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Hydrogeological Survey of Savcili Büyükoba Geothermal Field (Kaman, Kirsehir-Central Anatolia, Turkey)

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ABSTRACT

Savcili Büyükoba geothermal field is located in the east of Kaman district of Kirsehir province of Central Anatolia. This study is focused on the evaluation of geological, hydrogeological, hydrogeochemical, geophysical and drilling studies. Previous investigations and exploration wells for producing of thermal waters were carried out by MTA and Iller Bankasi General Directorates in this field. Subsequently, Hacettepe University performed geological and hydrogeological studies. Within the framework of the study, geology, hydrogeology, water chemistry and isotope hydrology studies have been carried out and geology, hydrogeology maps and cross sections were prepared. Geological and hydrogeological properties of the reservoir rock were determined; the relationship of thermal waters and the cold waters, the recharge area and a conceptual hydrothermal model of the studied area was proposed. The geological units consist of Kirsehir Metamorphics, Baranadag Granitoids, Barakli Formation, Mesedag Formation, Kizilirmak Formation and Alluvium. The basement complex is formed of Paleozoic aged Kirsehir Metamorphics (marbles, schist, quartzite). Granitoids are Mesozoic (Late Cretaceous-Paleocene?) aged. Eocene units (Barakli and Mesedag Formations) marl, claystone, limestone, alternating clayey limestone, sandstone and marl Miocene-Pliocene?(Kizilirmak Formation) deposits overlie unconformably on this basement. Quaternary aged alluvium lie at the top. Savcili Büyükoba geothermal area is controlled by mainly NE-SW, N-S and E-W faults. Thermal waters emerged along the intersection of the faults. In the research area, there are 5 hot water exploration (SB-1, SB-2, SB-3, SB-4, SB-5) wells. The first deep well (SB-1) was drilled by MTA General Directorate in 1986 and later SB-2, SB-3, SB-4 and SB-5 were drilled. They are shallow wells. The well depths varies between 37-550 meters in the research area. In the study area, there is a limited resistivity survey by MTA. The basement rocks are Paleozoic Kirsehir Metamorphics (marbles, quartzite) and Mesozoic (Late Cretaceous-Paleocene?) granodiorites are reservoir rocks. Eocene sediments constitute the caprock of the field. In the study area, Kirsehir Metamorphics and granodiorites are basement rocks which are partially permeable that they have secondary porosity with tectonic activity. Alluvium is important aquifer for cold water. Temperature of thermal waters and hot wells in the field changes between 30.01°C - 34.5°C and average total flow rates of springs are 4.5 l/s. According to ionic content, the hydrochemical facies of the thermal waters are NaCl. Thermal waters of the study area located along the Local Meteoric Water Line (LMWL) and this suggests that geothermal waters have a meteoric origin.The low tritium content of Savcili thermal waters show that the thermal aquifer of Savcili Büyükoba geothermal area is recharged by groundwater having relatively long residence time which represents a deep groundwater circulation system in the study area.

1. INTRODUCTION

The study area is located in Central Anatolia, about 150 km southwest of Ankara and 5 km north of Hirfanlı Dam (Figure1). Savcili Büyükoba thermal spring is in the west of Kirsehir and 18 km far from the Kaman. In this study the aim is to explain the hydrogeochemical properties of the studied area. For this purpose it is necessary to study the geological structure, origin of the geothermal waters, relationship among geothermal water, groundwater, reservoir rock, properties of the reservoir rock, the feeding (water supply) and circulation system. At the beginning, previous geological works made by several authors are rewiewed (Ketin 1955, 1966, Oktay 1981, Seymen 1982, Bayhan 1988, MTA 2005, 1991). Previous investigations are mainly concentrated on geological, geochemical, petrographical studies. In the study area, there is a limited and shallow geophysical resistivity survey performed by MTA (Mineral Research and Exploration General Directorate) (Onder 1986). Savcili Büyükoba thermal spring which has a flow rate of ≈ 4.5 l/s and temperature of 34.5 ºC is the main spring in study area. In the research area, there are 5 hot water exploration (SB-1, SB-2, SB-3, SB-4, SB-5) wells (Tekin and Tekin, 1986). The first deep well (SB-1) was drilled by MTA in 1986 and later SB-2, SB-3, SB-4 and SB-5 were drilled (MTA 2005). They are shallow wells and depths are changing between 37- 550 meters. The bottom of the well temperatures range are 21-34.5 ºC. The well depths varies between 37-550 meters in the research area. Among these shallow wells, only SB-2 well is productive. The well depth is 55 meter and temperature ranging from bottom to top 21-34.5 ºC. In this research, the diagram approach that is widely used for hydrogeochemical evaluations. Circulation time of underground water in the aquifer is determined by one of the natural isotopes, tritium (^{3}H). The origin of thermal waters, feeding and the circulation relationship is determined by Oxygen-18 (^{18}O) and deuterium (^{2}H).

2. GEOLOGY

There are five basic rock sequences exposed in the study area which are, from the bottom to top, Paleozoic Metamorphic rocks, Late Cretaceous-Paleocene (?) Granitoids, Eocene units, Miocene-Pliocene? sedimentary units and Quaternary deposits. Basement rock in the region is Paleozoic Metamorphics, also called Kirsehir Metamorphics which is mainly comprised from marble, schist, gneiss, amphibolite, quartzite. The Mesozoic units consist of Baranadag Granitoids and Cicekdagı formations. The granitoids comprised from granite, granodiorite, quartzmonzonite. The upper surface of granitoids is decomposed. This unit has joints and fractures in fresh surfaces. Fractures become narrower and the unit becomes more massive with increasing depth. The Eocene units unconformably overlie Mesozoic units. The Eocene units consist of Barakli and Mesedag formations. Barakli formation contains terrestrial conglomerate, sandstone and mudstone. Mesedag formation is conformably lying upon the Barakli formation, can be described as conglomerate, sandstone, mudstone interbedded limestone. Miocene-Pliocene (?) Kizilirmak Formation unconformably cover the Eocene sediments consists of terrestrial sediments (alternating conglomerate and sandstone). Quaternary alluvium unconformably overlie older formations which is the youngest unit in the study area and located along the Hamamozu stream in the middle of the area. Savcili Büyükoba geothermal area is controlled by mainly NE-SW, N-S and E-W faults. Savcili Büyükoba thermal springs emerged from fault zones along the Hamamozu stream.

