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Conceptual Modelling of Pertek (Tunceli) Geothermal Field, Eastern Turkey

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ABSTRACT

The study area is located in Pertek town (Tunceli) in Eastern Anatolia. The geology of the study area is very important for the geodynamic evolution of the Eastern Taurus. The purpose of this study is to determine a hydrogeochemical and conceptual model of the Pertek geothermal system. The reservoir rock of the geothermal system in the study area are the crystallized limestone and marble units of the Keban Metamorphics. The sedimentary units of the Kırkgeçit and Karabakır formations act as impermeable barrier rocks. Moreover, alluvium is the most important and favorable unit for cold groundwater production. Geothermal resources in the Eastern Anatolia region are generally located at, or near the intersection points of East and North Anatolian fault lines due to volcanic and tectonic activity. Pertek geothermal area has been developed and controlled by fault lines formed by the interaction between North Anatolian Fault and East Anatolian Fault. There are several thermal springs with low temperatures (35–37°C) with a discharge of 3 L/s in the geothermal area. Most of wells are at shallow depths, 250 m. The temperature in the wells vary between 35 and 40ºC and the discharge from 10 to 30 L/s. The thermal waters can be identified as Ca-Mg-HCO_3 and the cold water are Ca-Mg-Na-HCO_3. Isotopic composition suggest that the thermal waters are of meteoric origin. The reservoir temperatures are calculated with several geothermometers as 110-120 °C. Geochemical, hydrogeochemical and isotopic studies indicate that the thermal waters, which rise from the geothermal reservoir by the faults, mix groundwater coming from the cold-water aquifer before surfacing.

1. INTRODUCTION

The study area is located in Pertek town (Tunceli) in Eastern Anatolia, Turkey (Fig. 1). The geology of the studied area is very important for the geodynamic evolution of the Eastern Taurus. Thus, numerous geologists have been interested in the geology of Eastern Taurus during last few years (Aksoy, 1994). From oldest to youngest, the geological formations in the study area are —Permo-Triassic Keban metamorphites, Upper Cretaceous Elazıg (Pertek) magmatics, Maastrihtian Harami Formation, Middle Eocene-Upper Oligocene Kırkgeçit Formation, Upper Miocene-Pliocene Karabakir Formation and Ouaternary alluvium (Fig 1). The purpose of this study is to determine the hydrochemical character of the reservoir in the Pertek geothermal system.

A total of 20 liquid water samples were collected from the geothermal system for chemical analyses to investigate the water quality. Water samples were analyzed in the Izmir Katip Celebi University, Central Reseach Laboratories.and Hacettepe University, Depatment of Geological Engineering Water Chemistry Laboratories, using the methods of inductively coupled plasma-mass spectrometry (ICP-MS) and ion chromatography, respectively. Aquachem (Calmbach, 1997) and PhreeqCi (Parkhurst and Appelo, 1999), chemical modelling programs were used to evaluate reservoir chemistry and its characterizations.

2. GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

The basement units of the studied region are Paleozoic-Mesozoic Keban metamorphics and Upper Cretaceous Elazıg magmatics (Fig. 1). The Keban metamorphics are marble and amphibolite in the study area. The younger (Coniacian–Campanian) Elazıg Magmatic Complex intruded into the Keban Metamorphics. The Keban Metamorphic Formation was thrust over the Elazığ Magmatic Complex (Herece and Acar, 2016). In the study area, diorite is the most common magmatic rock, granite and gabbro only crop out locally. The other units are the Karabakır Formation (Upper Miocene–Pliocene) which is continental volcanics and volcanoclastics, Upper Cretaceous-Paleogene units Harami and Karabakır formations. The upper part of the Harami formations is composed of carbonate cemented sandstone with plenty of nummulites and ophiolitic fragments. The Kırkgeçit formation, early Bartonian-early Chattian in age, is comprised of sandstone-siltstone-limestone intercalation. During the Maastrichtian, the Anatolian plate began moving westward which is bounded in the E-SE by the East Anatolin Fault. In the study area Pertek fault started to move as a right-lateral strike-slip fault (Herece and Acar, 2016).

The most important reservoir rocks of the thermal water in the study area are the Keban metamorphics because of its high porosity and permeability. Impermeable layers (marl and clay) of the Middle Eocene-Upper Oligocene and Upper Miocene-Pliocene units are the cap rocks of the thermal water aquifer. The heat source of the thermal waters are magmatic intrusions at depth related to the Upper Miocene– Pliocene volcanism. Highly fractured and karstified metamorphic rocks, fractured limestones, basalts, and alluvium make up the aquifers for the cold ground waters in the study area.

