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Geothermal Evaluation of the Bayramhacılı and Tekgöz-Çiftgöz area, Central Anatolia, Turkey by a New Conceptual Reservoir Model

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ABSTRACT

More than 250 low to medium enthalpy geothermal fields in Turkey cover an estimated potential of 60,000 MW. The Central Anatolian Volcanic Province hosts twelve geothermal areas. One of these fields is located near to Kayseri City, SE of Ankara.

In order to evaluate the geothermal area with a focus on hydrochemical characteristics hot and cold springs, as well as wells and rivers were sampled during dry and wet season. Water samples were analysed for major and minor elements. Rock analyses disclose the detailed petrography and alteration patterns, revealing the hydrothermal influence. Discontinuity measurements on fractures were conducted, as faults and fractures are assumed to be the controlling factor on geothermal groundwater flow.

The main outcome of this study is a conceptual reservoir model of the adjacent areas Bayramhacılı and Tekgöz-Çiftgöz. A considerable part of the water infiltrates downward through the fractured marbles, other discontinuities and the permeable and semi-permeable areas. But also the rise of fluids is controlled by fractures. Both the Tekgöz-Çiftgöz and Bayramhacılı springs are generally aligned at NE-SW and NW-SE trending faults. Residence times of Bayramhacılı springs are 45-50 years based on tritium.

During circulation, the infiltrated waters are hydrochemically enriched and heated by both the geothermal gradient and the magmatism feeding Erciyes volcano. The groundwater circulating in marbles is also partially in contact with volcano sedimentary cover units and with the syenites. As a result, they are enriched with Na by ion exchange. A Na/K vs. K/Rb plot shows that thermal waters are in equilibrium with the basement metamorphic rock units. The elevated concentration of Ca and HCO_3, and decrease of pH in springs, is mainly related to the high CO_2 content that results from interactions with carbonate rocks.

In conclusion, the formation and development of the mineral composition of Bayramhacılı, Tekgöz and Çiftgöz geothermal springs are influenced primarily by the geological setting, effectiveness of the active faults and high geothermal gradient based on magmatic activity. The Bayramhacılı springs are recharged by a regional hydrogeological system that is deep and wide, while the Tekgöz and Çiftgöz springs are recharged by a local shallower system. In the previous studies, only marbles were taken into consideration during geothermal reservoir exploration in the area but obviously syenites and basalts play a major role as well. This conceptual geothermal reservoir model is a new contribution to studies in the Central Anatolian area and general geothermal studies in Turkey as it explains general processes of subsurface fluid flow and water-rock interaction in geothermal systems.

1. INTRODUCTION

Bayramhacılı geothermal field is located in Kayseri city, Central Anatolia, Turkey. Besides Western Anatolia, Central Anatolia is one of the most important geothermal regions of Turkey. Active tectonism and young volcanism in this area are the main reasons for the formation of thermal springs in Central Anatolia. There are three different active magmatic regions: Galatian Volcanic Province (Northwestern part of Central Anatolia), Central Anatolian Magmatic Complex (Southeastern part of Central Anatolia) and Capadoccian Volcanic Province (Southern part of Central Anatolian Magmatic Complex). The study area is located in the Capadoccian Volcanic Province, which hosts the youngest volcanism in Central Anatolia. Studied springs are located at the western edge of the Quaternary Erciyes Volcano. They are one of the hottest discharges in the Capadoccian Volcanic Province. Furthermore, the study area is located at the conjunction of the NE-SW striking Kızılırmak fault zone and NW-SE striking Salanda fault zone. These structural features affect the study area and provide pathways for the circulation of geothermal fluids. Such properties in the region motivate one to investigate with a focus on geothermal energy potential and utilization possibilities for thermal waters. The most important step of geothermal exploration is to obtain formation characteristics of the geothermal system, which includes recharge areas, circulation of fluids, heat source location, and upflow and discharge patterns. With this aim, geological, structural, hydrogeological, petrographic and hydrogeochemical investigations have been combined in order to construct a conceptual model for the Bayramhacılı geothermal field.

2. GEOLOGICAL AND HYDROGEOLOGICAL SETTING

Bayramhacılı geothermal field, which includes Bayramhacılı, Tekgöz and Çiftgöz spring areas, is located on the Central Anatolian plate, which is surrounded by the North Anatolian Fault Zone, the East Anatolian Fault Zone and the Tuz Gölü Fault Zone. The study area is heavily affected by sub-faults related to these main fault zones (Figure 1).

The study area is composed of metamorphic and magmatic units in the basement (Figure 2). The Paleozoic Kırşehir metamorphic rocks are widespread and represented in the study area by marbles as the oldest lithology. Syenitoid type intrusions cut these metamorphic basement rocks.

Figure 1: Location map of study area.

300 different joint measurements have been done on the Paleozoic marbles to investigate the effect of tectonic movements. As seen in Figure-3 NW-SE directed compressional and NE-SW directed extensional regimes are effective in the study area. Fractures in the basement rocks allow circulation of thermal waters through fractured zones.

