Ocean bottom seismic: strategic technology for the oil industry

Kim Gunn Maver[*] illustrates how ocean bottom seismic methods (with the emphasis on OBC) provide improved seismic imaging compared with towed streamer seismic methods for certain applications and can be expected to benefit from increased industry take-up in the future.

Seafloor seismic data acquisition can be applied to many seismic and geological challenges and improve reservoir characterization and management. 2D, 3D, and 4D towed streamer surveys dominate offshore seismic survey acquisition using proven technology to achieve narrow azimuth coverage. To overcome some of the limitations new techniques such as single sensor recording, over-under, and wide-azimuth acquisition streamer data have recently delivered impressive results, but also raised the cost and complexity of streamer survey operations.

However, by placing sensors on the seafloor and decoupling the source and receiver, the acquisition lay-out and equipment can offer a number of significant advantages over towed streamer acquisition in some important exploration and production applications. This is the solution provided by ocean bottom seismic (OBS) a well established technology which resolves many of the known limitations of towed streamer seismic.

OBS is increasingly emerging as a strategic technology, confirmed by Davies et al. in a recent presentation. It was highlighted that ocean bottom cable seismic had made it possible for BP to significantly de-risk wells and improve the recovery factor through better imaging.

Of the OBS technologies OBC is the most mature in terms of testing and usage. More recently ocean bottom nodes (OBN) have begun to gain some traction. This paper reviews OBS technology and its many applications. Permanent reservoir monitoring (PRM) systems are not discussed.

OBS technologies

OBC utilizes seismic sensors connected using a steel cable which are either deployed as a number of short 6–12 km cables or as a few longer cables up to 72 km in length. Most cable-deployed systems require a dedicated recording vessel linked directly to the cables, which increases the number of vessels required for data acquisition. The VectorSeis Ocean (VSO) system from ION is an exception in that all data is recorded in an autonomous buoy for each cable. This makes it possible to retrieve data without having to recover the cable (Figure 1). The different types of cable-based systems

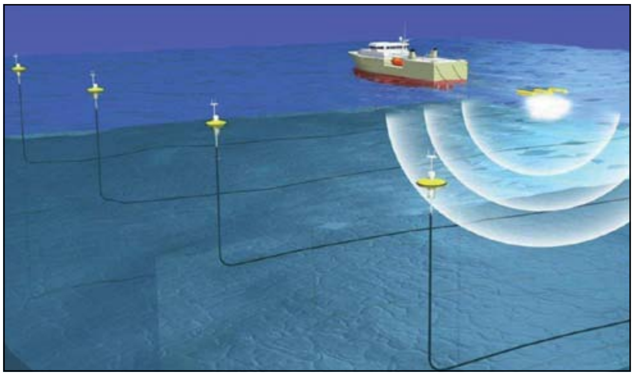

Figure 1 *Autonomous OBC system (VectorSeis Ocean) using cables connected to a buoy for power generation and data recording.*

can typically be deployed from 10–1000 m, however systems are under development for deployment down to 2000 m.

OBN utilizes individual seismic sensors and autonomous recording units placed on the seafloor. Each node has recording facilities and a battery. The battery life determines how long the system can be deployed without being retrieved and recharged. With improvements in battery life this issue is becoming less significant. Down to less than 1000 m the autonomous nodes can be deployed via simple, high-tensile strength rope, which provides an efficient and cost effective operation. In deep water the nodes are deployed at relatively coarse intervals (typically on a 400 m x 400 m receiver grid) using a remotely operated vehicle (ROV) for the deployment. This technique has only been commercially applied for a limited number of deep water surveys and in very heavily obstructed survey areas. Autonomous nodes can be a single vessel operation.

The OBS approach offers benefits compared to streamer data which is dependent for recording on hydrophones only embedded in the streamer cable. OBS systems deploy multi-component sensors: these can be two component (2C), which consist of one hydrophone and one geophone or accelerometer, or four component (4C), which is one hydrophone and three orthogonal geophones or accelerometers placed on the seafloor.

Hydrophones detect pressure which is a scalar quantity, i.e., there is no direction associated with the measurement.

