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Hydrogeochemical Evaluation and Geothermometry Application of the Gediz Thermal Waters, Kütahya Area, Turkey

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ABSTRACT

Kutahya-Gediz geothermal field has a great potential for space heating. The aim of this study is to evaluate the reservoir temperature by using the hydrochemical compositions of the thermal springs and borehole samples.

The Cenozoic aged conglomerate, sandstone, limestone and metamorphic rocks of gneiss, metaquartzite, various schists of Paleozoic age comprise the reservoir rocks. Fractures and faults in these rocks form the reservoir for waters to be heated at depth. Thermal waters hosted by Menderes metamorphic rocks emerge along fault lineaments in the Gediz geothermal area. Studies were carried out to obtain the main chemical and physical characteristics of thermal waters.

The thermal waters of the Gediz geothermal field, with temperatures range from 57 to 97 ºC and condutivities of 3000-5500 µS/cm. They are generally enriched in Na+K-SO4 and suggest deep water circulation. The reservoir temperature of the Kütahya-Gediz geothermal system is evaluated as 123ºC by using silica and cation geothermometers.

1. INTRODUCTION

Turkey has 187 geothermal fields, having temperature above 40 ºC. One of these important geothermal field is the Gediz geothermal field located in the western part of Turkey. The geothermal resources of this field serve for hot spring tourism besides central heating and greenhouse agriculture. The temperature and capacity of these resources located in the Gediz geothermal field is appropriate for establishing an central heating system for Gediz town.

The study field is located 18 km west of the Gediz town which is located in the west of Turkey (Fig. 1). There are nine natural thermal spring in the area. The thermal springs have discharge rates between 0.1-5.0 l/s and their temperatures vary from 57 to 75.5 ºC. Four geothermal wells having depths of 6-752 m have been drilled by MTA (General Directorate of Mineral Research and Exploration of Turkey). The total discharge rates of these wells are about 140 l/s and temperatures of geothermal water discharges form these wells vary from 78 to 97 ºC.

Geological mapping, geophysical surveys and exploration drilling were carried out in Kütahya-Gediz geothermal field by MTA (General Directorate of Mineral Research and Exploration of Europe). Although the geology, hydrogeology, hydrogeochemistry and geothermal potential of the thermal fields have been studied extensively (İzdar (1971), Ünlü (1971), Gün (1975), İça (1976), Akdeniz and Konak (1979), Özbayrak (1984), Günay et al. (1986), Özen (1995), Açıkgöz (1996) and MTA (2004)). These earlier studies mainly deal with site descriptions, general geological and hydrogeological properties of the area, and geothermal possibilities. However, earlier water chemistry studies in the area were not detailed. This paper discusses the hydrogeochemical characteristics of the thermal aquifers, the origin of geothermal fluids and reservoir temperatures.



Figure 1: Location map of the study area

2. GEOLOGICAL SETTINGS

Turkey is situated within the Alpine-Himalayan orogenic belt. A localized extensional tectonic regime prevails in western Anatolia where the lithospheric stresses are mostly related to continental collision of Alpine-Himalayan zone. Western Anatolia is characterized by east-west trending mountain range, and deep sediment filled valleys. The region experienced a north-south shortening until the beginning of the late Miocene. At the beginning of the Tortonian the region experienced an extension, and thick and the partially melted crust began stretching to form a thin and a brittle crust (Yılmaz, 1989; Alptekin et al., 1990). The magmatic activity in western Anatolia is characterized by volcanic/plutonic and calc-alkaline/alkaline associations. (Savaşcın and Güleç, 1990).

The basement in the Gediz field is represented by Menderes Metamorphics of Paleozoic age. In a general sequence, they are observed as; gneiss and schist. Tertiary age deposits, volcanic rocks and Quaternary sediments unconformably overlie the Paleozoic basement in the area (Fig. 2).

The fractured parts of Paleozoic age gneiss, schist and karstified limestone act as the aquifer for thermomineral waters. Sandy clay and marl of Yeniköy formation are the main cap rocks in the area. The circulation of thermal water in the Gediz geothermal area is closely related to major fault and fracture zones. The fracture and faults in these rocks also provide a means for circulation and rise of the heated waters to the surface. Plate movements were an important action in the formation of the shape of western Anatolia. The product of an effective volcanism related to tectonic activities began in the Miocene and continued during the Quaternary and occupy very large areas with large volumes (MTA, 2004). The basalt flows form the latest phase of the volcanic activities.

