

An Update of the Geothermal Potential in the Continental Rift Zone of the Büyük Menderes, Western Anatolia, Turkey

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ABSTRACT

Up to date, new laws and regulations released by the Grand National Assembly of Turkey regarding the use of Renewable Energy Sources and Geothermal Energy accelerate research activities on the geothermal energy in Turkey in last a few years. In Turkey, more than 200 geothermal areas that are mostly low to medium enthalpy fields were discovered in last few years which are mainly suitable for direct use applications (3.000 MWt) such as space and greenhouse heating and balneological targets. Nowadays, the total capacity of geothermal power plants is about 600 MWe in Turkey. The good investigated thermal waters of Kızıldere, Salavatlı, Germencik, Pamukören and many others located in the continental rift zone of the Büyük Menderes represent typical examples of active geothermal systems and advise to indicate a big potential up to 860 MWe in the area for next future.

1. INTRODUCTION

In Turkey, the eastern Mediterranean area between the Eurasian and African plates is controlled by the Anatolian and Aegean microplates tectonically. This plate tectonic evolution results in the uplift of the Menderes Massif which shows a dome shaped structure due to compressional tectonic features through Oligocene and Miocene. During Early to Middle Miocene, the continental rift zones of the Büyük Menderes, Küçük Menderes and Gediz were formed by extensional tectonic features striking E-W generally and representing a great number of active geothermal systems, epithermal mineralizations and volcanic rocks from Middle Miocene to recent. The thermal waters are associated with the faults which strike preferentially NW-SE and NE-SW and locate diagonal to general strike of the rift zones of the Menderes Massif in the Western Anatolia. These NW-SE and NE-SW striking faults were probably generated by compressional tectonic regimes which leads to the deformation of uplift between two extensional rift zones in the Menderes Massif. In addition to heat flow anomalies in the rift zone of the Büyük Menderes, there is very intensively volcanic activity which is represented by various localities of a great number of calcalkaline towards acidic volcanic rocks and ranges from Middle Miocene to 10.000 a in age. The volcanic rocks are of products of continental crust based on isotope analyses of $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{144}\text{Nd}/^{143}\text{Nd}$ and can be considered as heat source for the heating of the thermal waters in the rift zone of the Büyük Menderes and elsewhere. Additionally, the geothermal gradients may contribute to heat the thermal waters in the reservoir consisting of limestones, marbles, quartzites and gneisses. One of these continental rift zones is the rift zone of the Büyük Menderes which represent a great number of thermal waters such as very important locations of Kızıldere, Salavatlı and Germencik (Figures 1 and 2).

The aim of this paper is to give an overview and to present enhanced hydrogeochemical and isotope geochemical data of the thermal waters in the rift zone of the Büyük Menderes in combination with interpretation of the origin and the evolution of these waters as well as the latest potential for electricity.

2. GEOLOGIC SETTING

The thermal field of Kızıldere with about 28 production and reinjection wells up to a depth down to 2872 m is located in the north of the eastern part of the Büyük Menderes rift zone (Figures 1 and 2) where three geothermal power plants with a capacity of approximately 100 MWe were installed. In Kızıldere, the Paleozoic basement rocks are overlain by Pliocene sedimentary rocks which consist of Kızılkaya formation, Sazak formation, Kolonkaya formation, and Tosunlar Formation (Figure 3; Özgür, 1998; Şimşek, 1985) and play an important role as basement and cap rocks. The Sazak formation composed of silicified limestones forms the first shallow reservoir. The Paleozoic İğdecik formation consisting of quartzites, marbles and mica schists is of second deep reservoir. The thermal field of Salavatlı with two production wells to a depth down to 1510 m is located in the north of middle part of the rift zone of the Büyük Menderes (Figures 1 and 2) and consists of Paleozoic metamorphic rocks and Miocene to Pliocene sedimentary rocks (Figures 1 and 2; Karamanderesi, 1997). Paleozoic marbles and quartzites in alternation of mica schists, marbles and quartzites form the thermal water reservoir in the field of Salavatlı. The capacity of geothermal power plants in the area is about 68 MWe. The thermal field of Germencik with approximately 100 production and reinjection wells to a depth down to 2600 m is one of the geothermal areas with high enthalpy located in the north of the western part of the rift zone of the Büyük Menderes and consists of Paleozoic metamorphic rocks and Miocene to Pliocene conglomerates (Correia et al., 1990; Figures 1 and 2). In the area, the conglomerates form the shallow reservoir whereas marbles and quartzites in alternation of marble, quartzite and mica schists are deep reservoir rocks. The total capacity of geothermal power plants is about 120 MWe. In addition, the thermal fields of Efeler in Umurlu, Yılmazköy, Pamukören, Sultanhisar, Durasallı and Atça will contribute to the geothermal potential up to 2018. These thermal fields are composed of Paleozoic metamorphic rocks and Miocene to Pliocene sedimentary rocks (Figures 1 and 2). The marbles and quartzites in alternation of mica schists, marbles and quartzites form the reservoir rocks in the thermal fields with temperatures up to 180 °C.