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Thus the output from a hydrophone has the same polarity (is positive or negative) for a pressure wave travelling up from a subsurface reflector as for a pressure wave reflected down from the sea surface.

Geophones or accelerometers detect ground motion velocity or acceleration, which are vector quantities, i.e., there is a direction associated with the measurement. Thus the output from a geophone or accelerometer has a different polarity depending on whether the ground motion is due to a wave reflected up from a subsurface reflector or down from the sea surface.

Acquiring 4C OBS provides a compressional (PP) data volume and converted shear wave (PS) data volume. The PP data consists of a down going compressional wave that is reflected and recorded as a compressional wave at the seafloor. The PS data consists of a downgoing compressional wave that is converted and reflected as shear wave and recorded at the seafloor (also called a converted shear wave).

Applications of OBS

OBS data, therefore, offer a range of benefits ranging from acquisition flexibility, to the basic quality of the seismic data, and finally the possibility of extracting rock and fluid properties.

Obstructed areas

The obstructed nature of most offshore production areas restricts the application of towed streamer surveys. Ironically this is especially true with the increasing number of streamers being used for efficient coverage and with the need for longer offsets to improve subsurface resolution and to image deeper targets.

OBS is suited for acquisition in obstructed areas as both cables and nodes can be placed close to subsurface and surface infrastructure providing a better data coverage and reducing the need for undershooting (Figure 2).

Cooke et al. (2011) in a case study of the Campos basin offshore Brazil on high-resolution multi-azimuth towed-streamer seismic acquisition and processing indicated that shooting two-azimuth streamer data over a 100 km^2 area with three obstructions will result in significant uncovered areas even after optimization. However, OBS over 100 km^2 can be acquired at equivalent or slightly longer duration with both full surface and full azimuth coverage.

Repeatability

Increasingly oil companies are acquiring time-lapse seismic data to optimize field development. Key to understanding the fluid and rock physics effects from the baseline and between each monitor survey is the repeatability of the seismic acquisition and processing, as any seismic changes from survey to survey can then be fully attributed to fluid and rock property effects.

Being able to position the sensors accurately and repeat the location over time is a cornerstone of any time-lapse project.

***Figure 2** OBC deployment by the* Sanco Star *in a heavily obstructed area.*

OBS data is ideal for sensor repeatability, especially for ROV-deployed nodes and OBC.

The VSO OBC is deployed under slight tension of the weight of the cable and using the acoustic transponders it is draped across the seafloor ensuring a high positioning accuracy of less than 10 m. When deployed the sensor package is isolated from the steel-armoured cable using a series of Kevlar ropes as part of the cable/sensor attachment (Figure 3). This de-tensioning device allows the sensor package to couple well to the seafloor and eliminates inline cable noise by providing approximately ~ 22dB of mechanical isolation between the stress member and the sensor housing. This deployment method also ensures excellent vector fidelity.

Enhanced data quality

Placing sensors at the seafloor provides significant benefits in comparison with streamer data; improved signal-to-noise ratio, enhanced subsurface resolution, and efficient multiple elimination.

Signal-to-noise ratio

By placing the sensors on the seafloor, two sources of noise, which impact both data quality and operational performance of towed streamer surveys, are avoided, i.e., the noise arising from towing the sensors through the water and the noise induced by the movement of the sea surface are eliminated.

By combining the data from scalar and vector sensors, often referred to as dual sensor summation, it is a straightforward process to separate the recorded data into upward and downward traveling components, which can be used in multiple elimination.

Bandwidth

OBS provides superior bandwidth in comparison to streamer data by placing the equipment on the seafloor, as optimal sensor coupling is achieved and the ray path is shorter. Sensor coupling is dependent on the exact system. ROV-deployed geophones achieve a consistent sensor coupling. For nodes on a rope and OBC the system design is important. With the VSO OBC system, the weight of the cable and fins on the sensor housing ensure the entire system and especially the sensors get buried into a soft seafloor. However, to be able to record

Figure 3 *Cable for the OBC system being deployed.*

the signal the sensor has to have a sufficient dynamic range as with the sensors shown in a comparison with streamer data in Figure 4. For low frequencies the sensor can record down to 1.5 Hz. A stationary sensor has a further advantage because during acquisition of a towed streamer recording, the receiver locations continuously change (by about 2 m per second) creating potential losses in high frequency. OBC data enable a more detailed interpretation and better fault definition, and the low frequency information will improve the quality of derived seismic inversion results.

