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Sub-basalt exploration in the Kutch-Saurashtra basin using EM

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Abstract

New technologies can aid explorationists in the quest to find hydrocarbons in frontier areas. The Kutch-Saurashtra basin offshore the west coast of India has not been explored extensively due to the challenges of proper imaging of basalt thickness and identifying sub-basalt sediments. There is no single technology that can provide the end-to-end solutions for a detailed understanding of the trap thickness, geometry and presence or absence of sediments beneath. To reduce the exploration uncertainty in the sub-basalt EM based technologies (Controlled Source Electro-Magnetics (CSEM) and Magnetotellurics (MT)) can provide the information to determine the thickness of basaltic layer and the presence of sediments beneath; and identify stratigraphic events, which are challenging in both structural studies and petroleum exploration. A synthetic study, based on EM, has been carried out to scale basalt and sub-basalt properties.

Introduction

The oil and gas industry has started looking into unconventional hydrocarbon reservoirs. Searching for prospective sedimentary regions underneath basalt is of particular interest as basalt can act as a seal for hydrocarbons. Because of heterogeneity and high seismic velocity in basalts, it has been very challenging to map base or sediments below basalts using seismic. EM methods can complement seismic in this regard.

The Kutch-Saurashtra basin offshore the west coast of India contains basalts which vary in thickness from hundreds to thousands of meters. Seismic reflections from the top of the basalt can be strong and it is therefore easy to identify the top of basalt with seismic. However it is difficult to identify base of basalt and sediment beneath due to inter-basalt scattering and multiples.

The Kutch-Saurashtra basin has sediments from the Mesozoic age underneath basalts. Presence of these sediments makes this area a potential exploration target. Jegen et al. (5) and Chatterjee et al. (2) showed that MT can be used to map sedimentary basins below basalt. However a field MT inversion carried out by Pandey at el. (9) in Kutch demonstrates that only MT is not enough to delineate the base of basalt due to deposition of thin basalt layers and sediments that constructs anisotropic basalts. Anisotropy is directional dependent propagation and EM response is imaged with the property of resistivity. Kumar et al. (6) and Hoversten et al. (4) showed how CSEM (Controlled Source Electro-Magnetics) and MT (Magnetotellurics) can determine the thickness of anisotropic basalt and sub-basalt sediments from west of Shetland.

In this synthetic study we have investigated various thicknesses of the anisotropic basalt and the presence or absence of sediments beneath the base of basalt for the Kutch-Saurashtra basin. MT and CSEM methods have been used to demonstrate the applicability of these methods in this basin.

Study area and well log

Figure 1 shows the study area of the Kutch-Saurashtra basin. We have used well log data from the Saurashtra basin, and resistivity values from the well log to validate efficiency of EM methods.

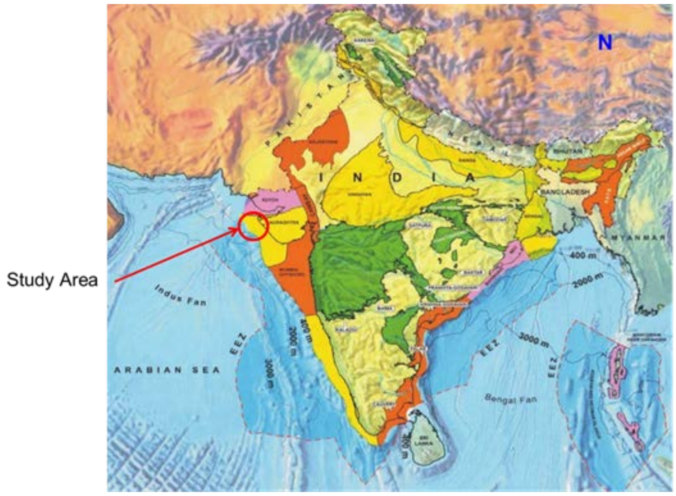

Figure 1:- Study area map (source)

A well was drilled in the Saurashtra basin to measure thickness of basalt, and the thickness was found to be more than 2000m. The well log used as a resistivity reference for EM models is presented in Figure 2.

