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Geological And Hydrogeochemical Features Of The Hidirlar Geothermal Area(Nw Anatolia-Türkiye)

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Abstract
Biga Peninsula, located in the north western Anatolia, has many important geothermal resources. Hıdırlargeothermal area is within the south eastern part of the peninsula, and is situated to the north west of a depressional (tectonosedimantary) basin, controlled by active tectonics. Early and Middle Triassic Nilüfer unit of Karakaya complex comprise the basement of the Hıdırlargeothermal area. Upper Oligocene Çakırobagranitoid and Çanvolcanicsunconformably overly the basement rocks. Neogene Örencikformation, Quaternary slop debris and alluvium can be seen in study area and unconformably overly all the units. Four important geothermal resources (Hıdırlar main hot spring, spring from NW of Hıdırlar village, Hıdırlar drilling and Hıdırlar-Uyuz spring) are found in Hıdırlargeothermal area.Hydrogeochemical properties of the springs in Hıdırlargeothermal area were investigated regularly from 2005 to 2007. The results show that the surface temperature of these springs are ranging from 54.6 to 84 ^{0}C. Hydrogeochemical results indicate that hot springs are Na-SO_4 and Na-SO_4-HCO_3, and cold spring is Ca-Mg-HCO_3 type waters Cation geothermometers were used for determining reservoir temperature of geothermal resources in region. The results show that reservoir temperature of these geothermal resources change between 81 and 163 ^{0}C. Hydrogeochemical data are also evaluated by mineral saturation index and it seen that the average temperature of the reservoir is ranging from 125-140 ^{0}C. Isotope compositions of all springs are located on meteoric water line. The isotopic data indicate that the thermal waters are formed by local recharge and deep circulation of meteoric waters.

Keywords*: Geothermal resources, Hydrogeochemical, Isotope, Biga Peninsula*

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I. INTRODUCTION

Geothermal energy, which is one of the alternative energy sources, is a renewable, non-polluting, sustainable, domestic and environmentally friendly energy type that comes to the forefront if appropriate technologies are used.

Çanakkale province, which contains almost all of the Biga Peninsula within its borders, is closely related to active tectonic lines since it is located in the western part of the North Anatolian Fault. For this reason, there are various geothermal systems that contain many hot water sources in the region (Baba et al., 2008a; Baba et al., 2008b; Baba and Ertekin, 2007; Baba et al., 2009). The Hıdırlargeothermal area is one of the important geothermal resources located in the southeast of the Biga Peninsula. In this region, in and around the Hıdırlargeothermal area, some researchers have carried out geological, tectonic, hydrogeological and geothermal studies of the area. Studies on geothermal resources in this area have increased after 1980. In 1980, Özbayrak investigated the geothermal energy possibilities of the region by examining the geothermal and geological features of the Hıdırlararea. It gave information about the reservoir rock, cover rock and heat source. In addition, the researcher mentioned the studies that should be done to increase the geothermal potential of the area and made suggestions. In 1984, Özbayrak conducted a geothermal study in the Hıdırlararea and clarified the reservoir rock, cover rock and heater rocks. Researcher emphasized that reaching the surface of hot waters up to 87 ^{0}C depends on a certain crack system. In 2003, a series of researches on the characteristics of hot waters in the region within the scope of the İTÜ-MTA Bigajoint project were carried out. In this study, they emphasized that the waters of Hıdırlar and HıdırlarUyuz are soft, whereas the waters of Hıdırlar village, are hard water. In 2004, Karagülle conducted a study called the balneological evaluation of the hot waters in the Hıdırlar region. In this study, he emphasized that the use of hot water and bath cures in the study area can be beneficial in rheumatic diseases, skin diseases and diseases of the regulatory system. Since 2005, studies on the hydrogeological and hydrogeochemical properties of Hıdırlar geothermal resources have been carried out (Ateş, 2007; Baba and Deniz, 2008).

Within the scope of this study, the hydrogeochemical and isotopic properties of hot and cold water resources in the Hıdırlar (Yenice-Çanakkale) geothermal area were studied in detail. The data obtained from the analysis of hot and cold waters in the field, at ÇanakkaleOnsekiz Mart University, Science and Technology Application Center (ÇOBİLTUM)-Central Laboratory and ACME (Canada) Laboratory were used. Analysis of Oxygen-18 (^{18}O) and Deuterium (D) isotopes from water samples taken in order to determine the origin of hot water resources in the study area (processes such as rock-water interactions, condensation, boiling, evaporation, etc.) The Tritium (^{3}H) analysis was carried out at the Isotope Laboratories of the Technical Research and Quality Control Department of the DSİ, and at the Hacettepe University, Hydrogeology Engineering Water Chemistry Laboratories.

II. RESULT AND DISCUSSION

The Hıdırlargeothermal area is located in Northwest Anatolia, southeast of the Biga Peninsula, approximately 8 km west of the town of Yenice district, Çanakkale province (Figure 1). The study area is an area of about 25 km^2 located in the northwest part of the 1/25 000 scale BalıkesirI18 a3 topographic map.