Imaging

Recently we have seen a marked uptake in the use of towed streamers adopting multiple-azimuth, wide-azimuth, and rich-azimuth seismic acquisition techniques for improved imaging in complex geological environments. These are in fact applications ideally suited for an OBS strategy, where the decoupling of source and receiver allows true full-azimuth data to be acquired rather than the sparse azimuth ranges achievable using towed streamers. OBS provides the opportunity for wide-azimuth and full-azimuth designs, as there is a lot of flexibility in how to place the receiver arrays relative to the source arrays (Figure 5). Multiple vessels and multiple passes are not required with OBS in order to acquire wide azimuth data. In addition, the cost per km^2 of some of the new streamer acquisition methods for azimuthal coverage is as high or higher in some cases than for OBS.

Gas clouds

The problem of imaging through gas clouds is experienced in many offshore areas, and only 4C OBS can provides a reliable solution through PS data. Towed streamer seismic is unable to provide any meaningful data over the central part of a reservoir due to the presence of gas in the overburden and this applies for the PP data as well (figure 6). By contrast, 4C OBS provides PS data, which based on the insensitivity of shear waves to gas can image inside the gas areas.

An application of PS data (Rønholt et al., 2008) showed improved imaging of the Snøhvit field through integration of 4C OBC and dual-azimuth streamer seismic data. The objective of acquiring 4C OBC data over Snøhvit was to assess the potential for PS imaging through the gas cloud. The improved

