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Improved efficiency in marine CSEM with a novel towed acquisition system

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Summary

The towed marine EM acquisition system has been under development since 2004 and two field tests were recently completed in the North Sea. Conventional CSEM is based on a small number of sparsely spaced receiver stations located on the seafloor with the source dipole towed in the water column close to the bottom. The source signal is transmitted continuously and typically consists of a square- wave, or a modified square-wave.

In the towed EM system the source bipole is towed 10 m below the sea-surface and the receiver cable is towed at a nominal depth of 100 m. The prototype system used for these tests is sufficiently powerful to work in water depths up to 400 m, with a depth penetration of 2,000 m below the seafloor. The source signal is a transient signal that can be a modified square-wave or a PRBS. All aspects of the data acquisition are monitored real time and the data is pre-processed onboard facilitating quality assurance and optimization of all acquisition parameters.

Successful field tests were completed over the Peon gas field and the Troll oil and gas field. One of the sail lines over the Troll field was simultaneously acquiring EM and seismic 2-D data as a proof of concept. The level of induced electrical noise on the seismic streamer never reached levels where it would become an issue.

A total of 615 line km were acquired over 138 hours and the data has been successfully processed and inverted to delineate all targets.

Keywords*: CSEM, marine EM, acquisition, towed EM*

Introduction

Marine controlled source EM has ever since its inception been based on a sparse grid of stationary receivers on the seafloor and a source signal transmitted continuously. An early survey is described by Ellingsrud et al. (2002). Further evaluations followed by Amundsen et al. (2004) and by Jurgen et al. (2009). The autonomous receivers contain all the recording equipment together with very accurate clocks. At the end of a survey the receivers are recalled to the surface where they are collected. The data is subsequently downloaded, quality controlled and processed.

Towed EM as described by Anderson and Mattsson (2010) offers numerous advantages over conventional CSEM:

- Improved efficiency: source and receiver towed from the same vessel.
- Operationally similar to 2-D seismic
- Real-time QC of source signal and receiver data.
- On-board pre-processing.
- Dense subsurface sampling.
- Receivers towed above the seafloor. The influence of strong local anomalies on the seafloor is minimized.
- Facilitates simultaneous acquisition of EM and 2-D seismic data.

The reason towed EM has not been available until now is that the relative movement between the receiver sensors and the seawater generates a voltage that is typically much

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larger than the signal voltage. This was a crucial issue that had to be resolved before bringing the system to the market.

The two surveys described here were acquired in the North Sea in July 2010. The Peon gas field is located very shallow in 380 m water depth and only 160 m below the seafloor. The Troll Oil and Gas Field is located in 320 –350 m water depth, with the reservoir another 1,100 – 1,200 m below the seafloor. One of the lines over Troll was acquired simultaneous with a conventional seismic streamer as a proof of concept test. Both surveys were entirely successful, and the data was processed and inverted to delineate all targets.

The towed EM system

The prototype acquisition system shown in Figure 1 below is operationally similar to marine 2-D seismic. The EM bipole source was 400 m long for the Peon survey and 800 m long for the deeper target in the Troll survey. The source strength was in both cases 800 A and the bipole was towed 10 m below the sea surface. The EM receiver cable was towed at a depth of 100 m and had offsets ranging from 500 m to 5,500 m. The conventional streamer was towed at 6 m and kept laterally separated from the EM source to minimize induction into the seismic streamer.

The first version of the commercial system to be introduced in 2012 will have 1,500 A source current. There will be 22 offsets ranging from 1,000 m to 7,300 m, and the length of the receiver dipoles will range from 50 m for the shortest offset to 1,100 m for the longest offset. When combined with a seismic streamer, it will be our de-ghosting dual–sensor seismic streamer towed at 15-20 m. In addition to offering the widest possible band-width and improved S/N, it will also increase the depth separation between the EM-bipole source and the seismic streamer further reducing the possibility of induced electrical noise in the seismic data. Maximum water depth is 400 m and the maximum nominal imaging depth is 2,000 m.

