

Conceptual model of geothermal resources of Alaşehir in the continental rift zone of the Gediz within the Menderes Massif, Western Anatolia, Turkey

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ABSTRACT

Geologically, the gneisses from the basement rocks in the study area which are overlain by an Paleozoic to Mesozoic intercalation of mica schists, quartzites and marbles, an Miocene intercalation of conglomerates, sandstones and clay stones and Plio-Quaternary intercalation of conglomerates, sandstones and clay stones discordantly. In the study area, Paleozoic to Mesozoic quartzites and marbles form the reservoir rocks hydrogeologically. The geothermal waters anions with Na+K>Ca>Mg dominant cations and HCO₃>Cl> dominant anions are of Na-HCO₃ type and can be considered as partial equilibrated waters. According to the results of geochemical thermometers, the reservoir temperatures area of about 185 °C in accordance with measured reservoir temperatures. Stable isotopes of δ¹⁸O versus δ²H of geothermal waters of Alaşehir deviate from the meteoric water line showing a intensive water-rock interaction under high temperature conditions. These data are well correlated with the results of the hydrogeochemical analyses which also indicate intensive water-rock interaction and reactions with silicates.

In the study area, the geothermal waters of meteoric origin. The infiltration takes place along the Menderes Massif. Due to the deep circulation which is made possible by the deep reaching fault system of the rift zone of Gediz, the meteoric waters are heated by recent subvolcanic activity such as Kula volcano with human foot prints. In the area of Alaşehir, the meteoric waters percolate at fault zones and permeable clastic sediments into the reaction zone of the roof area of a magma chamber (of Kula volcano) situated at a probable depth of 2-4 km where meteoric waters are heated by the cooling magmatic melt and ascend to the surface due to their lower density caused by convection cells. The volatile components of CO₂, SO₂, HCl, H₂S, HB, HF and He out of magma reach the geothermal water reservoir where an equilibrium between altered rocks, gas components and geothermal waters performs. Thus, the geothermal waters ascend in tectonic zones of weakness at the rift zone of the Gediz in terms of hot springs, gases and steams. Finally, the geothermal waters of Alaşehir are distinguished by a 2,0 percent CO₂ of productions in geothermal power plants especially. The geothermal waters of Alaşehir form the biggest potential in the rift zone of Gediz with a capacity of about 100 to 200 MWe.

1. INTRODUCTION

The Anatolian and Aegean micro plates control the plate tectonical position of the Eastern Mediterranean area between the Eurasian and African plates. Accordingly, the plate tectonical development results in the lifting of the Menderes Massif in western Anatolia, Turkey showing a dome structure due to compressional tectonic features from Oligocene to Miocene (Özgür, 1998). From Early Miocene to Middle Miocene, the continental rift zones of the Büyük Menderes, Küçük Menderes and Gediz within the Menderes Massif 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. In addition to earthquake activities and heat flow anomalies in the continental rift zones of the Menderes Massif (Alptekin et al., 1990), the localities of a great number of kalkalkaline basic towards acidic volcanic in these continental rift zones which range in age from Middle Miocene to 18.000a (Özgür, 1998). These volcanic rocks are of products of continental crust based on isotope analyses of ⁸⁷Sr/⁸⁶Sr and ¹⁴³Nd/¹⁴⁴Nd and might be considered as heat source for heating of the geothermal waters in the continental rift zones of the Menderes Massif. In correlation with epithermal mineralizations and volcanic rocks, the geothermal 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. 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. The one of these rift zones is Gediz which is distinguished by a great number of geothermal waters such as Alaşehir, Kurşunlu, Çamurlu, Pamukkale and Urganlı (Figure 1 and 2).

The aim of this paper to give an overview and to present enhanced hydrogeological, hydrogeochemical and isotope geochemical data of the geothermal waters in Alaşehir and environs at the rift zone of the Gediz within the Menderes Massif in combination with the origin and the evolution of these geothermal waters as well as the latest potential for electricity.

