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Focused Source EM Survey - As an efficient solution for Standard Marine CSEM problems

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Summary

The marine CSEM survey despite being the unifying and ruling technology in petroleum industry is yet to address some serious problems. To name a few these includes (i) Airwave effect which can significantly mask the reservoir response when applying standard CSEM on a shallow water continental shelf or on land. (ii) Failure of CSEM to detect hydrocarbon reservoir below the salt layer (iii) Failure of CSEM in some deep water areas (iv) Effects of bathymetry.

This paper basically highlights some of these problems related to marine CSEM data interpretation and how to mitigate these problems with the aid of a modified technique called Focused Source Electromagnetic survey (FSEM).

Background

The controlled source electromagnetic method (CSEM) attempts to detect and characterize resistive layers for hydrocarbon exploration for hydrocarbon exploration or for crustal studies. Marine CSEM uses a horizontal electric dipole source towed near the sea bed and an array of receiver dipoles on the sea bed. The transmitting dipole emits a low frequency electromagnetic signal that propagates into the subsurface.

Diffusion of the electromagnetic field for any fixed frequency depends on the resistivity of the subsurface and / or the thickness and resistivity (for instance caused by the hydrocarbon solution) the electromagnetic field propagates through it with less attenuation than in the surrounding more conductive sediments. On the contrary the focused source electromagnetic method exploits the idea of focusing the EM- field in a vertical direction to provide deep resistivity data (Davydycheva et al.2006). The theoretical background is given by Davydycheva et al. (2006). Development of FSEM began in the late 1980s and early 1990s in Russia for land or shallow water surveys. Conventional CSEM often called Sea bed logging (Ellingsrud et.al; 2002) was first developed as a deep water method. But the application of CSEM in shallow water create some problems and can prevent the detection of small buries hydrocarbon layer. Not only that presence of salt layer above the reservoir, the effects of bathymetric high (Li, Y., and Constable, S, 2007) can also mislead data interpretation. All these problems can be removed by Focused source electromagnetic survey FSEM due to its higher spatial resolution and for taking into account the effect of induced polarization

Interpretation Methodology

CSEM surveys allow remote sensing of subsurface resistivity contrast. Subsurface resistivities are controlled by permiability, pore space geometry and pore fluid composition. While water wet sediments generally have resistivities in the range of 1-5 ohm-m, hydrocarbon bearing sediments have much higher resistivities of around 10-100 ohm-m.

In CSEM survey periodic EM energy is generated by a dipole source. The receivers record energy travelling directly from source to receiver, reflected and refracted energy from the subsurface and reflected and refracted energy from the sea-air interface. If the reservoirs resistivity is high due to hydrocarbon saturation, the energy from the subsurface will include guided energy from the reservoir. Depending on source receiver distance, subsurface structure and water depth, one of the three energy modes will dominate the recorded signal. The direct energy will dominates the continuously recorded signal at short source receiver offsets. As the offset increases, energy from the subsurface will dominate the recorded signal. The offset at which this occurs depends both on subsurface structure and water depth. The energy refracted along the

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sea-air interface (airwave) will dominate the recorded signal at relatively large offsets. Exactly where depends strongly on the water depth but also on the strength of returned energy from the subsurface. In deep water (more than about 1500 mt), only a minor airwave contribution to the recorded signals is seen for offsets less than 10 km.

Magnitude versus offset:

An interpretation approach commonly used in hydrocarbon industry is based on examining Normalized in line magnitude versus offset plots. The normalized MVO equals the observed magnitude divided by the magnitude at a reference receiver. This approach is based on the following assumption. If a proper reference receiver is selected (for instance, in an area where hydrocarbon absence has proven), the normalized magnitude versus offset can indicate resistive layers, possibly associated with the presence of hydrocarbons. In other words the presence of a resistive hydrocarbon bearing layer reduces the attenuation of the electric field with distance so when the magnitude of the data measured in the unknown area is divided by the magnitude of the reference data at any given offset, this ratio (Normalized magnitude should be greater than 1) .