Basement rocks are overlain by Upper Cretaceous-Quaternary sedimentary and volcanic rocks. The oldest cover unit Göynük Formation (Upper Cretaceous-Lower Paleocene) is composed of conglomerate, sandstone, siltstone, and mudstone. The Göynük Formation is assumed to be semi-permeable. The first phase of volcanism in the study occurred in Miocene forming agglomerate tuff, basalt and tyrachyandesite. Basalts hosting fractured zones have permeable character, while tuffs are impermeable. The second phase of volcanism, which occurred during Plio-Quaternary, is represented in the study area by thick and impermeable ignimbrites and basalts. Also the younger basalts are permeable due to fracture zones. The Quaternary period is represented by alluvial sediments, which are loosely cemented and highly permeable.

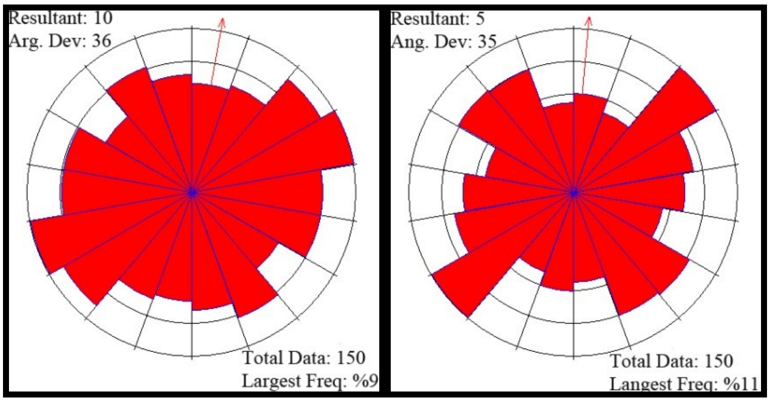


Figure 2: Discontinuity measurements from two different location on Paleozoic marbles.

3. GEOCHEMICAL INVESTIGATIONS

3.1 Water Chemistry

In order to understand the hydrogeochemical characteristics, 9 thermal water and 9 fresh water samples have been taken for detailed chemical analyses and their physico-chemical parameters are measured in-situ (Table-1). Physico-chemical measurements indicate that Bayramhacılı thermal waters are the hottest (up to 46.5 ^{o}C) and most mineralized (1830 µS/cm) waters in the study area, while Çiftgöz waters have lower values (33.5 ^{o}C and 588 µS/cm).

Detailed hydrochemical analyses of water samples (Table-2) have been conducted to obtain the origin of thermal springs and the circulation characteristics of the water. In the Schoeller diagram (Figure 4) three different hydrochemical pattern can be observed: Bayramhacılı thermal waters (Ca-HCO_3-Cl type waters and relatively high salinity), cold waters (Ca-Mg-HCO_3-SO_4 type waters and moderate salinity) and Çiftgöz-Tekgöz thermal waters (Ca-HCO_3 type waters and relatively low salinity).

In order to estimate the water rock interaction, elemental ratios have been plotted for both rock and water samples. They indicate that K/Rb and Mg/Ca ratios of thermal waters are compatible with syenites and basalts (Figure 5). Na/K ratios of waters are incompatible with host rocks and reveal a Na source most probably in schists of the methamorphic basement, which is assumed to be the impermeable bottom of the carbonate reservoir.

Table 2: Results of physico-chemcal measurements of water samples

		Physico-Chemical Parameters		
Sampling Season	Sample ID	T (°C)	pH	EC (µS/cm)
Rainy Season	BMS	21.5	6.12	1810
	BKK-1	41.2	6.18	1618
	BKK-2	39.2	6.24	1649
	TGK-1	39.8	7.05	596
	CGK-1	33.5	7.34	592
Dry Season	BKK-3	44.7	6.10	1527
	YKK	46.5	6.35	1830
	TGK-2	40.5	6.66	592
	CGK-2	34.5	7.17	588
	BSK-1		7.31	656
	BSK-2		7.54	810
	BSK-3		7.73	872
	BSK-4		7.03	1552
	BSK-5		7.47	681

*BMS: Bayramhacili Motel Well; BKK: Bayramhacılı Therma Spring; YKK: Yalı Thermal Spring; TGK: Tekgöz Thermal Spring; CGK: Çiftgöz Thermal Spring; BSK: Bayramhacılı Spring.

