TECH TALK

Towed Streamer EM - Resistivity in Context

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INTRODUCTION

Controlled Source Electromagnetic (CSEM) data acquisition systems have historically been based on the sea floor node method. Receiver nodes are deployed on the seabed and record data generated from an EM dipole source towed behind a vessel. Such a method is inherently inefficient and in order to improve the cost-effectiveness of acquisition, a sparse grid of nodes is generally used. This lack of data density can adversely affect the quality and resolution of the final data. It was these challenges, alongside PGS' pioneering attitude and expertise in high tech marine engineering which inspired the development of a Towed Streamer EM system.

This system was specified to acquire data at the same speed as towed streamer seismic (4-5 knots), as well as to overcome the challenge of sparsely sampled data resulting in low resolution resistive anomalies. To ensure maximum efficiency when acquiring Towed Streamer EM data, the whole system was designed to be deployed from the same vessel as a GeoStreamer®; enabling the acquisition of both dual-sensor broadband seismic and high density Towed Streamer EM data simultaneously. PGS anticipates being able to deploy a full 3D GeoStreamer seismic spread simultaneously with Towed Streamer EM in the future.

Not only does this approach save time and keep acquisition costs to an absolute minimum through the use of only a single vessel to acquire two complimentary datasets but it sets the scene for seamless and timely detailed integration of Towed Streamer EM and GeoStreamer data.

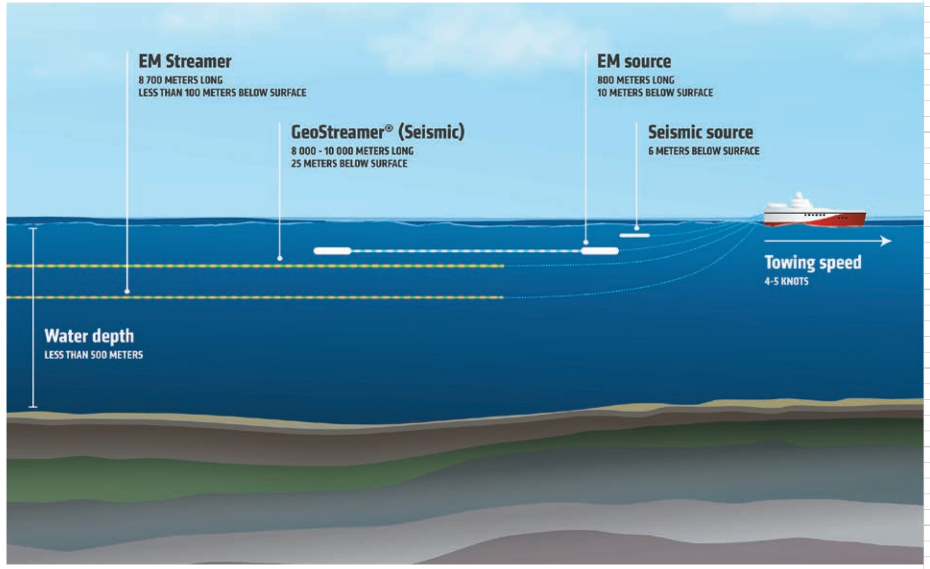

FIGURE 1: *A typical simultaneous Towed Streamer EM and GeoStreamer acquisition setup.*

There were some challenges to overcome with this design brief; it was believed by some that it was impossible to engineer a Towed Streamer EM system due to the fact that when a receiver electrode pair is moving in the earth's magnetic field, a noise voltage will be generated that is likely to exceed the recorded signal-voltage originating in the resistivity variations in the subsurface. This particular problem was overcome by designing an acquisition system with an exceptional signal to noise ratio using varying length receiver bi-poles; again the value of high density EM data is clear.

PGS' Towed Streamer EM system is designed to operate in shallow water (see Figure 1); up to 500 m water depth with the ability to accurately recover sub-surface resistivity to a depth of 2,500 – 3,000 m below the mud line. The system can recover sub-surface resistivity in deeper water depths, but signal penetration and sensitivity to resistivity variations in the sub-surface is reduced.

To ensure our client's confidence in our ability to accurately recover sub-surface resistivity in a particular setting PGS conducts feasibility studies prior to acquisition.

