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# Hydrogeological Modelling of Geothermal Waters in Dikili (Izmir) and environs, Western Anatolia, Turkey

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## ABSTRACT

Study area is located 100 km N of province capital of Izmir in western Anatolia, Turkey. In the area, a great number of geothermal waters with surface temperatures of 100 °C and groundwaters occur. The Camoba and Kinik formations in Permian age form the basement which are overlain by Paleocene Kozak granodiorites, Yuntdagi volcanics 1 in Paleocene to Miocene age, Miocene Yuntdagi volcanics 2, Pleistocene Yuntdagi volcanics 3 and Pleistocene Dededag basalts discordantly. These are overlain by Quaternary alluvium discordantly. In addition to in-situ measurements such as temperature, pH, Eh, EC, dissolved oxygen and alkalinity values in the area, we have collected 5 samples of geothermal waters which were analyzed for cations by ICP-OES and anions by IC. In order to clarify the origin of geothermal waters and mixing rate of geothermal waters and groundwaters, the stable isotopes of $\delta^{18}O$ and $\delta^{2}H$ and tritium contents were analyzed. Hydrogeochemically, geothermal waters display Na+K more than Ca more than Mg dominant cations and $HCO_3$ more than $SO_4$ more than Cl dominant anions. Geothermal waters are of Na-($SO_4$)-$HCO_3$ type and show immature waters as well as partially equilibrated waters with reservoir temperatures up to 130 °C. The geothermal waters in Dikili and environs were represented as hydrogeological modelling due to hydrogeological, hydrogeochemical and isotope geochemical data.

## 1. INTRODUCTION

The study area is located 100 km north of the province capital of Izmir in the western Anatolia, Turkey (Figure 1). In the area, which is built up by volcanic rocks in the age from Paleocene to Pleistocene, there are also groundwaters and geothermal waters. Geothermal waters are related to the tectonical controls. First of all, the hydrogeological features of reservoir rocks were investigated especially. In the second step, the hydrogeochemical features and origin of geothermal waters were studied by using the software program AquaChem (Calmbach, 1999) comprehensively. Finally, saturation indexes of minerals and temperatures of geothermal reservoirs in the area were calculated by using the above mentioned software program.

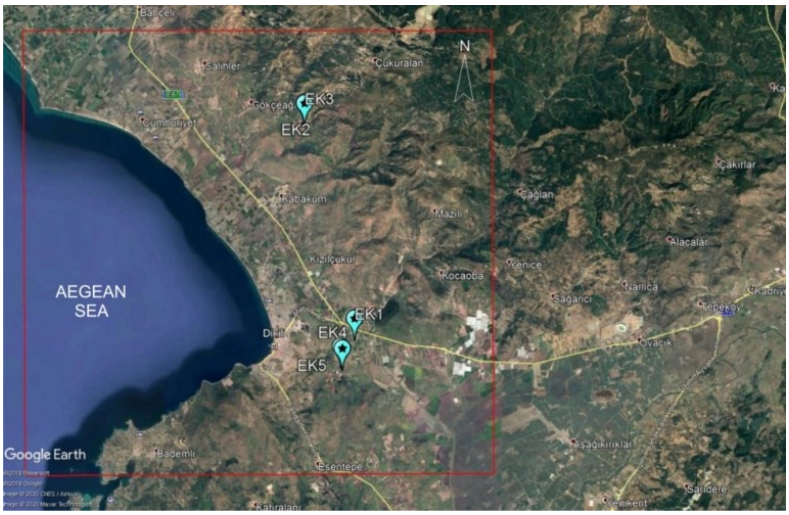


**Figure 1: Location map of the study area and sample locations of the geothermal waters in Dikili and environs.**

## 2. GEOLOGIC SETTING

In the study area, The Camoba and Kinik formations in Permian age form the basement which are overlain by Paleocene Kozak granodiorites, Paleocene to Miocene Yuntdagi volcanics 1 consisting of hornblende andesites and biotite-hornblende andesites overlain by felsic pyroclastics composed of dacitic lavas, andesites, ignimbrites , Miocene Yuntdagi volcanics 2, Pleistocene Yuntdagi volcanics 3 and Pleistocene Dededag basalts discordantly (Özen and Tarcan, 2005; Koyuncu, 2019). These are overlain by Quaternary alluvium discordantly. In the area of geothermal fieds Sections and subsections should be numbered. in Dikili and environs, the hydrothermal alteration is recognized by a distinct color change of rocks. It is noticeable at the surface which is distinguished by argillic and silicic alteration zones especially.