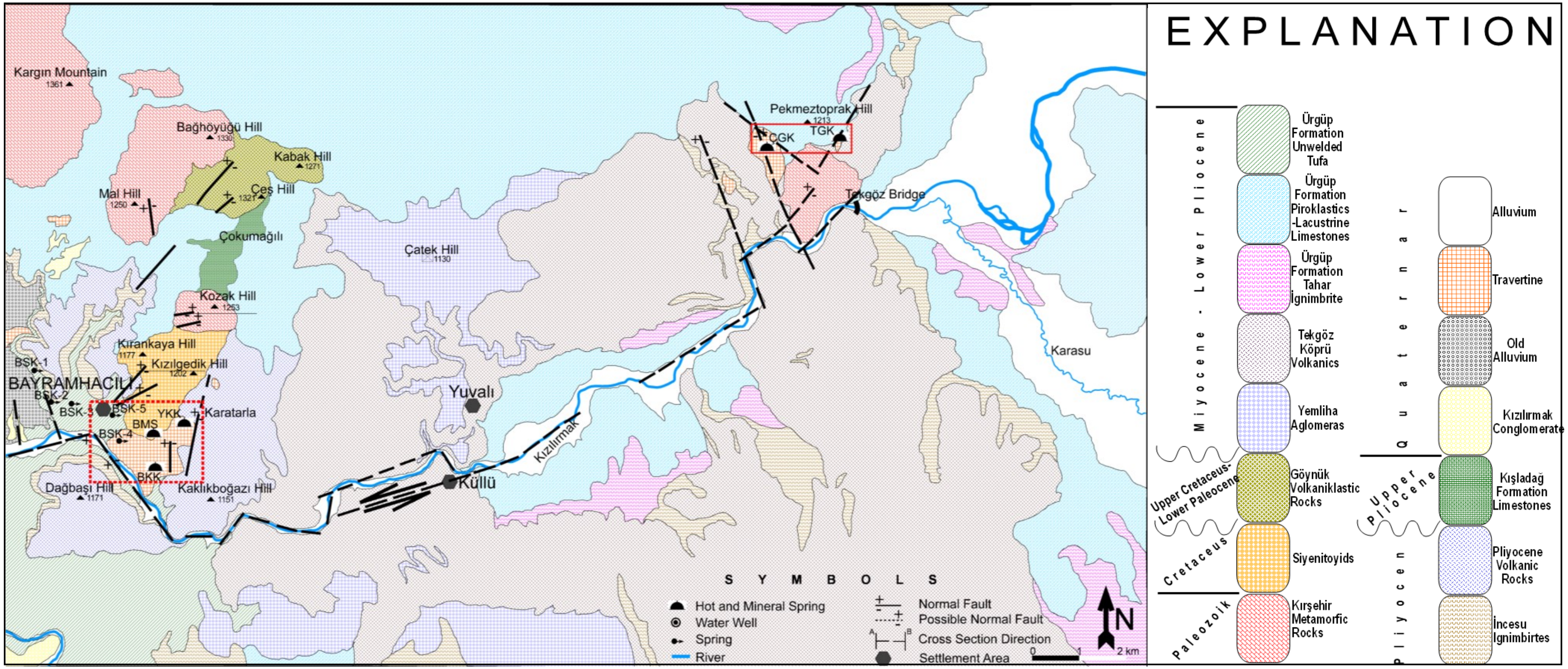


Figure 2: Geologcial map of study area.

Table 2: Results of hydrochemical analyses of water samples

	Main Ions (meq/l)							Trace Elements (mg/l)								
Sample ID	**Na^{+}**	**K^{+}**	**Ca^{+2}**	**Mg^{+2}**	**Cl^{-}**	**SO_4^{-2}**	**HCO_3^{-}**	**As**	**B**	**Ba**	**Li**	**Mn**	**P**	**Rb**	**Sr**	**Th**
BMS	10.85	1.98	10.85	1.98	0.62	1.25	15.2	0.02	0.73	0.26	0.16	0.25	0.08	0.05	3.25	0.04
BKK-1	4.96	0.40	13.26	2.47	5.49	2.63	13.2	nd	1.38	0.26	0.26	0.05	0.07	0.08	3.04	0.04
BKK-2	3.95	0.35	11.01	2.04	1.18	2.46	13.6	nd	0.09	0.1	0.26	0.1	0.09	0.08	3.22	0.04
BKK-3	4.41	0.35	12.49	2.17	4.51	1.90	13.2	0.07	1.83	0.24	0.27	0.15	0.10	nd	4.27	nd
BKK-4	5.06	0.42	13.95	2.46	6.06	2.50	13.6	nd	1.91	0.24	0.29	0.15	0.08	0.06	4.53	0.02
YKK	3.81	0.31	11.12	1.94	4.23	1.71	10.6	nd	1.86	0.25	0.28	0.22	0.1	0.04	4.34	nd
TGK-1	0.56	0.10	3.69	1.26	0.28	0.35	5.0	nd	0.02	0.07	0.04	nd	0.08	0.06	0.72	0.03
TGK-2	0.58	0.10	3.98	1.27	0.28	0.38	5.4	nd	0.1	0.34	nd	nd	nd	nd	0.95	0.02
CGK-1	0.63	0.09	3.53	1.34	0.25	0.44	5.0	nd	nd	nd	nd	nd	0.07	nd	0.07	nd
CGK-2	0.54	0.08	3.47	1.16	0.17	0.29	5.0	nd	0.10	0.35	0.04	nd	0.08	0.05	0.98	nd
BSK-1	1.32	0.21	4.02	1.94	0.68	2.08	4.9	0.08	0.28	0.04	0.05	nd	0.07	0.07	1.60	nd
BSK-2	1.38	0.17	4.83	3.08	1.04	3.65	5.0	nd	0.03	0.04	nd	nd	0.08	0.1	0.42	nd
BSK-3	1.34	0.15	4.62	2.97	1.04	3.44	6.4	nd	0.05	nd	nd	nd	0.08	0.10	0.09	nd
BSK-4	4.86	0.26	9.08	2.68	5.49	2.88	8.4	nd	0.21	0.05	nd	nd	0.08	0.07	0.31	0.01
BSK-5	1.34	0.19	3.46	1.54	0.70	1.35	4.4	0.05	0.42	0.13	0.05	nd	0.09	0.09	0.97	0.01