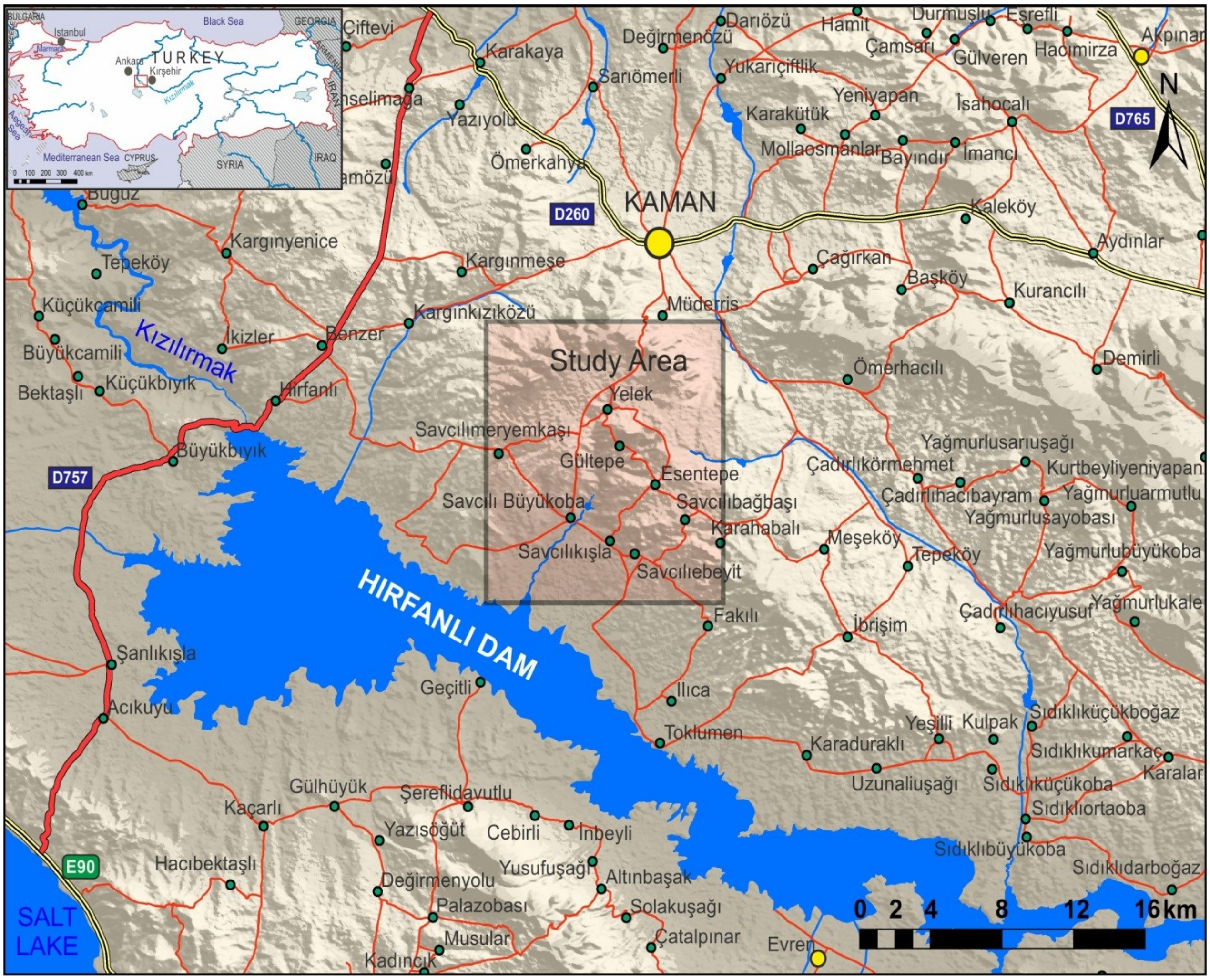

Figure 1: Location map of study area

3. HYDROGEOLOGY

The study area is located in Central Anatolia which is characterized by arid climate. Mean annual precipitation and temperature 361 mm and 11.4°C. Average altitude changes between 1000-1200 meters. Paleozoic metamorphic basement, magmatic (intrusive) and ultramafic rocks which crop out mainly at the highlands of the area have low permeability. However, active tectonics caused the development of along the joint and fracture systems and enhancement of secondary permeability to the magmatic rocks such as granitoids in the study area. The upper surface of granitoids are decomposed and this unit has joints and fractures in fresh surfaces. Fractures become narrower and the unit becomes more massive with increasing depth. Alluvium in the Hamamozu stream part of the Savcili geothermal area forms main hot (warm) and cold groundwater aquifers. Kizilirmak formation sediments, consisting of conglomerate, sandstone, claystone and marl are mostly impermeable, but loosely cemented sandstone and conglomerate layers are permeable and have local importance as an aquifer. Claystone, marl, mudstone, limestone with clay levels of Eocene sediments mostly impermeable units and are the caprock of the area, but fracture zones of the units, local limestones and base conglomerate may be permeable. In terms of hydrogeology, the Late Cretaceous-Paleocene (?) aged granitoids form the reservoir rocks, and the alternating claystone, marl and sand- clay Cenozoic (Eocene and Miocene-Pliocene?) deposits form the cap rock.

