Investigation of Deep Structure of Sultandağı Fault by Magnetotelluric, Gravity, GNSS, and Tectonic studies; First Results

Özcan ÖZYILDIRIM[1], İsmail DEMİRCİ[2], Çağlar ÖZKAYMAK[3,4], Özcan BEKTAŞ[5], Can BAŞARAN[1,3], Ibrahim TİRYAKİOĞLU[4,6], Doğukan Mert ÖZCAN[7] and Ahmet YILDIZ[1,3]
[1]Afyon Kocatepe University, Geothermal and Mineral Resources Application and Research Center, ozyildirim@aku.edu.tr
[2]Ankara University, Faculty of Engineering, Department of Geophysical Engineering
[3]Afyon Kocatepe University, Faculty of Engineering, Department of Geological Engineering
[4]Afyon Kocatepe University, Earthquake Application and Research Center
[5]Cumhuriyet University, Faculty of Engineering, Department of Geophysical Engineering
[6]Afyon Kocatepe University, Faculty of Engineering, Department of Map Engineering
[7]Afyon Kocatepe University, Graduate School of Natural and Applied Sciences

SUMMARY

Afyon-Akşehir Graben is one of the most seismically active neotectonic structures in Anatolia. There are previous scientific studies on the surface geometries, geomorphology, kinematics, and active tectonic features of the fault segments of the Sultandağı Fault, which is the most seismically active main edge fault of the graben. However, studies on the geometries and depths of these faults are very few at the crustal scale. The devastating earthquakes on the Sultandağı Fault in recent years show that segments of this fault are active, the seismogenic zone has reached 15 kilometers, and the geometry of these faults should be investigated in detail at the crustal scale by geophysical, geological, and geodetic methods. The first results of the main project, which includes developing a three-dimensional joint inversion algorithm for Magnetotelluric and Gravity data, are described in this study. In the study, the magnetotelluric data measured along the lines selected perpendicular to the main faults in the part covering the Sultandağı fault, which is the most important seismogenic belt of the region, were solved with the two-dimensional inversion algorithm and two-dimensional resistivity models were obtained. In addition, surface geology was used to analyze the active tectonic features of the fault segments on the Sultandağı Fault, and GNSS-based geodetic measurements were made to monitor the current tectonic activities of the segments. Preliminary findings have shown that the NW-SE trending and NE dipping Sultandağı Fault, which is a dip-slip normal fault, was formed between Sultandağı and Ilgın districts under NE-SW extensional forces. It also indicates that there are synthetic and antithetic fault branches extending approximately parallel to the Sultandağı Fault in the graben and that the fault has a depth of at least 10 km with an average angle of 70°.

Keywords: Magnetotelluric, Inversion, Gravity, Tectonics, Sultandağı Fault

INTRODUCTION

Sultandağı Fault is a 90 km long dip-slip normal fault. It can be traced along morphologically distinct steepnesses that show a linear course between Çay in the west and Doğanhisar in the east, well-developed alluvial fans are typical along the mountain front (Koçyiğit et al. 2000; Emre et al. 2011; Tiryakioğlu et al. 2015; Özkaymak et al. 2017). The northern margin faults located in the northeast of the graben are represented by NE-SW trending dip-slip normal faults from west to the east such as Bolvadin Fault, Büyük-Karabağ Fault, Çukurcak Fault, and Yunak Fault Zone (Emre et al. 2011; Özkaymak et al. 2017). On the seismically active Sultandağı Fault, during the instrumental period, many earthquakes occurred. While the right lateral GPS sliding speed determined on the Simav Fault is 3.9 mm/, the GPS-based opening speed value measured on the Sultandağı Fault is 3.4 mm/year (Aktuğ et al. 2013).