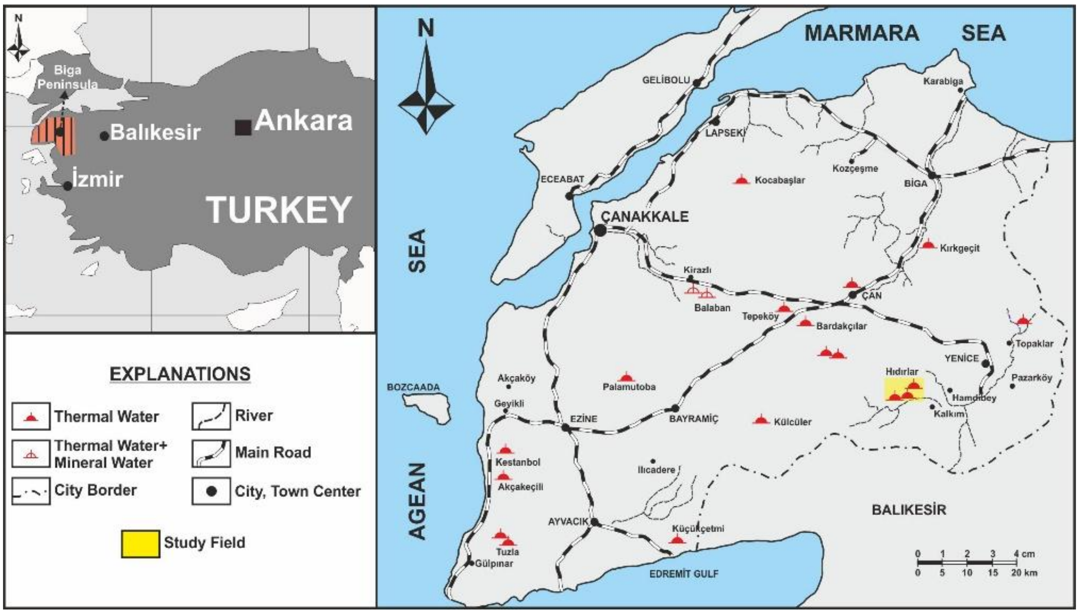

Figure 1: Location map of the Hıdırlargeothermal area (modified from Oktu and Dilemre, 1997)

2.1. Geology and Hydrogeology of the Study Area

The rocks exposed in the study area were classified into five different rock units, taking into account the field characteristics and the findings of previous studies. These are: (i) Lower-Middle Triassic Karakayacomplex, (ii) Upper Oligocene aged Çakırobagranodiorite, (iii) Upper Oligocene aged Çanvolcanics, (iv) Neogene aged Örencikformation, and (v) Quaternary aged slope debris and alluvium overlying all units in the study area unconformably. (Figure 2). The Triassic aged Karakayacomplex, which forms the basis of the study area and consists of different tectonostratigraphic units represented by active continental margin deposits, consists of metabasics and phyllites, which are very small in the west of the study area and large outcrops in the northeast. Phyllites was observed at relatively lower elevations around Hıdırlarvillage, located just southeast of the Hıdırlarthermal spring and northeast of the study area. The altered surfaces of the phyllites are yellowish brown, the fresh surface is grayish, fine-grained, medium-poor strength, abundantly cracked, with distinct foliation. In the study area, the Karakaya complex was cut by the Çakıroba granodiorite. Granodiorites cropping out in areas where geothermal springs exist, altered surface is grayish white, fresh surface is light grayish, and the minerals that make up the unit can be easily distinguished. The minerals that make up the rock are quartz, feldspar, plagioclase, hornblende and biotite. The unit, which is highly altered (arenitization) around the spa, is relatively more durable at higher elevations and contains many irregular cracks. Within the granodiorites, there are aplite dykes with NE-SW trending and thicknesses varying between centimeters and meters. Cooling cracks are quite common in the granodiorites, and the levels affected by tectonism are quite fractured and cracked. Çanvolcanics crop out in the west of the study area. Çanvolcanics are composed of andesite, dacite, rhyodacite type lava, tuff and agglomerates. The altered surface of the andesites in the Çanvolcanics is dark grayish green, and the fresh surface is grayish. Plagioclase, quartz, feldspar, amphibole and mica minerals can be clearly seen. Opalizations and argillizations due to hydrothermal alteration are observed in this unit, which has moderate to good strength. The volcanic units in the study area were emplaced by cutting the basement rocks and intrusive rocks and covered these rocks unconformably. The upper contact of the unit is the Örencik formation, which consists of clastic rocks and outcrops in the south of the study area. Örencik formation starts with a conglomeratic level and is overlain by a clayey, sandy and caliche layer. On the conglomeratic level, alternation of claystone and sandstone with altered surface dark yellowish-dark brownish, fresh surface yellowish-brownish, poor strength, non-bedded caliche nodules and levels were observed. Quaternary aged alluvial units, consisting of gravel, sand and clay units, crop out in the southeast of the study area.

Some of the geothermal resources in the study area emerge within the Karakayacomplex, which forms the basis of the area. The flow rate of the springs in this area (the springs in the NW of Hıdırlarvillage) is 5 l/sec. In general, the unit outcropping in this area is impermeable. However, the units in this area are quite deformed. For this reason, water can be taken in the second pores. Geothermal resources in the study area are tectonic controlled. The heat anomaly zones that tectonic fractures can reach constitute the heat source for geothermal systems. The springs in the area where the Hıdırlar thermal spring is located and the Hıdırlar hot spring, Uyuz spring are derived from the granodiorite units in the region. Granodiorites are receptacle rocks in the area, as the hot fluid circulates and even heats the fluid. Surface waters descend to the depths with the help of both the units belonging to the Karakaya complex and the crack systems of the granodiorites, and the waters heated in the depths due to the geothermal gradient reach the surface with the crack systems of these units. The Neogene aged Örencikformation outcropping in the south of the study area is the cover rock of the geothermal system (Figure 3).

