Using high-density OBC seismic data to optimize the Andrew satellites development

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Abstract

The processed data from conventional towed-streamer seismic surveys over the Andrew satellite fields in the Central North Sea are of poor quality because of anomalously fast sand-filled channels in the Eocene overburden. The channels attenuate the primary energy and produce strong multiples. A step change in data quality has been achieved by acquiring a wide-azimuth seismic survey using ocean bottom cables and a high shot density. The new data have much higher signal-to-noise ratio and better resolution. The imaging under the Eocene channels is greatly improved in the processed results of the new survey. Furthermore, the acquisition and processing were completed in time to meet the tight development schedule for the 2008 Kinnoull discovery.

Introduction

The BP-operated Andrew Hub is located in the Central North Sea, 240 km ENE of Aberdeen. It consists of the Andrew platform, which produces from the Palaeocene and Lower Cretaceous reservoirs and also serves as the processing hub for the Cyrus and Farragon subsea developments (Figure 1). In May 2008, BP drilled the Kinnoull discovery well in block 16/23, to the north of the Andrew Field. On the back of this significant North Sea discovery, the Andrew Area Development Project was started with the objectives of delivering Kinnoull oil via a subsea tieback to the Andrew platform and providing subsequent options for other small pools in the area (Kidd, Arundel).

Successful development of the Andrew satellites will depend strongly on the ability to place development wells in optimal positions in the poorly imaged, subtle structures. The quality of conventional towed-streamer seismic data is poor at the Palaeocene reservoir level due to the presence of anomalously fast Eocene sand channels in the overburden. The poor data quality results in low confidence both in the top reservoir pick and in the prediction of reservoir presence. The towed-streamer seismic gathers are very noisy, and as a result the AVO products generated from them are of poor quality. This is especially true for the seismic gradient, which is a lithology indicator for the Palaeocene reservoirs in the area. Improving the estimates of seismic gradient is key to reducing the risk on reservoir presence.

With the start of the Andrew Area Development Project, the expected date of first oil from the Kinnoull discovery was also set. When the time needed for the construction of the subsea facilities and the drilling of the development wells was taken into account, only a very short time window was left

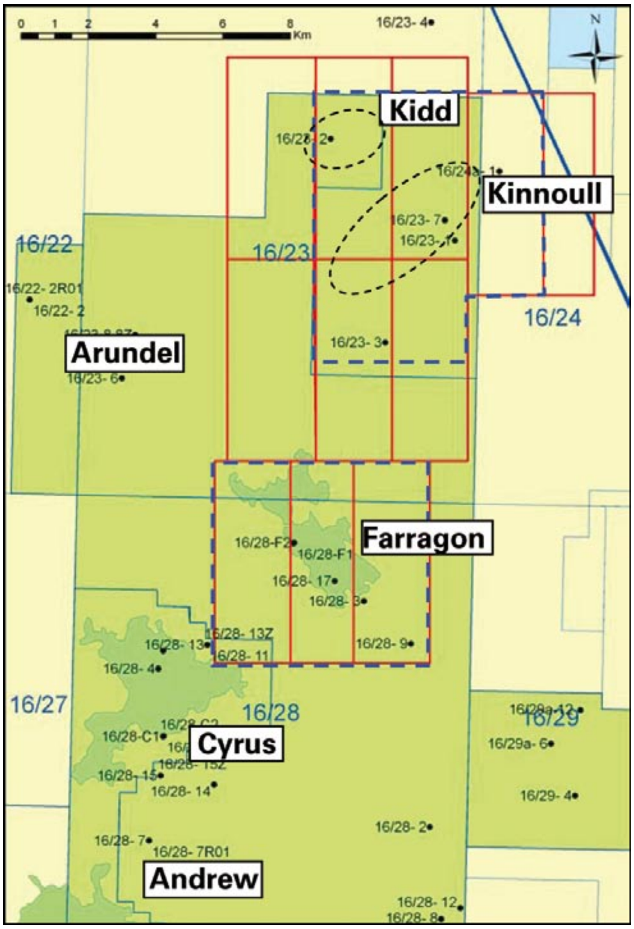

***Figure 1** Location map showing fields and discoveries in the Andrew area. Acreage operated by BP is shown in green. The 11 acquisition patches of the OBC survey are outlined by red rectangles, and the Phase I processing areas are outlined by blue dashed lines.*

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to address the issue of producing seismic data of sufficient quality for development purposes.

