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Geological and Hydrogeological Properties of the Girelli Geothermal Field (Alaşehir Graben, Western Turkey)

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ABSTRACT

The Girelli Geothermal area is located on the southern margin of the Alaşehir (Gediz) Graben in the west of Turkey where N-S trending extensional tectonics have been developed since Miocene time. The Gediz graben has a WNW–ESE trending structure bounded by crustal-scale Gediz detachment faults that graben controlled supradetachment basin-fill deposits. The footwall of the Gediz detachment comprises gneiss, marble, and schist of the Menderes metamorphic core complex, as well as Miocene synextensional granite. The hanging wall of the detachment fault comprises Miocene to Quaternary sedimentary units reaching up to 3000 m thick towards the basin center. It pinches out northward and thus forms an asymmetric geometry. Many geothermal resources occur along the southern margin of the Gediz Graben. One of them is the Girelli area that covers a depression having developed on the horst of one of the branches of the Gediz Detachment Fault.

The measured reservoir temperature has been found to be as high as 287 °C in the northwest of the Girelli area. Geothermal fluid is one of the most significant indications in this area where intense silicic and argillic alteration is observed. Cation and anion concentrations in thermal waters are related to the level of chemical equilibrium the waters have achieved with the surrounding rock. Cold water resources are rich in Ca-Mg-HCO_3 and Na-Ca-Mg-HCO_3 ions and the fact that the anion and cation are parallel with each other at the water points shows that these waters have the recharge and reservoir of the same origin in the area. The geothermal fluid of the region is rich in Na-HCO_3 ions and the fact that the anion and cation values are parallel with each other just like in the case of cold waters shows that these waters have the recharge and reservoir of the same origin. Geothermometers based on cation and silica concentrations have been used to estimate reservoir temperature. They are based on the interaction between the water and surrounding rock chemistry. The geothermal fluid is likely equilibrating with chalcedony or quartz. Silica geothermometers suggest reservoir temperatures could be between 160°C and 180°C. A total of 30 MT survey points were conducted across the Girelli region. MT results provide potential geophysical evidence that helps to understand the occurrence of the partially hot point in the west part of Girelli village.

1. INTRODUCTION

The western Anatolia region is one of the most seismically active regions in the world. It has a considerably high level of geothermal energy potential thanks to its geological and tectonic settings. The distribution of thermal springs in Anatolia roughly coincides with the distribution of the fault systems, young volcanism and hydrothermally altered areas. Geothermal energy is used in various applications such as power generation, greenhouse and district heating and balneology in western Anatolia. Most of the geothermal sites are high enthalpy fields, which are suitable for power generation. Turkey is one of only five countries that have more than 1 GW installed geothermal power capacity. The total installed geothermal power capacity is 1,347 MW_e. In addition, some geothermal power plants are under construction and some of them are in the planning stage in western Anatolia. In this paper, we focus on the southeastern part of the Alaşehir (Gediz) graben, where the Girelli geothermal field is located (Fig. 1).

Figure 1. Location map of study area

Most of the geothermal resources are located on The Gediz Detachment Fault (GDF). N-S oriented expansion occurring in western Anatolia in the Late Tertiary period terminated the crustal-scale detachment faults and the metamorphic core complexes developing in association with them (Hetzel et al., 1995; Emre, 1996; Emre and Sozbilir, 1997; Kocyigit et al., 1999; Seyitoglu et al., 2000; Yilmaz et al, 2000; Bozkurt, 2000; Sozbilir, 2001). As a result of this, the detachment fault extending approximately in the W-E direction comprises the bounding faults in the south of the Gediz Graben and the northern margin of the Buyuk Menderes Graben (Lips et al., 2001). These faults are characterised by the fact that they are low-angled and that they possess the Menderes metamorphic core complex in their footwall blocks. The Gediz Detachment Fault (GDF) constitutes the southern bounding fault of the Gediz (Alasehir) Graben. This fault was designated as the Karadut Detachment Fault (Emre, 1996) and Camkoy Detachment Fault (Kocyigit et al., 1999) in former studies. The designation of Gediz Detachment Fault was used in the publication of Lips et al. (2001). GDF starts to be observed south of Alasehir and continues until the south of Turgutlu toward the west. The basement block of the fault is made up of the metamorphic rocks of the Menderes Massif comprising the Bozdaglar range. The metamorphic rocks of the basement block are Paleozoic-aged and crossed by Miocene-aged granitic intrusions. The topographic slope facing the Gediz plain of the Bozdaglar comprises the surface of the Gediz Detachment Fault. Dip angles of GDF vary between 0° and 30° along the southern margin of the Gediz graben. The gradient value of the fault reduces from north to south. The fault surface has developed to create northeast-dipping anticlinal and synclinal structures. Other faults on the southern margin of the graben are faults having developed synthetically to the Gediz Detachment Fault, and display regeneration towards the basin. The Girelli geothermal filed is located on the southeastern tip of the Gediz Detachment Fault (Fig. 2).

