PROCEEDINGS, 45th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2020
SGP-TR-216

Building Preliminary Conceptual Model of Geothermal System in Late-Tertiary Extensional Basin, Kalkım-Çanakkale, NW of Turkey

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Keywords: Conceptual Model, Turkey, Geothermal, Kalkım, Çanakkale

ABSTRACT

The Late-Tertiary Kalkım Basin, located in the Biga Peninsula, NW part of Turkey, offers a remarkable potential for an exploitable geothermal reservoir. In conjunction with two E-W high angle active faults bounding the basin in the north and south, geothermal waters ascent to surface with temperature up to 84 °C. As a result of pull-apart tectonics and graben-like depressional basin, Neogene to Quaternary cover rock series present in the hanging wall, while Paleozoic-Triassic basement rocks expose in the foot wall. Drilled shallow wells provided a conductive geothermal gradient from 4 to 6 °C/100m within the hanging wall, which evidence to a regional thermal anomaly. As the many of subsidiary members of geothermal system meet in the Kalkım basin, we attempted to build up a preliminary conceptual model to reveal main elements of Kalkım geothermal system; (i) reservoir temperature, (ii) size of geothermal system, (iii) geological settings (iv)Hydrogeology and hydrogeochemistry and (v) heat source. This study involves preliminary interpretation of analytical data from a water sampling survey of 22 locations. The conceptual model is depicted on a N-S resistivity section of 3D magnetotellurics study, together with inferred faults from seismic survey and lithological associations.

1. INTRODUCTION

Biga Peninsula is one of the outstanding geothermal province in the NW of Turkey. Products of the Neo-tectonic extension; Western Anatolian Grabens and Northern Anatolian Fault (NAF) are both recognized in the Biga Peninsula, resulting to constitution of economic geothermal resources. So far, the major part of investments in the peninsula have been conducted in the Tuzla area, where two major faults (NEE-SWW and NW-SE) intersects and geothermal spring with temperature up to 100 °C occur. With an installed two geothermal electric power plants and exploration wells drilled to the maximum depth of 2500 m, Tuzla province has already proved its geothermal power potential. However, there are still undiscovered geothermal resources in the Biga Peninsula, mainly being controlled by transtensional tectonic of NAF. Our study area; Kalkım is an example of Late-Tertiary depressional basin controlled by NAF, offers a remarkable potential with geothermal springs up to 84 °C. Two E-W orientated high-angle active faults in the north and south creates a graben-like, pull-apart tectonic control. High- and low-grade Paleozoic metamorphics in the hanging wall in conjunction those active faults and cover series signified by Neo-Quaternary volcanic and volcano-sedimentary rocks are complementary members of the Kalkım geothermal system. This study attempts to build up a preliminary conceptual model of the Kalkım geothermal field with intention to reveal geothermal potential of such an unknown prospect.

2.GEOLOGICAL SETTINGS

The tectonic belts of the Biga Peninsula are explained by three distinct stratigraphic units; (i) Ezine Zone, (ii) Çetmi mélange and (iii) Sakarya Zone from west to east respectively (Duru et al, 2012). These fragments are distinguished based on their metamorphism grade, stratigraphy and structural features (e.g. Şengör et al. 1984, Okay and Tüysüz 1999). Before Tertiary rock units of the Kalkım area are contained by the Sakarya Zone, which are made up with Paleozoic high-grade metamorphics; gneisses, meta-ophiolites, granitic gneisses and marble lenses and low-grade metamorphics; phyllite, meta-pelitic rocks, meta-basalt, calc-schist and marble layers. Mesozoic accretion related mélange unit (Karakaya Complex) and Jurassic neritic limestone unit overlie the Paleozoic basement rocks with an unconformity. Post-collisional Oligo-Miocene plutonic bodies showing granodiorite, quartz monzonite and granitic composition intruded into the Paleozoic-Mesozoic basement rocks. Following to the plutonism, terrestrial volcanism took place and produced andesitic, dacitic to rhyolitic volcanic rocks ignimbrite and pyroclastic rocks. Neo-Quaternary lacustrine and fluvial conglomerate, sandstone and limestone successions covered all units.

