Investigation of Earthquake Swarm and Buried Geothermal Resources By Magnetotelluric, Gravity Modeling and Seismological Analyses of Upper Crust Structure of Yalova-Termal Region

E. Pekşen*,[1], D. Çaka[2], B. Tunç[3], B. Oruç[4], E. Budakoğlu[5], T. Türkmen[6], F. Sevim[7], D. Durdağ[8], K. Zengin[9], M. E. Erkan[10], G. Durdağ[11], Ş. Barış[12]
[1]Kocaeli University, ertanpeksen@kocaeli.edu.tr, [2]Kocaeli University, caka@kocaeli.edu.tr, [3]Kocaeli University, berna@kocaeli.edu.tr, [4]Kocaeli University, bulent.oruc@kocaeli.edu.tr, [5]Sakarya University, ebudakoglu@sakarya.edu.tr, [6]AFAD-Yalova, taylanturkmen@gmail.com, [7]TÜBİTAK-MAM Earth and Marine Sciences Research Group, fatih.sevim@tubitak.gov.tr, [8]Kocaeli University, dogukan.durdag@kocaeli.edu.tr, [9]Kocaeli University, zenginkaderrr@gmail.com, [10]Kocaeli University, eezgibabir@gmail.com, [11]Kocaeli University, gamzeayhandurdag@gmail.com, [12]Kocaeli University, sbaris@kocaeli.edu.tr

SUMMARY

In this study, velocity, resistivity, and density structure of Termal district and its surroundings were investigated. The seismic activity of the region was monitored for three years. During this period, 4792 earthquake data were read. 3D tomography of the region was obtained by performing the LOTOS program. Thus, the lateral and vertical distributions of seismic wave velocities were obtained from local earthquake tomography studies as well as Vp / Vs ratios. Resistivity distributions in three dimensions from 39 MT and TEM data were obtained in the vicinity of Termal district. As for the gravity method, the topography of basement in three dimensions was obtained up to 1.1 km using gravity data measured at 268 points. Density distributions of the corresponding area were estimated by an inversion method with the gravity data. Although the resolution of the three different geophysical methods performed in the study area varies, their results support each other.

Keywords: Local Earthquake Tomography, Magnetotelluric, Gravity, Geothermal, Earthquake

INTRODUCTION

The Armutlu Peninsula has very active seismicity. The study area and its territory has been monitored by an earthquake network station (Armutlu Earthquake Network Stations-ARNET) since 2005. The most important and highest of these activities as took place in August 2014. After this event, the earthquake activity of the Termal district and its vicinity for 3 years was monitored using the ARNET by adding 8 temporary stations to the existing network more detail. The places where the station to be established were determined specifically. To do this, the measurements were taken in these locations whether the selected places were suitable for the earthquake station by analyzing the measured data. After locations of the temporary station were determined, the installation of earthquake stations was completed.

Beside earthquake data and tomography study, three different geophysical methods applied in the study area. These were Transient electromagnetic (TEM), magnetotelluric (MT) and gravity methods. Standard MT (EDI) files were created by analyzing the data of MT measurements. The static shift effect in the MT measurements was eliminated by using TEM measurements (Pellerin and Hohmann, 1990). Consequently, 3D MT data (impedances) was performed using ModEM software (Egbert and Kelbert, 2012; Kelbert et al., 2014). Gravity data were measured in the corresponding area and Bouguer anomaly map was obtained as well. 3D gravity inversion (Oldenburg, 1974) and 2D gravity density inversion (Constable et al., 1987) were achieved using gravity data. Earthquake data were collected and read from stations periodically. Using earthquake data, tomography results were obtained (Koulakov, 2009). By using all these methods and results, comments were suggested about the region. Alteration zones, fault and dyke systems, and intrusive intrusions associated with possible heat sources were modeled depending on the density variations.

GEOLOGICAL SETTING

The geological map of the study area is shown in Figure 1. Neotectonic features of the district of Termal and its surroundings was studied by Yiğitbaş et al. (2006). Thermal hot water is on the border of Gemiciköy formation and Kızderbent Volcanite in Termal. The boundaries of our study area are generally located in these two units according to the geological map of the Armutlu Peninsula. Our study area consists of Eocene younger units and Eocene older units. Eocene aged rocks are andesitic and basaltic volcanics (Akbayram, 2011; Genç et al, 2004).