3. HYDROGEOLOGICAL FEATURES

The circulation of thermal waters in the geothermal systems is closely related to major fault and fractured zones. Fractured metamorphic rocks of the Menderes Massif such as gneiss, metaquartzite, various schists and especially marbles are assumed to be the main reservoir rocks for the Gediz thermal waters. The fractures and faults in these rocks provide a means for circulation to depth and return of the heated waters to the surface. Relatively impermeable Neogene rocks cap the Gediz geothermal system. Plate movements were important in the formation of western Anatolia. The subduction of the African-Arabian plate beneath the Anatolian plate caused the fusion of the lithosphere. The melting plumes, emplaced at shallow depths in the crust, supply the heat in the thinning of the rift structure (Koçak, 1990). The estimated thickness of the lithosphere in western Turkey is about 30–40 km indicating that the asthenosphere is rather shallow, and a high mantle contribution to surface heat flow is suggested. The average value of heat flow in western Turkey is 107+45 mW m^{-2}, which is approximately 60% higher than the world average (Alptekin et al., 1990). The historical earthquakes are evidence of tectonic activity in and around the study area. Increasing geothermal gradient because of the graben tectonism and the Quaternary basaltic volcanism could be the heat source of the Gediz geothermal field. Meteoric waters descending through the discontinuities are heated in the aquifer rocks, and move up to the surface along the faults (Fig. 3). Isotopic data (^{18}O and ^{2}H) suggests that thermomineral waters in Gediz geothermal area are of meteoric origins but shifted in ^{18}O, indicating deep circulation and water rock interactions (MTA,2004).

4. HYDROGEOCHEMICAL EVALUATION

Hot and cold water samples, compare and investigate the major chemical characteristics were collected from springs and wells. Two samples from each site were stored in polyethylene bottles. One was acidified with HNO_3 and the other was unacidified for anion analysis. The samples were analyzed in the Hacettepe University Water Chemistry Laboratory, with standard methods described in Apha (1989).

The results of the chemical analysis of the cold and thermal waters are given in Table 1, and 2 respectively. Ionic sequence of cold waters are $Ca>Mg>Na+K-HCO_3>SO_4>Cl$ and of hot waters are $Na+K>Ca>Mg-SO_4>HCO_3>Cl$ (Fig. 4 and 5). The major thermal water type is $Na-SO_4$. The chemistry of cold waters and thermal waters in the study area are clearly differentiated. Cold waters are $Ca-HCO_3$ type. Some of cold waters, like Üçbaş Köyü and Sofular, contain relatively high chloride concentration. This Cl enrichment could be considered as mixing with ascending thermal waters. Piper diagram of thermal and cold water samples shows that thermal springs and hot water wells originated from the same reservoir (Fig. 6).

