Simultaneous acquisition of towed EM and 2D seismic – a successful field test

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SUMMARY

A towed marine EM acquisition system has been under development for seven years, and two field tests were recently completed in the North Sea. Traditional CSEM technology is based on sparsely spaced receiver stations placed on the seafloor and the source dipole is towed close to the seafloor. The source signal is a square-wave, or a modified square-wave, that is emitted continuously.

In the towed EM system, the source dipole is towed at 10 m below the sea-surface and the receiver cable is towed at a nominal depth of 100 m. The prototype system described here is sufficiently powerful to work in water depths up to 400 m, with a nominal depth penetration of 2,000 m below the seafloor. The 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 pre-processed on-board facilitating quality assurance and optimization of all acquisition parameters.

Two successful tests were conducted over the Peon shallow gas field and the Troll oil and gas field. One of the sail-lines over the Troll field was simultaneously acquiring EM and 2-D seismic data. By keeping the EM source and the seismic streamer separated, the level of induced electrical noise on the streamer was never reaching levels where it would become an issue.

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

Key words: CSEM, Marine EM, Transient EM, Towed EM

INTRODUCTION

Marine controlled source EM has ever since its inception been based on a sparse grid of stationary receivers placed on the sea-floor and a dipole source towed close to the sea-floor. 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 receivers contain all the signal recording equipment together with very accurate clocks. When the survey is finished, the receivers are recalled to the surface where they are collected. The data is then downloaded, quality controlled and processed.

Towed EM, as described by Anderson and Mattsson (2010), has numerous advantages:

- Improved efficiency: source and receiver towed from the same vessel.
- Operationally similar to marine seismic.
- Real time monitoring and QC of source and receiver cable.
- On-board pre-processing.
- Dense sub-surface sampling.
- Receivers towed above the seafloor. The influence of strong local anomalies at the seabed is minimized.
- Facilitates simultaneous acquisition of EM and 2D seismic.

The reason towed EM has not been available until now is that the relative movement between the receiver sensors and the seawater generate a voltage that is typically much 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 at 540 m below sea-level with 380 m water depth. The second survey was over the Troll Oil and Gas field where the water depth is 320 – 350 m and the target depth is around 1,100 – 1,200 m below mud-line. Both surveys were successful and the data was processed and inverted to delineate all targets.

THE PROTOTYPE TOWED EM SYSTEM

The acquisition system shown in Figure 1 below is operationally similar to 2D seismic. The EM dipole source was 400 m long for the Peon survey and 800 m long for the Troll survey. The source strength was in both cases 800A and the dipole was towed 10 m below the sea surface. The EM receiver cable was towed at a depth of 100 m and had offsets from 2,500 m to 5,500 m. The conventional seismic streamer was towed at 6 m.

The commercial system to be introduced in 2012 will have 1,500A source strength, and the receiver offsets will range from 500 m to 8,000 m. When combined with seismic the streamer will then be our de-ghosting dual-sensor seismic streamer towed at 20 m. In addition to offering widest possible bandwidth and improved S/N, it will also increase the depth separation between the EM-dipole source and the seismic streamer further reducing the possibility of induced electrical noise in the seismic data.

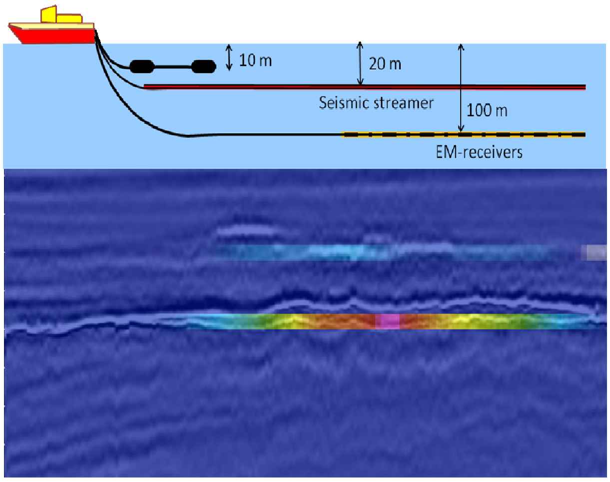


Figure 1. Schematic layout of the towed acquisition system showing the EM dipole-source, receiver-cable and the seismic streamer. A preliminary unconstrained inversion of the Peon reservoir is shown by warm colours in the subsurface.

Any kind of source signal 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.

