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Hydrogeology and Environmental Study at the Karahayit Geothermal Field (Western Turkey)

Ali Gokgoz[1], Ismail Edip Yilmazli[2], Ilhan Gungor[2] and Ibrahim Yavuzer[2]

[1]Pamukkale University, Department of Geological Engineering, Denizli-Turkey and [2]Denizli Governorship, Denizli-Turkey

agokgoz@pau.edu.tr

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ABSTRACT

The Karahayit geothermal field is located at intersection of the Buyuk Menderes and Gediz grabens in the Denizli Province, Western Turkey. The reservoir rocks in the field are Paleozoic marble, various schist and quartzite which have high secondary permeability. The impermeable sediments of Neogene have good caprock characteristics. The temperatures of thermal waters in the field range from 33 to 61.5°C. The thermal waters are in the type of Ca-SO_4-HCO_3 and of meteoric origin.

The Karahayit village is a natural beauty and thermal tourism place and visited by more than 1,000,000 tourists annually. The thermal fluid from the wells is used for swimming pool, bath and spa. Each hotel and pension in the Karahayit village has one or more wells producing hot water. At the present, there are about 200 wells in a part of 1.0 km^2 of the Karahayit geothermal field. The depths of wells vary between 5 m and 140 m. All wells work in summer season, especially. The uncontrolled over exploited of the thermal water has led to lowering of piezometric level of the reservoir. Consequently, while there were many thermal springs, which have a temperature of 50-56°C, deposited red travertine in Karahayit area before 1981, almost all of them have disappeared in 1981-1994 period. Also, shallow wells have been dried up and the piezometric level lowered in the deep wells.

To provide sustainable utilization of the geothermal system, Denizli governorship is made a decision to drill three deep thermal water production wells and one re-injection well, to distribute to the hotels and pension to be produced the thermal water and then to close all private thermal well in the Karahayit village. After geological, hydrogeological and geophysical studies, the three production wells in the depths of 452 m, 468 m and 570 m were drilled in 2007. The temperatures and total discharge of the thermal waters from these wells are 58°C to 61.5°C and 92 l/sec, respectively. According to physico-chemical and bacteriological analyses, the thermal waters are applicable to therapeutic use. The drilling of the re-injection well and construction of distribution piping system to the hotels of thermal waters will be completed in 2009. It is hoped that utilization-protection balance of the thermal waters in the Karahayit geothermal field would be established in the near future.

1. INTRODUCTION

Turkey is located on an active tectonic belt with many tectonic structures such as faults, grabens, overthrusts, folds, and widespread acidic volcanism, hydrothermal alteration zones and geothermal areas. Most of the geothermal areas in Turkey are located in the western part where geological and hydrogeological conditions are favorable for the formation of geothermal systems, whereas the regional tectonic structures are more widespread. One of most important tectonic structures at the western part of Anatolia is the Buyuk Menderes graben which has been formed as a result of extentional neotectonic regime continuing since Miocene. The high (Kizildere and Germencik fields) and low-medium enthalpy geothermal fields (Aydin, Yilmazkoy, Salavatli, Sultanhisar) are situated in the Buyuk Menderes graben (**Figure** 1).

Denizli Province is a very important region in point of geothermal resources. There are nine geothermal fields in Denizli Province (**Figure** 2). One of them is the Kizildere geothermal field which has the highest reservoir temperature of Turkey. Others are low enthalpy fields. The geothermal waters in the Denizli province are used for electricity, dry ice (dry CO_2) and liquid CO_2 production, district and greenhouse heating, thermal bath, health spas, swimming pools and scenery such as snow white Pamukkale travertines.

The Karahayit town (**Figure** 3) is a thermal tourism place and is visited by more than 1,000,000 tourists annually. Each hotel and pension in the town has one or more wells produced hot water. The thermal fluid from the wells is used for swimming, bath and spa. The uncontrolled exploitation of thermal water leads to lowering of piezometric level in the hydrothermal system. It has caused drying up many thermal springs having temperatures of about 50-56°C in the Karahayit area. Also, shallow wells have been dried up and the piezometric level lowered in the deep wells.

This paper is focused on works performed in order to prevent utilization-protection balance of the thermal waters in the Karahayit geothermal field.

