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Geothermal Potential of the Banaz-Hamamboğazı Thermal and Mineral Waters

Suzan Pasvanoğlu, Baki Canik[2], and Zafer Arıgün[3]

[1]Kocaeli University, Department of Geological Engineering, IZMIT- Turkey

[2]University of Ankara, Department of Geological Engineering, Ankara- Turkey

[3]Mineral Research and Exploration General Directorate (MTA), Ankara-Turkey

E-mail adress, suzan@kou.edu.tr

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ABSTRACT

The Hamamboğazı spa is located 7 km NE of the Banaz town along the E-23 Izmir highway. Its elevation is 970 m. Alluvium deposits of the Hamamboğazı creek extending to the southwest form the Banaz plain. The annual precipitation in the Banaz region is 672.3 mm. Miocene and Quaternary deposits are exposed in the area. Miocene deposits are composed of conglomerate, sandstone, silt, claystone, clayey limestone, marl, tuff and tuffite units. Volcanism was active during the deposition of unit in the Miocene lake. Foot prints on the volcanic ash deposits around the Salihli at west of the area may indicate that volcanic activity continued during Quaternary.

Quaternary alluvium is composed of fan and debris deposits and travertine. Green rocks such as serpentine, radiolarite and chert are found at a depth of more than 300 m in deep wells. Left flank of the Hamamboğazı valley is faulted and thermal waters issue through this fault. Drilling studies in the Hamamboğazı area were started in 1994 by MTA. As a result of drilling of 4 wells, thermal water with a discharge of 124.82 l/sec and with a temperature of 62–73ºC was produced. On the basis of AIH classification, thermal water is sodium-magnesium, carbonate, sulfate, boron, silica bearing waters containing significant amount of CO_2 gas.

In this study, origin, recharge and physico-chemical characteristics of the Banaz Hamamboğazı thermal waters are investigated. In order to determine reservoir temperature of the area various chemical geothermometers were used. Assuming a reservoir temperature of 80°C for the Banaz area, fluid potential was computed as 350 l/sec.

Applications of district heating and green house as well as building of new spas in the area are seriously considered by the Banaz Municipality.

1. INTRODUCTION

The Uşak-Banaz region in the western Anatolia comprises an area of about 20 km^2 (Figure 1). The Hamamboğazı spa is located on the eastern flank of the Hamamboğazı valley 7 km NE of the Banaz town. The railway and E-23 highway connecting the city of Izmir to Anatolia lie 200 m west of the spa. Facilities are established on a hill covered with pine trees. The elevation of the spa area and the Hamam creek valley 2.5 km at west are 970 m and 935 m, respectively. The highest peaks in the region are Dibektaşı hill at east (1226 m), Noşu hill at northwest (1196 m), and Kakış hill at south (1034 m). The average annual rainfall in the Banaz area is 672.3 mm and the annual temperature is 11.1°C.

2. GEOLOGY

Paleozoic, Mesozoic and Tertiary rocks are exposed around the Banaz area (Figure 1 & 2). The basement is represented with metamorphic rocks that are northeastern elongation of the Menderes massive exposing 8 km south of Banaz and the southern flanks of the Murat Mountain. Metamorphic rocks generally develop in green schist facies and overlain by upper Paleozoic-lower Mesozoic marbles. Schist and marbles continue with an ultrabasic complex series of upper Mesozoic age exposing 4 km west and northwest of Banaz. This sequence consists of various limestone, radiolarite, chert, serpentine and peridotite. Older formations are overlain by Neogene lacustrine deposits widely exposing around the Banaz area (Figure 1 & 2). Except for alluvium filling the Hamamdere valley around the spa, lacustrine deposits are observed throughout the study area. Lacustrine units are composed of conglomerate, sandstone, limestone, siltstone, claystone, marl and their alternations. Tuff and tuffire bands as well as gypsum levels are also detected in between. Lacustrine deposits are yellowish beige colored and generally contain significant amount of clay. Bonding material in conglomerate and sandstones is mostly carbonate or clay. In some cases, clastics exceed coarse block size. In wells drilled around the Hamamboğazı spa, their thickness is found as more than 300 m. They exhibit well bedding. Layers have various dip and strike; former is generally 12°-30°. Flute marks and burrow structures are observed in fine grained sandstones around the Kaplangi village. Geologic cross section for the spa area given in Fig. 2 explains the geologic structure of the region.

Alluvium filling the Hamamdere valley has a thickness of 20-25 m. In areas where rivers joined with valleys, alluvium is mixed with talus and debris deposits. Strike slip normal faults are formed on the left slope of the Hamamdere valley. On the basis of well logs and field observations, slip rate was calculated as maximum 100 m. There is another normal fault on the right slope of the valley. Since exposures are not continuous, faults cannot be well traced. However, the presence of thermal waters, sudden steep changes in topography and discontinuity in layers are the indicatives of faulting.