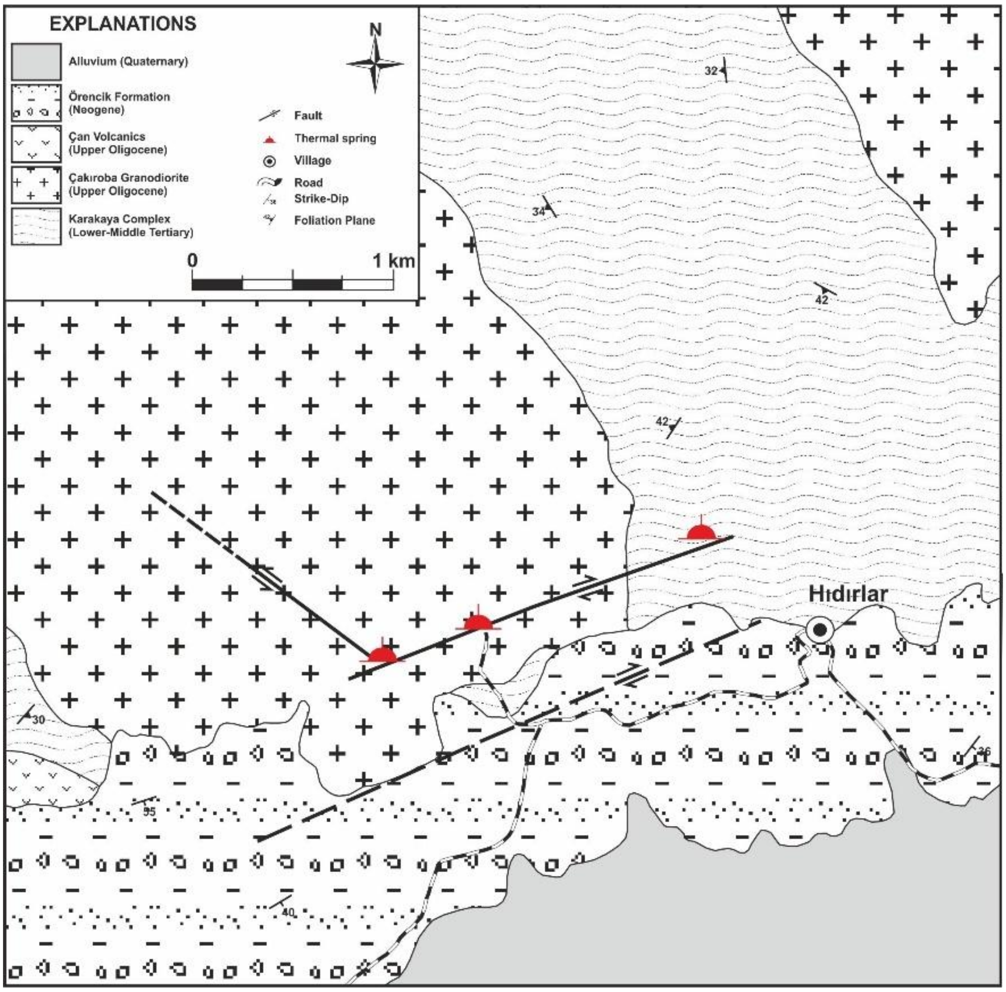

Figure 2: Geological map of the study area (Ateş, 2007)

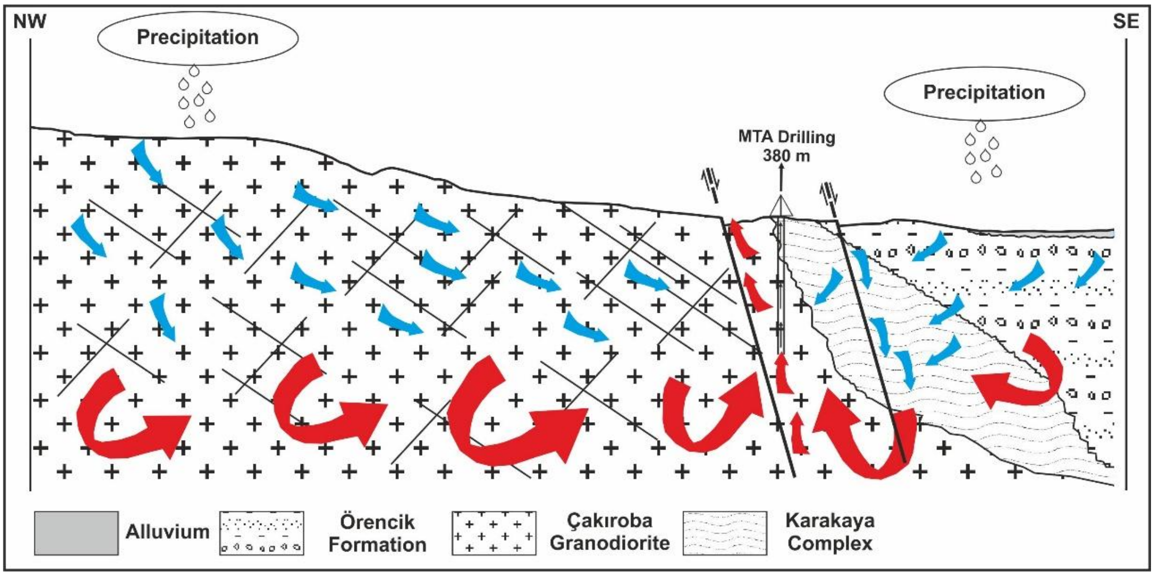

Figure 3: Schematic model of the Hıdırlargeothermal area (Ateş, 2007).

2.2. Hydrogeochemical Characteristics of Water Resources

2.2.1. Physical and Chemical Properties of Geothermal Resources

The outflows of hot waters in the Hıdırlargeothermal area were observed in three regions: the hot spring in the NW of the Hıdırlarvillage, the Hıdırlar thermal spring, Hıdırlar drilling and the Uyuz hot spring (Figure 4). Since there is a mixture of hot and cold water in the hot spring in the NW of Hıdırlarvillage, no measurement or sampling was made from this source. Other hot springs in the study area are divided into three locations: Hıdırlar Thermal Spring "HK", HıdırlarDrilling "HS" and Uyuz Hot Spring "HU" in the Bıçkıdere valley in the NW of Hıdırlar hot spring (Figure 5). In-situ measurements and water sampling studies were carried out in the field from these hot springs in five different periods (September and October 2005, February and August 2006 and March 2007). The results of the analysis made at the beginning of the water resources in the field and the physical properties of the waters (temperature, electrical conductivity and pH) and the major ion concentrations are given in Table 1.