Thermal waters in the area:

In the study area, Savcili Büyükoba thermal waters and hot water exploration wells' water samples have been collected.

Savcili Büyükoba thermal waters: Savcili Büyükoba thermal waters discharge from the intersection point of right strike slip fault NE- SW direction and normal fault NW-SE direction. It is quantified that the highest temperature is 34.5 °C. Total flow rate of thermal spring and well (SB-2) are 4.5 l/s and pH: 9.58.

Hotwater exploration wells: In the study area there are 5 hot water wells (SB-1, SB-2, SB-3, SB-4, SB5) drilled by MTA. Depth of these wells varries from 37-550 meters. But, it is determined that only SB-2 well had been discharging hot water. Flow rates of other wells (SB-1, SB-3, SB-4, SB-5) are very low.

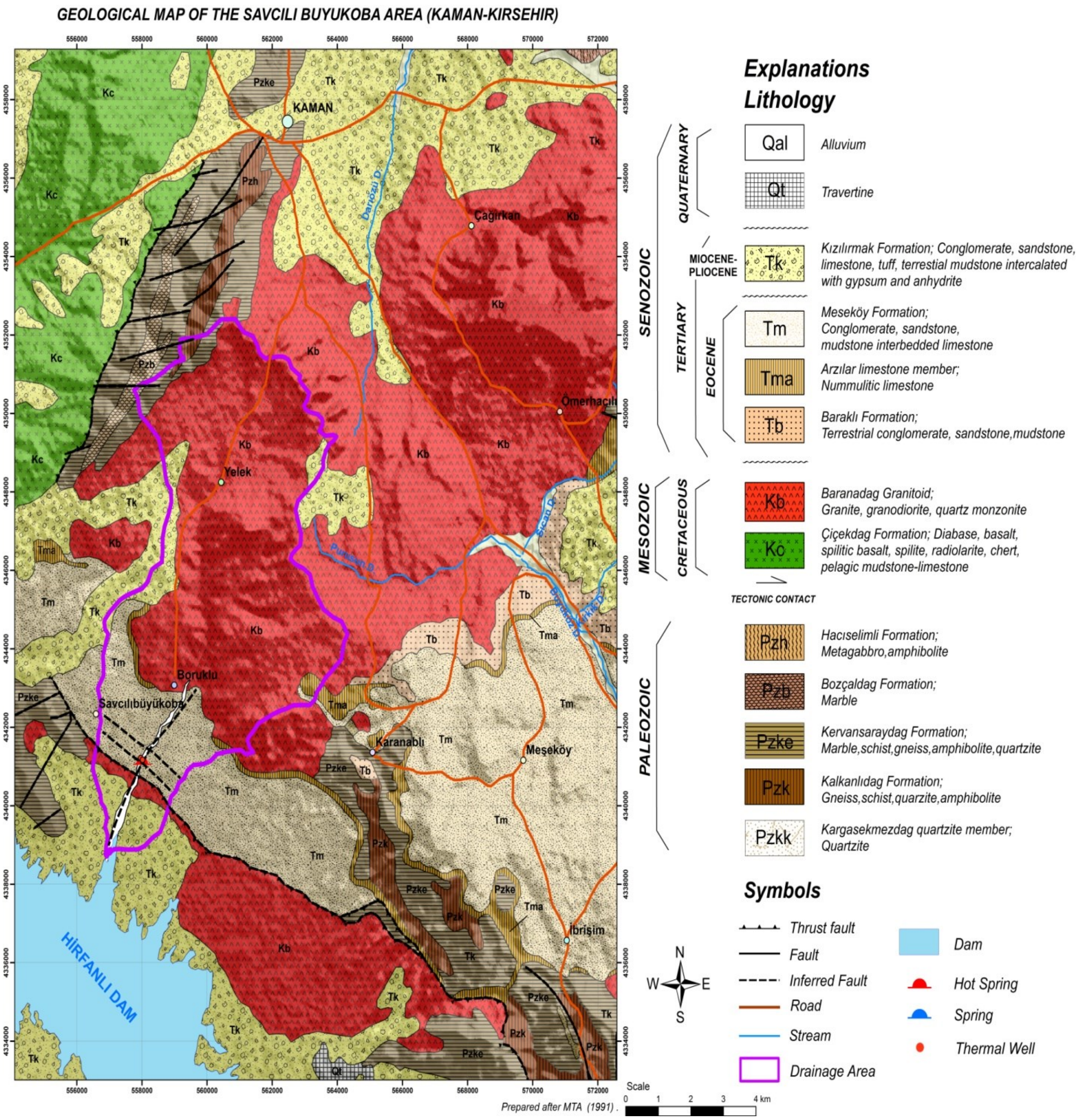

Figure 2: Geological map of research area.

4. HYDROGEOCHEMISTRY

Within the aim of this study, springs around Savcili Büyükoba town, KSBO-1, KSBO-2, KSBO-3, KSBO-4, KSBO-5, KSBO-6, KSBO-7, KSBO-8, KSBO-9a, KSBO-9b, KSBO-10 and KSBO-11 springs were sampled to trace the hydrochemical behaviour of Savcili Büyükoba spring group during a water year**.** Chemical data for hot and cold waters have been obtained from the samples of springs and well waters. The field studies started in 2014 and in-situ EC, pH, temperature and TDS measurements were carried out. In the research area, temperatures of hot and cold springs vary between 7.2-34.5 ^{o}C. Electrical Conductivities (EC) vary between 179-1449 µs/cm.