## 3. HYDROGEOLOGY, HYDROGEOCHEMISTRY AND ISOTOPE GEOCHEMISTRY

### 3.1 Hydrogeology

In the area, the Yuntdagi volcanics (1) form the first reservoir due to secondary permeability. Pyroclastic rocks are of impermeable and can be considered as first cap rocks for the reservoir. Yuntdagi volcanics (2) are of second reservoir in the area. Yuntdagi volcanics can be considered as second cap rocks in the area. In the area, the alluvium forms the aquifer for groundwaters.

### 3.1 Hydrogeochemistry

In the area, the geothermal waters are of Na-($SO_4$)-$HCO_3$ type (Figure 2). The anions of $SO_4^{2-}$ and $HCO_3^-$ in geothermal waters are enriched during Cl- anion is depleted (Figure 3). In geothermal waters, there are a cation order of $Na^+ + K^+ > Ca^{2+} > Mg^{2+}$ and an anion order of $SO_4^{2-} > Cl^- > NO_3^-$(Figures 3 and 4). In the diagram of Na1/1000-K1/100-√Mg, the geothermal waters of EK1, EK3 and EK4 are of immature waters during the geothermal waters of EK2 and EK 5 represent partially equilibrated geothermal waters (Giggenbach, 1988; Figure). In the study area, geochemical thermometers of quartz and quartz steam loss seems to be suitable thermometers and show reservoir temperatures ranging from 80 to 130 °C (Koyuncu, 2019; Fournier, 1977). In the area, saturation indexes of geothermal waters were calculated by AquaChem software program (Calmbach, 1999; Özen and Tarcan, 2005). Accordingly, the geothermal waters in the study area show important features which solve fluorite and amorphous silica and cause calcite precipitation.