METHODS

In this study, seismic tomography, MT, and gravity methods were applied to examine the earthquake activities, to understand the location of faults and the boundaries of the hot water reservoir in the region.

Seismic Tomography

To obtain the tomography result of the study area, 5228 earthquakes with Ml magnitudes ranging from 0.1 to 4.9 were utilized. The data set contains a total of 92642 phase, 49232 P and 43410 S readings. The local earthquake tomography study was carried out using the LOTOS algorithm (Koulakov, 2009). Thus, the velocity structure of the study area was obtained. Figure 2(a) shows the variation of Vp perturbations at 1 km depth. The variation of Vs perturbations is illustrated in Figure 2(b). Figures 2(a) and 2(b) are superposed on a digital elevation map of the study area and faults with all together.

Magnetotellurics

MT measurements were acquired at 39 locations. MT locations are shown in Figure 1 with orange squares. Four set of Metronix equipment were utilized to measure MT data with one of the equipment fixed at a reference point. After collecting the data, the data processing was applied to get EDI files. The inverse solution was applied to the measured TEM data. TEM result was applied to static shift correction. Thus, the corrected MT data was obtained. 3D MT inversion was achieved using ModEM program with the corrected MT data set. The inversion of 3D MT data are illustrated at 1 km depth in Figure 2(c). One can distinguished the difference between the scanned area by tomography and MT methods from Figure 2(a), (b) and Figure(c). The reason for this is the distribution of the earthquake and the MT stations.

Gravity

The location of the gravity measurement points is shown in Figure 1 with white circles. The gravity data were measured at 268 points. The gravity data requires some basic data processing as latitude, free-air, Bouguer, terrain corrections to obtain Bouguer anomaly map of the study area. The low pass filter was also applied to the data to get rid of some noise from the measurement. The base undulation at 1.1 km depth was estimated by 3D inversion algorithm. 3D inversion was developed by Oldenburg (1974). Besides the 3D inversion of gravity data, 2D inversion of some of profiles were inverted by Occam inversion to estimate density variation.

CONCLUSIONS

Seismic Vp and Vs velocities were obtained by local earthquake tomography. MT resistivity volume of the study area was achieved by a 3D MT inversion program. 3D undulation depth of the base was estimated by a 3D gravity program. The seismic velocity structure of the region was revealed in detail with the local earthquake tomography study. Although the Vp/Vs distributions were expected at high values due to the geothermal fluid, low Vp/Vs ratios were obtained, especially at a depth of approximately 1 km. We also observed that the earthquake focal depths were concentrated in regions where the Vp/Vs ratios change sharply laterally. The electrical resistivity sections modeled from the MT data provided a solution up to a depth of 3.5 km, where the geothermal resources that cause changes in the local earthquake tomography velocity sections. Gravity anomalies provided solutions for revealing shallow lineaments of the project area and distribution of density differences. Using spectral analysis of Bouguer anomalies, the depth of the metamorphic basement rock to the medium was estimated as 1.15 km. Further, the geometric structure of the basement rock, modeled by the Parker-Oldenburg algorithm, varies between 0.75-1.5 km. This rapid changes in a local area reveals the importance of tectonic forces in the structural deformation of the basement rock and magma activity feeding deep geothermal processes. We also suggest that the aquifer of Termal city needs to be characterized more details. The drilling activities around the study should be controlled by the local authority.

ACKNOWLEDGEMENTS

This study was supported by the Scientific and Technical Research Council of Turkey (TÜBİTAK) under grant 117Y184. We would like to thank to PhD. Cemal Kaya for MT data processing. Unfortunately, PhD. Cemal Kaya passed away very sadly. He had a very helpful personality. We will never forget him with his very good memories.

REFERENCES

Akbayram K (2011). İstanbul ile Sakarya Zonları Arasındaki Potid-İçi Kenedinin Armutlu Yarımadası Doğusu'ndaki Evrimi. PhD thesis, İstanbul Technical University, İstanbul.

Constable SC, Parker RL, Constable CG (1987). Occam's inversion: A practical algorithm for generating smooth models from electromagnetic sounding data. Geophysics, 52, 289-300.