nd: not determined

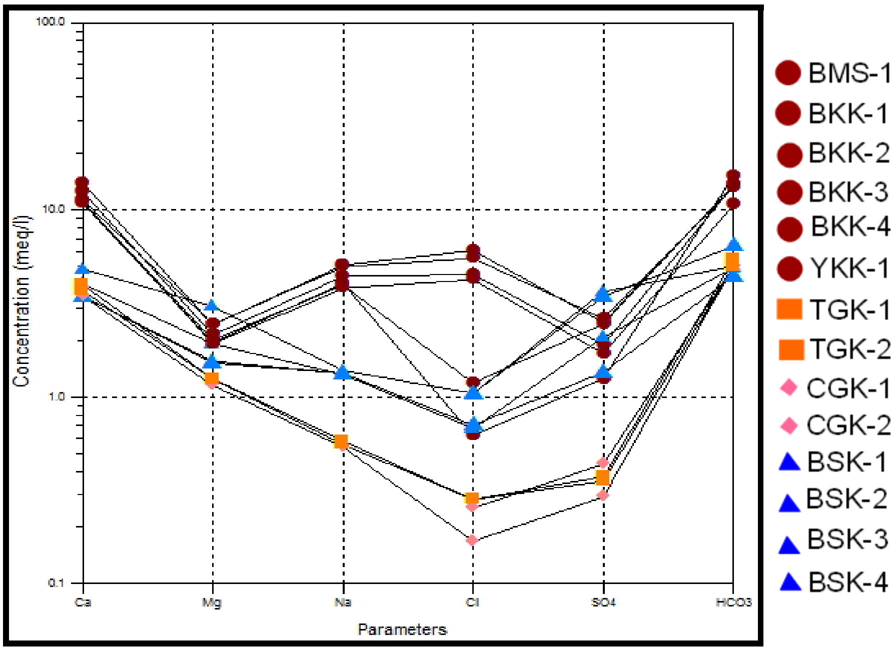


Figure 4: Schoeller plot of water samples

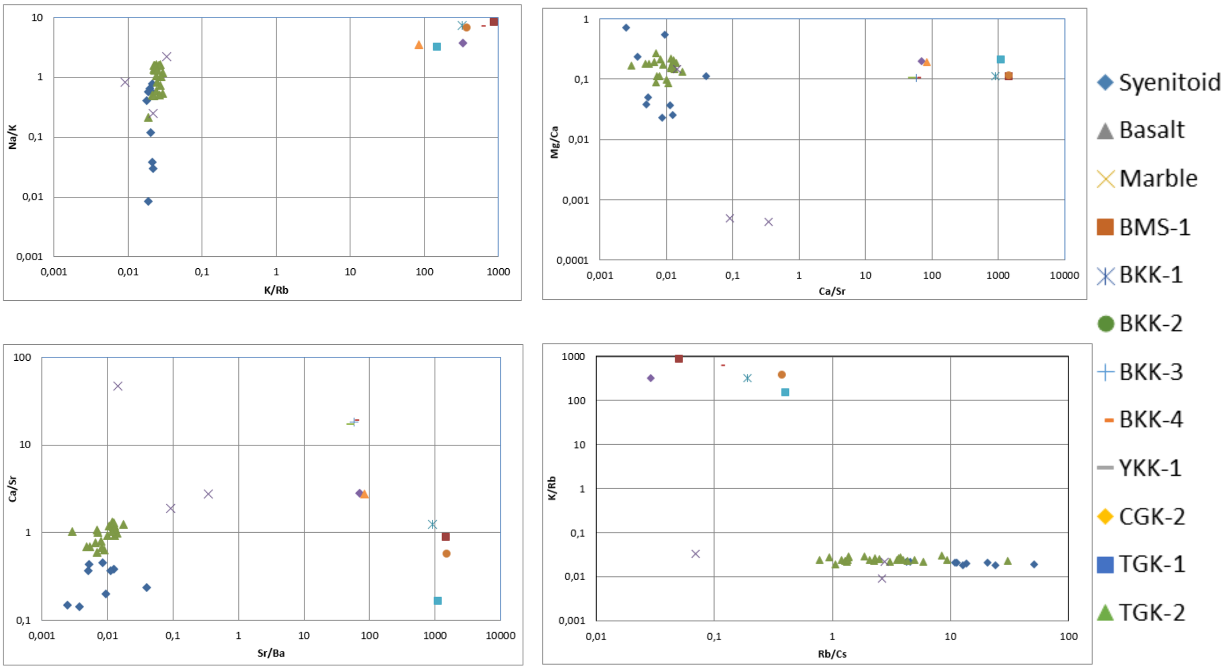


Figure 5: Scatter plot of element/element ratios of water and rock samples.

3.1.1 Geothermometry Applications

In order to determine the method to use for geothermometry calculations, a Giggenbach triangle plot was to indicate that all the thermal water samples are immature. Therefore it has only been possible to use silica geothermometers. According to results from 10 chalcedony and quartz geothermometry calculations (Fournier 1977; Arnorsson et al. 1983; Fournier and Potter 1983), Bayramhacılı springs had a range of 47-84 ^{o}C for reservoir temperature while Tekgöz and Çiftgöz thermal springs had 40-75 ^{o}C. These results are compatible with the results from geothermometry estimations made using saturation states (Figure-6).

3.2 Rock Chemistry

In order to estimate circulation characteristics and water-rock interaction, rock-geochemistry is used as an additional tool. LOI (lost on ignition) values are used as an indicator for alteration of rocks, as it represents the amount of volatile materials that have been enriched during hydrothermal alteration. Highly altered rocks will have more volatile materials, which have been enriched during thermal water-rock interaction and therefore will have relatively LOI values. With this aim, element values are plotted against LOI values. Na, K, P, Ca, Mn, Cu, Co, Rb, Y, Ce concentrations are depleted due to hydrothermal alteration while Al, Cr, Ga, Ge, As, U and Nd are enriched (Figure 7). However, a negative correlation on element-LOI plots was only observed for syenitoids (Figure 8). This geochemical evidence indicates that mature waters more likely circulate in basalts than in syenitoids.

