Geothermal Waters in the Area between Guvendik and Malgaçemir (Aydın), Western Anatolia, Turkey

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Abstract. The study area is located in the N of the town of Sultanhisar in the northern part of the continental rift zone of the Büyük Menderes within the Menderes Massif. In the area, the Paleozoic rocks consisting of intercalations of mica schists and marbles form the basement rocks which are overlain by Miocene and Pliocene sediments. The deep circulated geothermal waters in the area are of Na-HCO₃ type and immature origin and were represented in terms of conceptual modelling in this study.

1. Introduction

In Turkey, geothermal waters with temperatures of up to 290 °C form within the Menderes Massif with respect to tectonics, volcanism and earthquake activities. In depending upon these very important features, there are numerous geothermal waters which supply geothermal power plants with a capacity up to 1000-1200 MWe in the Büyük Menderes rift zone. The area is located between Malgaçemir and Güvendik [Figure 1]. For that, the municipality of the province capital of Aydın has a license for investigation and operation of a geothermal power plants. In the area, there is production well in depth of 850 m. This paper aims to (i) to describe geothermal waters in the area by geological, hydrogeological, hydrogeochemical and isotope geochemical data and (ii) develop an hydrogeological model for formation of geothermal waters.

2. Material and methods

The field works of geothermal waters in the area between Güvendik and Malgaçemir were realized in March, 2016 and August 2017. In this study, physical parameters and sampling of geothermal waters in locations of 1 production well and two hot springs for hydrogeochemical ans isotope geochemical were carried out [1]. The samples were analyzed for cations and anions in the Laboratory of the Mineral Research and Exploration Institute, Ankara, Turkey. For the evaluation of geochemical analyses, the AquaChem software program was used [2].

3. Results

3.1. Geological setting

The basement in the area between Güvendik and Malgaçemir consists of Paleozoic alternations of metagranites, chlorite schists and marbles which are overlain by garnet-amphibole schists and gneisses caused by Bozköy thrust [1]. These metamorphic rocks are cut by Pre-Miocene gabbros which are
overlain by Miocene and Pliocene intercalations of sedimentary rocks concordantly. In the area, alluviums, travertine deposits and colluvial fans form the youngest sedimentary rocks. In the study area, especially in the W of Söke and in the E of Germencik, Middle Miocene volcanic rocks, which cut Miocene sedimentary rocks, are located. These volcanic rocks play an important role for the formation of geothermal waters as heat source. In study area, clayey metamorphic schists can be considered as impermeable basement rocks for the formation of geothermal waters, while marble intercalations in Paleozoic metamorphic rocks form the geothermal reservoirs. Moreover, clayey metamorphic metamorphic schists also form the impermeable cap rocks in the area.

![Figure 1](image-url)

**Figure 1.** Location map of geothermal waters in the area between Güvendik and Malgaçemir in the Büyükmenderes rift zonewithin the Menderes Massif. [3].

### 3.2. Hydrogeology

In Relation to the area between Güvendik and Malgaçemir, hydraulic gradient of the groundwaters is from the N to the south which supply geothermal waters. Recharge of geothermal waters cover an area of up to 150 km². In general, the Büyükmenderes rift zone shows continental climate features with an annual precipitation rate of 450 mm and an annual temperature of 18,0 °C. From December to March, there is an high precipitation period in the area. Otherwise, the area is dry in other months of the year which causes a groundwater deficiency. In the study area, marble alternations form the first and second main reservoirs. In addition, Precambrian to Cambrian gneisses form third deepest main reservoir due to good developed fissures and fractures.

### 3.3. Hydrogeochemistry

Geothermal waters (ST-2) in the area between Güvendik and Malgaçemir are of Na-HCO₃ type, whereas the waters from Malgaçemir and Güvendik hot springs are classified as Ca-Mg-(Na)-HCO₃ type [Figure 2; 1].
Figure 2. Geothermal waters in the area between Güvendik and Malgaçemir in Piper diagram.

