GEOTHERMAL INVESTIGATION OF THE KESENÖZÜ THERMAL SPRINGS (BOLU, TURKEY)

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Abstract

Located in north western Turkey, the study area is 10 km south of the town of Seben. This study aims at sheding light onto the potential use of the Seben-Kesenözü thermal springs for dwelling heating in the City of Bolu. The dominant rocks in the study area are of Mesozoic age sediments. The fractured limestone and conglomerate in the Kesenözü formation is member comprise the features of an aquifer and are overlain by the cover rocks of marl, shale, clay and clayey limestone. Thermal waters of the Seben region emanates from a strike slip fault with the sense of north-northwest, along the Hamamboğazı Creek. Emerging from 8 different points, the thermal waters have temperatures ranging from 56 to 78 ^{0}C. These waters are of meteoric origin and considered to have been heated by the geothermal gradient as they flow downward and return to ground surface through the faults and other types of fractures. The total dissolved solid content of the waters range from 1160 to 1920 mg/l. They are $NaHCO_3$ waters. The predominant mineral types around the thermal springs are calcite and aragonite. The loss of CO_2 in HCO_3 rich thermal waters causes a rapid increase in pH which subsequently leads to the increase with the calcite-saturation. The temperature of the geothermal system was found to range from 82 to 119 ^{0}C using the various geothermometer techniques.

Keywords: Seben, thermal waters, hydrogeology, geothermometry, Turkey.

1. Introduction

The investigation area is located in northwest Turkey, about 45 km south of the Bolu city and 10-km south west of Seben Town (Fig1). It covers Seben (Pavlu or Kesenözü Spa) thermal and mineralised water spring and its surroundings. These spring waters emerge from 8 different places and their temperatures are between 41- 78°C. There is only one well and the temperature of the water at the well head is 60°C. A historical (bath) Spa for health purposes is located at the spring sites. The altitude of the springs in the area is 720m. The annual temperature and precipitation means at Seben for 40 years observations are 11.6°C and 471.3 mm respectively. Seben- Kesenozu Spa resort has a tourist attraction for its thermal and mineralized water. Hot waters are used for the purpose of bath and treatment. The reservoir's temperature is interpreted by using different geothermometers. There is good potential of geothermal water that may be further utilised in f Bolu City’s heating.

2.Geology

The geological and hydrogeological stuides in the area and its surrounding have been done by Wedding (1954), Becker (1956), Abdulsselamoglu, (S-1954), Kalafatcioglu, A-Uysalli, H.,(1964), Turkunal, S., (1963), Unlu and Balkas, (1975), Canik, B., (1980**).**

Upper Cretaceous rocks outcrops at the study area. (Figure 1 and 2). Outside of the field, in the North and East, Tertiary aged sediments and volcanik rocks outcrop Upper Cretsceous, begins with conglomerate,sandstone and limestone, continuse upward with marl, clayey limestone and fine grain sandstone comprise the " Kesenozü Formaton``Sandstone and limestone are thin and moderatly thick. Their dips vary between 15º - 38º. The conglomerates and sandstones are gray and carbonate cemented with various schist, gneiss, quartzite, and marble clasts. Marl is gray-green, and underlies sandstones and clay-limestones. In the Hamambogazi valley they include inoceramus and globotruncana (Kalafatcioglu, 1964). All of Upper Cretaceous formations have flysh facies. and are over 800 m thick. Quaternary deposits occur deposited at the Gökpınar River situated at the south flowing from west to east and the arm of this River, the Hamambogazı River bed. These are loosely packed sediments, and are made up of conglomerates, sands, silts, and clays. Lateral and vertical facies changes occur. It is about 25 m thick. Outside of the observation field, both the east and north large areas are covered with volcanic rocks, composed of andesitic and basaltic lavas and tuff, tuffite and agglomeras along Seben – Bolu road; a variety of these rocks can clearly be seen. Volcanism was most common in Miocene and Pliocene time in the area. Volcanic rocks were originated from the Kızılcahamam Egri plain and from farther west southwest Craters like Mahya, having diameters of several kilometers. The most important fault in the study area is the thermal water springs' fault; lying NNW-SSW, along the Hamambogazı river.Lithology is generally folded therfore, some evidence of the fault is erased. Nevertheless, breccias in the valley and reversals in the layers and hot water resources occur. The thermal water springs' fault is a strike slip dextral fault with a vertical component. Along Gokpınar River there is another possible fault, sometimes causing brecciation and crushing of upper-Cretaceous formations, but mostly buried below the alluvial deposits.

