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Interpretation and evaluation of hydrocarbon prospects using Marine Controlled Source Electromagnetic data: A 2.5D forward modeling study

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Summary

2.5 D forward modeling can be used for interpreting Marine controlled source Electromagnetic data. We present 2.5D forward modeling study for successful interpretation of controlled source electromagnetic data acquired in deep offshore, east coast of India. Synthetic models were built on the basis of seismic interpretation and nearby well log data. Two targets, in the Pliocene and Miocene interval, were modeled. Model responses were computed using 2.5D finite element forward modeling code for several frequencies and offset ranges. Real data and modeled responses for different offsets and frequencies were compared. Model responses for lower frequencies and higher offsets showed good agreement with real data and hence indicated the presence of resistive reservoir at Miocene level. Model for higher frequencies and shorter offsets responses were found greater than the real data for assumed resistivity values and hence indicated non existence of shallower resistive reservoir at Pleistocene level.

Introduction

Controlled Source Electromagnetic (CSEM) is an emerging geophysical technique for mapping electrical resistivity in geological structures beneath the sea floor. The method is based on towing a horizontal electric dipole (HED) close to the sea bed, transmitting EM signals within a frequency range of approximately 0.1–10 Hz; and measuring the resultant signals at EM receivers placed on the seabed. As the signals propagate through the sea floor, their amplitude and phase are modified depending on the resistivity of the rocks through which they pass. By measuring these characteristics of the signals at several receivers and transmitter positions, it is possible to build up a two- or three-dimensional image of the electrical resistivity structure of the subsurface [Eidesmo et al.; Ellingsurd et al.; Macgregor et al.; Srnka et al.]. In CSEM for two-dimensional conductivity structures, the problem is described as 2.5D because an EM source emits a 3D field [Li et al.; Kong et al.].

The Krishna Godavari Offshore Basin [Figure1] off the East Coast of India was a major intracratonic rift within Gondwanaland until the Early Jurassic. Since the middle Cretaceous, the basin has become a pericratonic rift basin.

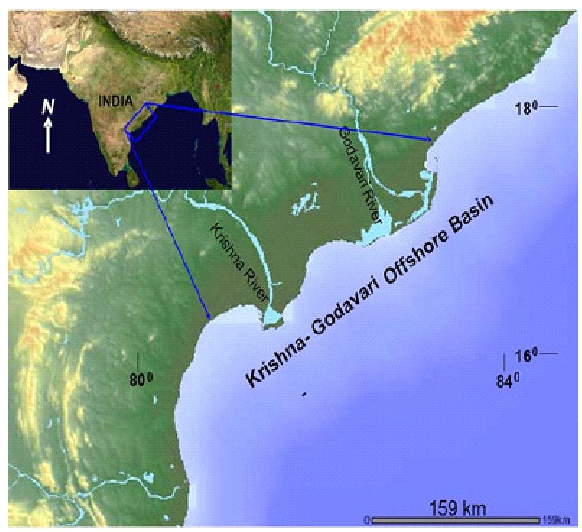

Figure 1: Field location and study area, KrishnaGodavari basin (Bastia et al. 2007).

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The basin comprises a wide range of depositional settings from coastal plains, deltas, shelf-slope aprons to deep sea fans. Commercial accumulations of hydrocarbons occur in sediments from the Permian to Pliocene. The main offshore hydrocarbon potential lies in the tertiary channel – levee – overbank Miocene to Pliocene reservoirs in the deep waters as the currently targeted play type, [Bastia et al. 2007].

CSEM Survey

CSEM data was acquired along the proposed line in Krishna Godavari Basin, Offshore India. The bathymetry along this line ranges from 1600 to 2600 m. A total of 38 receivers were deployed along the line with 1.25 km spacing. All receivers measured both the horizontal electric and the magnetic field in two orthogonal directions. The line was towed twice using different source base frequencies, 0.30 Hz and 0.05 Hz for better sensitivity and resolution of deeper as well as shallower reservoirs. High quality data in general was recorded [Figure 2].

