# Resistivity Structure of the Kula Volcanic Area (Turkey) inferred from Three Dimensional Magnetotelluric Data Inversion

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## Summary

The Kula volcanic area in western Turkey is a rare location globally where the asthenospheric mantle source is melting, leading to volcanic eruptions. The main aim of this study is to investigate the magma pumping system underlying the Kula Volcanic Area (KVA). For this purpose, we conducted an MT survey of a 60 x 60 km2 area surrounding KVA. The MT data were acquired from 126 broadband and 13 long-period MT stations. After editing, we used 13 Long Period and 92 broadband MT stations data in 3D inversion. The 3D resistivity model was obtained for 60 km depth. The resistivity model demonstrates the presence of complex distributed asthenospheric melts spread through the crust, reaching depths of up to 40 km below the KVR.

Through inversion analysis, significant pure and partially molten magma zones have been delineated. This is exhibiting varying resistivity values and geometries, including elongated tabular structures and spherical bodies, distributed across the Kula volcanic field. The distribution of these melting zones reaching ~1400 km3, particularly those characterized by resistivity values of 3-5 Ω m, suggests dynamic processes of magma ascent and redistribution within the crust, potentially influenced by specifically post-exhumation tectonics of Menderes massif since 2 My. This study revealed the presence of east-west directional extensional tectonics surrounding the KVR, a phenomenon seen for the first time in the last 2 My and driven by the force of north-south directed vertical tearing.

**Keywords:** Magnetotelluric, 3D, inversion, Kula Volcanic Area, Türkiye

## Introduction

The Kula Volcanic Region (KVR) located in Western Anatolia, is situated in the northern part of the Menderes Massif. It is a rare location globally where melting of the asthenospheric mantle source occurs, leading to volcanic eruptions witnessed even in historical times. Seismic tomography findings (Biryol et al., 2010) suggest that the Kula volcanic field sits directly above an upwelling hot asthenosphere linking an N-S directing tear.
Kula volcanics, representing the most recent magmatic activity in the region, date back approximately 1.9-0.026 My ago, with some eruptions as recent as 0.2 My ago. These lavas are believed to have been propagated along active normal faults associated predominantly with the Gediz graben, which primarily trends in an E-W direction and developed during the Miocene-Quaternary period of N-S extensional tectonic activity in Western Anatolia.

There are limited studies in Anatolian plate that investigates volcanic areas and with MT method (e.g. Tank and Karaş 2020; Başokur et al. 2022). Information on the magma pumping system underlying the Kula Volcanic Region (KVR) is not investigate until this study. In this study we conducted an MT survey of a 60 x 60 km2 area in the vicinity of KVR. The first time MT provided data demonstrates the presence of complex distributed asthenospheric melts spread through the crust, reaching depths of up to 40 km below the KVR.

## METHODS

The MT data were collected in the KVR. The MT stations were densely distributed west-east and north-south margins of the KVR and, in turn, a rectangular network station involving the KVR (see Figure 1). MT data were acquired from 126 broadband and 13 long-period MT stations. The 67 broadband MT data collected along two EW-directional profiles and one SW directional line were collected by Candansayar et al. (2012). The other broadband and 13 long-period data were collected under project, 120Y237, in 2022. After time series analysis and esmitaing the impedance and tipper tensor data in frequency domain, we edited MT data and over-scattered data are masked. Also, some noisy stations are removed from the data set before 3D inversion. After data editing, we used 13 Long Period and 92 broadband MT stations data in 3D inversion.

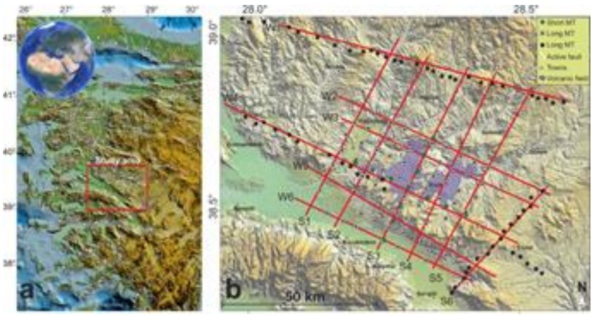

Figure 1. Survey Area maps. Dots show previously measured MT stations (Candansayar et al. 2012), rectangle symbols show MT stations (in 2022), and green coloured circles show the long period MT data stations. The red lines show cross-section profiles over the 3D resistivity model.

