Analysis of magnetotelluric data from Damavand volcano

Seyed Masoud Ghiasi[1*], Banafsheh Habibian Dehkordi[1], Behrouz Oskooi[1]

[1]*Institute of geophysics, University of Tehran, Masoud.ghiasi@hotmail.com*

Abstract

The Damavand volcano is located at the northern of Iran and currently is asleep. This peak is the highest one in the middle east, and its height is 5670 meters above the sea level. In order to study and model the magmatic reservoir of Damavand volcano, the magnetotelluric measurements have been conducted. The surveying is designed as a lattice around the mountain. In this study have been tried to analyze the MT data in term of dimensionality, penetration depth, and geoelectrical strike which are important for cognition the region and the modeling. These analyses have been obtained by Mtpy toolbox package.

Keywords: Magnetotelluric, Damavand volcano, penetration depth, phase tensor, MTpy

Introduction

The magnetotelluric method maps the electrical resistivity variations of the subsurface formations by simultaneous measurements of the natural electromagnetic fields on the Earth's surface. Electromagnetic field (E, H) components are related through magnetotelluric responses or transfer functions, the most important of which is the impedance tensor, Z:

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \end{bmatrix}$$

The obtained data are then analyzed, corrected, if necessary, modeled and interpreted. Thus, data analysis, including dimensionality determination, strike estimation, level of distortion evaluation and estimation of approximate penetration depth is a very important step before modeling and interpretation.

The Mtpy software package allows handling, processing, and imaging magnetotelluric data sets. It is written in python and accessible as an open-source code. It is worth noting that some of the toolbox's processing features are strike determination, phase tensor dimensionality analysis, and penetration depth computation (Krieger et al. 2014 and Kirkby, 2019). In this paper, the Mtpy software package is used for analysis of the MT data from Damavand volcano.

The study area and MT data

The Damavand volcano mountain area is a composite cone which possesses more than 400 km^3 bulk. It is in the Alborz Mountains; the Alborz Mountains constitute an active, arcuate fold-and-thrust belt (Davidson et al., 2004). The average elevation of the mountains is more than 2000 meters, but it is worth noting that based on the gravity data, the crustal thickness of the underside of the area is about 35 km (Dehghani et al., 1984). The most abundant rocks which are formed from magma eruption, are trachyte, andesite, and basalt (Davidson et al., 2004). The MT stations are located around the Damavand volcano. This survey has been done to determine and study the magmatic reservoir of the Damavand volcano by modeling the data. As shown in figure.1, the surveyed points are latticed and distributed. Thirty-seven stations have been used for the purpose, and their dimensionality would acquire in the following.

Figure.1. MT station locations overlayed on the geographical map of the area.

Methodology

Here, the phase tensor method is used to determine the dimensionality and estimate the azimuth of strike, if existent. The magnetotelluric phase tensor is defined as (Caldwell et al. 2004):

$$\Phi = X^{-1}Y$$

Where X and Y are real and imaginary parts of the impedance tensor, respectively. It is free from non-inductive distortions resulted from the small-scale near-surface inhomogeneities (Caldwell et al. 2004; Booker, 2014). Ellipticity α and skew angle β are obtained as:

$$\alpha = \frac{1}{2}\tan^{-1}\left(\frac{\Phi_{xy} + \Phi_{yx}}{\Phi_{xx} - \Phi_{yy}}\right)$$

$$\beta = \frac{1}{2}\tan^{-1}\left(\frac{\Phi_{xy} - \Phi_{yx}}{\Phi_{xx} + \Phi_{yy}}\right)$$

can determine the strike angle of the geoelectrical structure. Weaver et al. (2000) have been provided a collection, consisting of 7 independent parameters and one dependent from impedance tensor invariant to analyze the MT data dimensionality. The most important property of these invariants is that without any initial assumption for the geoelectrical structure dimensionality, we can extract a significant amount of information from the impedance tensor (Weaver et al. 2000).