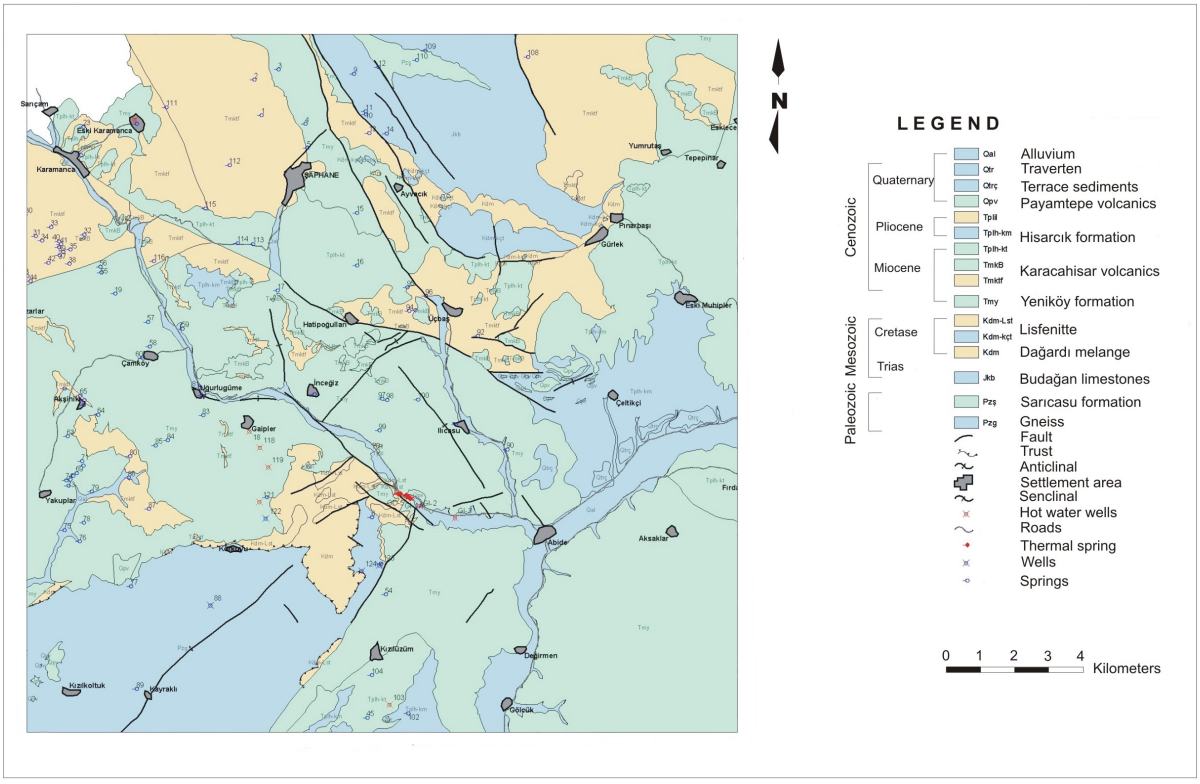

Figure 2: Geological map of the study area (modified from MTA, 2004)

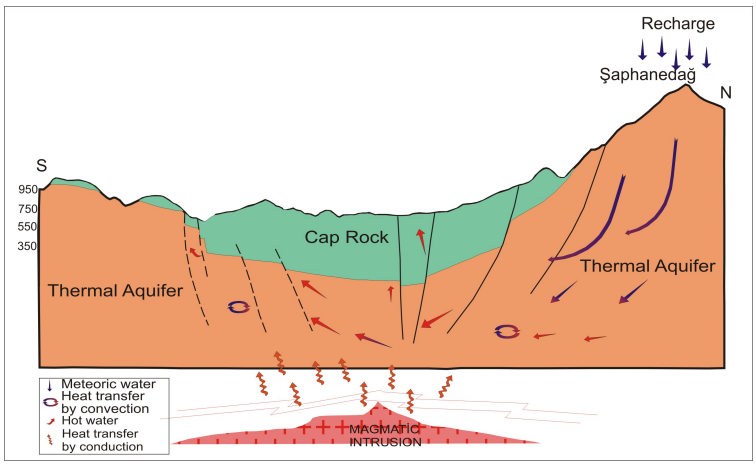

Figure 3: The conconceptual model of the Kütahya-Gediz geothermal model

The Cl-B-Li triangular diagram indicates that Li is least affected by secondary processes, since it is one of the alkali metals, and it may be used as a tracer for the initial deep-rock dissolution processes for evaluating the possible origin of the two important conservation constituents (Li,Cl) of thermal waters (Giggenbach, 1991). Thermal waters located near to the B corner, indicate absorption of the high B/Cl steam (Fig. 7). This water type could be considered as a relatively younger geothermal system. The relative distribution of Cl, B and Li in the thermal waters from Gediz geothermal system is thought to reflect the abundant supply of B from water-rock interaction.

Table 1. The chemical analysis results of the cold water samples from Kütahya-Gediz geothermal fields.

Örnek No	Lokasyon	Referans	Örnekleme Tarihi	T (°C)	pH	EC (mS/cm)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	CO_3 (mg/l)	HCO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)
53	Topalahmet	MTA, 2004	2003	18,5	7,2	457	30	4,8	40,4	16,7	0	267	7,8	5,2
123	Uzümlü Kuyusu	MTA, 2004	2003	18,8	7,6	616	6,8	2	36,2	63	0	371	19,1	30,4
54	Kızılüzümyolu	MTA, 2004	2003	17,1	7,9	732	5,6	2	54,1	84,2	0	586	14,8	46,6
124	Üzümlü	MTA, 2004	2003	16,5	7,5	666	4,2	1	30,1	82,8	0	533	9,26	16,9
6	Kızılüzümyolu	MTA, 2004	2003	15	7,8	812	11,2	2,48	57,9	88	0	632	20,5	39
93	Üçbaş Köyü	MTA, 2004	2003	14,3	7,3	911	39,4	8,82	65,5	32,5	0	359	70,6	25
121	Körkuyuyolu	MTA, 2004	2003	21,3	7,3	1018	6,4	1,57	88,3	111	0	551	13,2	296
119	Körkuyuyolu	MTA, 2004	2003	21,8	7,4	1934	18	9,65	158,4	262,2	0	783	21,7	918,7
118	Körkuyuyolu	MTA, 2004	2003	20,5	7,6	1176	7,6	4,5	102	128,7	0	667	14,6	302,7
78	Körosman	MTA, 2004	2003	15,4	7,4	908	5,8	5,18	117	67,7	0	528	6,1	207
77	Altıntaş	MTA, 2004	2003	14,5	6,8	332	9,8	1,51	36,6	24,2	0	209	12,2	35,3
88	Sofular	MTA, 2004	2003	22	7,3	418	38	5,6	54,1	6,9	0	215	25,9	21,6
84	Sofular	MTA, 2004	2003	18,8	7,2	848	12,8	2,98	106	47,9	0	499	3,55	139
12	Kocapınar	MTA, 2004	2003	7,1	7,9	279	1	1,34	35,4	16	0	168	4,66	16,7
127	Çeltikçi	MTA, 2004	2003	20,6	7,3	641	6,4	2,89	80	55,3	0	533	5,92	17,7
130	Şaphane	MTA, 2004	2003	26,9	7,1	679	5	1,89	120	32,6	0	342	1,42	190
107	Şaphane	MTA, 2004	2003	7,2	7,1	686	5	1,86	110	32,4	0	354	6,39	156
20	Şaphane Sıcaksu	MTA, 2004	2003	27,6	7,6	409	23	7,68	35,8	19,1	0	209	3,55	70,5
21	E.Karamanca	MTA, 2004	2003	14	5,9	89	3,3	5,35	11,8	1,5	0	23	3,2	25,9
92	Üçbaş	MTA, 2004	2003	13,7	7,1	563	11	3,73	64,7	28,6	0	255	13,9	67,1

