

Geological and Hydrogeological Study of Afyon-Gazlıgöl Geothermal Field, Turkey

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ABSTRACT

The Gazlıgöl geothermal field is located 20 km to the North of Afyon city. In the present study, geological and hydrogeological investigations of an area about 150 km² were carried out. The Paleozoic metamorphic schists, which locally include quartzites are widely exposed. The metamorphic schists are overlain by Neogene sediments. Hot and mineralized water spring orifices are located on a NE-SW oriented normal fault line. Temperature and discharge of the springs are 32-40 °C and 0,1-1 l/s respectively. The temperature and water in the wells drilled in the area varies between 43-74 °C and the discharge rate ranges from 2.3 to 28 l/s. Depths of the wells are between 60 and 300 m. The warming up of hot and mineralized waters is due to high geothermal gradient related to neotectonics and volcanisms. The reservoir rocks are quartzites and schists of Paleozoic age. The cap rocks are the Neogene clay and tuff bearing rocks. Gazlıgöl thermal water can be classified as sodium bicarbonate rich hot water. According to SiO₂ geothermometers reservoir temperatures are estimated between 77-111 °C. Isotope analysis of hot and mineralized waters indicates a meteoric origin and groundwater circulation over 50 years. Three protection zones around the springs were proposed, potential pollution sources in each zone were assessed and some measures were recommended against pollution.

1. INTRODUCTION

The Gazlıgöl plain is located 20 km to the North of Afyon, Turkey (Fig. 1). Some studies have been carried out on the geological and hydrogeological features of the area by Calvi (1935), Niehoff (1961) and Simsek et al. (1993). In this area 1/25.000 scale basic geological mapping was carried out. The water temperatures were measured using a glass thermometer and some measurable spring capacities were measured using containers with known volume values. The pH of water was determined through the use of a model 300 WTW mark pH meter and the electrical conductivity (EC) was determined the use of type 700 chemtrix mark portable conductivimeter.

2. GEOLOGY

Paleozoic and Cenozoic rocks crop out in the study area. Paleozoic schists and marbles, called the Afyon Metamorphics, represent the basement. Middle-Upper Miocene Gebeciler Formation overlies The Afyon Metamorphics discordantly. This formation consists of, from bottom to top, conglomerate member, Seydiler volcanic tuff, agglomerate. All of these units are cut by karakaya basalts Quaternary alluvium and travertine deposits lie at the top (Fig. 1)

Schists, of the Afyon Metamorphics are yellowish, brownish- green, ash-gray in color and characterized by quartz-muscovite-serisite schist, quartz-albite-chlorite

schist, metasandstone, metaconglomerate and calcschist. Quartz veins are common in fractures in and around Gazlıgöl area. The age of the unit is Middle–Upper Triassic (Metin, 1987).

