Magnetotelluric Data Modeling to Resolve Hydrocarbon Reservoirs

Behrooz Oskooi[1] *and Isa Mansoori*[1,2]
[1]*Institute of Geophysics, University of Tehran, Iran, Email: boskooi@ut.ac.ir*
[2]*National Iranian South Oil Company (NISOC), Ahwaz, Iran*

Abstract
A huge and high resolution magnetotelluric (MT) investigation was conducted on Sehqanat oil field (SOF), SW of Iran, in 2013, to map the geoelectrical structures of the region from surface down to several kilometers. The Sehqanat oil field is a part of sedimentary Zagros zone comprising ranges of the biggest oil fields in Iran. The most interesting target in this survey is the geological contact between Gachsaran (the cap rock) and Asmari (the reservoir) formations. According to the infromation from electrical logs, large resistivity contrast exists at the boundary of the two above mentioned formations. The Gachsaran formation is formed by a succession of tens to hundreds m of highly conductive (ca. 1-10 ohmm) evaporites and the Asmari formation consists of relatively resistive (more than 100 ohmm) dense carbonates . on the contrary. Broadband magnetotelluric data were collected in a regular grid at more than 500 stations along five parallel SW-NE profiles crossing the main geological trend of the study area. In order to image a comprehensive subsurface resistivity map throughout the Sehqanat oil field, two-dimensional (2D) and three-dimensional (3D)inversion codes were performed on the MT data. The 2D inversion results depicted the main resistivity structures while the 3D inverted model shows significantly more details and reliability.

Key words: Aniticline, Asmari, Gachsaran, inversion, magnetotelluric, Sehqanat.

Introduction

The MT method can be a robust alternative in areas where quality of the reflection seismic data is not acceptable (Strack et al., 1991 and Spratt et al., 2006). Due to large extent exposure of the high velocity (ca. 4500 m/s) and heterogeneous Gachsaran formation on the surface in the Sehqanat oil field (SOF) in the study area (Fig. 1), imaging of the underlying layers is become difficult with the reflection seismic technique. On the other hand, the big contrast of the electrical resistivity range (based on the electrical log obtained from the explorative Sehqanat well) between the Gachsaran formation and the underlying layers is favorable for magnetotelluric exploration. The Gachsaran formation is mainly composed of evaporites with variable thickness from 500 to 2000 meters which is highly conductive (ca. 1-10 ohmm) and the Asmari formation, in contrary, comprising of dense carbonates with more electrical resistivity range (more than 100 ohmm). With respect to the complexity of the subsurface geology in the investigation area, 2D and 3D inversion of MT data were performed to image hydrocarbon bearing structures via resistivity models. Three dimensional inversion of the magnetotelluric data is a sophisticated tool to image subsurface resistivity distribution with more details and consistency than one or two dimensional schemes. The 3-D resistivity models with a broad view on the resistivity distribution provided us to make a comprehensive interpretation for the Sehqanat anticline. Although the 2D resistivity models showed the Gachsaran-Asmari formations boundary as well as the Sehqanat anticline but in 3D models, as one would expect, integrity and continuation of geological features are more considerable. In this article, results of 2D and 3D inversions of MT data, measured over Sehqanat oil field, will be presented in several models. Recent study verifies that 3D modeling of the magnetotelluric data can reliably image the shape of the subsurface geological structures in more stability and it improve 2D inversion ambiguities.