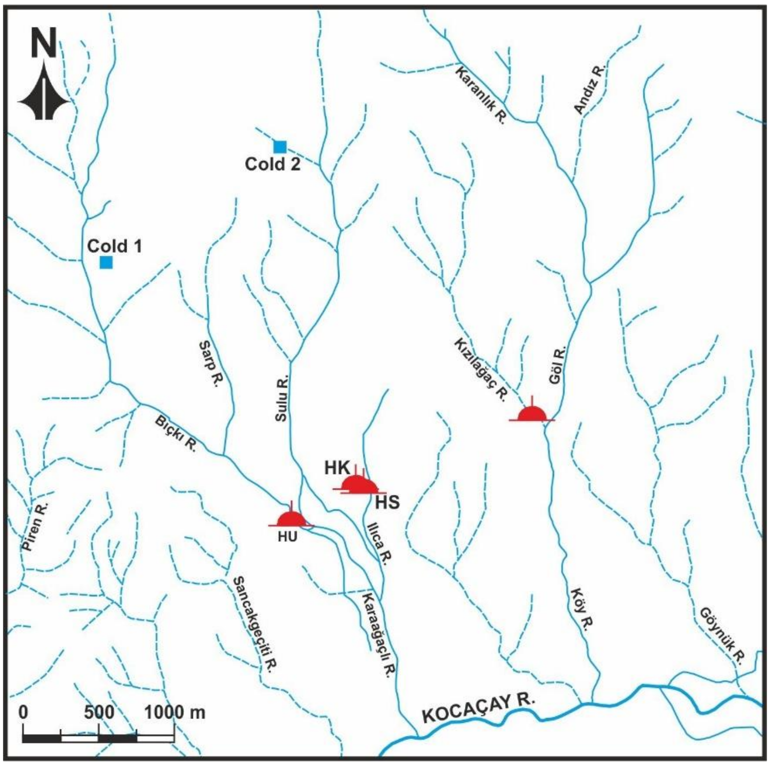

Figure 4: Hot and cold water resources in the study area (Ateş, 2007)

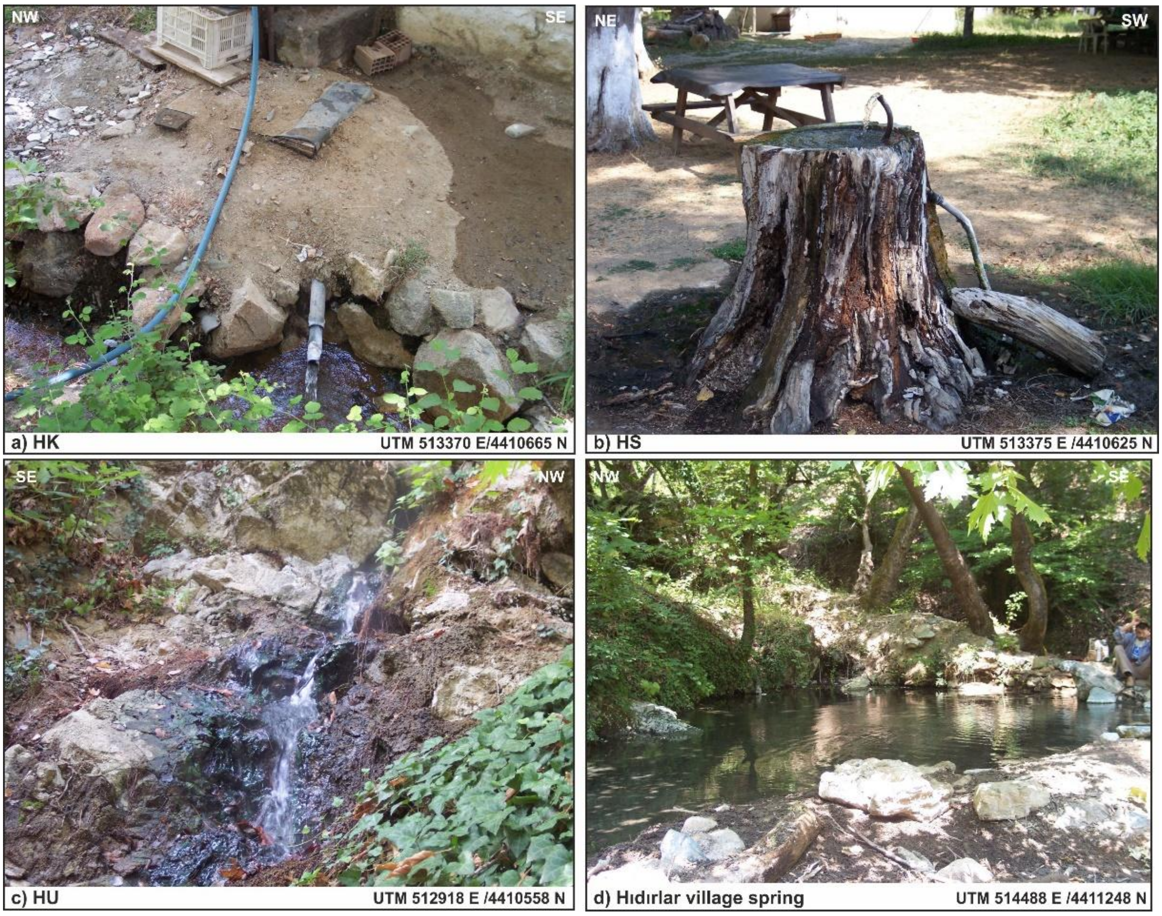

Figure 5: View of the geothermal springs in the study area; a) HK, b) HS c) HU, d) Springs in the NW of Hıdırlar Village