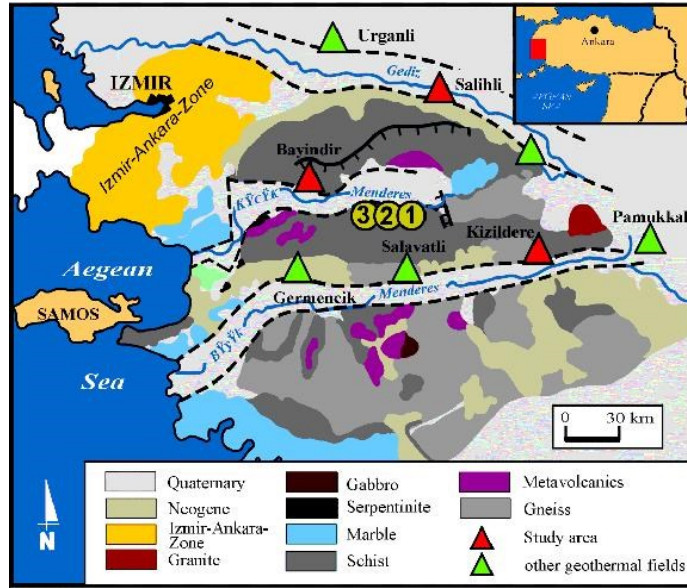


Figure 1. Geologic setting of the Menderes Massif and location map of the investigated some thermal fields of Kızılder, Salavatlı and Germencik. Epithermal mercury (1), antimony (2) and arsenopyrite-gold deposits (Özgür, 1998).

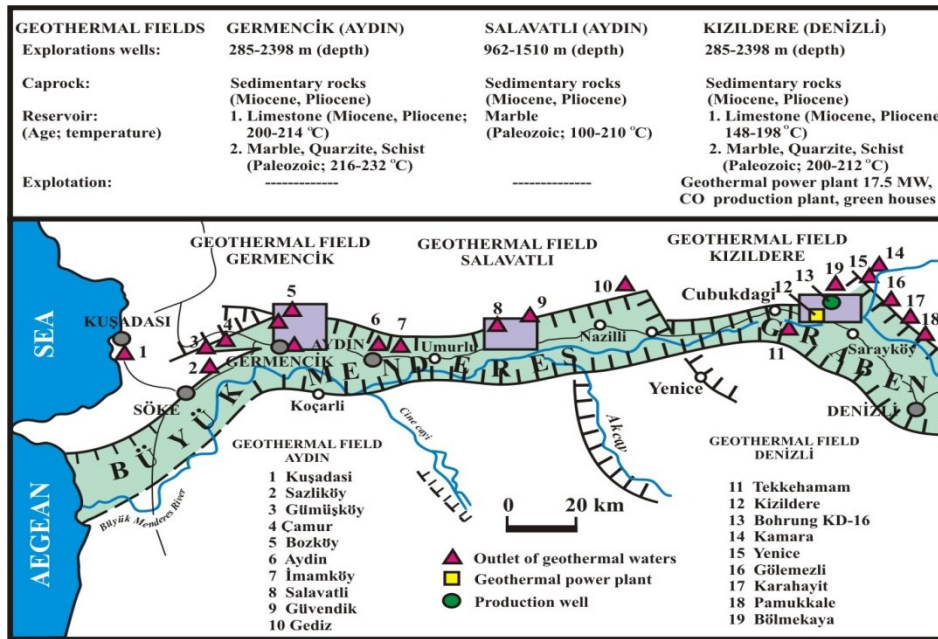


Figure 2. Distribution of the thermal fiels in the rift zone of the Büyük Menderes within the Menderes Massif (Özgür, 1998).