Table 2. The chemical analysis results of the hot water samples from Kütahya-Gediz geothermal fields.

Örnek Adı	Örnek Türü	Referans	Örnekleme Tarihi	T (°C)	pH	EC (mS/cm)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	HCO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	B (mg/l)	Br (mg/l)	F (mg/l)	Li (mg/l)	SiO_2 (mg/l)
GI-1	Kuyu	H.U.	2004	78,6	5,81	6000	533,46	74,65	158,2	57,54	966,14	66,91	828	4,025	0	2,6	1,38	194,55
GI-2	Kuyu	H.U.	2004	91	6,71	7200	651,92	92,82	110	23,09	744,93	102,4	1004	4,301	0	4,1	1,78	167,65
GI-3	Kuyu	H.U.	2004	76	6,07	7100	667,76	85,11	180,3	51,28	1095,5	80,62	1004	4,706	0	5,06	1,621	131,15
GI-1A	Kuyu	H.U.	2004	77	5,99	5500	491,87	67,03	152,3	61,76	923,01	62,59	781,4	3,417	3,55	3,79	1,237	77,85
GD-1	Kaynak	H.U.	2004	63	6,3	4800	489,28	65,66	142,4	66,02	884,5	63,65	774	3,243	0	3,65	1,281	65,8
GD-4	Kaynak	H.U.	2004	95	6,79	5100	501,42	69,97	152,2	62,7	941,49	59,15	800,6	3,630	0	3,68	1,276	112,3
GD-5	Kaynak	H.U.	2004	93,1	6,72	5500	578,48	87,84	164,3	61,73	969,49	86,44	884,4	3,841	0	3,5	1,444	65
GI-1A	Kuyu	MTA, 2004	2003	77,9	7,2	2870	498	128	93	58,3	1006	97	947	-	-	-	-	59,934
GI-2	Kuyu	MTA, 2004	2003	93,1	7,6	3160	648	170	55,4	17,5	799	122	1157	-	-	-	-	93,743
GI-3	Kuyu	MTA, 2004	2003	78,6	7,3	3410	690	165	60,2	43,4	1160	118	1128	-	-	-	-	82,217
GD-1(MTA)	Kaynak	MTA, 2004	2003	65,5	6,5	2830	488	122	102	66,5	1006	95	900	-	-	-	-	44,94
GD-2(MTA)	Kaynak	MTA, 2004	2003	69,1	6,5	2680	452	114	105	66,9	959	88	845	-	-	-	-	44,95
GD-3(MTA)	Kaynak	MTA, 2004	2003	49,3	6,6	2550	413	99	105	69,8	952	80	756	-	-	-	-	57,936
GD-4(MTA)	Kaynak	MTA, 2004	2003	75,3	6,8	2710	458	118	106	59,5	953	88	849	-	-	-	-	59,934
GD-5(MTA)	Kaynak	MTA, 2004	2003	71,5	6,9	2980	542	140	116	55,3	1036	103	955	-	-	-	-	65,927
GD-6(MTA)	Kaynak	MTA, 2004	2003	76,1	6,9	2990	536	141	114	54,7	1036	102	961	-	-	-	-	-
GD-7(MTA)	Kaynak	MTA, 2004	2003	74	7	3000	533	133	111	55,6	1036	104	893	-	-	-	-	63,93