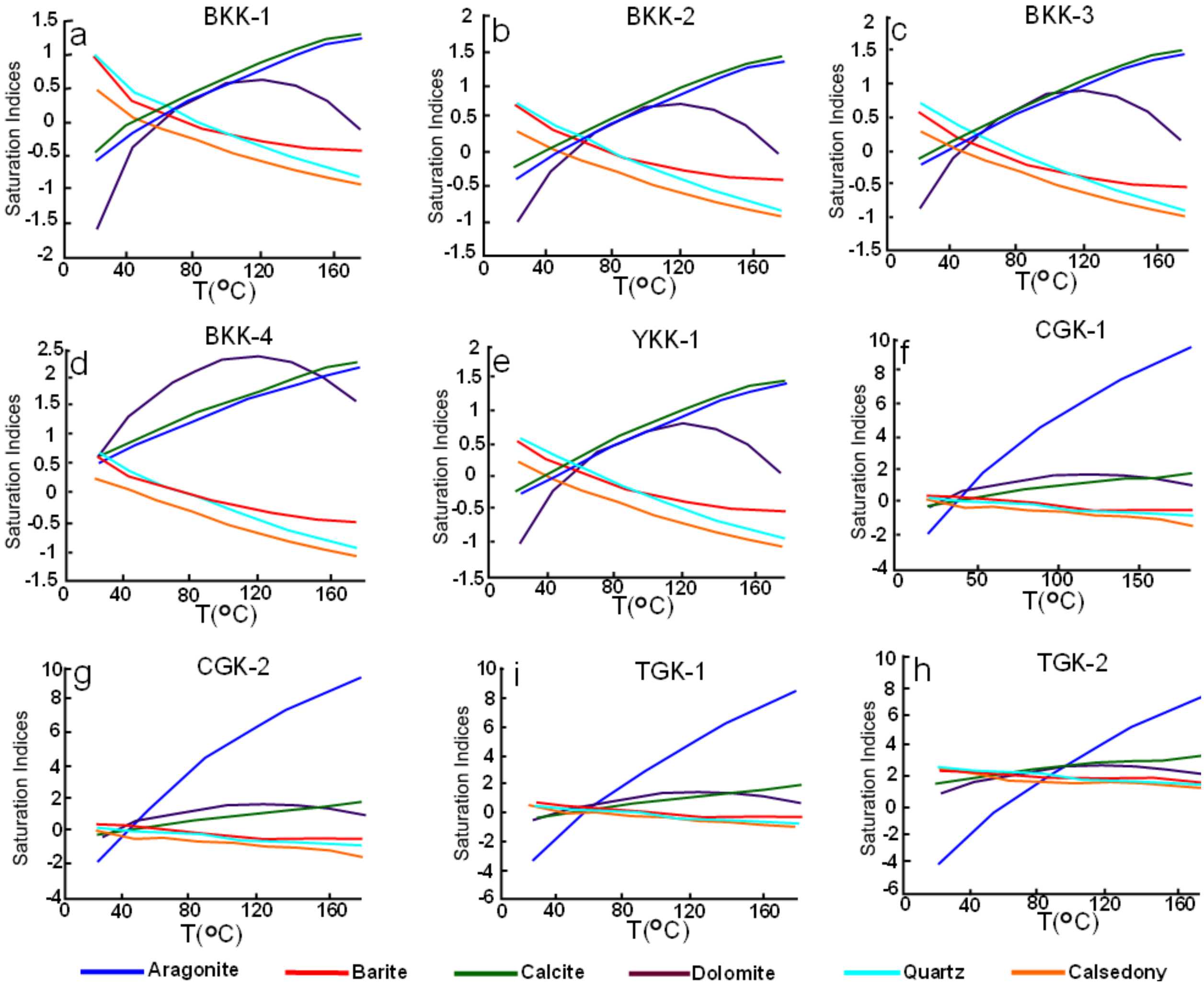


Figure 6: Geothermometry estimations that made by using saturation states.

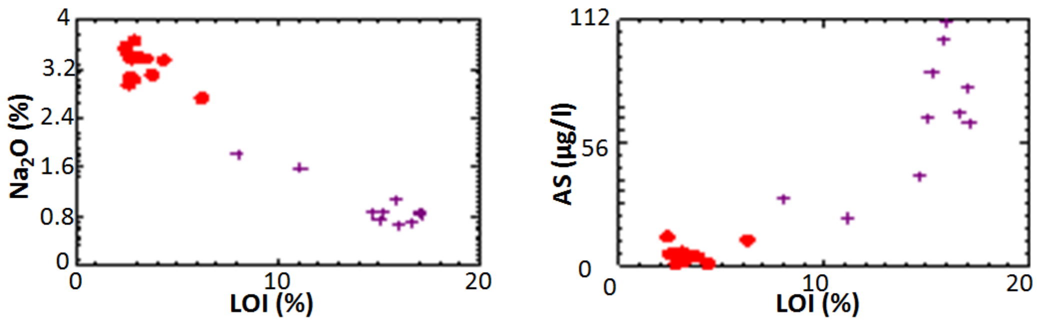


Figure 7: Selected Element-LOI plot of rock samples

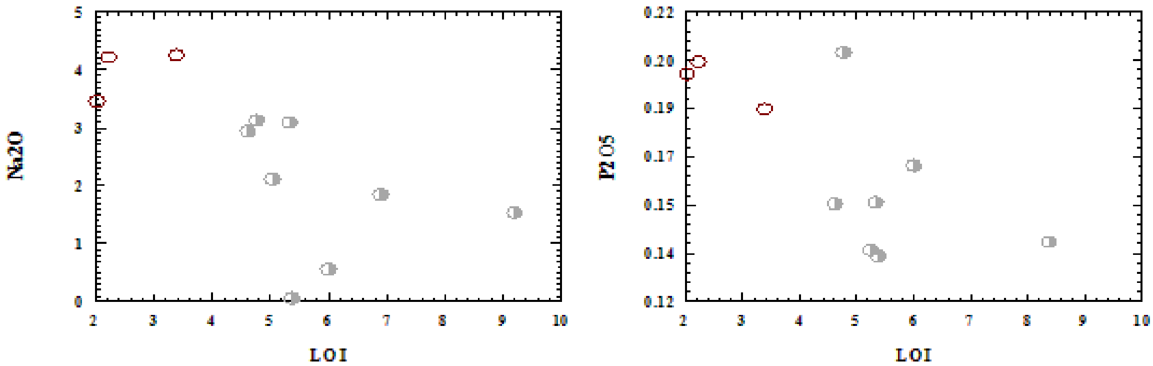


Figure 8: Scatter plot of Element oxide (%)-LOI (%) plot of syenitoid samples.

4. PETROGRAPHIC INVESTIGATIONS

In order to understand the circulation characteristics of thermal waters and water-rock interactions, petrographic investigations have been conducted on possible reservoir rocks. Many fractures and fissures have been detected in marbles often filled with Fe-Mn precipitations (Figure 9). Evidences of hydrothermal fluids have also been found in syenitoids in the form of carbonatization, sericite formation and silisification (Figure 10). Basaltic rocks at both spring sites show amygdaloidal texture that formed through vesicular pores, filled with carbonate that indicates the activity of $CaCO_3$ rich fluids (Figure 11A). Opaque mineral formation, clay formation and iddingsitization are some alterations to basalts (Figure 11B) which indicate the circulation of thermal waters more than 150 °C (Siegel 1979, Barnes 1979).