3. HYDROGEOLOGY AND HYDROGEOCHEMISTRY

3.1 Hydrogeology

At the surface, the metamorphic and sedimentary rocks in the thermal fields of the rift zone of the Büyük Menderes with localities such as Kızılder, Salavatlı, and Germencik are intensively altered recognized by a distinct color change of the rocks and studies of rock microscopy on various thin sections and x-ray diffractometry analyses. The hydrothermal alteration is distinguished by phyllic, argillic, and silicic ± haematitization zones. The phyllic and argillic alteration zones occur in the Paleozoic metamorphic rocks whereas silicic ± haematitization alteration zones are an overprinting type and observed in Paleozoic metamorphic and sedimentary rocks. In addition, a new alteration type of carbonatization is recognized in sedimentary rocks which can be observed in the thermal fields of Kızılder especially (Özgür and Pekdeğer, 1995). Due to high temperature, pressure, and CO₂ content in the thermal water reservoir of the study area, high temperature acid water infiltrates the soil formations and dissolves CaCO₃. The solution aims to get in an equilibrium onstantly, but does not reach the suitable parameters of the corresponding environment. Thus, the solution loses the temperature,

pressure, and CO₂ on its way to the surface, for which reason the pH values increase up to 9.2. Consequently, the geothermal fluid is unable to keep CaCO₃ in solution, but it precipitates and occurs in sedimentary rocks near the surface. The Silicic alteration zone can be observed in both Paleozoic metamorphic and Miocene to Pliocene sedimentary rocks (Özgür, 1998).

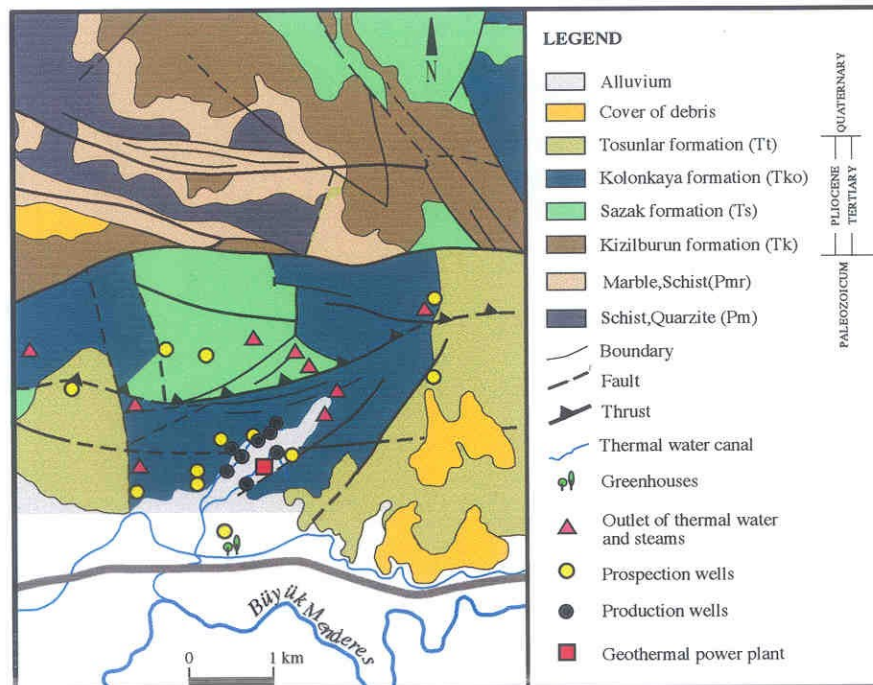


Figure 3. geological map of the thermal field of Kızıldere in the continental rift zone of the Büyük Menderes (Özgür, 1998).

