W4 NORWEGIAN SEA – SBL CASE STUDY

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Summary

A SeaBed Logging (SBL) survey has been carried out by ElectroMagnetic GeoServices AS (EMGS) on a prospect in the Norwegian Sea. Good quality data were recorded with a total of 31 receivers along two crossing receiver lines. Processed data shows large and systematic MVO (Magnitude Versus Offset) responses in a limited part of the survey area. These MVO anomalies are most likely caused by subsurface resistivity variations. However, care must be taken when relating MVO responses to subsurface hydrocarbons. Pitfalls are present and a full integration with geophysical data is required in order to fully explain the observed anomalies.

Introduction

The purpose of SeaBed Logging (SBL) is to detect and characterize hydrocarbon-bearing reservoirs in the subsurface using electromagnetic (EM) energy. While traditional exploration methods use acoustic waves to obtain information about subsurface lithology, the SBL method uses EM energy in order to identify pore-fluids. As a consequence, joint analysis of seismic data and SBL data makes it possible to reduce the risk of drilling dry wells.

SeaBed Logging method

The concept of Sea Bed Logging is based on the fact that attenuation of electromagnetic energy primarily is determined by formation conductivity and the frequency of the propagating energy. Formation conductivity is defined as the ability to conduct electrical current flow through the formation. The relationship between conductivity and resistivity is simple: resistivity is the inverse of conductivity. Due to high attenuation of electromagnetic energy in conductive media, frequencies used in Sea Bed Logging are low.

Formation conductivity is a complex variable, depending on several factors. These include, amongst others, porosity, permeability, type of pore fluid, pore fluid geometry, fluid saturation etc. Hydrocarbon saturated sediments have in general a much higher resistivity than brine saturated sediments due to the fluid properties; brine is conductive, oil and gas are not. However, subsurface resistivity anomalies are not only caused by hydrocarbon-saturated sediments. Lithologies such as tight (cemented) sediments, limestones, salt and magmatic intrusions are known to have high resistivities.

During an SBL survey, receiver arrays are positioned on the sea floor. A marine controlled source in the form of a horizontal electric dipole is towed above the seafloor and continuously emits a periodic low-frequency electromagnetic signal in all directions; i.e. energy is propagated both in the water column and down into the subsurface. Hence, receivers record both the direct wave traveling from the source to the receiver, reflected and refracted energy from the sea-air interface and reflected and refracted energy from the subsurface. Receivers may record both the electric and magnetic field, in two horizontally orthogonal directions.

In general, the direct wave will dominate the recorded signals at short source-receiver offsets. With increasing source-receiver offsets, energy from the subsurface will start to dominate the recordings. At large offsets, however, the so-called air-wave refracted at the sea-air interface will be the dominating contribution to the recordings. The offset at which the subsurface energy and air-wave energy will start dominating depends on both water depth and subsurface resistivity distribution.

Survey Layout

A total of 31 receivers were positioned on the sea floor along two crossing receiver lines. Line 01 comprises 16 receivers in the west-east direction. Line 02 (15 receivers) was towed in the southwest-northeast direction. A source frequency of 0.25 Hz, square pulse, was used for both lines. Electric channels recording the electric field were implemented on all receivers. In addition, 23 receivers recorded the magnetic field.

Data Processing

The source signal, the navigation data and the receiver data were judged to be of good quality. After merging navigation and receiver data, receiver time series were subdivided into time segments so that a constant source-receiver offset could be adapted as a good approximation. The time series were therefore cut into a number of equal-length time intervals (an integer number of periods). A Gauss function, normalized in width and height, was fitted to the windows.

For each time interval, a (scaled) single-frequency discrete DFT (Discrete Fourier Transform) was computed to obtain the magnitude and phase at the selected frequency (0.25 Hz). In this case, time intervals of 30 periods were used due to source frequency and speed of vessel, with 15 periods overlap (moving windows) enabled. This might be considered equivalent to stacking of a certain number of single time periods. The time interval chosen must be small enough to ensure a low degree of spatial smoothing, but large enough to filter out noise.