3.STRUCTURAL GEOLOGY

The Biga Peninsula is tectonically shaped and affected by the extensional tectonic regime as a result of the Western Anatolian Neo-Tectonism. Active tectonic control is being controlled by the NE-SW right lateral Northern Anatolian Fault (NAF) regime and Western Anatolian Grabens. NAF is a crustal scale fault, begins from the eastern Turkey with pure right-lateral strike slip movement towards to west. It is recognized by multiple segments in direction of NE-SW, ENE-SWS in the Biga Peninsula, represented by high-angle, right-lateral strike slip faults (Emre et al, 2016 and references therein), and produced major earthquakes over M=7. One of the member of the NAF, the Pazarköy fault (PF) in the south of Kalkım Basin extends for almost 42km and demonstrates right-lateral, oblique and strike slip displacement (Duru et al, 2012; Emre et al, 2016) Th PF is thought to be one of the major tectonic controller in formation of the Kalkım Basin. Although, there is no record of earthquake in both historic and instrumental period, geological and geomorphological studies show it is activity for at least for the Holocene time. The Kalkım Basin is bounded by E-W trending Hıdırlar- Reşadiye Fault in its north, extending for almost 7 km. Additionally, “Hıdırlar Geothermal Springs” and wide-spread argillic alteration are in association with the “PF”. Given that the presence of hot-springs and sharp morphological variation in topography, the Hıdırlar-Reşadiye Fault is classified as an active fault (Figure 1).

5. METHODOLOGY

Geochemical water sampling in the Kalkım basin was completed by 7 thermal and 18 cold water samples (Figure 1). HANNA HI83141 and HANNA HI98130 multimeters were used for in-situEC, pH and Eh measurements. Alkalinity was analyzed by titration with hydrochloric acid as soon as the samples were collected. In-situ analysis of SiO_2 was carried out by a Portable DR1900 Hach-Lange spectrophotometer. The pH of the cation samples were reduced to 2 with ultra-pure nitric acid. Geothermal waters were diluted ten times for silica analysis. Cation and trace element analysis were conducted in Bureau Veritas laboratory (Canada). All filtration procedures were performed with 0.45µ nitrocellulose membrane filters using a vacuum filter.

5.GEOCHEMISTRY

Geothermal springs are located along with the Hıdırlar-Reşadiye fault zone, showing discharge temperature between 35 ^{0} C and 79 ^{0} C with 3-4 l/s flow in the NW of the Kalkım basin. Brine geochemistry shows that these springs are Na-HCO_3-SO_4 while cold waters are Ca-Mg-HCO_3 type of water (Figure 1). EC values of the geothermal waters vary between 600-3010 µS/cm, whereas cold waters are generally in range of 200-600 µS/cm. According to Piper and Giggenbach diagrams, geothermal waters have similar origin and are classified as "immature" and "partially immature” (Figure 2, Figure 3). Mg and Ca variation is interpreted as a result of cold-water flux into the thermal waters.

Linearity of thermal waters in Boron-Chloride scatter graph and Giggenbach diagram reveals the evidence of cold-water mixture with thermal waters (Figure 3, Figure 4). Based on the Giggenbach diagram, reservoir temperature is around 160 ℃ prior to cold water mixing. Silica-enthalpy mixture model has shown the cold-water mixture is in range of %56-83.3. The mean measured temperature and silica concentration of cold waters are 10.8 °C and 20.7 mg/l respectively. Cation (Na-K-Ca, Na/K) and Silica (SiO_2) geothermometers were employed for thermometric estimations. Calculated results are in between 94-111 °C (cation), 30-143 °C (silica) respectively. Because of the immature composition of geothermal waters, the silica geothermometers are found to be reliable than cation’s result.