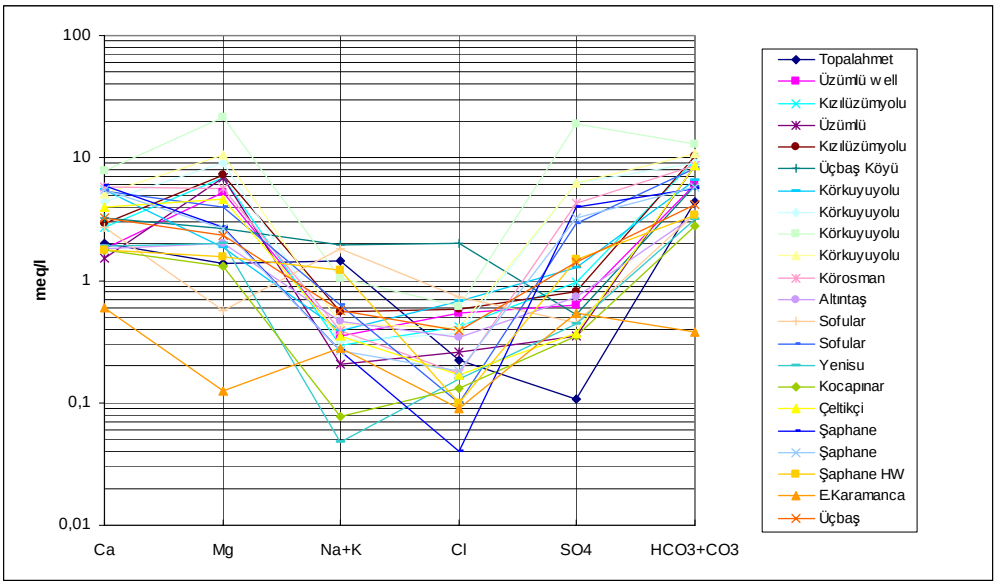

Figure 4: The schoeller diagram for the cold water

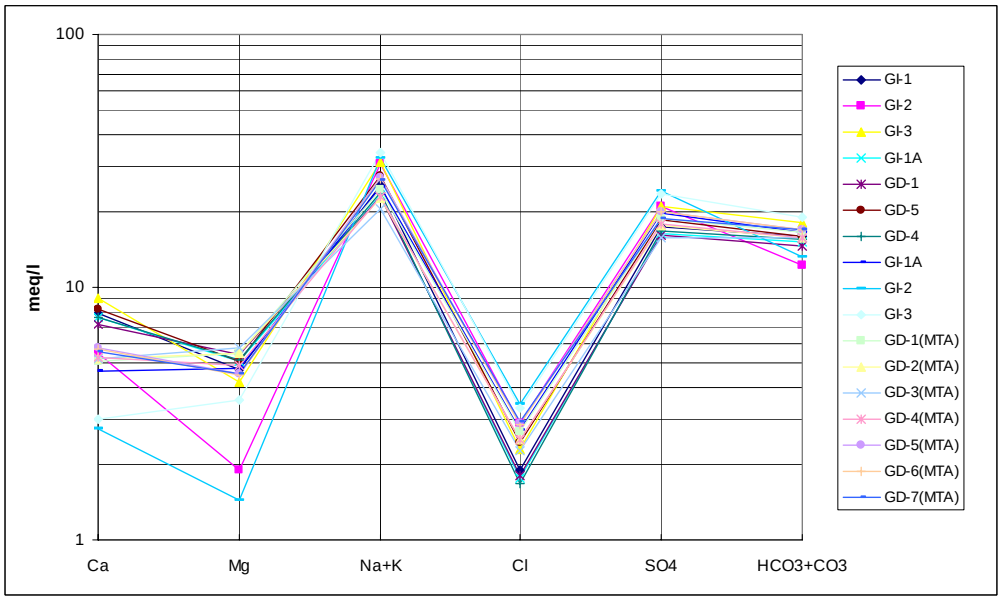

Figure 5: The schoeller diagram for the hot water

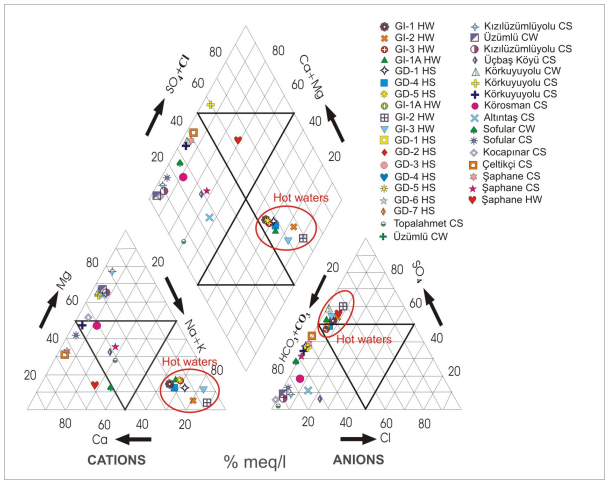

Figure 6: The piper diagram of Gediz geothermal waters

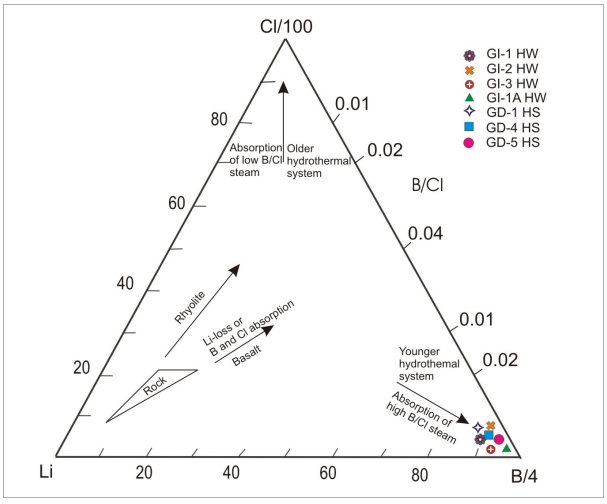

Figure 7: The Cl-Li-B diyagramı of Gediz geothermal waters (modified from Giggenbach, 1991)

5. SATURATION INDEX

It is possible to predict the reactive minerals in the subsurface form the groundwater data by using the saturation index approach. It is important to know saturation indices for some carbonate (calcite, aragonite, and dolomite; minor siderite and magnesite), sulphate (quartz and calcedony) minerals to predict which ones may precipitate during the extraction and use of the fluids. The saturation index of zero indicates that the ion activity product and the solubility product are equal, and that thermodynamic equilibrium exists with the solid phase. A negative or positive index indicates undersaturation or oversaturation, respectively

The WATEQ computer program was used to calculate the saturation indices of minerals with respect to given water compositions. Quartz, chalcedony, aragonite and calcite are oversaturated for thermal waters from the study area. In contrast, the saturation indices for all of the thermal waters from the area give negative values for gypsum and anhydrite (Fig. 8). Scaling of carbonate and silicate minerals is expected for all the thermal waters.

6. GEOTHERMOMETRY APPLICATIONS

Chemical analysis of geothermal fluids can be used to estimate subsurface reservoir temperatures (Lund et al., 1998). Several geothermometry techniques have been developed to predict reservoir temperatures in the geothermal systems during the past decades (Fournier and Truesdell, 1973; Fournier, 1977; Fournier and Potter, 1979; Fouillac and Michard, 1981; Arnorsson et al., 1983; Giggenbach et al., 1983; Kharaka et al., 1985; Giggenbach, 1988; Kharaka and Mariner, 1988). All of them are based on the assumption that temperature dependent water-mineral equilibrium is attained in the reservoir.