The youngest volcanic activity in the region started in Miocene and continued until Quaternary with some breaks. Acidic volcanism 10 km east and northeast of the spa and the Elmadağ andesites 15 km west of Banaz are the main volcanic units in the region. Quaternary Uşak-Kula volcanism (Ercan, 1979) and the foot prints on volcanic

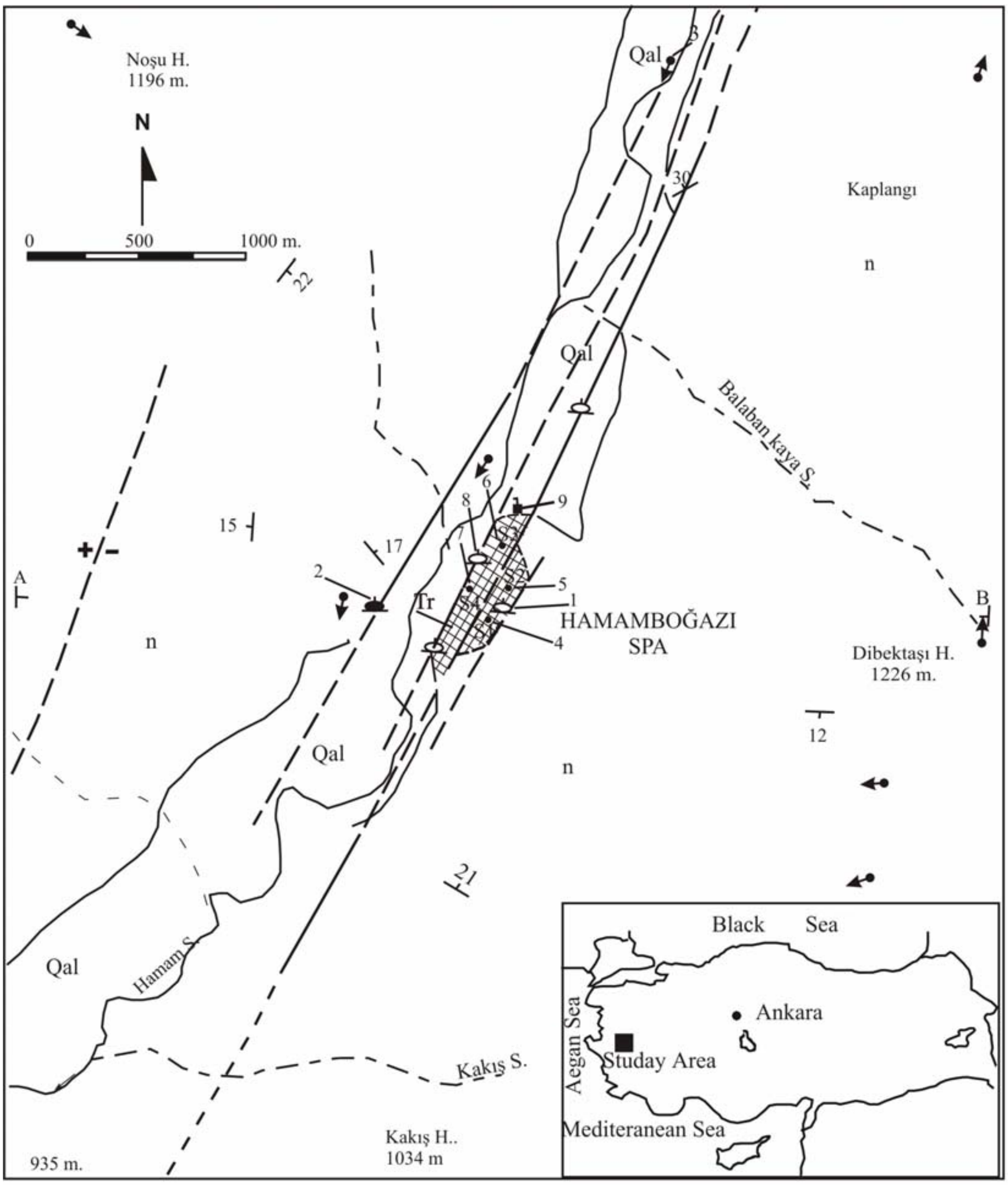


Figure 1: Geological map of the Banaz Spa area

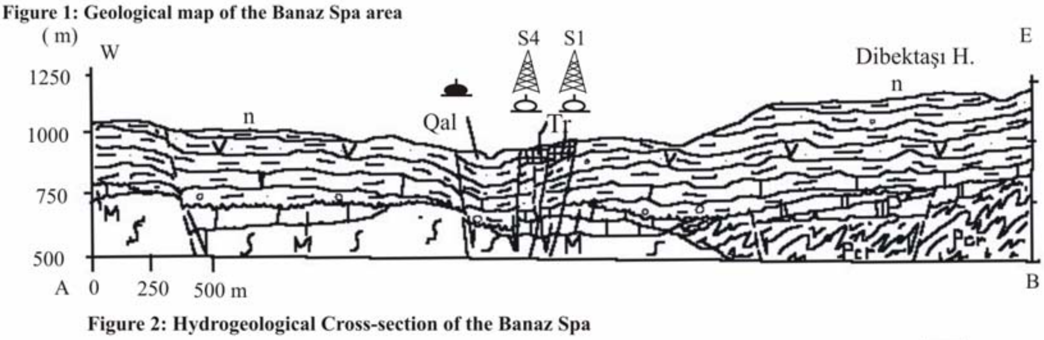
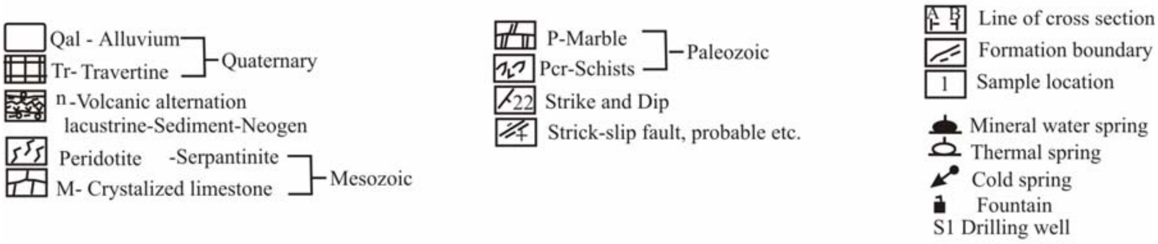


Figure 2: Hydrogeological Cross-section of the Banaz Spa



ashes around the Salihli- Köprübaşı region are the most important evidences of recent volcanism.

3. HYDROGEOLOGY

Thermal and mineral waters of the Hamamboğazı spa 7 km NE of the Banaz area are issue through the NE-SW trending normal faults. A number of 4 wells were drilled until late 2003 in order to determine fluid potential of the area for application of district heating in Banaz (Figure 1, 2 & 3). As a result of intense drilling, discharge rates of water were decreased and some of the springs became extinct. In addition, well no.1 was a flowing artesian and its pressure level was lowered when well no.2 was drilled (Ölmez, 1998).

Travertine deposits precipitating from thermal waters that issue from the faults around the spas cover an area of about 50.000 m^2 especially a long the fault line where the Hamamboğazı springs discharge. Travertine deposits are beige and light brown in color and they have a thickness of about 75-80 m. Their formation still continues. The travertine's deposition starts from the pools. Generally the trends of travertine deposits are parallel to the surface flow lines of these thermal outlets. Waters issuing from the faults flow to the Hamamboğazı valley at west. Travertine deposits exhibit well bedding