2. GEOLOGICAL SETTING

The Karahayit geothermal field is located at intersection area of the Buyuk Menderes and Gediz grabens in the Denizli Province, Western Turkey. In the part of the region, the graben is named as the Curuksu graben. The basement rocks in the Karahayit geothermal field are Paleozoic Menderes methamorphics which are characterized by alternations of marble, calcschist, quartzite and schist (the İgdecik formation; Simsek 1985), schist and gneiss.

The basement is overlain by Neogene sediments which have continental and lacustrine characteristics (**Figure** 4). These sediments have been divided into four lithologic units (Simsek 1985). From bottom to top these units are:

1. Kizilburun formation which is composed of alternating red and brown conglomerates, sandstones and claystones,

2. Sazak formation which consists of intercalated gray limestones, marl, sand siltstones,

3. Kolankaya formation composed of alternating layers of sandstone, claystone and clayey limestone and

4. Tosunlar formation which is characterized by poorly consolidated conglomerates, sandstones and mudstones with fossiliferous claystone.

The first three units mentioned above are Miocene in age (Taner 2001) whereas the Tosunlar formation is Plio-Quaternary. The Tosunlar formation overlay the Miocene and Paleozoic rocks uncorformably. The Quaternary formation consists of terrace deposits, alluvium, slope debris, alluvial funs and travertine.

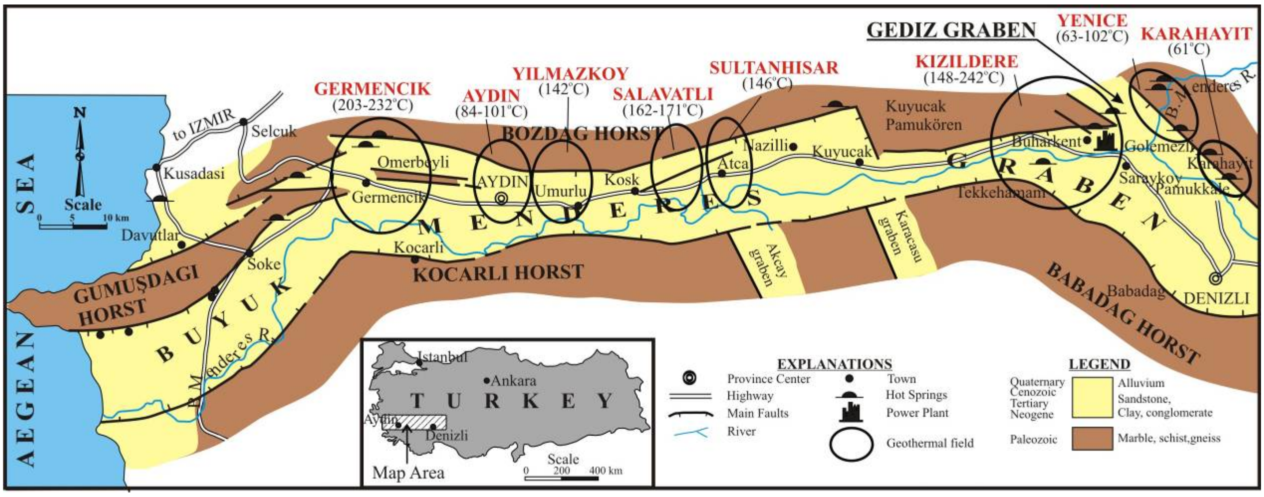

Figure 1: The location map of the geothermal fields in the Buyuk Menderes graben (numbers in bracket show the temperatures of the geothermal fluids discharged from these fields), (modified from Simsek, 2005).