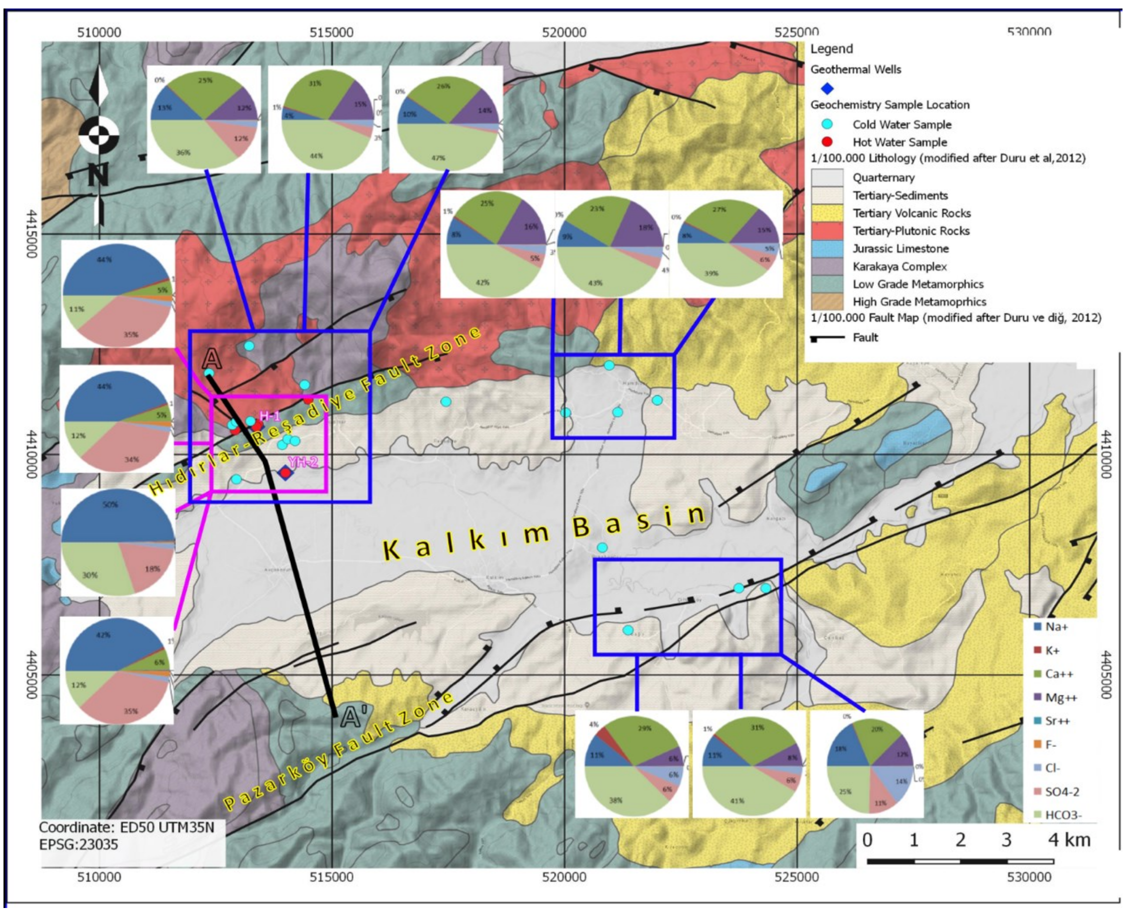

Figure 1. Geology map of the Kalkım basin showing location and composition of hot and cold water samples.

