JOSHUA MAY, PGS, DETAILS A NEW APPROACH TO THE ACQUISITION AND INTEGRATION OF COMPLEMENTARY DATA, WHICH IS DESIGNED TO PROVIDE IMPROVED DRILLING SUCCESS RATES.

DELIVERING *INCREASED* CSEM DATA DENSITY

The motivation to develop Towed Streamer EM technology was twofold; to improve CSEM data acquisition rates while increasing the sample density of the acquired data. Improving not only acquisition rates but also EM imaging and resolution has simultaneously reduced the cost of acquiring 3D CSEM while increasing its value. PGS first commercially deployed the Towed Streamer EM system during the days of over US$100 oil. With the drop in the oil price over the intervening years, this acquisition efficiency and high-resolution data have only become more valuable to the explorationist. This article will discuss operational and technical advantages of Towed Streamer EM acquisition using real world data and examples. The aim is to provide an objective summary of how Towed Streamer EM can assist in exploration risk reduction and to demonstrate the value of its application at various stages of the E&P lifecycle.

Historically, the majority of marine CSEM surveys have been acquired using sea floor node acquisition techniques. Node acquisition is inherently inefficient and involves an unavoidable trade-off between node (and consequently data) density and time spent acquiring the survey. Sparse node spacing allows a higher square kilometre acquisition rate, but the density of the data, and therefore the resolution, will be limited. PGS' Towed Streamer EM technology offers a dramatic reduction in comparable survey acquisition duration while simultaneously providing a higher density dataset, rich in both frequencies and offsets. This enables oil companies to acquire large areas of high density 3D CSEM data quickly and cost-effectively, improving screening of large areas and allowing for rapid high grading of leads. For example, PGS acquired over 15 000 km^2 of high-density 3D CSEM data in the Barents Sea over just two seasons (Figure 1).

Operations – increase coverage while reducing exposure

Towed Streamer EM can be acquired in two operationally distinct ways; simultaneously with 2D dual-sensor GeoStreamer® seismic or over existing or planned 3D seismic in EM only mode.

In contrast to streamer seismic, both 2D and 3D Towed Streamer EM projects are acquired using a single EM streamer. A line spacing of 1.5 km or less allows for anisotropic inversion of both 2.5D resistivity sections (one per sail line) and a 3D resistivity volume. Projects with a line spacing of greater than 1.5 km are considered 2D with resistivity sections generated from 2.5D inversion (Figure 2).

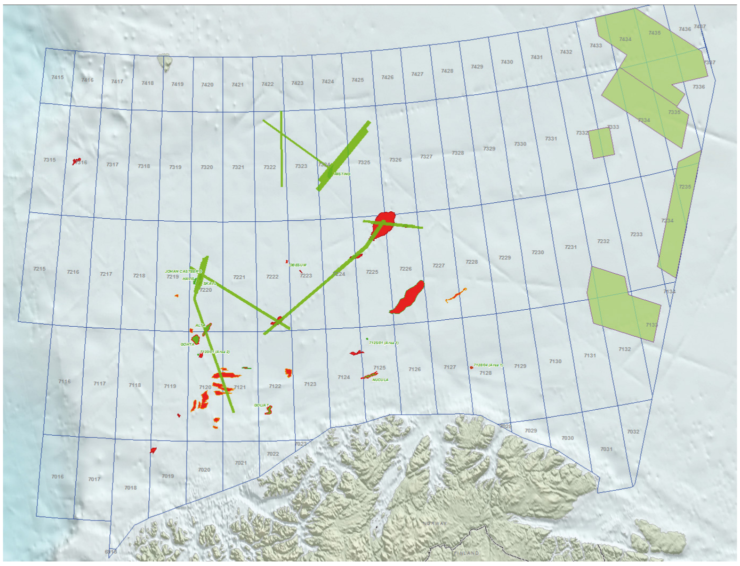

Figure 1. *Coverage map showing 2.5D and 3D Towed Streamer EM data in the Barents Sea.*

