2D inversion of Magnetotelluric Data for Imaging the Subsurface Geological Structures Derived from Magnetotelluric Soundings

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Abstract

During year 2006 wide frequency range magnetotelluric measurements was carried out at the western part of Arak city in Iran to understand the crustal electrical conductivity of the region by putting emphasis on relocating the fault zones. The electric and magnetic field components were acquired from along a profile across the geological trend at 15 stations. A robust single site processing followed by the inversion and one dimensional as well as two dimensional modeling was performed. The inversion results revealed electrical conductivity structures in good correlation with geological features. As significant results, true locations of two major faults, Talkhab and Tabarteh Faults, were recognized in Arak area.

Keywords: Magnetotellurics, geoelectrical resistivity, Talkhab Fault, Arak, Iran.

1. Introduction

Because of the reflection and refraction of EM waves at vertical interfaces separating media of different electrical parameters, geoelectromagnetic methods have been developed and employed to recognize the fault zones in many regions. Due to its lateral resolution and also greater depth penetration MT method is one of the effective electromagnetic techniques to electrically image the subsurface structures.

Magnetotelluric (MT) transfer functions are calculated from measurements of horizontal electric and magnetic fields at the surface of the earth and could image the subsurface electrical resistivity in Arak area located in west central Iran (Fig. 1).

From the tectonostructure point of view the area of study is in the west of two NW-SE compressional strike-slip fault systems which are located in the border of the Central-Iran and Sanandaj-Sirjan zones. The faults are hidden under Quaternary alluviums. The seismicity of the area is controlled by these two parallel faults, especially Talkhab Fault which is the source of the slight seismicity of the region. Small magnitudes earthquakes on these long faults suggest an ambiguity in that; these faults are capable of producing great earthquakes. There are great numbers of earthquakes occurred in this area with ambiguous seismicity characteristics. The recurrence intervals of these faults are so long that can not be determined by instrumental seismicity. Therefore, identifying the characteristics of these faults must be dealt with first degree priority.

In this paper we present a case study of magnetotelluric survey conducted in 15 stations with site spacing varying from 5 to 10 kilometers to image the subsurface structures related to fault zones in Arak area.

2. Geological setting

The area of study is a part of Arak watershed located in the two Central-Iran and Sanandaj-Sirjan Zones. A simplified geological map of Arak area is shown in Fig. 1. The presence of folded mountains and pressure ridges are the main characteristics of this region. Two parallel faults named Talkhab and Tabarteh Faults pass through the region and divide it in to three blocks. These blocks are “Ashtian-Naragh” (ANB), “Haftad-Gholeh” (HGB) and “Sanandaj-Sirjan” Blocks (SSB). The Talkhab Fault separates ANB from HGB while Tabarteh Fault separates HGB from SSB. The amount of water discharge in HGB, SSB and ANB are different and decrease respectively. Talkhab and Tabarteh Faults control the seismicity of the region. Talkhab spring, travertine and the emanation of gas from some wells are the reasons indicating the activity of Talkhab Fault in Quternary. Statistical analysis regarding the hypocenters of earthquakes shows that most of the events are located near Talkhab Fault. The oldest block in this region is SSB which involves crystallized limestones, slates from the Jurassic to cretaceous period that underwent faulting and metamorphism without any volcanic activity. The HGB contains shale, Jurassic sandstones and cretaceous limestone with no metamorphism but severely folded and has a sequence of anticline and syncline without any volcanism.

3.Methodology

Magnetotelluric method is a passive electromagnetic technique that uses the natural, time varying electric and magnetic fields components measured at right angles at the surface of the earth to make inferences about the earth's electrical structure which, in turn, can be related to the geology tectonics and subsurface conditions. The depth of investigation of MT method is much higher than that of other electromagnetic methods. Measurements of the horizontal components of the natural electromagnetic field are used to construct the full complex impedance tensor, Z, as a function of frequency,

$$Z = \begin{pmatrix} \mathrm{Z}_{\mathrm{xx}} & \mathrm{Z}_{\mathrm{xy}} \\ \mathrm{Z}_{\mathrm{yx}} & \mathrm{Z}_{\mathrm{yy}} \end{pmatrix} \tag{1}$$