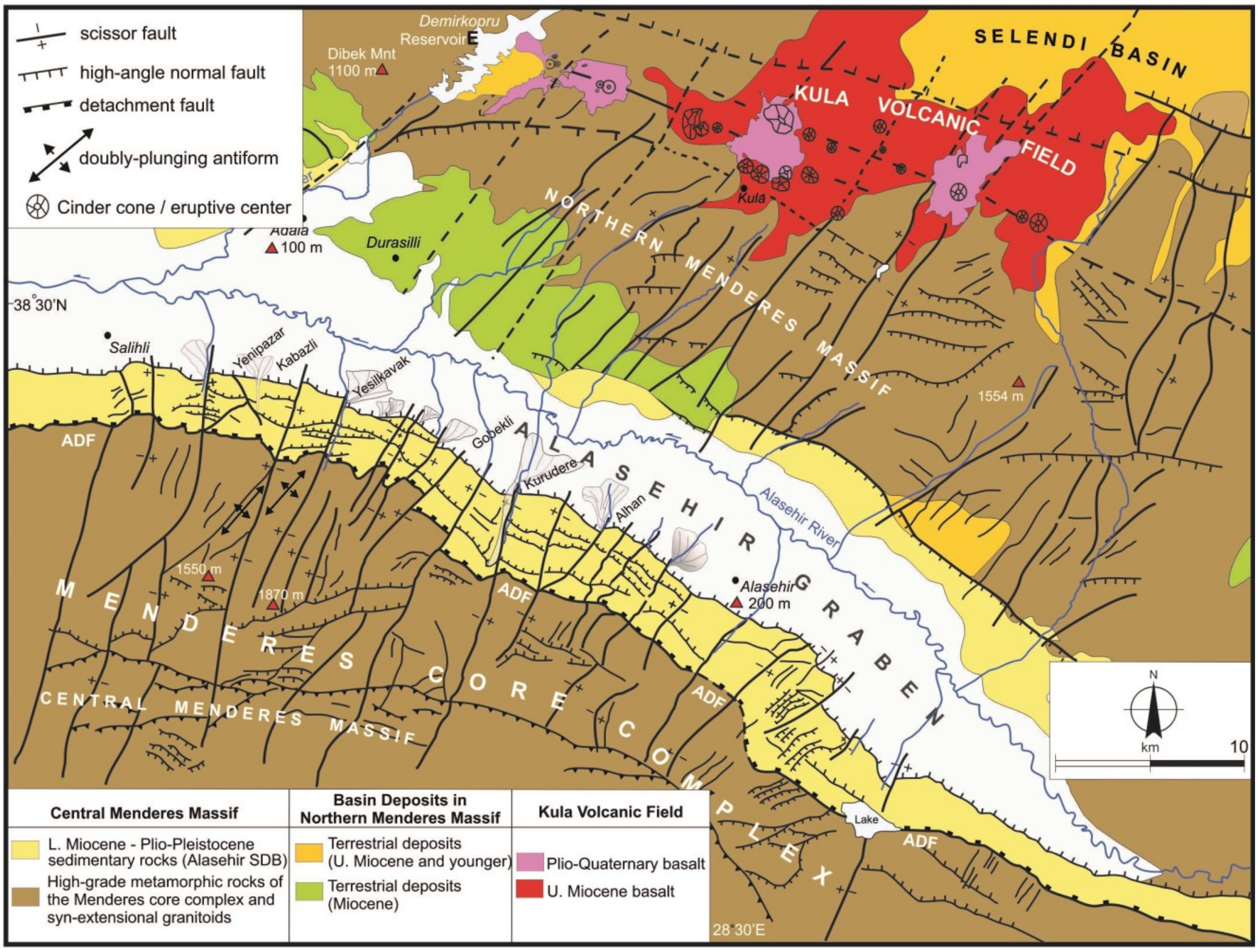

Figure 2. 1:25,000 scale geologic map of the Alasehir sub-basin (Öner and Dilek, 2011).

The aim of this study is to evaluate the geological and hydrogeological properties of the Girelli (Alaşehir-Manisa) geothermal area and its surroundings. The Girelli geothermal area is located on the southern margin of the Alaşehir (Gediz) graben in the west of Turkey (Fig. 1). The study area covering the Girelli Village-Carikbozdag district has a morphology consisting of two horsts extending in the NW-SE direction, and the Girelli depression remaining between them. It covers an approximate area of 24 km^2.

2. GEOLOGY OF THE STUDY AREA

The Alasehir (Gediz) graben, which possesses the largest alluvial area in the Gediz Basin, is 140 km long and 5-15 km wide. The graben extends in the NW-SE direction between Sarıgol and Alasehir in the west. It is divided into two main branches as from the town of Salihli towards the west. The Southernmost branch, extending in the E-W direction, is divided into two branches, namely the Kemalpasa Basin and the Manisa Basin, as seen from the Town of Turgutlu (Fig. 2). The branch extending in the NW-SE direction from the Town of Salihli is known as the Golmarmara Basin. Southeast of the basin is the Girelli geothermal area, where the Girelli fault divided gneiss-dominated metamorphic units from the schist-dominated metamorphic of the Menderes Massif (Fig. 3).