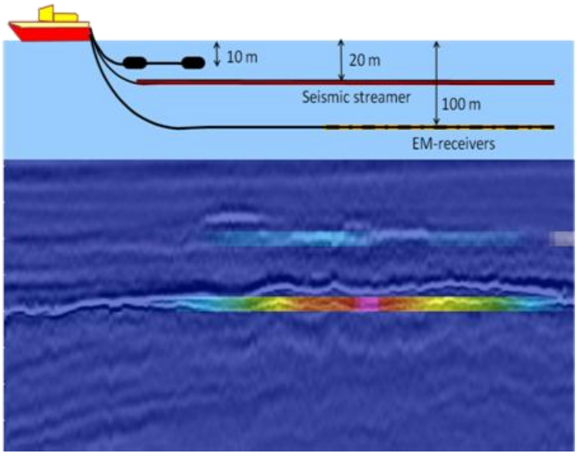

Figure 1: Schematic layout of the towed acquisition system showing the EM bipole-source, receiver cable and a seismic dual sensor streamer. A preliminary unconstrained inversion of the Peon reservoir is shown in warm colors overlain on the seismic cross-section.

Source signals of any shape can be implemented. So far we have tried the pseudo random binary sequence (PRBS), a standard square-wave, and an optimized repeated sequence (ORS), which can be described in terms of spectral content as a square-wave with the addition of the even harmonics. The spectral content of the three source signals are illustrated in Figure 2 below.

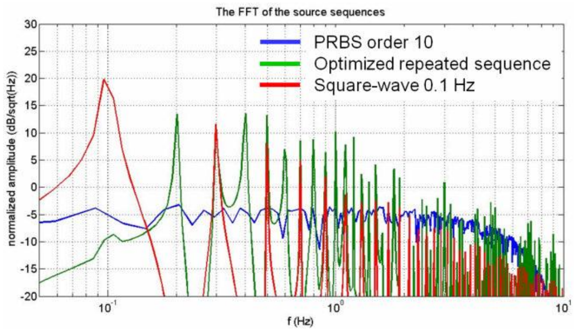

Figure 2: The three source signals tested so far: PRBS (Pseudo-random Binary Sequence), optimized repeated sequence (ORS), and a square-wave.

The acquisition parameters are shown in Table 1 below. Notice that the source length was reduced to half the nominal length for the Peon survey, since the field is so shallow. The offset range was also reduced for the same reasons.

Following deconvolution and noise reduction the amplitude and phase spectra of the measured signal were compared with the modeled signal for a range of offsets. Figure 3 below shows an example of the amplitude spectrum from the Troll West gas province (TWGP). The lines appear in modeled and measured pairs with one pair per offset. The agreement between modeled and measured data is seen to be very good.

Parameter	*Peon*	*Troll*
Source depth/length	**10/400 m**	**10/800 m**
Source current	**800 A**	**800 A**
Source waveform	**ORS**	**ORS**
Towing speed	**4 knots**	**4 knots**
Shot-point interval	**250 m**	**250 m**
Shot length	**120 s**	**120 s**
Receiver depth	**100 m**	**100 m**
Offset range	**650-3,650 m**	**2,500-5,500m**

Table 1: Acquisition parameters for the Troll and Peon Fields. Notice the shorter source length and offset range for the shallower Peon Field

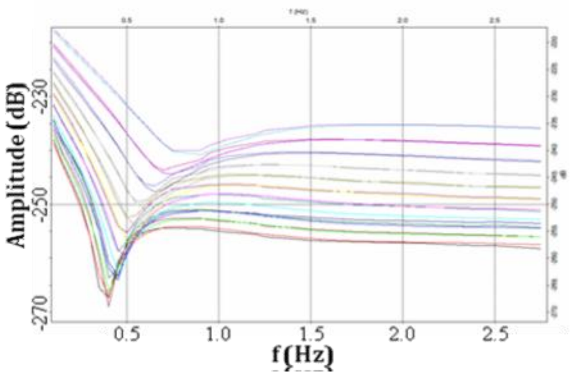

Figure 3: Amplitude versus frequency display where the modeled and the measured data appear in pairs and where each pair of lines represents one particular offset.

Figure 4 below shows the phase spectra for the same data set. Once again the lines appear in modeled and measured pairs with each pair representing a particular offset.

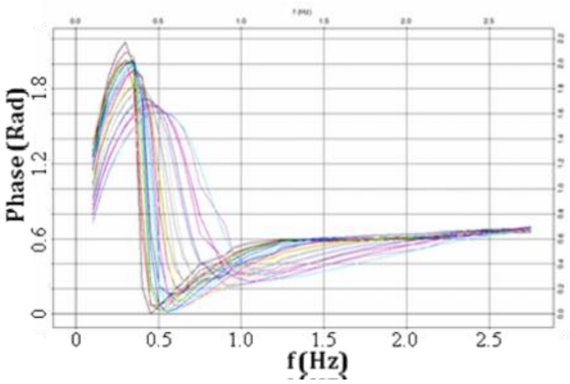

Figure 4: Phase versus frequency display where the modeled and measured data appear in pairs and where each pair of lines represents one offset.

