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Magnetotelluric signature of anticlines in Iran's Sehqanat oil field

Isa Mansoori [a], Behrooz Oskooi [a,*], Laust B. Pedersen [b]

[a] Institute of Geophysics, University of Tehran, Tehran, Iran
[b] Dept. of Earth Sciences, Uppsala University, Uppsala, Sweden

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ABSTRACT

The magnetotelluric (MT) method has proved to be an effective tool in hydrocarbon exploration especially in areas with geological structures/formations where seismic reflection provides neither good quality data nor images. The Sehqanat oil field located in the sedimentary zone of Zagros in SW of Iran is a typical example. It is covered by the high velocity and heterogeneous formation of Gachsaran, which is exposed at the surface and has a thickness varying from 500 m to more than 2 km in the region. Gachsaran is composed mainly of salt and evaporites overlying, as a cap rock, the Asmari limestone formation which is the main reservoir in all oil fields of Iran along the Zagros range. The main geological interface which is targeted to be imaged with the MT method is the contact between the highly conductive evaporites of the Gachsaran formation and the underlying more resistive carbonates of the Asmari formation. MT data at more than 600 stations along five parallel SW–NE profiles crossing the main geological trend of the study area and transient electromagnetic data over 400 stations to be used for static shift corrections of the MT data were available. Dimensionality and strike analysis of the MT data show dominant two-dimensional (2-D) conditions in almost all sites and periods. The 2-D resistivity models resolved the boundary between Gachsaran and Asmari formations as a transition zone from highly conductive to resistive structures. The Sehqanat anticline has also been delineated throughout the 2-D resistivity sections as a resistive dome-shaped body located in the middle part of the MT profiles. There is a considerable correlation between the 2-D resistivity models and the adjacent 2-D reflection seismic sections so that a more reliable interpretation on the hydrocarbon trap of the Sehqanat anticline can be obtained.

1. Introduction

The magnetotelluric (MT) method is used for imaging subsurface structures in hydrocarbon exploration surveys especially in areas in which the reflection seismic technique shows poor quality (Orange, 1989; Beamish and Travassos, 1992; Warren and Srnka, 1992; Hoversten, 1996; Warren, 1996; Travassos and Menezes, 1999; Martini et al., 2005; Xiao and Unsworth, 2006; Pandey et al., 2008). The ability of modern broadband MT instrumentation for mapping the structural boundaries of hydrocarbon bearing basins is also mentioned by Spratt et al. (2006). Strack et al. (1991) have likewise proven the usefulness of combining different exploration techniques to perform an integrated and more reliable interpretation.

One of the most ambiguous situations in reflection seismics is where a high velocity layer is exposed at or near the surface. The quality of the seismic data is usually degraded by the high-velocity near-surface layer (HVSL) due to many factors including energy scattering and seismic wave reverberation in the HVSL in the low-velocity layer overlying the HVSL. Other factors include source-generated noise, weak energy transmission from the low-velocity layer to the HVSL, etc. (Chen and Lawton, 1992)

The Sehqanat oil field (SOF) in SW Iran (Fig. 1) and some other adjoining oil fields in that region are composed of such high velocity (ca. 4500 m/s) formations at the top, the so-called Gachsaran formation. This strongly heterogeneous formation overlies the desired reservoir of the Asmari formation. A 2-D reflection seismic survey was conducted in SOF along five profiles of MUN_N19, MUN_N20, MUN_N23, MUN_N24 and R_1062 with low quality, discontinuous and spurious seismic events in most parts of the stacked sections. Fig. 2 shows examples of such 2-D seismic sections with a high degree of interpretational ambiguities.

Most practical information about the lithological properties of subsurface geology of the study area has been obtained from the exploration Sehqanat well which was drilled down to the Sehqanat anticline based on the reflection seismic information. According to the information from the Sehqanat's well log (Fig. 3), the velocity values show variable and heterogeneous characteristics from the surface down to a depth of 500 m which is correlated with the Gachsaran formation. Below the Gachsaran formation to an approximate depth of 900 m comprising the Asmari formation, velocity variations are much smaller and with a higher average than in the Gachsaran formation. The electrical resistivity, on the other hand, behaves differently with generally stable

* Corresponding author at: Institute of Geophysics, University of Tehran, Kargar Shomali street, Tehran, Iran.
E-mail addresses: emansoury@ut.ac.ir (I. Mansoori), boskooi@ut.ac.ir (B. Oskooi), laust.pedersen@geo.uu.se (L.B. Pedersen).