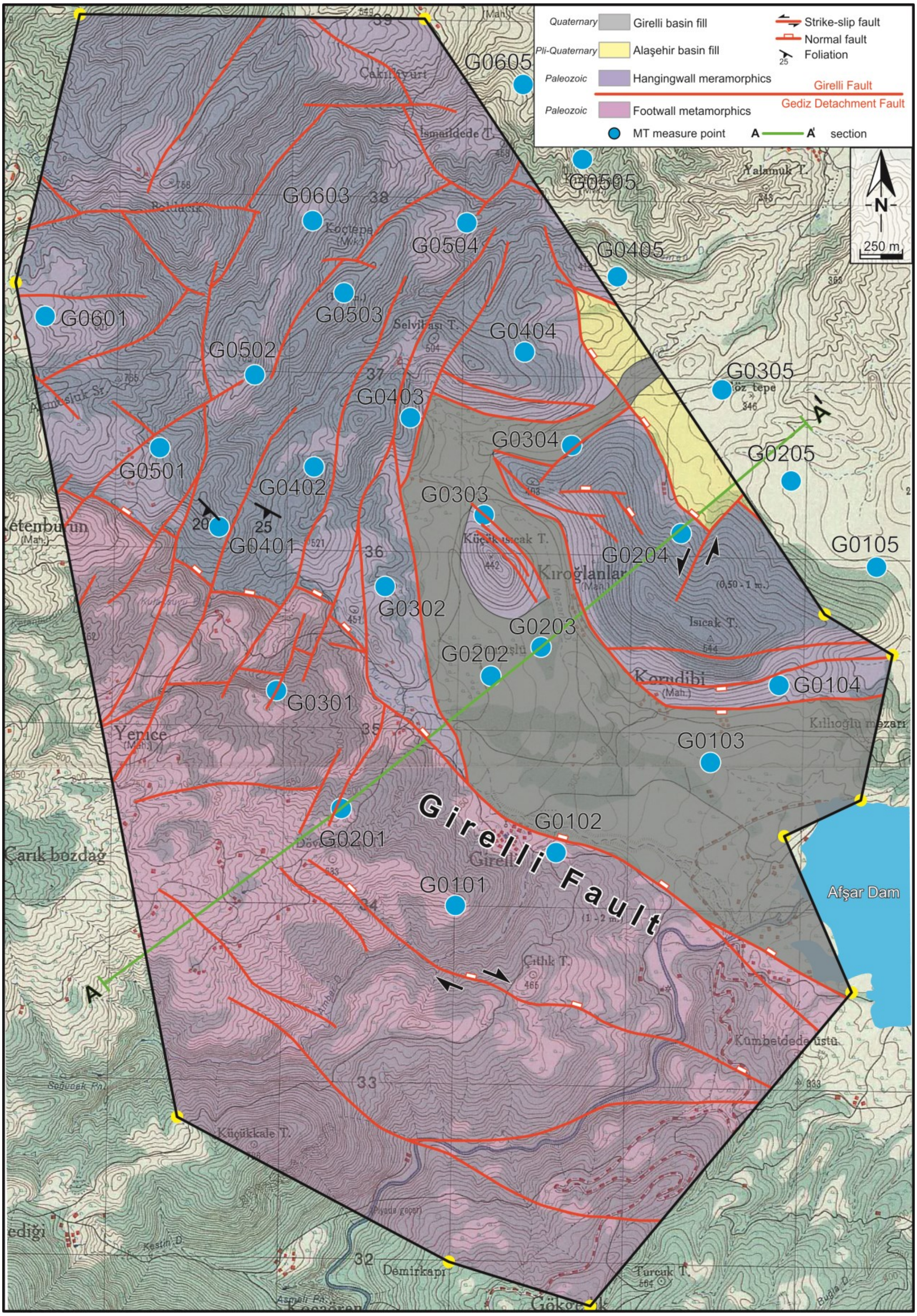

Figure 3. Geologic map of the study area.

The basement in the Girelli area is composed of the metamorphic rocks of the Menderes Massif and consists of gneiss, mica-schist, phyllite, quartz schist and marbles. Metamorphic rocks in this area are comprised of many different rock types. Of these, the most dominant ones are mica-schists. Besides these, fine-grained gneiss, garnet-mica schist, metaquartzite, and marbles are other rock types surfacing in the area. Marbles form lenses of different sizes in schists. Metaquartzites are usually in the form of intercalation, lens, and, from time to time, veins crossing the schists (Fig. 4a). These metamorphic rocks are rather fragmented and faulted as they are affected by the tectonics in the study area (Fig. 4b).