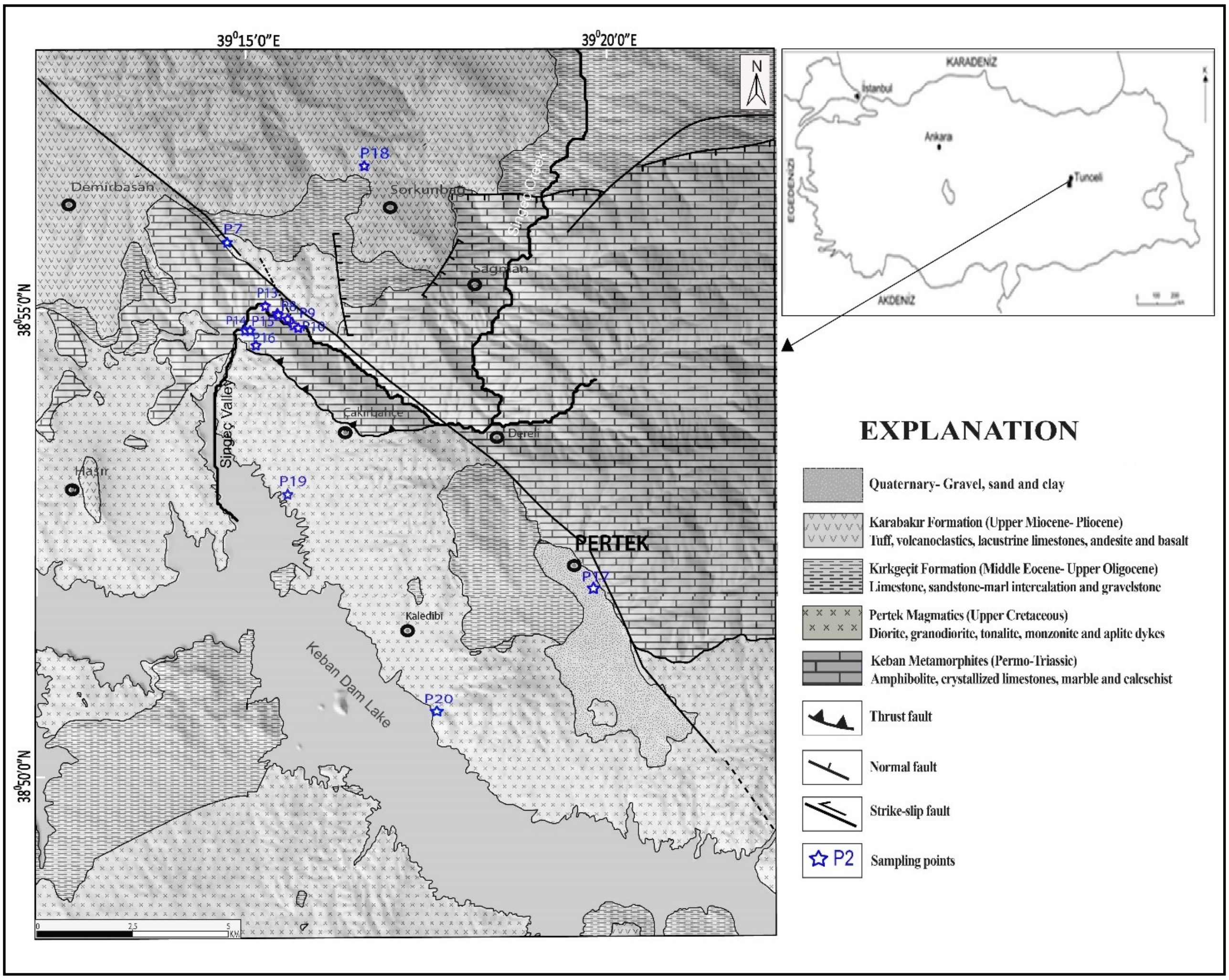

Figure 1: Geology and sampling map of the study area.

Groundwater recharge area is estimated high levels (from 1000 to 1500m) of the north part of the study area. Important streams are Munzur, Murat, Peri, Singeç creeks. The streams flow from southwest to north east towards Keban Dam Lake in the study area (Fig. 1). The Keban Dam Lake is important for multi-purpose use such as hydropower, flood control, and irrigation in the study area. The lake is formed at the confluence of Munzur, Peri and Karasu rivers. Storage volume of the reservoir is 30.6 billion m^3 with a length of 125 km. The maximum water depth is 163 m.

