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Tectonic Setting and Hydrogeochemical Properties of the Geothermal System of Kula Volcanic Region, Western Anatolia, Turkey

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ABSTRACT

Kula Volcanic Region is represented by young basaltic outcrops of mantle origin in the northern horst of the Gediz Graben. Kula is located on a block of crystalline rocks of the Menderes Massif, which is delimited by a southward-tilted footwall block of the Simav Graben or a southward-tilted hanging-wall block of the Alaşehir graben. Menderes Massif has formed the basement of the study area and is composed of gneisses and various schist with marble interlayers. The ophiolitic rocks of the Vezirler mélange outcrops in a small-scale, tectonically overlie the basement rocks. The Vezirler Mélange is overlain unconformably by a 700 to 1000 m thick Neogene-Quaternary volcano-sedimentary sequence. Basaltic volcanism, which is composed of basaltic lava and pyroclastic material, developed in the Quaternary period and spread over large areas. Field-based structural studies together with remote sensing methods have been applied to the Kula Volcanic field. Our studies suggest that the Kula volcano was emplaced within a releasing bend of NE-SW trending strike-slip fault, which is established in the present study for the first time and named as Kula Fault. Kula fault is accepted as a crustal scale zone of weakness was formed oblique to the direction of N-S extension during Quaternary time. The geothermal fluids of the region are mainly tectonically controlled by these types of faults and are seen in the intersection of within the NW-SE trending normal faults. Different alterations have been observed along these fault zones and thermal springs appeared on the surface at these points. Hydrogeochemical data show that the fluids of the study area come from the same reservoir and recharge from the meteoric origin. Water samples from Kula can be classified as sodium bicarbonate ($Na\text{-}HCO_3$) type water. The geothermal wells have similar chemistry and, thus a likely similar source. Kula geothermal water plots in the immature range compared to thermal waters worldwide. Stable isotopic composition of Kula waters generally falls along the meteoric mixing line. The isotopic composition of the waters suggests that recharge to the geothermal system is precipitation. Geothermal springs appear to be fed by a mixture of thermal water and groundwater resources. Cation geothermometers data indicate that the reservoir temperatures of the fluid are range from 80-142 ^{O}C in the study area.

1. INTRODUCTION

Western Anatolia (WA) where subduction-related mountain building followed by continental extension is a well-exposed example of a seismically active continental rift system (e.g., Dewey and Sengör, 1979; Şengör et al. 1985; Bozkurt, 2001) with a high amount of geothermal energy (Baba and Sözbilir, 2012). The region is built up by a series of stacked nappes consisting of Pan-African to Eocene tectonostratigraphic units (Özer et al. 2001). The first phase of extensional collapse in the region is marked by the Lycian orogenic collapse, which may have been initiated by the beginning of the Oligocene, following the main Menderes metamorphism. NW-SE-trending extensional collapse of the Lycian Allochthon resulted in the development of an Early Oligocene- Early Miocene Lycian molasse basin in the hinterland of the orogeny (Sözbilir, 2005). The second phase of extensional collapse is marked by detachment faulting, granitic intrusions and the formation of Miocene supradetachment extensional basins that are linked by a NE-trending transfer zone (eg., Lips et al. 2001; Sözbilir et al. 2011). This phase has been related to the exhumation of the Menderes metamorphic core complex that was highly dissected in Miocene time and resulted in crustal thinning and regional-scale faulting along low-angle detachment faults (Emre and Sözbilir 1997; Bozkurt and Sözbilir, 2004; Çiftçi and Bozkurt, 2009, Öner and Dilek, 2011). Two Miocene detachments are superimposed on the thrust of the Bozdağ and Aydın Mountain, including the Gediz detachment and the Büyük Menderes detachment fault, respectively. Both of them separated upper plate metamorphic consisting of a series of low- to high-grade, Pan-African basement-bearing nappes, Cycladic units, Late Cretaceous ophiolites and Miocene basin, fill units from the lower plate green-schist facies metamorphic unit intercalated by Upper Cretaceous carbonates (Figure 1). The neotectonic structures of WA have been shaped by deformation model which is affected by the westward tectonic escape of the Anatolian block along the North Anatolian Fault (NAFZ) and East Anatolian Fault (EAF) and back arc spreading in the Aegean region (Figure 1a) (e.g. Dewey and Sengör, 1979; Şengör et al. 1985; Bozkurt, 2001).