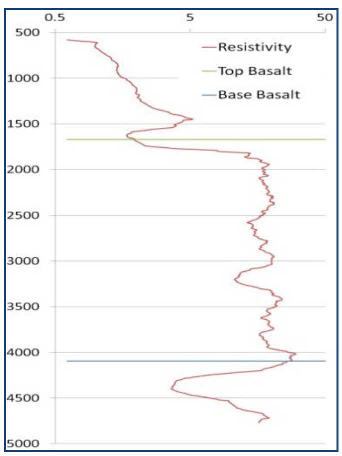

Figure 2: Resistivity reference well log (Saurashtra basin).

Geological setting of offshore Kutch-Saurashtra basin

The Kutch-Saurashtra basin is located west of Gujarat state, and the water depth in this basin ranges from 0 – 3,000 m (1). The extension of the ENE-WSW trending faults, and the Saurashtra arch into the Kutch deep-waters suggest the initiation of rifting in the area in late Triassic/early Jurassic. Basins in this region evolved after break up of eastern Gondwanaland from western Gondwanaland (8). As a result of block faulting and continuous subsidence, a mainly marine phase prevailed during the Middle Jurassic, without the differentiation of the area into shelf, slope and basin floor (10)

EM acquisition and methodology

The CSEM method uses a towed horizontal electric dipole source and sea-bottom receivers. This source transmits low-frequency electromagnetic signals to the sub-surface. The signals interact with the sub –

surface and its response is measured in terms of two orthogonal components of the horizontal electric and magnetic fields (3).

During a survey the source is towed across the array of receivers. By measuring the amplitude and phase of the signal detected by each receiver as a function of source-receiver geometry and separation, the resistivity structure of the underlying sea floor can be determined at scales of between several tens of metres and several kilometres (7).

EM geological modeling and imaging

Based on the well log information, several synthetic EM models were tested. In Figure 3 we show the resistivity values chosen for each geological age.

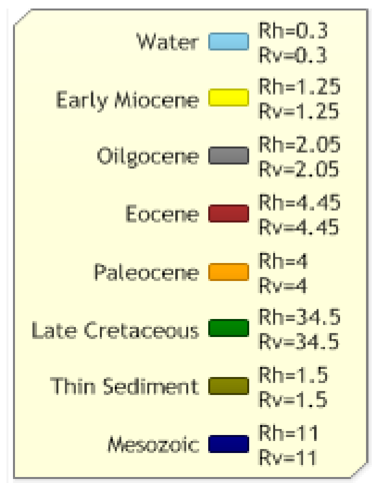

Figure 3: Table for correlating geology to EM (source)

Several synthetic models have been built and their EM responses have been modeled to get an indication of the sensitivity of these methods to the thickness of basalt and sediments beneath. Figure 4 shows the models for varying basalt thickness, and Figure 5 represents the corresponding MT response. Figure 6 shows MT response for increasing sediments thicknesses while keeping basalt thickness (2500m) fixed.