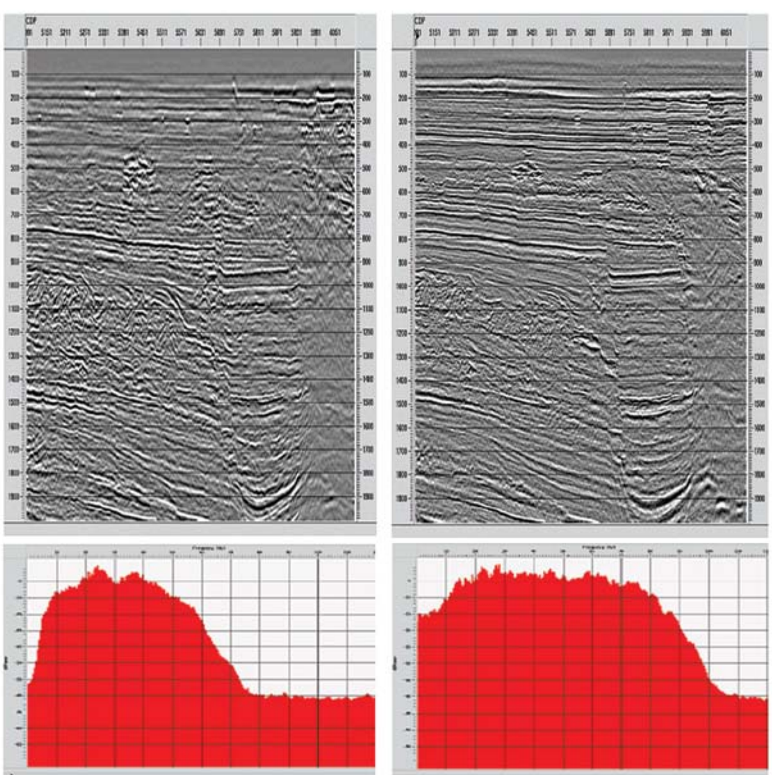

Figure 4 *Bandwidth comparison of streamer (left) and VSO OBC data (right).*

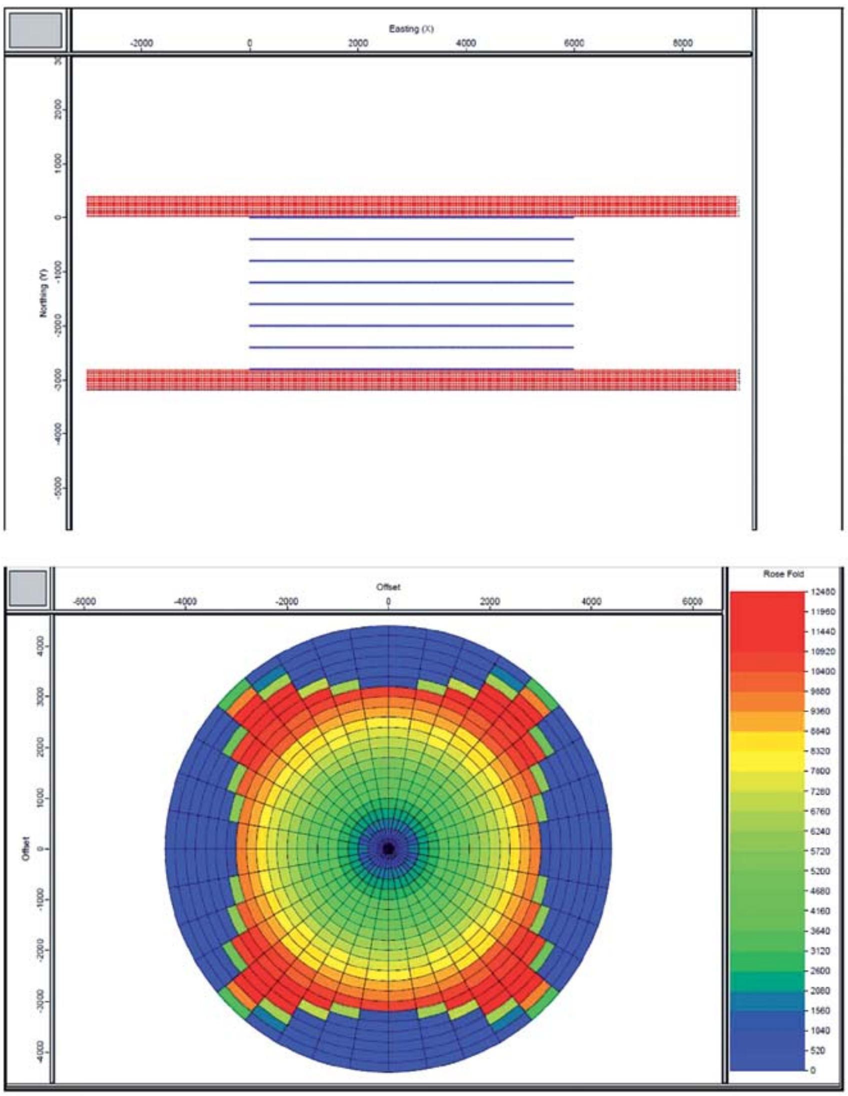

Figure 5 *Top image is an example of a survey design (Dark blue lines are receiver cables and red lines are acquired source lines) with full-azimuth as represented by the rose diagram (lower image). The bin size is 25 m by 12.5 m with up to 70 fold coverage.*

PS image resulted in a reduction of the oil in-place estimation and in a decision not to develop a specific oil zone.

Complex geology

Since source and receivers are entirely decoupled when acquiring OBS data, full azimuth coverage can be readily achieved. That makes OBS ideal for imaging subsalt and in relation to complex geological structures, particularly, where there are illumination problems with streamer data and multi- and wide-azimuth seismic is required. For deeper targets requiring larger offsets the decoupling of source and receiver makes it possible to acquire the necessary offsets.

A high density OBC (25 m by 25 m bins with up to 760 fold) survey has been very successful in improving the imaging under Eocene channels (Figure 7). It has improved the illumination of the reservoir, and been effective in suppressing the multiples generated by Eocene channels. Both these effects can clearly be seen where the seismic quality under the channels is now comparable to the quality away from the overburden channels.

