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Interpretation of magnetotelluric data from the Gachsaran oil field using sharp boundary inversion

Mohamadhasan Mohamadian Sarvandani[a], Ali Nejati Kalateh[b,*], Martyn Unsworth[c], Abbas Majidi[d]

[a] Faculty of Mining, Petroleum and Geophysics Engineering, Shahrood University of Technology, Iran
[b] Faculty of Mining, Petroleum and Geophysics Engineering, Shahrood University of Technology, Iran
[c] Department of Physics & Department of Earth and Atmospheric Sciences, University of Alberta, Canada
[d] Advisor of Exploration Directorate, National Iranian Oil Company, Tehran, Iran

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ABSTRACT

The magnetotelluric (MT) method is used in hydrocarbon exploration in situations where seismic exploration gives low quality data, or is logistically difficult. Static effects caused seismic data collected in the Gachsaran oil field to be of low quality, so a magnetotelluric survey was used to investigate the subsurface structures of this important reservoir. A total of 79 MT sites were collected on a 16.5 km long profile that was oriented perpendicular to the main geological strike direction. Dimensionality analysis indicated that the resistivity structure of the region is 1D or 2D mixed with some local 3D structures at shallow depths. It was found to be mainly 3D at greater depths. Dimensionality analysis, phase tensor and tipper all showed that the prevalent geoelectrical strike in the Gachsaran oil field is in a NW-SE direction. The time domain electromagnetic (TEM) method was utilized to remove the effects of static shifts. To obtain physically reasonable 2D resistivity models of the Gachsaran oil field, the nonlinear conjugate gradients (NLCG) and sharp boundary inversion algorithms were used. In the inversion of the Gachsaran MT data, the NLCG method recovered the general resistivity distribution of the subsurface structures, but the sharp boundary inversion recovered a layered resistivity model with substantially less internal variation within the layers. The model obtained by the sharp boundary inversion showed that the top of reservoir formation (Asmari) in the study area was located at a depth of 1400–1900 m below sea level. The inversion results were in reasonable agreement with mapped geological features and well logs. The results of this study show that the magnetotelluric method can be utilized effectively in hydrocarbon exploration in the Gachsaran oil field, and similar types of hydrocarbon reservoir elsewhere in the world.

1. Introduction

Seismic reflection is the primary geophysical tool used in hydrocarbon exploration. However certain lithologies can reduce the quality of seismic data. Salt sheets can result in problems with seismic data, because the high velocity contrast between the salt and the surrounding sedimentary rocks can cause focusing effects. Near surface volcanic rocks and carbonates can also challenge seismic exploration through static effects, which have the effect of introducing an undetermined depth factor at each site. The geometry of overthrusts can place high-velocity rocks above lower velocity layers, thus the resolution at depth with seismic exploration is degraded. In addition, variations in the thickness of the weathered layer and severe topography in the overthrusts can make static problems that make it difficult to obtain high quality seismic data. In these situations where seismic imaging is ineffective, magnetotelluric (MT) exploration can be used to provide complementary information about subsurface structure. While MT cannot image the fine scale structure of sedimentary sequences, as is possible with seismic, it can often be effective in imaging the bulk structure. In recent decades, the magnetotelluric method has been widely used in this role in hydrocarbon exploration (Christopherson, 1991; Watts and Pince, 1998; Matsuo and Negi, 1999; Xiao and Unsworth, 2006; Abdul Azeez et al., 2011). The magnetotelluric method measures the time variation of natural electromagnetic (EM) fields to image subsurface electrical resistivity structure. Due to the fact that the depth penetration of the EM fields depends on their frequencies, the variation of resistivity with depth can be obtained from the magnetotelluric data (Marti, 2006).

Geophysical studies can contribute to effective hydrocarbon exploration in two ways. Most often, geophysical methods are utilized to

* Corresponding author.
E-mail address: nejati@shahroodut.ac.ir (A.N. Kalateh).

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determine structures that could host potential reservoirs and/or source rocks. In certain cases, they may also provide direct evidence of the presence of hydrocarbons (Unsworth, 2005). Hydrocarbon reservoirs commonly include an impermeable cap that traps the hydrocarbons below in a high porosity reservoir. There is not always a predictable resistivity difference between the cap rock and the reservoir which can be detected by magnetotelluric method (Zhang et al., 2014). MT is most sensitive to a structures associated with a decrease in resistivity with depth. This configuration can occur in hydrocarbon exploration e.g. when a carbonate formation is located above a formation of clastic sedimentary rocks e.g. Xiao and Unsworth (2006). This configuration can also occur in sub-salt exploration, where the base of a salt sheet is associated with a decrease in resistivity. The opposite situation with an increase in resistivity with depth is more difficult to resolve with MT, but is regularly encountered in hydrocarbon exploration e.g. where the cap rock is shale or evaporite and the underlying reservoir is hosted in a carbonate formation (Smith et al.., 1999). This is the scenario described in this paper at the Gachsaran oil field in Iran. In recent years, the algorithms available for MT inversion have greatly improved. However many of them use regularized inversion which finds the smoothest resistivity model consistent with the data. This is not generally successful in studying structures where resistivity increases with depth. We show that MT inversions that allow for sharp changes in resistivity are much more appropriate for this type of reservoir structure.