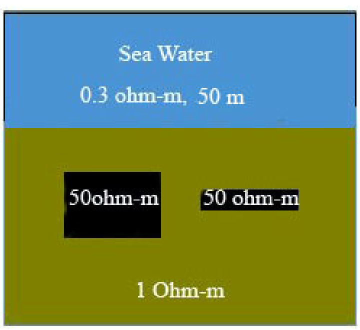


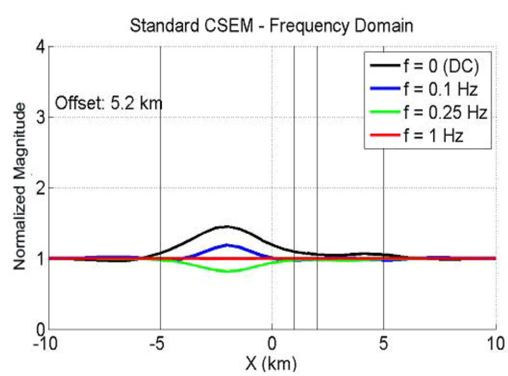
Figure 1: 1D model of the two 50 ohm-m hydrocarbon reservoir (black) 1 kn below the 1ohm-m seafloor (green) ,at water depth of 50 mt.

Problems and solutions

Though CSEM is very specialized technique for characterizing the hydrocarbon reservoir due to its resistivity, yet it has restricted applicability in presence of strong airwave effect and complex geological environments .The typical problems that has been discussed here with model and field examples basically include:

(i) The effects of airwave which significantly mask the reservoir response when applying standard CSEM in shallow water.
(ii) Failure of CSEM in detecting hydrocarbon reservoir below salt layer.
(iii) Very weak response in some deep water cases.
(iv)The effects of Bathymetric high associated with the hydrocarbon reservoir.

The first field example demonstrates the more challenging job in CSEM and assume the same structure (Figure 1). The structure is situated 2 km below the sea floor and in shallower (50m water). This is a very challenging for standard CSEM due to strong airwave effect and the 5 km offset. Figure 2 shows standard CSEM both in frequency domain and in time domain has very weak responses over the structure. It shows the responses to the model for the offset of 5.2 km. The graph shows relative or normalized responses (i.e. electric field divided by the response measured at a reference point sufficiently far from the reservoir,) which allows visualizing the anomaly over the reservoir. Frequency domain CSEM provides an anomaly of 45 % above the larger structure and the time domain CSEM upto 75 % but the smaller structure is virtually lost in its "shade". Varying the excitation frequency on measurement time is useless in this case : Nonzero/ frequency time does not seem to provide any additional information and only reduces the CSEM response , as compared to the DC response, due to the airwave and skin effect. Whereas the FSEM provides very clear reservoir responses, more than 250 % above the larger structure and 20-50% above the smaller one and can be clearly distinguished.



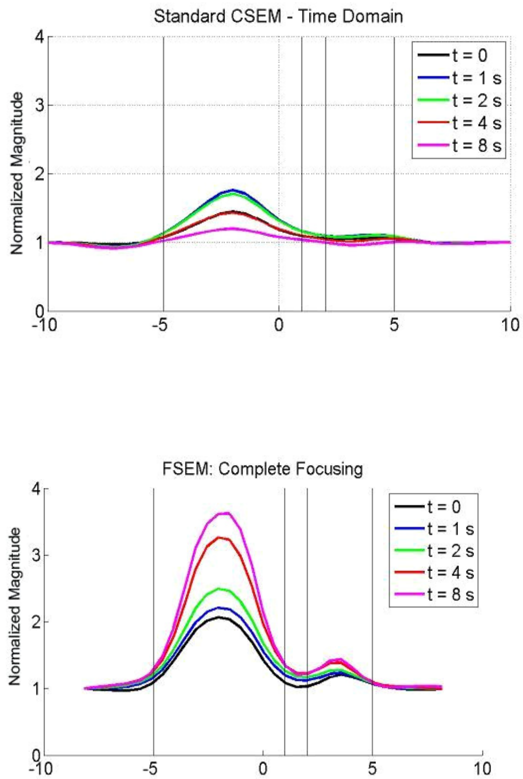


Figure 2: Water depth 50 mt, reservoir 2km below the sea floor (a) frequency-domain (b) time domain CSEM (c) FSEM responses.

Remarkably the relative FSEM reservoir responses become stronger as the measured time increases, whereas the standard time domain CSEM responses (both relative and absolute) fade away.

Figure 3.1D model of hydrocarbon reservoir below the salt layer.

The next example is associated with a hydrocarbon reservoir below a salt layer. Figure 3 shows a 1D model of hydrocarbon reservoir at 1 k below the seafloor and at 1000 mt water depth.