There are several springs at low temperatures (35–37°C) with a discharge of 3 L/s (Akkus, 2016). Since 2007, a total of 6 wells have been drilled in the Singeç valley and surrounding area. Most of wells are at shallow depths between 50 and 250 m. The temperatures in these wells vary between 35 and 40ºC and the discharge from 10 to 30 l/s.

3. HYDROCHEMICAL STUDIES

For the investigation and comparison of the major chemical characteristics, thermal waters were collected from natural springs and thermal wells at outlet conditions from 2017 to 2018. Table 1 also includes total anion-cation, % error values, and the classification of waters according to the principles of the International Association of Hydrogeologists (IAH, 1979). The sum of total equivalents of cations and anions were recorded as 100 %, and ions with more than 20 % (meq/l) were used for the classification.

The Schoeller diagram shows common trends and gives an overall idea of absolute cation (Ca^{2+}, Na^+ and Mg^{2+}) and anion (Cl^-, SO_4^{2-} and HCO_3^-) distribution in the waters as a semi logarithmic function of the concentration (meq/L). Fig. 2a shows the Schoeller diagram (Schoeller, 1965) for the procured water samples from the thermal springs and wells. These waters all have high concentrations of calcium (Ca^+), bicarbonate (HCO_3^-), low concentrations of sodium (Na^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{2-}) and chloride (Cl^-). However, the Schoeller diagram is not particularly useful when investigating potential mixing between the different reservoirs. Fig 2b shows cold waters in the Schoeller diagram. The ion concentrations are in order of abundance for cations: $Ca^{2+} > Mg^{2+} > Na^+ + K$ and $HCO_3^- > SO_4^{2-} > Cl^-$ for anions. The waters also show a similar trend and same water type compared to each other.

Classification of water types and major ion composition was plotted on a Piper diagram (Piper, 1979) in Fig.3. Most of the thermal waters can be classified as hardness of carbonate is more than 50%. Thermal water characteristics are explained as mixed waters ($Ca^{2+}+Mg^{2+}$) > ($Na^+ + K^+$) and ($CO_3^- + HCO_3^-$) > ($Cl^- + SO_4^{2-}$).

Table 1. Chemical parameters and water classification results of waters in the study area (Sample numbers are as in Fig. 1)

No	ΣAnion	ΣCation	%Error	Water Type
P1	6.08	6.50	3.33	Ca-Mg-HCO_3
P2	10.21	11.08	4.08	Mg-Ca-HCO_3
P3	4.70	5.00	3.03	Ca-HCO_3
P4	4.41	4.76	3.80	Ca-HCO_3
P5	11.42	12.25	3.50	Ca-Mg-Na-HCO_3-SO_4
P6	8.57	9.03	2.64	Na-Mg-Ca-HCO_3-SO_4
P7	4.70	4.91	2.13	Mg-Ca-HCO_3
P8	24.14	25.25	2.24	Ca-HCO_3
P9	5.57	5.73	1.45	Ca-Mg-HCO_3
P10	5.98	6.08	0.88	Ca-Mg-HCO_3
P11	24.48	25.95	2.93	Ca-HCO_3
P12	7.54	7.57	0.21	Ca-HCO_3
P13	12.30	13.18	3.46	Ca-Mg-HCO_3
P14	25.57	26.58	1.94	Ca-Mg-HCO_3
P15	6.17	6.31	1.15	Ca-Mg-HCO_3
P16	24.72	26.52	3.52	Ca-Mg-HCO_3
P17	3.68	3.76	1.07	Ca-Mg-HCO_3
P18	3.69	3.81	1.66	Ca-Mg-HCO_3
P19	3.82	4.01	2.42	Ca-Mg-HCO_3
P20	12.84	13.60	2.88	Ca-Mg-HCO_3