As a result, the WA is currently experiencing an approximately N–S continental extension and contains major depression areas with geothermal potentials such as Gediz, Büyük Menderes, Simav, Denizli and Afyon-Akşehir grabens (Dewey and Şengör 1979; Şengör and Yılmaz 1981; Şengör et al.1985; Seyitoğlu and Scott 1991; Yilmaz et al.,2000; Bozkurt 2001; Sözbilir 2005; Özkaymak et al., 2013). During Quaternary, a widespread basaltic volcanic activity rests unconformably on the basin, fill units of Selendi basin. Although their mantle origin derived from an initial magma rise through plumes has been widely accepted, as it is rift volcanism, its emplacement mechanism and relationships with geothermal energy are poorly known. To fill this gap, field-based structural and hydrogeological studies have been applied to the Kula Volcanic field.

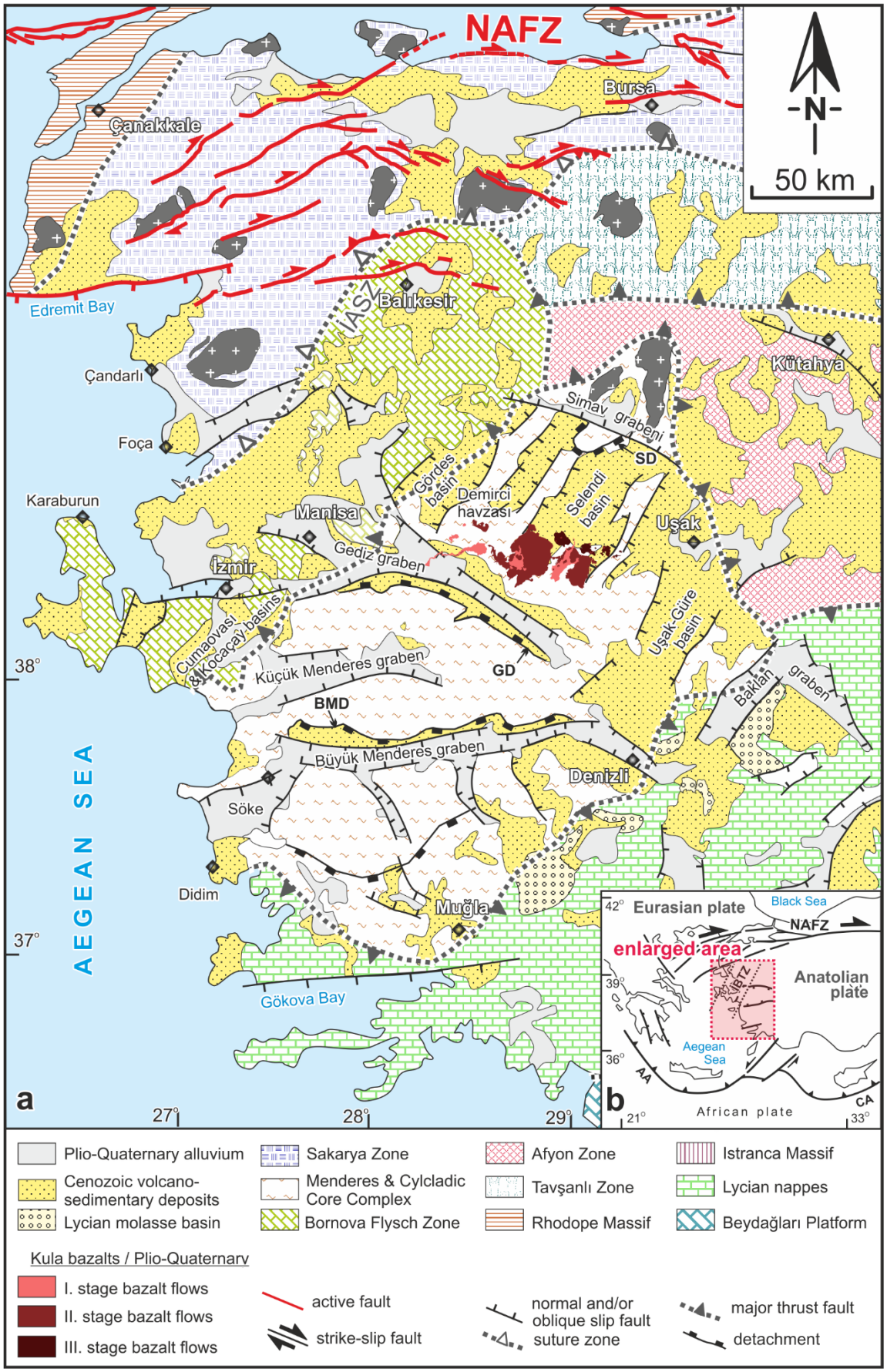

Figure 1. Simplified geological map of western Anatolia showing major tectonostratigraphic units and fault zones. Note Kula volcanic region is located at the southern of Selendi Basin (Modified from Sözbilir et al. 2011). NAFZ: North Anatolian Fault Zone.

2. KULA VOLCANIC REGION

The Kula Volcano (KV), is located 12 km west of the town of Kula District, resting on E-W trending horst separated Gediz graben from the Simav Graben. KV is the youngest volcanic region in Turkey and was active from the Quaternary period to historic times, and recently it is inactive. It rests unconformably on the metamorphic basement of the Menderes Massif, the ophiolitic mélange units of the İzmir-Ankara Zone, and Miocene lacustrine volcano-sedimentary sequence of the Selendi basin fill (Figure 2). According to petrographic and petrochemical investigations, Kula lavas are alkali basalts becoming potassic-rich trachybasalts, alkali olivine basalts and hawaiites with minor mugearites and tephrites. Our studies suggest that the Kula volcano was emplaced within a releasing bend of NE-SW trending strike-slip fault, which is established in the present study for the first time and named as Kula Fault. Kula fault is accepted a crustal scale zone of weakness was formed oblique to the direction of N-S extension during Quaternary time. This suggests that strike-slip fault development is more common than considered in the western Anatolian extensional province.