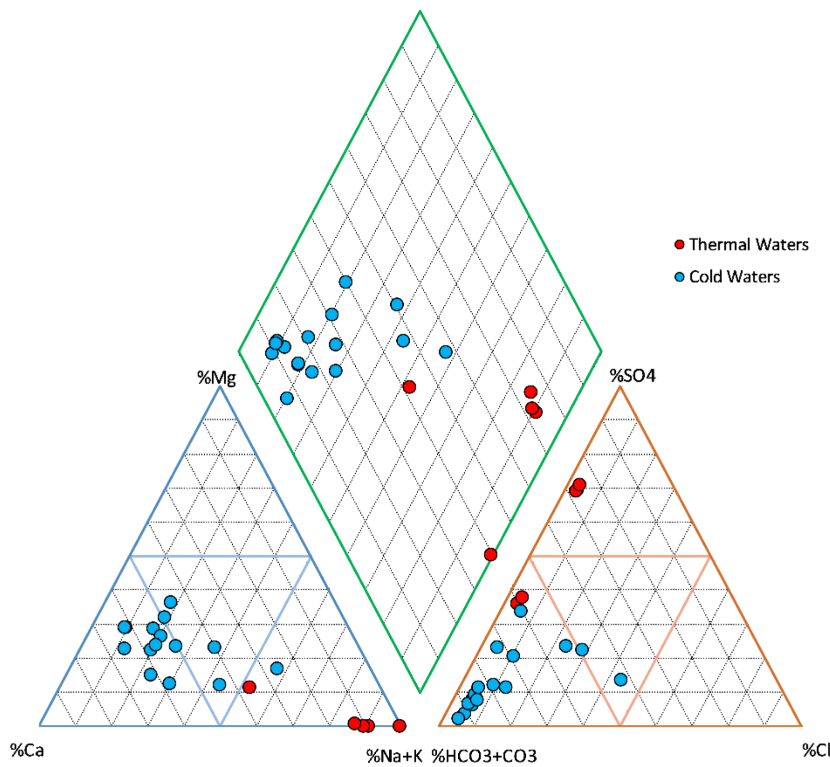

Figure 2: Piper Diagram of sampled waters. Thermal waters have similar geochemical characteristics. Some thermal waters are cooling as a result of cold-water mixing.

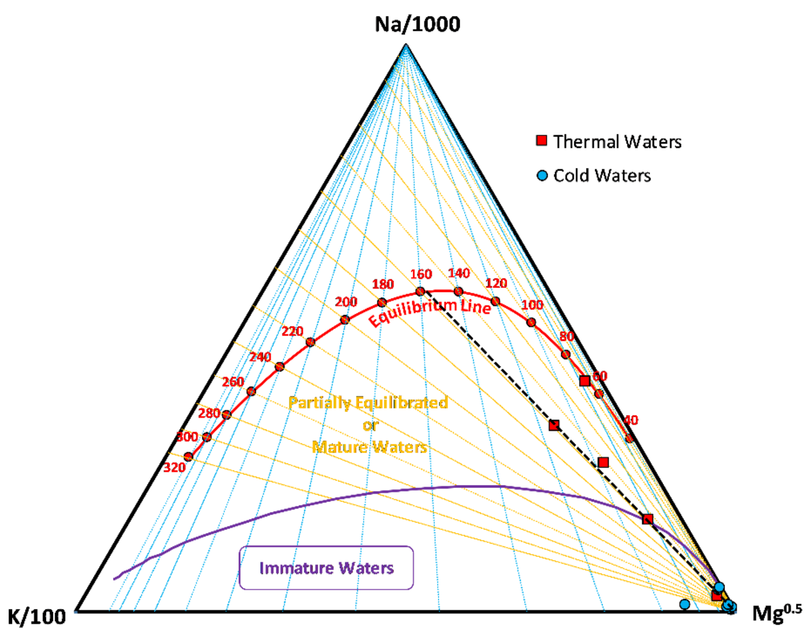

Figure 3: Giggenbach Diagram of the waters. Linear sequence of the thermal waters points out the mixing of thermal and cold waters in variable ratios. Based on the diagram, reservoir temperature is around 160 ℃ prior to cold water mixing.

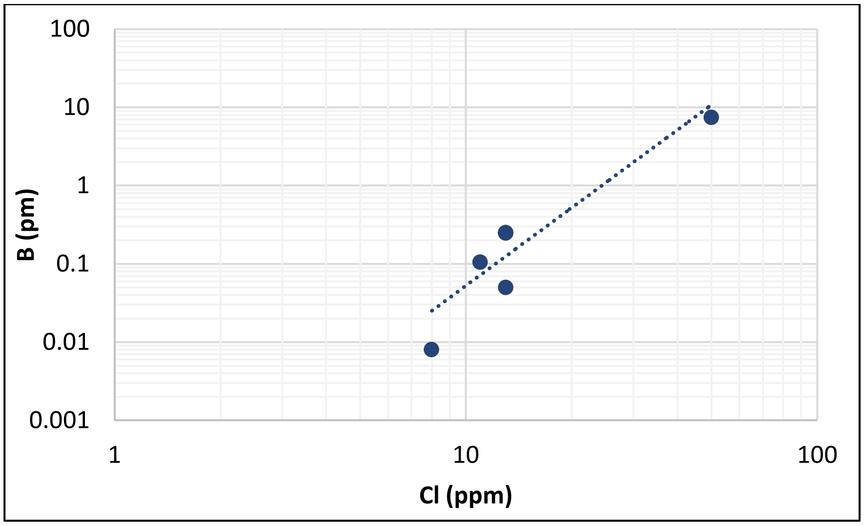

Figure 4: Boron-Chloride scatter graph of thermal waters. Since Boron and Chloride are conservative constituents in natural water, the linearity in the graph supports thermal-cold water mixing.