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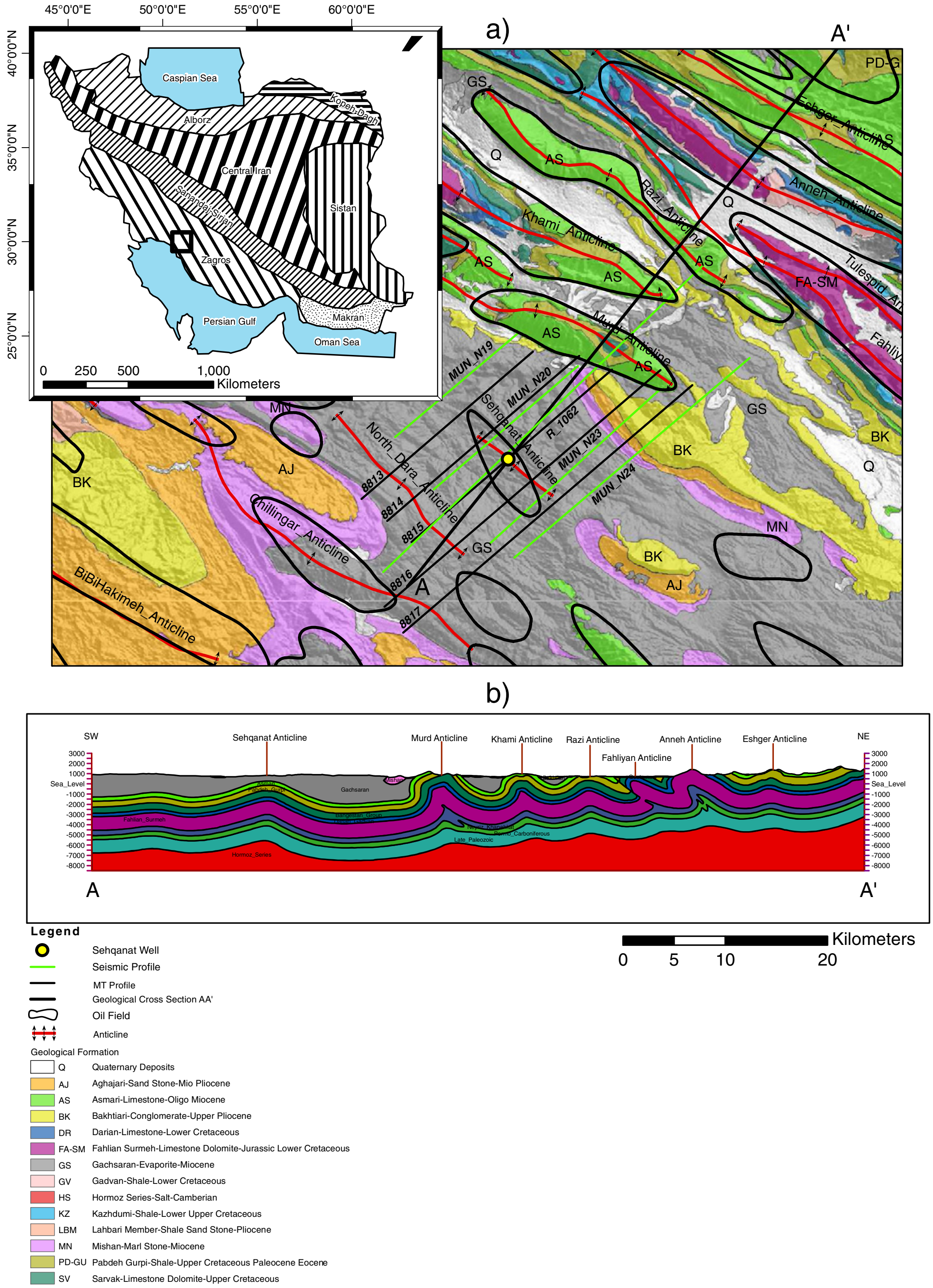

Fig. 1. The upper left panel is a simplified structural geology map of Iran with seven main zones; Alborz, Central Iran, Kopeh Dagh, Makran, Sistan, Sanandaj–Sirjan and Zagros. The black square shows the geographical location of the study area. a) Geological map of the study area; red lines represent anticlines, parallel black lines depict MT profiles, green lines show seismic profiles, yellow circle is the Sehqanat wellbore position and several adjacent oil fields to the Sehqanat oil field are shown with black rings; b) Geological section along the AA′ line.

values and with step-like changes from 1 Ω-m in the Gachsaran formation to nearly 100 Ω-m in the Asmari formation.

Since the subsurface lithology of the study area is believed to be similar to that found in the borehole zone (see Fig. 1b) it is reasonable to generalize these petrophysical properties to the whole investigation area. By looking at the geological map in Fig. 1a one can infer that the Gachsaran formation, which is outcropping at the surface, is poorly imaged on the seismic sections at depth. On the other hand the Gachsaran formation and the underlying layers should be resolved by magnetotellurics due to the large resistivity contrast. In a previous study Oskooi et al. (2015) successfully exploited such a big resistivity contrast for an MT survey in the Zagros range over an ophiolite zone. Although the 2-D reflection seismic sections from the study area are of bad quality they give a broad view of the subsurface structural geology