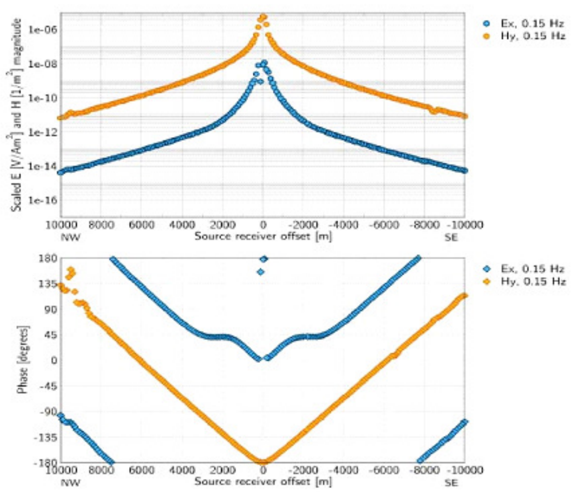

Figure 2: Standard processed electric & magnetic magnitude (upper) and phase response (lower) for receiver Rx16 at 0.15Hz (third harmonic).

2.5D Forward Modeling

Models are built on the basis of seismic interpretation (Figure 3) and nearby well log data. CSEM line has two prospects XX, ZZ and one drilled discovery well YY.

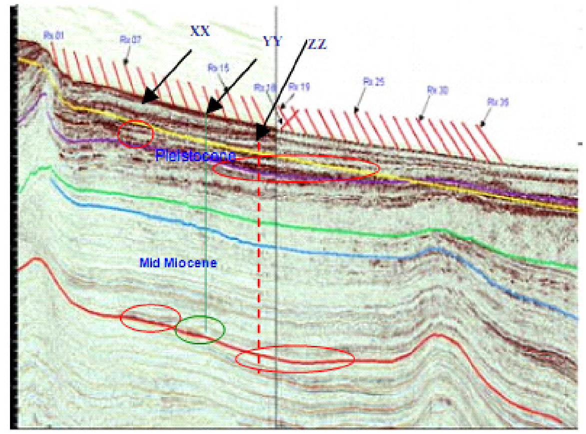

Figure 3: Seismic cross section along CSEM line showing different levels and prospects.

2.5D forward modeling is performed by using "MARE2DCSEM Version 2.0" package, developed at Scripps Institute of Oceanography, California. The main advantages of MARE2DCSEM are the use of unstructured triangular finite elements and an automatic, adaptive grid refinement method. An Unstructured triangular grid, in which elements are arbitrarily shaped triangles, allows for modeling arbitrarily complicated structures such as seafloor topography, dipping layers and other highly variable geologic formations. Adaptive refinement consists of iteratively computing the CSEM solution on successively refined finite elements grids until the desired solution accuracy is obtained. These codes calculate Ex, Ey, Ez, Hx, Hy and H_z field's amplitudes and phase for the given geo-model for given parameters [Li et al, 2007].

Modeling is done for shallow (Pleistocene) and deep (Miocene) targets separately to understand contributions in CSEM response, and then combine into a final model, figure 4. Resistivities (background & reservoirs) are derived from the well YY and thicknesses of targets are taken from seismic interpretation. To get best match with real data, resitivities of reservoirs are refined but well data is also honored. For modeling, 0.05, 0.15, 0.25, 03, 0.9 & 1.5 Hz frequencies are used. Responses are calculated for only first 29 receivers with 43 transmitter positions, to reduce the computation time. The receiver spacing is taken 1.25 km (similar to acquired geometry) and transmitters are spaced at every 1.25 Km.

Electric & magnetic field amplitude and phase responses of different models are calculated at several offsets and frequencies, some of the responses are discussed here. Normalized responses are calculated by using background model (model without target reservoirs) as a reference.

