8th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2010"

P-121

A Synthetic Study on the Feasibility of CSEM Application in Mapping Shallow Hydrates

Lim Toon Hoong*, Tan Kian Wei
Electromagnetic Geoservices (EMGS) Asia Pacific, Kuala Lumpur, Malaysia.

Summary

A synthetic study has been conducted to quantify the effect of marine gas hydrates on mCSEM data and the factors which contribute to its sensitivity. The study confirmed that mCSEM sounding is feasible for shallow hydrates detection in deep sea environments. Results indicate high anomalous reading at short offsets, and shallow resistors are therefore easily identifiable. However, factors such as resistivity contrast, frequencies used in acquisition, size, geometry and volume of hydrates and the survey configuration will influence the sensitivity of EM signal towards its detection.

Introduction

Methane hydrates can occur in high pressure environments as found in gas pipelines or oceanic sediments (Laherrere, 1999). They are being evaluated as a non-conventional energy source and at the same time, commonly regarded as drilling hazard. Drilling through gas hydrate zones could result in "blow-outs", collapsing drilling platforms and endangering work crews. As the oil and gas industry ventures deeper into the ocean, the occurrence of gas hydrates in the area of interest has become a concern, and therefore, much effort has been made to detect and locate shallow hydrates.

Marine Controlled Source Electromagnetic (mCSEM) sounding has been used as a geophysical tool to map subsurface resistivity distribution where the standard acquisition mode is a horizontally towed dipole along the subsurface and ocean bottom receivers deployed on the seafloor. Due to the sensitivity of certain components of the electromagnetic field to thin resistors, mCSEM methods are further increasingly being applied for hydrocarbon exploration. The enhanced resistivity of methane hydrates of typically 3-20 Ωm compared to typical background resistivities of approximately 0.5-2 Ωm in offshore sediments, together with their shallow depths suggest to use the CSEM methods for characterization and mapping. Several hydrate cruises have been conducted by academic groups, see for example Weitemeyer et al., 2006. EM signal rapidly attenuates in seawater and seafloor sediments. However, in high resistive media, such as shallow hydrates, the EM energy will be partially guided along the resistive layer before it is refracted back to the seafloor. As the signal from the shallow hydrates is less attenuated, stronger responses will be observed at near offset data, indicating the presence of shallow resistive features. These data can be quantitatively analysed, such as was done by Zach and Brauti, 2009, who presented hydrate signatures in standard mCSEM surveys targeting hydrocarbons.

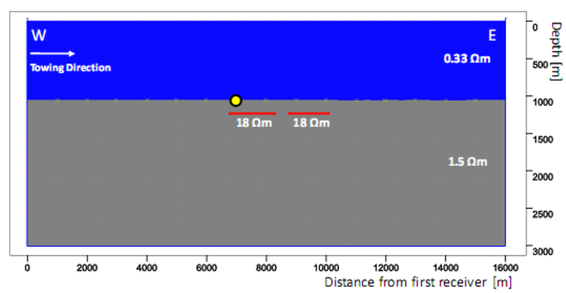

Figure 1: Cross section of a 3D resistivity model. Two shallow resistors of 18 Ωm and 50 m thickness are placed 200 m below mud line. Towing direction is from west to east. Near offset synthetic data of the yellow receiver is analysed.

A synthetic 3D model (Figure 1), with a formation resistivity of 1.5 Ωm and shallow gas hydrates of 18 Ωm and 50 m thickness, located 200 m below seafloor is modelled using a proprietary finite difference time domain

EMGS Asia Pacific Sdn. Bhd., Unit E-15.2-4, 15th Floor, East Wing, Wisma Rohas Perkasa, No. 8 Jalan Perak, 50450 Kuala Lumpur, Malaysia; tlim@emgs.com

(FDTD) code to demonstrate the effect of shallow resistive features on the near offset CSEM data. The inline (i.e., along the towing direction) electric magnitude versus offset (MVO) response and phase versus offset (PVO) response of a synthetic receiver placed at the edge of a hydrate patch are shown in Figure 2. On the out-towing part of the receiver, where the hydrates are located in the model, a prominent shoulder effect is observed at near offset in the PVO response, starting from approximately +250 m to +1800 m offset. This feature is not present in the in-towing part coinciding with the absence of hydrates. The effect of shallow resistive feature on CSEM response is more prominent on the phase data compared to the magnitude data due to the rapid decay of EM signal.

