi ve tektonik evrimi. TPJD Bülteni, 4/1, 9-34.

Erişen, B., Akkuş, İ., Uygur, N. and Koçak, A. 1996. Türkiye Jeotermal Envanteri, Maden Tetkik ve Arama Genel Müdürlüğü, 480p.

Filiz, Ş. 1982. Ege Bölgesindeki önemli jeotermal alan ların 18O, 2H, 3H,13C izotoplarıyla incelenmesi. Ege Üniversitesi, Yebilimleri Fakültesi, Doçentlik Tezi, 95p. İzmir (unpublished).

Fouillac, C. and Michard, G. 1981. Sodium / lithium ratio in water applied to geothermometery of geothermal reservoirs. Geothermics, 10, 55-70.

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

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

Fournier, R. O and Truesdell, A. H. 1973. An emprical Na-K-Ca geothermometer for natural waters. Geochimica et Cosmochimica. Acta, 37, 1255-1275.

______, and Potter, R. W. 1979. Magnesium correction to the Na-K-Ca chemical geothermometer. Geochim. Cosmochim. Acta, 43, 1543-1550.

Gat, J. R. and Carmi, I. 1970. Evolution of the isotopic composition of atmospheric waters in the Mediterranean Sea area. Journal of Geophysical Research, 75, 3039-3048.

Gönen, F. 1998. Dereköy (Bayındır) çevresinin jeolojisi ve hidrojeolojisi. DEU Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü, 56p. İzmir (unpublished).

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

______, and Coralles, R. 1992. The isotopic and chemical composition of waters and steam discharges from volcanic-magmatic-hydrothermal systems of Guanacoste Geothermal Province, Costa Rica. Applied Geochemistry, 7, 309-332.

Hetzel, R., Romer, R.L., Candan, O. and Passchier, C.W. 1998. Geology of the Bozdağ area, central Menderes Massif, SW Turkey: Pan-African basement and Alpine deformation. Geol. Rundsch, 87, 394-406.

İzdar, K. E. 1969. Menderes kristalin masifi kuzey kıs mının jeolojik yapısı, petrografisi ve metamorfizması. Ege Üniversitesi, Doçentlik tezi, İzmir (unpublished).

______, 1971. Introduction to geology and metamorphism of Menderes Massif of Western Turkey; Geol. And History of Turkey; Petroleum. Expl., Soc. Of Libya, Tripoli, 495-500.

İzdar K. E., 1975. Batı Anadolunun jeoteknik gelişimi ve Ege Denizi çevresine ait üniteler ile karşılaştırılması. EÜ Mühendislik Bilimleri Fakültesi yayını, 58-59.

Kharaka, Y. K. and Mariner, R. H. 1989. Chemical Geothermometers and their Application to formation waters from sedimentary basins. In: N. D. Naser, McCulloh, T.H (Eds.). Thermal History of Sedimentary Basins; Methods and Case Histories Springer, 99-117.

Konak, N., Akdeniz, N. and Öztürk, E. M. 1987. Geology of the south of Menderes Massif. Correlation of Variscan and Pre-Variscan Events of the Alpine Mediterranean Mountain Belt, Field Meeting.IGCP Project No. 5. Min. Res. Expl. Inst. Turkey Pub, 42-53.

Köktürk, U. 1978. Sarıyurt Kurşun Çinko Yatağı ve Jenetik Konumu. Ege Üniversitesi, Mühendislik Bilimleri Fakültesi, Doktora tezi, 98p. İzmir (unpublished).

MTA, 1980. Türkiye Sıcak ve Mineralli Sular Envanteri, Ankara, 78p.

Özcan, H. 1972. İzmir İli Bayındır İlçesi Sarıyurt köyü Ilıcadere civarı Pb-Zn-Cu etüd raporu. Maden ve Tetkik Arama Genel Müdürlüğü. Rapor no: 4797. Ankara (unpublished).

Özgür, N. and Pekdeğer, A. 1995. Active geothermal systems in the rift zones of the Menderes Massif, western Anatolia, Turkey. In: Kharaka, Y. K. and Chudaev, O.V. (eds): Proc. Intenat. 8th Symposium on Water-Rock Interaction, Vladivostok/Russia, 529-532.

Parkhurst, D. L. and Appelo, C.A.J. 1999. User's guide to PHREEQC (version 2) a computer program for speciation, batch-reaction, ondimensional transport and inverse geochemical calculations: U.S.Geological Survey Water-Resources Investigations Report 99-4259, 312pp.

Reed, M. and Spycher, N. 1984. Calculation of pH and equilibria in hydrothermal waters with aoolication to geothermimetry and studies of boiling and dilution. Geochim. Cosmochim. Acta, 48, 1479-1492.

Reman, R. 1942. Şifalı suları kullanma ilmi, balneoloji ve şifalı kaynaklarımız. İstanbul. 420p.

Rimmela, G., Oberhanslı, R., Goffe, B., Jolivet, L., Candan, O. and Çetinkaplan, M., 2003. First evidence of high presurre metamorphism in the caver series of southern Menderes Massif. Tectonicand metamorfic implications for the evolotion of SW Turkey. Lithos, 71,19-46

Satır, M. and Friedrichsen, H. 1986. The origin and evolution of the Menderes Massif, W-Turkey: a rubidium/strontium and oxygen isotope study. Geol. Runsch, 75, 703- 714.

Schuiling, R. D. 1962. On petrology, age and structure of the Menderes migmatite complex SW Turkey). Bull. Miner. Res. Explor. Inst. Turk. 58, 71-84.

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

Şimşek, Ş. 2002. Research on Isotope Techniques for Exploitation of Geothermal Reservoirs in Western Turkey. IAEA TEC-DOC Publication, Vienna.

Tarcan, G. 2000. Hydrochemical assesment of the Bayındır Geothermal Area. International Earth Sciences Colloquium on the Aegean Region, IESCA 2000, İzmir, 177-187.

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

TSE 266, 1997. İçme ve kullanma suyu standartları, Türk Standartları Enstitüsü Ankara, 33p.

WHO, 1975. İçme suyu standartları. Kayabalı, K (ed). Yeraltı suyu. Gazi kitapevi, Ankara, 356-357.

Yenal, O., Usman, N. and Kanan, E. 1975. Türkiye Maden Suları Ege Bölgesi, İstanbul Üniversitesi Tıp Fakültesi, Hidroklimatoloji Kürsüsü, İstanbul, 3, 335 p.

Yılmaz, Y. 2000. Ege Bölgesinin aktif tektoniği. Batı Anadolu'nun Depremselliği Sempozyumu, 24-27Mayıs 2000, İzmir, 3-12.