The Gachsaran oil field is one of the largest carbonate hosted oil fields in Iran. The reservoir is located in the Asmari formation which is moderately folded. Evaporites at the surface often degrade the quality of seismic reflection data and make structural studies of the depth of the Asmari formation difficult. The low quality of seismic data suggests that structural imaging with the magnetotelluric method may be a viable alternative and is investigated in this paper. In this study, two strategies were applied for the inversion of MT data. In the first strategy, 2D smooth inversion was performed and the resulting model shows a resistivity structure in general agreement with the mapped geological structures. However, sharp boundaries were not well imaged so in the second strategy, we used the 2D sharp boundary inversion to obtain a quasi-layered resistivity model. It will be shown that the sharp boundary inversion of the Gachsaran MT data compare well with the results of well logs and surface geological mapping. We show that the sharp boundary inversion method can be utilized to generate a more useful resistivity model in a complex geological environment.

2. Gachsaran oil field

Iran is one of the largest heavy oil exporters in the Middle East and has 32 producing oil fields, of which 7 are offshore and 25 onshore. The Gachsaran oil field is 70 km long and 6–15 km wide and is one of the largest carbonate hosted reservoirs in Iran. It was discovered in 1928 and has been developed by the National Iranian Oil Company

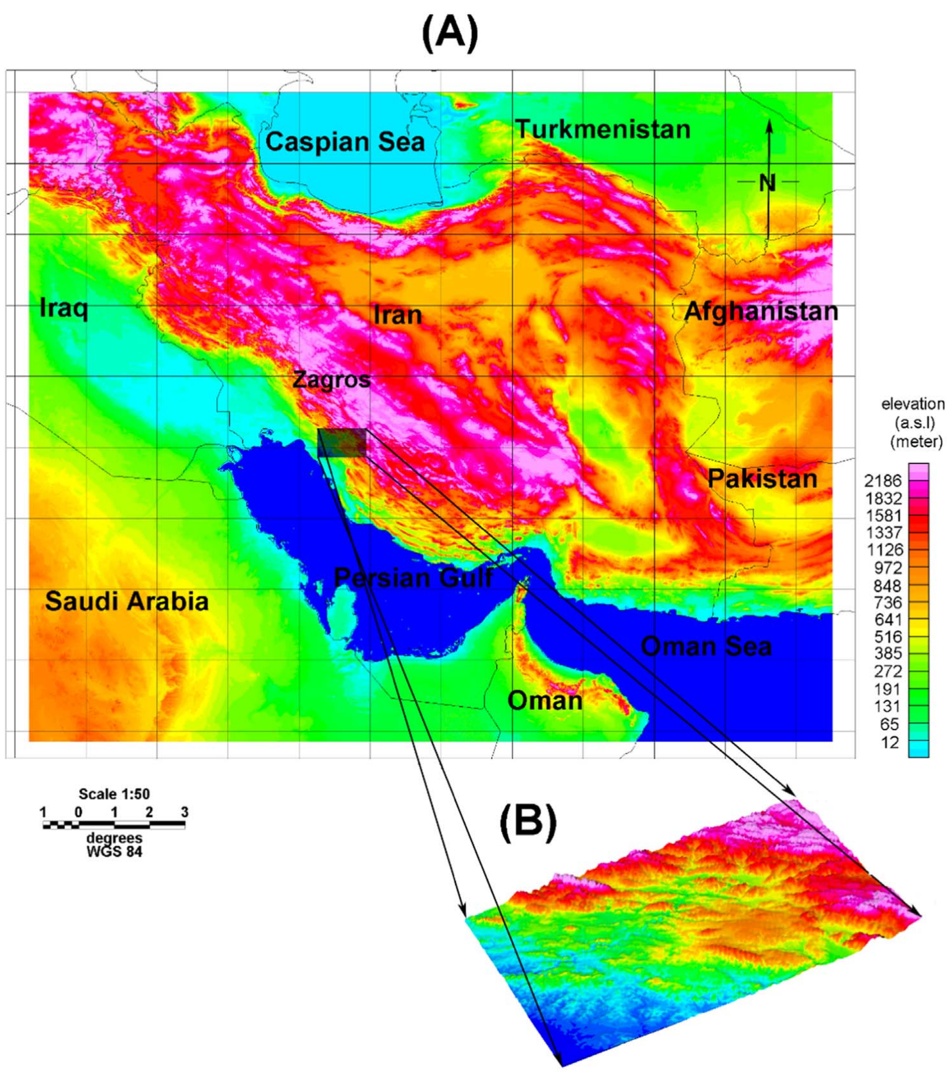

Fig. 1. A) Topographic map showing the Zagros Mountains and foothills in southwest Iran. B) 3D view of southwest Iran including Gachsaran oil field.