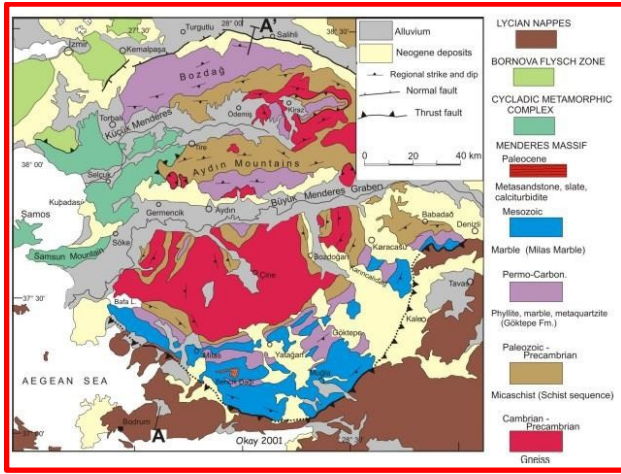


Figure 1. Geologic setting and continental rift zones of the Menderes Massif in western Anatolia, Turkey (Okay, 2001).



Figure 2. Continental rift zone of the Gediz and locations of geothermal waters.

2. GEOLOGIC SETTING

In the study area, the Paleozoic to Mesozoic metamorphic rocks which form the basement are overlain by Early to Middle Miocene Alaşehir and Kurşunlu formations (Figures 3 and 4; Seyitoğlu and Scott, 1996) discordantly. The metamorphic rocks are mostly gneisses, mica schists, carbonate schists and quartzites. Moreover, the marble intercalations within these rocks showing intensively fissures can be observed. The metamorphic rocks are overlain by Early to Middle Miocene Alaşehir formation consisting conglomerates and an intercalation sandstones and mudstones discordantly (İztan and Yazman, 1990; Seyitoğlu et al., 2002). Early to Middle Pliocene Kurşunlu formation overlies the Alaşehir formation concordantly. The both Alaşehir and Kurşunlu formations are overlain by Pliocene Sart formation discordantly. The sediments consisting of paleo alluvium, travertine and recent alluvium form the latest units and overlie all the units discordantly.

In the Menderes Massif, the continental rift zones were formed by the detachment faults in neotectonic period. Therefore, the continental rift zone of the Gediz can be considered as half graben. In the area of Gediz, there are three fault systems: (1) the first fault systems are normal faults and show 10 to 20 °C dipping to north which limit the Early to Middle Miocene Alaşehir and Kurşunlu formations tectonically (Seyitoğlu, 2002). The second fault systems control Pliocene Sart formation tectonically and show a strike of N75W and a dip of 45-50° NE (Seyitoğlu et al., 2000). This second fault system with high angles is located in the upper part of the first fault system and reach forth 25-30 km between Alaşehir and Salihli (Seyitoğlu et al., 2000). The third fault system is a fault system which separates Neogene units from the Quaternary alluviums.

3. MATERIAL AND METHODS

The field works for investigations of geothermal waters in Alaşehir and environs were realized February and March 2016. In this study, in-situ measurements such as temperatures, pH, Eh (mV), dissolved oxygen (mg/l), electrical conductivity ($\mu\text{S}/\text{cm}$) and alkalinity as well as sampling of geothermal waters in locations of 5 production and 1 reinjection wells for the analyses of anions, cations and stable isotopes such as $\delta^{18}\text{O}$, $\delta^2\text{H}$ and ^3H have been carried out (Figure 3; Table 1: Bostancı, 2016; Anılır Yürük, 2017). In the field, the pH values of the water samples were adjusted in an interval between 2 and 3 by dropping of pure HNO_3 for cation analyses. The samples were analyzed for cations anions in the Laboratory the Mineral Research and Exploration Institute, Ankara, Turkey and for stable isotopes (^{18}O and ^2H) and tritium (^3H) in the Isotech Laboratories, Inc. (Illionis, USA).