Geothermal waters (ST-2) show a cation sequence of Na+K>Ca>Mg, whereas geothermal waters from Malgaçemir and Güvendik hot springs are of a sequence of Ca>Mg>Na+K. In comparison, the anion sequence is of HCO₃>Cl>SO₄ in sample of ST-2 while the samples of ST-1 and ST-3 show an anion sequence of HCO₃>SO₄>Cl. The sample from ST-2 has a boron content of 53 mg/l [1] which correspond with increasing boron contents from Kızıldere to Germencik in the Büyük Menderes rift zone [3; 4; 5]. Moreover, quartz (steam loss), quartz with steam and quartz are the suitable geochemical thermometers for estimation of reservoir temperatures [6], and they show reservoir temperatures between 133 and 138 °C. Geothermal waters in the area between Güvendik and Malgaçemir are of immature waters as shown in [Figure 3; 7].

Figure 3. Geothermal waters of the study area in the Na/1000-K/1000-√Mg diagram according to [4].
3.4. Isotope geochemistry

In geothermal field of the area between Güvendik and Malgaçemir, two analyses of δ\textsuperscript{18}O, δ\textsuperscript{2}H and δ\textsuperscript{3}H are based on [1]. The plot of δ\textsuperscript{18}O versus δ\textsuperscript{2}H lie along the meteoric water line which shows a strong mixing of the meteoric groundwaters with geothermal waters [Figure 4; 1]. This is confirmed by δ\textsuperscript{3}H contents of 2.6 TU.

![Figure 4](image_url)

**Figure 4.** Plot of δ\textsuperscript{18}O vs. δ\textsuperscript{2}H in geothermal waters in Güvendik and other areas in the Büyük Menderes rift zone[1; 3].

4. Discussion and conclusions

In the area between Güvendik and Malgaçemir, Paleozoic metamorphics form the basement rocks which are overlain by Pre-Miocene gabbros and Miocene via Pliocene to Quaternary sedimentary rocks. Paleozoic schists with high quantities of clay contents represent impermeable basement rocks of the geothermal reservoir which consist of marble alternations. These metamorphic schists with high quantities of clay contents overlie the marble alternations and play an important role as cap rocks for the formation of geothermal reservoir. The deeper geothermal waters between Malgaçemir and Güvendik are of Na-HCO\textsubscript{3} type and can be considered as immature waters [Figures 2 and 3; 7]. Quartz (steam loss), quartz with steam and quartz are the suitable geochemical thermometers for the determination of reservoir temperatures [6] which show reservoir temperatures between 133 and 138 °C. Boron contents up to 53 mg/l in geothermal waters between Güvendik and Malgaçemir can be related to the sea water intrusion from the Aegean Sea.

In the catchment area of geothermal waters from Malgaçemir and Güvendik, the geothermal waters flow through faults, fractures, fissures and permeable rocks into the reaction zone of a magma chamber, situated at a probable depth of up to 5 km, where meteoric waters in the reservoir are heated by the cooling magmatic belt and ascend to the surface due to lower density caused by plate tectonical convection cells [Figure 5]. Besides, some subvolcanic rocks from Middle Miocene to recent in age
occurred in the continental rift zones of the Menderes Massif, i.e. Middle Miocene Denizli volcanics and recent Kula volcanics with an age of 18,000 a.

The volatiles in the magma chamber get to geothermal reservoir, where an equilibrium between rocks, gases, and waters must take place. Thus, geothermal waters ascend through tectonic zones and permeable rocks to the surface in form of hot springs, gases, and steam. The volcanic rocks from Middle Miocene to recent (The Kula volcano, located in the rift zone of Gediz within the Menderes Massif with a last eruption age up to 18,000 years represents an excellent example), might be considered as heat source for formation of geothermal waters in the area between Güvendik and Malgaçemir.

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