The Bostick transformation (Bostick, 1977) and the Niblett approximation (Niblett et al. 1960) give a penetration depth in a half space medium of resistivity equal to the apparent resistivity at the particular period T. According to Niblett-Bostick approximation, the penetration depth is given by:

$$h = \sqrt{\frac{\rho_a(T)T}{2\pi\mu_0}}$$

It is worth noting that this penetration depth implies at attenuation factor of approximately 1/2 instead of the more usual skin depth attenuation of 1/e (Jones 1983).

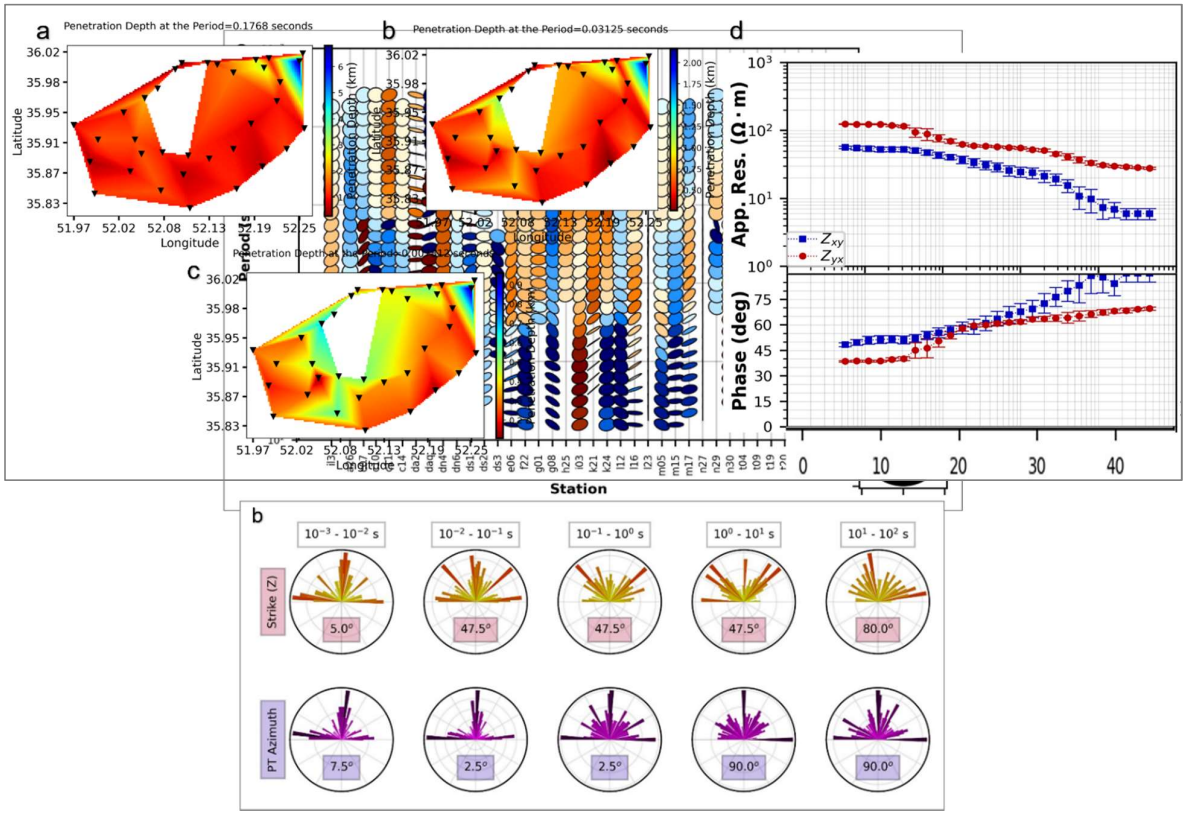
Results

Niblett-Bostick penetration depths at three characteristic periods are shown in Figure 2. We see that stations located at northeastern parts have larger pentration depths (>6 km), indicating that the resistivities are higher compared to other parts. According to the 3D penetration depth (PD) maps, the southeast and west section of the area illustrate lower penetration depth (<500 m) which means there are more conductive structures. In order to study precisely, apparent resisitivity of station l23 which belong to the higher PD section have been obtained. As expected, l23 station states resistive structure. As can be observed, by depth increasing the resistivity decreases. The

outlier phase (>90 deg) might be the effectiveness of 3D structures or anisotropy existence.