Table 1: Physical properties and major ion concentrations of hot water in the study area

Date	Location	Temperature T °C	Conductivity EC (µS/cm)	pH	Na (mg/l)	Ca (mg/l)	K (mg/l)	Mg (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)
19.09.2005	HK	83.30	1016	7.36	193.00	19.00	7.00	0.13	16	385	87.6
	HS	60.80	970	7.99	190.00	22.00	5.30	0.23	16	385	96.1
	HU	55.80	960	8.18	183.00	26.00	6.50	1.10	16	380	84.2
15.10.2005	HK	76.70	948	7.80	195.57	19.19	6.01	0.10	13	280	146.4
	HS	54.90	965	7.87	198.62	22.19	4.89	0.22	14	388	92.8
	HU	46.80	959	7.85	191.71	26.40	5.62	0.97	13	345	80
15.02.2006	HK	75.50	968	7.87	200.13	18.89	7.33	0.13	15	277.65	162
	HS	51.00	970	7.40	199.47	21.13	5.67	0.43	15	392	94
	HU	38.80	1005	7.75	187.88	26.85	6.62	1.39	15	351	94
01.08.2006	HK	77.50	1087	8.32	199.78	18.28	5.47	0.12	13	352.19	92
	HS	57.70	1106	8.05	201.37	20.37	4.31	0.32	13	340.06	100
	HU	53.60	1121	8.47	193.88	24.69	5.47	1.01	13	357.12	82
29.03.2007	HK	79.00	940	7.82	193.79	17.65	6.74	0.11	14	345.29	99.92
	HS	58.00	952	7.83	193.05	20.12	5.38	0.32	14	352.81	96.20
	HU	54.00	948	7.93	187.68	25.69	6.31	1.18	13	351.46	108.16

According to the analyzes made from the hot water sources in the study area, all hot waters reflect the water type with Na-SO_4 (Table 2).

Table 2: Ion order of hot water sources in the study area

Location	Date	Cation Order	Anion Order	Water Type
HK	19.09.2005	Na>Ca>K>Mg	SO_4>HCO_3>Cl	Na-SO_4
	16.10.2005			Na-SO_4-HCO_3
	15.02.2005			Na-SO_4-HCO_3
	01.08.2006			Na-SO_4
HS	19.09.2005	Na>Ca>K>Mg	SO_4>HCO_3>Cl	Na-SO_4
	16.10.2005			Na-SO_4
	15.02.2005			Na-SO_4
	01.08.2006			Na-SO_4
HU	19.09.2005	Na>Ca>K>Mg	SO_4>HCO_3>Cl	Na-SO_4
	16.10.2005			Na-SO_4
	15.02.2005			Na-SO_4
	01.08.2006			Na-SO_4

The main cation in all hot waters studied in the Hıdırlargeothermal area is Na, followed by Ca, K and Mg in order of concentration. The main anion is SO_4, followed by HCO_3 and Cl.

When looking at the thermal water types in the area, a transition from the dry period to the rainy period from the Na-SO_4 type to the Na-SO_4-HCO_3 type is striking in the hot water source called "HK". This situation shows that the hot waters are enriched in HCO_3 with the intrusion of surface-based waters into geothermal waters with the effect of seasonal precipitation in the area and the mixture of waters with shallow groundwater increases during the rainy period.

As can be seen in the Piper and Schoeller diagrams (Figure 6) prepared after the analyzes made from the hot waters taken from the study area, the hot waters in the study area reflect the water type with Na-SO_4.

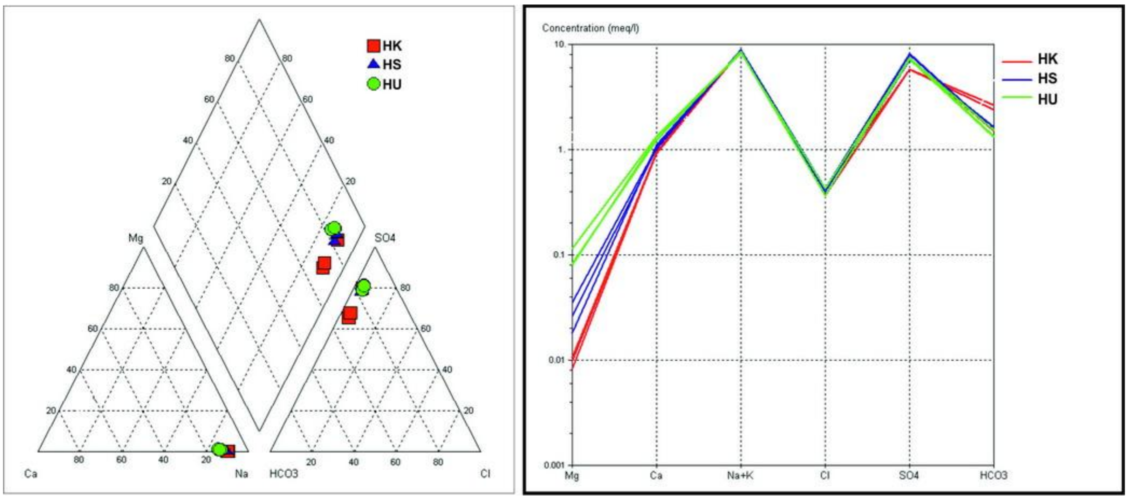

Figure 6: Piper and Schoeller diagrams prepared according to the data obtained from the hot waters in the study area

2.2.2. Hydrogeochemical Properties of Cold Water Resources

The cold water sources in the study area are divided into two locations as Cold 1 and Cold 2 (Figure 4). In-situ measurements and water sampling were carried out from these cold water sources in two periods (August 2006 and March 2007). The results of the analysis made at the beginning of the water resources in the field and the physical properties of the waters (temperature, electrical conductivity and pH) and the major ion concentrations are given in Table 3. According to these data, the pH of the cold water springs in the study area is between 6.68 and 7.48; it is seen that their EC vary between 477 and 576 µS/cm.