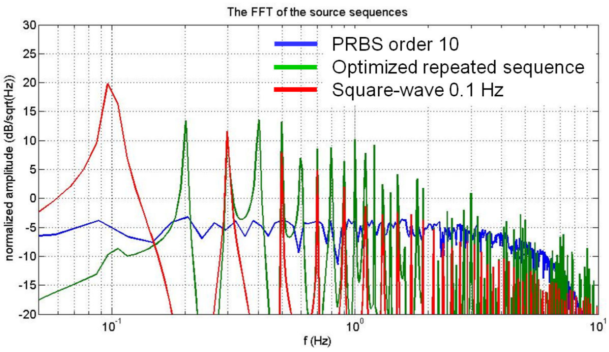


Figure 2. The three source signals tested so far: PRBS (Pseudo-random Binary Sequence), optimized repeated sequence (Custom), and a square-wave.

The towing speed was 4 knots and 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.

Following deconvolution and noise reduction the amplitude and phase spectra of the measured signal were compared with the modelled 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 modelled and measured pairs with one pair per offset. The agreement between modelled and measured data is very good.

Parameter	*Peon*	*Troll*
Source depth/length	**10/400 m**	**10/800 m**
Source current	**800 A**	**800 A**
Source waveform	**ORS**	**ORS**
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. Nominal towing speed was 4 knots.

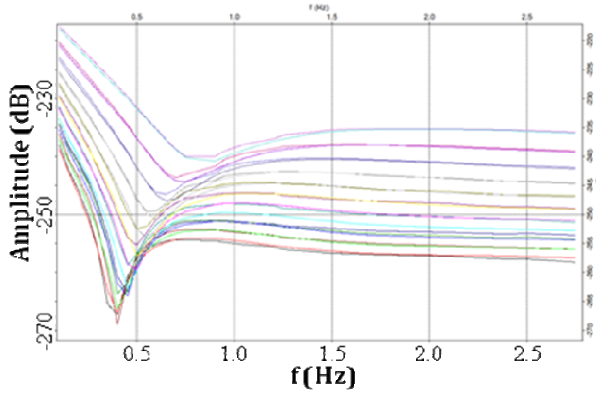
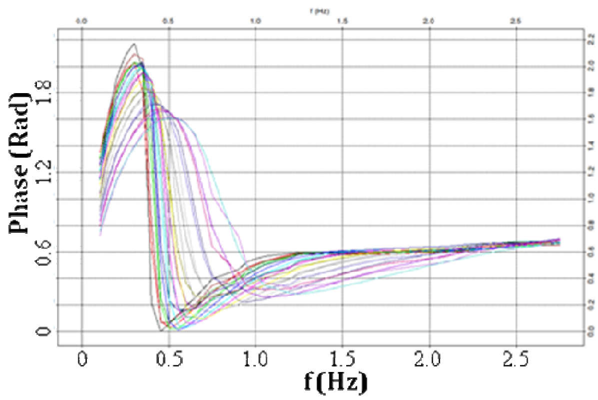


Figure 3. Amplitude versus frequency display where the modelled and measured data appear in pairs and where each pair of lines represents one offset.

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



Fiure 4. Phase versus frequency display where the modelled 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 depth. 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 that there are some differences between the areal extent of the field as mapped and published based on seismic data and the edge detection defined 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 3D 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 investigates some of the potential satellite deposits in close proximity to the main volume. Two of these lines also cross the two existing well locations to facilitate calibration.

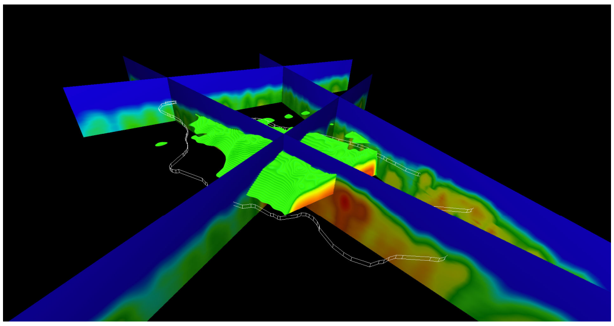


Figure 5. The Peon Field where the body in light green is the inverted 3D rendition of the transverse resistance. The four long regional lines tie the 3D volume together with the two existing well locations and also evaluate some potential satellite deposits.

THE TROLL FIELD

The Troll Field is located in the northern part of the North Sea, Figure 6. The water depths range from 320 – 350 m with the top of the reservoirs around 1,100 – 1,200 m below mud-line. 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 9 densely spaced lines were acquired to create an image in 3D.

In addition there were three regional lines acquired. One line was acquired simultaneous with 2D seismic as a proof of concept. The potential for the source dipole to induce electrical noise in the seismic streamer was found to be an issue only if the dipole 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 dipole and streamer and the processed seismic is of expected quality.

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 modelled 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 field 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 charged reservoir thickness in TWOP is also reduced compared to the TWGP.

Figure 8 shows the measured transverse resistance for the TWOP where the red colour represent maximum transverse resistance and the dark blue the lowest transverse resistance.