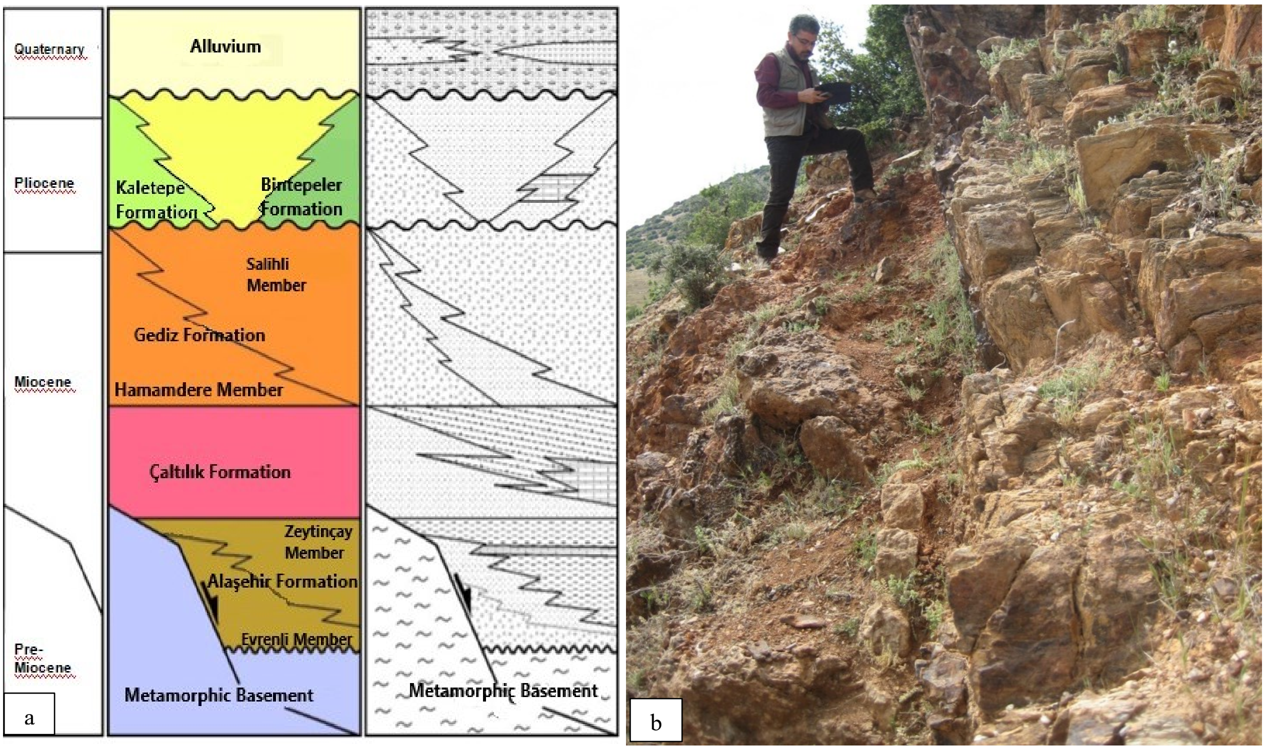

Figure 4. a) Lithostratigraphic columnar-section of the Alasehir Sub-Basin (Çiftçi, 2007; Ciftci and Bozkurt, 2009). b) Fault zone in the study area.

3. HYDROGEOLOGIC PROPERTIES OF GİRELLİ GEOTHERMAL REGION AND ITS SURROUNDING AREA

Many studies have been done by government, private sector and other researchers about hydrogeology and hydrogeochemical properties of Gediz Graben (Urgun, 1968; Ozcicek, 1969; Gulay, 1970; Karamenderesi and Ozgurler, 1988; Yilmazer, 1988; Filiz et al., 1993; Tarcan, 1995; Ozgur et al., 1998; Burck, 1998; Tarcan et al., 2000; Temimhan, 2005; Tokcaer, 2007; Ozen and Tarcan, 2009; Ozen, 2009; Bulbul, 2009; Baba and Murathan, 2012). In addition, resistivity and seismic surveys have been carried out by both the private and the public sectors in order to identify the thickness of the units in the Gediz basin, thickness variations of the units, plain-trending dispersion of the alluvial fans extending along the margin zones of the basin, buried faults, and water-bearing aquifers. First, resistivity surveys carried out by the General Directorate of State Hydraulic Works (DSI) are not of deep expansion, as they are intended for the shallow groundwater in the basin. However, the surveys carried out contain significant information about both the cap and reservoir rocks of the geothermal resources in the region. These data show that the Paleozoic marbles and Mesozoic crystalline limestones are very good geothermal reservoirs of the system. These rocks have karstic cavities. In addition, these rocks have fractures and faults in the study area. Domestic and irrigation water are obtained from the karstic carbonate in the study area. Also, calc-schite, which is located in Menderes Massif, is one of the important groundwater aquifers in the study area. At the same time, the Neogene aged units, which outcrop NE of the study area, usually have low resistivity and low permeability. Also, deep seismic surveys have been carried out only in the Alasehir-Sarigol section of the Alasehir (Gediz) Graben in the basin so far by Turkish Petroleum (TPAO).