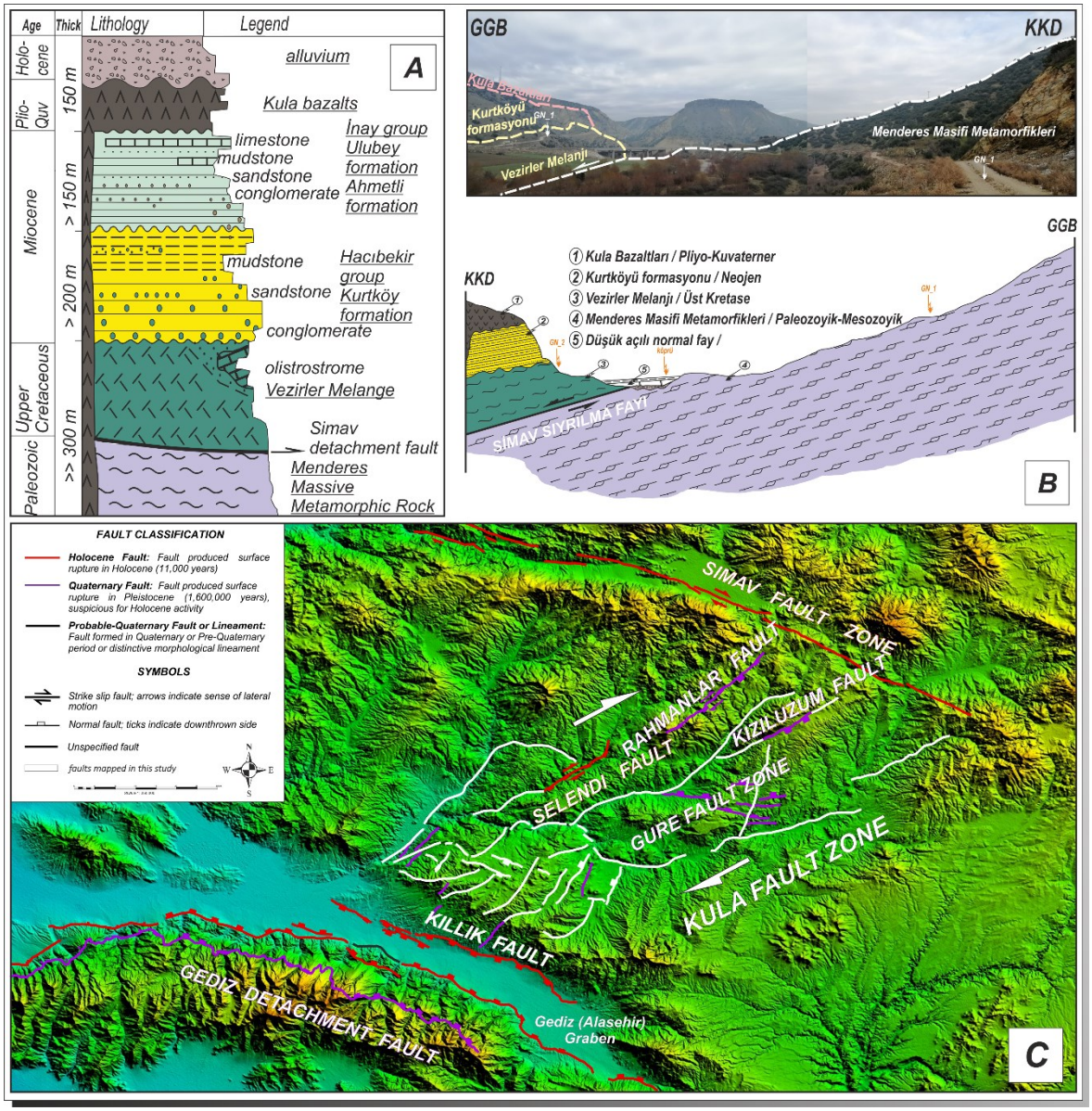

Figure 2. a) Lithostratigraphic columnar section of the study area, b) field photograph and cross-section showing reservoir (unit 3 and 4) and cap rocks (unit 1 and 2) of Kula volcanic region c) global mapper map showing main structural elements of the Kula volcanic region

3. HYDROGEOLOGICAL AND HYDROGEOCHEMICAL CHARACTERIZATION OF KULA GEOTHERMAL FLUID

Metamorphic rocks of the Menderes Massif and some part of Vezirler mélange have secondary porosity and permeability and thus have significant potential in terms of water resources and reservoir of the Kula Geothermal System. Miocene Yeniköy Formation, which consists of silty, clayey marl, is the caprock of the geothermal system in this region (Figure 3). It can be seen geothermal spring and geothermal well, which have high flow rate (Figure 4).