Figure.2. Map of interpolated Niblett-Bostick penetration depths at three characteristic periods and apparent resistivity section. (a) PD at low period (0.1768), (b) PD at mediocre period (0.03125), (c) PD at high period (0.007812), (d) apparent res and phase for station l23.

Ellipses are the graphical way to display the phase tensor results. Pseudo-section of phase tensor ellipses is shown in Figure 3a. As can be seen, circles at short periods change to more



general ellipses at long

Figure.3. Pseudosection of phase tensor ellipses, colored with skew angle (a); Strike and phase tensor azimuth for different period intervals (b).

periods. The corresponding skew angle also increases and point to increasing three-dimensional effects and complexity with depth. Distribution of all strike directions are shown in diagram of Figure 3b. We see that it is difficult to select a dominant direction and the strike direction is very different for the different period intervals.

Conclusion

Magnetotelluric data from Damavand volcano have been analyzed using the Mtpy software package. The phase tensor and skew angle have been utilized to determine the dimensionality of the 37 magnetotelluric stations in the Damavand volcano area. Also, a 3D penetration depth map of the stations was used to specify the skin depths for the study area. Generally, it can be inferred that the dominant penetration depth for the entire area is about 750 meters. For most stations, in the shallow depths (short periods), the 1D and partly 2D structures can be considered. By increasing depth, the 3D structures are dominant. The preferential PT strike of the area would be N87.5E. The estimated direction has $\pi/2$ ambiguity of geoelectrical strike in the MT. Considering the geoelectrical information such as the west-east geological trend and active faults (Davidson et al., 2004) in the region the mentioned strike has been chosen.

References

Booker, J. R. (2014). The magnetotelluric phase tensor: a critical review. *Surveys in Geophysics*, *35*(1), 7-40.

Bostick, F. X. (1977). A simple and almost exact method of MT analysis. In *Workshop on electrical method in geothermal exploration, Snowbird Utah, 1977*.

Caldwell, T. G., Bibby, H. M., & Brown, C. (2004). The magnetotelluric phase tensor. *Geophysical Journal International*, *158*(2), 457-469.

Davidson, J., Hassanzadeh, J., Berzins, R., Stockli, D. F., Bashukooh, B., Turrin, B., & Pandamouz, A. (2004). The geology of Damavand volcano, Alborz Mountains, northern Iran. *Geological Society of America Bulletin*, *116*(1-2), 16-29.

Dehghani, G. A., & Makris, J. (1984). The gravity field and crustal structure of Iran. *Neues Jahrbuch für Geologie und Paläontologie-Abhandlungen*, 215-229.

Jiracek, G. R. (1990). Near-surface and topographic distortions in electromagnetic induction. *Surveys in Geophysics*, *11*(2), 163-203.

Jones, A. G. (1983). On the equivalence of the" Niblett" and" Bostick" transformations in the magnetotelluric method. *Journal of Geophysics*, *53*(1), 72-73.

Kirkby, A. L., Zhang, F., Peacock, J., Hassan, R., & Duan, J. (2019). The MTPy software package for magnetotelluric data analysis and visualisation. *Journal of Open Source Software*, *4*(37), 1358.

Krieger, L., & Peacock, J. R. (2014). MTpy: A Python toolbox for magnetotellurics. *Computers & geosciences*, *72*, 167-175.

Niblett, E. R., & Sayn-Wittgenstein, C. (1960). Variation of electrical conductivity with depth by the magneto-telluric method. *Geophysics*, *25*(5), 998-1008.

Weaver, J. T., Agarwal, A. K., & Lilley, F. E. M. (2000). Characterization of the magnetotelluric tensor in terms of its invariants. *Geophysical Journal International*, *141*(2), 321-336.