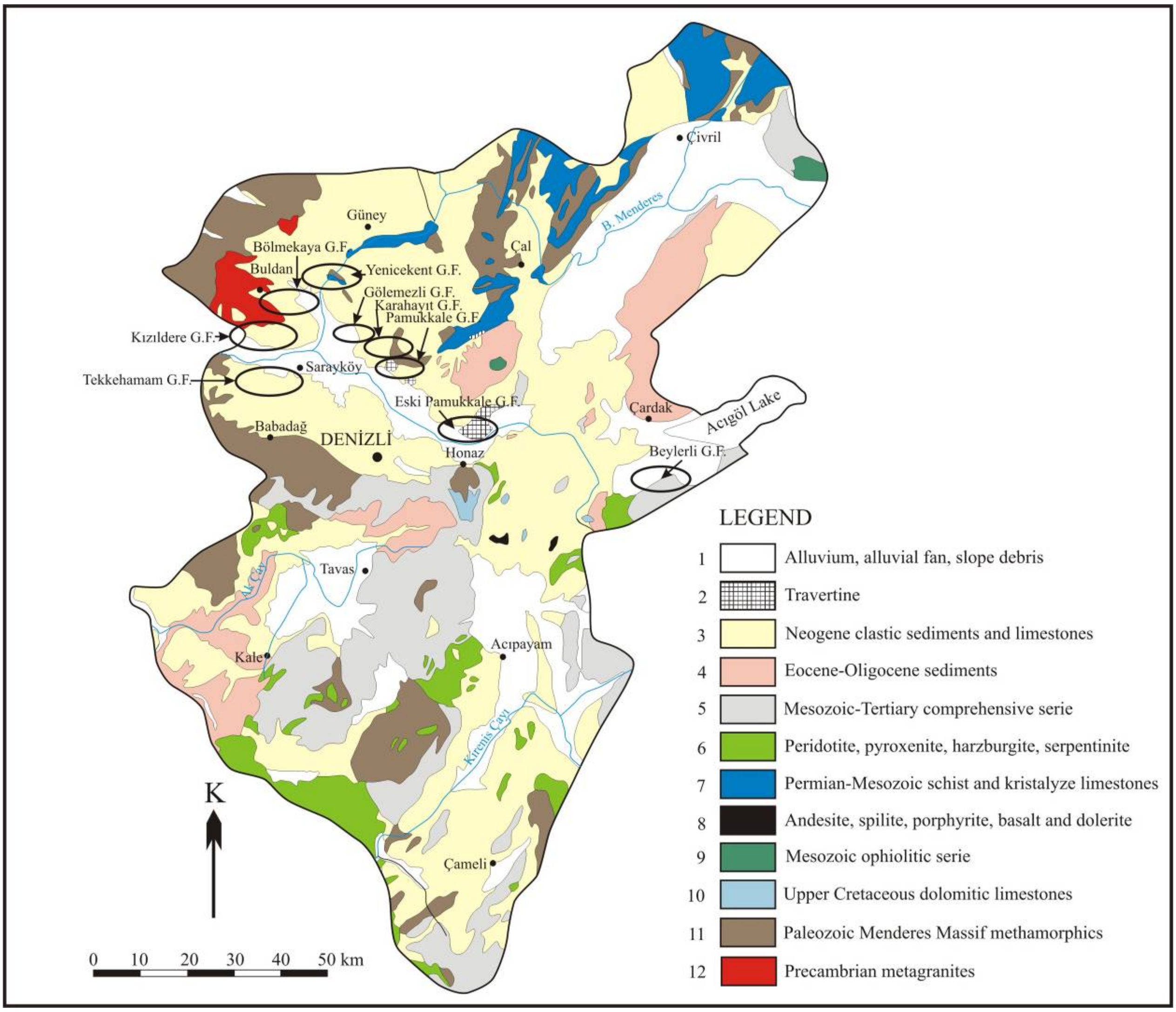

Figure 2: The geothermal field in the Denizli Province (modified from MTA, 1964).

Figure 3: Karahayit town and the geothermal field.

