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EM survey in Flemish Pass Basin, East Canada

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Summary

EMGS has begun a comprehensive multi-year, multi-client campaign of 3D wide-azimuth CSEM (Controlled Source Electromagnetic) and 3D marine MT (magneto-telluric) data in around the Flemish Pass Basin offshore East Canada. The 2014 program covered a total of 1986 km^2 in the North Flemish Pass basin, with calibration over the Mizzen, Harpoon and Bay du Nord discoveries. In the upcoming years the goal is to cover open acreage before future bid rounds.

Inversions of the current 3D CSEM survey show a good correlation between existing well log data and resistivity anomalies. At depth, the resistivity models obtained from 2D MT and 2.5D joint CSEM and MT inversions show lateral resistivity trends where seismic data alone do not clearly image possible structural and stratigraphic boundaries; these resistivity results enable differentiation of shale-cored highs and highly resistive layers such as salt, volcanic, or carbonate in the deeper Mesozoic section. Both CSEM and MT data provide additional insights to improve the geologic model of the complex structural and depositional geology of the East Canada Flemish Pass area.

EM integration improves decision making throughout Exploration and Development stages, refining play models, defining focus areas, acreage evaluations, and participation via farming in, or managing risk by farming out. Integrated EM interpretation, together with recent 2D seismic data provides an excellent tool to identify and de-risk leads and prospects on open acreage in the Flemish Pass basin.

Introduction

Flemish Pass Basin, located off the east coast of the Provinces of Newfoundland and Labrador, Canada, is situated between the Grand Banks and the Flemish Cap. It is close to major producing fields in the Jeanne d'Arc Basin, a southwest-northeast elongated Mesozoic rift. Recently, three significant discoveries, Mizzen O-16 (100-200 million barrels of oil) and Bay du Nord (300-600 million barrels of oil) and Harpoon, have been made in the Flemish Pass basin.

The basin contains thick Mesozoic sediments from mid Jurassic to Late Cretaceous. Thin carbonate packages with the Mesozoic section have been encountered in some of the wells (Enachescu, 1987, 1988 and 1992). Sandstones deposited during Late Jurassic and Cretaceous time are potential reservoirs in the area. A series of large structural traps have been identified on seismic data, with stratigraphic and combination traps possible.

Historically, exploration wells have been drilled on the basis of seismic data alone, targeting four-way dip or fault bounded structures. With numerous potential structural and stratigraphic leads in the area the CSEM data can be used as an interpretation tool combined with seismic to de-risk and prioritize the leads. This will optimize the exploration drilling strategy and improve the success ratio in structurally complex frontier area with limited well control. Recent 3D CSEM results in e.g. the Barents Sea and Mexico, show that integrated interpretation can be powerful in the exploration phase (Darnet et al., 2007; Alcocer et al., 2012, 2013; Gabrielsen et al., 2013; Lorentz et al., 2013).

The wide-azimuth 3D CSEM and MT data have been acquired over Mizzen, Harpoon and Bay du Nord discoveries in 2014 (Figure 1) and open acreage with a total of 1986 km^2 coverage. The water depths range from 900 to 1,400 m. The resistivity responses inverted from the CSEM data have a good correlation with existing well data.

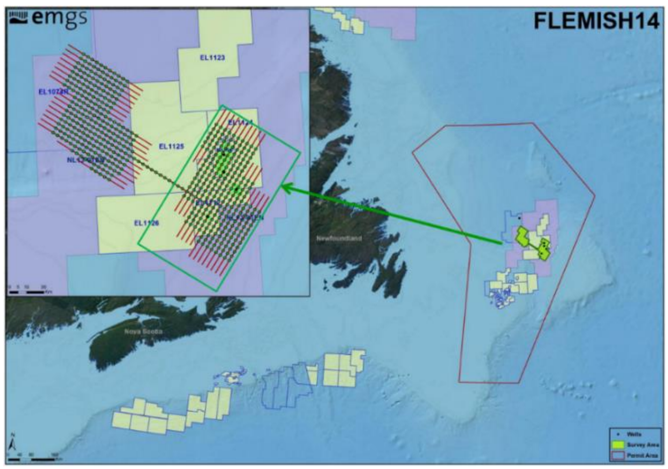

Figure 1: Red polygon: Survey area of planned multi-year, multi-client 3D EM program. Details of 2014-2015 program is shown in the inlaid box. The green rectangle highlights the 2014 data.