The major ion analyses results of the springs were evaluated by using Schoeller and Piper diagrams. According to Schoeller diagram, the dominant cation order of ion contents in thermal and mineralized water from the research area is Na+K>Ca>Mg and anion order is Cl> HCO_3+CO_3>SO_4 (Table 1). The triangular (Piper) diagram has been used widely to classify water type by major cation and anion concentrations to trace hydrogeochemical process of water caused by interaction between water with aquifer materials. The relationship between thermal water springs, lithology and hydrogeochemical evolution processes induced through circulation systems are explained using Piper diagrams. Triangular (Piper) diagram of thermal springs, wells and cold water samples is given in (Figure 3). This diagram indicates that the origin of waters that are grouped together in the same part of the diagram is the same origin. As it is explained above for ion arrangements, hot waters are classified as NaCl type waters and these springs are fed by an aquifer of meteoric origin. Cold water springs in the area are generally classified as having $CaHCO_3$ type water. These springs are fed by an aquifer of carbonate origin. A semi-logarithmic Schoeller diagram is formed to determine the similarities and differences between hot and cold water springs (Figure 4). According to this diagram, in the study area, hot water springs and wells have the same chemical character and show big differences from the cold water springs with Ca and HCO_3

contents. Savcili Büyükoba thermal spring and well's waters have similar compositions indicating that these waters originate from the same lithological units.

Sample ID	Type	Date	T (ºC)	pH	EC (25°C)	Na^{+} (ppm)	K^{+} (ppm)	Ca^{+2} (ppm)	Mg^{+2} (ppm)	Cl^{-} (ppm)
KSBO-1	Cold Spring	14.03.2014	8.23	6.73	179	6,86	0.59	26.77	4.82	1.69
KSBO-2	Cold Spring	14.03.2014	10.38	7.07	274	1.59	0.46	65.05	1.96	1.52
KSBO-3	Cold Spring	14.03.2014	7.49	7.11	267	2.39	1.47	58.31	3.32	1.72
KSBO-4	Cold Spring	14.03.2014	11.96	6.91	454	8.15	0.45	89.07	7.86	2.14
KSBO-5	Değirmenözü Stream	14.03.2014	7.25	7.31	576	19.59	0.51	105.15	15.50	13.69
KSBO-6	Hirfanlı Dam	14.03.2014	8.04	7.71	1449	172.06	6.36	126.19	35.70	256.50
KSBO-7	Cold Spring	15.03.2014	13.61	7.00	796	34.55	12.36	125.22	21.18	31.81
KSBO-8	Savcili Pond	15.03.2014	8.52	7.37	409	18.96	1.32	63.02	15.65	11.66
KSBO-9a	Thermal Water	15.03.2014	30.01	9.49	513	111.27	1.24	9.30	0.32	88.93
KSBO-9b	Thermal Water	15.03.2014	33.58	9.58	527	111.88	1.38	9.15	0.14	88.27
KSBO-10	Cold Spring	15.03.2014	12.62	6.96	535	28.99	0.59	84.65	13.27	13.20
KSBO-11	Rain+snow	15.03.2014	16.52	7.59	289	6.06	2.41	58.76	3.49	3.63
SB-2*	Well	1986	34.5	8.5	500	106	1.0	4.4	0.2	78
SB-3*	Well	1986	25	8.5	478,3	104	1.1	13.0	0.4	75
SB-4*	Well	1986	19	8.82	483,7	114	1.3	5.6	0.5	81
SB-5*	Well	1986	20	8.83	478,3	106	1.0	4.4	0.2	78

Sample ID	Type	Date	SO_4^{-2} (ppm)	HCO^{3-} (ppm)	CO_3^{-2} (ppm)	F (ppm)	Li (ppm)	SiO_2 (ppm)	B (ppm)
KSBO-1	Cold Spring	14.03.2014	9.63	94.82	0.00	0.18	0.01	24.043	0.000
KSBO-2	Cold Spring	14.03.2014	5.93	195.96	0.00	0.09	0.00	8.5475	0.000
KSBO-3	Cold Spring	14.03.2014	6.87	177.00	0.00	0.10	0.00	14.411	0.000
KSBO-4	Cold Spring	14.03.2014	22.88	246.54	0.00	0.41	0.01	20.85	0.021
KSBO-5	Değirmenözü Stream	14.03.2014	47.20	328.27	0.00	0.38	0.02	18.494	0.003
KSBO-6	Hirfanlı Dam	14.03.2014	388.68	151.71	0.00	0.30	0.04	9.9609	0.120
KSBO-7	Cold Spring	15.03.2014	70.55	379.29	0.00	0.36	0.02	28.597	0.046
KSBO-8	Savcili Pond	15.03.2014	31.85	233.89	0.00	0.37	0.02	11.165	0.027
KSBO-9a	Thermal Water	15.03.2014	49.35	12.64	37.31	7.76	0.06	47.443	0.110
KSBO-9b	Thermal Water	15.03.2014	48.96	31.61	37.31	7.70	0.07	47.076	0.109
KSBO-10	Cold Spring	15.03.2014	66.95	227.57	0.00	0.54	0.01	14.254	0.057
KSBO-11	Rain+snow	15.03.2014	14.89	177.00	0.00	0.16	0.00	10.223	0.009
SB-2*	Well	1986	45	61	12			51	*
SB-3*	Well	1986	59	73	12			47	*
SB-4*	Well	1986	63	61	12			50	*
SB-5*	Well	1986	45	61	12			51	*

*** MTA analyses from the wells discharged water (Tekin and Tekin,1986).**

Table 1: Chemical analysis results of water samples taken from research area (March, 2014).