A typical feasibility study involves forward modelling of various water depths, target depths, target sizes and resistivity scenarios, followed by inversion of the synthetic data which has been created.

By conducting such tailored feasibility studies PGS ensures client confidence in the suitability of our technology to their specific survey.

Case Study

EFFICIENT EM ACQUISITION IN THE BARENTS SEA

PGS has acquired MultiClient EM data in the Barents Sea every year since 2013, starting with a simultaneous 2D EM and GeoStreamer survey in 2013, progressing to a large scale high density 3D EM survey in 2014, with further 3D EM being acquired in the Barents Sea Southeast at the time of writing.

During the 3D EM 2014 survey PGS acquired high density Towed Streamer EM data with an average acquisition speed of 4.6 knots. The line spacing was 1.25 km, resulting in an average daily production of 150 sq km, on one day production reached 250 sq km in a single 24 hour period. This accomplishment of acquiring almost 12,000 sq km of high density 3D EM data in less than four months was achieved while conducting crew changes in port as the third party vessel used didn't have helicopter landing capability.

Case Study

DATA DENSITY AND EFFECT ON SENSITIVITY AND PENETRATION

As alluded to earlier, when attempting to accurately invert CSEM data it is critical to have a high density dataset to input to the inversion process, especially to achieve high resolution accurate models of the sub-surface resistivity with strong sensitivity at depth.

Figure 2 shows the results of three seismically guided 2.5D inversions; one using PGS' standard 250 m EM shot spacing, one with every second shot (500 m spacing), and a final where we have only included every fourth shot in the inversion (1,000 m shot spacing). The results are clear; the higher the data density, the more accurate the recovery of the sub-surface resistivity, especially at depth.

PGS' EM streamer is designed with 72 offsets (electrode pairs), these range in length from 200 m at the near offsets to 1,100 m at the far offsets. It is this in-line shot density and high number of varying length receivers which ensure PGS' Towed Streamer EM delivers high resolution, accurate inversion results and such high sensitivity (see Figure 3).

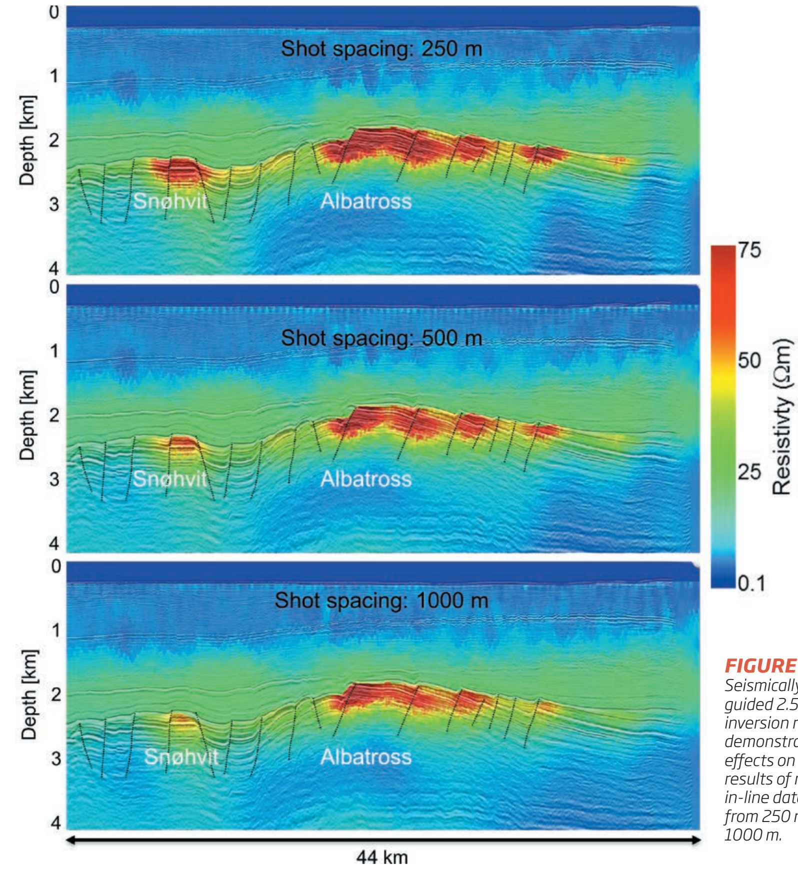

FIGURE 2: *Seismically guided 2.5D inversion results demonstrating the effects on inversion results of reducing in-line data density from 250 m to 1000 m.*