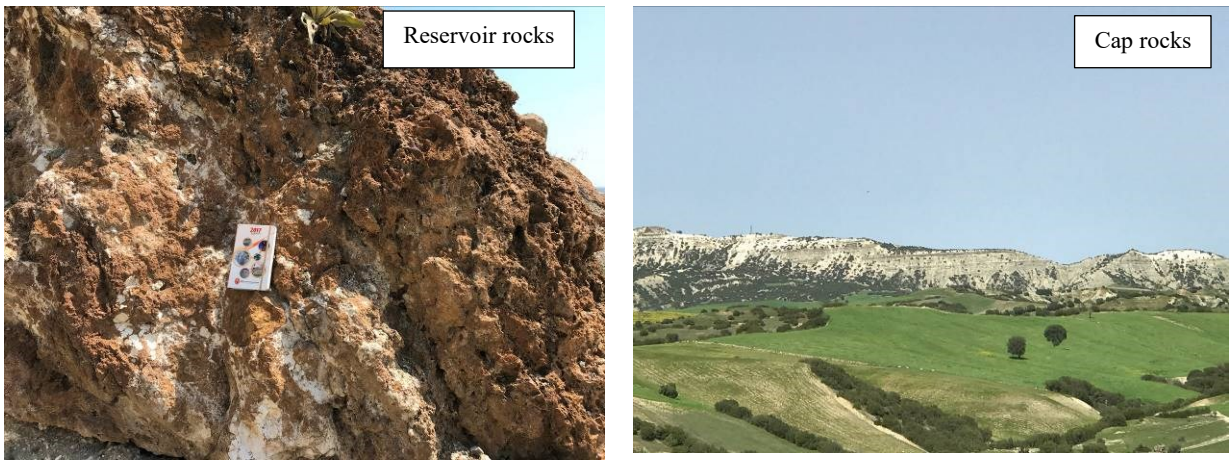

Figure 3. Reservoir and cap rocks in the study area



Figure 4. Geothermal springs and exploding well in the study area

The surface temperatures of the geothermal fluid are range from 32.4 and 54 °C and the Electrical Conductivity (EC) values are changed between 3230 µS/cm and 4930 µS/cm. The hottest geothermal fluids are centered near the Eymir Spa Region. Water samples for chemical analysis were taken from the wells and springs around the study area by some researchers in different years. Tokcaer (2000) reported that the EC values and temperature of the geothermal resources are range from 1113 to 5190 µS /cm and from 21 to 65 ºC, respectively. Also, some major anion and cation-anion were measured in hot springs. Schoeller and Piper diagrams of key cation and anion concentrations are presented as Figure 5, respectively. Water samples from Kula can be classified as sodium bicarbonate (Na-HCO_3) water. All samples from the geothermal wells cluster together on Figures, showing that the geothermal wells have similar chemistry. Cation and anion concentrations in geothermal resources are related to the level of chemical equilibrium the waters have achieved with the surrounding rock. Giggenbach (1980) has classified mature and immature geothermal water using cation and anion trilinear diagrams. Kula geothermal fluid plots in the immature range compared to thermal waters worldwide (Figure 6). Fluid from the geothermal wells is characteristic of deep thermal water. Thermal springs appear to be fed by a mixture of thermal fluid and groundwater. The cation and anion concentrations of thermal spring water may be increased by evaporation at the surface.

Na and Cl concentrations in hot spring samples are high relative to a temperature consistent with evaporation. Samples collected from MTA wells near Emir Spa and Hamam Tepe appears to be affected by evaporation. Stable isotopic composition of Kula waters (Oxygen-18 and deuterium) generally fall along the meteoric mixing line (Figure 7). The isotopic composition of the waters suggests that the cold-water source recharge to the geothermal system. 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 Chalcedony and Quartz geothermometers from this well estimate reservoir temperature to be 138°C and 162°C, respectively. This might be minimum temperature if subsequent mixing occurred.