Geothermal water has heat transfer with contact rocks until coming to surface and they have lower temperatures than the reservoir temperature due to various rates of mixing with cold underground waters. Thus, reservoir rock temperatures of thermal and mineralized waters calculated by a geothermometer method. Reservoir temperature of Savcili Büyükoba geothermal area estimated by geothermometric equations proposed several authors. Cation geothermometers indicated very wide temperature ranges and position of thermal waters in Na-K-Mg diagram proposed by Giggenbach, 1988, indicates that the chemical equilibrium has been partially provided (Figure 5). For that reason, silica geothermometers are assumed to be more applicable and give more reliable results than cation geothermometers. Reservoir temperature were calculated as 69-71 °C based on chalcedony geothermometers of for Savcili Büyükoba thermal spring (Fournier, 1977 and Arnórsson et al, 1983).

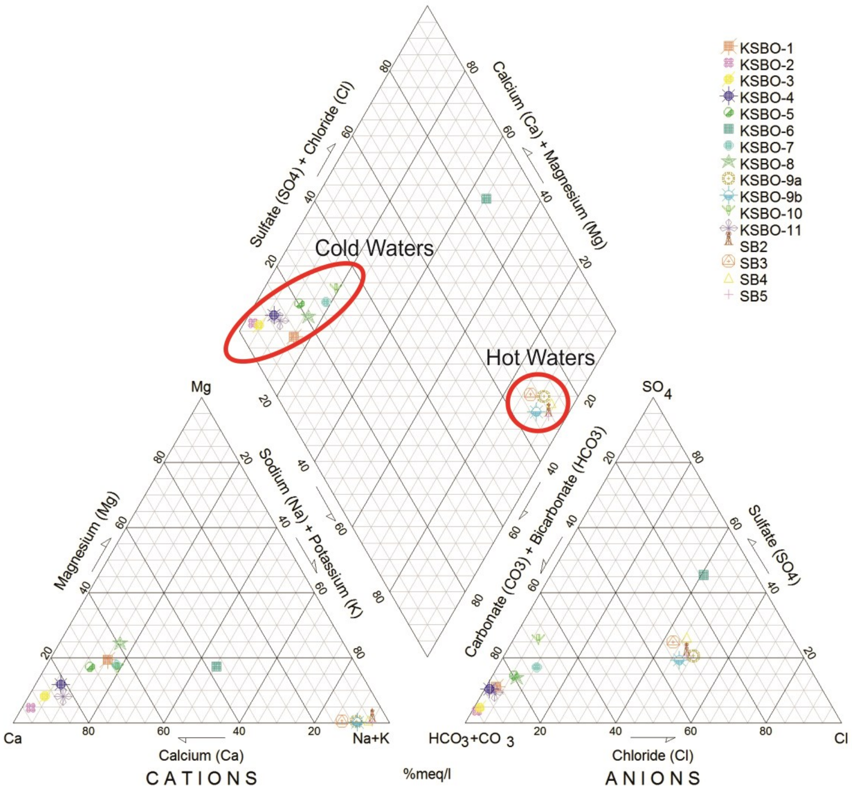

Figure 3: Piper (1944) triangular diagram which identifies types of the waters in the Savcili Büyükoba region.

5. EVALUATION OF ISOTOPE ANALYSIS

The recharge area of geothermal fluids, the origin of thermal and mineral waters and water-rock interaction processes are explained by examining isotope analysis of thermal and mineralized water springs and cold water springs (Craig, H.: 1961, Clark, I., Fritz, 1997). In this research, ^3H analyses and stable isotopes ($^{18}0$ and ^2H) were performed in H.U. Geological (Hydrogeological) Engineering Department Tritium Laboratory and UKAM Stable Isotopes Laboratory. Stable isotopic ^{18}O and ^2H analyses were carried out to determine the origin of thermal waters and the recharge area of geothermal reservoirs. The equation of the relation between ^{18}O and ^2H in precipitation is linear and this relation for Central Anatolia Region as follow $\delta^2H = 8*^{18}O + 10$ (Onhon et al., 1979). Accordingly, this relation is used to define the local meteoric water line for Kirsehir province. Sample points are located along this local meteoric water line. This shows that geothermal system is fed by meteoric precipitation. Thermal waters have no apparent ^{18}O shift from LMWL and cold springs and thermal waters are located along the same meteoric water line. This indicates that a relationship can be established between cold and thermal waters which can be used to estimate approximate elevation of Savcili Büyükoba thermal water's recharge area. Average recharge area altitudes calculated from ^{18}O – altitude relationship reveal that Savcili Büyükoba thermal waters are recharged mainly from the highland parts of the Baranadag Mountain with peak elevation of 1677 meters which is located NE part of the study area. In the research area, samples are taken from hot and cold water springs. ^3H contents of Savcili Büyükoba thermal waters vary between 0.18-0.28 TU. (Table 2). This suggests that Savcili Büyükoba thermal waters have low tritium contents. Low tritium content of thermal waters shows that the springs are fed by underground waters having a relatively long term passing time and have a deep circulation groundwater flow system in the study area.

6. CONCEPTUAL HYDROTHERMAL MODEL

Natural mixture of groundwaters and geothermal waters exist in the Savcili Büyükoba geothermal field. The geothermal waters mostly have meteoric origin and are fed by normal groundwaters. The groundwater gets mineralized by dissolving the elements from the rocks due to rock-water interaction and its heated mainly by the geothermal gradient. The heated and mineralized waters moved to the surface by means of these faults (Figure 9).

According to the conceptual hydrothermal model of the Savcili Büyükoba geothermal field, meteoric waters (rain and snow) infiltrate underground, warm up with the geothermal gradient and flow up along fracture and fault zones. Existence of young tectonics in the region shows that the thermal gradient of the field is higher than in other regions. Geothermal waters, rising up through the faults, are stored in the faulted, fructured and altered zones of the granodiorites, Eocene basal conglomerates, local limetones and spread in the alluvium at the top.