The ternary plot of Na-K-Mg was proposed by Giggenbach (1988) for the estimation of reservoir temperature by the application of solute geothermometers. This diagram was proposed to allow a clear distinction to be made between waters suitable for the ionic solute geothermometers. Giggenbach (1988) divided thermal fluids into three main groups depending on the equilibrium of Na, K and Mg ions as fully equilibrated waters, partially equilibrated waters and immature waters. The ternary diagram of Na-K-Mg1/2 of (Giggenbach and Coralles, 1992) was modified from Giggenbach (1988) for lower temperature geothermal systems and used to estimate reservoir temperatures of waters that are most suitable for geothermometry. The thermal waters in Kütahya-Gediz geothermal system fall into the immature field (Fig. 9). Since the thermal waters has not yet been attained equilibrium, the evaluation of equilibrium temperatures are not applicable and the results obtained by the cation geothermometry should not be taken into account. For this reason silica geothermometry are assumed to be more applicable. Chemical analysis from thermal waters from the study area were used to estimate the reservoir temperature of Gediz geothermal field by several solute geothermometry (Table 3). Among the silica geothermometry, the quartz geothermometry of Fournier and Potter (1982) and Fournier (1973) yield reservoir temperatures ranging from 97 to 179ºC. The chalcedony geothermometry of Fournier (1977) and Arnorsson et al. (1983) display relatively low reservoir temperatures between 67 to 157ºC. Silica temperatures of the waters from thermal springs are lower than the drilled wells.

The quartz geothermometry give reservoir temperatures ranging from 146 to 179ºC and the chalcedony geothermometry display reservoir temperatures between 123 to 157ºC for high temperatures GI-1, GI-2 and GI-3 wells. The results of chalcedony geothermometry give more applicable results, therefore these results can be accepted as the reservoir temperature. By the assessment of the whole geothermometry techniques it is concluded that the reservoir temperature can be reach up to 123 ºC.