Finally, resulting magnitudes were corrected for the calibration (AD converter and gain) and frequency response of the receiver and normalized by the receiver dipole length.

Examples of processed SBL data are shown in Figure 1 and Figure 2. The data shown represent the so-called polarization ellipses of the electric and magnetic field. The polarization ellipse is constructed for each given time by taking the length of the vector sum (major axis) calculated on the basis of the two orthogonal field components measured by the receiver. Phase is calculated along the direction of the major axis.

Figure 1 shows electric and magnetic magnitude versus offset (MVO) plots for one receiver. Phase plots are shown in Figure 2. Negative offsets denote in-towing offsets, i.e. the source is towed towards the receiver and positive offsets denote out-towing offsets (the source is towed away from the receiver). At zero offset, the source is located above the receiver.

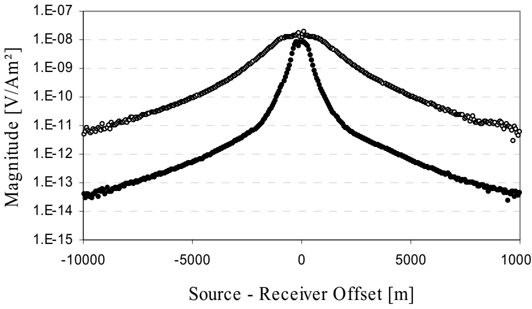


Figure 1: Magnetic (top) and electric (bottom) magnitude versus offset (MVO) data for one receiver.

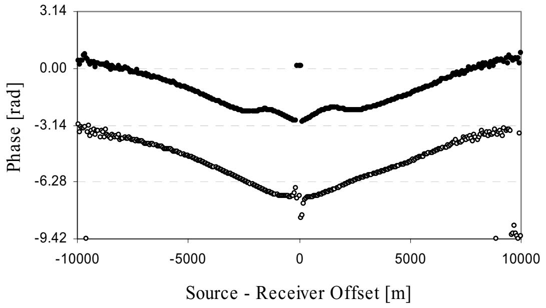


Figure 2: Electric (top) and magnetic (bottom) phase versus offset (PVO) data for one receiver.

Results

In order to compare MVO signatures along the lines, magnitudes are normalized to illustrate differences in magnitudes relative to a reference receiver. The reference receiver is primarily chosen on the basis of data quality, and normally represents MVO data from an area where subsurface hydrocarbons are unlikely to occur. The normalization process is performed by approximating a curve fit representing MVO data at the reference receiver. When normalizing MVO data for a specific receiver, the MVO data are divided by the curve fit calculated at that receiver's offset.

Electric MVO data are shown for two receivers in Figure 3. The dots represent the reference receiver. Figure 4 shows the corresponding normalized data, i.e. MVO data for both receivers have been normalized to the curve fit of the reference receiver. Magnetic MVO data are shown in Figure 5. In a similar way, the dots represent the reference receiver. Normalized magnetic MVO data are shown in Figure 6.

Figure 3 – Figure 6 illustrate MVO responses observed along the receiver lines. Receivers in a limited part of the survey area show large and systematic MVO responses relative to the reference receiver along both lines. Figure 3 and Figure 4 show 210 % increase in electric magnitudes at 6000 m offset. Figure 5 and Figure 6 show 130 % increase in magnetic magnitudes at 6000 m offset.

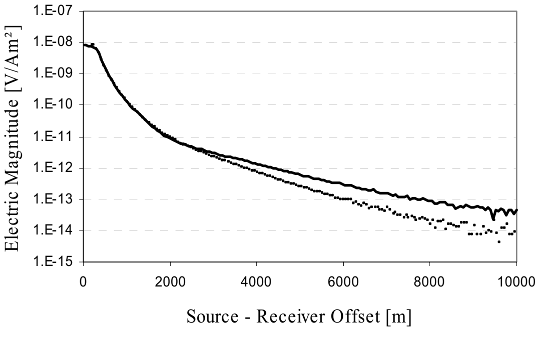


Figure 3: Electric MVO plots for two receivers; the dots represent the reference receiver.