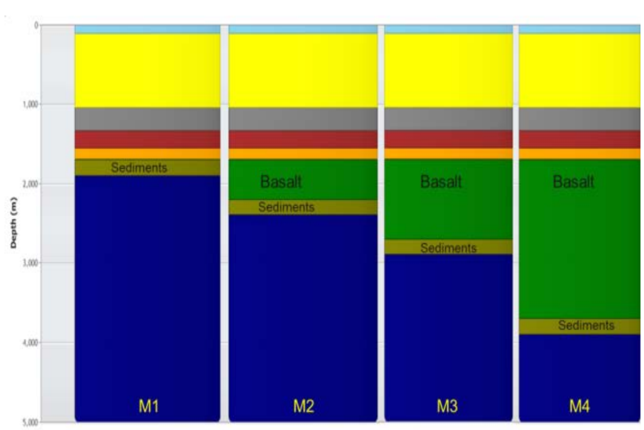

Figure 4: EM models for varying basalt thickness

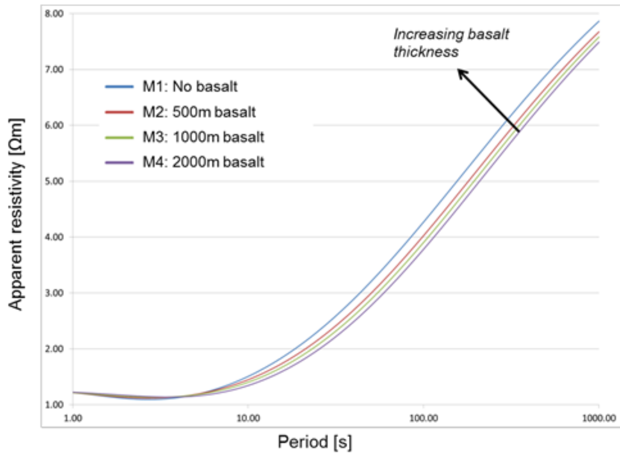

Figure 5: MT Response of varying basalt thickness

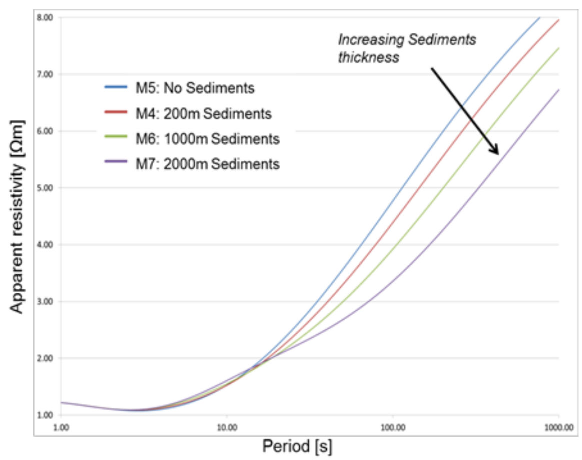

Figure 6: MT Response of varying sub-basalt sediment thickness.

As thickness of basalt increases, the apparent resistivity in Figure 5 moves upwards as expected. In Figure 6 when sediment thickness increases while keeping basalt thickness fixed to 2500m, the sensitivity to sediment thickness is higher more due to MT is more sensitive to conductors than resistors.

Moving from modeling to imaging, we have used anisotropic models for the CSEM inversion study. The vertical and horizontal resistivity models were used to create datasets of which 3D anisotropic inversions were run. Two basalt thicknesses of 1000m and 2000m have been tested, the true models and inversion results for the vertical resistivity are shown in Figure 8 for 1000m and 2000m thicknesses, respectively. The CSEM inversion is able to reconstruct the base of basalt of different thicknesses.

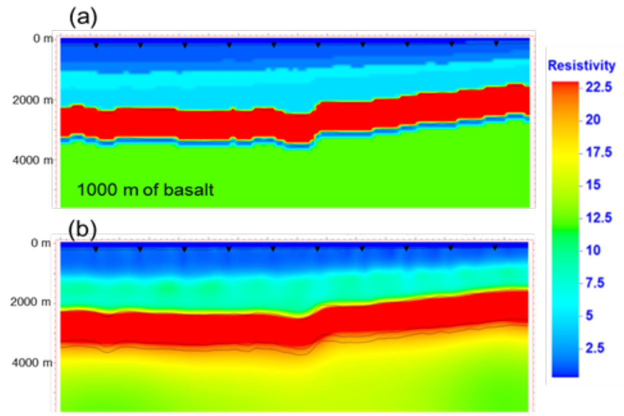

Figure 7: (a) synthetic EM model for vertical resistivity (Rv) with1000m basalt thickness; (b) 3D inverted image of the model

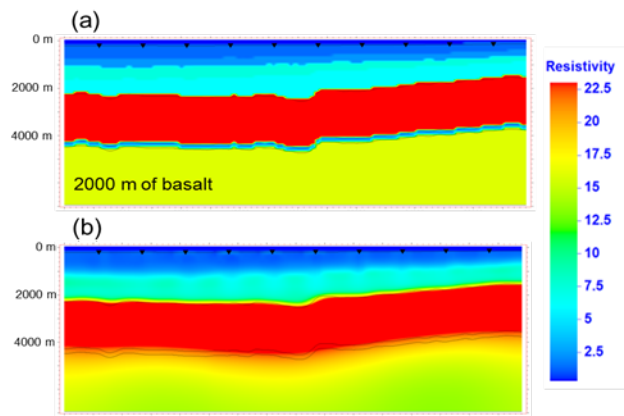

Figure 8: (a) synthetic EM model for vertical resistivity (Rv) with 2000m basalt thickness; (b) 3D inverted image of the model

Conclusions

CSEM and MT can be used to explore sub-basalt sediments where seismic data experience difficulty. Both of CSEM and MT can help to understand complex geology and EM derived models can be transformed to a new velocity model to enhance seismic data or structures.

This synthetic study shows that CSEM and MT are useful for mapping base of basalt for different thicknesses, and identifying sediments underneath.

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