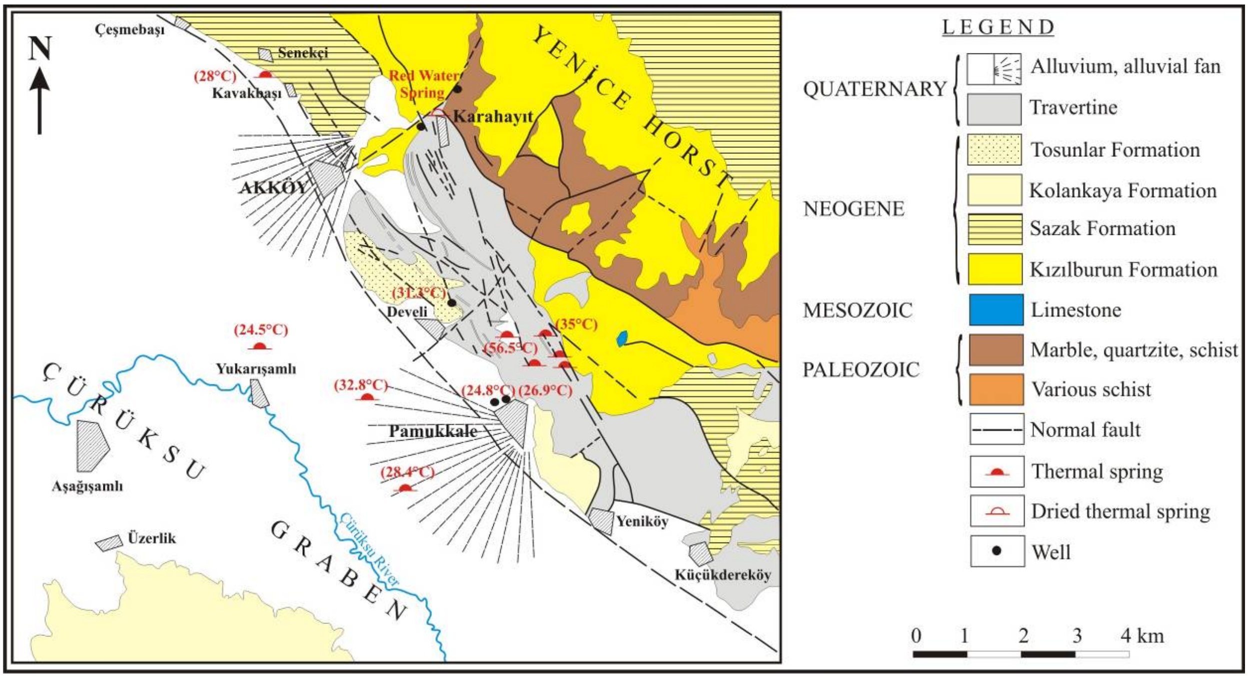

Figure 4: Geological map of Karahayit and Pamukkale geothermal fields (Modified from UKAM, 1994).

The collision between the Anatolian and Arabian plates started westward movement of the Anatolian plate along the North Anatolian and East Anatolian Faults during the Middle Miocene. Impediments of this movement by the Greek Shearing Zone created east-west compression in the Menderes Massif which in turn led to a north-south extension and the formation of graben-horst systems such as Büyük Menderes, Gediz, Çürüksu grabens and Babadağ, Buldan, Yenice horsts in the Aegean geographical region of Turkey. Almost all of the boundary faults of the grabens are normal faults which are in listric character. The driving force of the extension is the subduction of the North African oceanic crust beneath the westward moving Anatolian plate along the Hellenic Trench (Sengor and Yilmaz, 1981).

3. HYDROGEOLOGY

The reservoir rocks of the Karahayit geothermal field are Paleozoic marble, various schist and quartzite which have high secondary permeability due to tectonic activity. Average outlet temperature of the geothermal fluids came from this reservoir is about 50-56°C. Neogene aged impermeable units have good caprock characteristics. There is no young volcanic activity in Karahayit area. Volcanism near Karahayit is closely related to the rift system (Ercan, 1979). Plate tectonics models proposed for western Turkey involve mantle uplift, particularly below the Menderes masif (Arpat and Bingol, 1969; Alptekin, 1973; Bingol, 1976; Kaya, 1981). A heat flow map of the region reveals high heat flow anomalies along the grabens (Tezcan, 1979) probably due to magmatic intrusions. Filiz (1982) suggested that the origin of CO_2 gas in Pamukkale springs is magmatic. Gulec (1988) revealed that helium-3 in the regional waters is of mantle origin. According to these data, meteoric waters which percolate deep into the crust gain heat from magmatic intrusions and from magmatic emanations from the intrusions. The recharge is mainly meteoric and involves surface and underground waters infiltrating the basin. The geothermal fluid ascends to the productive aquifers through the major faults bounding the grabens after being heated at greater depths. The wells in the area are discharged thermal waters ascending to the surface through the extensional fissures and the faults (**Figure** 5, **Figure** 7).

Figure 5: An extensional fissure in the Karahayit area.

All wells in the Karahayit area were drilled to relatively shallow depths (5 to 140 m) and only penetrated the travertine and Neogene units. The temperatures and electrical conductivities (EC) of the thermal waters in the field range from 33 to 56°C and from 2730 to 3100 µS/cm, respectively. The pH values are slightly acidic (5.90-6.99). The temperatures and EC values of some waters produced from shallow depths are lower because of mixing with cold groundwater of thermal waters.

