Magnetotelluric imaging of the Mitidja Basin structure, North of Algeria

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SUMMARY

The Mitidja basin is located in central northern Algeria, thus it is an active seismic zone. Studies have shown destructive earthquakes along the southern and northern sides of the area. It is associated with Quaternary compressive deformation revealed by thrust focal mechanisms (Maouche et al. 2011; Meghraoui 1991). Due to a lack of deep geophysical data, evidences about the lithospheric structures related to the formation of the Mitidja basin are limited. Magnetotelluric data from 10 stations on an 11 km N-S profile were acquired and inverted to derive an electrical resistivity model. Phase tensor analysis indicates a 2D resistivity structure with presence of 3D local features. The 2D inversion model illustrates electrically conductive basin with depth of ~ 3.5 km. The lack of seismic profiles and deep wells throughout the basin makes it impossible to know its depth, exact development time, geometry and dip of surrounding faults. Only modeling of recent gravity data highlights the direction of deep and steep north-dipping NE-SW tectonic contact at the northern basin boundary (Hamai 2011). The subject of this work is to image the underlying geoelectric structures beneath Mitidja basin.

Keywords: Mitidja Basin, Tipasa, Magnetotellutic, inversion, Algeria.

INTRODUCTION

The north of Algeria is one of the most active seismic area in northern Africa. The Mitidja basin is located within the central northern Algeria. This basin is marked by E-W to NE-SW trending fold structures and related reverse and thrust faults, accommodating 2 to 3 mm/yr shortening across the Tell Atlas (Guemache 2010; Maouche et al. 2011; Meghraoui 1991).

In order to obtain a geoelectrical model of the Mitidja basin, a magnetotelluric survey was performed. Basically it consisted of an 11 km N-S profil in Sidi-Rached, near Tipasa town in the western part of Mitidja basin. MT method uses natural origin electric and magnetic fields (Electrical thunderstorms and ionosphere-magnetosphere interactions). It is the most effective method to characterize the electrical resistivity of the subsoil (Aymé et al. 1954). A frequency dependent impedance tensor (Z) is obtained from the time variations of the horizontal electric and magnetic fields measured at the surface.

This paper presents a 2D inversion results obtained from minimizing the misfit of calculated model responses and observed data. This work is made to image the underlying geoelectric structures beneath Mitidja basin which is the focus of interest of the scientists working on seismic hazards and risk.

Geological setting

The Mitidja basin is situated in the central Tell Atlas in the north of Algeria. It is interpreted as a syncline bounded by compressive structures. It is characterized by E-W to NE-SW trending fold structures, over 150 km, being more or less parallel to the coastline (Maouche et al. 2011; Meghraoui 1991).

The most important active structure of Algiers area form the southern and northern edges of the Mitidja Quaternary basin, are the Blida thrust and fold system and the Sahel anticline respectively. The main part of the Mitidja basin is filled by sediments and volcanic rocks. NW-SE to NNW-SSE compressions formed the actual frame of the Mitidja region, between lower Pliocene and Quaternary (Derder et al. 2018; Guemache 2010; Maouche et al. 2011; Meghraoui 1991).

To the north of the basin, a 70 km long Sahel asymmetrical anticline shows a blind reverse fault (Guemache 2010; Maouche et al. 2011; Meghraoui 1991) which is probably at the origin of several earthquakes in the North of Algeria. The Mitidja basin is an active structure; many seismological studies have shown the existence of destructive earthquakes along both the southern and northern sides of the basin (Heddar et al. 2013; Maouche et al. 2018).

Data acquisition and processing

The Mitidja broadband MT sites were collected between 2008 and 2022, where the data was acquired on an 11 km profile of 10 stations, with sites spacing between 0.6 and 3 km.

Sites MTJ02, MTJ03, MTJ06 and MTJ07 are located over the Sahel fold. MTJ09 was located above the limit between the Sahel fold and the Mitidja basin. The rest of sites were installed on top of the Quaternary deposits of the Mitidja basin. The sites are distributed along N-S profile, that is, orthogonal to the geological structures direction. At each sounding the electrical (E_x , E_y) and magnetic components (H_x , H_y H_z) are recorded using MTU-5A of Phonix Geophysics. The AMT recordings were performed during approximately 1 hour, whereas the MT ones were carried out over a time range of 3 to 24 hours.