Reservoir characterization

Direct hydrocarbon identification

PS data from 4C OBS provides a unique hydrocarbon prediction attribute. The PP data will be influenced by hydrocarbons in the reservoir, however the PS data will not be impacted. It is therefore possible to distinguish between a lithological/diagenetic effect and hydrocarbons, because an amplitude brightening on the PP data will only be a hydrocarbon effect if not present on the PS data.

PS data were used in the de-risking of a Paleocene seismic amplitude anomaly identified in Block N-33/6. The anomaly is located in a virgin area for Paleocene exploration and there is no analogous anomaly that has been described or drilled within this or in adjacent parts of the North Sea (Figure 8).

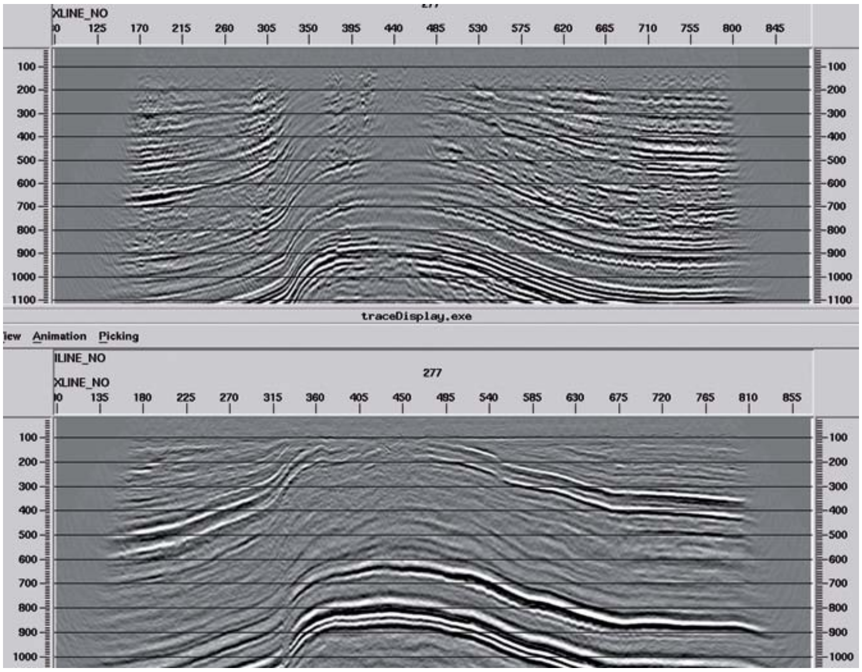

Figure 6 *Imaging comparison for a gas area between PP (top image) and PS (bottom image) seismic.*

One of the ways to de-risk the anomaly was acquiring an OBC survey. The results of conventional AVO analysis of 3D streamer seismic, and joint AVO inversion of the PP and PS data are consistent with an acoustically soft hydrocarbon filled sand, but are inconclusive with respect to saturation and reservoir quality. The bright anomaly seen on the PP data is absent on the PS data, indicating that the anomaly is a saturation effect and that the amplitudes are consistent with the presence of hydrocarbons as either unconsolidated oil sand, or heterogeneous gas sand.

Seismic inversion

Improved signal-to-noise ratio and enhanced bandwidth makes OBS ideal for seismic inversion to extract rock properties. The signal-to-noise ratio influences the basic quality and accuracy of seismic inversion results and how well the result correlates with well log data. For more unbiased inversion results and accurate rock property predictions for each layer, the seismic bandwidth is important. To achieve absolute rock property values, the low frequency information from well log data normally has to be integrated into the seismic inversion process to compensate for the lack of low frequency information in the seismic data. As the OBS is richer on this information than streamer data, the inversion will be less biased. The higher frequencies ensure better fidelity prediction of rock properties for individual layers.