Results

Normalized electric field magnitude along line with only Miocene target with 30 Ωm resistivity (assumed resitivity derived form well YY) shows anomaly of 1.2 between the receiver no. 6 to receiver no. 12 and anomaly of 1.3 between receiver no. 16 to no. 24 at offsets 8750 m and frequency 0.15 Hz. Normalized electric filed magnitude along line for only Pleistocene targets having resistivities 3, 8 &10 Ωm (rsistivity assumed initially derived from well YY subsequently refined for matching the real data) shows anomaly 1.35 between receiver no.14 to no.19 and 1.85 between receiver no. 20 to receiver no. 24 for 3718 offset and 1.5 Hz. Response at 2479 m offset shows anomaly of 1.2 a d 1.55 magnitudes for same receiver positions and frequency, [Figure 6].

In model having all targets 3, 8 &10 Ωm resistivities are used for pleistocene targets and 30 Ωm resistivity is used for Miocene targets, figure 7.

Normalized magnitude along line shows anomaly of 1.2 from receiver no. 4 to no. 13 and 1.4 from receiver no. 14 to no. 25 at longer offsets (8676 m) and lower frequency (0.15 Hz). In this case anomaly shows combined effect of deep and shallow targets which is evident both in magnitude and shape of the anomaly if compared with the response of the model having only deep targets, figure 5. For shorter offset and higher frequency anomaly is 1.3 and 1.8 for same receiver positions. In this case only the shallower portion of the model is illuminated by EM energy due to shorter offsets, [Figure7].

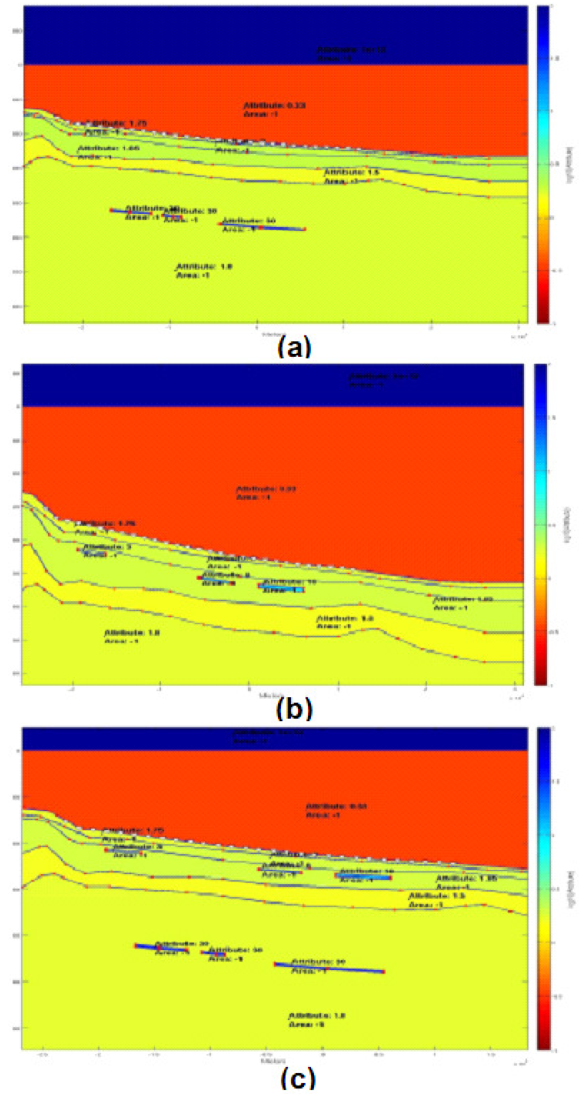

Figure 4: Different Models (a) Only deep targets (b) Only shallow targets (c) All deep & shallow targets. The horizontal axis is the distance along the profile in meters and vertical axis is depth in meters. The color attributes are the resistivity values.