INVERSION AND INTEGRATION

PGS' standard 2.5D EM deliverables are Frequency Responses (navigation merged, de-noised field data) and unconstrained 2.5D sections generated using the parallel adaptive finite element MARE2DEM code. PGS starts the 2.5D inversion process with a value assigned to a half space, in the Barents Sea this value is typically between 5-20 ohm m. One result of acquiring such dense data when using the Towed Streamer EM system is that altering this initial value doesn't have a significant effect on the final output of the inversion. The only significant impact resulting from varying this starting value is the number of iterations the inversion has to run before it reaches the final model, the closer the initial value is to reality, the fewer iterations required.

By performing unconstrained inversion of the Towed Streamer EM data to determine sub-surface resistivity PGS aims to extract the maximum possible value from the data prior to considering any constraints on the solution. The 2.5D inversions (unconstrained and seismically guided) are undertaken

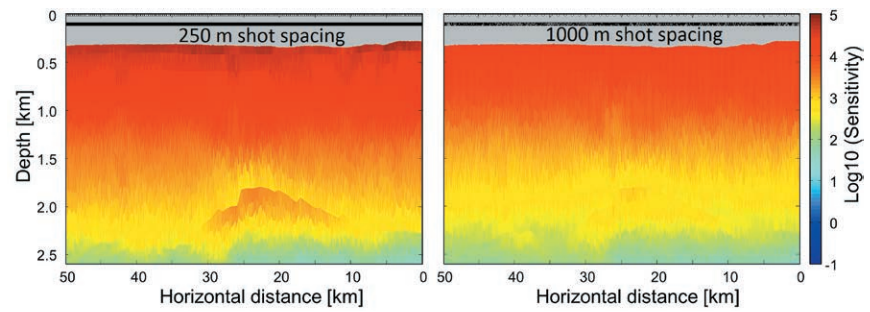

FIGURE 3: *Plot showing sensitivity variation with respect to in-line data density. Note the significantly increased sensitivity when utilising a high in-line shot density compared to a lower shot density, particularly at depth.*

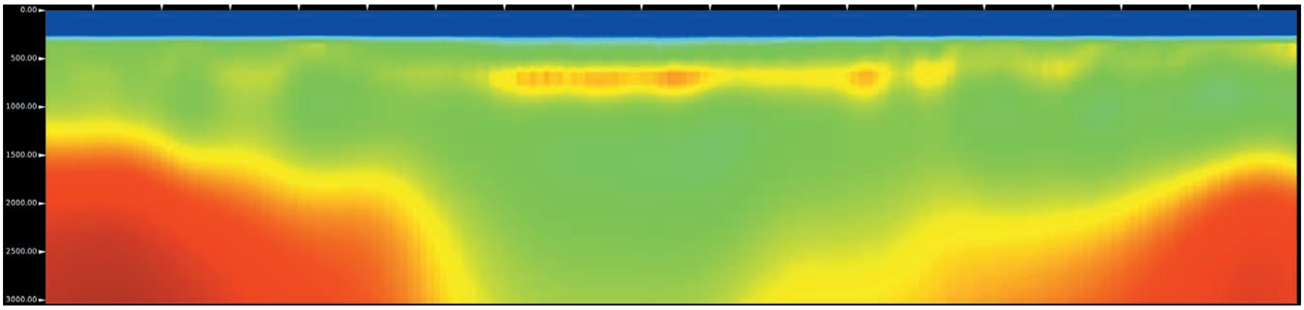

FIGURE 4: *Resistivity determined from unconstrained anisotropic inversion of data in the Barents Sea Southeast as a 2.5D section.*