At present, a great number of deep wells are being drilled for geothermal purposes in the Alasehir (Gediz) Graben by the private sector. From these wells, the existence of a sedimentary fill reaching 3000 meters has been revealed in the middle of the basin. There are levels bearing aquifers for both cold and hot waters at different depths in this sedimentary fill. Three boreholes drilled for petroleum purposes in the region are 2120, 2450 and 2524 meters deep. Metamorphic basement is encountered at 2462 meters in the Alasehir-1 well. Seismic cross-sections and boring data show that the Alasehir (Gediz) Graben continues underneath the Neogene units and Plio-Quaternary units mapped on the southern and northern margins. In the wells, the alluvium thickness varies between 270 m and 380 m in the middle of the plain. As a result of geological, hydrogeological and geophysical surveys, approximately 200 deep geothermal wells have been drilled in the area. A depth of 2954 meters has been reached in the wells, and temperatures reaching 287 °C have been measured. Also, deeper geophysical surveys have started to be carried out since 1995 due to the possibility of the existence of oil and high geothermal potential of the graben.

Local people have drilled boreholes in alluvial aquifers for domestic and irrigation water in the study area. Depths of the wells in this area range from 30 m to 100 m. Their flow rates range from 1 L/sec to 10 L/sec. Also, the metamorphic rocks contain groundwater resources. Marbles of the Menderes Massif are highly permeable, as they are karstic, multi-fractured, and are aquiferous rocks for both cold and hot waters. In the south of the surveyed area, the gneiss and mica-schists of the metamorphic rocks of the Menderes Massif bear the characteristic of a geothermal reservoir in places due to their fractured and faulted features. It is found out by the geophysical and boring data carried out that the thickness of the Neogene-aged fractured sediments which comprise the cap rock of the geothermal systems in the Gediz graben is approximately 3000 meters in the study area and its surrounding area. The Neogene sedimentary rocks contain poorly cemented clay planes having formed in the sealed fluvial medium surfacing in the vicinity of the study area comprise the cap rock of the geothermal systems due to the fact that they are impermeable or little permeable in hydrogeological terms.

4. MAGNETOTELLURIC MEASUREMENTS IN THE STUDY AREA

The three-dimensional (3D) inversion software called ModEM (Egbert and Kelbert, 2012; Başokur, 2015) was used in the study area. The grid created for modeling consists of a total of 254,320 cells (Fig. 5). The average height in each cell obtained from SRTM90 data was used for topography. The three-dimensional resistivity model is made up of cubes with different resistivity. The resistivity of these cells is calculated by the inverse solution process. Making sense of the underground resistivity distribution using the existing information in terms of geology forms the interpretation process. The cubes representing the same geological unit are expected to be represented with very close resistivity values. The greatest difficulty in interpreting such resistivity models of cubes is the determination of the boundaries of geological units.

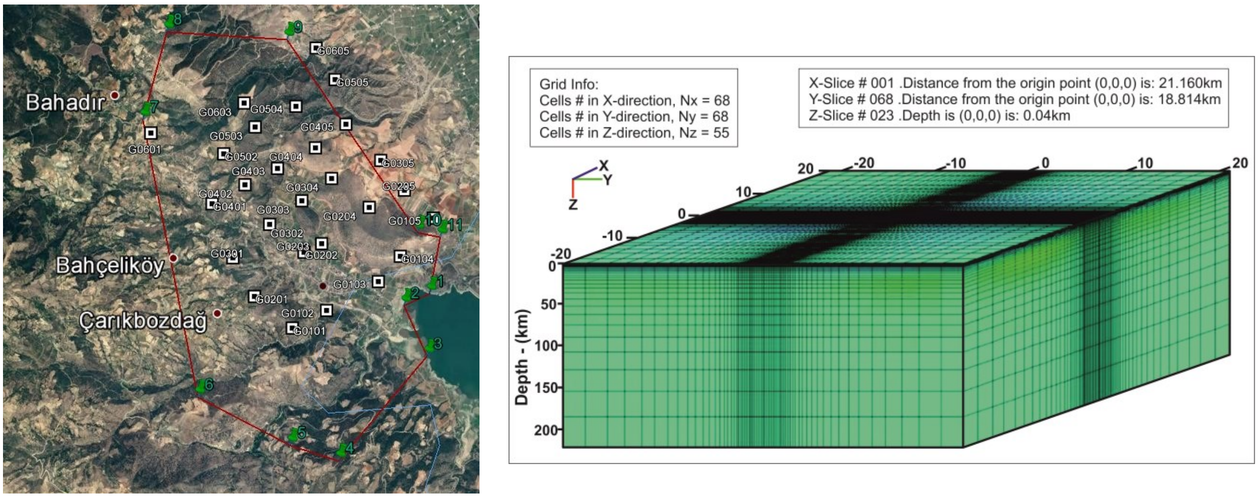

Figure 5. a) Model network used in three-dimensional inversion. b) The model network mesh consists of a total of 254,320 cells with 68, 68, and 55 lines in the x, y and z directions, respectively.