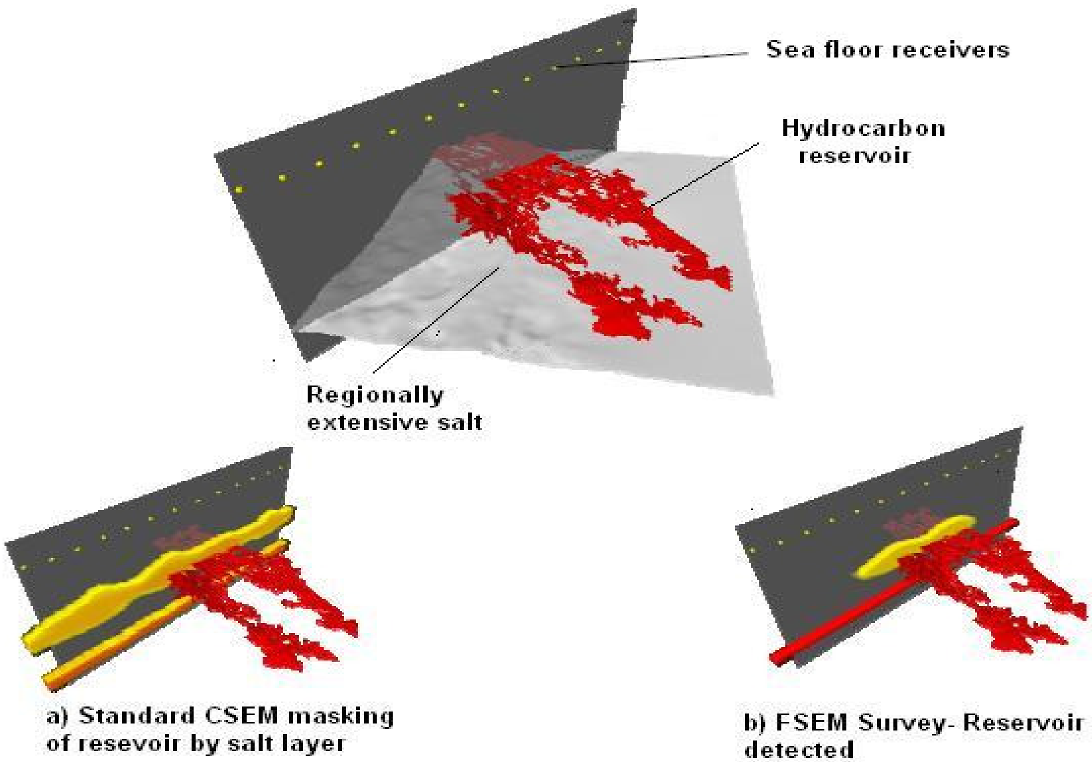


Figure 4.Model data shows (a) Masking of reservoir due to salt layer in CSEM (b) Detection of reservoir by FSEM.

This is a very typical model in which most of the cases there is a strong masking of the reservoir due to presence of resistive salt bodies. The Figure 4. shows the strong masking of the hydrocarbon reservoir due to the presence of salt layer above the reservoir.

Standard CSEM frequency domain responses to this model for the offset of 5.2 km have been shown in Figure 5. Here standard frequency domain CSEM gives very weak responses over the hydrocarbon reservoir. However the FSEM shows a very good anomaly on this aspect due to its higher spatial resolution.

Another important thing is the induced polarization coefficient (Ip) which is typically zero in case of salt but are non zero for sandstone and hydrocarbon bearing rocks. As FSEM considers the effect of induced polarization so it is very effective in differentiating between salt and hydrocarbon.

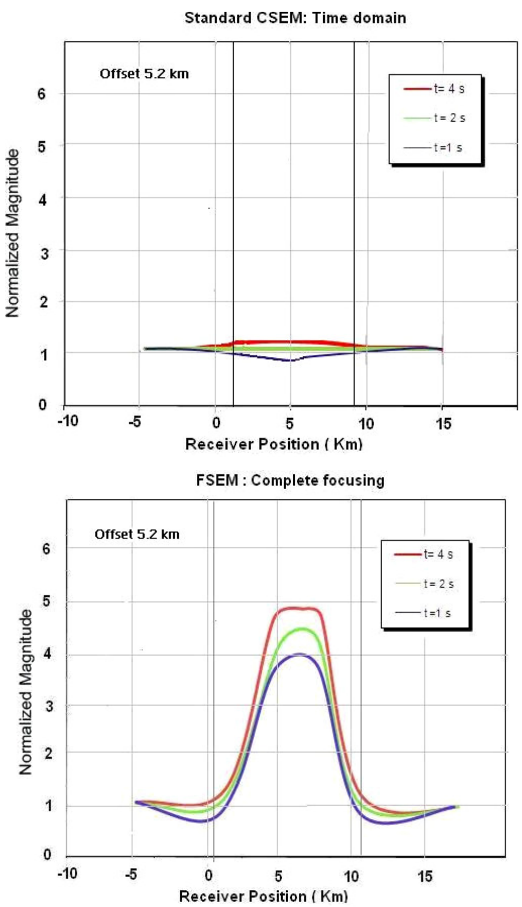


Figure 5.Reservoir below the Salt layer (a) time domain CSEM (b) FSEM responses.