The observed time series were processed using SSMT2000 software, yielding impedance tensors Z and Tipper T_Z within the period rang $10^{-4} – 10^{3}$s.

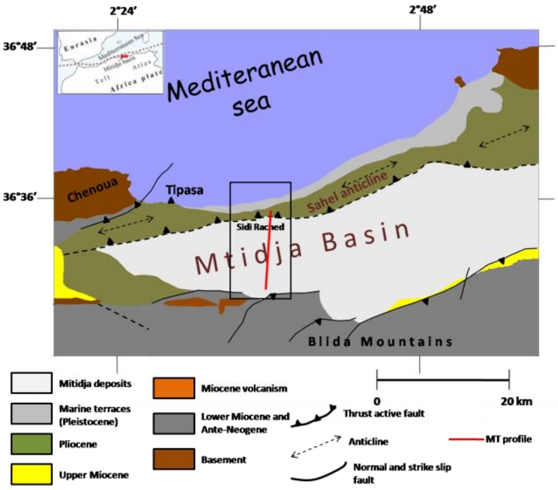

Figure 1. Simplified geological map of Mitidja basin modified from (Maouche et al. 2018). The red line indicates the position of MT profile.

Figure 2. MT sites distribution plotted in red circle along a N-S profile (Google earth image)

Dimensionality and strike analysis

The MT data were edited to remove estimations that were clearly contaminated by noise. A dimensionality analysis using phase tensor was carried out. This approach provides also estimates of regional strike starting from the analysis of the magnetotelluric impedance tensor (Caldwell et al. 2004).

To measure the structural dimensionality (Caldwell et al. 2004), a skew angle β was calculated from phase tensor. When $|\beta| < 3$, a 2D structure is interpreted while for $|\beta| > 3$ a 3D structure should be considered. The phase tensor can be displayed by an ellipse. The shape of the ellipse represents a dimensionality of the resistivity responses: Circular for 1D and elliptical for 2D or 3D.

Figure 3 shows that for most of the periods β values are below the threshold ($|\beta| < 3$). Some large β values appear at the longest period ($|\beta| > 3$). Accordingly, the subsurface structure may be regarded as 2D, in general.

In this study, induction vectors were useless due to the high level noises contaminated the measured vertical magnetic field.

Figure 4 shows the rose diagram values for all periods at each station. The results suggest a strike angle of N80°E which coincides well with the regional geology. The rotated xy and yx curves were assigned to the TE and TM mode, respectively.

Two dimensional resistivity modeling

The MT data was inverted using the finite element inversion algorithm MARE2DEM (Key 2016) to derive a 2D smoothest resistivity model that fits the data. In order to find the best inversion strategy, several tests were carried out.

Both transverse electric (TE) and transverse magnetic (TM) modes were inverted jointly using 50 Ωm homogenous half space as a starting model. An error floor of 10% was applied to the apparent resistivity and 2.87° in the phases. Figure 5 shows the model obtained finally. This model achieved an RMS misfit of 2.03. In order to check the consistency of the result, sensitivity tests were carried out. The latter have shown that there are no inversion artifacts.

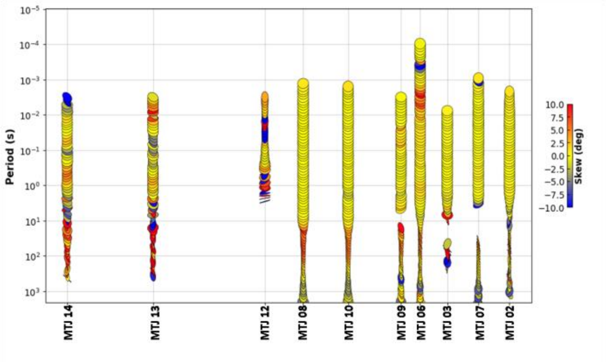

Figure 3. Skew angle β plot along the profile

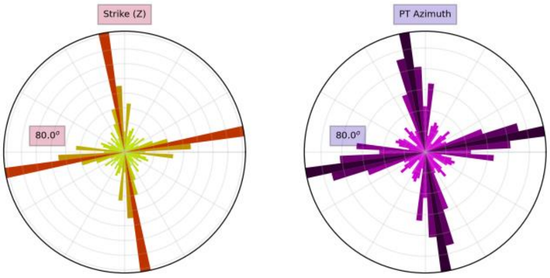

Figure 4. Rose diagram of strike angles obtained by the phase tensor method for all sites and all periods.