A total 33 water samples were collected and analyzed in the period of April-May 2007 in order to compare physico-chemical characteristics of the thermal waters in Karahayit geothermal field. Major ions were analysed at the geochemistry laboratory of the Geological Engineering Department in Pamukkale University, Denizli, Turkey. Most of waters are of Ca-SO_4-HCO_3 type (Group I), whereas four samples which have relatively lower temperature are of Ca-HCO_3-SO_4 type (Group II) due to mixing between thermal and cold groundwater during ascend to the surface of thermal water along extensional cracks (**Figure** 6). The other ion contents in the waters are similar. The plotted area on Piper diagram of the waters indicates that generally percentage of each ion in miliekivalan/l is not exceeding 50%. The Karahayit thermal waters come from same reservoir and have similar chemical composition. According to δ^{18}O-δ^{2}H diagram, the Karahayit thermal waters are located along a line between GMWL (Global Meteoric Water Line) and East Mediterranean Water Line (Filiz, 1984; Simsek, 2003). This suggests a meteoric origin. The Karahayit thermal waters have hardly any ^{3}H (tritium) indicating that the minimum ages of them and minimum residence time at the reservoir are 50 a (Filiz, 1984; Simsek, 2003).

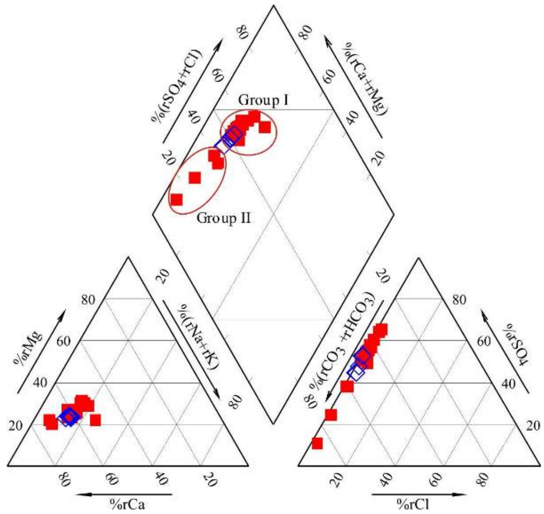

Figure 6: Piper diagram showing composition of thermal waters in the Karahayit geothermal field.

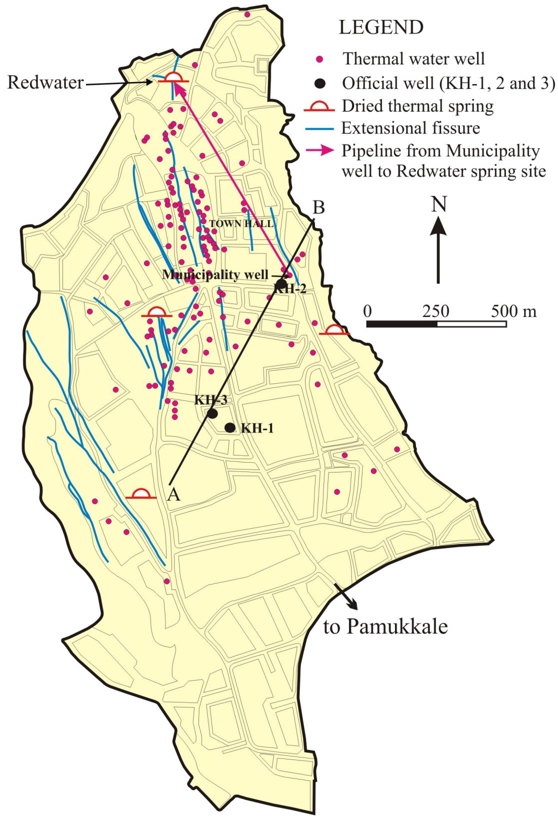

Figure 7: Well locations drilled in the Karahayit Municipality area.