3.2 Hydrogeochemistry

During the present study the outflow of 14 thermal springs and 14 production wells has been sampled in different seasons since 1992. Additionally, about 240 rock samples were collected. The thermal waters flow out of clastic sediments of Miocene to Pliocene age. The discharge of thermal waters is linked to faults which strike in E-W direction dip vertically. The surface temperatures of the thermal waters are 99 °C in Kızıldere, 45 to 95 °C in Salavatlı, and 30 to 92 °C in Germencik whereas the geochemical thermometers show reservoir temperatures of 200 to 240 °C in Kızıldere, 162 to 180 °C in Salavatlı, and 216 to 232 °C in Germencik. The total dissolved solids of the thermal waters ranges from 1800 to 6000 mg/l. At the surface the scale formations are generated by decreasing temperature and pressure. The scale formations consist of carbonates with high Sr anomalies and minor contents of silicates and sulfides. These minerals are mostly aragonite and calcite with high Au and Sb contents. Hydrogeochemically, the thermal waters can be considered as Na-(Cl)-(SO₄)-HCO₃ type (Figure 4) and are distinguished by an increase and a decrease of dominantly cations, anions, and trace elements from marine towards continental environment. Trace elements which indicate intensive high-temperature water-rock interaction such as B^(III) and F⁻, are found in high concentrations in these waters. With exception of As, Sb, and Hg, the thermal waters in the investigated fields are very poor in heavy metals. As, Sb, and Hg are known to precipitate mostly at the surface. There is a close correlation between F and B in depending of the increasing Na contents and the decreasing Ca contents in high temperature waters (Özgür and Pekdeğer, 1995; Özgür 2001, 2002). The origin of B^(III) can be attributed to mineral phases, i.e. tourmaline, biotite in metamorphic rocks, and boron deposits at depth (Özgür, 2001). Fluorine can be lead either to a volcanic activity or to the lower Ca contents in the fluids (Pekdeğer and Özgür, 1992).

4. ISOTOPE GEOCHEMISTRY

Samples from hot springs, production wells, and groundwaters in the rift zone of the Büyük Menderes have been analyzed for their oxygen-18, deuterium and tritium contents. Additionally, the thermal waters of Kızıldere were considered due to contents of $\delta^{13}\text{C}$ and ^{14}C .

The stable isotope contents of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ are represented in Figure 5. The above mentioned rainwaters and mixed groundwater-thermal water systems lie along the meteoric water line whereas the high temperature deep groundwater systems deviate from the MWL suggesting a fluid-rock interaction under high temperature conditions. The differences in the degree of isotope shift from Kızıldere to Germencik indicate a mixing between three thermal waters which are characterized by $\delta^2\text{H}$, $\delta^{18}\text{O}$, $\delta^{13}\text{C}$, ^3H , and ^{14}C values. The tritium measurements reveal that (i) the thermal waters of Kızıldere, Salavatlı, and Germencik do not contain any measurable tritium and (ii) the mineralized groundwater and groundwater-thermal water systems contain atmospheric and anthropogenic tritium. Therefore, the

tritium is not suitable for the age determination of the thermal waters of Kızıldere, Salavatlı, and Germencik. According to ^{13}C data, the origin of CO_2 might be attributed to magmatic activity as well as to reaction of thermal waters with carbonate rocks at depth [4]. These thermal waters show ^{14}C contents under detection limit because of the dilution of ^{14}C by high contents of CO (Figure 6). Under the consideration of this fact, the thermal waters of Kızıldere, Salavatlı, and Germencik might be interpreted as old waters with a relatively age of 10.000 to 30.000 a.