4. RESULTS

4.1 HYDROGEOLOGY

The study area around the township Alaşehir belonging to the province capital of Manisa is located in the zone of semi-arid and extremely continental climatic conditions with an annual temperature 16,5 °C and annual precipitation of 478,8 mm. These climatic conditions are of most important features for the supply of geothermal reservoir in depth by meteoric waters. The mica schists in the geothermal field form the impermeable basement rocks as well as impermeable cap rocks. In general, the reservoir rocks are of marbles, quartzites and limestones with intensively fissures. Moreover, the widespread conglomerates and sandstones might be considered as reservoir rocks. Finally, the shales within mica schists, Tertiary clay stones, clayey limestones and clayey limestones are considered as common cap rocks in the area of Alaşehir and environs.

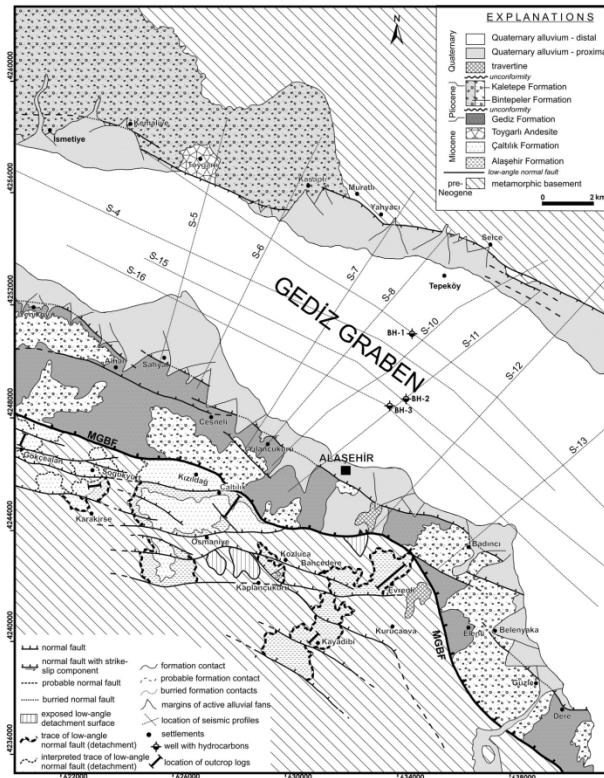


Figure 3. Geological map of Alaşehir and environs in the continental rift zone of the Gediz within the Menderes Massif (Çiftçi and Bozkurt, 2009).

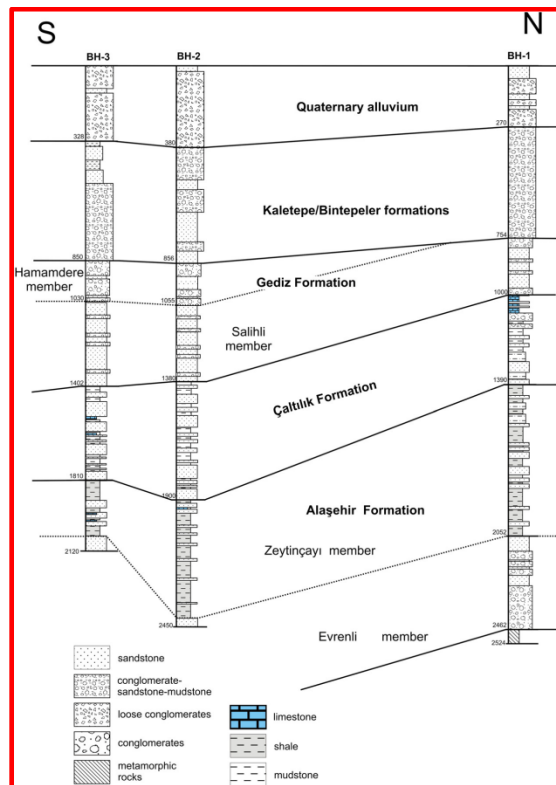


Figure 4. Geological section correlating the boreholes drilled in the continental rift zone of the Gediz (Çiftçi and Bozkurt, 2009).