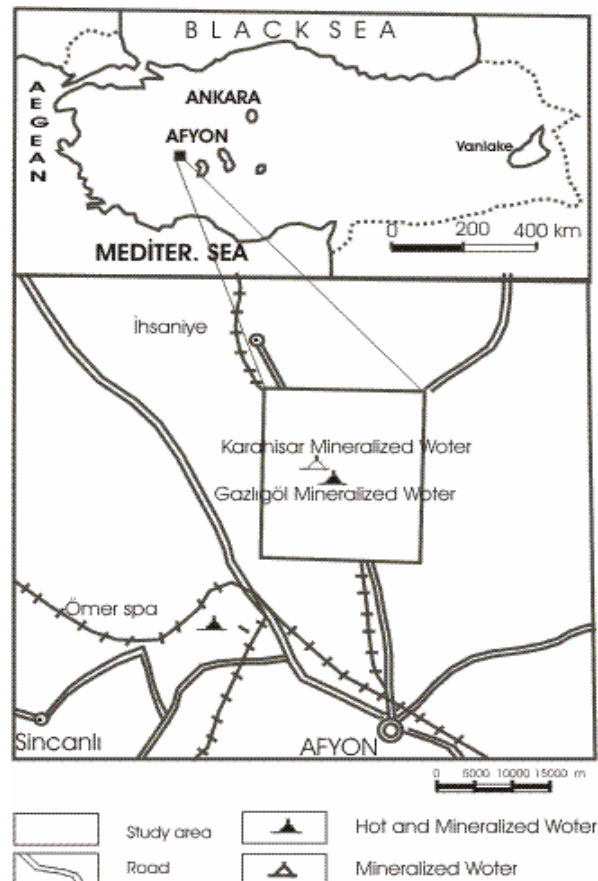


Figure 1 : Location map of the study area

The Middle -Upper Miocene Gebeciler Formation unconformably overlies the Afyon Metamorphics and consists of in ascending conglomerate, sandstone, agglomerate, tuff, tuffite, marl, argillaceous limestone and silicified limestone. The conglomerate member of the unit is yellow, orange, red and claret red colored, thick and poorly bedded, and it consists of alternating conglomerate-sandstone-claystone. Ordered, sedimentary structures like cross bedding, mud cracks and flow marks can be seen. Seydiler Volcanic Tuff -Agglomerate member, characterized by dacitic-andezite tuff and agglomerate is produced by a volcanic activity from Late Miocene to Pliocene. Very thick bedded (approximately 20-70cm) tuffs are milky white and cream colored. Basalts are calcalkaline and alkaline in character and represent partly crustal origin. The talus is composed of pebble sand, silt and clay. Grains are derived from volcanics, metamorphic and Neogene detritic rocks. Alluvium is characterized by sand, pebble, clay and unconsolidated deposits. Travertines can be seen around the springs, Gazlıgöl spa and on the Neogene units. (Fig. 2)