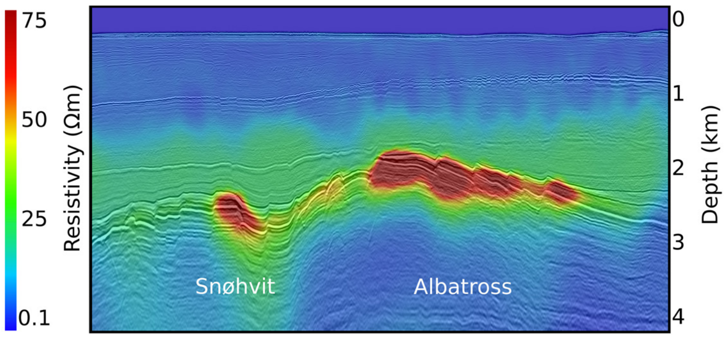

Figure 2. *2.5D seismically guided resistivity section showing Snøhvit and Albatross fields in the Barents Sea.*

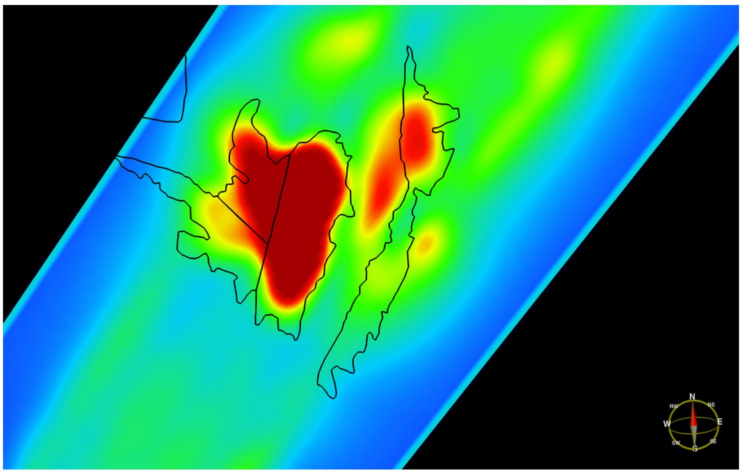

Figure 3. *Depth slice from unconstrained anisotropic 3D inversion showing Wisting (Barents Sea) at 700 m.*

The system is designed to operate in shallow water (Figure 4); in water depths of up to 500 m, sub-surface vertical resistivity is accurately recovered to a depth of 3000 m below the mud line, and horizontal resistivity up to 6000 m below mud. The system can operate in deeper water depths but signal penetration and sensitivity to resistivity variations in the sub-surface is reduced. Vertical resistivity is well suited to imaging thin resistive layers in the sub-surface, such as hydrocarbon reservoirs, whereas horizontal resistivity lends itself to imaging large regional resistivity variations. The interpretation of both vertical and horizontal (and the anisotropic ratio of the two) is key to fully understanding the information provided by CSEM data. Anisotropy is particularly useful in areas of relatively low contrast between target and background resistivity, as subtle changes in resistivity can be seen more clearly on plots of relative anisotropy where the background trend has effectively been removed. Efficient acquisition of significant volumes of CSEM data using a towed streamer further ensure a more accurate picture of the sub-surface is gained as imaging and interpreting resistive anomalies requires an accurate understanding of the background resistivity. The large survey areas, which can be acquired cost-effectively using Towed Streamer EM, enable resistive anomalies to be interpreted in the context of this background resistivity, enabling more subtle anomalies to be considered. Large-scale resistivity information is complementary to seismic data; it is recommended that the two be interpreted together in order to extract the most value from each. This integrated interpretation of independent-yet-complementary attributes provides the explorationist with a more robust understanding of geology and the sub-surface when compared to interpreting a single dataset.