Table 1. In-situ parameters and concentrations of cations and anions of the geothermal waters of Alaşehir and environs in the continental rift zone of the Gediz,

No	Sample	Well	X	Y	T (°C)	pH	Eh (mV)	EC (μ S/cm)	Na ⁺ (mg/l)	K ⁺ (mg/l)	Ca ²⁺ (mg/l)	Mg ²⁺ (mg/l)	B ³⁺ (mg/l)	F ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	Cl ⁻ (mg/l)	Si ⁴⁺ (mg/l)	NO ₃ ⁻ (mg/l)	HCO ₃ ⁻ (mg/l)
1	YB-1	BY-2	35S0623766E	04251108N	190°C	7.31	-296.4	2550	590	53.6	5.15	1	104	3.2	22.5	174	165	0.1	1403
2	YB-2	BY-4	35S0623390E	04251470N	185°C	7.64	-309	2540	539	63.5	3.61	1	103	3.4	22.6	174	190	0.1	1342
3	YB-3	BY-1	35S0623847E	04251579N	170°C	8.53	-334.4	2590	534	54.8	7.93	1	98.1	3	18.9	181	145	0.1	1391
4	YB-4	BP-1	35S0625183E	04251730N	68°C	7.22	-277	2600	537	54.1	6.13	1	98.5	2.9	14.3	168	154	0.1	1270
5	EY-1		35S0633846E	04248946N	88 °C	7.36	20.5	4090	939	42.9	99.1	8.95	76.7		55.8	367	-	0.1	2410
6	EY-2		35S0633138E	04249148N	82 °C	7.14	-144.5	3880	842	65.3	108	4.95	85.8		37.7	382	-	0.1	2166

4.2 HYDROGEOCHEMISTRY

4.1.1 Hydrogeochemical analyses

For the geochemical analyses of the results, we have used the Aquachem version 3.7 software (Calmbach, 1999). The samples of geothermal waters in localities of 5 geothermal production wells and 1 reinjection well can be considered as Na-HCO₃ type waters hydrogeochemically (Figure 5). There, the geothermal waters belong to the cations of Na+K>Ca>Mg and anions of HCO₃>Cl>SO₄ facies. The ternary Na+K-Mg-Ca diagram of the study area shows that Na+K are the predominant cations (Figure 6). This is expected because Na contents in water increase with temperatures while Ca and Mg contents decrease explaining the low values of these elements in the geothermal waters of the study area. In the diagram of Na-K-Mg^{1/2}, the geothermal waters can be classified as immature waters (Figure 7; Giggenbach, 1988; Bostancı, 2016; Anılır Yürük, 2017).