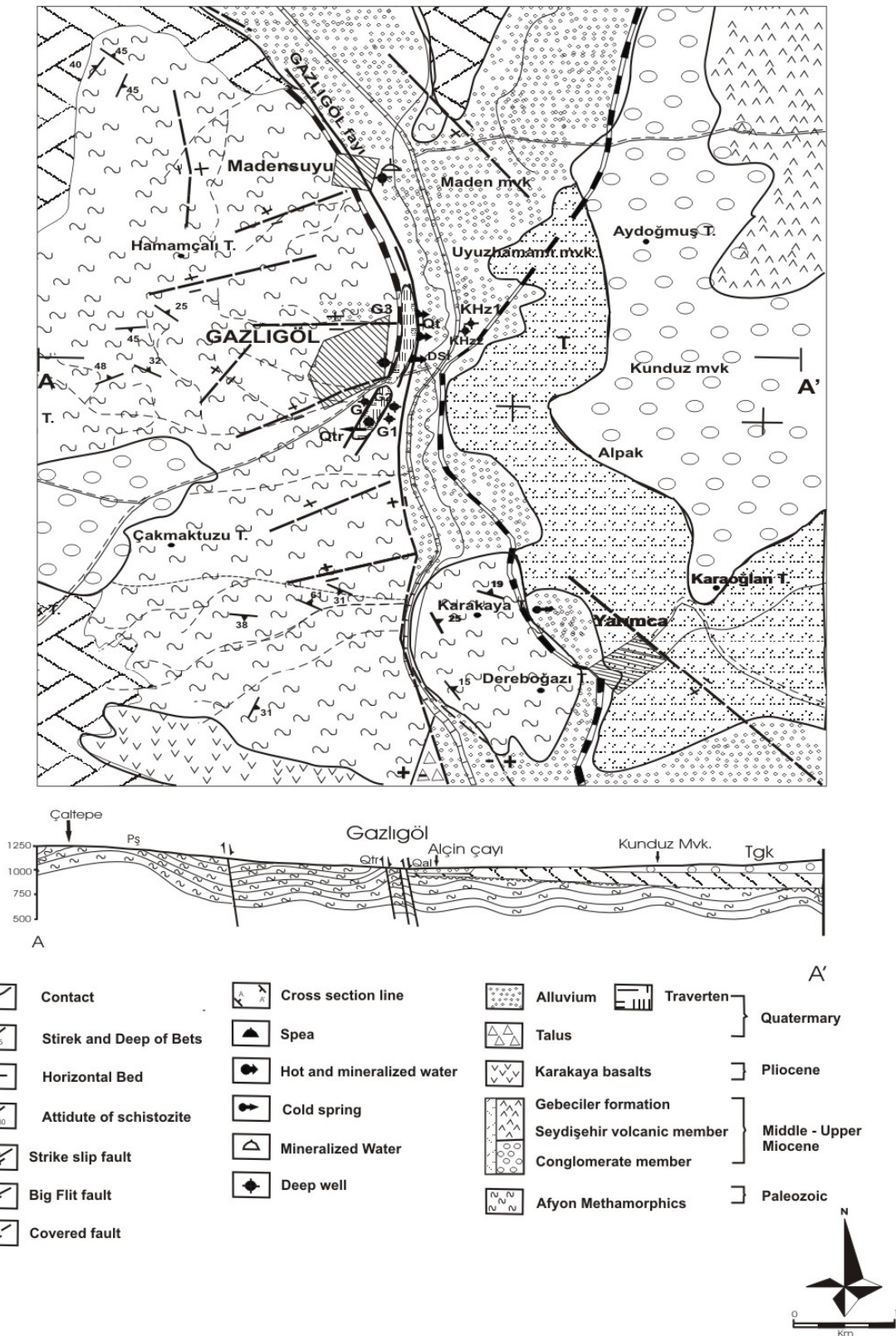


Figure 2 Geological Map and Cross Section of the Study Area

3. TECTONICS

In the study area, the main tectonic structures, entering from the south with the direction NW-SE and N-S strike slip faults are called the Gazlıgöl faults. This layer lies between and along Alçın creek and hot spring is approximately 5 kilometers long.

The upthrown block belonging to the Gazlıgöl fault is crystalline schist. The slip of the fault is not known because there is Alçın creek alluvions in front of the downthrown block.

There are lots of small faults with different directions in metamorphic schist depending on the Gazlıgöl faults.

Furthermore, NNE-SSW joints are seen along the spa. All the hot water with minerals are on these joints and springs along the Gazlıgöl spa are in line with the joints.

4. HYDROGEOLOGY

4.1. Cold Springs

A few cold springs are seen in the study area. Springs come to the surface between bedding planes, along the fractures, faults and at the formation boundaries. Waters from the springs are partly used. Flow rates are 0,1-2.0 l/s and the rates change depending on the rain fall.

The Yarımca spring, the most important spring at the west of Yarımca village, discharges at the contact between metamorphic schists and alluvium. Discharge rate and the temperature of the spring are 1 l/s and 11 °C respectively. The discharged fluid is used as drinking water. Another spring is found at the southern part of the study area. Temperature and discharge of the spring are 15°C and 0.5 l/s.

4.2. Thermal and Mineralized springs

Thermal and mineralized springs can be seen around Gazlıgöl. They are located along NE-SW, N-S directed normal faults. Temperatures of the springs are between 32-40 °C, and discharge rates are 0,1-1 l/s (Table 1). Travertine cones are formed at the orifices of the hot springs. The length of the ellipsoidal cones lies along the fracture. Cones are symmetrical with respect to fracture direction.

4.3. Drilled Wells

In order to get hot and cold water, various wells have been drilled to a depth of 60-300 m. Temperatures and discharge rates are 41-71°C and 3-28 l/s respectively. G-2, the deepest well drilled in the study area is 300 m deep (Demirel, 1988).

4.4. Mineralized Springs

To the north of Gazlıgöl, in the Madensuyu area there are four mineralized springs with discharge rates between 0,12-0,54 l/s, temperatures 13-18 °C and a 60 m depth well with discharge rate 0,5-2 l/s.. In addition, at the NW of mineralized water ward, there is a drilled well with 0,83 l/s.

4.5. Gas and Steam Extrusion

Thermal and mineralized springs have gas bubbles. Since H₂S gas has not been determined from the analysis, these should be CO₂ gas.

4.6. Formation of Thermal Waters

Meteoric waters going down through the fissures and fractures by the effect of gravity, are heated by the geothermal gradient. Heated waters rise through the faults acting as hydrothermal channels due to hydrostatic pressure, fissures, density contrast between hot and cold water, expansion etc. and form hot and mineralized springs at the surface.