This paper will discuss in more detail the feasibility of using the CSEM method for the detection of thin shallow hydrates of varying resistivity at different frequencies.

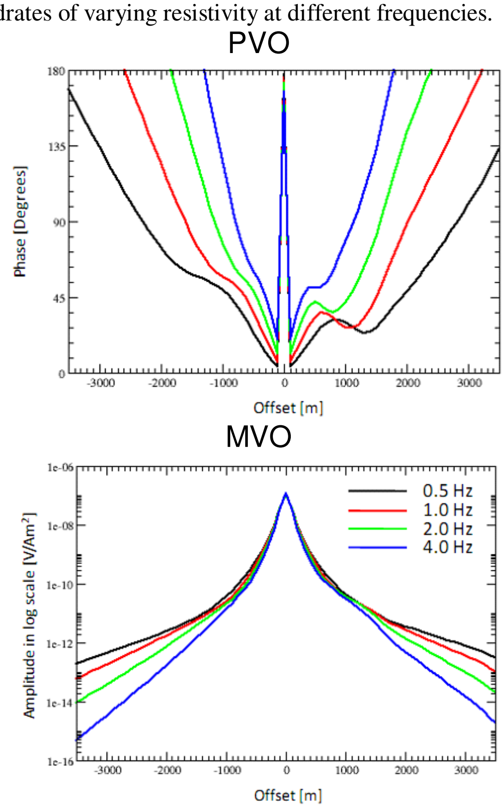

Figure 2: PVO plot (upper) and MVO plot (lower) of a synthetic receiver located at the edge of a shallow resistor.

Method

A 3D geo-model was built, covering an area of 37 km x 31 km. Hydrate patches of varying geometry and resistivity (3 Ωm, 9 Ωm and 18 Ωm) were randomly assigned to the model. The hydrate patches with a thickness of 50 m were placed 200 m below mud line. A formation resistivity of 1.5 Ωm was assumed. Inline EM responses were simulated over a grid of 32 towlines with 17 receivers on each line. Towline and receiver spacing is 1 km by 1 km. Figure 3 illustrates the receiver-towline (Rx-Tx) configuration and the location, geometry and resistivity of the hydrate patches over the seafloor map. Figure 4 shows the crosssection of the model along line 01Tx019.

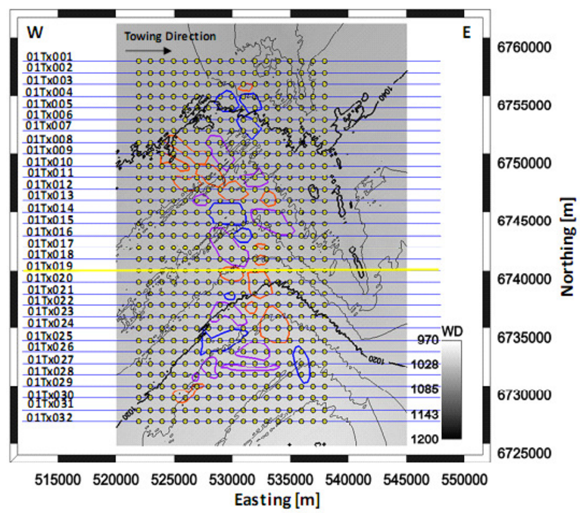

Figure 3: Receiver (yellow circles) and towline (blue lines) configuration over seafloor map (in grey scale). Coloured polygons indicate the location of the randomly assigned hydrate patches with varying resistivity, 18 Ωm (Blue polygon), 9 Ωm (Purple polygons) and 3 Ωm (Orange polygons). Yellow line shows line 01Tx019.