When tectonic studies supported by geophysical methods are classified, strike-slip faults that produce more earthquakes in the world are generally examined (Stanley et al. 1990; Ogawa et al. 2001; Tank et al. 2005; Türkoğlu et al. 2008; Kaya et al. 2013). Normal faults, which are generally located in the west of Turkey and cause Horst graben structures, are mostly studied from a geothermal point of view (Erdoğan and Candansayar 2017). It is observed that Normal faults are less frequently investigated in terms of tectonic and seismicity than strike-slip faults such as the North Anatolian and East Anatolian Fault Systems with the studies conducted with electromagnetic methods such as magnetotelluric. However, the earthquakes that have occurred in recent years show that the deep structures of normal faults in the Western Anatolia region should be investigated in detail with geophysical methods.

This study was carried out to fill this gap in the literature.

In the study, 2D resistivity models were obtained by inverting the MT data obtained on the Sultandağı Fault with the 2D MT algorithm using the unstructured mesh developed by Özyıldırım et al. (2017). The models were interpreted comparatively with the tectonic studies and gravity data in the field. In addition, within the scope of this study, the current slip rates, strain amounts, and directions of the fault segments in the region are measured using the GNSS technique; The geodynamic structure of the region is evaluated by comparing the findings obtained from the Geological and Geophysical studies carried out within the scope of the project.

METHODS

Along the Sultandağı Fault, it was planned to measure Magnetotelluric (MT) data as well as tectonic and GNSS studies in the determined area to view the deep structure of the part that intersects with Afyon K25, K26, and L26 sheets of 1/100,000. The distance between the MT lines is 3-3.5 km and consists of 24 lines. In each line, 10 MT points were determined with a distance of approximately 2.5 km from each other (Figure 1).

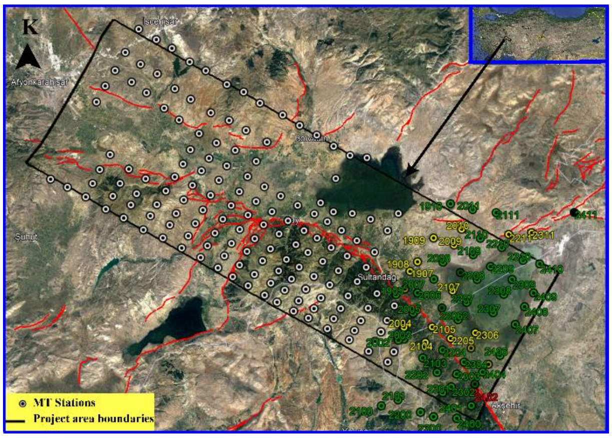

Figure 1. The location of the study area with locations of the MT stations on the Google Earth satellite image, the active faults (red lines) defined in the region (Emre et al. 2011).

In Figure 1, the MT stations that were measured at the study area and that will be measured in the future are shown together. The yellow and green stations show the measured data to be presented in this study on the Sultandağı fault, which is a segment of the AAG during the period.

MT data acquisition and analysis

In this study, MT data were measured on lines 19-24 from west to east(Figure 2).

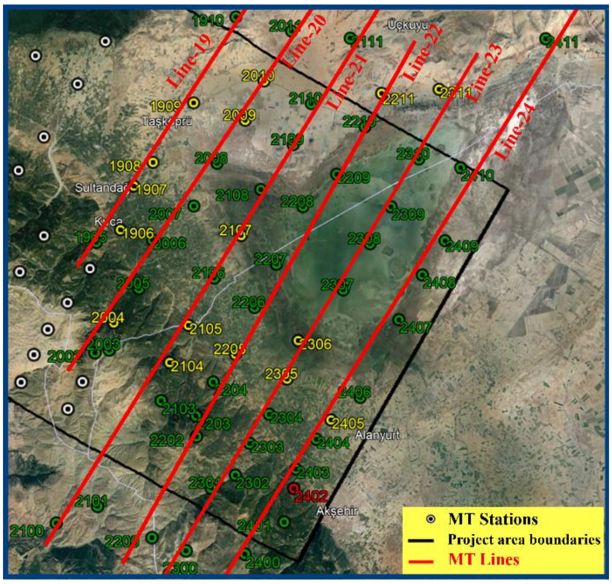

Figure 2. Locations of The MT stations measured data and designated MT lines for 2D inversion of these data