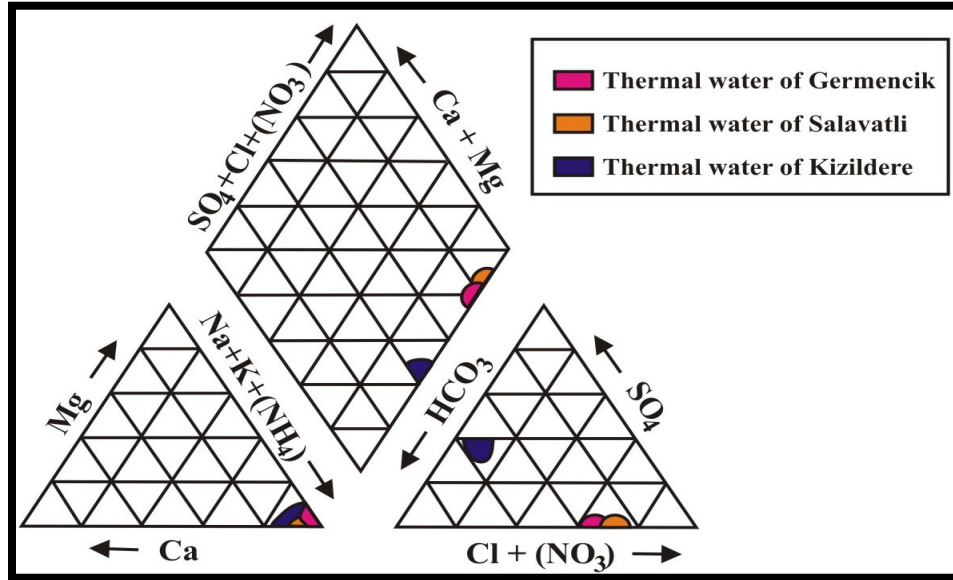


Figure 4. Thermal waters of Kızıldere, salavatlı and Germencik in the continental rift zone of the Büyük Menderes (Özgür et al., 1998)

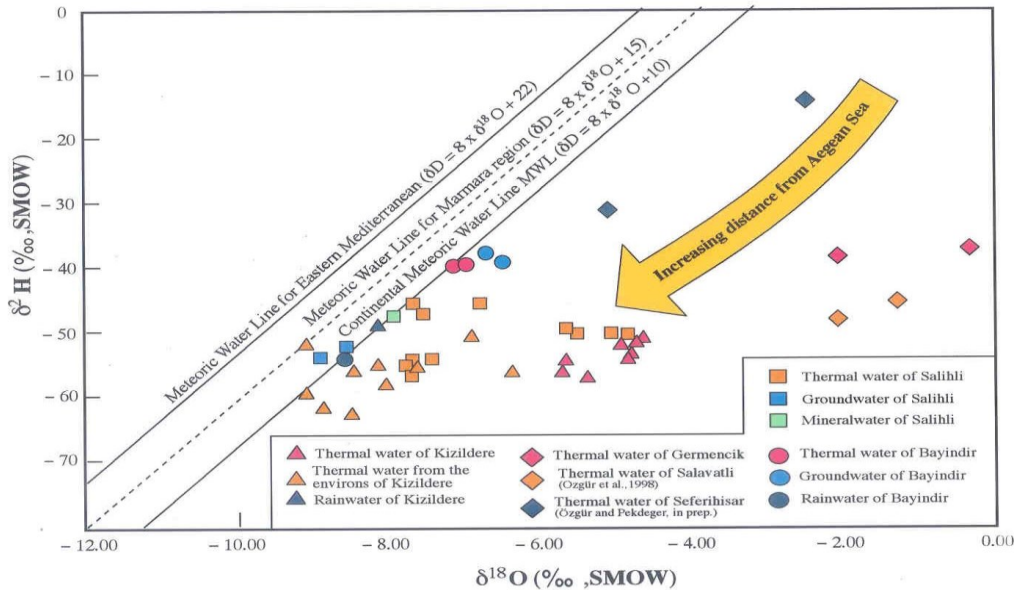


Figure 5. Plot of $\delta^2\text{H}$ versus $\delta^{18}\text{O}$ of thermal waters of Kızıldere, Salavatlı, Germencik and other localities in the continental rift zone of the Büyük Menderes (Özgür, 1998).

5. RESERVOIRS AND GEOTHERMAL POTENTIAL

5.1 Kızıldere

In Kızıldere, the Sazak formation forms the first shallow reservoir. In the course of this, the Upper Pliocene Tosunlar formation and Kolonkaya formation constitute impermeable cap rocks against which the Pliocene Kızılburun formation the impermeable basement rocks. The thermalwater reservoir in limestones of the Sazak formation is in a depth of 800 m and shows a thickness of 400 m and temperatures ranging from 150 to 198 °C (Figure 6). The marbles, quartzites and quartz schists form the second thermal water reservoir. In the course of this, the Early Pliocene Kızılburun formation the impermeable cap rocks during the Paleozoic impermeable rocks in

bedrock display the basement (Figure 6). Due to good developed fractures, the rocks of the İğdecik formation form the second deep thermal water reservoir in a depth from 1700 to 2800 m with a temperatures up to 250 °C. Thus, the thermal field of Kızıldere and environs has a potential of 260 MWe in next future.