The results show that there are low resistivity zones that can be associated with hydrothermal activity in the study areas, and this shows a positive situation in terms of geothermal energy. The resistivity layer map shown in Figure 6a belongs to -2000 m below sea level and a low resistivity zone in north-south-east direction is observed. In Figure 6b, the low resistivity sign is given in the southwest-northeast direction; that is on a section perpendicular to the Gediz Graben. In order to better understand the geometry of this zone, a panel diagram image is given in Figure 7. The resistivity sign is quite likely the result of a hydrothermal activity that rises along the detachment fault and forms a reservoir. The resistivity model, which is one of the preliminary data types for drilling studies, indicates that there is geothermal potential on the site.

5. HYDROGEOCHEMICAL PROPERTIES OF THE GIRELLİ GEOTHERMAL SITE

The Gediz Basin is one the important geothermal fields where there have been intense activities for geothermal applications. In the graben, the rocks located in the tectonic zone are rather altered. This intense alteration is apparent in the study area. Both silicic and argillic alteration is observed in the area (Fig. 8). These alteration zones are very good indicators of high-temperature geothermal systems. There is no hot spring on the surface in the study area; however, a great number of wells have been drilled around the study area and reservoir temperatures reach 287° C in this region. A hydrogeochemical survey was carried out in study area and its surrounding region in order to identify the hydrogeochemical properties of the geothermal system. On-site instantaneous measurements have been made at some points of water in the study area and its surrounding area in order to identify the physical quality parameters. For this purpose, physicochemical parameters, such as surface temperature, pH and electrical conductivity, have been measured. Physical measurements have been carried out using a Hach-Lange HQ40D multiple parameter probe. Wwater sampling has been carried out on site for chemical analyses (for major anions and cations). The major anions (Cl^-, F^-, SO_4^{2-}) and cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) were analyzed by the ion chromatography method, and the carbonate (CO_3^-) and bicarbonate (HCO_3^-) ions measured by the titrimetric method. The result shows that the dominant cation is calcium in the water resources in the study area. Generally, the water resources have Ca-Mg-HCO_3 and Mg-Ca-HCO_3 types. Waters from the Paleozoic metamorphic rocks containing limited and local groundwater spreading over the highlands of the study area have Ca-Mg-HCO_3, Mg-Ca-SO_4-HCO_3 and Mg-Ca-HCO_3 water types. While calcium and magnesium cations are dominant in the groundwater resources from calc-schists, the sodium and calcium cations are more dominant in the groundwater resources from metamorphic rock, which consist of mica schists. Thermal fluid in the region is rich in Na-HCO_3 ions (Fig.8). On the basis of major ion chemistry, the Piper and Schoeller diagrams were drawn. The diagrams show that the cold water resources in the area are rich in Ca-Mg-HCO_3 and Na-Ca-Mg-HCO_3 ions. The thermal fluids are rich in Na-HCO_3 ions, and the fact that the anion and cation values are parallel with each other just like in the case of cold waters shows that these waters have the recharge and reservoir of the same origin.