Table 3: Major ion concentrations of cold waters in the study area

DATE		01.08.2006		29.03.2007	
LOCATION		COLD 1	COLD 2	COLD 1	COLD 2
Temperature	ºC	17.6	12.7	10	10
Conductivity	µS/cm	576	522	477	480
pH		6.68	7.12	7.48	7.36
Na	mg/l	15.8	11.35	13.853	10.301
Ca	mg/l	72.91	76.04	69.351	70.966
K	mg/l	0.54	0.82	0.623	0.902
Mg	mg/l	17.77	14.16	16.37	14.431
Cl	mg/l	17	12	13	10
SO_4	mg/l	6.79	6.95	6.07	7.98
HCO_3	mg/l	280	285	300.99	303.73

The main cation in the cold waters studied in the Hıdırlargeothermal area is Ca, followed by Mg, Na and K in order of concentration. The main anion is HCO_3, followed by Cl and SO_4. Considering the cold water types in the area according to the Piper and Schoeller diagrams prepared according to the analysis results of the samples taken from the cold water locations, both cold water sources represent Ca-Mg-HCO_3 type waters (Figure 7).

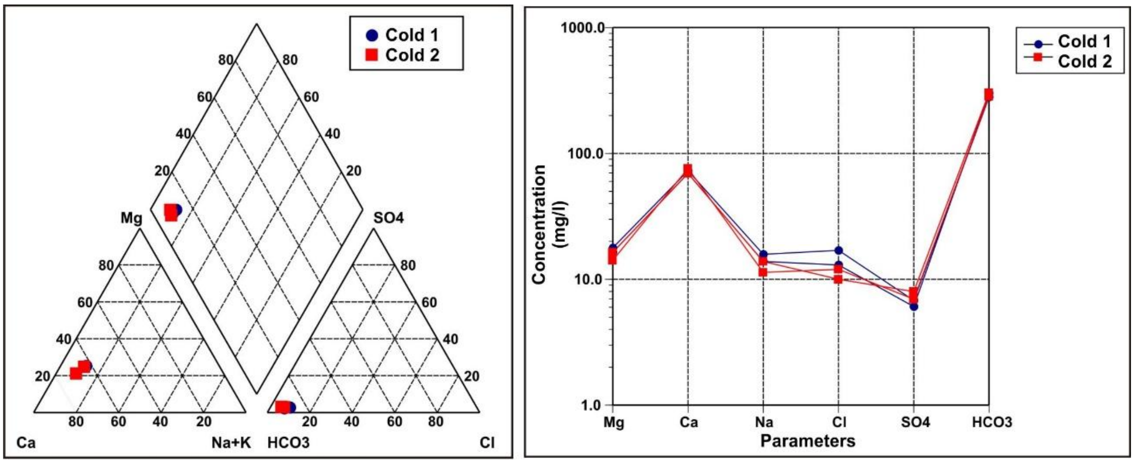

Figure 7: Piper and Schoeller diagrams prepared according to the data taken from the cold waters in the study area

3.2.3. Geothermometer Applications in Hot Waters

In the geothermometer calculations applied to determine the reservoir temperature of the hot waters in the study area, it is seen that the hot water sources are in the "water in partial equilibrium" class according to the Giggenbach diagram (Figure 8). Reservoir temperature values made with cation geothermometers applied using hydrogeochemical data were calculated as 90-163 ^{0}C for HK, 81-149 ^{0}C for HS and 83-161 ^{0}C for HU (Tables 4 and 5). When these values are evaluated by considering the mineral saturation index graphics, reservoir temperatures of 125-140 ^{0}C were determined for all hot water sources (Figure 9).

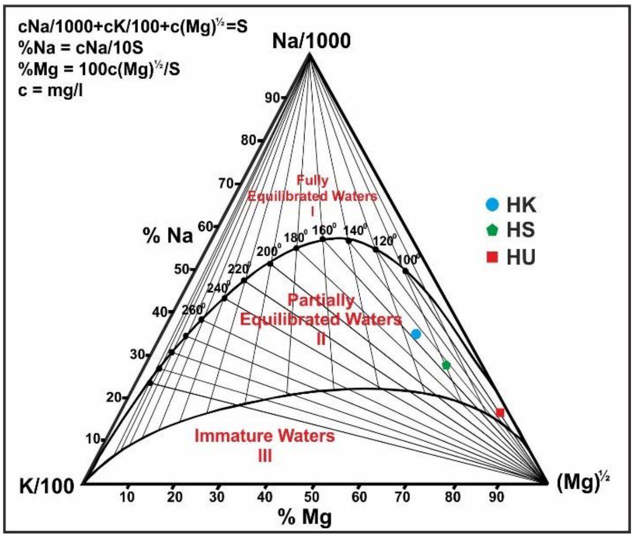

Figure 8: Equilibrium conditions in the Na-K-Mg triangle of the hot water resources in the study area (Giggenbach, 1988)

Table 4: Cation geothermometer equations (concentrations are in ppm)