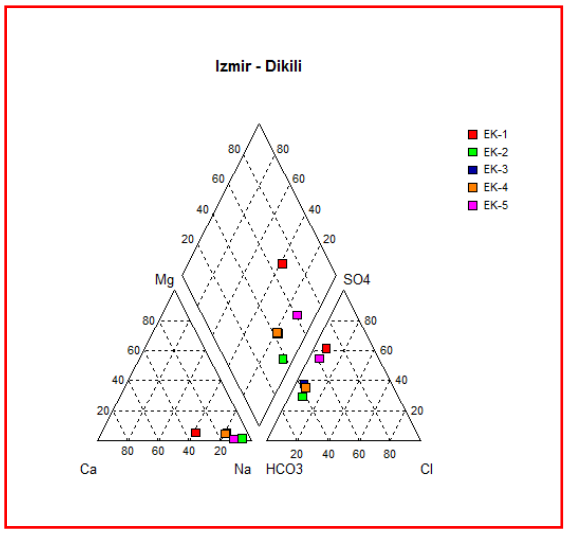


Figure 2: Geothermal waters in Dikili and environs in Piper diagram

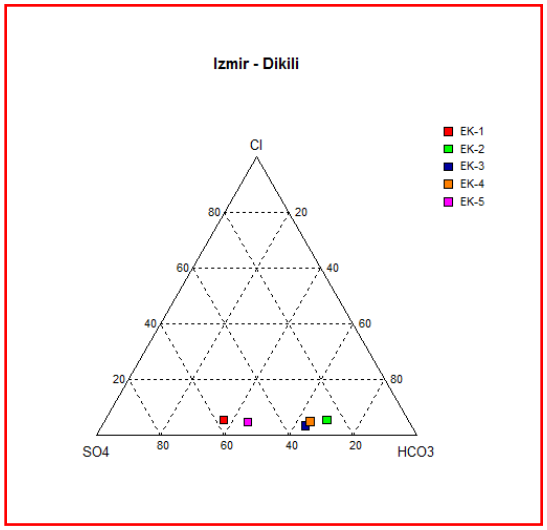


**Figure 3: Cl-$SO_4$-$HCO_3$ triangular diagram of geothermal waters in Dikili and environs.**

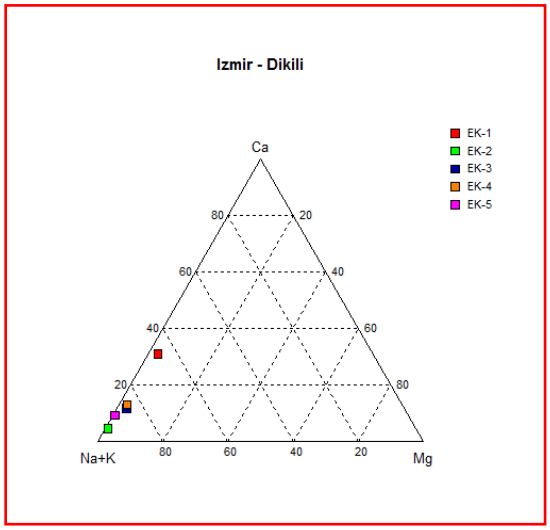


**Figure 4: Na+K-Ca-Mg triangular diagram of geothermal waters in Dikili and environs.**

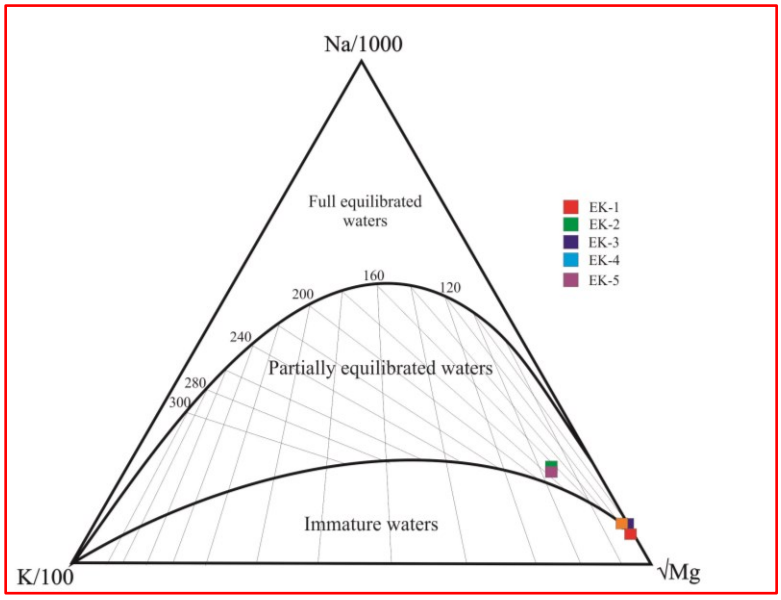


**Figure 5: Na 1/1000-K 1/100-√Mg triangular diagram of geothermal waters in Dikili and environs.**

### 3. 3 Isotope geochemistry

Stable isotopes of $\delta^{18}O$ and $\delta^{2}H$ of the geothermal waters are represented by values ranging from -4.8 to 6.4 ‰ and from 37.5 to 44.4 ‰ respectively. The strong deviation of $\delta^{18}O$ from meteoric water line proves intense water-rock interaction in hydrothermal environment (Figure 6; Özen and Tarcan, 2005). According to Özen and Tarcan (2005), the tritium values in the geothermal waters in the area are bigger than 5 TU which indicate at least an age of about 50 years.

## 4. DISCUSSION

In the study area, the geothermal waters are of meteoric origin. The meteoric waters in the drainage area located in the eastern part of Aegean Sea percolate at faults and fractures of Miocene to Pliocene volcanic rocks into the reservoir rocks where meteoric waters are heated by the cooling magmatic melt and ascend to the surface due to their lower density caused by convection cells (Figure 7). In addition, it is noticeable that the geothermal gradients form a second possibility for heating of the meteoric waters in the study area corresponding to heat flows and earthquake activity. Nevertheless, the geothermal waters at depth react with heated rocks which leads to water-rock interaction. The volatile components of $CO_2$, $SO_2$, HCl, $H_2S$, $HF^-$, $HB^-$ and He from the magma reach the geothermal reservoir where an equilibrium between rocks, gas components and geothermal waters is established (Özgür, 2018). Thus, the geothermal waters ascend in the tectonic zones in terms as hot springs, gases and steams. The geothermal waters in the study area can be used for district heating, construction of green houses and balneological purposes.