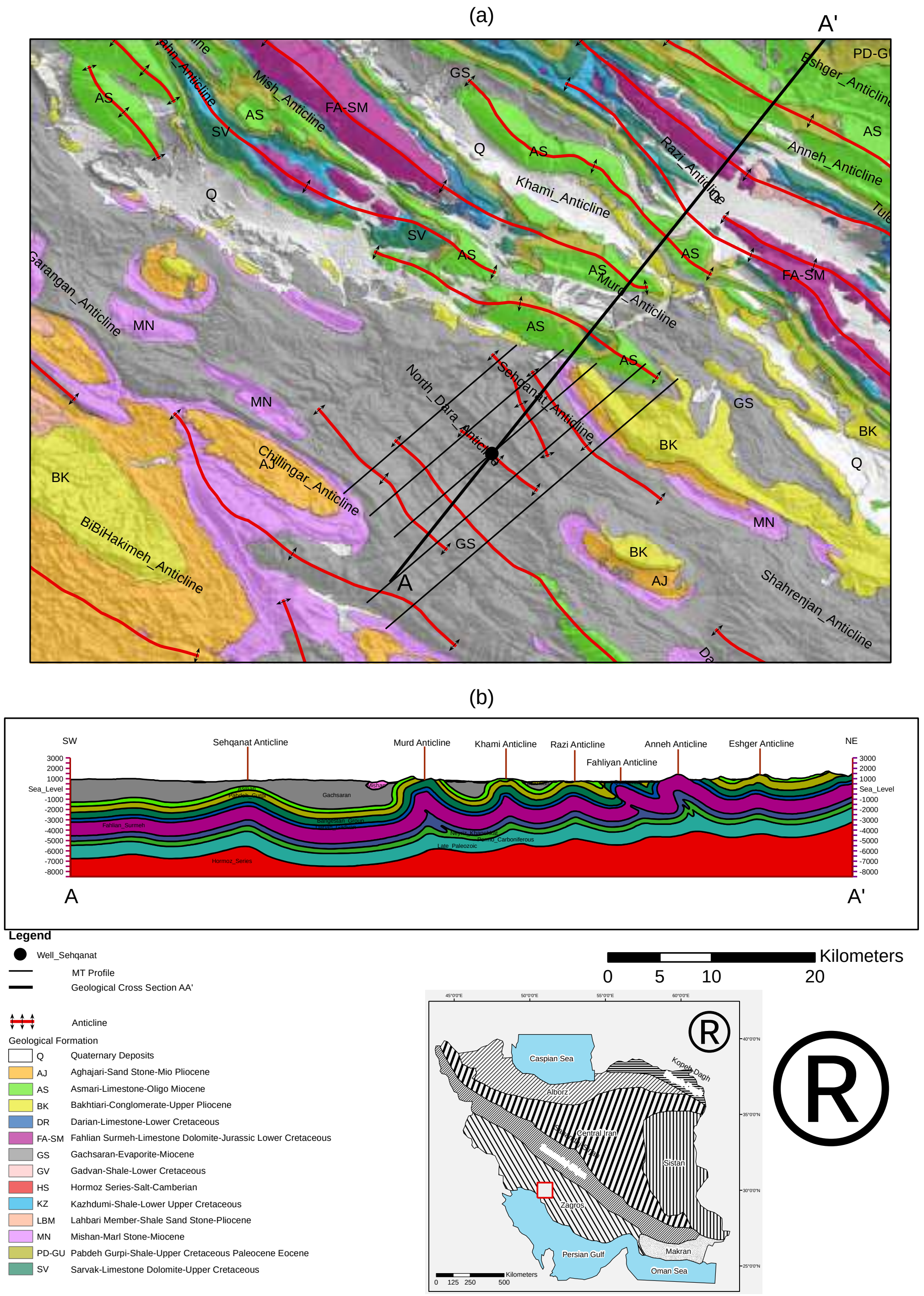

Fig. 1. Geographical location of the study area (red square in the upper left corner map) within the sedimentary Zagros zone extended in the west and southwest of Iran; a) Geological map of the study area; the parallel black solid lines show all five MT profiles, the red lines represent anticlines and the black circle is location of the Sehqanat well; b) Geological cross section along AA' line

MT Data Acquisition and Inversion

The high resolution MT data were acquired in a 3-D pattern over more than 600 sites with average interval spacing of 300 m, along five parallel southwest-northeast profiles (8813, 8814, 8815, 8816 and 8817; see Fig. 1). The data collected during 2013 under supervision of the National Iranian Oil Company (NIOC). The bearing of the profiles was N45°E which is perpendicular to main trend of Zagros zone. The MT data were measured within the period range of 0.003 to 1000 s during 12 to 15 hours as remote reference procedure. Magnetotelluric time series were processed, as the remote reference approach based on a robust processing technique proposed by Egbert and Booker (1986). The high resolution MT data including more than 500 stations along five profiles within the period range of 0.001 s to 700 s were employed for 2D inversion. The 2D inversion of the MT data was performed using a code from Siripunvaraporn and Egbert (2000) modified by Pedersen and Engels (2005) and Kalscheuer et al. (2010, 2012). The 2D inversion was conducted on the determinant impedance which is very practical because it is rotationally invariant and 3D and galvanic distortion effects (static shift) can be reduced with this data-mode (Pedersen and Engels 2005). The data-fits were generally satisfactory which was indicating that the observed data are well-fitted to the forward responses. 2D resistivity models derived from inversion of the determinant impedance, for all five profiles from surface down to four kilometers of depth are depicted in Fig. 2.