6.BUILDING PRELIMINARY CONCEPTUAL MODEL

6.1. Reservoir Temperature

The reservoir temperature of the Kalkım Basin is hypothetically estimated through geothermometers and temperature gradients of the drilled shallow well. Hot springs in the Hıdırlar geothermal area presents 84 °C flow on surface. The geothermometry results of these hot springs pointed to reservoir temperature is around 160-170 °C. Additionally, the shallow wells recorded static bottom hole temperatures; 78 °C at 380m (H-1well) and 58 °C at 800m (YH-2 well). The calculated mean gradient in YH-2 well is 4.95 °C/100m and 5.37 °C/100m within the "Alluvium + İlyasbaşı Formation" and "Cover Paleozoic Metamorphics", respectively. Conservatively assuming the average gradient is 4 °C/m and extrapolation to the 2200-3500m depths, it would be convenient to find the reservoir temperature is around 150-170 °C at drillable depths (3000-3500m).

6.2. Geological, Hydrogeological and Boundary Conditions

Geothermal waters in the Kalkım Basin discharge through "Hıdırlar-Reşadiye fault". Thermal waters in both well and spring have discharge temperature between 35°C and 79°C in the region. Ascending geothermal fluids mix cold water at variable rates between %56 and %86. Water samples of shallow boreholes (20-40m) are generally parallel to the cold water in the region, but have a higher content of Na, K and SO4, indicating that they are mixed with hot water. Therefore, shallow outflow zone into the Neo-Quaternary Sediments, sourced from Hıdırlar-Reşadiye fault is expected. As it indicated in Figure 13-3, cold meteoric water input can be derived from two sources; (i) descending through fractured network of granodiorite and/or (ii) from the south of the basin (Figure 5).

Adiabatic cooling is not likely to occur in the Kalkım geothermal system, as there is no fumaroles and/or hot spring at 100 °C, while conductive cooling through the outflow zones is expected. The isothermal lines of 50 °C and 80 °C are depicted based on the static well temperatures and geothermal springs on surface. The 120 °C and 160 °C isotherm lines are shown with linear extrapolation of 4 °C/100m conductive gradient. The geothermometer results (150-170 °C) are expectable in these settings. As a part of Kalkım geothermal system, volcanic clay cap may occur underneath the Neo-Quaternary sediments, which may be further evidenced by low resistivity in the magnetotellurics survey (yellowish-red zone). Similar alteration minerals (epidote, secondary quartz, undifferentiated clay) were reported in H-1 well completion report (Ölmez & Orkut, 1989), indicating the Propylitic conditions (Corbett and Leach, 1998).

6.3. Heat Source of the Geothermal System

Thermal waters in Kalkım geothermal area showed near neutral pH and moderate ammonium content. Therefore, there is no direct relation between magmatism-induced volatiles and the heating system in the Kalkım region. Rather than to the magmatism as the heating source, regional high temperature profiles associated with regional crustal thinning driven by high-angle faults is thought to have major contribution. Last tomography studies (Amaru, 2007) have shown the subducted beneath of Aegean slab in the Western Anatolia resulting in crustal thinning and shallowly seated asthenosphere, which would explain high temperature gradients in the Western Anatolia.