We did dimensionality analysis by using phase tensor analysis before 3D inversion (Caldwell et al. 2004). If the medium is 3D according to the resistivity parameter, the phase tensor skew angle (β in degree) is greater than 0$^{o}$ (Caldwell et al. 2004). However, the field data includes some errors. Therefore, we interpret that if β angles are outside of the ranges, (-5$^{o}$, 5$^{o}$), there are 3D structures in the survey area. In this study, we plot the β values as ellipses on the survey area map for different periods T=0.1, 1, 10, 100, 1000, and 5.000s (Figure 2).

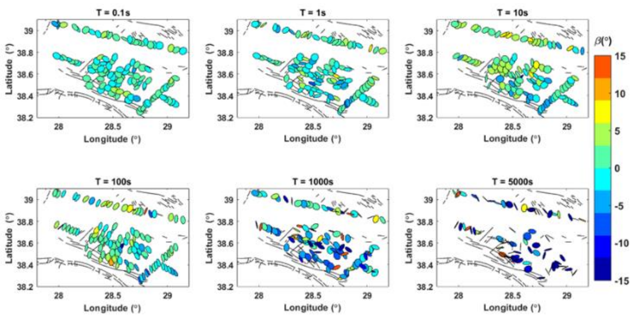


Figure 2. The phase tensor skew angle (β in degree) for different periods.

For short-period ranges (T<10s), the β values of almost all stations are between the ranges, (-5$^{o}$, 5$^{o}$). For the largest periods (T>10s), the β value amplitude is increasingly out of the range with an increasing period. This means higher period data are strongly influenced by medium and deep 3D structure effects.

We used ModEM software (Egbert and Keller, 2012; Kelbert et al. 2014) for 3D MT data inversion. It uses a non-linear regularized smoothing inversion solution with a conjugate gradient solver. In the survey area, the broadband and long-period MT data were obtained between the period ranges from 0.003s. to 2000 s. and 0.0001 s. to 10.000 s., respectively. However, we used 0.01s to 10.000s period ranges for 3D inversion. We inverted full-impedance and tipper data. We used 15% error floor for diagonal and a 5% error floor for off-diagonal impedance components and 0.05 for tipper components. We used tipper data in the period ranges between 0.01-1000s in inversion, to avoid external source bias on the tipper data (e.g., Egbert, 1989; Yang et al. 2021).

## RESULTS

The most prominent structure is the highly conductive (3-5 Ω m) region, which distributed tabular-formed conductive subzones settled between 10 and 30 km depth. These zones, defined by lateral extension and having low resistivity, are segmented as four major different compartments, particularly noticeable in E-W profiles through 80 km (Fig. 3).

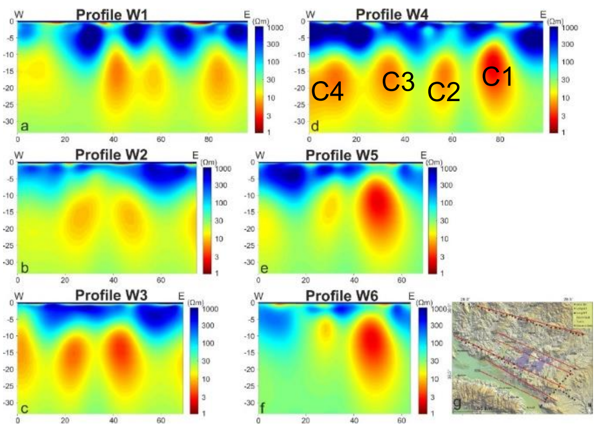


Figure 3. NW to SE directional cross sections of the 3D inversion results.