The principal values of the tensor Z are two complex quantities which expressed in terms of rotational invariants, and, hence are independent of the direction of the axes (Berdichevsky and Dimitriev, 2002). For a $1D$ structure in which the resistivity of the earth varies only with depth, the diagonal elements of above matrix are equal to zero, whilst the off-diagonal components are equal in magnitude and have apposite signs. In a $2D$ case, wherein X or Y are aligned along the geoelectric strike, the diagonal element of Z would be zero again. We can define the geometric mean of this principal values as effective impedance which is a simplest approximation of the Tikhonov-Cagniard impedance,

$$\mathrm{Z}_{\mathrm{DET}} = Z_{eff} = \sqrt{\mathrm{Z}_{\mathrm{xx}}\mathrm{Z}_{\mathrm{yy}} - \mathrm{Z}_{\mathrm{xy}}\mathrm{Z}_{\mathrm{yx}}} \tag{2}$$

The advantage of using determinant data is that it provides a useful average of the impedance for all current directions. Furthermore, it is unique and independent of the strike direction. Using the effective impedance, determinant apparent resistivities and phases are computed and used for the inversion.

4. Data processing and analysis of the MT data

Time series measurements collected and cross power spectra computed to estimate the impedance tensor as a function of frequency. MT data were processed using a processing code from Smirnov (2003) aiming at a robust single site estimates of electromagnetic transfer function. As the area of measurements is populated and close to cultural noise sources, the recorded data were not with good quality which justify the low coherency between electric and magnetic channels. The parameter Swift's (1967) skew which is called a measure of asymmetry of a medium (Berdichevsky and Dimitriev, 2002) showed us dominant 1D and/or 2D structures in the area (Fig. 2). Swift's Skew values for the majority of sites are generally below 0.2. Some signatures of 3D effects are disturbing our modeling which could not be avoided due to lack of a 3D code at our disposal.

5. Inversion

5.1. One-dimensional inversion

One-dimensional (1D) inversion of the data carried out showing a good fit between the measured data and the responses of the models. Generally speaking the better the fit between measured and predicted data result in better resolution for model. We performed 1D inversion of the determinant data using a code from Pedersen (2004) for all sites. The resistivity model at site 2, located at the northeastern end of the profile, together with data and model responses is shown in Fig. 3. A transition from a less resistive formation (about 150 Ωm) at surface to a moderately resistive structure (about 500 Ωm) at 1500 m depth is resolved. By 10 km depth a consequence of conductive-resistive-conductive structure is provided by the 1D model.

5.2. Two-dimensional inversion

Regardless of the true dimensionality it is practicable to earn an overview of the subsurface resistivity with 1D inversion of MT data and actually, inversion of rotationally invariant data like the determinant data. Based on the results of the 1D inversion, a reasonable starting model and strategy can be constructed for two-dimensional (2D) inversion. Since the quality of the determinant data was acceptable, we performed 2D inversions of determinant data using a code from Siripunvaraporn and Egbert (2000).

Due to relief topography compared with the depth of investigation, a flat topography is assumed. The final model, data, model responses and the residuals are shown in Fig. 4. Along with the profile at sites 1, 2, 3 and 4 a high resistive structure is resolved which corresponds to the red conglomerate (shown in Fig. 1 in red). A low resistive zone at the location of site 5 is a good signature of Quaternary clay formation. The data from site 6 is not involved in the inversion due to bad quality. Site 7 which is located on Talkhab fault shows a resistive thin layer at the surface which converts to a less resistive body towards the deeper parts of the ground. Site 8 is located on a resistive body which most probably is missed to be located on the geological map of Fig. 1. Site 9 at the border of the clay and limestone formations show a conductor from surface to the depth of a few kilometers. We measure this location as a probable hidden fault. Patches of limestone with clay at sites 10 and 11 show an intermediate resistivity structure. Site 12 located on Talkhab fault clearly shows a conductive zone spreading down to 3-4 km depth. At sites 13 to 15 again more resistive formations of garvel fans and travertine appeared.

6. Conclusions

The magnetotelluric technique is an influential method for recognizing fault zones. The case study presented here proved the efficiency of this method and the geological structures and formations are well recognized by interpretation of the MT data.

Highly resistive formations like conglomerate and limestone, a clay formation and two major fault zones were resolved along the profile. The 2D model significantly illustrate two highly conductive zones hidden under the Quaternary alluviums.

As significant results, in collaboration with geological information about the presence of Talkhab and Tabarteh faults the conductivity features can be attributed to the faults. Besides, a probable hidden fault is also recognizable.