3. Surface Manifestations and Hydrogeology

There are four important thermal and mineralized sources far the Kesenözü Hot springs (Fig 1). One of these is at east of the Hamambogazı River named as Kubbeli hamam springs. The other three springs are to the west of the Hamambogazı River named Hokok, Koko and Camli hamam springs. Thermal waters are also being obtained from shallow wells on both sides of the River. An artesian W-1 well has been drilled by MTA (General Directorate of Mineral Research and Exploration, Ankara). The temperature of the water at the well head is 60°C and its flow rate is 5 l/s. Thermal waters lie a long as the fault zone and form the Kesenözü water resources. The total flow rates of the Kubbeli hamam spring is 19 l/s, and the temperature of the water varies between 60-78°C. The total flow rate of the waters at the west is 16 L/sec, and their temperature varies between 56 and 70 ºC.
In order to determine the Geothermal energy potential in the area, the presence of hot rock at the depth or other factors likeporous and permeable aquifer level and an impermeable cover layer was explored (Fig 2).
Heated rock: In the East and north of Kesenözü, volcanism was dominant in its Miocene and Pliocene. This affected the Upper Cretaceous formations, especially those near the Kesenözü thermal springs, which lead to limonitization. Recently cooling must be distributing heat by conduction towards the surface, since there are other thermal water discharges in this volcanic area.