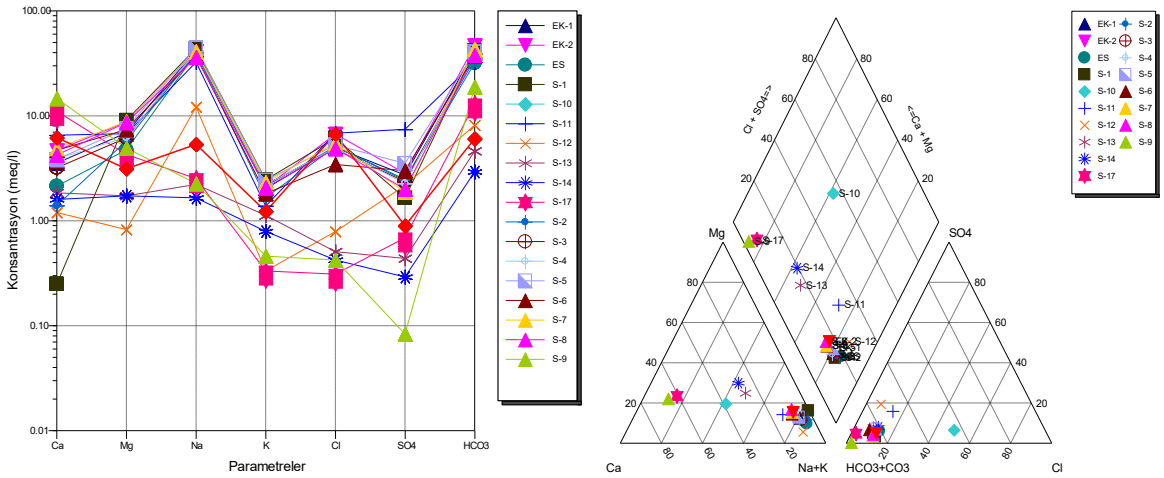

Figure 5. Schoeller and Piper diagrams of the study area

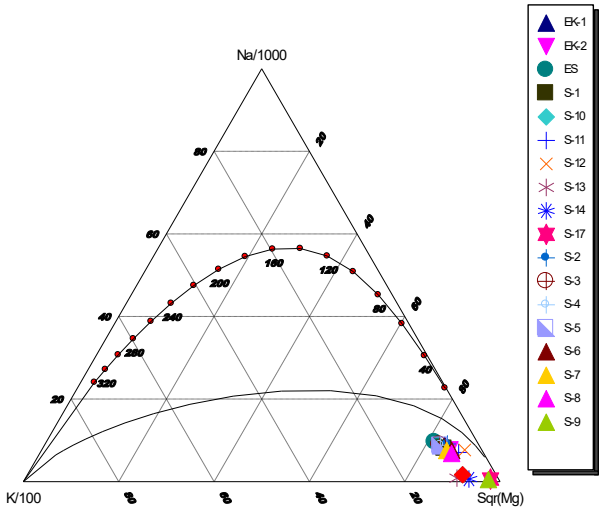

Figure 6. Giggenbach diagrams of geothermal fluid in Kula Region

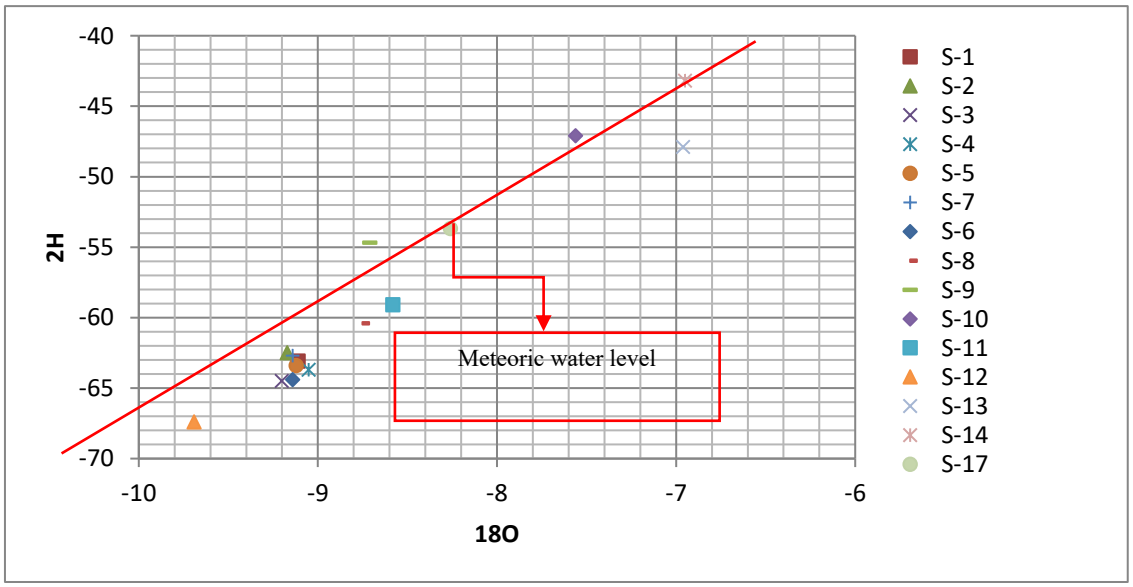

Figure 7. Isotopic composition of geothermal fluid in the study area

4. DISCUSSION AND CONCLUSIONS

In this study, the tectonic setting and geothermal features of the Kula volcanic Region, which is represented by young basaltic outcrops of mantle origin in the north of the Gediz graben, was investigated by geological and hydrogeological data. The result shows that Menderes Massif, which is the basement of the study area, is composed of gneisses and various schist with marble interlayers. The ophiolitic rocks (Vezirler Mélange), which are outcrops in a small-scale, tectonically overlie the basement rocks. The Vezirler Mélange is overlain unconformably by a Neogene-Quaternary sedimentary-volcano-sedimentary cap rocks. Basaltic volcanism, which is composed basaltic lava and pyroclastic material, developed in the Quaternary and spread over large areas. The Holocene alluviums, deposited in the tectonically controlled young streams in the Gediz River (Figure 8).