In this case study, we describe the imaging problem in the Andrew area and show the data quality improvements we have achieved by acquiring a wide-azimuth, high-shot-density, ocean bottom cable (HDOBC) seismic survey over Kinnoull and Farragon. We compare towed-streamer with HDOBC data and show that the HDOBC survey has been very successful in improving the imaging under the Eocene channels.

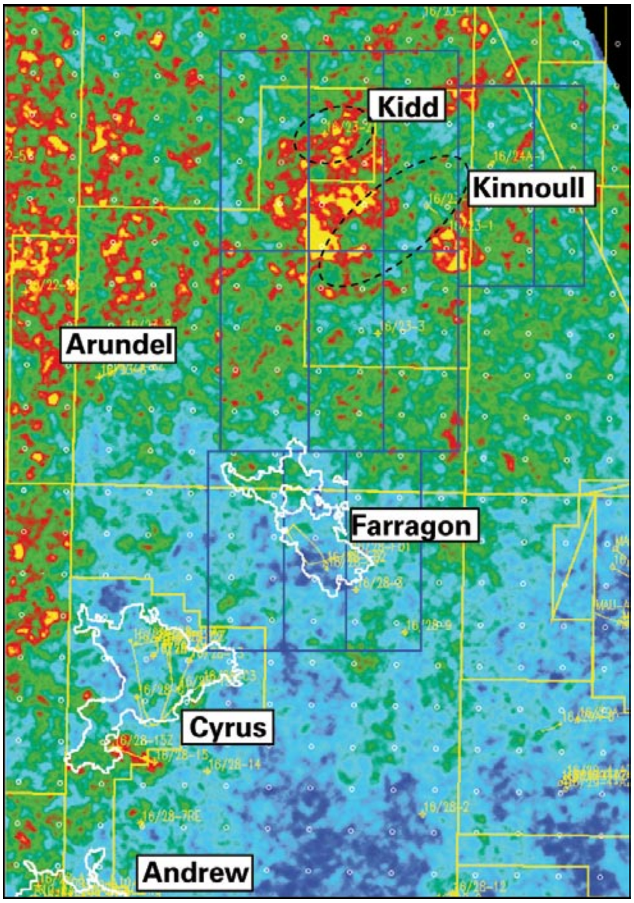

Figure 2 *Amplitude extraction over the Eocene interval, showing the areal extent of the Eocene channels (red/green amplitudes). Channels are more prevalent in the north of the area. Acquisition patches are shown as blue rectangles.*

Reservoir and overburden

In the Andrew area, the Palaeocene sandstones form the main reservoir interval at depths ~2500 m. The Andrew satellite fields are structures of low relief, with maximum column heights of 20–50 m and uncertain reservoir distribution. The overburden is generally benign, without major velocity contrasts, and has a layer-cake stratigraphy with gently dipping reflectors. In the Eocene, however, sand-filled channels are present. They are anomalously fast compared to the surrounding shales, with typical sand velocities of 3200 m s^{-1}, and shale velocities of 2400 m s^{-1}. As a result, they show up as bright amplitudes on the seismic data (Figure 2). They are more prevalent in the north of the Andrew area, where the sand package is also at its thickest. They occur over the north of Farragon, and the entire Kinnoull discovery is covered by a thick package of channels. On a basin scale their depositional direction is NW–SE, but at the field scale their orientation appears random making them very difficult to interpret. The imaging problems in the Andrew area are caused by these channels, which occur at different levels in the Eocene and mostly have total thicknesses in the range 50–150 m.