Genç C, İşseven T, Keskin M, Tüysüz O (2004). Armutlu Yarımadası (KB) Eosen manyetik kayalarının petrolojik evrimi ve paleomanyetizma özelliklerinin araştırılması: *TÜBİTAK Project No: 102Y032.*

Egbert GD, Kelbert A (2012). Computational recipes for electromagnetic inverse problems. Geophysical Journal International, *189*(1), 251-267.

Kelbert A, Meqbel N, Egbert, GD, Tandon K (2014). ModEM: A modular system for inversion of electromagnetic geophysical data. Computers & Geosciences, *66*, 40-53.

Koulakov I (2009). LOTOS code for local earthquake tomographic inversion. Benchmarks for testing tomographic algorithms. Bulletin of the Seismological Society of America, 99, 194-214.

Pellerin L, Hohmann, GW (1990). Transient electromagnetic inversion: A remedy for magnetotelluric static shifts. Geophysics, *55*(9), 1242-1250.

Oldenburg DW (1974). The inversion and interpretation of gravity anomalies. Geophysics, *39*, 526-536.

Yiğitbaş E, Bozcu M, Aylan E, Gürer ÖF, Yılmaz K, (2006). Armutlu Yarımadası'nın Yalova Batısında kalan kesiminin morfotektonik-jeolojik niteliklerinin incelenmesi: *TÜBİTAK Project No:101Y068.*

Web of General Directorate of Mineral Research and Exploration. http://yerbilimleri.mta.gov.tr/home.aspx Accessed 29 July 2022

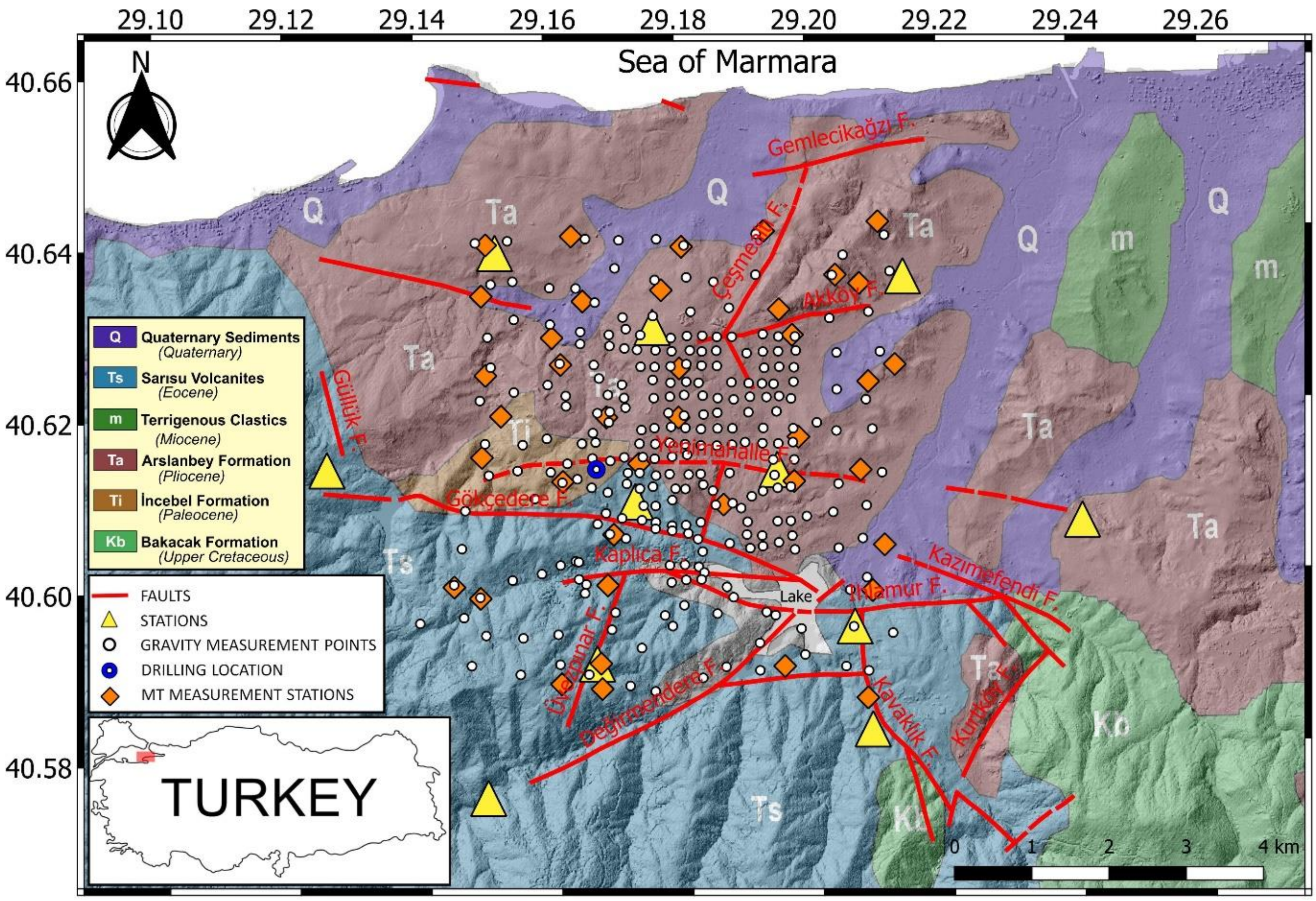
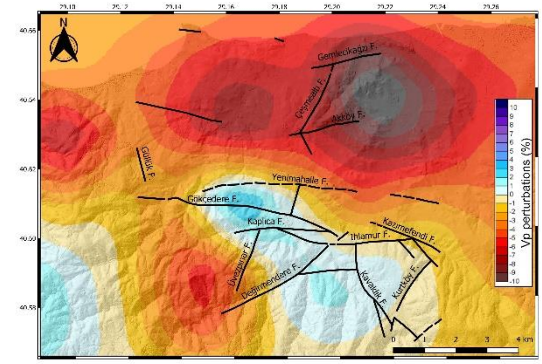
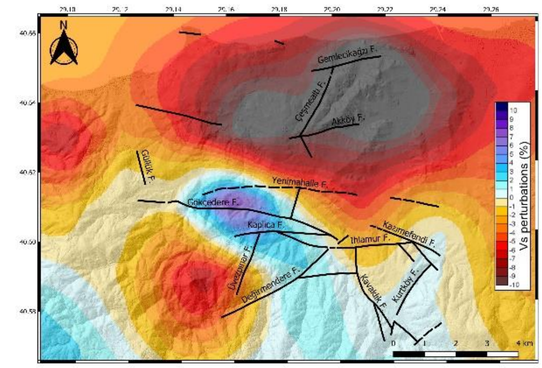