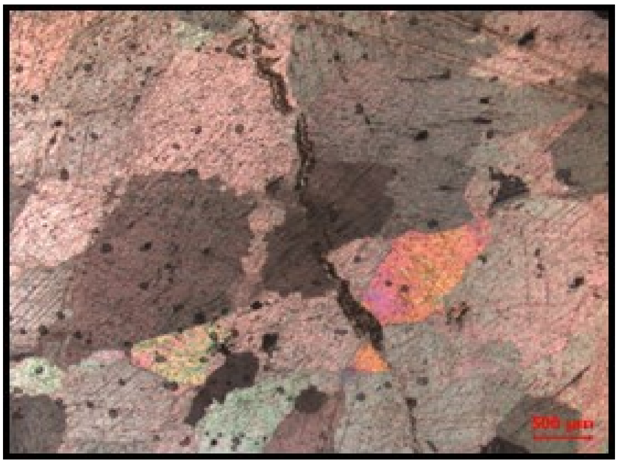


Figure 9: Microphotograph of marble sample under optical microscope.

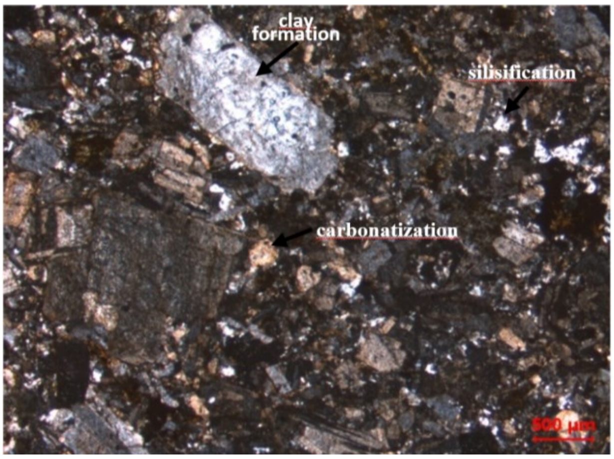
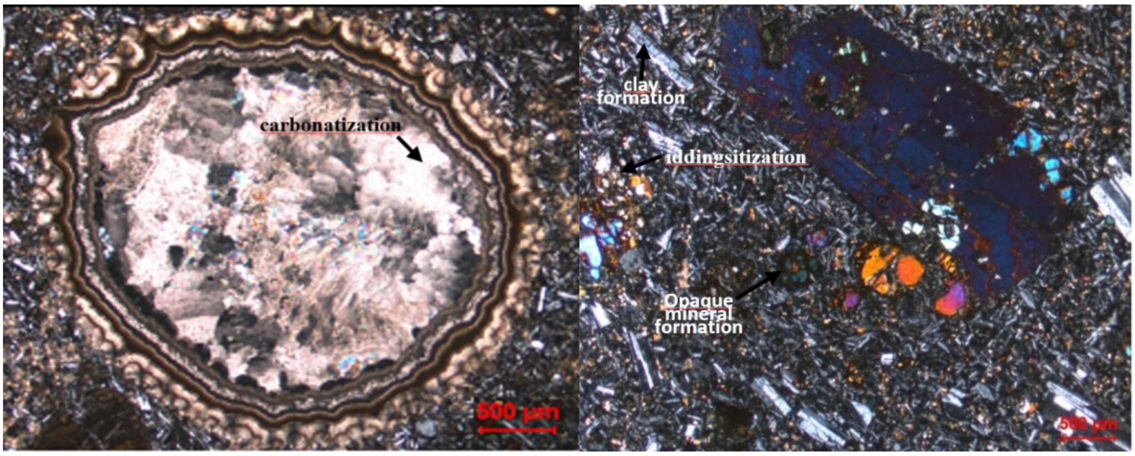


Figure 10: Microphotograph of syenite sample under optical microscope.



A B

Figure 11: Microphotograph of basalt samples under optical microscope.

5. CONCEPTUAL MODEL

As a result of geological, hydrogeological, hydrogeochemical investigations a conceptual model is developed for Bayramhacılı, Tekgöz and Çiftgöz thermal springs (Figure 12 and 13). According to this conceptual model the Palaeozoic marbles are the main reservoir of Ca-HCO_3 type thermal waters. This fractured aquifer is recharged by atmospheric water mainly through outcrops of this marbles at the surface. The young volcanism increases the local geothermal gradient, and heated water reaches the surface through fault zones. These fault zones are in syenitoids and basalts, which represent the secondary reservoir of thermal waters. During its circulation in syenitoids and basalts, the water is mainly enriched with Mg. It can be seen that Ca-HCO_3 type water, which heated up in marbles by young volcanism, precipitates $CaCO_3$ to the pores of basalts and leading to travertine deposits that can be seen at all spring sites. Physico-chemical and hydrochemical analyses indicate that Bayramhacılı, Tekgöz and Çiftgöz thermal springs cannot be classified as mature because of rapid circulation. Afsin et al. (2006), suggested 45-50 years of circulation time for Bayramhacılı springs according to their Tritium analyses (0-1,8 TU).

