Two-dimensional inversion of magnetotelluric profile data to image the structure of Nasrabad salt diaper, west Central Iran

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SUMMARY

This research focuses on an MT dataset collected over the NasrAbad structure, a component of the Shurab salt diapirs in west-central Iran. The study involves the inversion of MT data gathered from the NasrAbad structure in the Qom sub-basin, located northwest of Kashan. The inversion process utilized Winglink software to produce the smoothest model inversions of TE and TM mode impedances, along with tipper data. The result of these numerical tests is a two-dimensional electrical resistivity cross-section along the profile. The general structure of these models reveals a conductive upper layer, attributed to the barren soil resulting from rainwater dissolution. This layer appears more continuous in the northeast of the profiles than in the southwest, where it is disrupted due to structural complexity.

Keywords: magnetotelluric, inversion, nonlinear conjugate gradient, Nasrabad.

INTRODUCTION

This research focuses on MT data collected northwest of Kashan in the Qom sub-basin of Central Iran, specifically above the Nasrabad structure of the Shorab salt diapirs. Diapirs are complex geological structures, deformed under pressure from underlying layers, requiring high-quality geophysical data for accurate interpretation. Initial identification of these structures typically uses potential field methods (gravity, magnetism), while seismic methods (reflection, boundary fracture) are useful for final exploration and drilling.

MT data are effective for characterizing salt diapirs because of their ability to assess electrical resistivity variations in rocks produced by factors like porosity, water content, and mineral composition. Diapirs, often rock salt with high resistivity enclosed by overlying porous sedimentary rocks with lower resistivity, are good targets for MT data analysis and interpretation. This method distinguishes between conductive fluids (e.g., saltwater) and resistive substances (e.g., freshwater, gas, oil).

Using natural electromagnetic fields, MT data map changes in the electrical resistivity of subsurface structures up to greate depths. This study aims to accurately delineate the dimensions and geometry of the buried Nasrabad salt diapir extension.

MT data includes electrical impedances (**Z**) derived from orthogonal electric and magnetic field components, and tipper (induction vectors) from vertical to horizontal magnetic field ratios across different field oscillations (T).

$$\begin{bmatrix} E_x(T) \\ E_y(T) \\ H_z(T) \end{bmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \\ W_x & W_y \end{bmatrix} \begin{bmatrix} H_x(T) \\ H_y(T) \end{bmatrix} \tag{1}$$

In this equation, the variables x,y,z represent horizontal and vertical electromagnetic field components in the regional geomagnetic coordinates.

Impedance response functions

Electrical resistivity and phase sounding curves of two representative sites along profile 15 are shown in Figure 1. The transverse electric (TE) and the transverse magnetic data (TM) are in red and blue colors, respectively.

In profile 15, the apparent resistivity decreases sharply with increasing period, indicating the presence of a near-surface conductive layer across the entire region. The phase sounding curves show values higher than 45° at short periods, further confirming the existence of this conductive layer. After the initial sharp decrease, the resistivity sounding curves start to increase again at longer periods, suggesting that the inductive EM fields are penetrating through this conductive layer to greater depths.

As we move from southwest to northeast along the profile, the separation between the TE and TM resistivity sounding curves decreases and shifts to longer periods, indicating that the subsurface structures are becoming less complex. For some stations (e.g., 15-0), the TE and TM resistivity sounding curves are distinct, but the phase sounding curves overlap, which can be interpreted as the presence of a static shift effect in the response functions at those stations.

The presence of the basement Fault is manifested as the flipping-over of the TE and TM mode soundings at the either side of the fault.