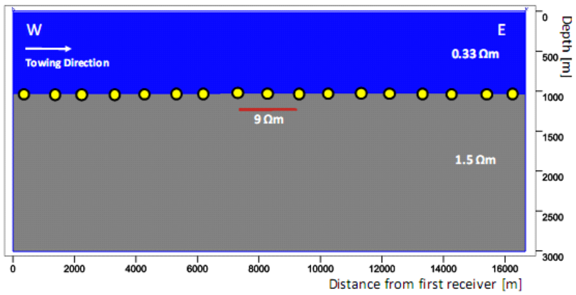

Figure 4: Cross section of the model at line 01Tx019. Yellow circles show receiver positions.

Simulated responses were generated only for inline data and four main frequencies, 0.5, 1.0, 2.0 and 4.0 Hz. The magnitude of the EM field falls below the noise threshold at shorter offset with increasing frequency. At a frequency of 4 Hz, the maximum offset maintaining adequate signal to noise ratio (SNR) in this study is at 3500 m. However, hydrates are of shallow origin and hence, the focus is on short offset data. Therefore, the simulated responses were windowed at 3500 m offset for both in-towing and outtowing for all frequencies. The simulated responses are then normalized against background responses to isolate information from the shallow resistors.

Results and Discussion

The normalized magnitude versus offset (NMVO) responses and phase difference versus offset (PDVO) responses along towline 01Tx019, plotted in the common mid point domain (line response), are shown in Figure 5.

Closed anomalies observed from the NMVO and PDVO plots are the results of the presence of hydrates with limited extension. The extension of the hydrate patch along line 01Tx019 is illustrated as grey boxes in Figure 5. For the CMP-anomaly plot at 1.5 km offset-bin, the lateral extension of the anomaly coincides well with the edges of the assigned hydrates. At larger offsets, the extension of the anomaly appears larger as the data carries subsurface information in a bigger volume.

The response of the four frequencies was compared. The normalized fields increase with increasing frequency, with an approximate 100% increase in response at 4 Hz, followed by 70% at 2 Hz, 45% at 1 Hz and 30 % at 0.5 Hz.

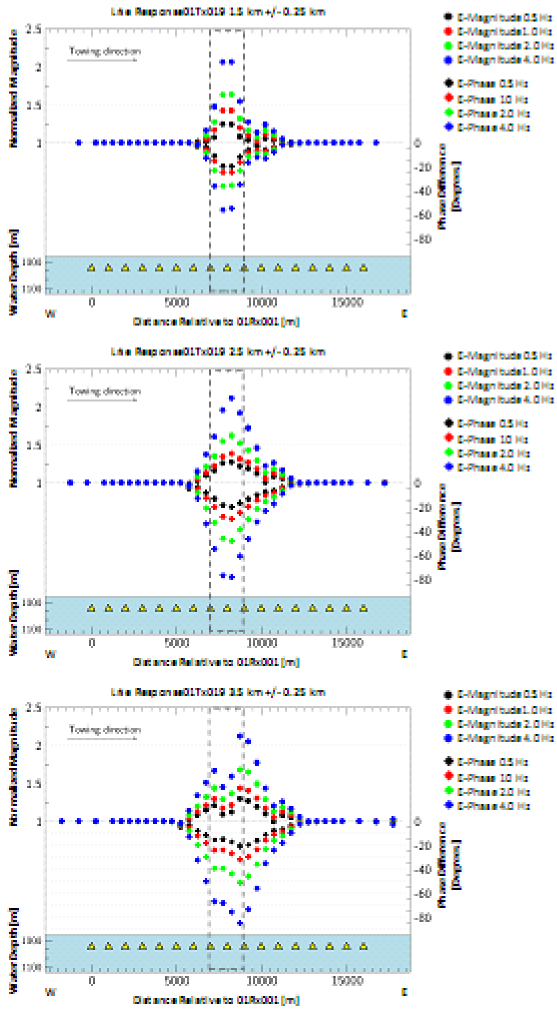

Figure 5: Line responses for line 01Tx019 at 1.5km (top), 2.5 km (middle) and 3.5 km (bottom) offsets. Four frequencies are shown for each plot and grey dashed rectangles indicate the hydrate outline.