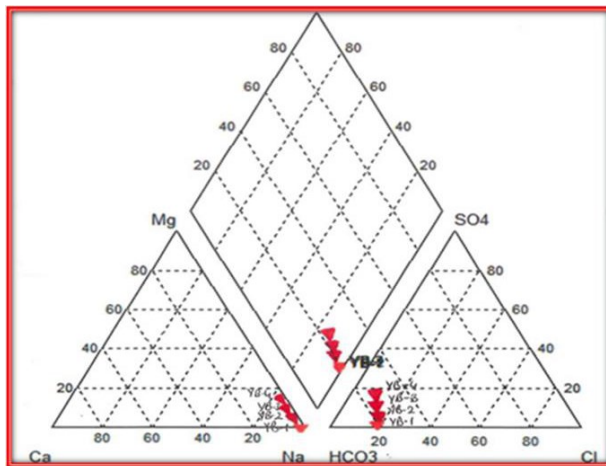


Figure 5. Piper Diagram of the geothermal waters of the study area

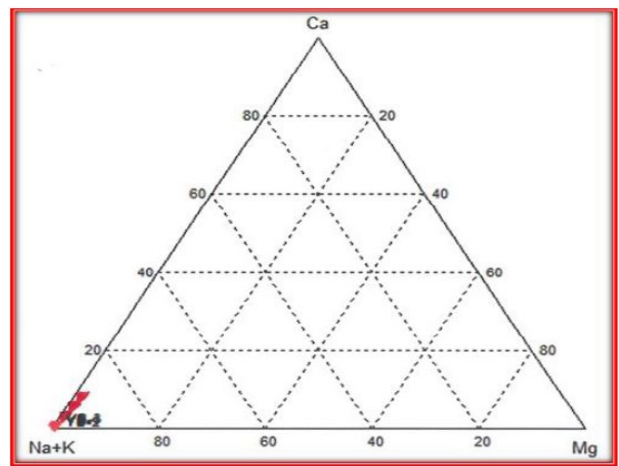


Figure 6. Na+K-Ca-Mg diagram of the geothermal waters in the study area

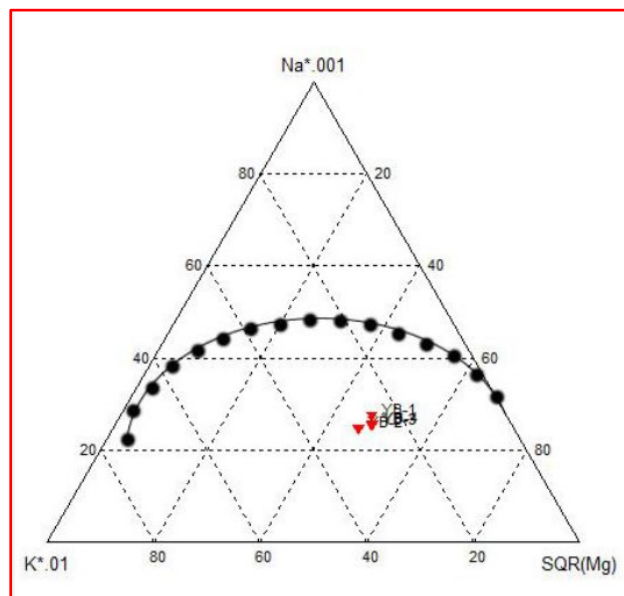


Figure 7. Distribution of the geothermal waters from the study area in the Na-K-Mg^{1/2} ternary diagram (Giggenbach, 1988).

4.1.2 Saturation indexes

The saturation index of some carbonates (commonly aragonite, calcite and dolomite) and chalcedony help us to estimate which one of these minerals may precipitate during the extraction and use of the geothermal fluids. These calculations are useful in predicting the presence of reactive minerals and estimating mineral reactivity in a water system. Moreover, saturation index also help us to evaluate the chemical equilibrium between fluid and rock in a geothermal system. This is accomplished by gathering information about the solubility of minerals in rocks that have undergone hydrothermal alteration and about the activity of the mineral type in the solution. Because of the large number ions, ion-pairs and complexes, generating the saturation index for each type as well as activities require the use a software program (Calmbach, 1999). The saturation index of the geothermal waters, for a given mineral, were calculated at the discharge temperature as well as considering the simulation with increasing temperatures and measured pH values. Aragonite, calcite and chalcedony are oversaturated at discharge temperatures (Bostancı, 2016; Anılır Yürük, 2017). In comparison, anhydrite, fluorite, dolomite, gypsum and quartz are under saturated at discharge temperatures. According to these saturation indexes, scaling of the carbonate minerals is expecting for the geothermal waters and this agrees with field observations as waters from deep wells cause scaling during extraction. Thus, inhibitors are employed in the prevention of scaling in the production wells.

4.1.3 Geochemical thermometers

In the study area, the hydrogeochemical analyses of the geothermal waters were evaluated using silica and cation thermometers (Na-K and Na-K-Ca geothermometers) in order to understand the reservoir temperatures of the geothermal waters. The silica thermometers indicate a reservoir temperatures between 194 and 234 °C (Bostancı, 2016; Anılır Yürük, 2017). In addition, Na/K geothermometers show temperatures between 229 and 259 °C which correspond with manual measured reservoir temperatures.