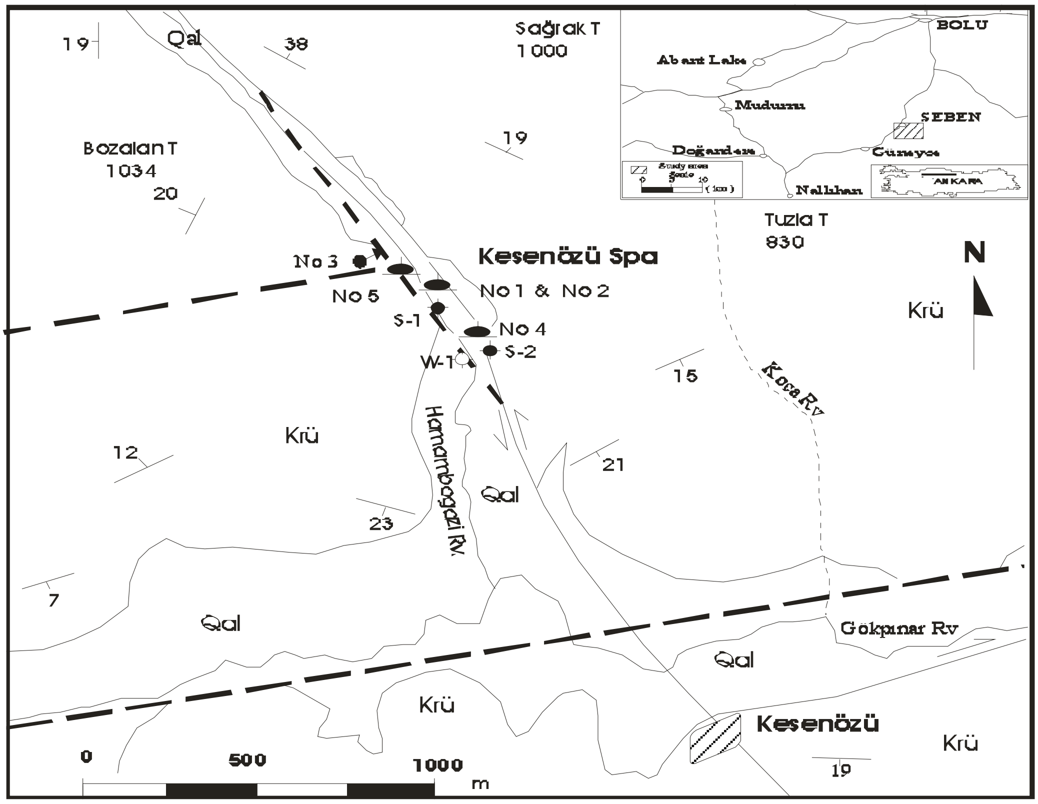

Figure 1: Simplified Geological Map of The Seben-Kesenözü Spa

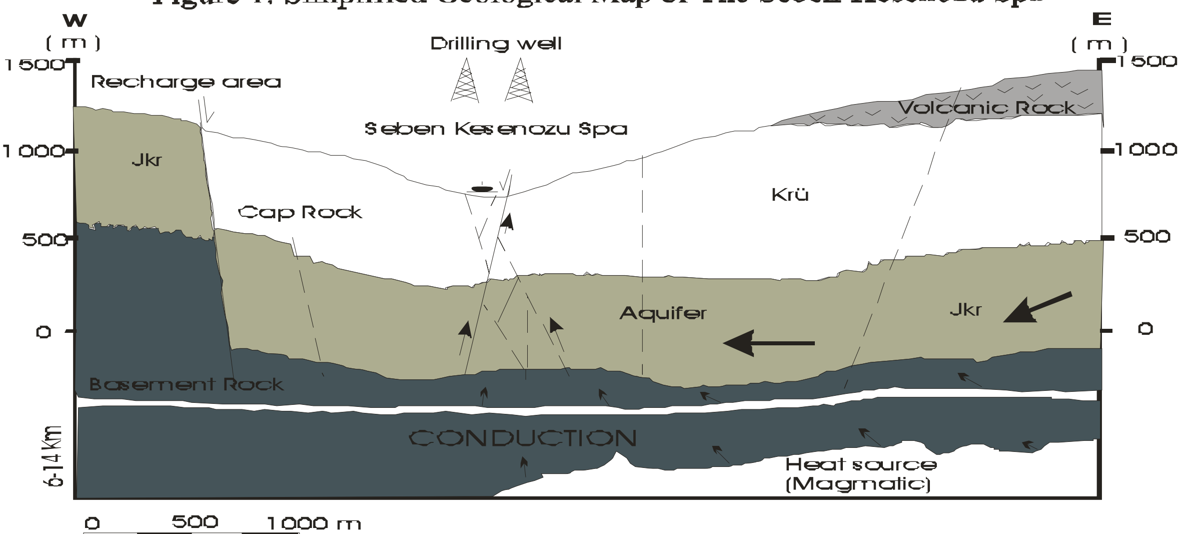

Figure 2: Conceptual model of Seben Kesenozu Geotermal Field in Turkey

Legand

Qal	: Alluvium (recent) - Quaternary		: Strike-slip Fault (probable etc.)
	:Volcanic Rock		: Thermal spring
Krü	: Conglomerate, sandstone, marl,limestone-Upper Cretaceous		:Drilling well
Jkr	:Limestone ,Jurassic -Lower Createaceous	S1-S2	: Drill localites
	:Metamorphic Schist	19	: Strike and dip of layer
	:Flow path	W-1	: Drill hole
	:Unconformity		:Cold water spring

***Aquifer Lithology*:** In the south east of the observation area there is Upper Jurassic – Lower Cretaceous aged Karageriş formation exist; being dominantly limestones with reservoir characteristic. The limestone surfaces in a wide area 5 km to the southeast and 10 km northwest of thermal resources. The limestons are Mesozoic in age and lie unconformably upon metamorphic rocks. The Jurassic– Lower Cretaceous limestons are a continuous series of white, shady and sometimes beige colored massive with thick beds. Fractured secondary porosity and permeability is well developed. In some cases they show karst characteristics. These formations are cryptocrystalline under the microscope and contain characteristic ammonite fossils (Kalafatcioglu- Uysalli, 1964). The recharges of the reservoir are a bout 20%.Its boundary with the Seben formation is fault. The reservoir is bordered by faults on three sides and its cover with volcanic rocks in the east side. Here, limestone strikes E-W in a wide area (Turkunal, 1963; Unlu and Balkas, 1975). Around the Seben-Kesenözü thermal springs, the Upper Cretaceous conglomerates and sandstones lie directly on top of these units; they also have aquifer properties. The porosity of the conglomerates ranges from 10 to15%. Here, recharge from rain is very important which falls10 km east of Spa area and spreading out on thousands of square kilometres of high porosity Miocene volcanic rocks. The sediments around the water resource are composed of calcite, aragonite and around % 8-10 SiO_2.