Methodology

The measurement of electrical resistivity in the subsurface is a well-known geophysical method used since the early 1920s to determine the character of the fluid content in sedimentary rocks. The same principles apply in marine CSEM surveying where resistive bodies are mapped, such as a hydrocarbon reservoir. The resistivity contrast between background geology and hydrocarbon reservoirs is often one or more orders of magnitude, making resistivity very suitable as a hydrocarbon indicator (Eidesmo et al., 2002; Ellingsrud et al., 2002). The use of CSEM is also well described in a review paper by Constable (2010).

By using numerical inversion processes, the sub-surface anisotropic resistivity distribution is reconstructed. The CSEM inversion uses a 3D finite-difference time-domain modelling code and a Broyden-Fletcher-Goldfarb-Shanno, BFGS, algorithm for the model update (Maao, 2007; Zach et al., 2008; Mittet, 2010). The horizontal electric field is sensitive to horizontal conductors or vertical resistors whereas the vertical electric field is the “opposite”, sensitive to vertical conductors and horizontal resistors. Thus, in a horizontally stratified media such as a sedimentary basin, the horizontal resistivity, Rh, provides information that is more of a resistivity “background” nature. The vertical resistivity, Rv, can give information about the potential presence of hydrocarbons as these can in general be considered to be thin horizontal resistors. Of course there are variations to this generalization depending on the complexity of the basin.

Marine MT uses the naturally occurring electric and magnetic fields to map the electrical properties of the earth. The responses are the ratio of electric and magnetic fields, which also can be used to map the spatial variation of resistivity. The MT data is similar to the horizontal electric field of the CSEM and thus more sensitive to horizontal conductors and vertical resistors. MT can image very thick resistive layers (Ryan, 2014). Compared to CSEM, the MT source contains very low frequency signals and offers better depth penetration (several tens kilometers). The combination of CSEM and Marine MT is a good method to identify resistive boundaries, such as salt, basalt, or basement, where the interpretation of the seismic data is challenging.

EM inversion results

The wide-azimuth 3D CSEM and MT data were acquired with a 3x3 km receiver grid. Acquisition is oriented northeast-southwest. The fundamental frequency of source waveform is 0.125 Hz, with high energy harmonics 0.25, 0.5, 1.0 and 1.875 Hz. The inversion start model is based on 1D-, 2.5D EM inversions, and available wells. The CSEM inversions use both inline and azimuth electrical fields (Ex and Ey) to obtain measurements containing both vertical and horizontal electric fields over a wide depth range.

The 3D CSEM anisotropic inversion provides vertical (Rv) and horizontal (Rh) resistivity cubes, displayed by using a color scale where red represents high resistivity and blue low resistivity. Around the Mizzen area, a depth slice of inverted CSEM model Rv is shown in Figure 2. The CSEM derived resistors match the well results, where an oil discovery was drilled in the larger resistive anomaly, an oil show in the smaller anomaly, and the dry well is located on the edge of resistivity anomaly.

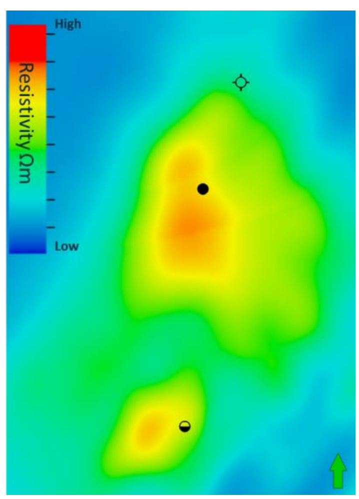

Figure 2: A depth slice through the vertical resistivity model from the 3D CSEM inversion with three Mizzen wells. The results show good correlation with the well data, oil discovery, oil show, and dry well. Warm colors indicate high resistivity and cold colors low resistivity.

Figure 3 shows resistivity sections for the Bay du Nord structure. The well data is confidential so an exact calibration with resistivity logs from the well is not possible yet, but there is a good correlation between known oil discovery at well location and higher resistivity observed in inverted vertical resistivity Rv model (left panel). The horizontal resistivity Rh, sensitive to the background, shows presence of deeper resistive sediments in the tilted fault blocks.

