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Hydrogeological Modelling of Some Geothermal Waters of Havran, Ivrindi and Gonen in the Province Capital of Balikesir, Western Anatolia, Turkey

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ABSTRACT

In this study, hydrogeological, hydrogeochemical and isotope geochemical features of Havran, Gönen and Ivrindi within the province capital of Balıkesir, Turkey were investigated in detail. The Early Triassic Karakaya formation in the study area of Havran forms the oldest rocks consisting of spilitic basalts, diabases, gabbros, mudstones, cherts and radiolarites. There are limestone blocks in this formation with intercalations with sandtones with feldspar contents, quartzites, conglomerates and siltsones. Oligocene to Miocene granodiorite intrusions were generated in association with intensively volcanic events in the area. Between Upper Oligocene and Early Miocene, andesitic and dacitic pyroclastic rocks cropped out due to intensively volcanism. Later, conglomerates, sandstones, claystones, marls and limestones as lacustrine sediments formed from Middle to Upper Miocene in the study area. In the study area of Gönen, the Lower Triassic Karakaya formation consists of basalts, diabases, gabbros, mudstones, cherts and radiolarites and forms the basement rocks overlain by Upper Jurassic to Lower Cretaceous sandy limestones. Upper and Middle Miocene volcanics which can be considered intensive Biga Peninsula volcanos outcrop in the area. These andesitic lava flows are of black, gray and red color with intensive fissures. Neogene lacustrine sediments consist of conglomerates, sandstones, marl, claystone and clayey limestones. Upper Miocene to Pliocene rhyolitic pyroclastics and dacitic lava flows are the volcanic rocks which are overlain by Pliocene conglomerates, sandstones and claystones. In the study area of Ivrindi, the Çaldağ limestones are the oldest formation in Permian age. Çavdartepe metamorphic rocks are of Lower Triassic in which can be observed marbles sporadically. The Kınık formation consisting of conglomerates, sandstones, siltstones and limestones are of Lower Triassic age and display a lateral stratigaphic progress with volcanic rocks. Upper Miocene to Pliocene Yürekli formation consists of dacites and rhyodacites. Upper Miocene to Pliocene Soma formation is composed of clayey limestone, marl, siltstone, intercalations of sandstone, agglomerate and andesitic gravels and blocks cemented by tuffs. Quaternary alluvium is the youngest formation. The samples of geothermal waters in the area of Havran can be considered as Na-Ca-(SO_4)-HCO_3, Na-(SO_4)-HCO_3 and Na-SO_4 type waters. In comparison, the geothermal waters in Gönen are of Na-(SO_4)-HCO_3 and Na-HCO_3 type waters. The geothermal waters of Ivrindi are considered as Na-Ca-HCO_3 type waters. In the area, a groundwater sample is of Ca-Mg-HCO_3 type water. The geothermal waters belong to the cations of Na+K>Ca>Mg in Havran, Gönen and Ivrindi and to the anions of SO_4>HCO_3>Cl in Havran, HCO_3>SO_4>Cl in Gönen and SO_4>HCO_3>Cl in Ivrindi.In the diagram of Na-K-Mg1/2, the geothermal waters in Havran, Gönen and Ivrindi of the province capital of Balıkesir can be classified as immature waters.

1. INTRODUCTION

In the province capital of Balıkesir within western Anatolia, Turkey, there is a great number of geothermal waters (Figure 1; Mutlu, 2007). The geothermal waters in Havran, Gönen and Ivrindi have surface temperatures between 25 and 98 °C. The aim of this paper is (i) to update of the geological mapping of the study area, (ii) to describe the reservoir rocks within the fluid-rock interaction petrographically, (iii) to investigate hydrothermal alteration mineralogy by rock petrograhical and geochemical methods, (iv) to study hydrogeochemical features of the geothermal waters and (v) to develop an Hydrogeological modeling of the geothermal waters in the areas of Havran, Gönen and Ivrindi of the province capital of Balıkesir.