The Peon Field

The Peon gas field is located very shallow at only 540 m below sea-level whereof 384 m is the water column. The reservoir thickness in the discovery well is 33 m with recoverable gas at the top 18.5 m followed by 9 m residual gas and a 5.5 m brine layer at the bottom. The target is easy to detect, but we wanted high quality data to confirm the inverted values of intersecting survey-lines show similar absolute values at the point of crossing, and this was confirmed. We also found there are some discrepancies between the areal extent of the field as mapped and published based on seismic data and the edge detection provided by the EM-data.

In Figure 5 below the QC result is shown for the inverted volume. A group of 10 closely spaced parallel lines were acquired to create a 3-D image of the Northern part of the gas charged reservoir. This also gives us an idea of how much spatial variation in transverse resistance can be seen within the reservoir. Then there are a set of longer acquisition lines placed along the main axis of the gas field, and one line evaluates some of the satellite deposits in close proximity to the main volume. Two of these lines also cross the two existing well locations to facilitate calibration.

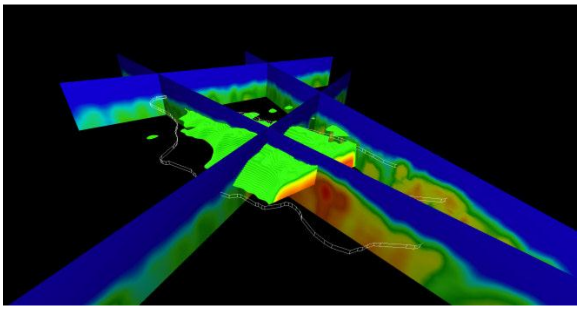

Figure 5: The Peon Field where the body in light green is the inverted 3D rendition of the transverse resistance. The four long regional lines tie the 3D volume together with the two existing well locations and also evaluate some potential satellite deposits.

The Troll Field

The Troll Field shown in Figure 6 is located in the Northern part of the North Sea. The water depths range from 320 – 350 m with the top of the reservoir around 1,100 – 1,200 m below the seafloor. The Troll West oil province (TWOP) has an oil column 22 – 26 m thick under a thin gas column. The Troll West gas province (TWGP) has a gas column up to 200 m thick over a 12 – 14 m oil column making it a much stronger target.

A suite of nine densely spaced lines were acquired to create an image in 3D. In addition there were three regional lines acquired. One of these was acquired simultaneous with 2D seismic as a proof of concept test. The potential for the source bipole to induce electrical noise in the seismic streamer was found to be an issue only if the bipole cable and the seismic streamer came in direct contact with each other. The issue was completely resolved by maintaining a vertical and lateral separation between the bipole and the streamer to render the processed seismic of expected quality.

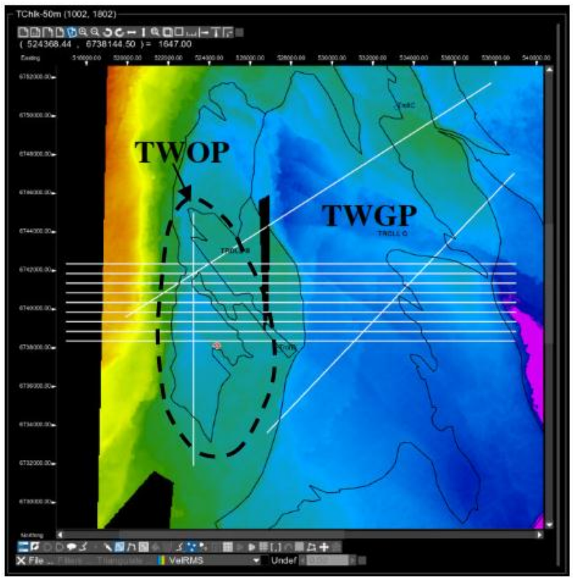

Figure 6: The Troll Field with the Troll West oil province (TWOP) encircled. The Troll west gas province (TWGP) is located to the right. There were 9 lines acquired in a closely spaced patch for 3D imaging and 3 additional regional acquisition lines. The colors are based on seismic amplitudes.

In Figure 7 below the target response is shown for one of the lines over the Troll Field as a function of offset & frequency versus shot-point for measured and modeled data. Our ability to achieve high S/N in the processed data is apparent in this side by side comparison.

The Troll West Oil Province (TWOP) is the more difficult province to image due to the lower transverse resistance (2,000 ohm-m^2) compared to the Troll West Gas Province (TWGP) where the transverse resistance reaches 6,500 ohm-m^2. The difference is due to the fact that the resistivity is lower in the oil saturated reservoir and the hydrocarbon charged reservoir thickness is also reduced in TWOP compared to the TWGP.