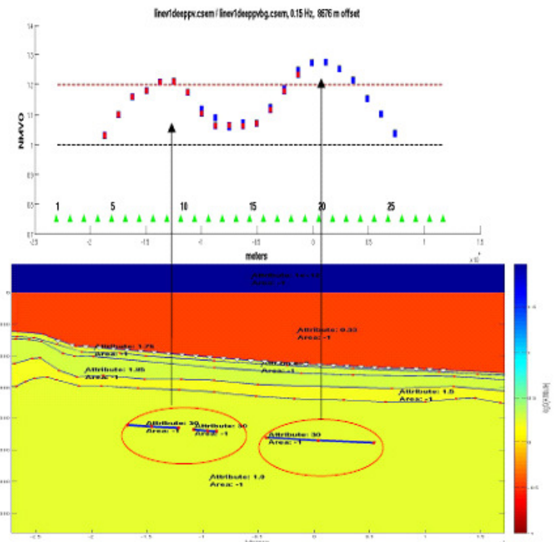

Figure 5: Normalized Magnitude plot at 8750 m offset and frequency 0.15 Hz having resistivity of targets 30 Ω.m

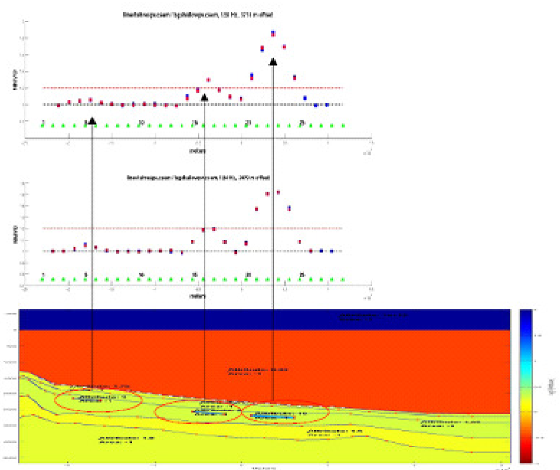

Figure 6: Normalized Magnitude plot at 2500m (lower) & 3718 m (upper) offsets and f = 1.5 Hz.

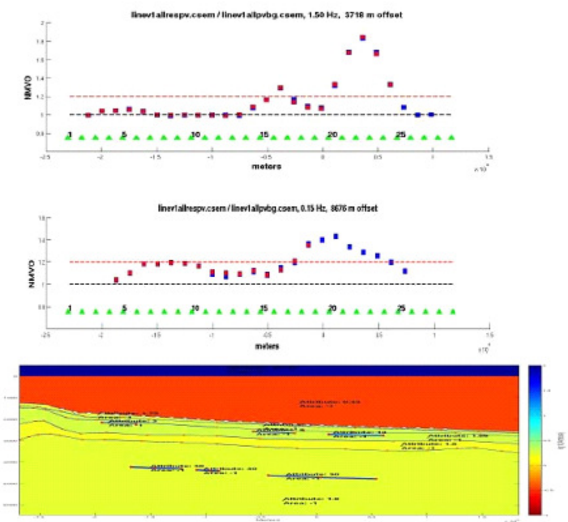

Figure 7: Normalized Magnitude plot at 3718 m offset and f = 1.5 Hz (upper) & at 8676 m and 0.15 Hz (middle) for geo-model having all targets (lower).

Discussion

To evaluate the models, the response of the synthetic models is compared with real data in the normalized domain. Magnitudes of anomalies calculated from forward modeling are comparable with acquired data for prospects at Miocene levels for longer offsets and low frequency [Figure 8]. Only difference is the presence of a regional trend in acquired data. This trend is absent in modeled response because modeled response of all receivers are normalized by background model where acquired data is normalized by the receiver on the line but away from the reservoirs. An anomaly of magnitude of 1.2

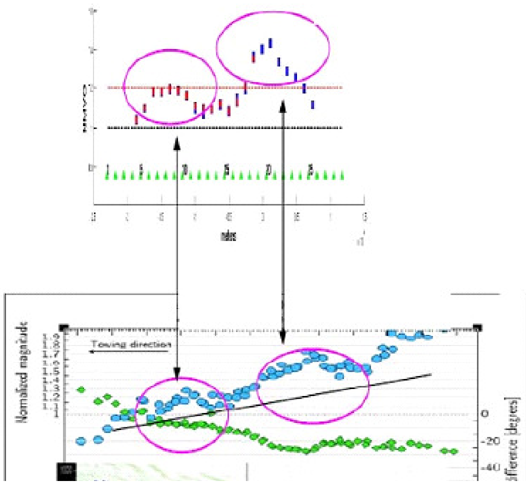

Figure 8: Modeled (upper) and acquired (lower) data at longer offsets 9000m and low frequency 0.15 HZ