Results and discussion

The subsurface of the Mitidja basin appears mainly as conductive intersected by various conductors' bodies (Kerbadj et al. 2022).

From N to S, the model (figure 5) shows in the upper part a conductive zone UC1 (0.1 ~ 1Ωm) a resistive zone UR1 (150 Ωm), a second conductor zone UC2 (10 Ωm), a second very resistive zone (1000 Ωm) and an alternation of conductors and resistors UC-R (10 – 150 Ωm). A very conductive zones C1 and C2 (0.3 – 1 Ωm) are identified in depth that extends to 3 km. This high conductivity might be related to fluid content within the marine Pliocene formation.

A number of resistive anomalies shown in the obtained model (figure 5) could be related to active deformation causing juxtaposition of older geological formation with the younger basin sediments.

The model illustrate well the Sahel anticline Neogene structure, this anticline shows thrust and flexural faulting affecting the vertical bedding of Quaternary units of the Mitidja basin. Between the upper Miocene and the Quaternary, NW-SE to NNW-SSE compressions forms the syncline of the Mitidja basin.

Minimum depth extent of the shown model can be determined as approximately deeper than 3.5 km due to the highly intense effect of the conductive structures which prevent the deep structures from being resolved properly.

CONCLUSIONS

Magnetotelluric profile was carried out in the central part of northern Algeria, into the east of Mitidja basin in order to reveal its structure at depth.

The phase tensor dimensionality analysis suggested that the data are generally consistent with 2D assumptions. The finite elements code MARE2DEM was used to resolve the 2D inverse problem. Sensitivity tests were carried out to confirm that resistivity structures are robust. The obtained model reveals structures that correlate with geological information and complementing them despite the noisy data.

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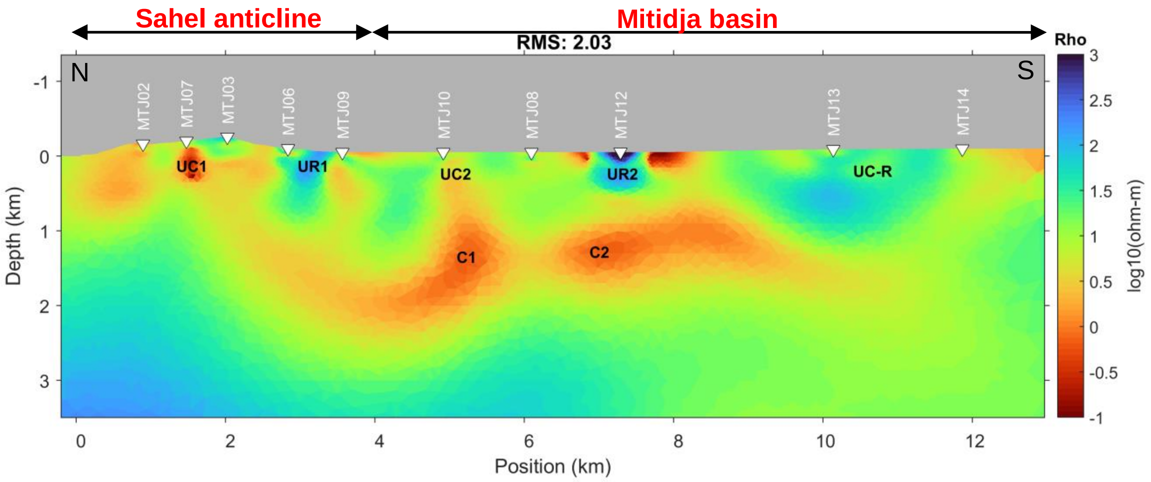

Figure 5. 2D Inversion results model obtained with RMS of 2.03