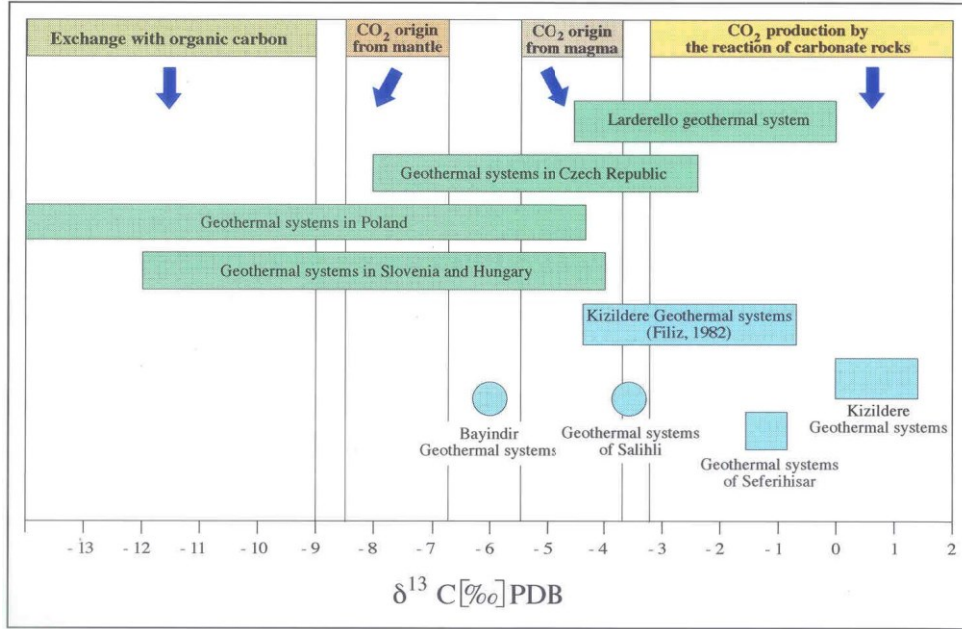


Figure 6. $\delta^{13}\text{C}$ values in the thermal waters of Kızıldere and environs within the continental rift zone of the Büyük Menderes (Özgür, 1998).

5.2 Salavatlı

The thermal field of Salavatlı with 10 production and reinjection wells to a depth down to 1800-2000 m is situated in the north of middle part of the middle part of the continental rift zone of the Büyük Menderes (Figures 1 and 2) and consists of Paleozoic metamorphic rocks composed of mica schists, marbles and quartzites and Miocene to Pliocene sedimentary rocks. Mica schists, marbles and quartzites form the thermal water reservoirs with temperatures up to 200 °C. The thermal field of Salavatlı end environs shows a geothermal potential of 75 MWe for the next future.

5.3 Germencik

The thermal field of Germencik with about 100 production and reinjection wells to a depth down to 2800 m is located in the north of the western part of the Büyük Menderes rift zone (Figures 1 and 2) and consists of Paleozoic mica schists, marbles and quartzites and Miocene to Pliocene sedimentary rocks. Paleozoic Mica schists, marbles and quartzites form the thermal water reservoirs with temperatures up to 240 °C. In the next future, the geothermal potential in Germencik and environs can be extended up to 250 MWe.

5.4 Other geothermal reservoirs

The other thermal fields in the continental rift zone of the Büyük Menderes are located in various parts of the continental rift zone of the Büyük Menderes, i.e. Umurlu, Köşk, Yılmazköy, Pamukören, Sultanhisar, Durasallı and Atça (Figure 1 and 2). In these locations, the Paleozoic mica schists, marbles and quartzites form the thermal water reservoirs with temperatures up to 180 °C. The geothermal potential in these locations can be assumed up to 275-300 MWe in the next future.