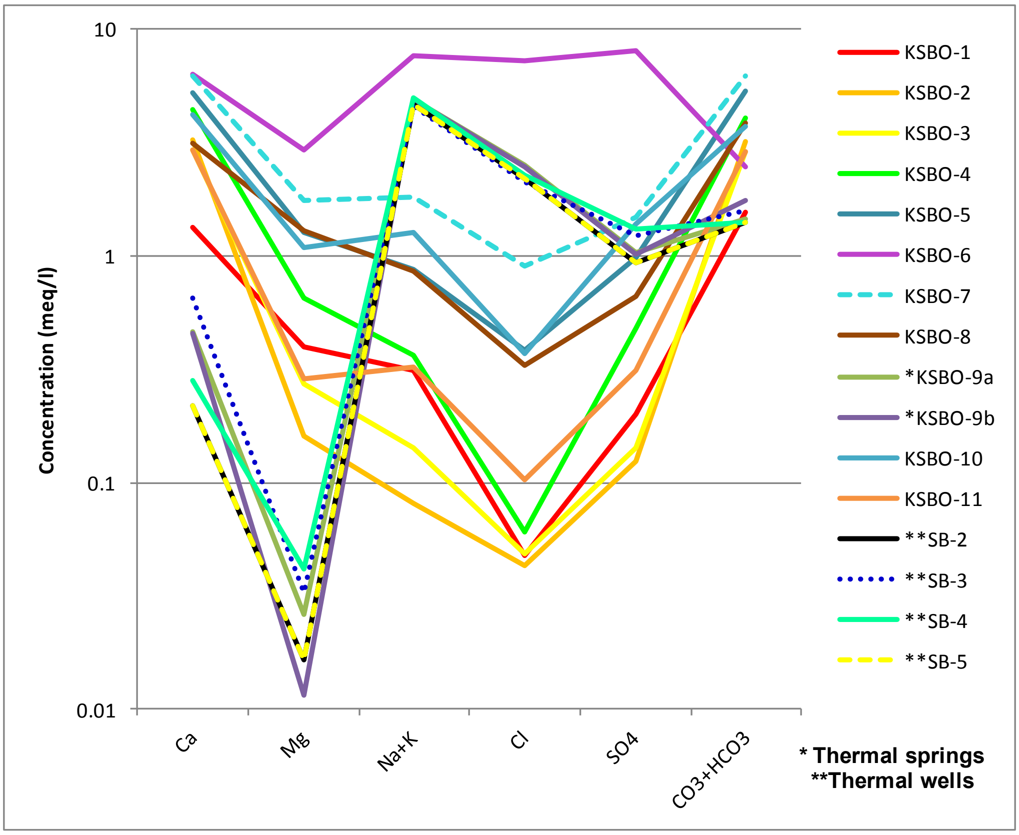

Figure 4: Schoeller (1977) diagram evaluation of water samples which are collected from the studied area.

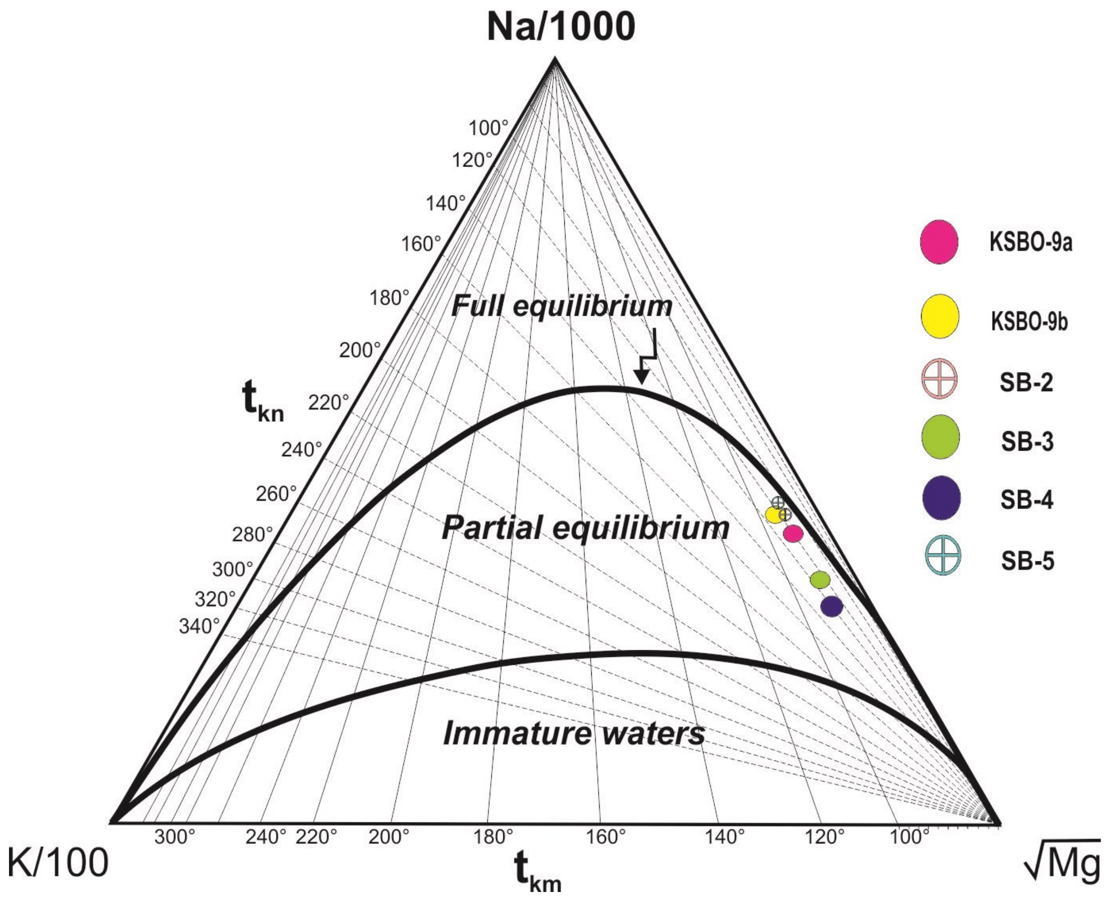

Figure 5: Triangular diagram of Na-K-Mg based on mineral rock equilibrium. Savcili Büyükoba thermal springs and hot water wells position in the Giggenbach diagram (Giggenbach 1988).