Figure 8 below shows the measured transverse resistance for the TWOP where the red color represents maximum transverse resistance and the dark blue the lowest transverse resistance.

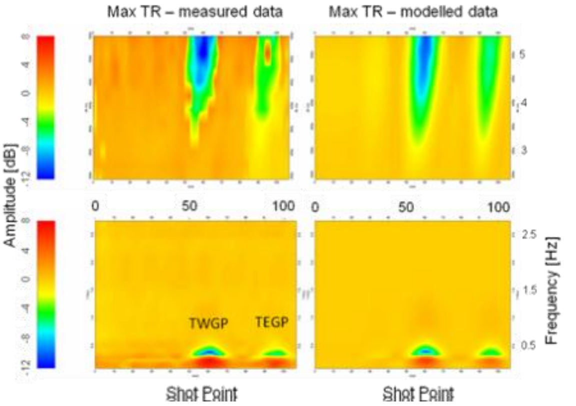

Figure 7: Maximum target response as a function of offset (above) and frequency (below) versus shot-point. Notice the excellent S/N in the processed data compared to the noise-free modeled data.

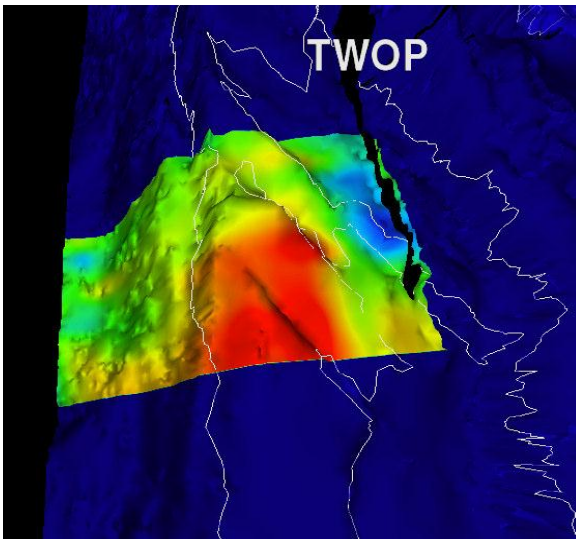

Figure 8: The transverse resistance shown in 3D based on the swath of nine lines acquired over the Troll West oil province. The maximum value is approximately 2,000 ohm-m2 represented by the red color. The underlying seismic map-view image shows the top of the Troll reservoir.

Conclusions

The two field trials were completely successful. Over a period of 138 hours of acquisition time a total of 615 line km of high quality EM was acquired. This was achieved with no Lost Time Incident (LTI) in spite of the 3.5 m high waves (sea state 5) during parts of the acquisition.

A total of 13 lines were acquired over the Peon Field, with 10 of them in parallel to facilitate 3D imaging of the target. Inversion of intersecting lines displayed similar values at the point of crossing, confirming the robustness of the inversion. The edge of the hydrocarbon charged field as defined by EM differs somewhat from the published seismic interpretation.

We believe the EM better delineates the economic limits of the field since only high gas saturations can be detected. Seismic, on the other hand, is almost insensitive to variations in gas saturation including residual gas saturation.

There were 12 lines acquired over the Troll West oil and gas provinces. Once again a swath of 9 lines was acquired in parallel to facilitate 3D imaging. Both provinces are imaged and inverted with very good results including the much weaker anomaly over the TWOP. The recovered values of transverse resistance and resistivity are in good agreement with published data.

In addition simultaneous acquisition of 2D seismic and EM was done on one line as a proof of concept.

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References

Amundsen H.E.F., Johansen S., and Rosten T., 2004, A Sea Bed Logging (SBL) calibration survey over the Troll Gas Field: EAGE 66th Conference and Exhibition, Expanded Abstracts.

Anderson C., and Mattsson J., An integrated approach to marine electromagnetic surveying using a towed streamer and source: First Break, vol 28.

Ellingsrud S., Eidesmo T., Johansen S., Sinha M.C., MacGregor L.M., and Constable S., 2002: Remote sensing of hydrocarbon layers by seabed logging (SBL): Results from a cruise offshore Angola: The Leading Edge, October, 872-982.

Jurgen J.Z., Frenkel A.M., Ostvedt-Ghazi A-M., de Lugao, P., Ridyard D., 2009: Marine CSEM methods for 3D hydrocarbon field mapping and monitoring: 11th International Congress of the Brazilian Geophysical Society.

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