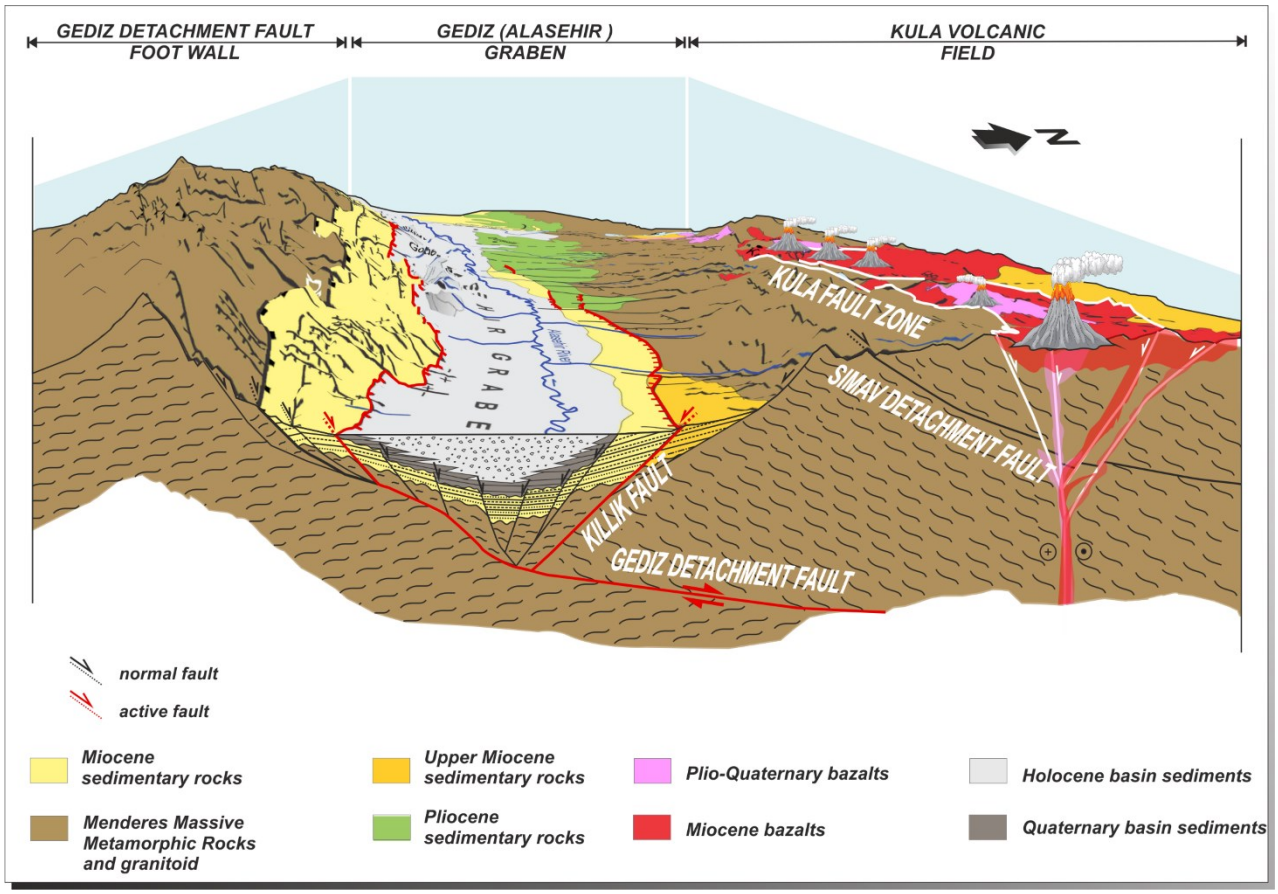

Figure 8. 3D block diagram showing structural relationships between Gediz Graben and Kula Volcanic region. Kula Fault Zone acted as a pathway for Quaternary Kula volcanic.

The geothermal fluid of the region is mainly tectonically controlled by NW-SE and NE-SW trending structural discontinuities and is seen in the intersection of them around Emir thermal spring. Different alterations have been observed along these fault zones and thermal springs appeared on the surface at these points. Hydrogeochemical data show that the fluids of the study area come from the same reservoir and recharge from the meteoric origin. Geothermal fluids have a Na-HCO_3 type. Geothermometers data indicate that the reservoir temperatures of the fluid are range from 80-142 ^{O}C in the study area.