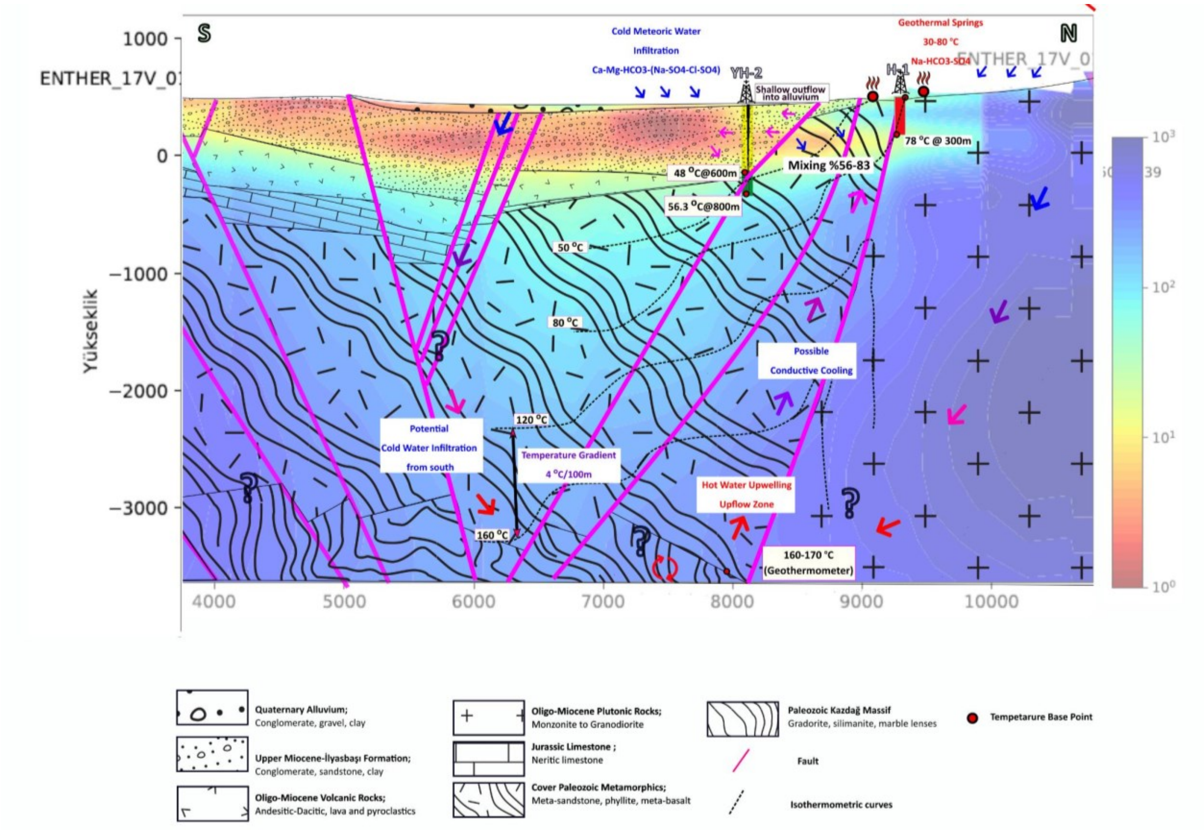

Figure 5. Preliminary conceptual model of the Kalkım Basin depicted on a N-S geology and resistivity section. Faults and lithological boundaries are drawn based on available geological and 2D-Seismic studies.

7.RESULTS

Kalkım basin in the Biga Peninsula, NW of Turkey, is one the promising geothermal prospect, which is being controlled by crustal scale NAF. High-angle E-W trending oblique and normal faults in the north and south creates a pull-apart and graben-like structural control and geographically limits the Kalkım Basin. On the NW edge of this Late-Tertiary basin, geothermal waters discharge to surface with output temperatures up to 84 °C and 3-4 l/s flow rate, using an upflow zone through south dipping "Hıdırlar-Reşadiye" fault zone. During the ascent of geothermal waters, cold water mixture occurs at variable rates (%56-83). Geothermometric estimations showed the geothermal waters have estimated temperature range in between 150-170 °C. The exploitable geothermal reservoir is expected to encounter at drillable depths (3000-3500m), based on a conductive gradient at 4 °C/100m. All Thermal waters have "immature and partially-mature" composition based on Giggenbach diagram. Cold water infiltration is expected to occur either from the hanging wall and footwall of the basin. Heat source of the Kalkım geothermal system is thought to be associated with a regional high temperature gradient, enhanced by high-angle active faults and crustal thinning. Considering the geological characteristics of the Kalkım Basin and enthalpy estimations, classification for the geothermal system is defined as "tectonically active convective system with deep water circulation" at "mid-enthalpy" and "Liquid-dominated" conditions.

ACKNOWLEDGMENT

This study is supported by Enther Enerji and we thank for their grant to access data and encouragement to contribute this paper to Proceedings of the 45th Workshop on Geothermal Reservoir Engineering, Stanford University.

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