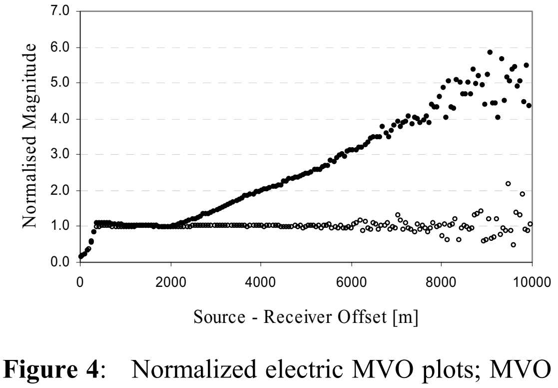
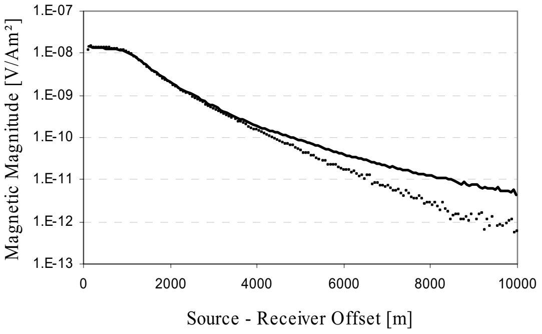


Figure 4: Normalized electric MVO plots; MVO data for both receivers are normalized to the curve fit of the reference receiver.



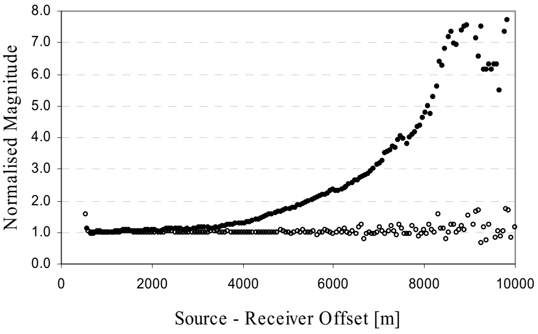


Figure 5: Magnetic MVO plots for two receivers; the dots represent the reference receiver.

Figure 6: Normalized magnetic MVO plots; MVO data for both receivers are normalized to the curve fit of the reference receiver.

Discussion

Large variations in water depth might influence the recordings significantly. A decreasing water depth will in general give a stronger signal since the air-wave is less attenuated. And even though water depth in the entire survey area is rather deep, hence only a minor contribution from the air-wave is expected, water depth variations are relatively large along the two receiver lines. However, MVO responses increase towards larger water depth.

Care must always be taken when relating MVO responses to subsurface hydrocarbons. We suggest three possible causes, plus combinations of these, for the observed MVO anomalies:

1. Deep hydrocarbon reservoirs. The prospect includes two potential reservoir levels.
2. Sill intrusions. The area is believed to also be affected by volcanic activity. Sills may have very large resistivities and might therefore affect the data significantly.
3. Shallow gas hydrates. High amplitude reflections are observed in the shallow part (seismic data).

Electric MVO responses occur at relatively short source-receiver offsets (2000 m at some receivers). At such short offsets, recordings should theoretically be dominated by the direct wave and the wave refracted at the sea bottom. Hence, recorded magnitudes should theoretically be the same for all receivers. However, experience shows that shallow resistivity variations might cause MVO responses to occur at relatively short source – receiver offsets.

The observed MVO anomalies can not be explained in terms of non-subsurface conditions. It is not sure whether the observed MVO responses are related to subsurface hydrocarbons, sill intrusions, shallow high-resistive structures or a combination of these. A full integration with geophysical data is needed in order to fully explain the observed MVO anomalies, and to possibly relate these to subsurface hydrocarbons.

Acknowledgements

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