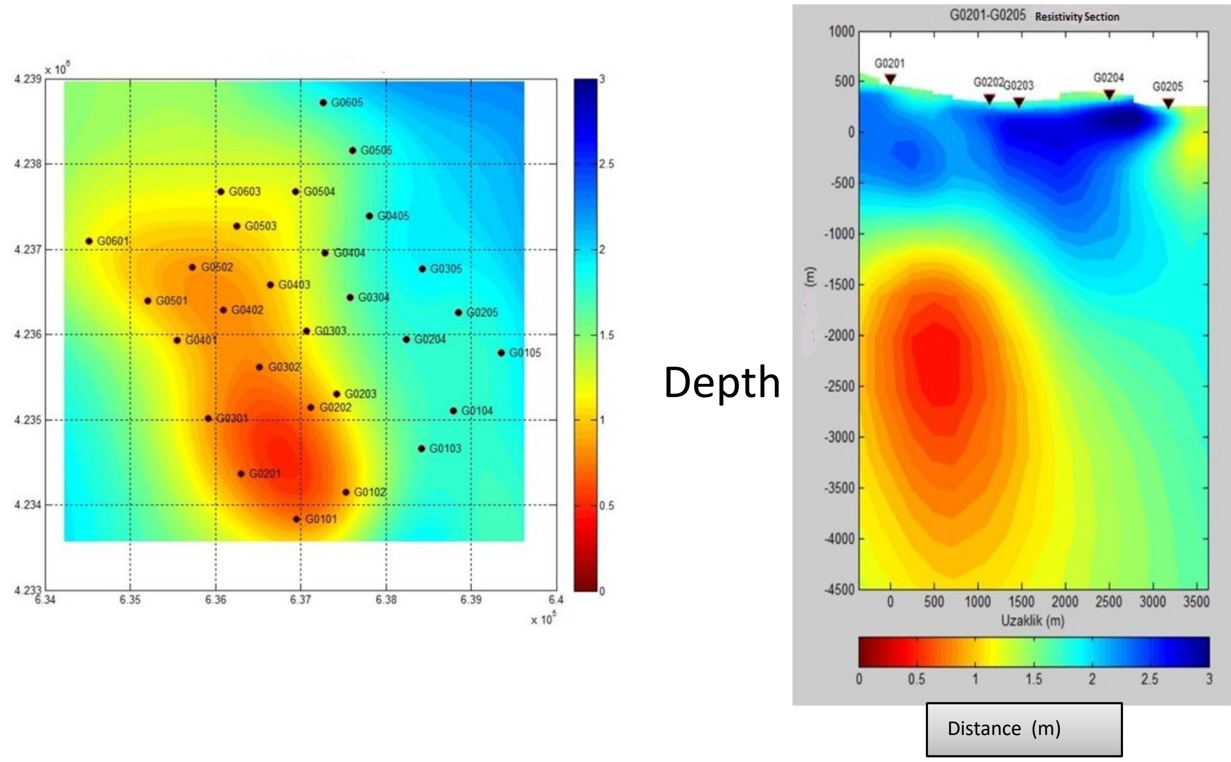

Figure 6. a) Resistivity distribution at -2000 meters depth below sea level. b) Appearance of a low resistivity sign on a southwest-northeast section.

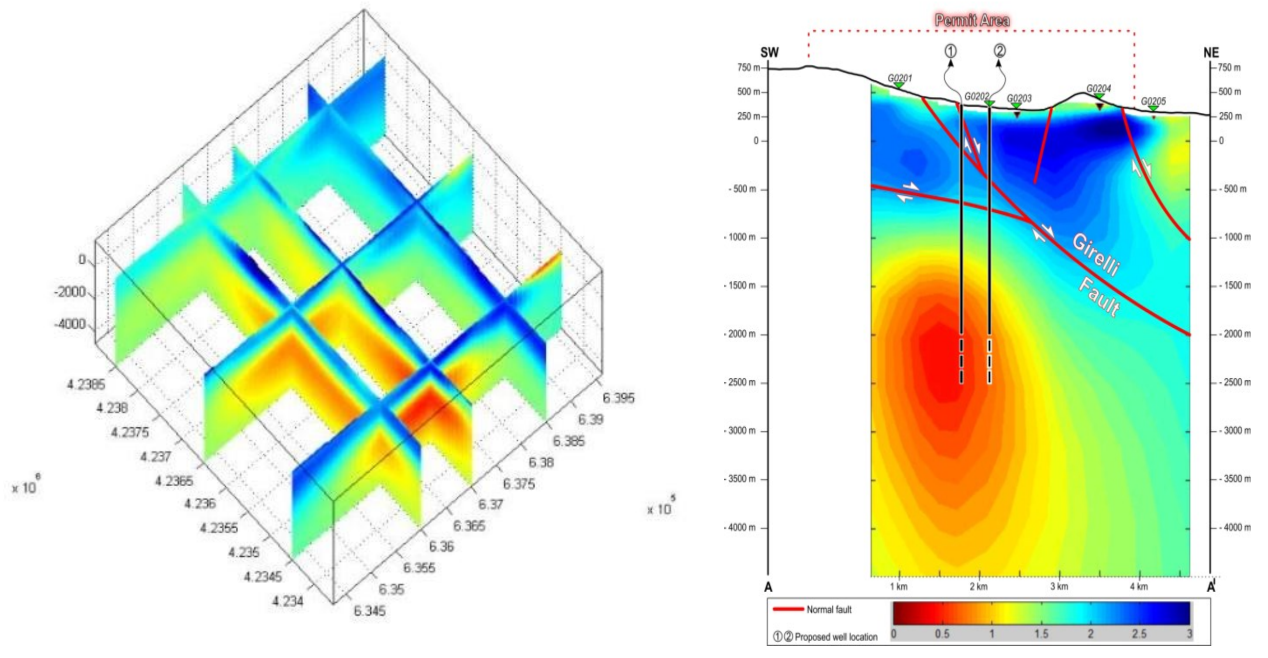

Figure 7. a) Panel diagram visualizing the low resistivity zone. b) Proposed well locations for the Girelli Geothermal Area.

Figure 8. Alteration zones in the study area.