5. ISOTOPE GEOCHEMISTRY

Samples of the geothermal waters in geothermal waters were analyzed for their ^{18}O , ^2H and ^3H contents (Bostancı, 2016; Bülbül, 2009). The mixed groundwater and geothermal water systems lie along the meteoric water line whereas the high temperature geothermal waters deviate from the meteoric water line showing intense water-rock interaction under high temperature conditions (Figure 8; Bostancı, 2016). These data are well correlated with the results of hydrogeochemical analyses which indicate high water-rock interaction and reactions with silicates. The tritium data reveal that (i) the geothermal waters in the study area do not contain any measurable tritium firstly and (ii) the sedimentary mineralized groundwaters and the low temperature geothermal waters contain atmospheric and anthropogenic tritium. Therefore, a mixing process between the fresh groundwaters and deep geothermal waters are evidenced for the geothermal waters elsewhere in the environs of the study area of Alaşehir.

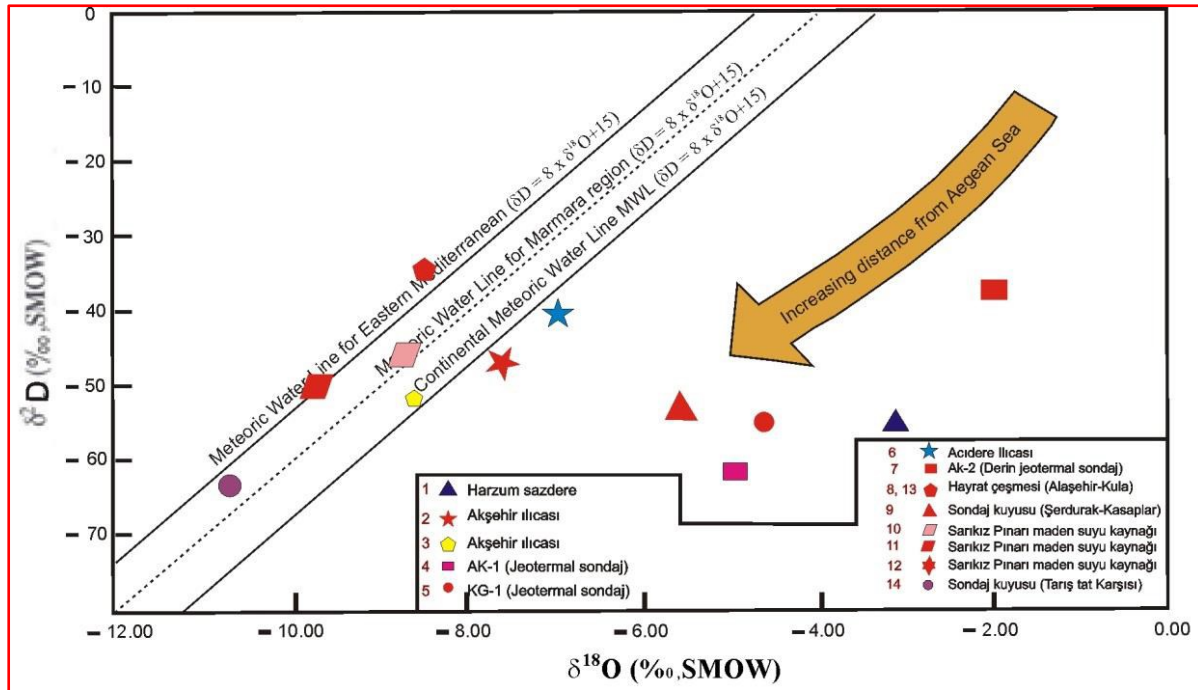


Figure 8. Plot of δD versus $\delta^{18}\text{O}$ in the different groundwaters and geothermal waters in Alaşehir and environs.