The simultaneous acquisition of 2D GeoStreamer seismic (Figure 4) and resistivity data provides two complementary datasets from a single vessel. This is exceptionally efficient because acquisition speed is the same as streamer seismic, providing cost-effective sub-surface imaging with the added environmental benefit of a reduced operational footprint via lower fuel consumption and reduced vessel days on prospect. The survey permitting process can also be simplified (when compared to acquiring seismic and EM data as separate projects), as fewer vessel days on prospect means the likelihood of multiple extended line changes for fishing, for example, is reduced.

Data density

The EM streamer has 72 offset pairs, ranging from 200 m in length at the near offset to 1100 m at the far offset; thus providing dense resistivity data including a wide range of offsets from the source. On the source side, PGS also acquires a dense dataset, particularly rich in frequencies. In a standard EM acquisition setup, PGS turns the EM source on for a period of 100 seconds, during which a range of frequencies from 0.1 to 10 Hz is cycled through, followed by a listening period of 20 seconds (similar to noise records in seismic). This high density, frequency rich dataset comprising a broad range of offsets enables the optimisation of data selection for inversion. These parameters can be evaluated during the planning phase of a project, ensuring selection of the frequencies and offsets, which will be most appropriate to image the target in question. Different frequencies and offsets may be selected for a small, thin and shallow target compared to, for example, a deeper target with a higher transverse resistivity. It is this density of data that provides improved resolution in resistivity profiles and volumes and enables detailed reservoir level QI workflows to be conducted.

Ensuring appropriate application

PGS considers it imperative only to employ Towed Streamer EM in areas where the technology is both operationally appropriate and will assist customers in exploration decision-making. When a proposed project or target pushes the operating parameters outlined above, the company undertakes EM feasibility studies, the process for which is outlined in Figure 5.

Inversion and imaging

PGS uses two distinct codes for 2.5D and 3D inversion; the 2.5D code (MARE2DEM) was developed through the Scripps Seafloor Electromagnetic Methods Consortium, and is freely available for oil companies to use themselves. There are various 3D codes that can be used to invert Towed Streamer EM data, both PGS and third party. The aim is to follow an open and well-understood process when inverting the data to ensure customers and end users have confidence not only in the field data but the processed and inverted deliverables too. To this end, the company works closely with customers and provides misfit information between measured and modelled data as a standard deliverable.

A further level of confidence in the sub-surface resistivity model determined from Towed Streamer EM data is the lack of dependence on an inversion start model: a homogenous half space is employed as the inversion start model as standard. Unconstrained inversion is a data driven iterative process, where no *a priori* information is used, a single half space value is assigned to the background and the inversion is allowed to converge on the best fit model. The inversion will eventually converge to the same final model, even if an inaccurate half space value is initially assigned. This is in contrast to more sparse data acquisition techniques, which can be start model dependent. Consider the value of being insensitive to the start model and associated confidence in the accuracy of inversion results when imaging in a frontier area that may be hundreds of miles from the nearest well control.

After the unconstrained inversion has been conducted, PGS conducts seismically guided inversion, where typically between one and five horizons can be included in the model. Seismically guided inversion can increase the resolution of the resistivity, as well as improve the data misfit, and is the next stage in integrating seismic and resistivity data.

This integration can be taken further; workflows have been designed to integrate seismic and resistivity data to estimate hydrocarbon saturation, and even, with the inclusion of rock physics models and well logs, the hydrocarbon volume in place index.

Applications

Traditionally, CSEM has been associated with de-risking prospects in a frontier exploration setting, but with the increase in data density and volume of data enabled by Towed Streamer EM this assertion is being challenged and higher resolution applications have become viable. Through integration of seismic and resistivity data the ability to estimate hydrocarbon saturation has application in mitigating drilling hazards as well as widening the focus of CSEM from pure exploration to appraisal and production well placement decisions. Considering the reservoir characterisation resolution there is even potential for integrated seismic and EM data to be applied in a 4D sense in appropriate environments. Near field exploration is of particular interest to oil companies at present, potentially enabling not only an increase in reserves but also an extension to asset life and the delay of decommissioning. With existing 3D seismic over producing fields, acquiring and interpreting Towed Streamer EM over high potential near field prospects can be a cost-effective way of prolonging field life and reducing production cost per barrel.