At all the frequencies responses of the reservoir is hardly been distinguished from the background and normalized amplitude ratio is almost getting 1.

The next example assumes a very deep water reservoir where the reservoir is situated 1000mt from the sea floor and 1500 mt water depth. Standard CSEM survey failed to provide reliable data in this area, the normalized responses is very weak. However, there are many reasons when the resistivity in the reservoir does not provide strong enough reservoir response. This may happen if

-The reservoir is not of high contrast in the resistivity; this may happen if it is saturated with oil mixed with salty water and water saturation is > 40-50%;

-The formation is anisotropic; the anisotropy reduces the relative reservoir response;

-The reservoir is not thick enough vertically, or its diameter is less than transmitter-receiver offset;

-The depth below the seafloor is more than 1 km, or more than the offset, or more than the reservoir diameter.

In this case the aforementioned scenarios is viable that means the Standard CSEM is failed to detect the hydrocarbon reservoir .The seismic and other combination of methods such as well log also provides indication of hydrocarbon at that depth (Figure 6).

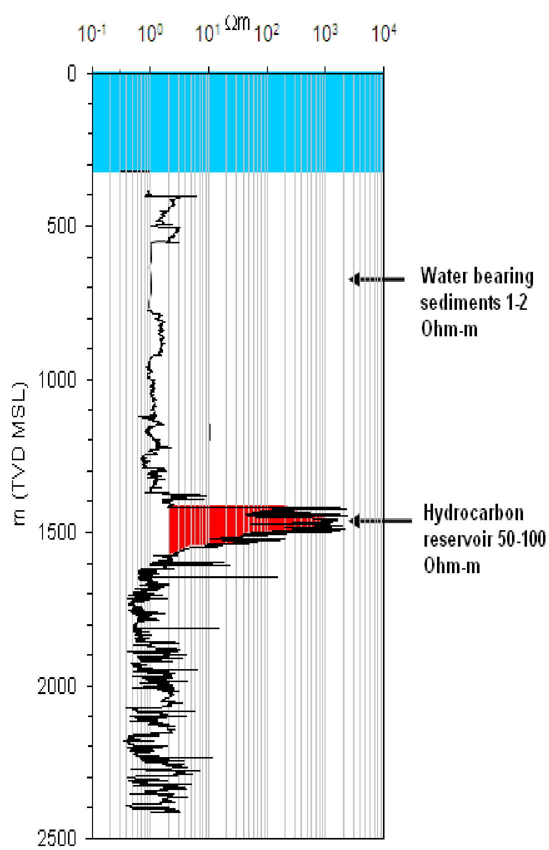


Figure 6.Response of the hydrocarbon reservoir at depth of 1550 mt in well log.

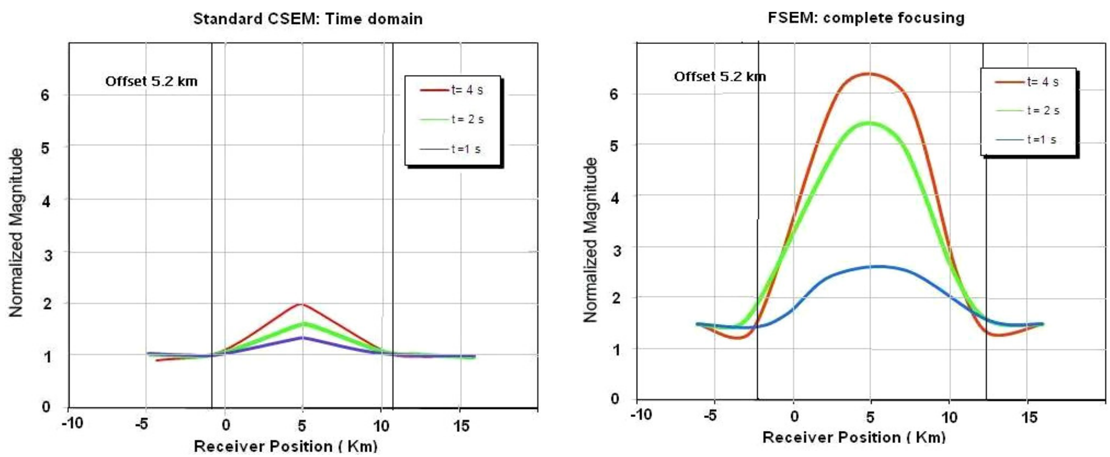


Figure 7: Water depth 1550 mt, reservoir 1km below the sea floor (a) time domain CSEM (b) FSEM responses.