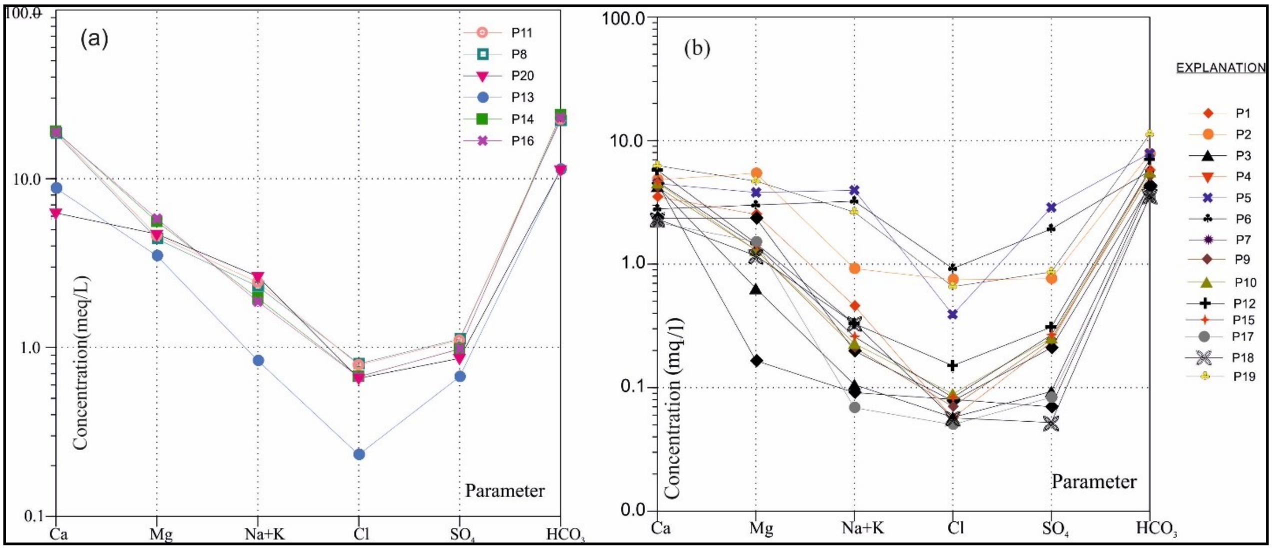

Figure 2: Scholler diagram for (a) thermal waters and (b) cold waters.

Generally, As, B, Li, Ba, Fe, Mn, Sr, Al, Cu, Zn, Cd and Pb concentrations are high in thermal waters. When the waters are evaluated according to national and international drinking water standards (Turkish Drinking Water Standards (TS-266) 2005, Turkish Water Pollution Control Regulation 1991, WHO 2004 and Turkish Spa Standards 2001), As and B concentrations were found to be high in almost all waters. Fe, Al and Pb concentrations are higher in some waters compared to the others.

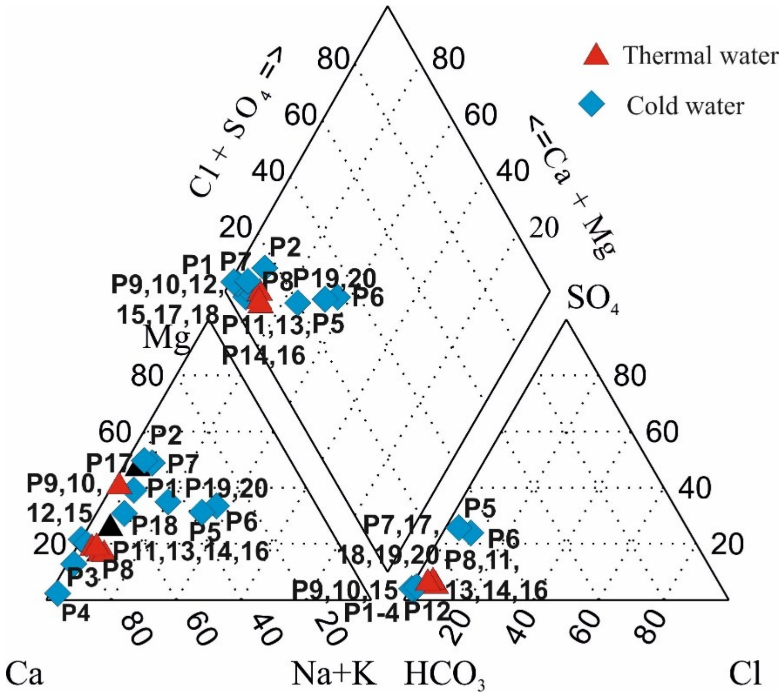

Figure 3: Piper plot showing the chemical variability of waters in the study area (Sample numbers are as in Table 1).

4. CONCEPTUAL MODELLING OF THE GEOTHERMAL SYSTEM

The geothermal systems are fed by meteoric water that infiltrates over a 50 km^2 area north of the fields. The average elevation of the recharge area is approximately 1500m above sea level. The distribution of the geothermal potential appears to be controlled by neotectonic features, such that the highest potential is associated with the tensional tectonics in the Eastern Anatolia, are being driven by the supply of heat from a deep-seated source (upwelling mantle material due to the release of lithostatic pressure) and deep circulation of waters along the fracture zones. Consequently, the meteoric waters penetrate deep into the system by following down a high-permeability fracture zone and move up to the surface associated with Riedell shears of Elazıg (Pertek) magmatic within the Singec Valley (Fig. 4).