2. GEOLOGIC SETTING

The study areas of Havran and Ivrindi are located in western part of the province capital of Balıkesir in NW Anatolia. The study area of Gönen lies in northern part of Balıkesir (Figure 1). In Havran, the Early Triassic Karakaya formation forms the oldest rocks consisting of spilitic basalts, diabases, gabbros, mudstones, cherts and radiolarites[Sarp et al., 1998; Özgür et al., 2017, 2]. There are Permian limestone blocks in this formation with intercalations of sandtones, quartzites, conglomerates and siltsones. Oligocene to Miocene granodiorite intrusions were generated in association with intensive volcanic activities in the area. Between Upper Oligocene and Early Miocene, andesitic and dacitic pyroclastic rocks cropped out due to intensively volcanism. Later, conglomerates, sandstones, claystones, marls and limestones as lacustrine sediments formed from Middle to Upper Miocene in the study area. In Gönen, the Lower Triassic Karakaya formation consists of basalts, diabases, gabbros, mudstones, cherts and radiolarites and forms the basement rocks overlain by Upper Jurassic to Lower Cretaceous sandy limestones (Sarp et al., 1998; Özgür et al., 2017). Upper and Middle Miocene volcanics which can be considered intensive Biga Peninsula volcanos outcrop in the area.

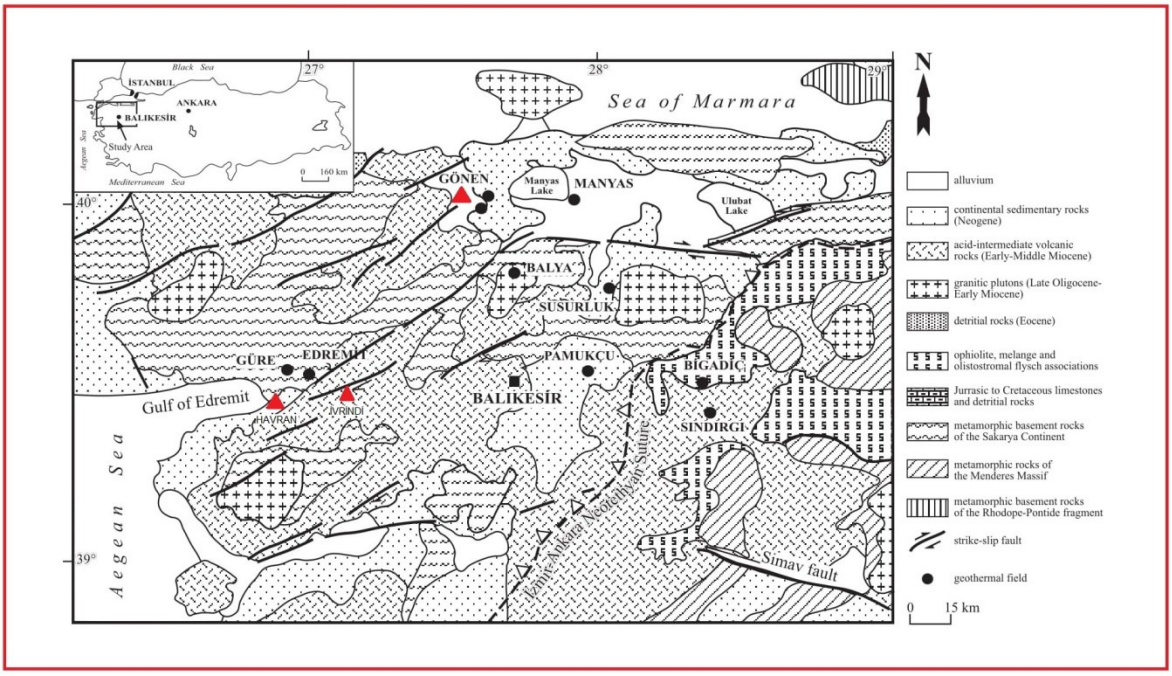

Figure 1. Geological map of the western and northern part of the province capital of Balıkesir and locations of the geothermal areas of Havran, Gönen and Ivrindi (Mutlu, 2017).

These andesitic lava flows are of black, gray and red color with intensive fissures. Neogene lacustrine sediments consist of conglomerates, sandstones, marl, claystone and clayey limestones. Upper Miocene to Pliocene rhyolitic pyroclastics and dacitic lava flows are the volcanic rocks which are overlain by Pliocene conglomerates, sandstones and claystones. In Ivrindi, , the Çaldağ limestones are the oldest formation in Permian age. Çavdartepe metamorphic rocks are of Lower Triassic in which can be observed marbles sporadically (Akyürek and Soysal, 1980; Özgür et al., 2017). The Kınık formation consisting of conglomerates, sandstones, siltstones and limestones are of Lower Triassic age and display a lateral stratigaphic progress with volcanic rocks. Upper Miocene to Pliocene Yürekli formation consists of dacites and rhyodacites. Upper Miocene to Pliocene Soma formation is composed of clayey limestone, marl, siltstone, intercalations of sandstone, agglomerate and andesitic gravels and blocks cemented by tuffs. Quaternary alluvium is the youngest formation.