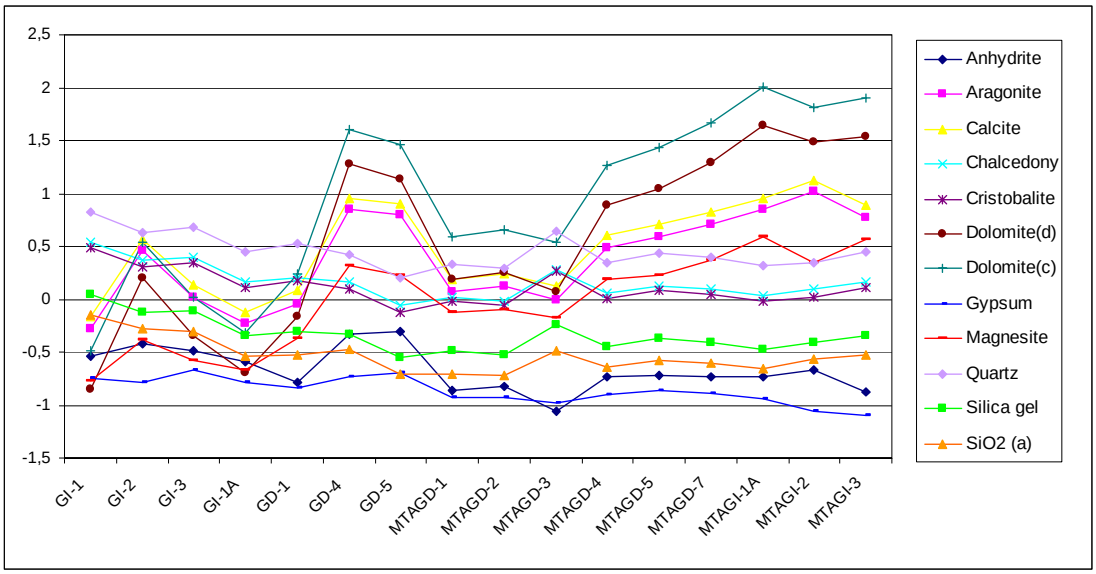

Figure 8: The mineral saturation of Gediz geothermal waters

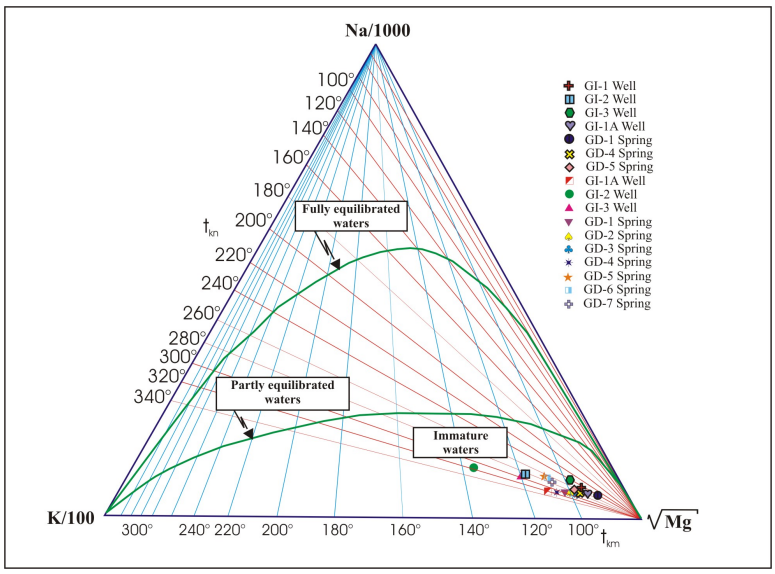

Figure 9: Na-K-Mg diagram of the geothermalwaters from Gediz geothermal field (modified from Giggenbach, 1988)

Table 3. Chemical geothermometers for the Kütahya-Gediz geothermal field (ºC).