Cap Lithology: Upper Cretaceous aged Kesenözü formation rocks composed of marl, clay and clayey limestone overlying the Karageris formation. The thickness of formation reaches 500 m and this makes form the cap rocks of the geothermal system. The formation comprises three units;
Lower Unit: gravel- sandstone. Grey greenish and dark Layering is not always clear. Its thickness is 150-200 m at most**.** It is permeable
*Middle Unit***:** Marl and clay limestone, with thin sandstone layer in between. Marl is yellowish; limestone is grey and beige, Sandstone with grey and dark blue. It has fossils and is up to 700m thick. It is Impermeable. Middle and Upper units forms the cap rocks of the geothermal system.
Upper Unit: Marl is greenish and grey blue, with sandstones and clay limestone between. It has fossils. Its thickness is 600- 650m. It is Impermeable. After the deposition of the cap rocks, volcanism was widespread. An existing of cupola of lacolith may reach approximately 6-14 km deep may occur. Thermal water from this source may reach the surface.

3. Hydrogeochemical properties of water samples

Thermal water samples were collected from the springs and well in October 2000 and again in April 2001. Samples were collected in several seasons in order to assess the possible influence of precipitation on spring water types and flow paths. The chemical analyses were done in the Water Chemistry Laboratory of the Technical Research and Quality Controls Department of General Directorate of water Works of Turkey, in Ankara. Temperature and pH were measured both in the field and the laboratory and the results for pH showed differences of approximately one unit (pH lab >pH field).

Table 1: The chemical analyses of waters of Seben – Kesenozu thermal spring in the study area (mg/l)

Location name	Sample no	Date	T (ºC)	pH (ºC)	Ec (μmho/cm)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	Total Alkalinity	SiO_2	B	F	NH_4	TDS
Hokok sp	1	4.4.1970		8.12		45	6.5	445	33.2	30	140	1182	0	78	5.4	5.8	0.61	1440
		29.10.2000	78	8.8	1926	33	5.5	410	27.7	69.3	62.5	1037	850	75	5	3.2	0.2	1923
		15.4.2001		6.9	2210	68	22	282	28.7	47.9	121.6	1144	937.5	68.5	6.4	2.9	0.17	1414
Koko sp.	2	29.10.2000	60	6.8	1901	36	12	405	26.1	60.3	132.4	1013	830	71	4.6	3	0.33	1216
		15.4.2001		6.7	2140	68	22	373	27.1	56.8	120.5	1095	897.5	61.5	6	2.5	0.17	1369
Cold water	3	29.10.2000	15	7	937	100	33	68.4	4.8	14.2	297.6	256	210	13	0	0.4	0.02	600
		15.4.2001		6.8	1091	110	35	67.9	4.9	14.2	345	244	200	11.7	0	0.1	0.02	698
Camli Hamam sp.	4	29.10.2000	41	7.3	1818	20	9.7	420	26.8	62.1	106.5	1025	840	70.6	4.7	3.1	0.03	1163
		15.4.2001		6.7	2160	64	21	365	27.2	62.1	135	1098	900	71.5	6	2.7	0.12	1382
W-1 well	5	29.10.2000	60	6.4	1959	24	14	431	28.4	63.9	117.2	1071	925	70.5	4.4	3.1	0.8	1254
		15.4.2001		6.4	2260	75	23	373	29	65.7	112.4	1129	877.5	65.5	6.3	2.9	0.17	1446
Kubbeli Hamam sp.	6	29.10.2000	60	6.6	1917	24	15	415	27.5	63.9	76.7	1080	885	69.5	4.1	3.2	0.07	1227
		15.4.2001		6.4	2200	72	24	362	26.7	62.1	130	1077	882.5	64	6.2	2.9	0.13	1408