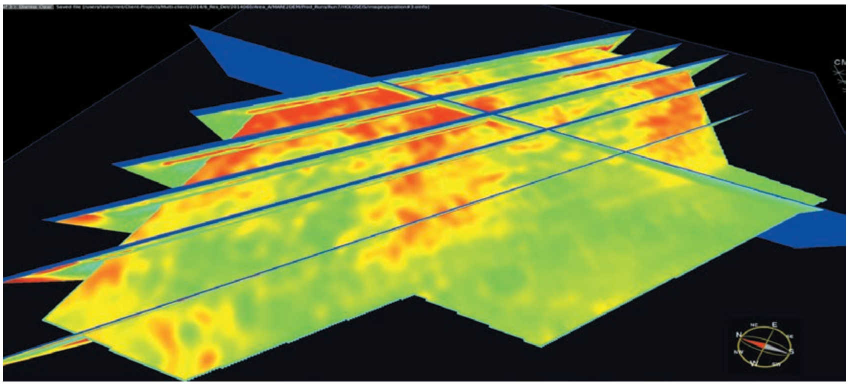

FIGURE 5: *Unconstrained 3D inversion (depth slice) from the 2014 high density 3D EM acquisition in the Barents Sea Southeast with selected 2.5D sections overlain, area shown is ~5,000 sq km.*

by PGS' specialist EM Imaging and Interpretation group in Oslo. In the event that 3D EM data has been acquired (with a Towed Streamer line spacing of 1.5 km or less) the 3D unconstrained inversion can be performed in parallel by TechnoImaging in Salt Lake City, as well as a tertiary standard deliverable this process provides an independent QC of the inversion process at an early stage (see Figure 5).

SEISMICALLY GUIDED INVERSION

To improve the resolution of the EM data; seismic horizons (or other geophysical data) can be used to guide the inversion (see Figure 2). This guiding is softer than the traditional constrained inversion, the inversion is allowed to anticipate a significant change in resistivity at a certain horizon, but remains free to populate the cells in the inversion above this horizon in a manner which best fits the model.

While guided inversion can improve the resolution unconstrained inversion remains a high value product, especially when interpreted in conjunction with dual-sensor broadband GeoStreamer data. Unconstrained inversion can highlight potential prospective structures identified on the seismic.

Seismically guided anisotropic 2.5D inversion of Towed Streamer EM data significantly improves the lateral and vertical resolution of resistivity anomalies, adding further value to the complementary seismic and EM data through integration of the two.

Outside the box -Innovative Applications of Towed Streamer EM

QUANTIFICATION OF SHALLOW GAS SATURATIONS

Consider an area with a large number of 3D seismic identified shallow amplitude anomalies, in the Southern North Sea for example; these may be associated with potential gas fields. One challenge when ranking these prospects comes from the lack of data available to analyse their potential gas saturation levels; this could mean the difference between commerciality and non-commerciality of a field. Towed Streamer EM enables significant de-risking of gas saturation levels pre-drill by providing an estimate of gas saturation of each anomaly. Highly efficient acquisition with 1km line spacing would provide dense EM data which can be inverted in 2.5D sections as well as a 3D volume, safely, quickly and cost effectively.

DRILLING HAZARD ID AND CHARACTERISATION

Towed Streamer EM has been shown to be sensitive to a vertical resolution of down to one meter in the very shallow sub-surface as a result of the density of data acquired through a rich range of offsets and frequencies. This means that the technology can be employed to identify, characterise and monitor changes over time in shallow gas in the over-burden of a production field, significantly reducing drilling hazards.

ESTIMATING HYDROCARBON VOLUME IN PLACE

PGS is developing a new integrated workflow which has been demonstrated to use seismic, well log and Towed Streamer EM data to accurately estimate total hydrocarbon volume in place. Work is ongoing on this project and PGS anticipates publishing a detailed paper soon.

CONCLUSION

When acquired, interpreted and integrated with seismic the maximum value can be extracted from Towed Streamer CSEM data. This makes it a highly cost effective method to de-risk frontier areas, improve well location decisions, provide drilling hazard identification and monitor changes in gas saturation over time. The key differentiators of Towed Streamer EM over traditional acquisition methods are acquisition efficiency and the dramatic increase provided in data density; resulting in cost effective and accurate mapping of sub-surface resistivity.