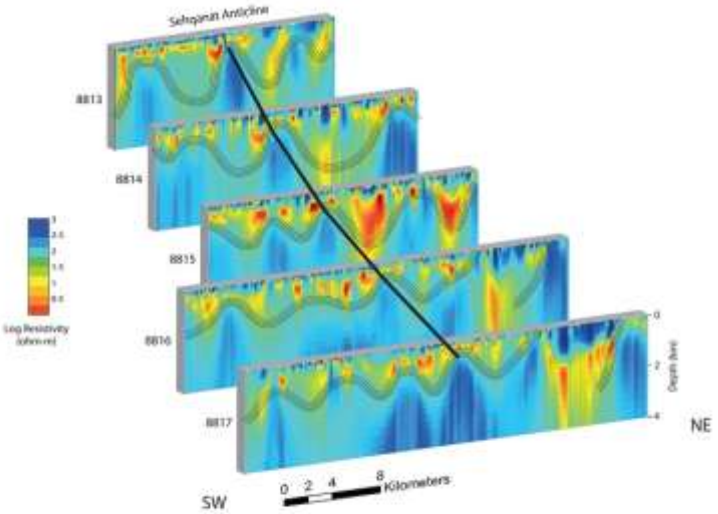

Fig. 2. 3-D view of 2-D inverted of the determinant impedance of SOF's MT profiles. The Gachsaran-Asmari formations boundary as well as Sehqanat anticline are significantly revealed in the resistivity models.

3D

inversion must be performed. To reduce of the computation costs, only 100 magnetotelluric stations with homogeneous coverage were selected to be inverted. This selection was focused on the middle part of the MT survey concentrating on the Sehqanat anticline (Fig. 3).

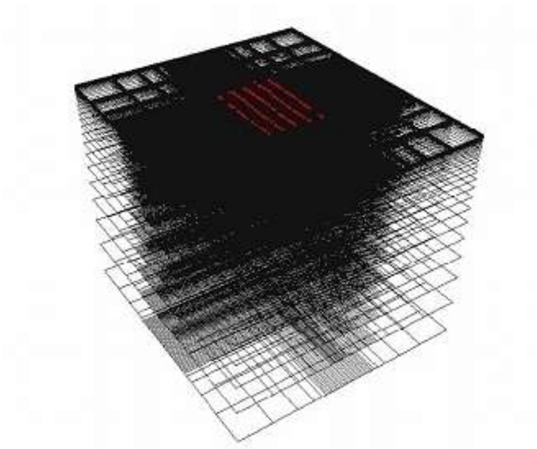

Fig. 3. Rectangular mesh designed to build initial model for running 3-D inversion in SOF; selecting of the MT sites for 3-D inversion is focused on the middle part of the study area where exactly located over Sehqanat anticline; mesh's cells are much denser in the center part to get more resolution.

The 3D inversion was conducted using WSINV3DMT routine (Siripunvaraporn et al., 2005; Siripunvaraporn and Egbert, 2009) which is based on the finite difference as a forward modeling scheme and solves the inverse problem in a data space method. In order to impose constraint on the 3D inversion process, the final 2D resistivity models derived from inversion of determinant data have been used as prior information successfully. Regarding the resistivity range which is obtained from 2D inversion result, the half-space with resistivity of 100 ohmm was chosen as an initial model for final session in 3D inversion. The 3D inversion of MT data was performed on a machine located in the Uppsala University (Uppmax) using 16-core and 64 GB of RAM. Convergence of the inverse problem with minimum RMS of 3.2 was obtained after 5 iterations during a few days. The data-fits are generally good for almost all sites and periods indicating that responses of 3D forward modeling are well-fitted with the observed data (Fig. 4). The volumetric presentation of the 3D inversion result is shown in Fig. 5.