Table 2: Results of different geothermometers of waters of Seben-Kesenözü thermal spring

Geothermometer (°C)	Hokok sp.	Koko sp.	Camli Hamam sp.	W-1 well	Kubbeli Hamam sp.
T_{measured}	78	60	42	60	60
$T_{\text{Qz-nost.loss (Fournier,1973)}}$	117	112	119	115	114
$T_{\text{Qz.st.loss at 100C}}$ (Fournier,1973)	116	111	118	114	113
$T_{\text{chalcedony, no steam.loss(Fournier,1973)}}$	89	83	90	86	85
$T_{\text{chalcedony,-max. steam.loss (Fournier,1973)}}$	90	85	92	88	87

The total dissolved solids in thermal waters from the Seben- Kesenözü springs and well range from 1160 to 1920 mg/L. The most common ions are sodium (Na) and bicarbonate (HCO_3), as shown in table 1. Na is sourced from alteration of Na- plagioclase in the volcanic rocks in the area. Clay minerals also enhance exchange of Na with Ca. HCO_3 is a result of CO_2-rich water interaction with Limestone. The source of SO_4 may be from evaporates deposits. The waters are colourless and odourless but contain CO_2 gas. At the point of discharge a whitish deposit and iron oxide deposits are visible. The results show that the Seben thermal springs and the water from borehole W-1 are similar in origin (Fig 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, F, SiO_2 bearing (AIH, 1979). From Cl- SO4 – HCO3 Giggenbach diagram Seben thermal and mineralised waters and W-1 well are

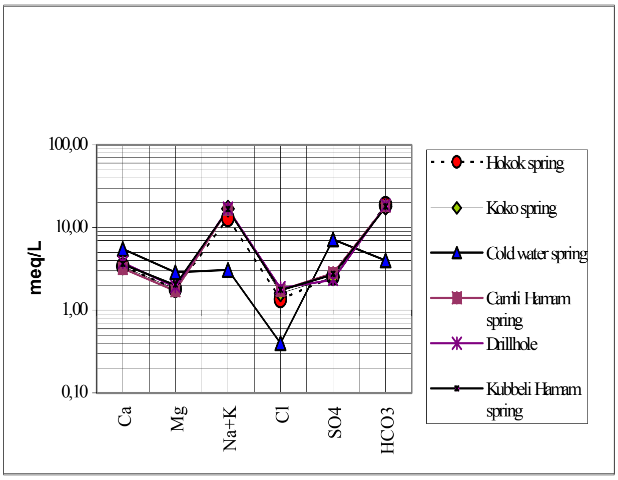

Figure 4: Schoeller diagram of Seben thermal waters

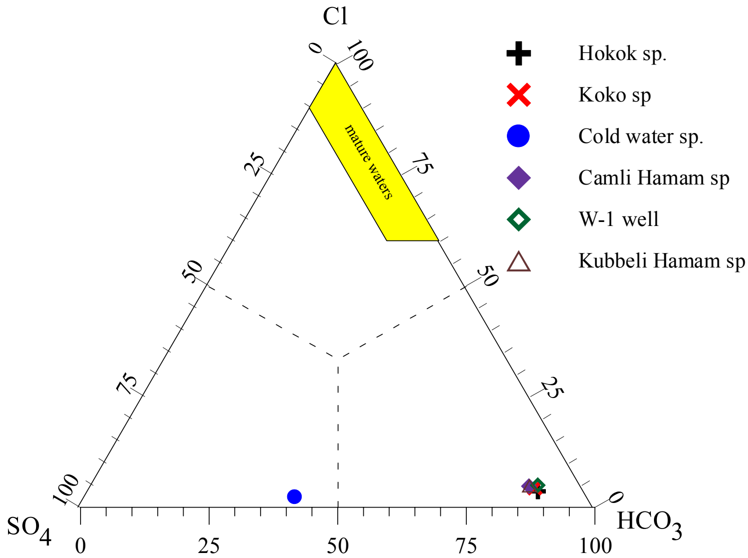

Figure 5: Plot of Cl-SO_4- HCO_3 diagram (Based Giggenbach, 1988)