Results from the inverted CSEM horizontal resistivity Rh and 2D MT (Figure 4) illustrates that both methods are in compliance with each other, the uplifted structure in the left side is less resistive than the sediments in the right hand side. This implies a lateral lithology change in the deep (early/pre Mesozoic) sediments, that seismic alone cannot discern.

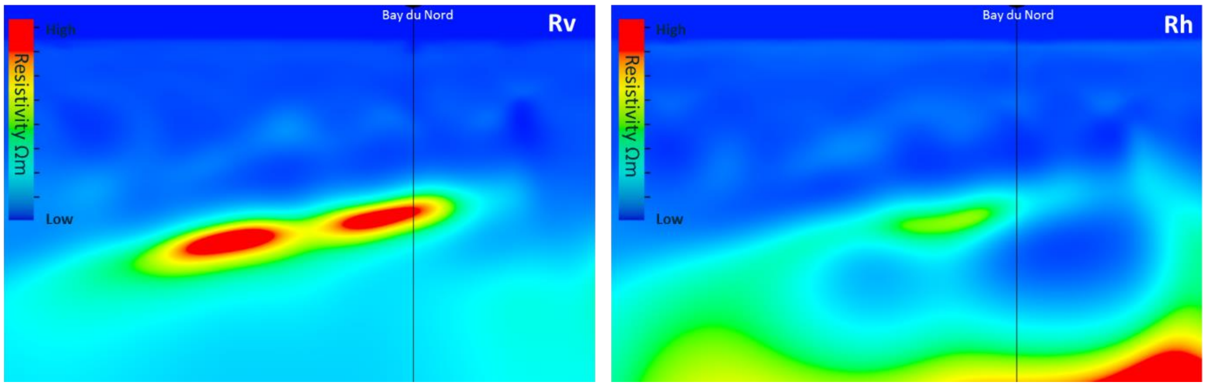

Figure 3: A section from 3D CSEM inversion models, vertical resistivity on the left and horizontal resistivity on the right. The section is crossing the Bay du Nord structure.

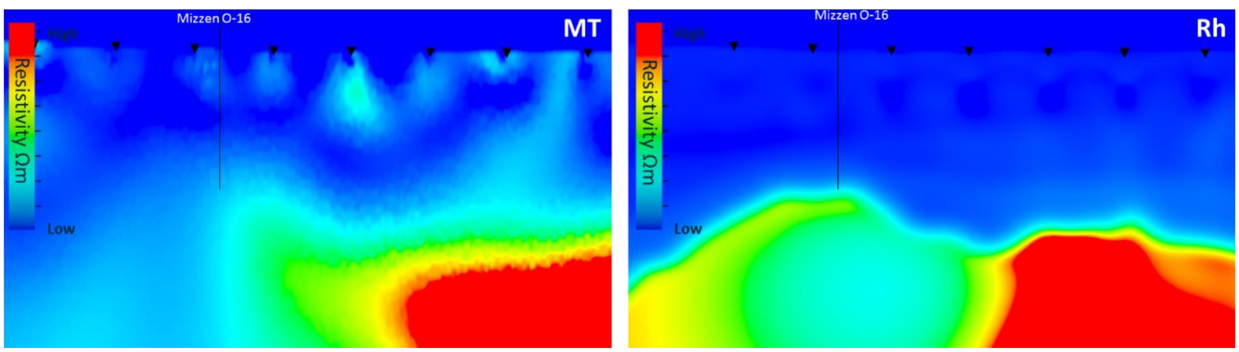

Figure 4: Left: a cross section of 2D MT result. Right: the horizontal resistivity Rh from 3D CSEM inversion. Both indicate lower resistivity in the Mizzen structure.

Conclusions

The CSEM dataset has recovered a number of resistivity anomalies within the survey area. The calibration with known hydrocarbon discoveries in the basin shows good correlation. It demonstrates the value of integrated interpretation of resistivity volumes, with well information and recent 2D seismic data. CSEM data can be an excellent exploration-stage tool to identify and de-risk leads and prospects in open acreage in the area of the Flemish Pass basin. During field development evaluation and planning, improved resolution could be obtained with a denser grid and cross line acquisition for imaging details within complex geologic setting. The comprehensive multi-client EM acquisition program can be undertaken to provide the industry with additional tools together with other available multi-client geological and geophysical data sets to help mitigate exploration risks. EM techniques can also give an indication of resistivity trends and information of deep resistors to improve the geologic model of the complex structural and depositional geology of the East Canada Flemish area.

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