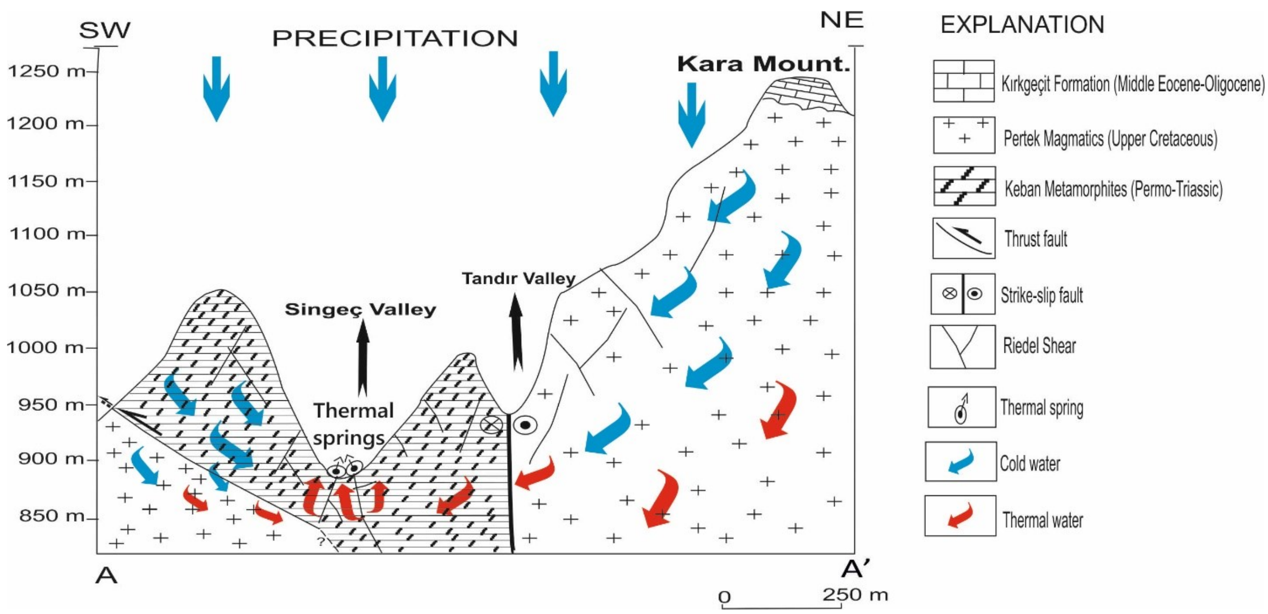

Figure 2: Conceptual modelling of the geothermal system.

5. CONCLUSIONS

Hydrogeological units were divided into the three units. First, the basement of the study area, marbles and dolomitic marbles within the Keban metamorphic rocks are the main reservoir for thermal waters. Sedimentary formations occur as impermeable barrier rocks. Some parts of the limestone and basalt units act as aquifers for fresh waters. Alluvium is the most important and favorable unit for cold groundwater production. Groundwater recharge area is estimated high levels (from 1000 to 1500m) of the north part of the study area. The geothermal system is closely related to major faults and fractures, as with many other geothermal areas in Turkey.

Classification of thermal waters are Ca-Mg-HCO_3 water type. Cold waters have Ca-Mg-Na-HCO_3-SO_4 wate$_r$ type in the study area. The Piper diagram shows that the thermal waters characteristics are explained as a mix of waters (Ca^{2+}+Mg^{2+}) > (Na^++K^+) and (CO_3^-+HCO_3^-) > (Cl^-+SO_4^{2-}). According to Schoeller diagrams, the classification of groundwater types and dominant ions are Ca^{2+}-HCO3 type.

Generally, As, B, Li, Ba, Fe, Mn, Sr, Al, Cu, Zn, Cd and Pb concentrations are high in thermal waters. These results show that thermal waters are affected by natural (weathering, hydrothermal alteration, etc.) and hydrogeological (water-rock interaction, bathing and transport) processes.

Although thermal waters are used for therapeutic purposes in spa treatments, it is recommended that these waters should not be used for a long period of time because of their high ionic content and high concentrations of As and B, which would have negative effects on human health.

6. ACKNOWLEDGMENTS

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