and their dips are variable, generally extending to the west with dipping of 30-60°. At present, most of thermal waters discharge from the lower levels of the travertine dome. Gas also emanates from near the top of the deposit. Travertine deposition blocks fluid paths causing the springs to migrate over time. The deposition rate of travertine is greatest at the rim of the terraces, where out gassing of CO_2 is enhanced by turbulent flow. However, the deposition rate is also significantly high where the water flow has high velocity and the flow thickness is small.

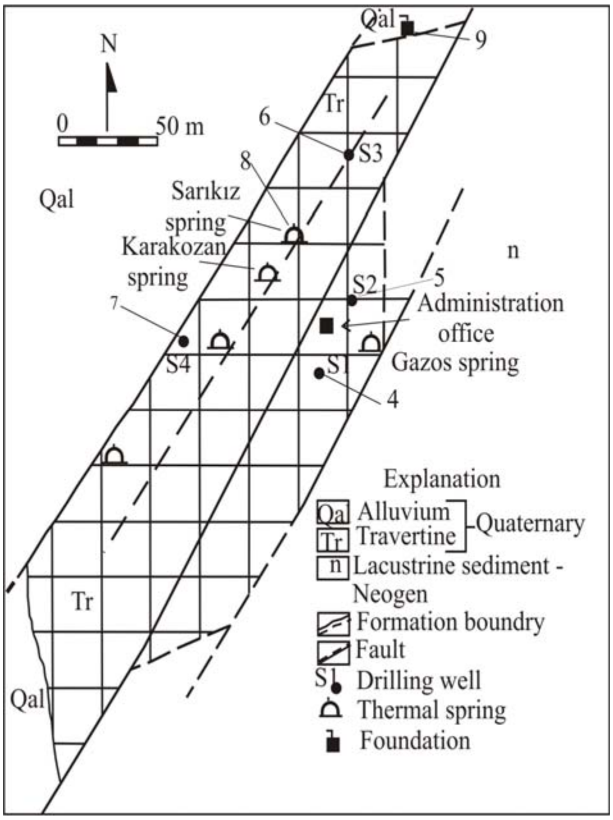


Figure 3: Sample location of thermal waters at Banaz field

3.1 Formation of Thermal and Mineral Waters

Springs recharging the Spa have a meteoric origin. They infiltrate downward and are heated by a magma chamber possibly seated at a depth of 10-12 km and then rise to the surface through the normal faults. Faults behave as a conduit for the thermal waters. Temperature of springs is between 30 and 44°C while temperature of artesian water of well no.3 is up to 72.5°C (Table 1). Due to their secondary porosity and permeability, ophiolitic rocks, Paleozoic schist, marbles and limestones below the lacustrine units found in wells opened around the spa area are believed to be possible reservoir rocks. In this respect, wells to be drilled in this area will possibly cut schist, marble, limestone or ophiolite complex that are thought to be present under the lacustrine units (Figure 1, 2 & 3). Lacustrine deposits of 250-400 m thickness with an impermeable character are the cap rocks of the reservoir. Thus, when meteoric waters are accumulated at depth temperature is not lowered significantly. It is possible that deep wells in this area will attain bottom-hole temperatures higher than 100°C.