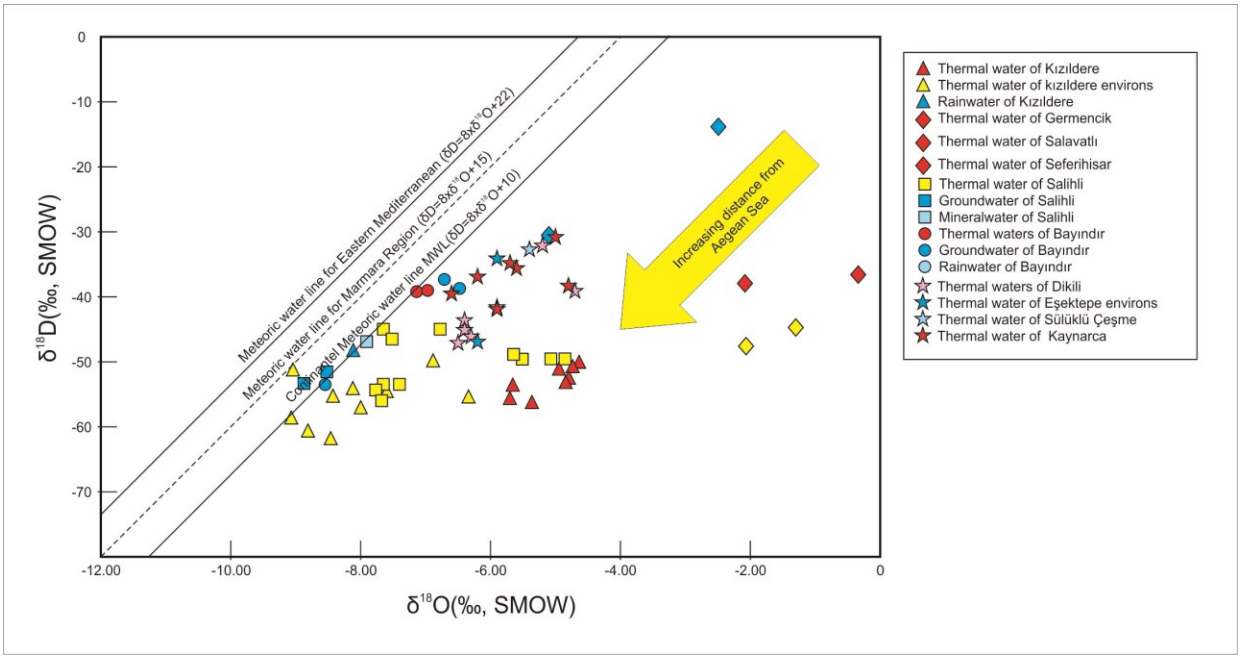


**Figure 6: $\delta^{18}O$ versus $\delta D$ in geothermal waters of Dikili and environs.**

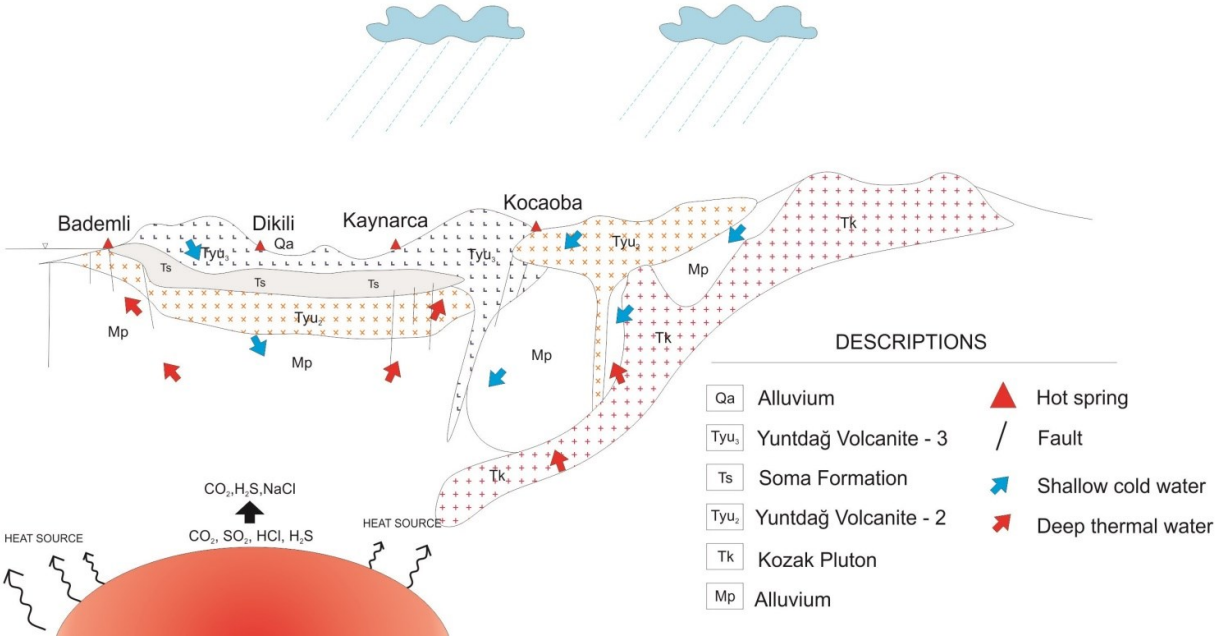


**Figure 7: Hydrogeological modelling of the geothermal waters in Dikili and environs.**

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