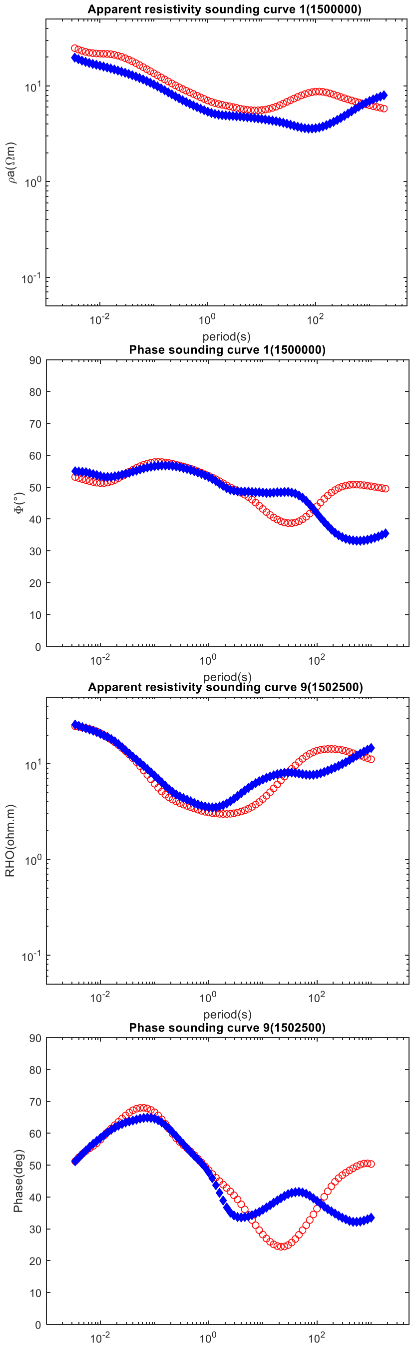

Figure 1. Apparent resistivity and phase soundings for two representative sites along profile 15.

Dimensionality and distortion analysis of field data

Subsurface electrical conductivity structures are evaluated using dimensionality analysis of MT data. We applied the phase sensitive η (Simpson and Bahr, 2005) and the phase tensor β skew angles (Caldwell et al, 2004) to determine the structural complexity of the study region.

The phase sensitive skew values ranging between 0 and 0.3 suggests a simple, one-dimensional, or two-dimensional structure. Values exceeding 0.3 indicate a more complex three-dimensional regional structure, necessitating a three-dimensional modeling approach.

The η Skew values in Figure 2 for this profile are mostly between 0.1 and 0.3, indicating predominantly one- and two-dimensional structures. Thus, a two-dimensional modeling approach is suitable for this dataset.

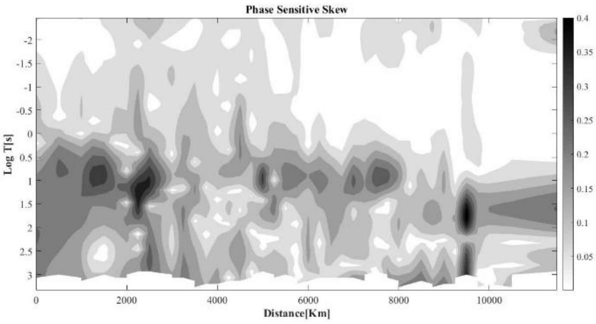

Figure 2. Pseudosection of the η phase sensitive skew values at all periods of different stations along profile 15

β skew angles above ±3° in the phase tensor method indicate a three-dimensional regional structure. Figure 3 illustrates the results of the application of this method for MT data along profile 15. It seems that β skew values are consistently below 3° at most periods, validating a regional 2-D geo-electric structure for the study region.

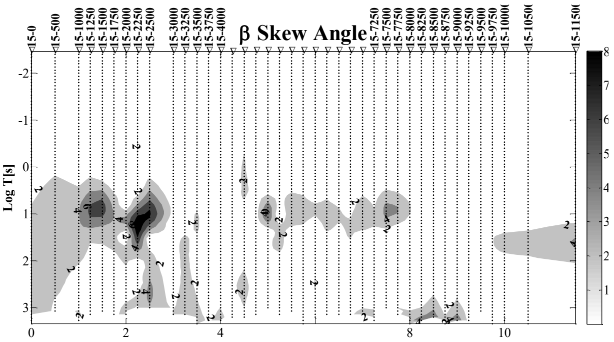

Figure 3. Phase tensor skew diagram related to profile 15.

dimensionality analysis indicates that the regional resistivity structure is predominantly two-dimensional. In the next step, we determine the strike direction of regional geo-electric structure, using α-β angles in the phase tensor method. Rose diagrams in Figure 4 illustrate their statistical distribution across various period ranges.