6. DISCUSSION

The investigated geothermal waters in the field of Alaşehir and environs in the continental rift zone of the Gediz are of meteoric origin. These meteoric waters in the drainage area percolate at fault zones and permeable clastic sediments into the reaction zone of roof area of a magma chamber located at a probable depth up to 4-5 km where the meteoric waters are heated by the cooling magmatic belt and ascend to the surface due to their lower density caused by convection cells (Figure 9). The volatile components such as CO_2 , SO_2 , HCl , H_2S , HB^- , HF^- , and He out of magma reach the geothermal waters where an equilibrium between altered rocks, geothermal waters and gas components is performed. Thus, the geothermal waters ascend in the faults of the continental rift zone of the Gediz as hot springs, steams, and gases.

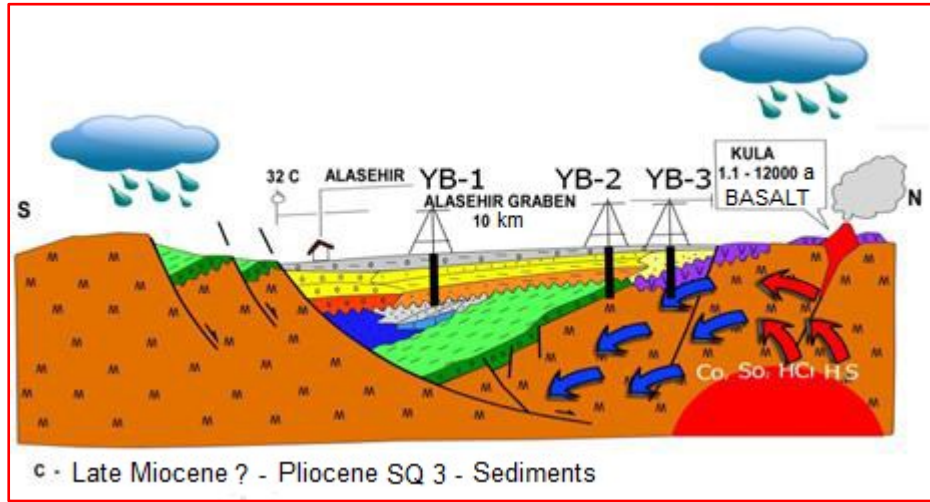


Figure 9. Hydrogeological modeling of the geothermal waters in Alaşehir and environs within the continental rift zone of the Gediz.

The heating of the geothermal waters by subvolcanic activities has been proven by the distinctly enrichment of mantle helium in geothermal waters of Kızıldere in the continental rift zone of the Büyük Menderes (Ercan et al., 1995; Güleç, 1988; Özgür, 1998) which might be interpreted as ^3He surplus in comparison to pure continental crust fluids. This high value of mantle helium might be interpreted that the basic volcanic rocks of the earth mantle show an interaction with geothermal fluids in Kızıldere and elsewhere. In the continental rift zones of the Büyük Menderes, the Küçük Menderes and the Gediz within the Menderes Massif, calcalkaline basic, intermediate to acidic volcanic rocks exist which are generated from Middle Miocene to recent. The basalts of Kula, located 25-30 km NE part of the study area, occur in an age from 7,5 Ma to 20.000 a (Ercan et al., 1992; Figure 10).



Figure 10. Human foot print on the surface of the Kula volcanic in the continental rift zone of the Gdz.

The geothermal waters in Alaşehir and environs in the continental rift zone of the Gediz have 2.0 percent CO₂ contents which represent very important environmental problems. Therefore, these CO₂ emissions must be reinjected into the reservoirs at the achievement of the geothermal energy. Finally, the geothermal waters of Alaşehir and environs contain boron contents up to 104 mg/l (Bostancı, 2016) and display environmental problems in the study area. By the reinjection of the geothermal waste waters in the geothermal power plants in the area of Alaşehir and environs, these environmental problems can be considered as finished. The geothermal waters of Alaşehir form the biggest potential in the rift zone of Gediz with a capacity of about 100 to 200-250 MWe in next future.

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