4. HYDROGEOCHEMISTRY

4.1 Water Samples and Analytical Methods

In order to assess the possible influence of precipitation on the spring water types and flow paths, water samples for chemical analyses were collected from the springs and well in July 2003. All the analyses were done in the State Hydraulic Works (DSI) Laboratory of Turkey, Ankara (Table 2). Electrical conductivity (EC) and pH parameters were measured both in the field and the laboratory and the results for pH showed differences of approximately one unit ($pH_{lab} > pH_{field}$) presumably due to degassing of CO_2.

4.2 Hydrochemical Evaluation

The total dissolved solids of the Banaz water range from 2982 to 2694 mg/l. The waters are colorless and odorless but contain CO_2 gas. Temperature, pH and EC values of these waters range between 42-73°C, 6.5–7.1 and 4460-4210 µS/cm, respectively. Thermal and mineral waters of the Hamamboğazı spa 7 km NE of the Banaz area are manifested along the NE-SW trending normal faults. Results of chemical analyses of spring and well waters collected in July 2003 period are given in Table 2.

According to the water analyses 2003 Banaz thermal springs and the water from boreholes are similar in origin (Figure 4). This suggests that the ground water comes from the local precipitation and has passed through similar rock types, i.e. aquifer. These waters are Na, HCO_3, SO_4, B, SiO_2, F, CO_2 bearing (AIH, 1979).

It is shown in Schoeller diagram that composition of Gazos spring and the water of well no.4 are very similar, and except for Na+K, Sarıkız spring water also resembles for their composition. There is a significant change in the composition of Sarıkız spring for the year of 2003 and 1948 (Çağlar, 1950) (Figure 4). Ca, K and SO_4 concentrations of 2003 water decreased while Mg, Na, Cl and HCO_3 concentrations significantly increased.

Table 1: Results of measured flowrate, and temperature of thermal waters in the field

Location	Gazos sp.	Sarıkız sp.	well-1	well-2	well-3	well-4	Yayla mineral water.sp.
Flow rate (l/sec)	0,86	0,675	4,155	37,7	38	45	0,034
Temperature (t°C)	42	54	65,5	65,5	72,5	72	18
Depth (m)	-	-	245	405	293	480	-

Table 2: Chemical composition of waters from the study area (in mg/l)

Sampling point	Gazos spring, No 1	Gazos spring, No1	Yayla mineral water, No 2	Hamamboğazı st. No 3	Well -1, No 4	Well -2, No 5	Well -3, No 6	Well -4, No 7	Sarıkız spring, No 8	Sarıkız spring, No 8	F.Çuhadur water spring, No 9
Sampling date	27.07.2003	12.09.1950	27.07.2003	27.07.2003	27.07.2003	37829	37829	37829	27.07.2003	12.09.1950	27.07.2003
Ca	133,8	364,2	108,6	80,20	90	113,4	114,8	125,4	113,4	347,9	121
Mg	192,5	125,7	243	81,2	182,4	243,2	237,5	194,2	200,9	115,2	101,2
Na	445	288,7	202	8,4	552	412	437	532	416	284,3	11,8
K	95	112,9	47	3,2	98	98	93	92	84	108,1	2,9
Cl	131	11,6	81,3	19,5	125,7	126	122	129	111,5	11,2	28,4
SO4	624	1111,3	142	118,5	670	604	896	635,6	634	1081	221
HCO3	1691,5	1106,9	1839,1	494,1	1745	1828	1506	1887	1596	1155	586
SiO2	84	40,3	11,8	18,8	86,8	77,7	83	87,5	74,5	38,3	15,1
B	12,8	n.m	5,6	0	13	12,2	12,4	12,2	12,5	n.m	0
F	8,9*	n.m	0,35	0	9,4*	2,73	3,31	2,82	3,18	n.m	0
As	0,56*	n.m			2,44*					616*	
Fe	0,12	0,09	0,02	0,04	0,28	0,28	0,06	0,01	0,52	0,12	0,03
T(°C)	42	22	18,1		64,5	65,5	72,5	72	54	37	16,4
pH(25^{o} C)	6,5	6,7	6,3	7,5	6,9	6,9	7	6,9	6,8	6,9	7,1
EC (µS/cm)	4410		3520	1040	4540	4560	4330	4660	4210		1404
TDS (mg/l)	2822,40	4589,8	2253	666	2906	2918,4	2771	2982	2694	3805	899
Total Alkalinity	1386,5		1507,7	405	1430	1498,5	1234,5	1547	13008	1308	480
Water class.(AIH)	Na, Mg, HCO_3, SO_4 ,H_2SiO_3, B, CO_2 thermal and mineralized water	Na, Mg, HCO_3, SO_4 ,H_2SiO_3, B, CO_2 thermal and mineralized water	Mg, Na, HCO_3, CO_2 mineralized water	–	Na, Mg, HCO_3, SO_4 ,H_2SiO_3, As, B, CO_2 thermal and mineralized water	Na+K, Mg, HCO_3, SO_4 ,B, H_2SiO_3, CO_2 thermal and mineralized water	Na+K, Mg, HCO_3, SO_4 ,B, H_2SiO_3, CO_2 thermal and mineralized water	Na, Mg, HCO_3, SO_4 ,B, H_2SiO_3, CO_2 thermal and mineralized water	Na, Mg, HCO_3, SO_4 ,B, H_2SiO_3, CO_2 thermal and mineralized water	Ca,Na, Mg, SO_4, HCO3, Br, CO_2 thermal and mineralized water	-