MT studies were carried out using “Metronix” brand “ADU07e” model receiver, “MFS06e and MFS07e” coils, and “Pb-$PbCl_2$” nonpolarized electrodes. The measurement period of the data collected as a time series at each station varies between 24-48 hours. Time series (raw) in four frequency bands (Sample frequencies: "128Hz-more than 24h", "512Hz-2h", "2048Hz-1h", "65536Hz-15min.") at each station were measured. Electric (E_x, E_y) and magnetic fields (H_x, H_y) were obtained in the frequency domain by taking the Fast Fourier transform (FFT) of the time series with the "ProcMT" software. Impedance values ($Z(\omega)$), including the ratios of Electric and Magnetic fields, were obtained for a total of 63 frequencies, 9 frequencies in each logarithmic period, in the range of 10kHz-10^{-3}Hz.

Files with the extension "edi" containing impedance values, apparent resistivity, and impedance phase values were recorded for each station and decomposition analysis was performed for global strike direction selection for 2D inversion. G&B decomposition was used as decomposition analysis (Groom and Bailey 1989). Analysis results are shown on the Rose diagram using three different frequency bands (10000-1Hz, 1-0.1Hz, 0.1-0.001Hz) and all frequencies (10000-0.001) on the same figure to see the dominant strike direction in different frequency bands. (Figure 3). In addition, the dominant strike direction was found by decomposing the data with the 'Strike' code of McNeice and Jones (2001) and the 'FNIDEC' algorithm developed in the master's thesis of the first author for the selected 3 frequency bands and all frequencies (Black arrows: Strike results, Red arrows: FNIDEC results in Figure 3). At the end of the analysis, the Strike was chosen as 5^o for 2D inversion. By rotating the Impedance Tensor to 5° Strike, the Zxy component of the diagonal elements was accepted as the TE-mode and the Zyx component as the TM-mode impedance.

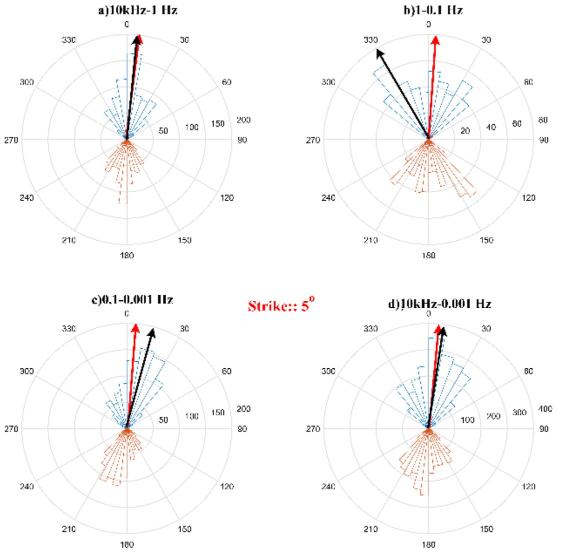

Figure 4. Presentation of G&B decomposition results in the rose diagram, with global strike angle values found from Strike (Black arrows) and FNIDEC (Red Arrows) codes

Gravity data

Measuring, correcting, mapping, filtering, modeling, and inversion Gravity data are the processing steps of the gravity method. This method is effective, especially in determining the density differences like as mines, sedimentary basins, fault zones, and buried geological structures. Due to the ill-definition of the Gravity method, modeling is performed rather than inversion in the literature, and deep and superficial tectonic edges are determined by filtering studies. Within the scope of this study, gravity data formed a basis for MT studies. Gravity data given in Figure 5, were obtained from the General Directorate of Mineral Research and Exploration of Turkey (MTA).