Undoubtedly, three-dimensional (3D) inversion of MT data gives substantial advantages in clarifying and grasping the spatial distribution of these melting zones. Through 3-D inversion analysis, a pure melting zone defined by a resistivity of < 3 Ω.m, elongated along the NE-SW direction, and with a tabular structure measuring 28 x 8 km was identified (Fig. 4a). This conductive material may be the major magma reservoir, situated at a depth of 9 km, has dimensions of 27x6.4x8.2 km³, resulting in a volume of 1417 km³.

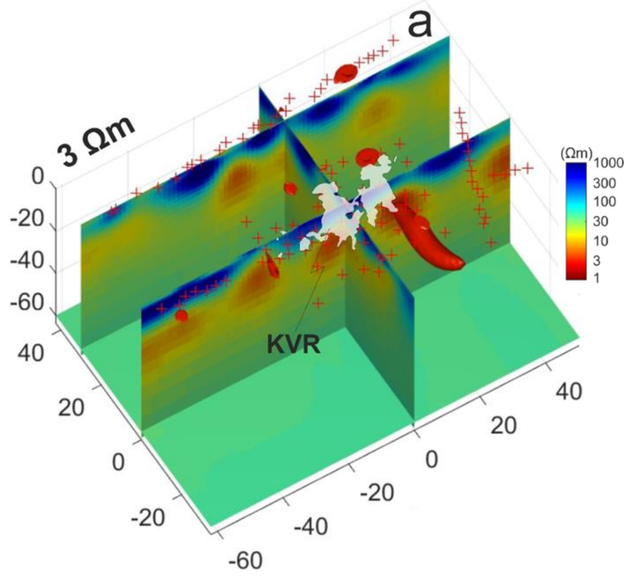


Figure 4. 3D resistivity model: isosurface plotted for rho=3 Ω.m

## DISCUSSION

Upon assessing the 2D resistivity sections oriented in the north-south direction, it is clear that the areas with low resistivity anomalies, which range from 3 to 5 Ω m, show a noticeable upward pattern towards the southern region (see Fig.3 and 3). This suggests that melting zones have propagated the Earth's crust to a depth of 5 km, specifically in the southeastern area between Alaşehir and Sarıgöl. The significant deformation of the upper crust is ascribed to detachment faults linked to the exhumation of the Menderes Massif in the Oligocene-Early Miocene era, followed by high-angle faults that mostly affected the region in an east-west direction since the Pliocene. Seismic reflection modeling indicates that the Gediz detachment fault, which separates the basin from the metamorphic massif, reaches a depth of approximately 4 km and extends in a northerly direction at a shallow angle (Çiftçi, 2013). The supporting evidence consists of high-angle faults that have controlled the filling of the Gediz Graben for the last 5 My (Seyitoğlu and Scott, 1991; Purvis and Robertson, 2005). These faults have primarily caused deformation at depths of 2.5 km, although occasionally they have reached a maximum depth of 4 km. The main geological characteristics that contribute to the propagation of magma melt zones to a depth of 5 km in Alaşehir-Sarıgöl seem to be the presence of low-angle faults that govern the creation of the Gediz Graben and subsequent high-angle faults that cause deformation in the area (Çiftçi and Bozkurt, 2009; Çiftçi, 2013).

## CONCLUSION

The 3D resistivity model constructed from MT data has revealed a prominent tabular conductive zone extending between 9 and 30 km depth beneath the Kula volcanic area, with distinct compartments evident in both E-W and N-S profiles.

Through inversion analysis, significant pure and partially molten magma zones have been delineated, exhibiting varying resistivity values and geometries, including elongated tabular structures and spherical bodies, distributed across the Kula volcanic field.

The distribution of these melting zones reaching ~1400 km3, particularly those characterized by resistivity values of 3-5 Ω m, suggests dynamic processes of magma ascent and redistribution within the crust, potentially influenced by specifically post-exhumation tectonics of Menderes massif since 2 My.

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