HCO_3 rich water (Fig 5). They have almost neutral pH, low chloride and their major cation is sodium. This area on the diagram represents peripheral water in many types of volcanic fields. But, this is not the case in the study area. High chloride, but low sulphate and bicarbonate water is typical for high temperature systems associated with andestic and rhyolitic magmatism. However, the reservoir rocks in the Seben and the neighbouring geothermal areas are composed of limestone. The water emerging from such a reservoir is naturally rich with calcium and bicarbonate ions as in the studied water. Also these waters contains slightly high concentrations of sulphate, the source of which maybe oxidation of H_2S gas escaping from magma, and /or dissolution of minerals like gypsum and celestite ($SrSO_4$). It is concluded that the relative abundance of SO_4 and HCO_3 in the Seben-Kesenözü Turkish geothermal water in relation to Cl, is a reflection of the sedimentary rocks in these areas but not that their abundance reflects a peripheral or steam heated origin. Based on Figure 6 all the data points plot in the area of immature waters, therefore solute geothermometry is not likely to yield meaningful Na / K equilibration temperatures (Giggenbach, 1988) .

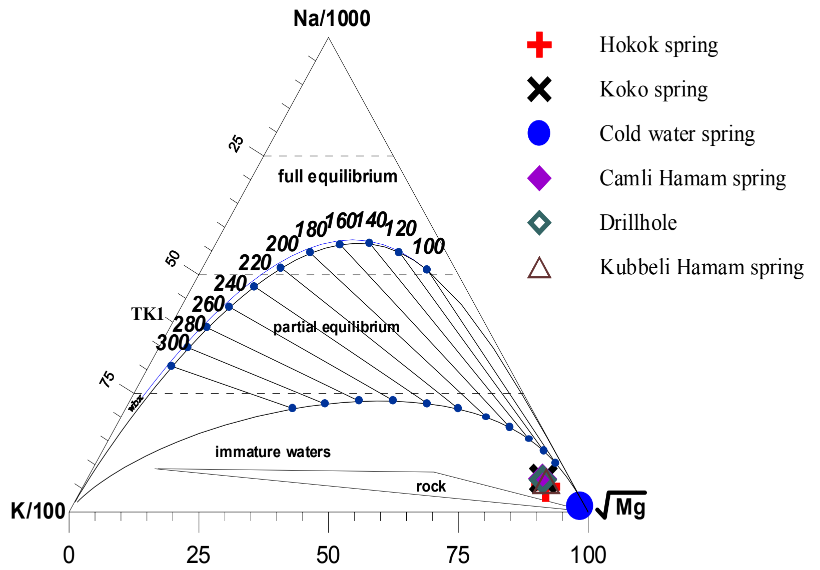

Figure 6: The Na – K-Mg equilibrium diagram (Based on Giggenbach, 1988)

The only option is to use silica geothermometer. Therefore quartz and chalcedony temperatures have been calculated (Table 2). Chalcedony geothermometer temperatures vary from 83 to 92°C. Quartz geothermometer temperatures vary from 111 to 119 °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 Seben is not higher than 100°C. So the chalcedony geothermometers are probably closer to the reservoir temperature than the quartz temperatures.

4. Mineral equilibrium

The saturation index (log Q / K) was calculated for minerals assumed to be relevant like calcite, anhydrite, chalcedony, quartz, amorph silica, fluorite and wollastonite for all four the thermal water samples and well using the WATCH aqueous speciation program in the temperature range 40-80°C (Arnorsson et al., 1982a, Bjarnason, 1994). The chalcedony temperature is used as a reference temperature when the speciation of the waters was calculated.

Thermal waters from well and springs of the area are undersaturated with respect to anhydrite, amorph silica, fluorite and wollastonite. They are oversaturated or nearly in equilibrium with respect to quartz, chalcedony and calcite. Scaling of carbonate minerals could be expected for all thermal waters. These results coincide with the field observations. For the study area, it is difficult to draw any definite conclusion about the most probable reservoir temperature. However, this temperature range is helpful to confirm the validity of the temperature calculated from other geothermometers.