*As ve F değerleri MTA nın aynı noktada 2000 yılında yaptığı tahlilden alınmıştır

Calcium (Ca): Lacustrine deposits contain little mount of carbonaceous rocks. Calcium is derived from underlying marble and limestones. It comprises 9.79-15% of total miliequivalent values of cations.

Magnesium (Mg): Magnesium is originated from the alteration of olivine, augite and hornblend in serpentine and peridotite. It comprises 32.89-43.72% of total miliequivalent values of cations.

Sodium (Na): It is known that lacustrine units in the region are composed of evaporite minerals. Na in waters is derived from dissolution of Na-bearing salts or alteration of feldspars in ultrabasic rocks and schists. Clay minerals also enhance exchange of Na with Ca. It comprises 38.63-51.93% of total miliequivalent values of cations.

Potassium (K): K in waters is originated from alteration of K-feldspars. It comprises 4.92-5.46% of total miliequivalent values of cations.

Chloride (Cl): Dissolution of evaporitic salts and enrichment of rain waters during the circulation at depth are possible sources of Cl in waters. It comprises 7.35-8.31% of total miliequivalent values of cations.

Sulfate (SO_4): SO_4 in waters is derived from dissolution of gypsum in sediments or oxidation of pyrite.

Bicarbonate (HCO_3): Bicarbonate is originated from the reaction between CO_3-rich waters and limestone and marbles during the circulation of meteoric waters. It comprises 52.77-65.01% of total miliequivalent values of cations.

Boron (B): All thermal waters in the area contain boron more than 12 mg/l. Its source could be the Neogene volcanism or serpentines (Şahinci, 1991).

Silica (SiO_2): Silica concentration in waters is between 74.5 and 87.5 mg/l. Most of silica is derived from the alteration of silicate minerals in chert, magmatic and metamorphic

From Cl- SO_4- HCO_3 triangular diagram (Figure 5) Banaz thermal and mineralized waters and boreholes are bicarbonate-rich waters. They are near neutral pH, low in chloride and the major cation is sodium. Also these waters contain slightly high concentrations of sulphate. Low Cl concentration in this type of waters is attributed to mixing of ascending thermal waters with cold groundwater. Decreasing Cl and increasing HCO_3 concentrations in thermal waters may indicate increasing water/rock interaction (Giggenbach and Glover, 1992). The source of SO_4 in the environment is explained by the oxidation of H_2S and/or dissolution of minerals like gypsum and celestite ($SrSO_4$). Meanwhile, Cl concentration decreases while that of HCO_3 increases. High bicarbonate concentrations are due to reaction of CO_2-rich waters with surrounding rocks. Moreover, thermal waters with high bicarbonate and dissolved CO_2 contents are found in the periphery of high-temperature geothermal systems or at shallow levels where hot waters are mixed with cold waters. In these environments, their temperature is well below the boiling point. Calcite is the main material they precipitate (Brown, 1991).

Based on Figure 6 all the data points plot in the area of immature waters, therefore solute geothermometers is not likely to yield meaningful Na / K equilibration temperatures (Giggenbach, 1988). The only option is to use silica geothermometers (Table 3). Therefore quartz and chalcedony temperatures have been calculated. Chalcedony geothermometer temperatures vary from 93 to 102°C. Quartz geothermometer temperatures vary from 111 to 130°C and are obviously higher than the discharge and chalcedony geothermometer temperatures. Quartz geothermometer temperatures may reflect deep reservoir temperatures near the thermal resource. But the results of drilling show that the temperature of thermal waters in Banaz is not higher than 100°C. So the chalcedony geothermometers are probably closer to the reservoir temperature than the quartz temperatures. The thermal waters are derived from conductive heating and geothermal gradient.