Formation of geothermal energy depends on heat source, reservoir, cover rocks and water supply. In the study area, Miocene-Pliocene aged volcanic rocks cover large areas. Basalt flows seen at the SW part of the field comprise the latest stage of volcanic activity. Magma chambers forming those volcanic rocks are thought of as heat source. Paleozoic Afyon metamorphics constitute reservoir rocks. Fractured schists and quartzites in the metamorphics also constitute reservoir. The Upper Miocene Gebeciler formation and silty and clayey levels of alluvium forms the cover rocks.

4.7. Water Chemistry

The origins of the waters were determined by drawing a semilogarithmic Schoeller diagram. According to the diagram, the ions are in following order;

Eskihamam spring:

$r(\text{Na}+\text{K}) > r\text{Mg} > r\text{Ca}, r\text{HCO}_3 > r\text{Cl} > r\text{CO}_3 > r\text{SO}_4$

G1, G2 drilled well:

$r(\text{Na}+\text{K}) > r\text{Ca} > r\text{Mg}, r\text{HCO}_3 > r\text{Cl} > r\text{SO}_4$

Cold water spring:

$r\text{Ca} > r(\text{Na}+\text{K}) > r\text{Mg}, r\text{HCO}_3 > r\text{Cl} > r\text{SO}_4$

KH₂ Basak, Güngörler:

$r(\text{Na}+\text{K}) > r\text{Ca} > r\text{Mg}, r\text{HCO}_3 > r\text{Cl} > r\text{SO}_4$

According to the Schoeller diagram of hot and mineralized spring and drilled wells, waters the lines combining the anions and rations are approximately parallel, this indicates the same origin for the waters. Miliequivalent values of the cold spring are very low. Lines are more or less parallel.

All the waters are in the 8. region in the Piper diagram. Waters of this group have the same properties: carbonate alkalinity>noncarbonated alkalinity. The waters are in the ultra-soft group and can rarely be seen in nature. Only the mineral waters fall to the 5. region. Waters of the group are rich in CaCO₃ and MgCO₃ and carbonate hardness is greater than 50 %

The waters of Eskihamam spring, G3 and DSI wells waters can dissolve CaSO₄, since S' is below S0. However carbonate is precipitated, because Kro is lower than Kr. (Table 2)

4.8. Classification of hot and mineral waters

In the study area it is possible to classify hot and mineral water springs in different ways.

- According to the geological proportion of the investigated area, all the springs are genetically different from each other

- When they are evaluated by their temperature, accept the mineral water cold waters, all the other waters are in the classes of hot waters.

- According the classification at indurations hydrogeologists' migni.

- All the waters of (hot-mineralized) springs evaluated from drill holes, are Na-HCO₃ type hot of poor minoset water.

4.9. Isotope Results

The relationship between O18 and deuterium is linear, this result shows that the waters are genetically meteoric.

The hot waters have high 3 H value but cold waters have low 3 H value. In other words, the hot waters are the waters having long term deep (>50 year) hydraulic cycles (Simsek et al, 1993). On the other hand, cold waters are fresh and have shallow hydraulic cycles.

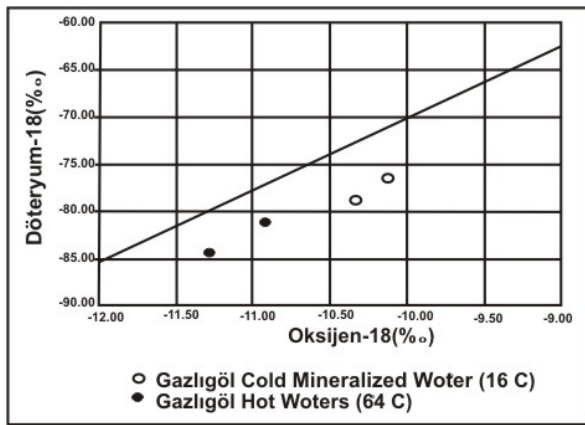


Figure 3: Oxygen-18/deuterium relationship of the samples

It can be said that the mineral waters are a mixture of hot and cold waters (Fig. 3).

5. CONSERVATION ZONES

In order to protect the hot and mineral waters from contamination by unhealthy substances and loss of their chemical properties, it is advisable to draw and report the conservation zones for each. (Kulaksızoglu, 1982, Demirel, 1988) The defined conservation zone contains the surface and underground of the geothermal area.