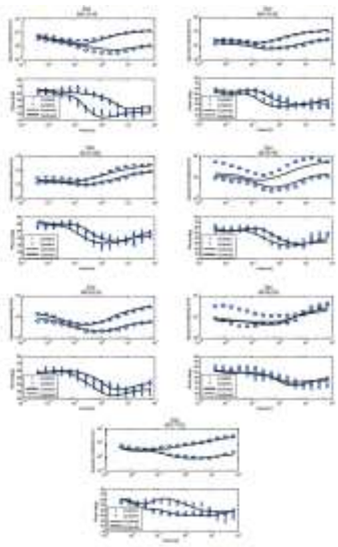

Fig. 4. Data-fits of seven MT sites resulted from 3-D inversion. The static shift suppression is obvious for sites 8815195 and 8816239.

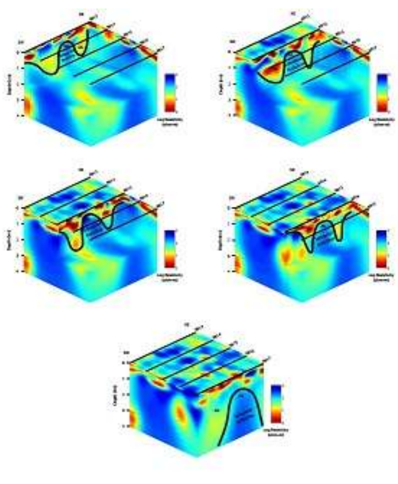

Fig. 5. Volumetric resistivity models of 3-D inversion of the SOF's MT data.

Conclusion

All the 2D resistivity models derived from the inversion determinant data show a very conductive near surface layer (less than 10 ohmm) which is corresponding to the Gachsaran formation and a more resistive underlying layer (variable from 10 to 100 ohmm) is correlated with the Asmari and deeper formations. The Sehqanat anticline is significantly resolved in the determinant inverted resistivity models thoroughout all MT profiles. Subsurface resistivity distribution of the SOF has been delineated in more consistency by means of the 3D inversion of the MT data. The 3D resistivity model shows a robust volumetric cube of the subsurface conductivity map beneath the investigation area. 2D and more precisely 3D resistivity models, resolved the boundary between Gachsaran and Asmari formations as a transition zone from a highly conductivee medium to a mouch more resistive one. The Sehqanat anticline has also been delineated in the 2D and 3D resistivity models as a resistive dome-shaped body assigned to to the middle parts of MT acquisition profiles.

Acknowledgement

Authors thank the National Iranian Oil Company (NIOC) and the National Iranian South Oil Company (NISOC) for their help, financial support and providing the data**.**

Reference

Egbert, G.D., Booker, J.R., 1986, Robust estimation of geomagnetic transfer functions, Geophys. J. R. Astr. Soc., 87, 173-194.

Kalscheuer T, Garcia M, Meqbel N, Pedersen LB (2010) Non-linear model error and resolution properties from two-dimensional single and joint inversions of direct current resistivity and radiomagnetotelluric data. Geophys J Int 182(3):1174-1188.

Kalscheuer T, Hübert J, Kuvshinov A, Lochbuehler T, Pedersen LB (2012) A hybrid regularization scheme for the inversion of magnetotelluric data from natural and controlled sources to layer and distortion parameters. Geophysics 77(4):301-315.

Pedersen, L.B., Engels, M., 2005, Routine 2D inversion of magnetotelluric data using the determinant of the impedance tensor, Geophysics 70, 33-41.

Siripunvaraporn, W., Egbert, G., 2000, An efficient data-subspace inversion method for 2D magnetotelluric data, Geophysics, 65, 791-803.

Siripunvaraporn, W., Egbert, G., Lenbury, Y., Uyeshima, M., 2005, Three-dimensional magnetotelluric inversion: data-space method, Phys. Earth Planet. Int., 150, 3-14.

Siripunvaraporn, W., Egbert, G., 2009, WSINV3DMT: Vertical magnetic field transfer function inversion and parallel implementation, Phys. Earth Planet. Int., 173, 317-329.

Spratt JE, Craven J, Jones AG, Ferri F, Riddell J (2006) Utility of magnetotelluric data in unraveling the stratigraphic structural frame work of the Nechako Basin, British Columbia from a re-analysis of 20-year-old data; in Geological Field work 2006, BC Ministry of Energy, Mines and Petroleum Resources, Paper 2007-1 and Geoscience BC, Report 2007-1, p. 395-403.

Strack KM, Hoerdt A, Wolfgram PA, Vozoff K (1991) Integrated electromagnetic and seismic methods for petroleum exploration. Exploration Geophysics 22:375-378.