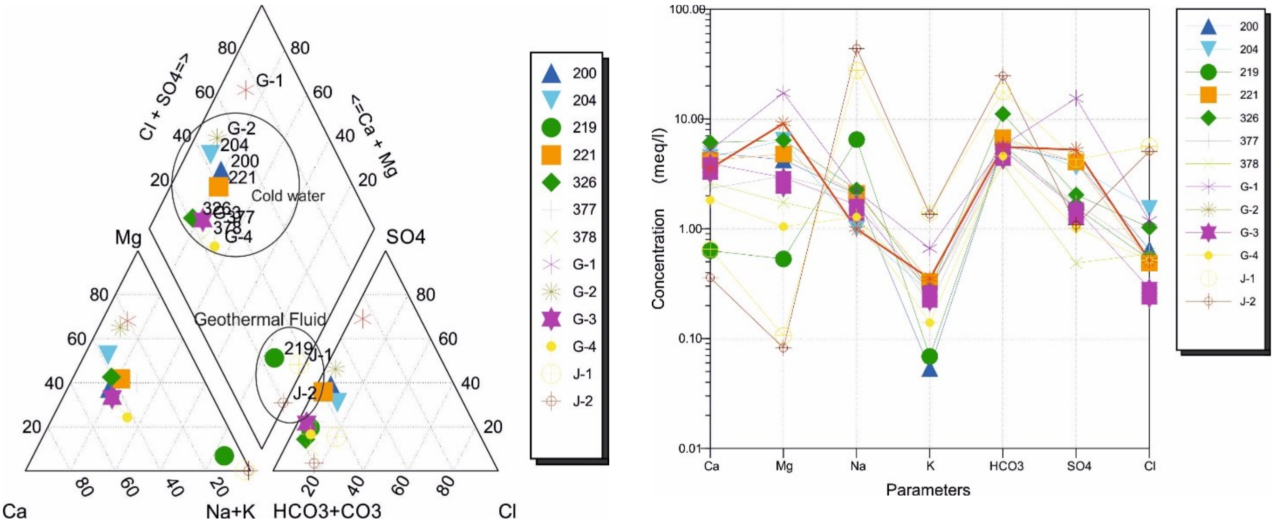

Figure 9. Classification of hydrochemical facies using a) the Piper diagram and b) Schoeller diagram.

Various equations and graphs have been developed in order to determine the reservoir temperatures of the geothermal fluids as well as their balance status with rocks and minerals. In the graph developed by Giggenbach (1988), the reservoir temperature of the hot fluids may be rapidly interpreted by a Na-K-Mg geothermometer. Whether or not it may be applied to the geothermal fluid for the calculation of the reservoir temperature of the cation geothermometers, or whether or not it may produce reliable results may be controlled. According to Giggenbach (1988), it is not proper to make an assessment of "unsaturated waters" by using the equilibrium temperature between K and Na in diluted geothermal fluids. Cation geothermometers of the geothermal fluids located in and on the "saturated waters" line will produce more accurate results. Geothermal fluids in the study area and its surrounding area are included in the "partially saturated waters" class in the Giggenbach triangle. According to this graph, the reservoir temperature of the fluid in the area ranges from 160 °C to 180 °C (Fig.10).

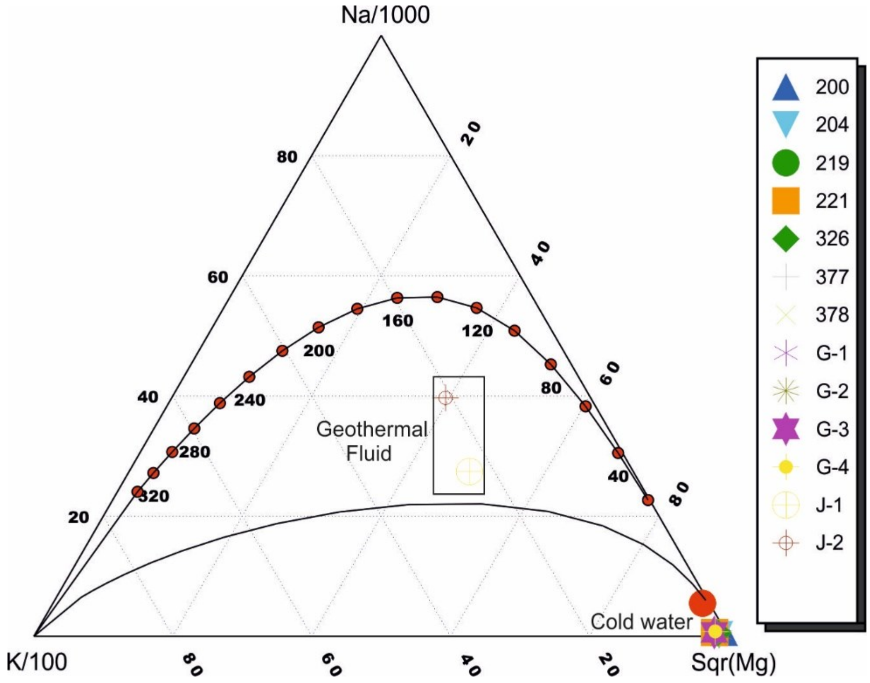

Figure 10. Giggenbach diagram for water resources of the study area.

6. CONCLUSION

The Girelli Fault, which is one of the branches of the Gediz Detachment Fault, passes through the south part of the study area. This is an area of complex geology with active tectonics and high geothermal potential. Faults accommodating the deep circulation of hydrothermal fluids of meteoric origin are the primary means by which of geothermal systems are controlled in this region. MT data show that result is from a hydrothermal activity that rises along the detachment fault and forms a reservoir in the south of the study area. Hot water is one of the most significant indications in this area where intense alteration (silicic and argillic alteration) is observed. The cold waters in the area are rich in Ca-Mg-HCO_3 and Mg-Ca-HCO_3 ions and the hot waters in Na-HCO_3 ions. According to the hydrogeochemical data, it seems to be possible to reach a temperature of 160-180 °C in this area.

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