No	Geothermometer	Geothermometer Equation (t= °C)	Temperature Range (°C)	Reference
1	Na-K	t°C =(856/(0.857+log(Na/K)))-273.15	100-275	Truesdell, 1976
2	Na-K	t°C =(833/(0.780+log(Na/K)))-273.15		Tonani, 1980
3	Na-K	t°C =(933/(0.993+log(Na/K)))-273.15	25-250	Arnorsson et al., 1983
4	Na-K	t°C =(1319/(1.699+log(Na/K)))-273.15	250-350	Arnorsson et al., 1983
5	Na-K	t°C =(1217/(1.483+log(Na/K)))-273.15		Fournier, 1979
6	Na-K	t°C =(1178/(1.470+log(Na/K)))-273.15		Nieva and Nieva, 1987
7	Na-K	t°C =(1390/(1.750+log(Na/K)))-273.15		Giggenbach, 1988
8	Na-K	t°C $=733.6-770.551Y+378.189Y^2-95.753Y^3+9.544Y^4$	0-350	D’Amore and Arnórsson, 2000
9	K-Mg[b]	t°C $=(2330/(7.35-\log(K^2/Mg)))-273.15$		Fournier, 1991
10	K-Mg[c]	t°C $=(1077/(4.033+\log(K^2/Mg)))-273.15$		Fournier, 1991
11	K-Mg	t°C $=(4410/(14-\log(K^2/Mg)))-273.15$		Giggenbach, 1988
12	Li-Mg	t°C $=(2200/(5.47-\log(Li/Mg^{0.5})))-273.15$		Kharaka and Mariner, 1989
13	Na-K-Ca[d]	t°C =(1647/(log(Na/K)+β[log(√Ca/Na) +2.06]+2.47))-273.15		Fournier and Truesdell, 1973
14	K-Ca	t°C =(1930/(3.861-log(K/√Ca)))-273.15		Tonani, 1980
15	Na-Li	t°C =(1590/(0.779+log(Na/Li)))-273.15		Kharaka et al., 1982

[a]Y= log([Na]/[K]) ; [b] log(K2/Mg)>1.25 ; [c] log(K2/Mg)<1.25;
[d] t°C>100 °C if β=1/3, t°C<100 °C if β=4/3, t°C<100 °C and [log (√Ca/Na)+2.06] < 0 if β=1/3

Table 5: Reservoir temperatures (^{0}C) calculated by cation geothermometers

Date	Equation	1	2	3	4	5	6	7	8	9	10	11	12	13		14	15
	Location													β=1/3	β=4/3		
16.10.2005	HK	*	*	*	138	133	122	153	121	213	*	112	*	-	90	245	108
15.02.2006		100	103	111	148	144	132	163	130	219	*	114	*	-	*	258	107
01.08.2006		*	*	92	131	126	115	146	115	197	*	107	*	-	*	241	102
16.10.2005	HS	*	*	85	126	120	109	141	109	165	*	95	82	-	81	229	113
15.02.2006		83	85	94	133	129	117	149	116	152	*	91	*	-	86	239	112
01.08.2006		*	*	*	118	113	102	133	102	144	*	87	*	-	*	224	112
16.10.2005	HU	85	87	96	135	130	119	150	118	126	*	80	*	-	81	232	109
15.02.2006		97	100	108	145	142	130	161	128	125	*	80	*	-	86	241	110
01.08.2006		83	84	94	133	128	117	148	116	123	*	*	*	-	81	232	103

** Very close to or lower than the weld outlet temperature*

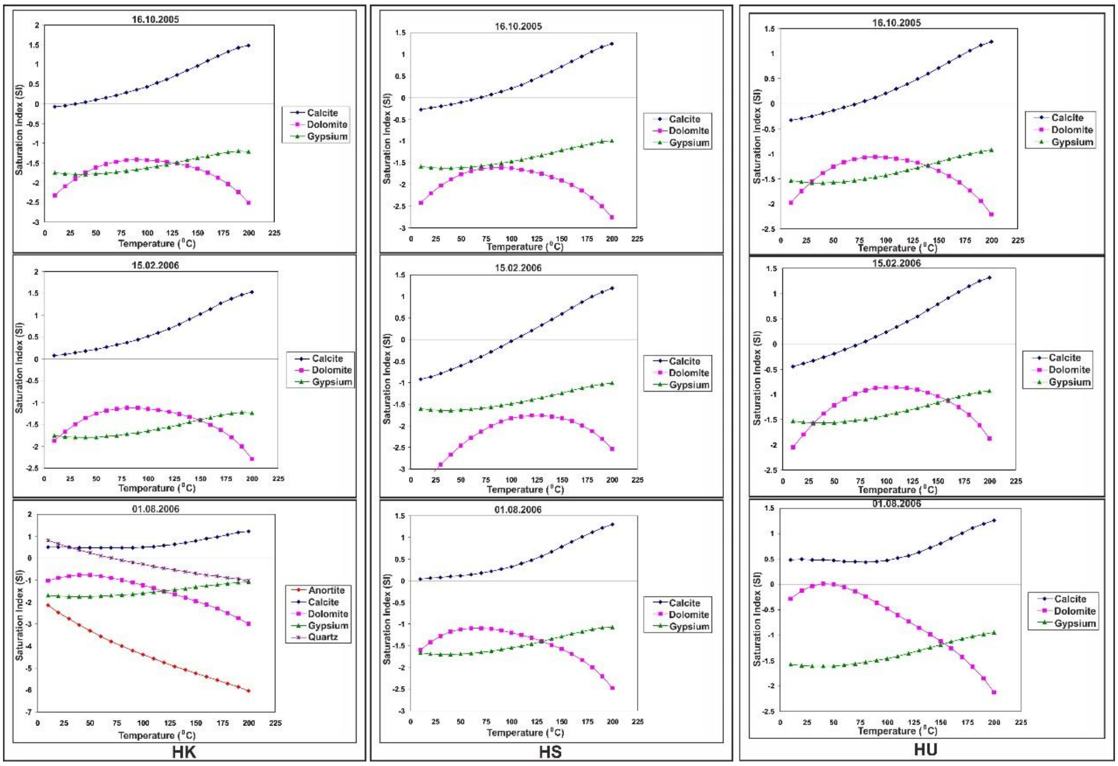

Figure 9: Saturation Index diagrams prepared for hot water resources

2.2.4. Isotope Studies in Geothermal Resources

Most stable isotopes are used in geothermal exploration, development and monitoring. The stable isotopes of hydrogen (Deuterium-^{2}H) and oxygen (Oxygen-18-^{18}O) ions are the most commonly used in examining hydrogeological conditions and physico-chemical processes affecting fluid properties in relation to fluid origins. Radioactive isotopes such as tritium (^{3}H) are used to determine the age of the geothermal fluid, while it is used to determine the temperature of the recharge areas and the fluid in the aquifer. In this study, Deuterium (^{2}H), Oxygen-18 (^{18}O) and Tritium (^{3}H) analyzes were made from the water samples taken in October 2005 and February 2006 periods (Table 6).