Area response maps were generated to analyse the overall response of the modelled area. Inline electric normalized magnitude data points at +1.5 km offset for all receivers are taken and extrapolated. Figure 6 shows the area response map for all four frequencies at an offset of 1.5 km.

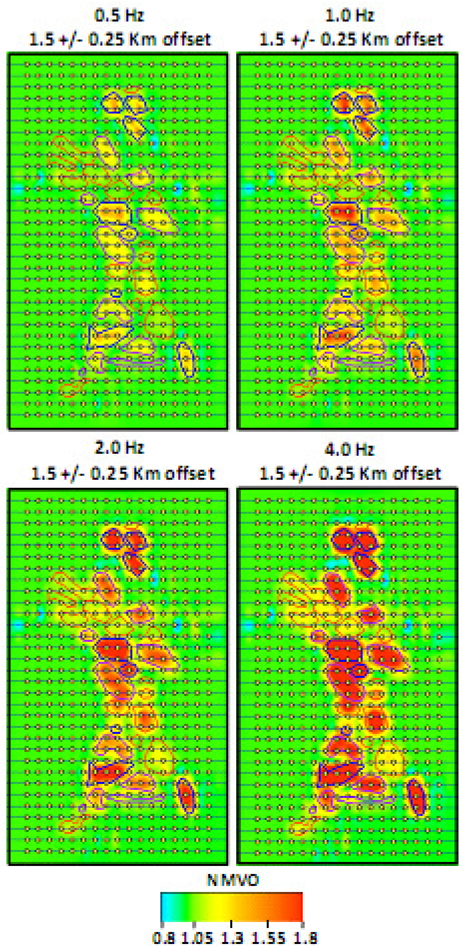

Figure 6: Area response maps at 0.5 Hz, 1.0 Hz, 2.0 Hz and 4.0 Hz plotted at 1.5 km offset. Blue polygons show 18 Ωm hydrates, purple polygons show 9 Ωm hydrates and orange polygons show 3 Ωm hydrates.

In general, the strength of the anomaly (i.e. field magnitude) increases with increasing target resistivity and frequency. The offset chosen is confirmed, as the response from the hydrate patches with resistivity of 9 Ωm and 18 Ωm were well mapped and their outlines were well delineated at all frequencies. However, weaker responses are observed over hydrate patches with a resistivity of 3 Ωm at low frequencies. In order to pick up more significant responses from the less resistive shallow resistors, higher frequencies are necessary to provide improved resolution.

Apart from the frequency and target resistivity, the size of hydrates and Rx-Tx configuration (survey design) will also influence the sensitivity of EM signal towards a given target, as demonstrated in Figure 7.

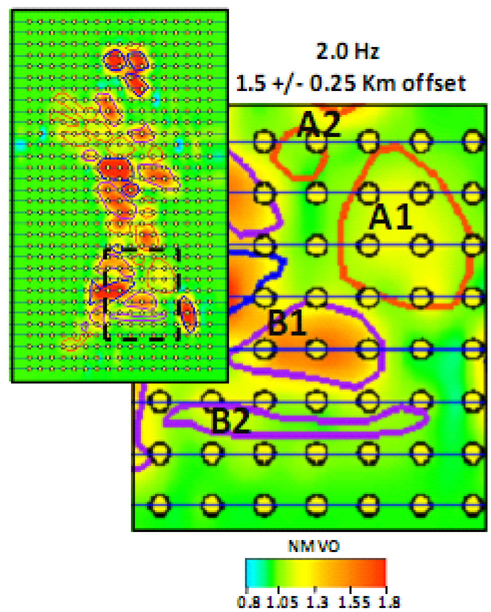

Figure 7: Area map of the dashed rectangle box is magnified. Area of interest is delineated with A and B. Blue polygons show 18 Ωm hydrates, purple polygons show 9 Ωm hydrates and orange polygons show 3 Ωm hydrates.