Sample ID	Type	Date	T (°C)	EC (25°C) (µS/cm)	$\delta^{18}O$ (0/00)	^{2}H (0/00)	^{3}H (TU)
KSBO-1	Cold Spring	14.03.2014	8.23	179	-10.7	-72.38	5.57
KSBO-2	ColdSpring	14.03.2014	10.38	274	-11.16	-74.91	7.16
KSBO-3	Cold Spring	14.03.2014	7.49	267	-11.33	-76.58	6.87
KSBO-4	Cold Spring	14.03.2014	11.96	454	-10.11	-72.09	6.52
KSBO-5	Degirmenözü Stream	14.03.2014	7.25	576	-10.02	-71.4	6.17
KSBO-6	Hirfanlı Dam	14.03.2014	8.04	1449	-7.84	-58.76	6.28
KSBO-7	Cold Spring	15.03.2014	13.61	796	-9.61	-69.66	7.27
KSBO-8	Savcili Pond	15.03.2014	8.52	409	-7.13	-55.77	7.04
*KSBO-9a	Thermal Water	15.03.2014	30.01	513	-12.07	-88.37	0.28
*KSBO-9b	Thermal Water	15.03.2014	33.58	527	-12.27	-88.4	0.18
KSBO-10	Cold Spring	15.03.2014	12.62	535	-7.74	-58.38	8.49
KSBO-11	Rain+Snow	15.03.2014	16.52	289	-7.79	-56.71	7.90

***Thermal waters in the study area.**

Table 2: Isotope analysis results of water samples taken from research area (March, 2014).

7. CONCLUSIONS AND RECOMMENDATION

The result of the geology, hydrogeology, hydrology, geochemical and isotope analysis performed for determining hydrogeochemical properties of the Savcili Büyükoba geothermal field are listed below:

- In this study, aquifer lithologies and reservoir temperatures were estimated via hydrogeological and hydrochemical techniques. Hard and brittle lithologies have acquired secondary permeability through active tectonism thus main aquifers are comprised from joints and fracture zones.

- In the research area thermal waters are grouped in the same part. They are classified as NaCl type of water and this shows that springs are fed by an aquifer in which granitoids are the main lithology. In the study area, thermal waters are the same origin according to the Schoeller diagram and they show differences from cold water springs with high Ca and HCO_3 contents. Thermal and mineralized waters taken from hot wells (SB-2, SB-3, SB-4, SB-5) have the same ionic composition with thermal waters in the study area.

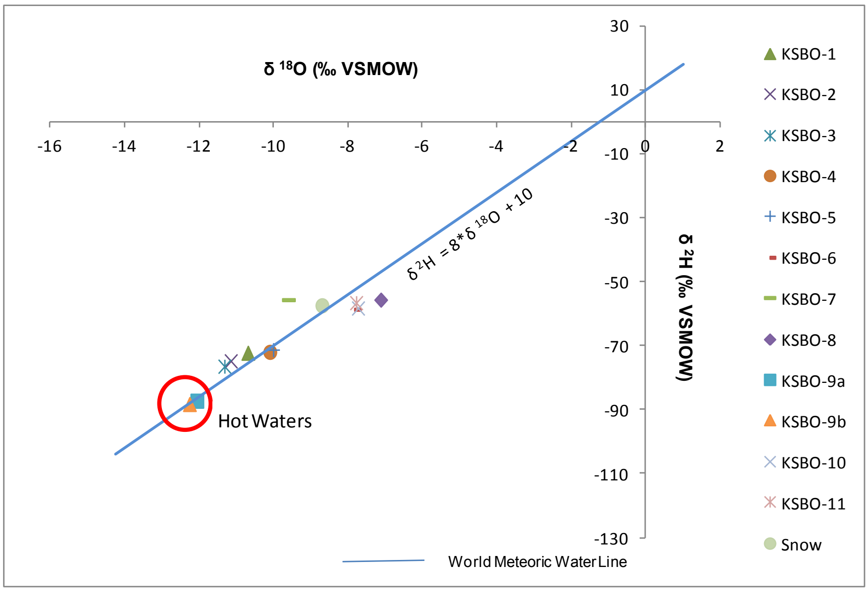

Figure 7: δ^2H vs δ^{18}O diagram of the thermal andcold waters of the Savcili Büyükoba geothermal field.

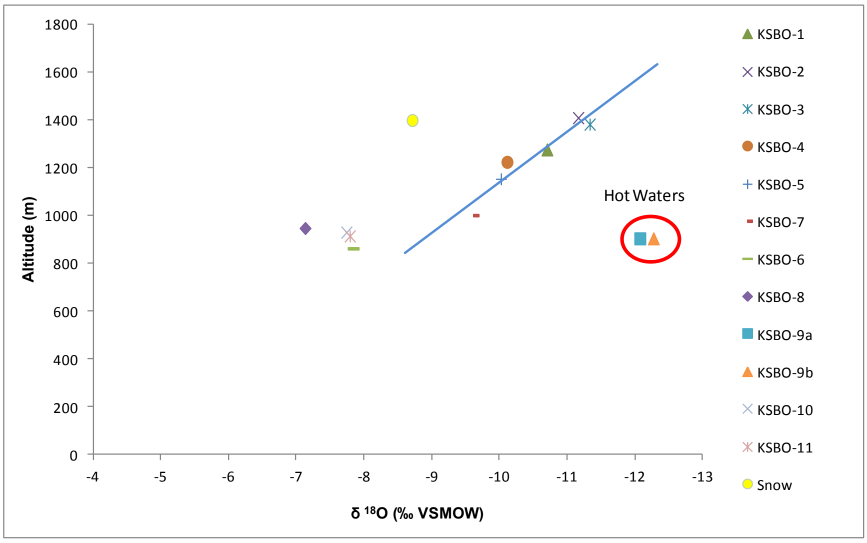

Figure 8. A relationship between δ^{18}O and altitude of the thermal and cold water springs of the Savcili Büyükoba geothermal field.