7. Acknowledgment

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8. References

Berdichevsky, M., and Dmitriev, V., 2002, Magnetotelluric in the context of the theory of ill posed problems: 12.2 Magnetotelluric in exploration for oil and gas, edited by Keller, G.V., published by Society of Exploration Geophysicists.

Pedersen, L.B., Engels, M., 2005. Routine 2D inversion of magnetotelluric data using the determinant of the impedance tensor. Geophysics 70, G33-G41.

Siripunvaraporn, W. and Egbert, G.: 2000, 'An Efficient Data-Subspace Inversion Method for 2-D Magnetotelluric Data', Geophysics 65, 791-803.

Smirnov, M. Yu., 2003, Magnetotelluric data processing with a robust statistical procedure having a high breakdown point. Geophys. J. Int. 152, 1-7.

Swift, C. M., 1967, A magnetotelluric investigation of electrical conductivity anomaly in the southwestern United States, PhD Thesis Massachusetts Institute of Technology, Cambridge, MA.

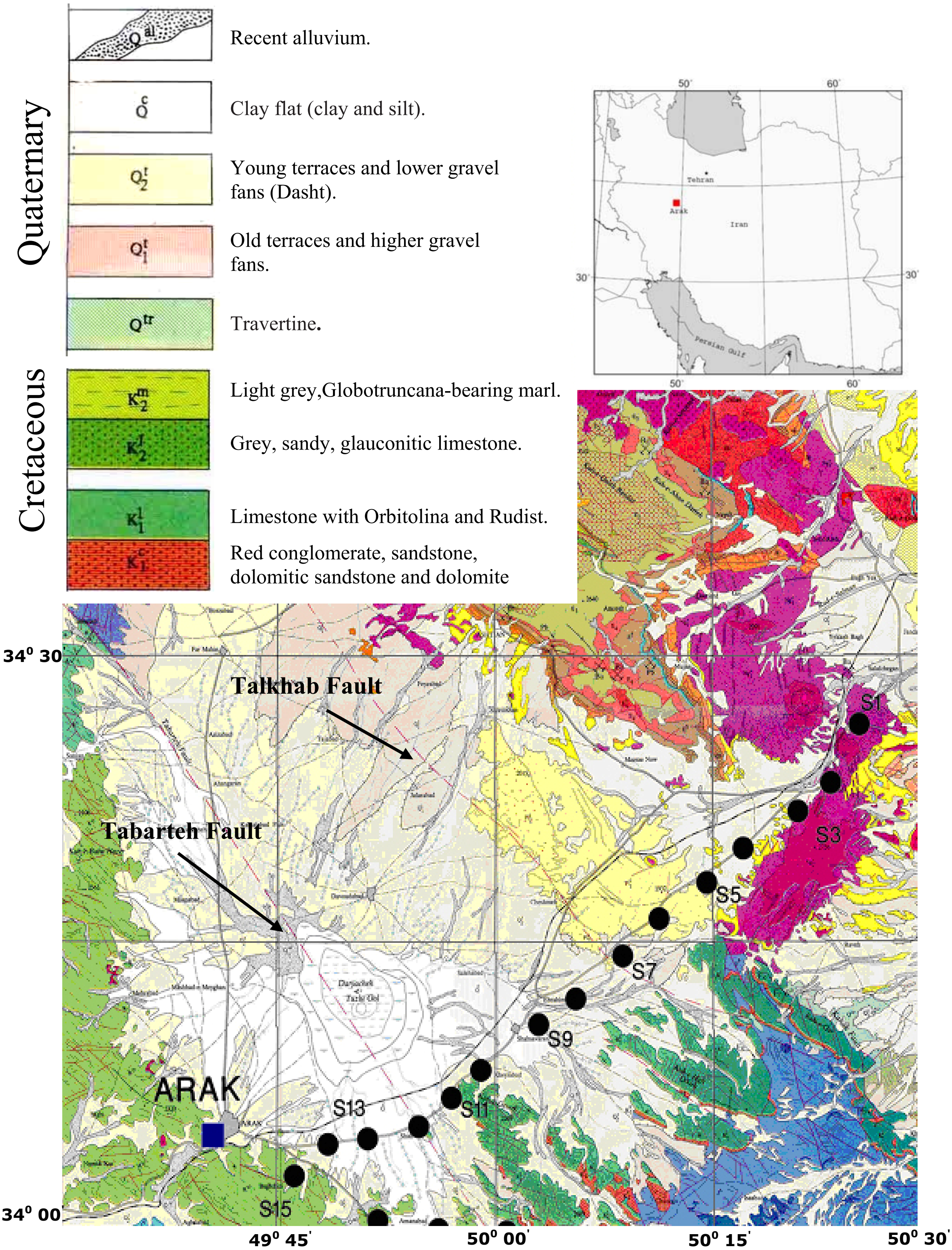
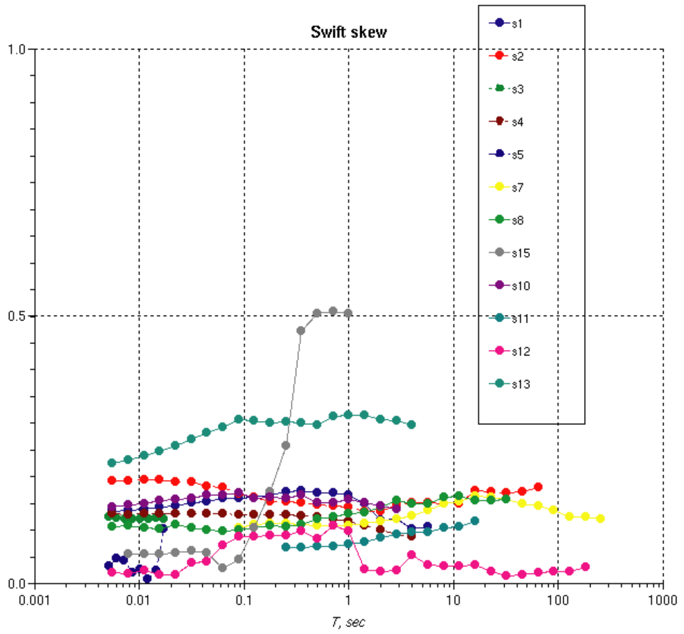
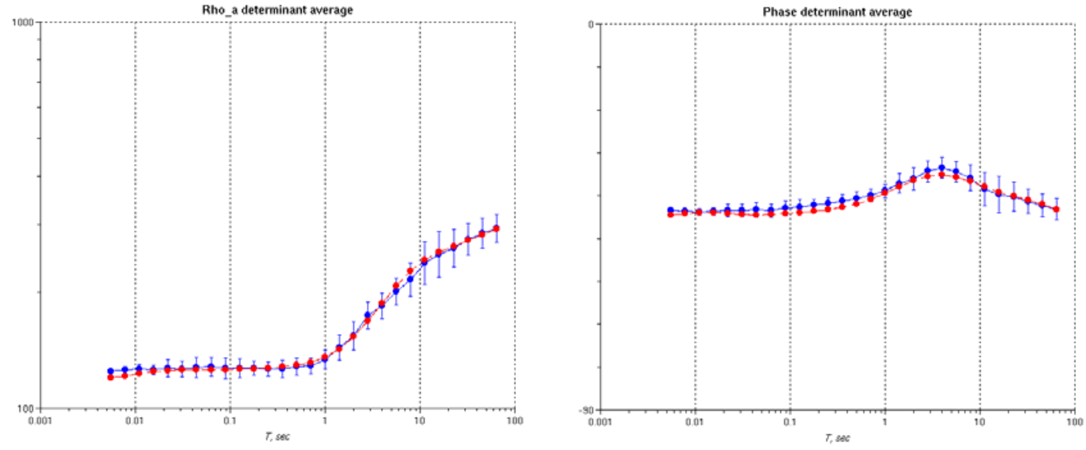