Using 4C OBS seismic it is possible from the PP gathers to ideally invert for acoustic impedance, shear impedance, and density and from the PS gathers to invert for shear impedance and density. The use of OBS for seismic inversion and

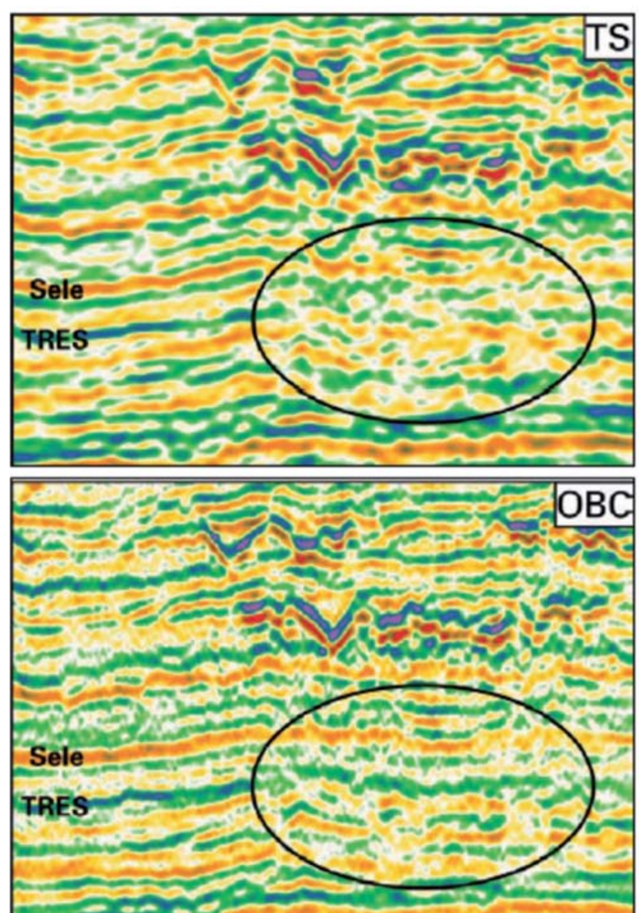

Figure 7 *Imaging comparison below a complex structure using streamer and VSO OBC seismic – Padmos et al (2010).*