between receivers no 6 to no. 12 (Figure 8) shows good agreement with acquired data indicating the presence of a resistor for target XX and well YY at mid Miocene level at longer offsets and low frequency. Response at Longer offsets and low frequency indicates sensitivity of deeper level. Since spatial separation between XX and YY is much lesser than the depth of burial of these targets so chances of differentiating these two targets are very unlikely hence modeled anomaly shows a combined effect of target XX and well YY. On drilling a resistor (HC) was encounter at Mid Miocene level of XX. Response for target ZZ at Miocene level for longer offsets and low frequency between receivers no. 16 to no. 24 also shows a clear detectable anomaly of magnitude approx 1.4 hence indicates the presence of resistor at that level. But compared to acquired anomaly modeled anomaly is shifted slightly towards in NW direction.

Magnitude of anomalies calculated from modeling at shorter offsets and high frequency is much higher than the acquired data using initially assumed transverse resistance 800 Ωm^2. The shape of the anomaly was also not matching. The modeling was redone with lower TR 480 Ωm^2, keeping thickness of targets constant with lower resistivity value. Magnitude of the anomaly was comparable in this case but shape was not matching. To match the shape of anomaly modeling was performed again with split targets and a good agreement was found in modeled and acquired anomaly for target ZZ. Anomaly for target XX still shows higher response for modeled response than observed data, [Figure 9]. Modeling shows anomaly 1.35 between receiver no.14 to no.19 and 1.85 between receiver no. 20 to receiver no. 24 for shorter offsets (3718 m) and higher frequency (1.5 Hz).

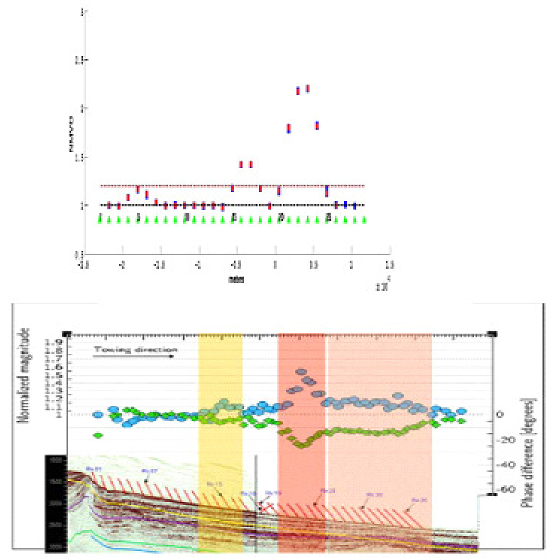

Figure 9: Modeled (upper) and acquired (lower) data at shorter offsets (2500 m) and high frequency 1.5 (Hz).

On comparison with real data, modeling results suggest presence of a non-uniform resistor with lower TR (480 & 600 Ωm^2) than initially assumed TR (1200 Ωm^2) at Pleistocene level for ZZ prospect having more resistivity accumulation in SE part. For XX prospects at same level modeled response shows much higher anomaly for assumed parameters (20 x 40 Ωm^2). In comparison with acquired data modeled response with even lower TR (3 x 40 Ωm^2) also shows higher anomaly which suggests absence of any resistor at this level for XX. On drilling no resistor was encountered at that level for target XX.

Conclusions

Post acquisition 2.5 D forward modeling is useful for interpreting marine CSEM data specially when updated seismic interpretation and nearby well data is used. In our study we performed 2.5 D forward modeling on the basis of seismic interpretation and well information. Models were generated along the CSEM line having two prospects and already drilled well. Forward response of an already drilled well showed detectable anomaly and good agreement with acquired data. For target XX modeling suggested presence of resistor at mid Miocene level and no resistor at Pleistocene level. Drilling confirmed the CSEM interpretation based on forward modeling. Modeling results also suggested presence of resistor at Pleistocene and Miocene level for target ZZ.

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