The conservation zones are determined according to the hydrogeological, structural, hydrochemistry properties and the thickness of the cover unit, and the reservoir parameters. The reservoir rocks are Paleozoic aged schist and quartzites. Since these rocks are fractured, their secondary permeabilities are increased.

Hot and mineral water springs are coming out along NE-SW directed fault. The innermost zone of conversation area has an ellipsoidal shaped geometry and its size 250 m. and its long axis is 1 km in length. This zone is bordering the springs. The middle zone borders the discontinuities around the springs. The width of this zone is nearly 9 km. (Fig. 2).

5.1. The balneogeological properties of springs and their usage

The Gazlıgöl spa is especially effective on rheumatic, gynecological and abdominal diseases.

The Gazlıgöl spa has the capacity of 1852 bath/person/day. Moreover because of the water mineralization is high in TDS value, it is very important for thermal tourism.

6. CALCULATION OF THE RESERVOIR TEMPERATURES

In order to calculate the reservoir temperatures optimum applicable are used according to chemical composition.

Solute geothermometers give reliable results when the water-rock interactions reach equilibrium. Mixing of thermal waters with cold waters while moving up to the surface will not lead to equilibration and thus the results are doubtful.

A ternary plot of $\text{Na}/1000\text{-K}/100\text{-Mg}^{0.5}$ was proposed by Giggenbach (1988) as a method to determine reservoir temperature and to recognize waters, which have attained equilibrium with the host lithology. The graphical

representation of the combined geothermometers for this study Gazlıgöl geothermal fields fall into the immature category indicating that none of these waters have attained equilibrium with their associated host rocks.

Table 1: Chemical Geothermometry results applied on the hot springs in the study

Spring and Well	t(°C)	SiO ₂ (mg/l)	Quartz after decrease steam	Calseduan	Quartz	Na-K-Ca
Eskihamam	35	50	102	71	101	215
G-1	69	48	100	70	100	186
G-2	65,5	26	77	42	73	185
G-3	74	61	112	82	111	240
DSI	57	55	106	76	106	185
KHz-1	63	36	89	56	87	195
Basak	43	20	68	31	64	179
Güngörler	46	33	86	52	84	177

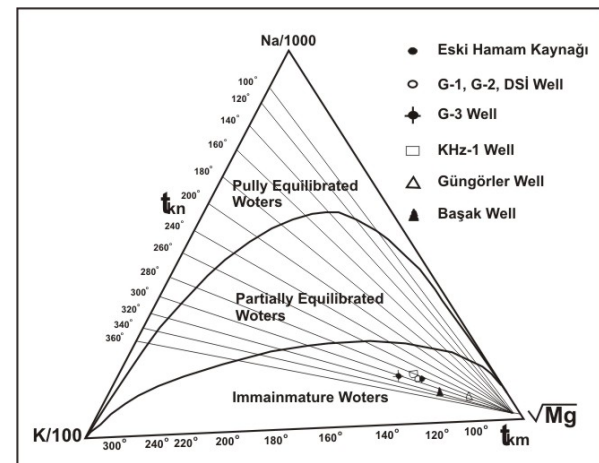


Figure 4 : Distribution of the thermal waters from the study area in Na-K-Mg tri-linear diagram (Giggenbach, 1988)

7. CONCLUSIONS

The oldest unit cropping out in the study area is Paleozoic aged schists and quartzites. They are overlain unconformably by Cenozoic aged units.

The depths of the drill holes in the investigated area are between 60 – 300 meters and their flows are between 2.3 - 28 l/s. The hot and mineral water springs discharging from different points along NE – SW, N – S directed faults are 32 - 40 °C in temperature & 0,1 - 1 l/s in discharge velocities.

In the Gazlıgöl area all the waters (hot and mineralized) are Na – HCO₃ type hot and mineral waters. But cold water springs are in type of poor mineral waters. According to Giggenbach diagrams, all the waters are immature and as a consequence of isotope analyses they are seen genetically to be meteoric waters.

The reservoir temperatures of the hot and mineral waters are around 80 - 175 °C according to different geothermometer methods.