PGS' Towed Streamer EM system resulted in a step change in CSEM acquisition efficiency in conjunction with dramatically improved sampling density; expanding application from frontier exploration to more detailed reservoir imaging and characterisation. When acquired, interpreted and integrated with seismic, the maximum value can be extracted from Towed Streamer EM data. This makes it a cost-effective method to improve well location decisions, provide drilling hazard identification and reduce frontier exploration risk. 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 to complement seismic data.

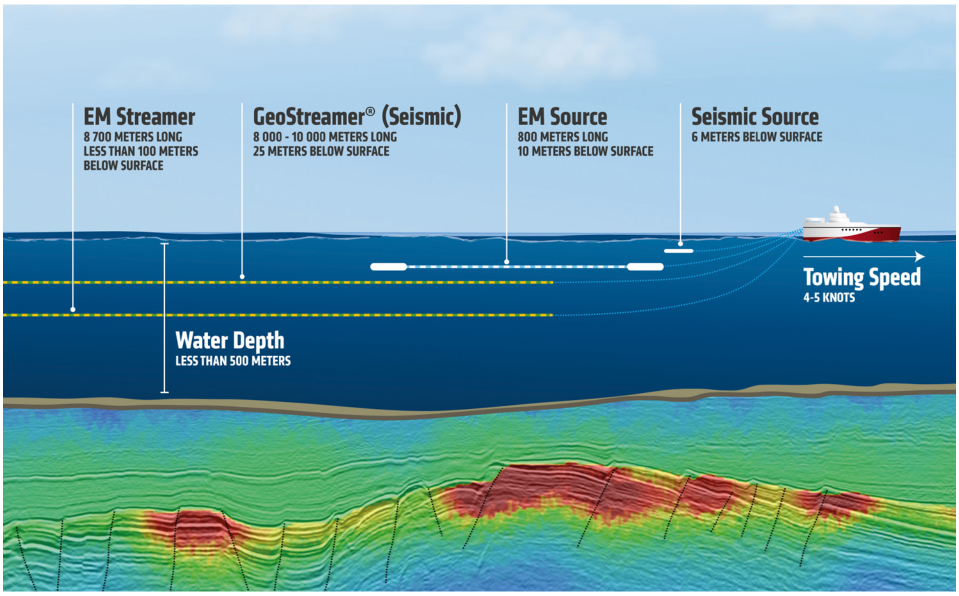

Figure 4. *Schematic showing simultaneous acquisition of 2D GeoStreamer and EM.*

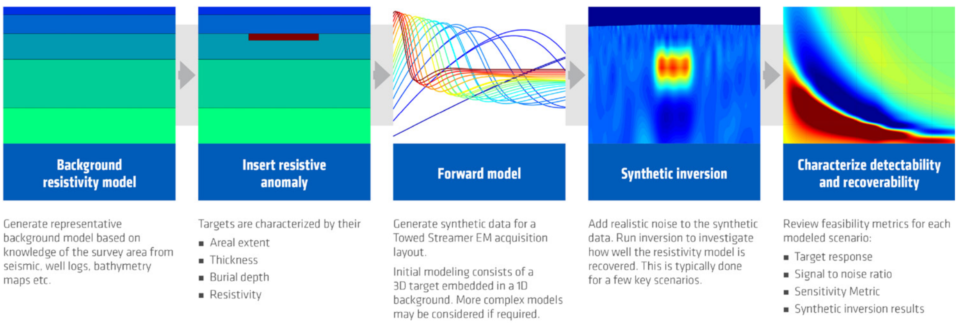

Figure 5. *Towed Streamer EM feasibility study principle and workflow.*