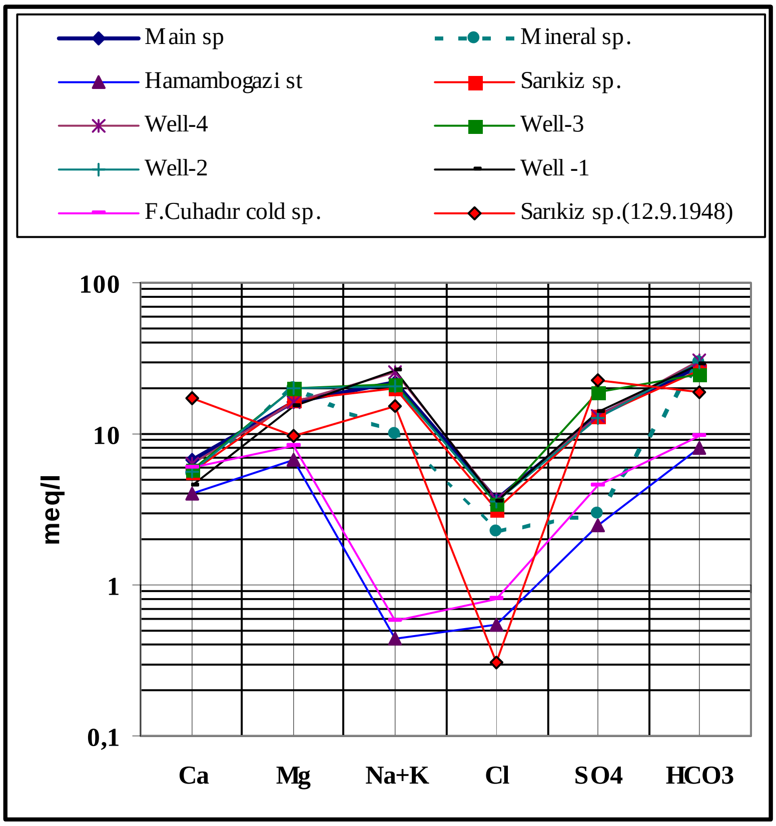


Figure 4: Schoeller diagram of Banaz Waters

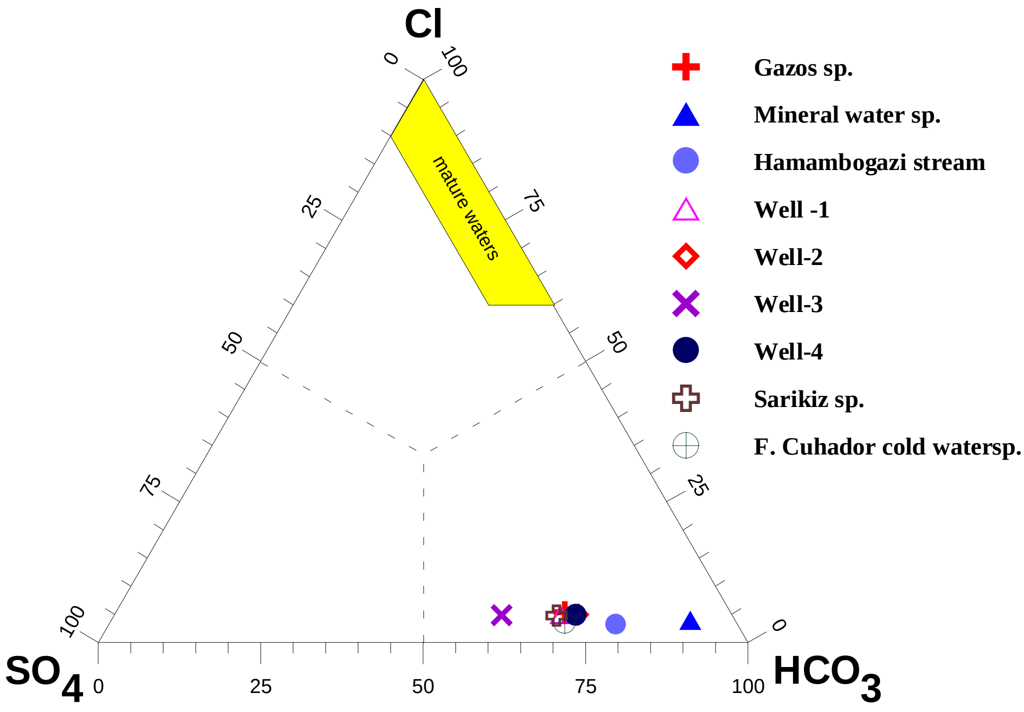


Figure 5: Cl-SO_4-HCO_3 diagram for waters from Banaz thermal springs

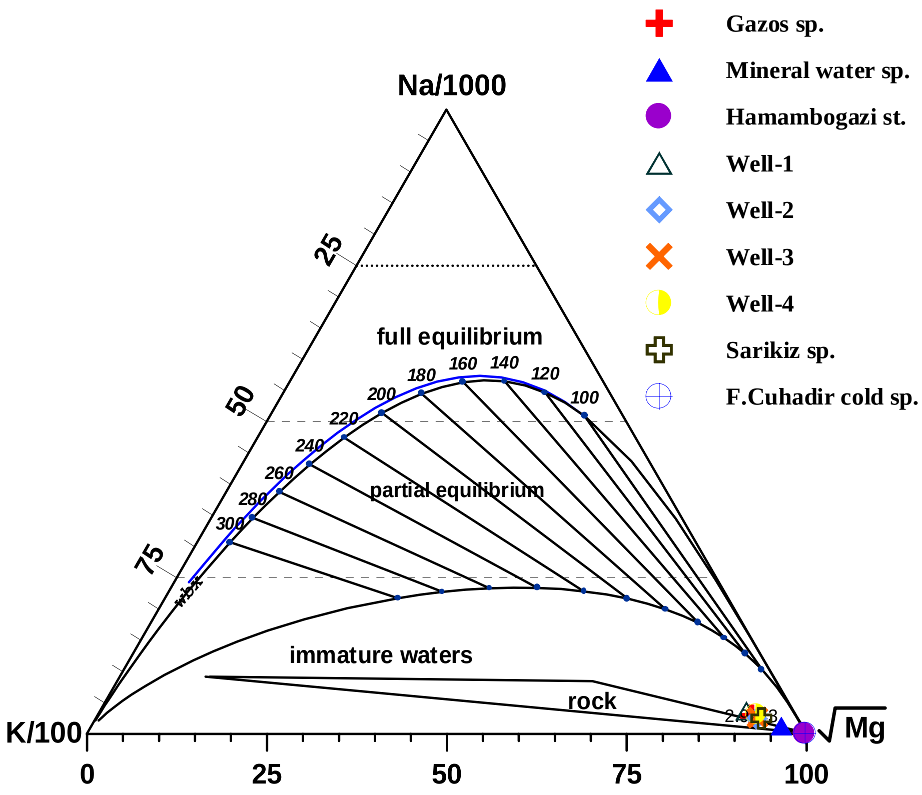


Figure 6: Plot of Na-K-Mg equlibrium diagram (Giggenbach,1988)

Table 3:Results of Different geothermometer of waters of Banaz thermal spring

Geothermometer	Gazoz sp.	well-1	well-2	well-3	well-4	Sarıkız sp.	Reference
T (°C)	42	64,5	65,5	72,5	72	54	Measured
SiO_2 (quartz, no steam loss)	128	130	124	127	130	122	Fournier et al, 1973
SiO_2 (quartz, max steam loss)	125	126	121	124	127	120	Fournier et al, 1973
SiO_2 (quartz, no steam loss)	118	120	114	117	121	111	Arnorsson et al, 1983
SiO_2 (quartz, max steam loss)	124	125	120	123	126	118	Arnorsson et al, 1983
SiO_2 (chalcedony, no steam loss	100	102	96	99	103	93	Fournier et al, 1973
SiO_2 (chalcedony, max steam loss	100	102	96	100	102	94	Fournier et al, 1973
SiO_2 (chalcedony, no steam loss	99	101	95	99	102	93	Arnorsson et al, 1983
SiO_2 (chalcedony, max steam loss	100	101	97	100	102	95	Arnorsson et al, 1983

5. EVALUATION OF GEOTHERMAL SYSTEM IN THE STUDY AREA

The Banaz - Hamamboğazı geothermal field is liquid dominated reservoir with reservoir temperature about 100°C (from geothermometry). A volumetric method is used to calculate the potential of the geothermal prospect following Hochstin (1975). The volumetric method involves the calculation of geothermal