Figure 7.Shows responses of standard CSEM in time domain and of FSEM. In time domain the standard CSEM has very weak responses over the structure. It shows the responses to the model for the offset of 5.2 km. Frequency domain CSEM provides an anomaly of 35 % above the reservoir whereas FSEM gives more than 200 % over the same reservoir.

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Remarkably the relative FSEM reservoir responses become stronger as the measured time increases, whereas the standard time domain CSEM responses almost fade away.

The most typical problem in CSEM interpretation is the effect of bathymetric high associated with the reservoir.

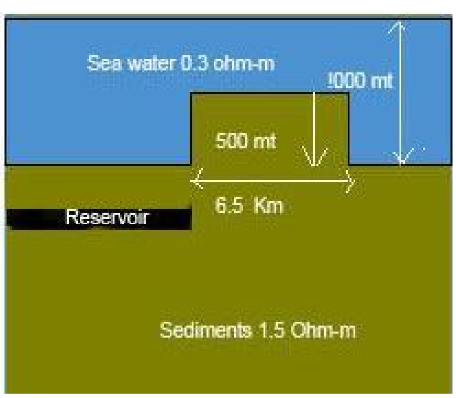

Figure 8.Model Showing the reservoir associated with a 500 mt bathymetric high.

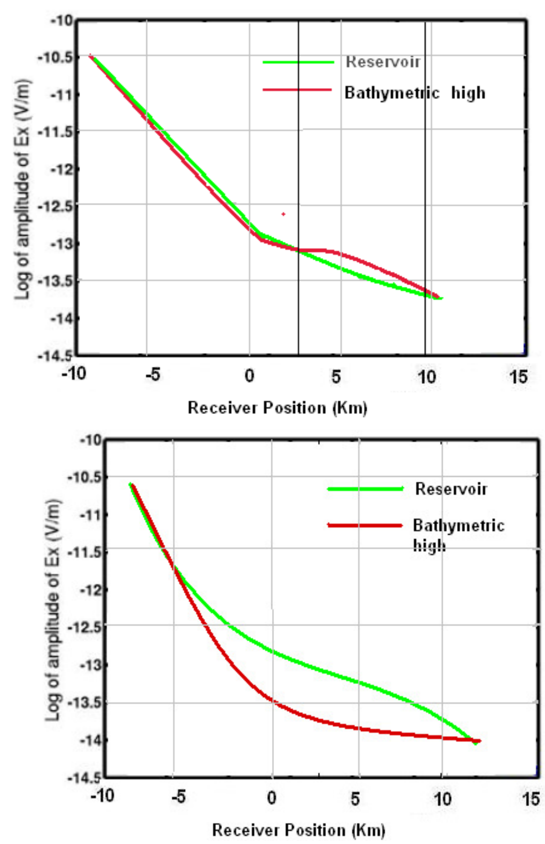

Figure 9.The radial electric field response for a 5.5 km resistive reservoir layer compared with the response from the bathymetric high (a) CSEM responses (b) FSEM responses.

Bathymetry plays a key role on understanding the interpretation process. Usually the bathymetry response and the response from a buried resistive target have different wavelengths which might facilitate their separation with accurate modeling. But the problem is a bathymetric high in sub-sea topography can be mistaken as a buried resistive target. Figure 8.shows a simple model of a hill on the sea-floor with a 6.5 km lateral extent and a height of 500 meters. The response over the high is shown in (Figure 9a) along with the response for the resistive reservoir layer associated with that high. There is a disturbingly close resemblance between the response of a bathymetry high and the response from a buried reservoir layer. Fortunately the application of FSEM with varied frequency i.e 0.75 Hz and 1 Hz provides a very good response to distinguish between these two scenarios (Figure 9b) they will certainly not be distinct to visual inspection in actual field conditions.

Conclusions

The paper highlighted the restricted applicability of CSEM in practical problems including the effect of airwave at shallow water areas or on land, salt layer effect and the effect of bathymetry high associated with the reservoir. On contrary the FSEM effectively removes all these problems due to its high spatial resolution and due to its consideration the effect of induced polarization.

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