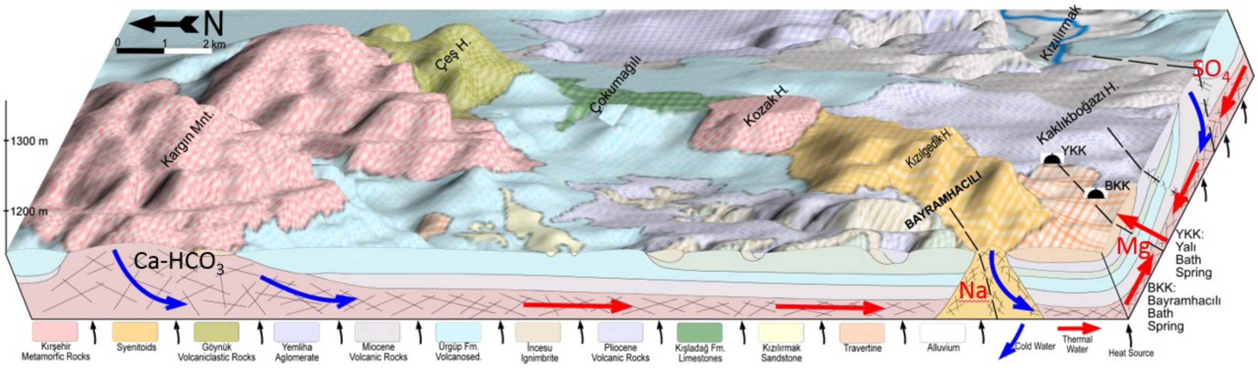


Figure 12: Block diagram for conceptual model of Bayramhacılı thermal springs.

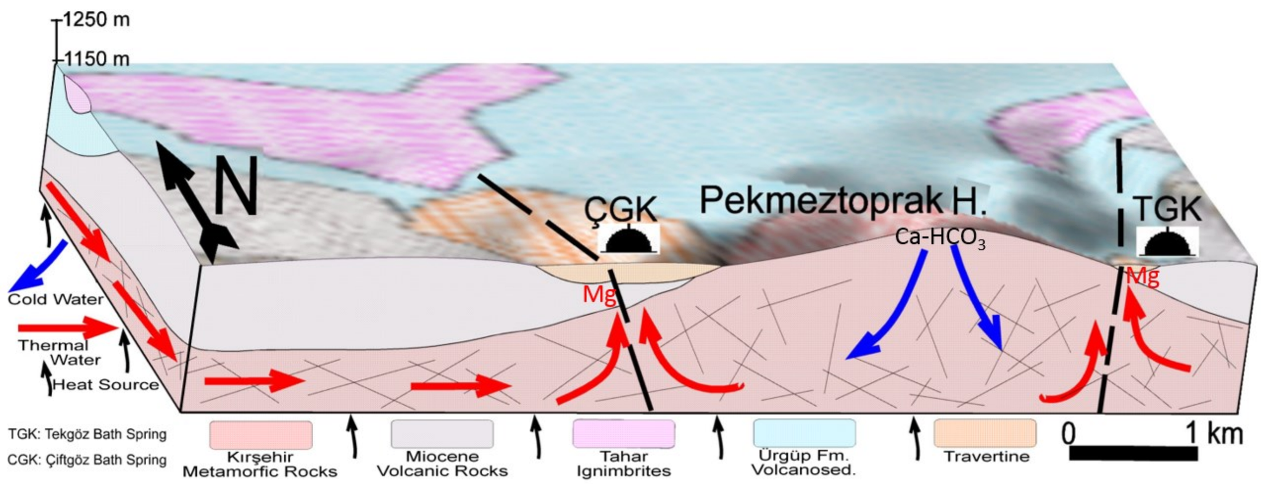


Figure 13: Block diagram for conceptual model of Tekgöz-Çiftgöz thermal springs

6. CONCLUSION

Detailed geological, hydrogeological, hydrogeochemical and petrographic investigations helped evaluate the occurrence of Bayramhacılı, Tekgöz and Çiftgöz (one of the hottest thermal springs in Central Anatolia). With this study it is possible to trace thermal waters during its circulation in primary (marbles) and secondary (syenitoids and basalts) reservoirs. According to the new conceptual model, atmospheric water infiltrates into the marbles through its fractures, is heated by the geothermal gradient increased by young volcanism and eventually reaches the surface through fault zones. Using hydrogeochemical and petrographic analyses of this study, it is possible to see fingerprints of the secondary reservoir composed of syenitoids and basalts in thermal waters. Furthermore, it is concluded from geological site investigations and discontinuity measurements that active tectonics creates both reservoir conditions and a flowpath to surface for thermal water.

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