Örnek Adı	Örnekleme Tarihi	Katyon Jeotermometreleri (Na-K-Ca-Mg)														Li-Mg-Na				Silis Jeotermometreleri						
		1	2	3	4	5	6	7	8	9*	9**	10[a]	10[b]	11	12	13	14	15[c]	15[d]	16[e]	17	18	19	20	21	22
GI-1A	Temmuz 03	318	335	316	303	314	299	321	15	245	194	-35	-107	17	432	-	-	-	-	111	110	110	81	84	82	85
GI-2	Temmuz 03	322	339	320	305	316	301	323	-9	260	240	-53	-125	9	498	-	-	-	-	134	134	130	107	106	105	106
GI-3	Temmuz 03	306	321	305	295	305	290	313	-8	253	235	-44	-115	13	489	-	-	-	-	127	127	124	99	99	98	99
GD-1	Temmuz 03	314	330	312	300	311	295	318	19	242	188	-33	-104	17	421	-	-	-	-	97	97	98	67	71	68	72
GD-2	Temmuz 03	315	331	313	301	312	296	319	22	240	182	-31	-103	18	413	-	-	-	-	97	97	98	67	71	68	72
GD-3	Temmuz 03	306	322	305	296	305	290	313	25	235	172	-28	-99	19	398	-	-	-	-	109	109	109	79	82	80	83
GD-4	Temmuz 03	319	335	317	303	314	299	321	22	242	183	-33	-105	17	416	-	-	-	-	111	110	110	81	84	82	85
GD-5	Temmuz 03	319	336	317	304	315	299	321	19	245	193	-38	-110	16	429	-	-	-	-	115	115	114	86	88	87	89
GD-6	Temmuz 03	323	339	320	306	317	301	323	19	246	194	-38	-110	15	431	-	-	-	-	-	-	-	-	-	-	-
GD-7	Temmuz 03	313	329	311	300	310	295	318	18	243	191	-37	-108	16	426	-	-	-	-	114	114	113	85	87	85	88
GI-1	Eylül 04	227	237	232	243	248	234	261	31	202	149	-24	-94	21	352	81	199	63	167	179	178	167	157	149	151	145
GI-2	Eylül 04	229	239	234	245	249	235	262	12	210	175	-38	-110	15	389	100	202	66	170	169	168	159	145	139	141	136
GI-3	Eylül 04	216	224	221	235	239	225	252	27	199	155	-28	-99	19	358	87	195	60	162	153	153	146	128	125	125	123
GI-1A	Eylül 04	224	233	229	241	245	231	258	32	199	144	-20	-90	22	344	78	197	61	165	124	124	121	96	96	95	97
GD-1	Eylül 04	222	231	227	240	244	230	257	30	199	145	-19	-89	23	345	78	200	63	167	115	115	114	86	88	87	89
GD-4	Eylül 04	227	236	232	243	247	233	260	32	201	146	-21	-91	22	348	78	198	62	166	144	144	138	118	116	116	115
GD-5	Eylül 04	238	248	242	251	256	242	268	29	208	157	-27	-97	20	365	81	197	61	164	115	114	113	86	88	86	88

1:Na-K,Truesdell and Foournier (1976); 2:Na-K, Tonani (1980); 3-4:Na-K, Arnorsson (1983); 5:Na-K, Fournier (1979); 6:Na-K, Nieva and Nieva(1987); 7:Na-K, Gigenbach et al. (1983); 8:Na-Ca, Tonani (1980); 9:Na-K-Ca, Fournier and Truesdell (1973); 10:K-Mg, Fournier (1991); 11:K-Mg, Giggenbach (1988); 12:K-Ca,Tonani (1980); 13:Li-Mg, Kharaka and Mariner (1988); 14:Li-Na, Kharaka and Mariner (1988); 15:Li-Na, Fouillac and Michard (1981); 16: Kuvars, Fournier and Potter (1982); 17-18:Kuvars, Fournier (1973); 19-20:Kalsedon, Fournier (1977); 21-22:Kalsedon, Arnorsson et al. (1983)

*: t<100ºC and log(Ca/Na)+2.06<0⇨β=1/3; **: t>100ºC and log(Ca/Na)+2.06>0⇨β=4/3

a: $\log(K^2/Mg)>1.25$; b: $\log(K^2/Mg)<1.25$; c: (Cl<=0.3M); d: (Cl>0.3M); e: $C1=-4.2198x10^{1}$, $C2=2.8831x10^{-1}$, $C3=-3.6686x10^{-4}$, $C4=3.1665x10^{-7}$, $C5=7.7034x10^{1}$ (S= SiO_2, mg/l)

CONCLUSIONS

Ionic characteristics of cold waters are Ca>Mg>Na+K - HCO3>SO4>Cl and hot waters are Na+K>Ca>Mg - SO4>HCO3>Cl. Triangular piper diagram shows that thermal springs and wells originated from the same reservoir. As seen from the Cl-Li-B diagram, thermal waters plot in the B area near the B corner, indicating absorption of the high B/Cl steam. This water type could be considered as a relatively younger geothermal system. The relative distribution of Cl, B and Li in the thermal waters from Gediz geothermal system is thought to reflect the abundant supply of B from water-rock interaction.

Chemical analysis from thermal waters from the study area were used to estimate the reservoir temperature of Gediz geothermal field. By the assessment of the whole geothermometry techniques it is conclude that the reservoir temperature can be reach up to 123 ºC.

Quartz, chalcedony, aragonite and calcite are oversaturated for thermal waters from the study area. In contrast, the saturation indices for all of the thermal waters from the area give negative values for gypsum and anhydrite. Scaling of carbonate and silicate minerals is expected for all the thermal waters.

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