3. MATERIAL AND METHODS

The field works for investigations of geothermal waters of Havran, Gönen and Ivrindi in the province capital of Balıkesir were realized August 2015. In this study, in-situ measurements such as temperatures, pH, Eh (mV), dissolved oxygen (mg/l), electrical conductivity (µS/cm) and alkalinity as well as sampling of geothermal waters in 10 locations for the analyses of anions, cations and stable isotopes such as $\delta^{18}O$, $\delta^{2}H$ and ^{3}H have been carried out (Özgür et al., 2017; Özgür, 2018a, b; Uğurlu, 2018). 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.

4. RESULTS

4.1 Hydrogeology

The study area around Havran is located in a zone of semi-arid and extremely continental climatic conditions with an annual temperature of 14,5.°C and annual precipitation of 669,5 mm. These climatic conditions are of most important features for the supply of geothermal reservoir in depth by meteoric waters. In Havran, intercalations of sandstones, quartzites and conglomerates in Lower Triassic Karakaya formation with Permian olistolithes of limestones are of reservoir rocks. The Karakaya formation can be considered as impermeable basement rocks. In Gönen, the Karakaya formation forms the impermeable basement rocks. Upper Jurassic to Early Cretaceous sandy limestones and andesitic to rhyolitic lava flows and pyroclastics are of reservoir rocks with different impermeable claystones as impermeable cap rocks. In Ivrindi, Early Triassic Çavdartepe metamorphic rocks form the permeable basement rocks. The intercalations of conglomerates, sandstones, siltstones and limestones in Early Triassic Kınık formation play an important role for reservoir rocks of geothermal waters.

4.2 Hydrogeochemistry

Upper Jurassic to Early Cretaceous sandy limestones and andesitic to rhyolitic lava flows and pyroclastics are of reservoir rocks with different impermeable claystones as impermeable cap rocks. In Ivrindi, Early Triassic Çavdartepe metamorphic rocks form the permeable basement rocks. The intercalations of conglomerates, sandstones, siltstones and limestones in Early Triassic Kınık formation play an important role for reservoir rocks of geothermal waters.

4.2.1 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 the area of Havran can be considered as Na-Ca-(SO_4)-HCO_3, Na-(SO_4)-HCO_3 and Na-SO_4 type waters (Figure 2). In comparison, the geothermal waters in Gönen are of Na-(SO_4)-HCO_3 and Na-HCO_3 type waters. The geothermal waters of Ivrindi are considered as Na-Ca-HCO_3 type waters. In the area, a groundwater sample is of Ca-Mg-HCO_3 type water. The geothermal waters belong to the cations of Na+K>Ca>Mg in Havran, Gönen and Ivrindi and to the anions of SO_4>HCO_3>Cl in Havran, HCO_3>SO_4>Cl in Gönen and SO_4>HCO_3>Cl in Ivrindi [Özgür et al., 2017). In the diagram of Na-K-Mg1/2(Figure 3), the geothermal waters in Havran, Gönen and Ivrindi of the province capital of Balıkesir can be classified as immature waters (Akyürek ve Soysal, 1980; Calmbach, 1999; Özgür, 2018b, Uğurlu, 2018).