Note the inherent 90° ambiguities in strike angles from this method. Short-period angles lack definitive orientation of the regional structure. However, longer periods (1-100 sec and 100-2500 sec) consistently show NW-SE and NE-SW angles.

Based on the values depicted in Figure 5, the subsequent modeling considers a structural strike angle of N30°W for the region.

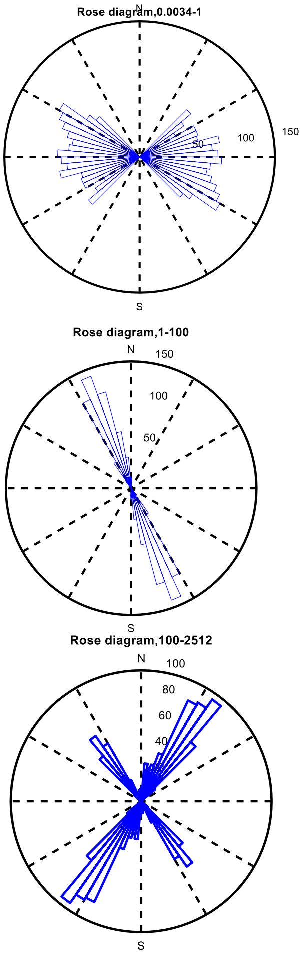

Figure 4. Alignment of regional structure trend calculated using phase tensor method for P15 profiles

2D inversion of MT data in the NasrAbad region

The objective of this section is to develop a two-dimensional model of the electrical conductivity parameter for the regional structure. To achieve this, the impedance and tipper data of profile P15 were inverted using the smoothest model method (Rodi and Mackie, 2005) implemented in the WingLink software. The software assumes an isotropic electrical conductivity value for each cell in the model space.

Previous numerical experiments conducted by Berdichevski et al. (1998) have indicated that while the TM mode data are more effective for recovering conductive structures in two dimension and are more sensitive to near-surface features, the TE mode data exhibit more sensitivity to deeper structures and provide higher accuracy in the two-dimensional modeling for resistive structures. In the case of Tipper data, where the vertical components of the magnetic field are close to zero across a wide frequency range above a conductive anomaly, the resolution of features recovered in the inversion results from these data is deteriorated.

The study emphasizes the significance of integrating multiple Magnetotelluric (MT) data types TE and TM mode impedances, and tipper data to comprehensively map subsurface electrical conductivity parameters.

The model spaces were discretized into 61 rows and 165 columns. The initial model included a 2 km thick layer with 100 Ωm resistivity overlying a half-space of 1000 Ωm. Relative error floors were set at 0.5% for resistivity and 0.25% for phase data, with an absolute error floor of 0.5% for tipper data.

The final inversion result indicates a highly resistive layer in deep part of the model (D4), a resistive body at intermediate depths (D5) and a discontinuous surficial conductive layer (C1) overlaid on the resistive structures.

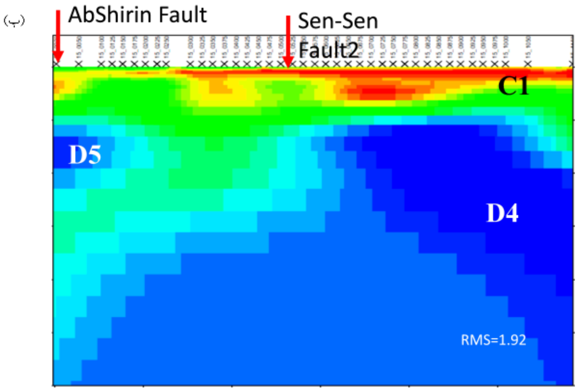

Figure 5. 2-D inversion result for MT data along profile P15

CONCLUSIONS

Following impedance data analysis on profile P15, a predominant two-dimensional regional structure with a strike direction of approximately N30˚W was identified. After data rotation to the strike direction, 2D inversion of MT data was carried out.

The final inversion result reveals a consistent resistive structure at deep part of the model extending throughout the profile. While inversions of TE and TM field data identified a conductive layer, no discernible impact was observed in the inversion result of tipper data. The recovered conductive layer in the southwest of this profile exhibits discontinuities attributed to fault activity in the region.

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