energy contained in a given volume of rock and water, but neglects all recharge to the system. The results obtained by this method are convenient for rough estimates of the resources. The thermal energy in the subsurface is calculated as follows:

$$E= E_r + E_w = VC_r \rho_r (1- \phi) (Ti -T_o) + V C_w \rho_w \phi (Ti - T_o)$$

Where E = Total energy in the rock and water (kJ); V= Reservoir volume (m^3);T_i = temperature of the aquifer (ºC);T_o = Reference temperature (ºC);C_r = Specific heat capacity of rock (kJ / kg º C);C_w = Specific heat capacity of water (kJ / kg º C);ρ_r = Density of reservoir rocks (kg/ m^3); ρ_w = Density of water (kg/ m^3); ϕ = Porosity. For the Banaz geothermal field the following assumptions were made:

A=1 km^2, V= 15.10^8 m^3, Ti = 80ºC. Because well head temperature in well no.3 was measured as 72.5°C T_o=13°C, $\rho_{w\ (80ºC)}$ =971, 78 kg/m^3, ρ_r = 2650 kg/m^3 (Goodmans, 1989), C_r =0,804 kj /kg°C, ϕ= 0,1, Δ´ T= (67-35) The difference between temperatures of waters produced and disposed.

Using the above state parameters in equation, the total heat energy in a volume (V) of fracture beneath a specified area which can be used by space -heating is 1.921E 16 J. Using stored heat and recovery method we assume a recovery factor of 0.25 and life time for exploration 25 years and assuming also that geothermal system works 240 days per year, the power potential estimated for the Banaz geothermal field of 92 MW_t.