The field data indicate that the gneissic rocks on the southern flank of the Gediz River have a northward dipping mylonitic foliation and lie along a low angle detachment fault under the Vezirler Melange to the north. Geophysical data show that the detachment fault, which is located below the Selendi basin-fill deepens, to the north, is considered as the target structural boundary for the geothermal potential of the region. This fault is thought to be the continuation of the Simav Detachment fault under which has metamorphic rocks with mylonitic and cataclastic deformation. The main geothermal reservoirs are thought to be found in the metamorphic rocks, which located below the cataclastic zone. Thick mylonitic zones are used as reservoir zone in the Gediz Graben. Therefore, it is important to make drilling that should be able to reach below the mylonitic zone in the region.

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REFERENCES

Baba, A. and Sözbilir, H.: Source of arsenic based on geological and hydrogeochemical properties of geothermal systems in Western Turkey. Chemical Geology, 334, (2012), 364-377f

Bozkurt, E.: Neotectonics of Turkey–A synthesis. Geodinamica acta, 14(1–3), (2001), 3–30.

Bozkurt, E. and Sözbilir, H.: Tectonic Evolution of the Gediz Graben: Field Evidence for an Episodic, Two-Stage Extension in Western Turkey. Geological Magazine, 141, (2004), 63–79.

Çiftçi, N.B. and Bozkurt, E.: Evolution of the Miocene sedimentary fill of the Gediz Graben, SW Turkey. Sedimentary Geology, 216, (2009), 49-79.

Dewey, J. F., and Şengör, A. M. C.: Aegean and surrounding regions: Complex multiplate and continuum tectonics in a convergent zone. Geological Society of America Bulletin, 90, (1979), 84–92.

Emre, T. and Sözbilir H.: Field evidence for metamorphic core complex, detachment faulting and accommodation faults in the Gediz and Büyük Menderes grabens (Western Turkey). In International Earth Sciences Colloquium on the Aegean Region, İzmir, Turkey, Pişkin Ö, Ergün M, Savaşçon MY, Tarcan G (eds). (1997). 73-94.

Giggenbach, W. F.: Geothermal Gas Equilibria. Geochimica et Cosmochimica Acta, 44, (1980), 2021-2032.

Lips, A.L.W., Cassard, D., Sözbilir, H., Yılmaz, H. and Wijbrans, J, R.: Multistage exhumation of the Menderes Massif Western Anatolia (Turkey). International Journal of Earth Sciences. 89, (2001). 781-792.

Oner, Z., and Dilek, Y.: Supradetachment basin evolution during continental extension: The Aegean province of western Anatolia, Turkey. Geological Society of America Bulletin 123(2011), 11-12, DOI: 10.1130/B30468.1

Özer S., Sözbilir H., Özkar (Tansel) I., Toker V., Sarı B.: Stratigraphy of Upper Cretaceous-Palaeogene sequences in the southern and eastern Menderes Massif, (W. Turkey): Int J Earth Sci 89: (2001), 852–866

Seyitoğlu, G., Scott, B.: Late Cenozoic crustal extension and basin formation in west Turkey. Geological Magazine 128, (1991), 155–166.

Sözbilir, H.: Oligo–Miocene extension in the Lycian orogen: evidence from the Lycian molasse basin, SW Turkey. Geodinamica Acta 18, (2005), 257–284.

Sözbilir H., Sarı B., Uzel B., Sümer O. And Akkiraz M.: Tectonic implications of transtensional supradetachment basin development in an extension-parallel transfer zone; the Kocacay Basin, western Anatolia, Turkey, Basin Research 23(4): (2011), 423 - 448

Şengör, A.M.C. and Yılmaz, Y.: Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics, 75: (1981). 181-241.

Şengör, A. M. C., Görür, N., and Şaroğlu, F.: Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. In K. T. Biddle and N. Christie-Black (Eds.), Strike-slip deformation, basin formation and sedimentation, Tulsa, Oklahoma: Society of Economic Paleontologists and Mineralogists Special Publication.vol. 37, (1985), 227–264,

Tokçaer, M.: Geochemistry of Kula Geothermal Area. MSc Thesis, Graduate School of Natural and Applied Sciences of Dokuz Eylul University [unpublished], (2000).

Yılmaz, Y., Genc¸, S.C., Gürer, O.F., Bozcu, M., Yılmaz, K., Karacık, Z., Altunkaynak, R., Elmas, A.: When did the western Anatolian grabens begin to develop? In: Bozkurt, E., Winchester, J.A., Piper, J.D.A. (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geological Society, London, Special Publications 173, (2000). 353–384.