Table 6:δ^{18}O, δD, Cl (ppm), T (^{3}H), EC (µS/cm) and T (^{0}C) analysis results of water samples taken from hot water sources in the study area

Date		16.10.2005			15.02.2006		
Location		HK	HS	HU	HK	HS	HU
δ D	(‰ SMOW)	-46.06	-48.58	-48.22	-52.28	-50.06	-51.02
^{18}O	(‰ SMOW)	-8.59	-8.49	-8.49	-8.33	-8.45	-8.33
T (TU)	(‰ SMOW)	0.32	0.07	0.95	0.19	0.02	0.19
Cl	(ppm)	13	14	13	15	15	15
EC	(µS/cm)	948	965	959	968	970	1005
T	(^{0}C)	76.7	54.9	46.8	75.5	51	38.8

The fact that all hot water sources in the study area are located near the local meteoric water line in the ^{18}O-^{2}H diagram (Figure 10) created for the hot water springs shows that the geothermal aquifers in the region are fed by the precipitation of meteoric origin. It is thought that the hot water sources being located at different points on the diagram in the October 2005 and February 2006 periods are due to the mixtures of these sources with the underground waters belonging to the shallow or deep circulation system.

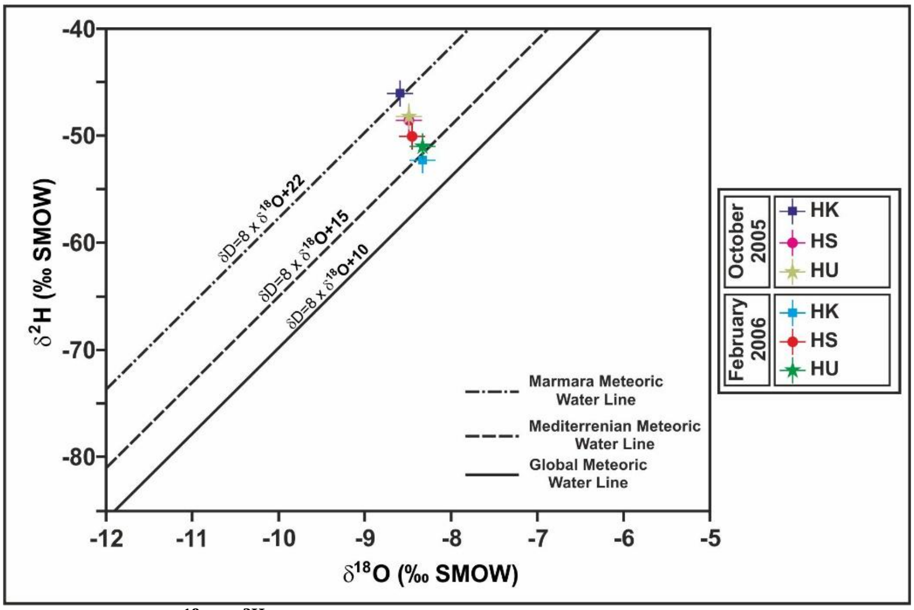

Figure 10:δ^{18}O-δ^{2H} relationship of hot water resources in the study area

III. CONCLUSION

The rocks exposed in the study area were classified into five different rock units, taking into account the field characteristics and the findings of previous studies. The base of the study area is the Nilüferunit belonging to the Lower-Middle Triassic Karakayacomplex. The Upper Oligocene aged Çakırobagranodiorite and the Upper Oligocene aged Çanvolcanicsunconformably overlie the basement rocks. Neogene aged Örencikformation and Quaternary aged slope debris and alluvium unconformably overlie all units in the study area.

When the hydrogeochemical facies types of the waters determined by using various water chemistry graphs are examined, it has been found that the HK source from the hot water sources corresponds to the Na-SO_4-HCO_3, HS source and the HU source corresponds to the Na-SO_4 type waters. The cold waters in the study area are of similar origin and these waters reflect the water type with Ca-Mg-HCO_3.

In the geothermometer calculations applied to determine the reservoir temperature, it is seen that the geothermal resources in the study area are in the "water in partial equilibrium" class according to the Giggenbach diagram. Reservoir temperature values made with silica geothermometer did not give a reliable result since they are very close to the outlet temperatures of hot water sources. The reservoir temperature values made with cation geothermometers were calculated as 90-163 ^{0}C for the HK source, 81-149 ^{0}C for the HS source and 83-161 ^{0}C for the HU source. When these values are evaluated by considering the mineral saturation index graphs, reservoir temperatures of 125-140 ^{0}C were determined for all hot water sources.

The fact that all hot water sources in the study area are located near the local meteoric water line indicates that the geothermal aquifers in the region are fed by meteoric precipitation. It is thought that the hot water sources being located at different points on the diagram in different periods are due to the mixtures of these sources with the underground waters with shallow or deep circulation system.

According to the results obtained within the scope of this study in the study area, it is expected that there will be aquifers with high temperatures in the region. However, in order to obtain detailed information about the depth and yield of these aquifers, geophysical studies should be carried out and research wells should be drilled as a result of evaluating all the data together.

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