Fig.1. A simplified geological map of Arak and adjacent areas illustrating the major geologic and tectonic features. Location of the MT sites and Talkhab and Tabarteh faults are also shown on the map.



.Fig. 2. Swift’s skew values for some sites along MT-profile



(a)

(b)

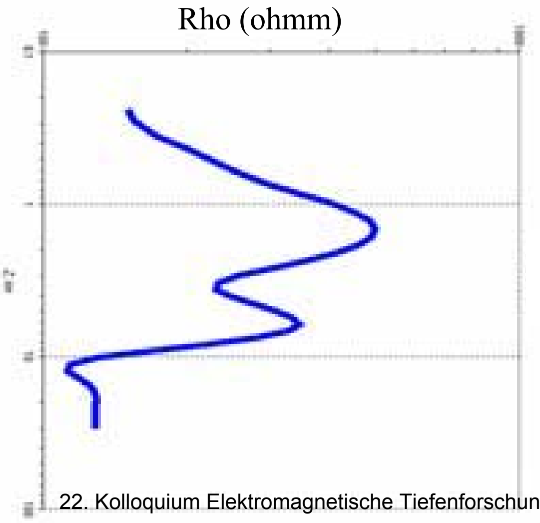


Fig.3. Data-fit and the 1D model of the data from site S2. (a) Apparent resistivity, (b) Phase and (c) 1D model.