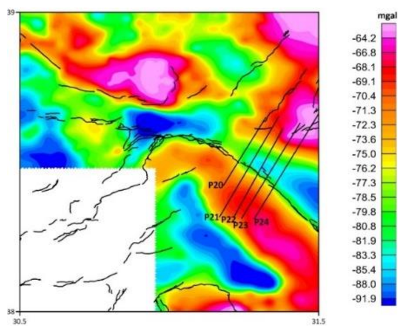

Figure 5. The gravity anomaly map of the study area and the locations of Lines determined for 2D gravity modeling.

Tectonic and GNSS studies

Tectonic studies were generally carried out in the form of field studies. In the study, data on the surface geometries, segmentation features, kinematic analyzes, and top/bottom block geology of the Sultandağı fault were collected. In this way, kinematic analysis studies were carried out in order to determine the kinematic properties of the region and the stress regime history. It was planned to make a GNSS measurement to determine the current tectonic movements of the faults in the region. GNSS measurement is one of the common geodetic measurement methods used to determine fault movements today. Source-fault parameters were tried to be obtained from the velocity fields to be obtained within the scope of the study.

Results

The rotated MT data to the Global Strike were inverted by the inversion algorithm that use the unstructured mesh developed by Özyıldırım et al. (2017), and the resistivity models were obtained along the determined 6 lines. The resistivity model obtained from the data measured along Line-24 is presented in Figure 5c. Measured gravity data on the MT Line-24 were modeled two-dimensionally with the "Wingling" software. The gravity model on Line-24 is presented in Figure 5b. In Figure 5a, the MT station locations measured on Line 24 and the locations of active faults determined by tectonic studies in the region are shown. Detailed tectonic studies carried out within the scope of the study were interpreted with 2D density and resistivity models and the faults were drawn on the models (Figure 5b-5c). In GNSS studies, unlike other studies, the amount of slip on the main faults was calculated by using the fault depths and slopes obtained from the MT studies as inputs.

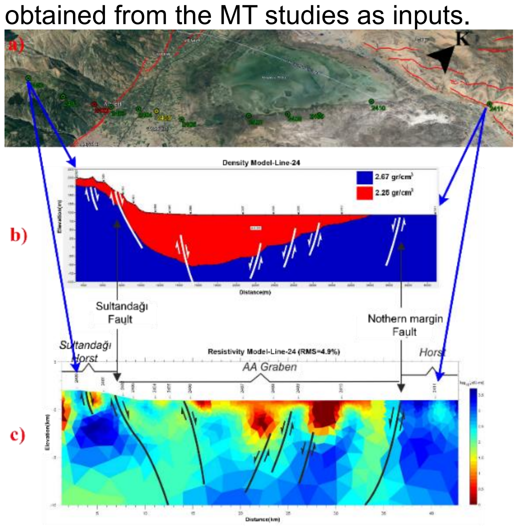

Figure 6. a. Line 24’ de bulunan MT istasyonlarının konumları (red lines are active faults), **b.** 2D density model and **c.** 2D resistivity model on Line-24.

CONCLUSIONS

In the geological field studies carried out within the scope of the study, surface data such as the geometry, kinematic analysis, and active tectonic features of the Sultandağı fault were collected. Preliminary findings obtained from the studies carried out between Sultandağı and Ilgın districts indicate that segments of the Sultandağı Fault operate in dip-slip normal fault character, are shaped under NE-SW directional extensional forces, and are typical with linear trending mountain front, especially between Sultandağı and Akşehir. The dip angles measured from the NW-SE trending and northeastward dipping fault planes vary between 65° and 75°.In addition, MT data collected within the scope of geophysical studies were evaluated with the 2D inversion algorithm developed by Özyıldırım et al. (2017), and resistivity models were obtained. Preliminary evaluations were made for the gravity data measured along the relevant Lines, and density sections were obtained for fault zones and buried geological units and structures. Obtained resistivity and density models were interpreted in the light of tectonic studies. The preliminary findings indicate the existence of synthetic and antithetic fault branches extending approximately parallel to the main fault buried within the ceiling block of the Sultandağı Fault and the fault has a depth of at least 10 km with an average angle of 70°.

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