In addition, on the basis of heat extraction formula, the minimum amount of water to be extracted from the Banaz geothermal field is computed as 350 l/sec.

6. CONCLUSION

The Banaz geothermal field is interpreted using different hydrogeochemical diagrams and geothermometers. Thermal and mineral waters of the Hamamboğazı spa are manifested through NE-SW trending normal faults. Thermal spa waters are meteoric in origin with a temperature of 30 – 40°C. Ophiolitic rocks, Paleozoic schist, marbles and limestones below the lacustrine units found in wells opened around the spa area are believed to be possible reservoir rocks due to their extremely fractured character. The total dissolved solid content of waters is from 2682 to 2694 mg/l. These waters are Na, HCO_3, SO_4, B, SiO_2, F, CO_2 bearing (AIH, 1979). According to the various geothermometer techniques the temperature of the geothermal system was found to range from 93 to 102^0C. According to the results of the reservoir assessment, the usable total energy potential of the Banaz field is about 1.921E 19 J. Its estimated power potential is 92 MW_t.

In addition, on the basis of heat extraction formula, the minimum amount of water to be extracted from the Banaz geothermal field is computed as 350 l/sec.

7. SUGGESTIONS

The potential of the geothermal area investigated is found to be suitable for heating of Banaz. Facilities around the Hamamboğazı spas should be removed. Except for use for extraction and storage of hot water, no other buildings should be permitted in the area. The water manifestation area has to be protected. There are more proper sites for establishment of modern spas such as, in the area between Banaz and the present facilities as well as on both sides of the Hamam creek valley. Facilities to be built a few km from the E-23 highway must be planned in a way to satisfy people of different income.

The Banaz plain is an ideal place for green house application. The presence of wide, fertile lands, suitable climate conditions and its locality between two large cities, Ankara and Izmir, will make green house application easy to develop. Moreover, since Banaz is located at the center of Izmir, Ankara, Eskişehir and Denizli cities, and it is surrounded with forests, plateau and mountains, it is clear that thermal tourism in the area will be rapidly developed if necessary investment is made. The Yayla mineral water is very tasty. Its chemical composition is composed of Mg, Na, HCO_3 and CO_2. Once necessary facilities are established, this mineral water should be bottled immediately. This attempt will promote evaluation of other mineral waters around the Banaz area. Development and widening of thermal water facilities in the Banaz area are no doubt dependent on drilling of deep wells and thus increasing of hot water discharge. There is such a potential in the study area and proposed project and investments should be started at once.

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REFERENCES

Browne, P. R.L.: mineralogical guides to interpreting the shallow paleohydrology of epithermal mineral depositing environments. Proc 13 th NZ Geothermal work – shop, Auckland pp 263-270 NZ, (1991).

Canik, B.: Hidrojeoloji, Yeraltı sularının aranması işletilmesi, kimyası. A.Ü. Fen Fakültesi, P. 291, ISBN 975 – 94414-0-3 Ankara, (1998).

Canik, B.: Kızıldere – Tekkehamam jeotermal sahasının sıcaklık ve akışkan potansiyeli, Doğan jeotermal raporu, Ankara, (2003).

Çağlar, K.Ö.:Türkiye maden suları ve kaplıcaları MTA yayını seri B, No: 11, Fas.3, P.454 – 456, Ankara,(1950).

Ercan, T.: Cenozoic volkanizm in western Anatolia, Thrace and the Aegean island. Jeoloji müh. Sayı 9, P. 23-46 Ankara (1979).

Giggenbach, W. F. Glover, R: TectonicRegime and major processes govering the chemistry of water and gas discharges from the Rotorua geothermal field? Geothermics, vol 21, No ½ pp 121 – 140, (1992).

Goodmans, R.: Rock mechanics 2nd edition. Wiley- Sons New York, (1989).

Grant M.A., Donaldson J. G., Biscley P.F.: Geothermal reservoir engineering, Academic pres, New-York, USA, (1982).

Koga, A.: Geochemistry of the waters discharged from drillhols in Otake and Hatchobaru areas (Japan). Geothermics. Special issue, 22(2), (1970), 1422-1425.

Hochstein, M.P.: Geophysical exploration of the Kawah Kamojang geothermal field, W.Java. Proc. 2nd UN Symposium on Development of geothermal resources, (1975), 1049-1058.

Ölmez, E.: Uşak, Banaz, Hamamboğazı-2 (HB-2) sıcak su sondajı, MTA Rap. No: 9804, Ankara, (1994).

Ölmez, E.: Uşak- Banaz Hamamboğazı jeotermal sahası jeoloji- hidrojeoloji etüdü, MTA Rap., Ankara, (2000).

Saptadji, N.M.: Reservoir simulation of kamojang field. Geothermal Institute Project report 87, School of Engineering library, University of Auckland, (1987).

Şahinci, A.: Doğal suların jeokimyası reform matbaası, İzmir (1991).

IAH: Map of mineral and thermal water of Europe. Scale 1: 500,000, International Association of Hydrogeologists, United Kingdom, (1979).