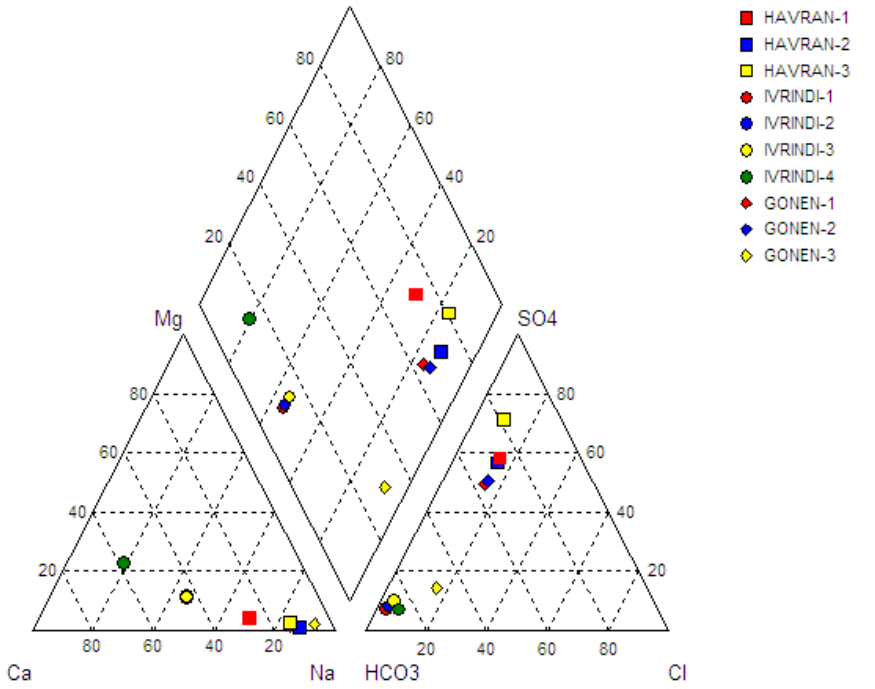

Figure 2. The geothermal waters of Havran, Gönen and Ivrindi of the province capital of Balıkesir in Piper diagram (Özgür et al., 2017)..

4.2.2 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 (Özgür, 1980). 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 (Özgür, 2018a, b; Uğurlu, 2018). 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.

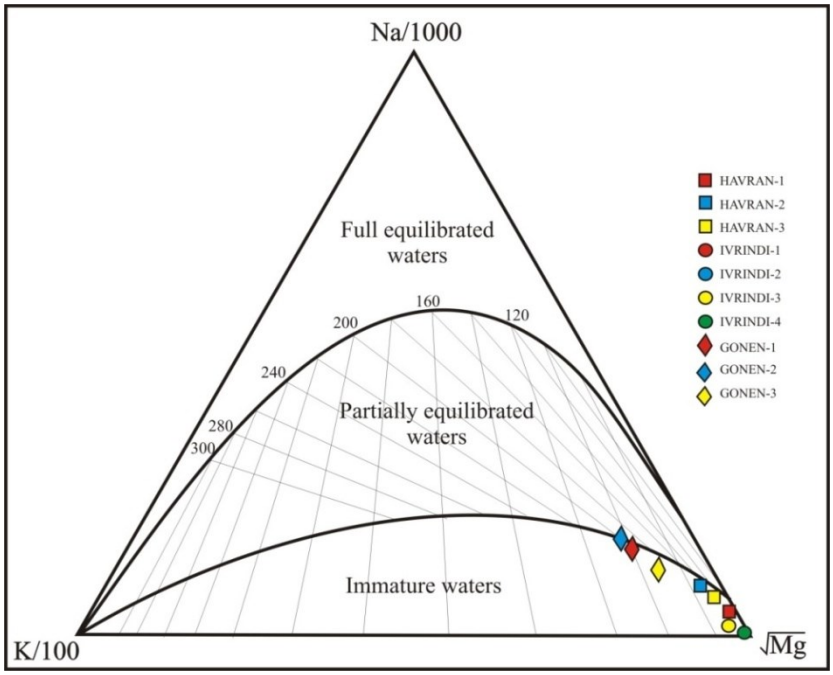

Figure 3. Na/100-K/100-Mg1/2 ternary diagram of the geothermal waters of Havran, Gönen and Ivrindi (Modified from Giggenbach, 1988; Özgür et al., 2017).

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 100 and 120 °C in Havran (Uğurlu, 2018), between 110 and 120 °C in Gönen (Özgür, 2018a) and between 85 and110 °C in Ivrindi (Özgür 2018a, b; Uğurlu, 2018). In addition, Na/K geothermometers show temperatures between 90 and 110 °C in Havran (Uğurlu, 2018), between 130 and 180 °C in Gönen (Özgür, 2018a) and between 160 and 220 °C in Ivrindi (2018b).

5. ISOTOPE GEOCHEMISTRY

Samples of the geothermal waters in geothermal waters were analyzed for their $\delta^{18}O$, $\delta^{2}H$ and ^{3}H contents (Özgür, 2018a, b; Uğurlu, 2018). 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 4). 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 areas of Havran, Gönen and Ivrindi in the province capital of Balıkesir.

6. DISCUSSION

The investigated geothermal waters in the fields of Havran, Gönen and Ivrindi of the province capital of Balıkesir 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 5). 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. 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 ^{3}He surplus in comparison to pure continental crust fluids.