6. DISCUSSION

The investigated thermal waters of Kızıldere, Salavatlı, and Germencik are of meteoric origin. The meteoric waters in the drainage area percolate at fault zones and permeable clastic sediments into the reaction zone of the roof area of a magma chamber situated at a probable depth of up to 4 km where meteoric fluids are heated by the cooling magmatic melt and ascend to the surface due to their lower density caused by convection cells. The heating of the thermal waters by a subvolcanic activity are proven by the distinctly enrichment of mantle helium in geothermal fluids of Kızıldere (Güleç, 1988; Ercan et al., 1992) which might be interpreted as ^3He surplus in comparison to pure continental crustal fluids. This high value of mantle helium might be interpreted that basic volcanic rocks from the earth mantle show an interaction with the geothermal fluids in the environs of the thermal field of Kızıldere. Besides some intrusive rocks in the rift zones of Menderes Massif, calcalkaline basic to intermediate volcanic rocks exist which are generated from Middle Miocene to recent. For example, the basalts of Kula 150 km northern part of the investigated area, occur in a young age of 18.000 a. Thereby, the presence of magma chamber at depth of the rift zone of Büyük Menderes is not to exclude and must be taken into consideration, i.e. volcanic activities in Denizli and Söke.

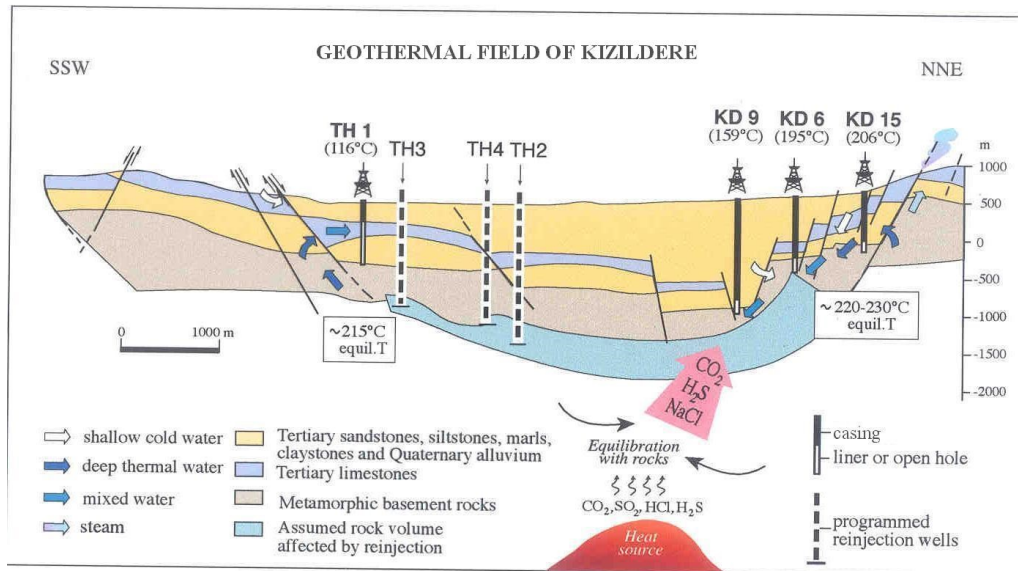


Figure 7. Geothermal model of the thermal waters in Kızıldere and environs within the continental rift zone of the Büyük Menderes.

Additionally, it is noticeable that the geothermal gradients form second possibility to heat the meteoric waters in the area, which correspond to the intensity of heat flow and earthquake activity. Nevertheless, the waters at depth react with heated rocks which leads to water-rock interaction. The volatile components of CO_2 , SO_2 , HCl , H_2S , HB , HF , and He out of the magma reach the thermal water reservoir where an equilibrium between altered rocks, gas components, and fluids performs. Thus, the thermal waters ascend in the tectonic zones of weakness at the rift zone of the Büyük Menderes in terms of hot springs, gases, and steams. The good investigated thermal waters of Kızıldere, Salavatlı, Germencik and many others located in the continental rift zone of the Büyük Menderes represent typical examples of active geothermal systems and advise to indicate a big potential up to 860 MWe (Kızıldere, Salavatlı, Germencik, Pamukören, other locations in the rift zone of the Büyük Menderes) in the area for next future.

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