4. THE PROBLEM AND REMEDATION STUDIES IN THE KARAHAYIT GEOTHERMAL AREA

There were many thermal springs, which have a temperature of 50-56°C, deposited red travertine in Karahayit area before

1981. Especially "Red Water Thermal Spring" was famous and second stop location for tourists visiting to Pamukkale antique and natural beauty site. In order to response to thermal tourism activity in Karahayit, the first thermal water well was drilled in 1981. In the following years, number of thermal wells has been increased dramatically and consequently all thermal springs in the area disappeared in 1981–1994 period. Later on, many wells were drilled by hotel and pension owners. Presently, a number of well drilled in a part of 1 km^2 of the Karahayit geothermal field is about 200 (**Figure** 7). The annual quantity of the thermal water exploited from wells in the area is about 1,550,000 m^3. The uncontrolled over-exploitation of the reservoir has led to lowering of the piezometric level and shallow wells have been dried up and consequently the piezometric level lowered in the deep wells. Recently, the thermal water of the Municipality well is conducted to the Redwater thermal spring site by pipeline and the thermal spring seems active (**Figure** 8).

Figure 8: Old Redwater spring area and artificial thermal spring. Thermal water is conducted to old wellhead from a well by pipeline (see Figure 7).

It is clear that a balance must be regained between quantity of water supplied to the reservoir and the amount discharging from geothermal wells for sustainable utilization of the Karahayit geothermal field. For that reason, the Denizli governorship is made a decision to drill three (thermal water) production wells and one re-injection well, to distribute the thermal water to the hotels and pensions and then to close all private thermal well in the area. The geological and geophysical studies were performed in order to understand subsurface geology, to determine low resistivity areas and their depths. In the result of these studies three geothermal well locations were determined. The wells namely KH-1, KH-2 and KH-3 were drilled to depths of 468, 452 and 570 m, respectively, in 2007. All the wells were penetrated into reservoir rocks (**Figure** 9 and **Figure** 10). The cap rocks were not cut in well KH-1 drilled at the nearest locations to the main graben fault. Temperatures of the thermal waters were produced from these wells are 58°C at KH-1, 58.5°C at KH-2 and 61.5°C at KH-3. The amounts of thermal water discharging from artesian wells KH-1, KH-2 and KH-3 are 12 l/sec, 22 l/sec and 58 l/sec, respectively. Total discharge of 92 l/sec is about two times of thermal water amount need for hotels and pensions.

Thermal waters taken from the wells were analyzed at the laboratories National Public Health Agency of Refik Saydam, in order to determine availability for therapeutics utilization of the thermal waters. Analytical results are given in Table 1 and plotted on Piper diagram (**Figure** 6). The chemical composition of these waters is similar to other thermal well waters in Karahayit area. The water types are Ca-HCO_3-SO_4 in wells KH-1 and KH-2 while Ca-SO_4-HCO_3 in KH-3. According to chemical and bacteriological analyses, the Agency reported that the thermal waters from the wells can be used for thermal spa.

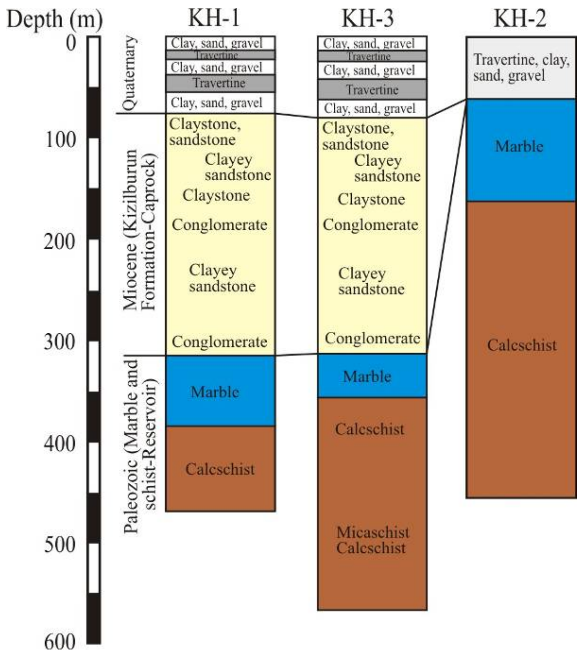

Figure 9: Geological logs of KH wells.