(c)

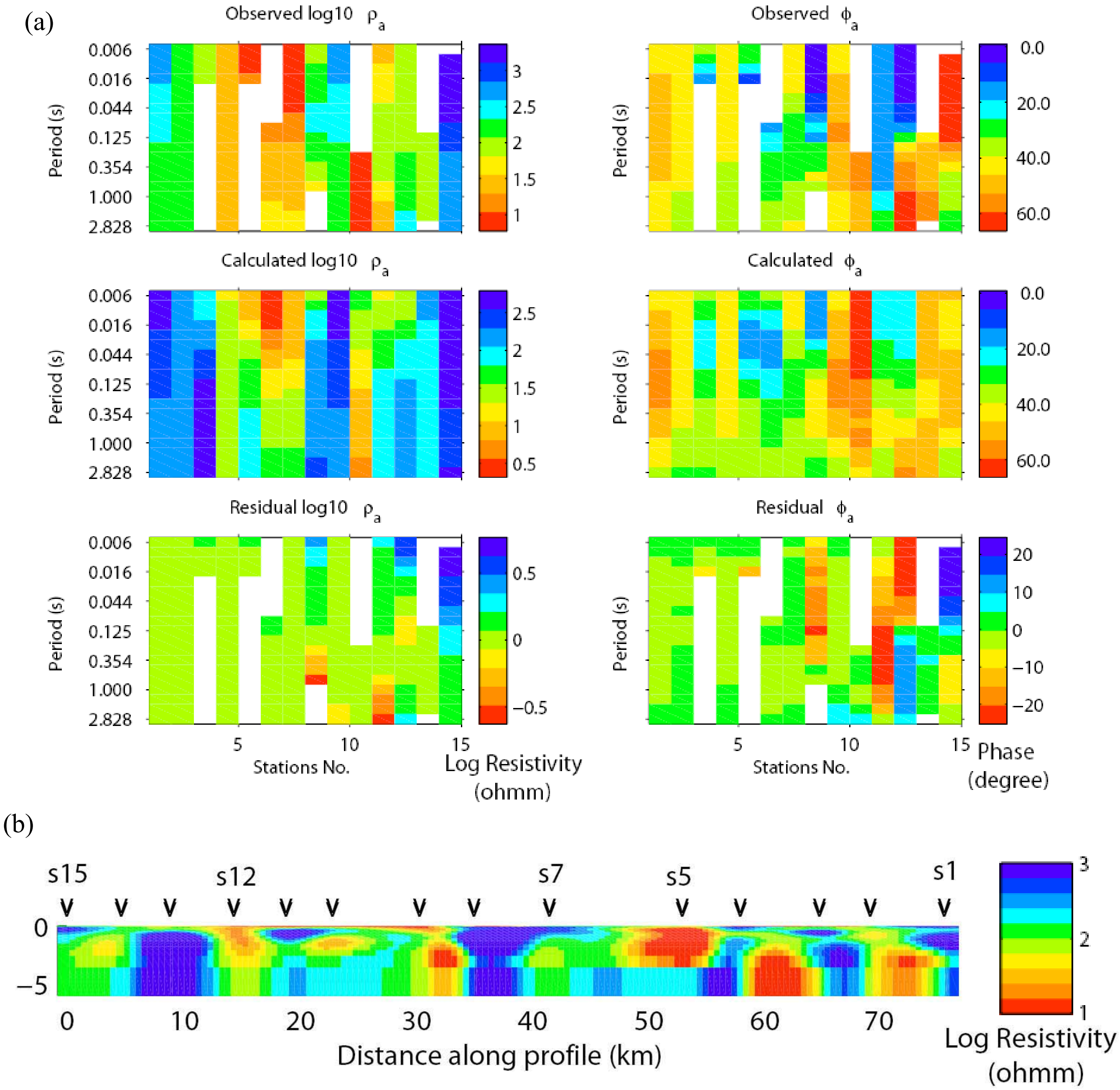


Fig 4. (a) Data, model responses and the residuals of 2D inversion of the determinant data along MT-profile. (b) Resistivity Depth Section of 2D modeling.