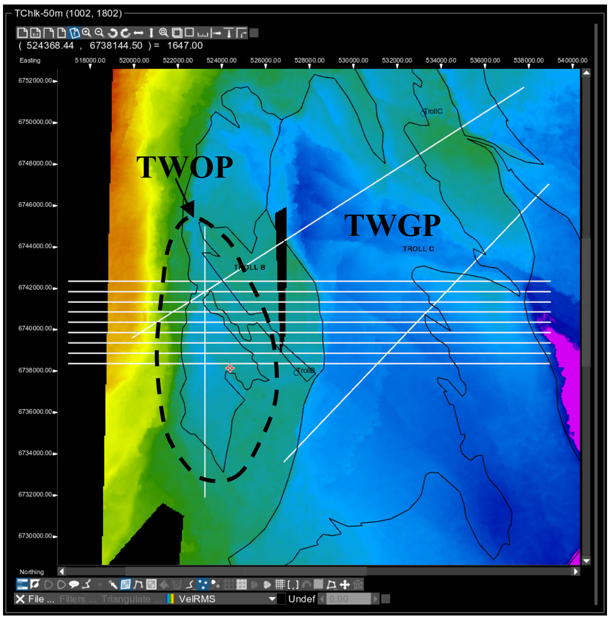


Figure 6. The Troll Field with the Troll West oil province (TWOP) encircled. The Troll west gas province (TWGP) is located to the right. There were 9 lines acquired in a closely spaced patch for 3D imaging and 3 additional regional acquisition lines. The colours are based on seismic amplitudes.

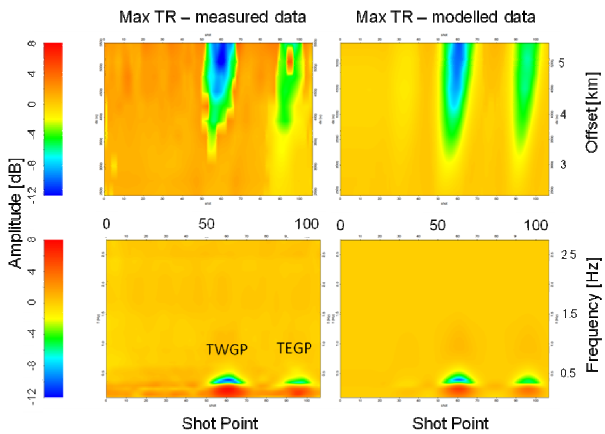


Figure 7. Maximum Target response as a function of offset (above) & frequency (below) versus shot-point. Notice the excellent S/N in the processed data compared to the noise-free modelled data.

CONCLUSIONS

The two field trials were completely successful. Over a period of 138 hrs of acquisition time 615 line km of high quality EM data was acquired. This was achieved with no Lost Time Incident (LTI) in spite of 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 in sufficient proximity to facilitate 3D imaging of the target. Inversion of intersecting lines displayed similar values at the point of crossing, confirming that the inversions are robust. The edge of the field as defined by the EM differs somewhat from the published seismic interpretation.

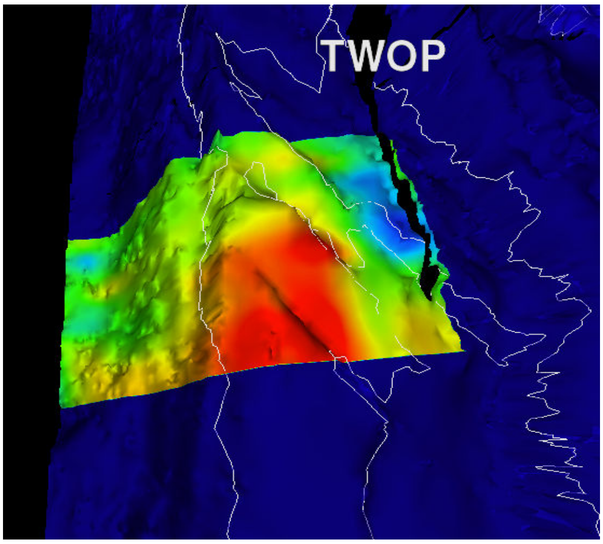


Figure 8. The transverse resistance shown in 3D based on the swath of 9 lines acquired over the Troll West oil province. The maximum value is approximately 2,000 ohm-m^2 represented by the red colour. The underlying seismic map-view image shows the top of the Troll reservoir.

We believe the EM better delineates the economic limits of the field since only high gas saturation 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 9 lines were acquired in parallel to facilitate 3D imaging. Both provinces are imaged and inverted with very good results including the much weaker anomaly of the TWOP. The recovered values of transverse resistance and resistivity are in good agreement with published data.

We also successfully acquired 2D seismic and EM simultaneously as a proof of concept.

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