The resistivity of hydrate patches A1 and A2 are both assigned 3 Ωm. As A2 is much smaller in size, the data which contains information from the hydrate patch is more limited and therefore, the imaged response from A2 is much weaker compared to the response from the bigger target, A1. A similar effect is observed for hydrate patch B2. For inline data, the electric component of the electromagnetic field will be mainly vertical and the recorded fields are thus sensitive to the vertical resistivity. Therefore, despite having a larger extension and higher resistivity compared to A2, the response from B2 which is elongated in shape and located off the towlines shows limited response compared to the response from hydrate B1, which is of the same resistivity value.

High frequency data is more sensitive to shallow resistors. However, a good trade off between frequency and SNR must be carefully evaluated especially when deeper prospects are expected to be present in hydrate areas. Hydrate varies in geometry and size. In the case where hydrate patches are expected to be insignificant in size, denser receiver spacing is necessary to increase the number of samples carrying information from the spatial distribution. On top of that, receivers should always be placed along the estimated hydrates location in order to maximize the response when only inline data is acquired.

Conclusion

The synthetic study on shallow hydrates has demonstrated the feasibility of Marine Controlled Source Electromagnetic (CSEM) application in detecting the occurrence of methane hydrates in oceanic sediments. Near offset data is analysed for the presence of shallow resistive features.

Results of the study demonstrated several factors that can affect the sensitivity of EM signal towards shallow hydrates. This includes the frequency of the data, resistivity contrast between the hydrates and water bearing sediments, size and geometry of hydrates, and the receivertowline (Rx-Tx) survey configuration.

Acknowledgments

We thank EMGS for the permission to publish the results and Lars Lorenz as well as JÜrgen Zach for their comments.

Reference

Zach, J.J. and Brauti, K., 2009, Methane hydrates in CSEM surveys – Analysis of a recent data example, *Geophysical Prospecting*, Volume 57, Issue 4, 601-614.

Laherrere, J.H., 1999, "Gas hydrates, uncertain resource size enigma; Offshore Magazine Part 1, August 1999, 140141

Laherrere, J.H., 1999, Data shows oceanic methane hydrate resource over-estimated; Offshore Magazine Part 2, September 1999, 156-158

MaaØ, F.A., 2006, Fast finite difference time domain modelling for marine subsurface electromagnetic problems; 76th Annual International Meeting, SEG, Expanded Abstracts, 740-744

Eidesmo, T., Ellingsrud, S., MacGregor, L.M, Constable, S., Sinha, M.C., Johansen, S., Kong, F.N. and Westerdahl, H., 2002, Sea Bed Logging (SBL), a new method for remote and direct identification of hydrocarbon filled layers in deepwater areas; First Break 20.3, 31-36

Johansen, S.E., Amundsen, H.E.F., RØsten, T., Ellingsrud, S., Eidesmo, T. and Bhuyian, A.H., 2005, Subsurface hydrocarbons detected by electromagnetic sounding; First Break 23, 31-36

Mittet, R., 2008, Normalized amplitude ratios for frequency-domain CSEM in very shallow water; First Break 26, 47-54

Constable, S. and Weiss, C.J., 2006, Mapping thin resistors and hydrocarbons with marine EM methods; Insights from 1D modelling; Geophysics 71, No. 2, G43-G51

Ridyard, D., Wicklund, T.A. and Petter, L., 2006, Electromagnetic prospect scanning moves seabed logging from risk reduction to opportunity creation; First Break 24, 53-56

Weitemeyer, K.A, Constable, S.C, Key, K.W., Behrens, J.P., 2006, First results from a marine controlled – source electromagnetic survey to detect gas hydrates offshore Oregon, Geophysical Research Letters 33, L03304