Table 2: Chemical analyses of water from the study area.

		Eski Hamam Kaynağı		G1		G2		G3		DSİ		KHz		BAŞAK		GÜNGÖRLER	
		mg / lt	mek/lt	mg / lt	mek/lt	mg / lt	mek/lt	mg / lt	mek/lt	mg / lt	mek/lt	mg / lt	mek/lt	mg / lt	mek/lt	mg / lt	mek/lt
C A T I O N S	K ⁺	76	1,94	76	1,94	76	1,94	75	1,87	76	1,94	80,1	2,05	43	1,10	34	0,87
	Na ⁺	900	39,15	900	39,15	900	39,15	770	33,48	900	39,15	940	40,89	580	25,23	465	20,20
	NH ₄ ⁺	20,0		7,5		3,7		5,3	0,29	7,0							
	Ca ⁺⁺	26	1,30	72	3,59	76	3,79	2,5	1,25	72	3,59	37	1,85	87	4,34	99	4,49
	Mg ⁺⁺	16	1,32	17	1,40	27	2,22	8,8	0,73	15	1,23	15,3	1,26	20	1,65	24	1,94
	Fe ⁺⁺	< 0,1		< 0,1		< 0,1		< 0,1		< 0,1		2,2		0,1		4,2	
	As	< 0,01		< 0,01		< 0,01		< 0,01		< 0,01				< 0,01			
	B	11,6		12		11,8		13		11,6		12		11,6		4,2	
	Mn	< 0,1		< 0,1		< 0,1				< 0,1				< 0,1		< 0,2	
	Al ⁺⁺⁺							< 0,02				0,02		< 0,02		< 0,5	
I O N S	HCO ₃ ⁻	2568	42,1	2696	44,2	2696	44,2	2501	41	2696	44,2	2471	40,5	1696	27,8	1618	27,8
	CO ₃ ⁻	10	0,3	10	0,3	10	0,3	< 1		10	0,3	< 10		< 10		< 10	
	SO ₄ ⁻	10	0,2	10	0,2	10	0,2	6	2,51	10	0,2	< 10		< 10		< 10	
	Cl ⁻	139	3,92	137	3,86	164	4,53	89	0,13	139	3,92	225	6,35	93	2,62	98	2,76
	I ⁻	< 0,5		< 0,5		< 0,5				< 0,5		< 0,5		< 0,5		< 0,5	
	F ⁻	3,4		3,6		3,5		1,7	0,089	3,5		3,5		3,5		< 1,0	
	OH ⁻	< 1		< 1		< 1				< 1		< 1		< 1		1	
	NO ₂ ⁻	< 0,01		< 0,1		< 0,01		0,01		0,01		0,01		0,01		< 0,01	
	NO ₃ ⁻	3		1,0		1,0		0,17		2,5		0,01		2,5		< 1	
	PO ₄ ⁻	< 0,1		< 0,1		< 0,1				< 0,1		< 0,1					
THE OTHER ELEMENTS	SiO ₂	50		48		26		61		55		36		20		33	
	CO ₂	29		171,7		3348				412		412		412		415	
	Ph (25 °C)	8,15		7,4		7,11		7,40		7,02		7,11		7,13		7,12	
	Specific Cond. (25 °C)	3000 µmho/cm		3000		3000		3130		3000		3100		2010		2018	
	Specific grav. (25 °C)	1,002 gr/cm ₃		1,002		1,002		1,002		1,002		1,002		1,002		1,002	
	EC Buh. Kalint. (180 °C)	2596 mg/lt		2720		2710		2652		2700		2700		2700		2700	
	Total Hard (As)	7,34		1377		16,83		9,73		13,5		16,83		13,5		12,9	

For hotter waters, the location of new drill holes must be chosen in places where the thickness of the cover unit is high. Such a place in the Gazlıgöl area may be on the Aydogmus hill and in its vicinity. The depth of the drill holes should be between 200 – 250 meters.

The production of G2 and G3 drillings must be under control. Chemical species of cold water and hot and mineral water must be observed periodically in the geothermal area. Isotope analysis of water and steam and a deep search about the root and hydrothermal system must be done.

At the same time production wells must be taken under control and taking more water than necessary must be forbidden.

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