Figure 1. The geological map of the study area (Web of General Directorate of Mineral Research and Exploration). Faults are compiled by Yiğitbaş et al. (2006).

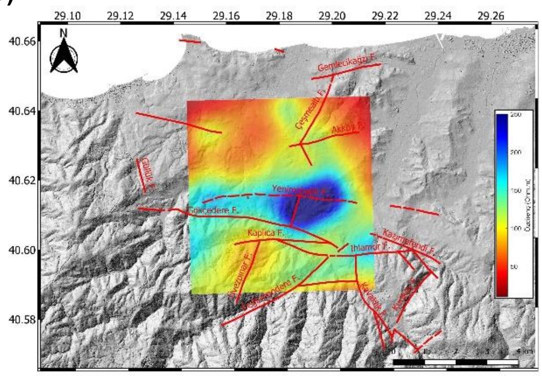
(a)



(b)



(c)



(d)

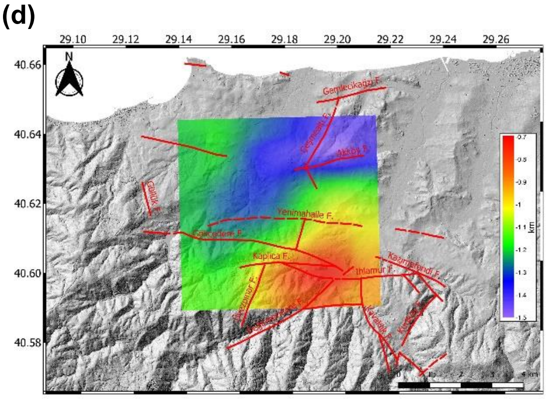


Figure 2 (a) Vp perturbations, **(b)** Vs perturbations, **(c)** MT resistivity variations, **(d)** Topography of basement at 1 km depth based on gravity data.