- The estimated reservoir temperature of the Savcili Büyükoba geothermal area is about 69-71 °C according to geothermometer calculations. Low tritium content of thermal waters shows that the springs are fed by underground waters having a relatively long term passing time.

- According to the conceptual hydrothermal model developed by geological, hydrogeological and geochemical data obtained in the research area, thermal waters in Savcili Büyükoba area are formed by precipitation filtered through a faulted and fractured zone, then meteoric origin waters heated by the geothermal gradient and returned to the surface through permeable rock. Existing fault zones and young volcanic activities around Central Anatolia shows that the geothermal gradient is high in this region.

- The Savcili Büyükoba geothermal field is suitable for development. New exploration studies (mainly geophysical survey as gravity, magnetic, deep resistivity, MT and seismic) and exploration/production wells should be drilled and the necessary tests should be made for increasing the thermal water production.

- The geothermal water could be utilized more efficiently and widespread for spas and other integrated geothermal applications (thermal tourism, balneology etc.) to provide clean, safety, healthy and sustainable use of thermal waters in the region.

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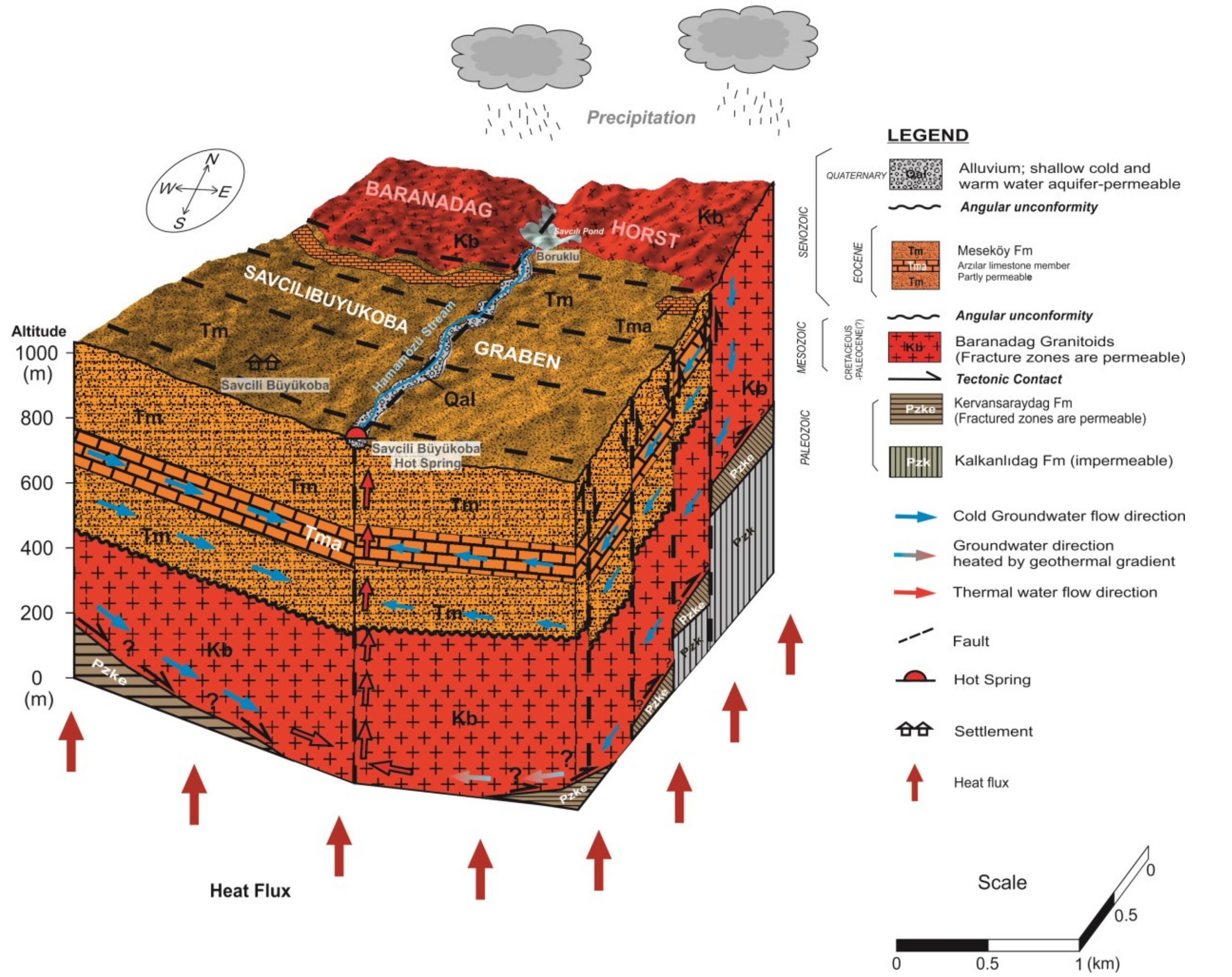

Figure 9. Schematic conceptual model of Savcili Büyükoba Geothermal Field

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