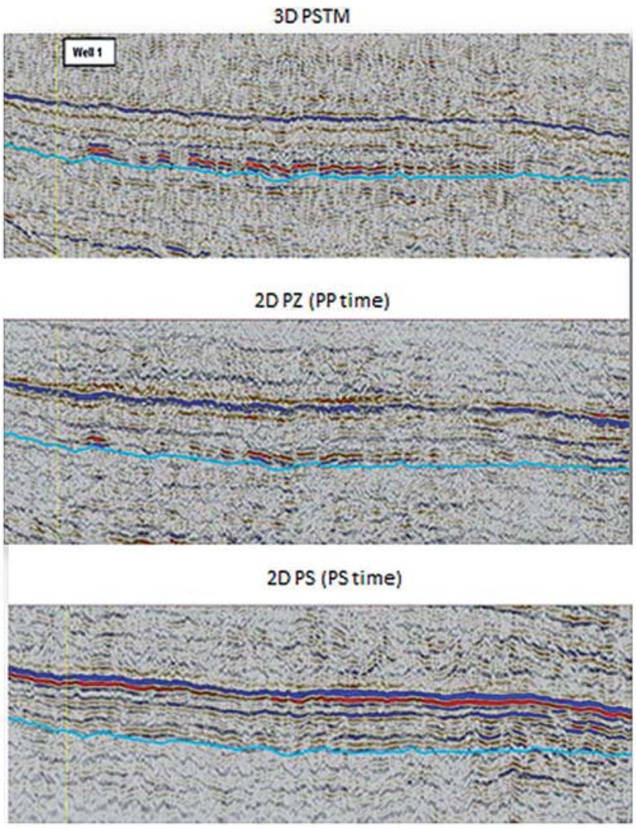

Figure 8 *Streamer, PP and PS data comparison – Hughes et al (2010).*

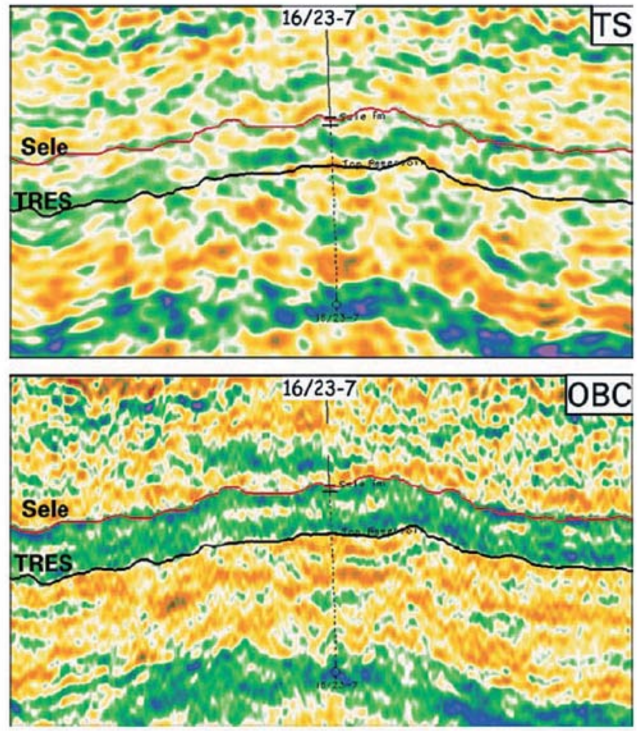

Figure 9 *Gradient impedance sections comparing streamer and high density OBC data. The high density OBC section clearly images the top reservoir event. Horizons were picked on the high density OBC data, and posted on the streamer data.*

the uplift in the quality of the results are illustrated in Figure 9 utilizing OBC data acquired by RXT. The inversion of the gradient, which is a lithology indicator, now allows the interpretation of the top reservoir event, which was not possible on the towed-streamer gradient impedance data.

The density term is in general difficult to accurately predict by inverting the PP and PS data separately. However, by doing joint PP and PS gather inversion, it becomes possible to more reliably predict density (Leiceaga et al., 2010).The density term may be a good indicator of gas and a differentiator between commercial gas and fizz gas (water with small amounts of gas).

Summary

Placing sensors on the seafloor was the first way in which marine seismic data were acquired, Since then, OBS data acquisition has shown substantial development even though it is still a minority offshore exploration and production seismic tool. With recent advances in instrumentation, which have addressed many of the limitations in the technology, the application of OBS is expected to grow substantially in the coming years. New streamer technology is narrowing the bandwidth gap between streamer data and OBS. However the additional value in OBS is still substantial with a number of unique attributes like full azimuth and converted shear component data that can't be achieved by streamer seismic.

References

Cooke, A., Moreira, L., Garrity, J., Luthy, S., Silva P. and Hsaio, H. [2011] High-Resolution Multiazimuth Towed-Streamer Seismic Acquisition and Processing – A Case Study from the Campos Basin Offshore Brazil. *12th International Congress of the Brazilian Geophysical Society*, Extended Abstract.

Davies, D., Mannaerts, H., McGarrity, J., Ibram, M., McKenzie, C., Campbell, S., Alexander, G., Lozano, A., Kommedal, J., Barkved, O. and Van Gestel, J-P. [2011] High-density OBC – a step change in reservoir imaging – BP North Sea view. *Offshore Europe*, Aberdeen, UK. SPE-146144.

Hughes, P., Hatland, O.H, Haynes, J.M., Øygaren, M. and Drivenes, G. [2010] De-risking a Palaeocene amplitude anomaly prospect using multi component seismic and controlled source electromagnetics. *NPF Biennial Geophysical Seminar,* Expanded Abstracts.

Leiceaga,G.G., Silva,J., Artola, F., Marquez, E. and Vanzeler, J. [2010] Enhanced density estimation from prestack inversion of multicomponent seismic data. *The Leading Edge*, **29**(10), 1220–1226.

Padmos, L., Davies, D, Davies, M. and McGarrity, J.1. [2010] Using high-density OBC seismic data to optimize the Andrew satellites development. *First Break*, **28**(10), 61–67.

Rønholt, G., Aronsen, H.A., Hellmann, T. and Johansen, S. [2008] Improved imaging of the Snøhvit field through integration of 4C OBC and dual-azimuth streamer seismic data. *First Break*, 26(12).