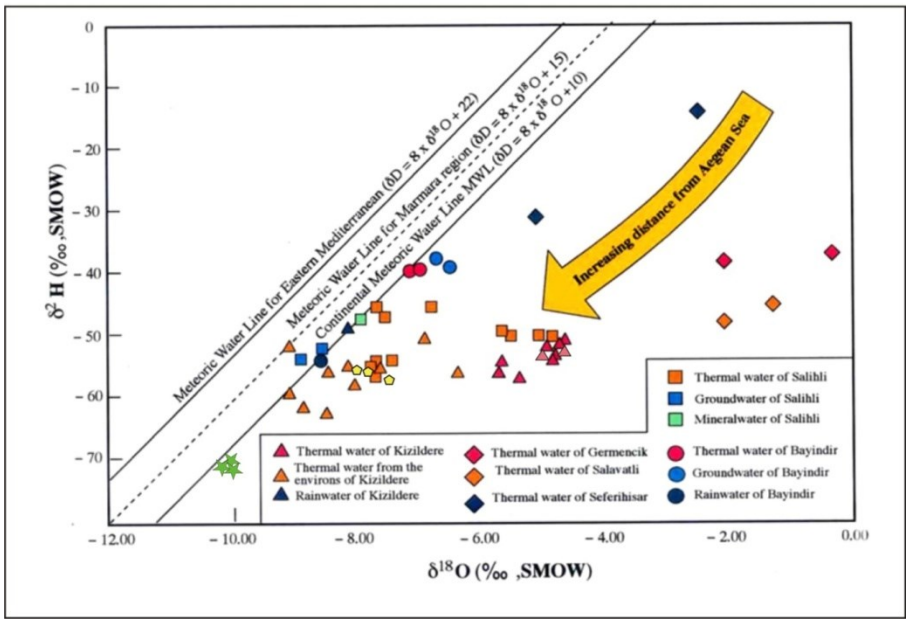

Figure 4. $\delta^{18}O$ versus $\delta^{2}H$ in geothermal waters of Havran, Gönen and Ivrindi in province capital of Balıkesir (Özgür et al., 2017).

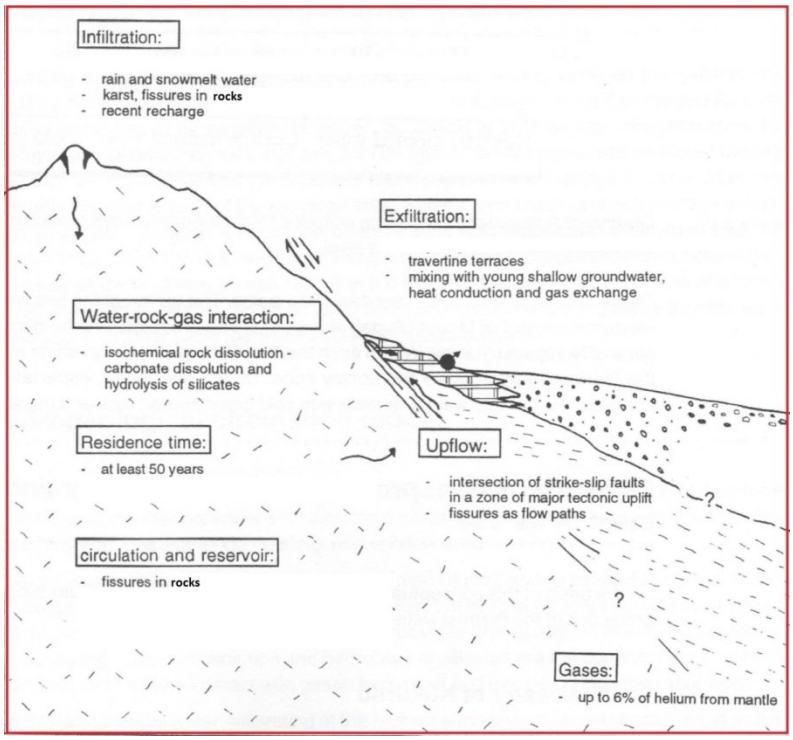

Figure 5. Hydrogeological modeling of the geothermal waters of Havran, Gönen and Ivrindi in the province capital of Balıkesir. Stars: Geothermal waters of Gönen(modified from Imbach, 1997; Özgür et al., 2017).

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 Havran, Gönen and Ivrindi, basic, intermediate to acidic volcanic rocks exist which are generated from Middle Miocene to Pliocene and can be considered as heat source of the geothermal waters.

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