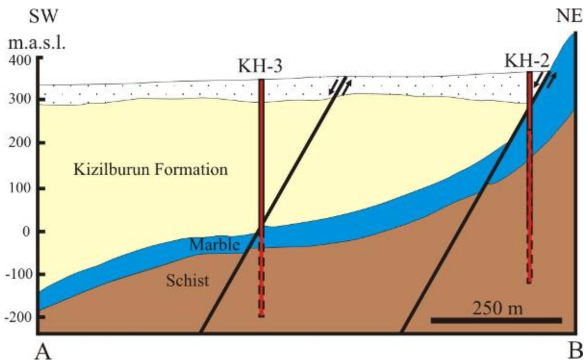

Figure 20: Geological cross section through A-B line in Figure 7.

There is no problem regarding the discharge of thermal water from hotel and pensions after utilization in the Karahayit area. The thermal waters used in the baths and swimming pools will be discharged into sewage and conducted to treatment facility in this way, whereas the waters coming from space heating will be discharged into re-injection well for the purposes of feeding of the reservoir and removed of thermal waters cooled.

Domestic wastes filling extensional fissure are an important problem in the area. The fissure is close to SW part of the municipality area (**Figure** 7). In the past, the extensional fissure was widened to provide building stone and then abandoned. The fissure has been filled with domestic waste by surrounding municipalities in the last 20-25 years (**Figure** 11). The waste is the potential contaminant for the thermal and cold groundwater reservoirs. Primarily the waste in the extensional fissure has to be removed from the geothermal field to prevent the contamination of the ground waters.

Table 1: Chemical analysis of the thermal waters discharged from official wells in the Karahayit geothermal field (nd: not detected).

	KH-1	KH-2	KH-3
Depth (m)	452	468	570
T (°C)	58.0	59.0	60.0
EC (µS/cm)	3110	2990	
pH	7.0	7.8	7.0
Na (mg/l)	108.0	120.0	116.8
K (mg/l)	17.8	22.4	23.6
Ca (mg/l)	484.4	563.0	505.2
Mg (mg/l)	105.6	132.4	117.2
NH_4 (mg/l)	3.89	3.5	1.0
Cl (mg/l)	26.9	25.3	24.5
SO_4 (mg/l)	971.7	837.6	863
HCO_3 (mg/l)	1329.8	1305.4	964
NO_3 (mg/l)	37.3	10.6	nd
PO_4 (mg/l)	0.05	nd	nd
F^- (mg/l)	3.10	2.7	2.9
Br (mg/l)	0.16	0.13	0.12
I (mg/l)	0.19	0.07	0.06
As (mg/l)	nd	0.005	0.007
Al (mg/l)	nd	nd	0.004
Ba (mg/l)	0.09	0.03	0.04
Cr (mg/l)	nd	0.002	nd
Fe (mg/l)	1.70	0.007	0.30
Hg (mg/l)	nd	0.002	nd
Mn (mg/l)	0.06	0.04	nd
Ni (mg/l)	nd	nd	0.005
Se (mg/l)	nd	0.003	0.004
H_2SiO_3 (mg/l)	44.46	33.8	42.5
H_3BO_3 (mg/l)	5.72	8.6	18
CO_2 (free)	264.7	74.9	120

Figure 11: The extensional fissure filled with domestic water in the Karahayit area.

5. CONCLUSIONS

In the Karahayit geothermal area, temperature of the thermal waters range from 33 to 61.5°C. The thermal waters ascend along the NW-SE trended boundary faults and interconnected cracks through the reservoir rocks of Paleozoic schist and marble. The thermal waters are of generally $Ca\text{-}SO_4\text{-}HCO_3$ type and meteoric in origin. The Karahayit geothermal area is a poor example in sustainable use. All the thermal springs were dried up and piezometric level was dramatically lowered as a consequence of uncontrolled thermal water pumping from the reservoir by about 200 wells drilled in the area.

A balance must regain between quantity of thermal water supplied to the reservoir and the amount discharging from wells for sustainable utilization of the Karahayit geothermal field. To this end, three deep wells were drilled in the first stage of remediation studies made. The thermal water from the wells have a temperature of 58-61.5°C and yield of 92 l/sec. Total yield of the wells has been increased up to 135 l/sec by the pumping tests.

In second stage of the studies, the underground work will have been completed in 2009 on distribution of the thermal waters to hotels and pensions in the area. In the last stage all the private wells would have been closed and drilled a re-injection well in the aim of feeding of the reservoir in 2010.

The thermal waters from the wells will not only be used for thermal spa, but also for space heating.

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