The chalcedony equilibrium temperatures calculated by Watch gives a value of 82 - 90°C. This is the most accurate way of finding the chalcedony temperature, since the speciation is all accounted for. There is only a difference of a few degrees from the values of chalcedony geothermometer by using silica concentrations directly in the formula. However, it is still smiler.

5. Isotope Hydrology

The samples were collected from the field in October 2000 and April 2001, respectively. The relationship between $\delta^{18}O$ and δD values are plotted on Fig.7, which also shows the worldwide meteoric line ($\delta D = 8\delta^{18}O + 10$) of Craig (1961) and the Konya meteoric water line (KMWL) ($\delta D = 8\delta^{18}O + 16$) of Şentürk (1970). The δD values for thermal waters ranging -75.39%o to -89.76%o with an average δD =83.16%o. They are meteoric water origin, which has infiltrated to depth through fractures in the area of rock, and being heated during deep circulation. The spring waters are feed by rains that have the same isotope values during the rainy and drought periods (Fig 7). No oxygen shift is found showing that either the sub surface temperature of geothermal reservoir in the Seben field are low and the thermal waters belong to low- enthalpy geothermal resources or the water/rock ratio is quite high in the system. The thermal waters show a negative $\delta^{18}O$ shift from the local meteoric line. Interaction with CO_2 enriched in ^{16}O might explain the negative $\delta^{18}O$ shift. Mixing with colder water could explain such differences. The effect of different rock type and the higher elevation of the thermal springs (which lie between 700 – 1000m) could also have contributed to these differences. All the waters in the study area are recharged by large reservoirs and they have similar turnover times. According to the tritium values(0.65 – 1.55 TU) the entire thermal springs and well represents high altitude, long flow paths, deep circulation and mixing with cold water(Fig 8).

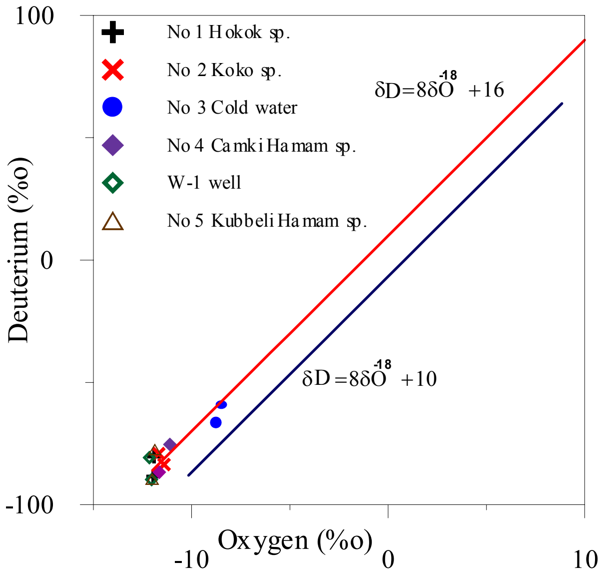

Figure 7: Plot of δ^{18} versus δD

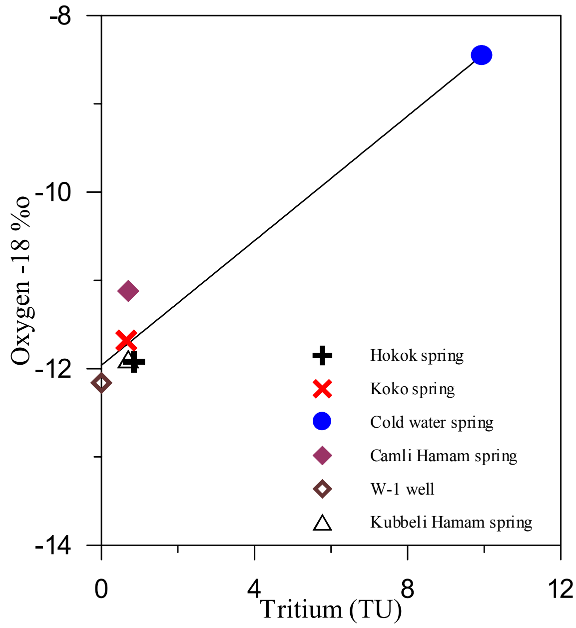

Figure 8: Plot of Oxygen-18 versus Tritium

6. Reservoir assessment

The Seben - Kesenözü geothermal field is liquid dominated reservoir and low temperature system, 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 and then the estimation of how much of this energy might be recoverable. The thermal energy in the subsurface is calculated as fellows:

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

Where E = Total energy in the rock and water (kJ); V= Reservoir volume (m^3); T_i = Average temperature of the springs (°C); T_o = Reference temperature (°C); C_r = Specific heat capacity of rock (kJ / kg °C); C_w = Specific capacity of water (kJ / kg °C); ρ_r = Density of reservoir rocks (kg/ m^3); ρ_w = Density of water (kg/ m^3); ϕ = Porosity. For the Seben geothermal field the following assumptions were made: A=385.10^6 m^2, V= 115.10^9 m^3, Ti = 60°C, T_o=15°C, ρ_r = 2700 kg/m^3 (Goodmans, 1989), $\rho_{w\ (60°C)}$ =983.18, C_r =1000 J /kg°C, ϕ =6%.Using the above parameters in equation, the total heat energy which can be used by space -heating is 1.443E 17 J. Using stored heat and recovery method we assume a recovery factor of 0.25 and life time for exploration 25 years, the power potential estimated for the Seben geothermal field of 46 MW_t .This should be sufficient power to heat more than 800.000m^2 of living space, or about 10.000 average- sized apartments (assuming 80 m^2 for each apartment).

7. Evaluation of Seben spring waters from standpoint of thermal energy and healing potential

Seben's thermal waters analysed belong to a low temperature hydrothermal system. From the Romans' time up to present, the Seben spa has been used extensively for curing some illnesses like inhaling difficulties, women's diseases, arthritis rheumatism, etc. It offers its services with 4 pools. It has accommodation with special bathtub rooms for guests. However, is little developed. The Seben thermal springs are the most important thermal features in Bolu province. City of Bolu is a winter sports Centre. In addition to this, it has the potential for mountain tourism. Thus to support increasing tourism, more thermal water must be secured and this depends on the drilling of the two boreholes and using the water for Bolu City's heating. Hence 2 deep wells must be drilled. Based on a field study two location are suggested (Fig 1). The location of these wells could be determined according to data obtained from 8-10 thermal gradient wells of narrow diameter to 125-150 m. The first well location must be 25m north of the Camli Hamam spring. This well is located approximately in the middle of Hokok and Camli hamam springs. The second well location must be 50 m south of Camli Hamam spring in the south. The hot fluid gathered from the 54 km south of Bolu, from Seben – Kesenözü thermal springs, can be carried with minimum heat loss to Bolu. The boreholes here must reach the Upper Jura-lower Cretaceous limestone.

8. Conclusion

The Seben geothermal field were interpreted using different hydrogeochemical diagrams and geotermometers. The fractured limestone and conglomerate in the Kesenözü formation is member comprise the features of an aquifer. Thermal waters of the Seben region emanates from a strike slip fault with the sense of north-northwest, along the Hamamboğazı Creek. According to the various geothermometer techniques the temperature of the geothermal system was found to range from 82 to 119 ^{0}C. The isotopic value proves that the origin of the thermal fluid is meteoric. They are $NaHCO_3$ waters. Thermal waters of well and springs are oversaturated with respect to quartz, chalcedony and calcite .Scaling problem is expected during the production. Two well sites are proposed for opening of new boreholes to increase the water production in Seben and then be used for heating Bolu City. According to the results of the reservoir assessment, the usable total energy potential of the Seben field is about 1.443E 17 J. Its estimated power potential is 46 MW_t. This should be sufficient to heat more than 800,000m^2 of living space, or about 10,000 average- sized apartments (assuming 80 m^2 for each apartment). It is optimistic that the Bolu City project will be economic. The hydrogeological setting of the area has to be further investigated and recharge and flow of the geothermal system better defined. Additional work is required to determine the geothermal potential of the area in terms of possible direct applications of the thermal energy that could be extracted from the system. Production from the area would open it up with new roads. Increased tourism could be expected and some services in the area expanded.

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