OBC justification

The data most recently used for the interpretation of the Andrew satellite fields are a merge of two 3D towed-streamer surveys acquired in 1992 and 1994. They were reprocessed with isotropic prestack depth migration (PSDM) in 2008. At the time of reprocessing, more recent towed-streamer seismic data, shot in 2004, were available, but it was thought that the anticipated improvement in image quality would not

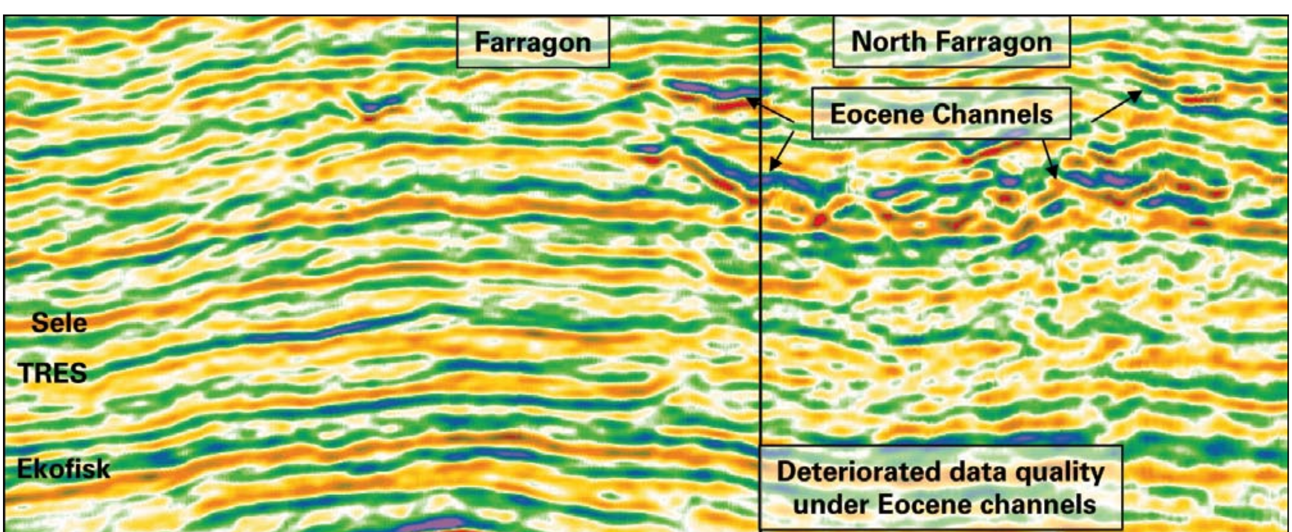

Figure 3 *South–north vertical section from the processed 3D towed-streamer seismic survey over the Farragon Field, illustrating the deterioration of data quality under the Eocene channels (TRES = Top REServoir).*

justify the increased cost of licensing because the acquisition quality of the 1990s data was considered to be good. The fundamental issue with the towed-streamer data is that these surveys are not successful in imaging through the channelized Eocene overburden. The channels attenuate the primary energy and produce strong multiples, both water leg and internal, that interfere with the reservoir reflections. The quality of the towed-streamer data is deemed insufficient for development drilling.

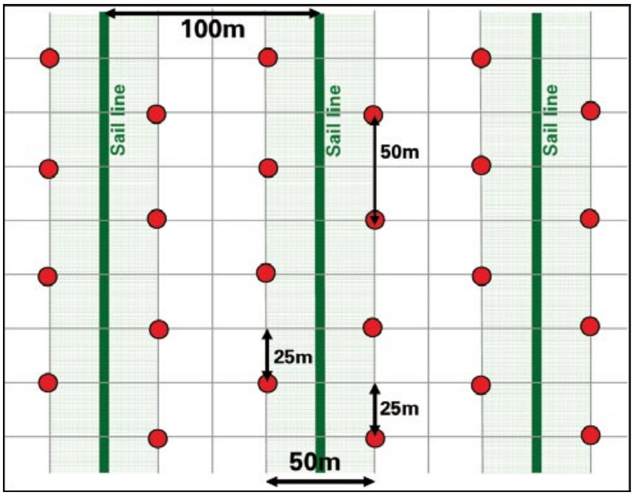

***Figure 4** Shot point grid for the Andrew area HDOBC survey. A sail line interval of 100 m, airgun array separation of 50 m, and a flip-flop shotpoint interval of 25 m produces a regular 50 m × 50 m staggered grid of shots.*

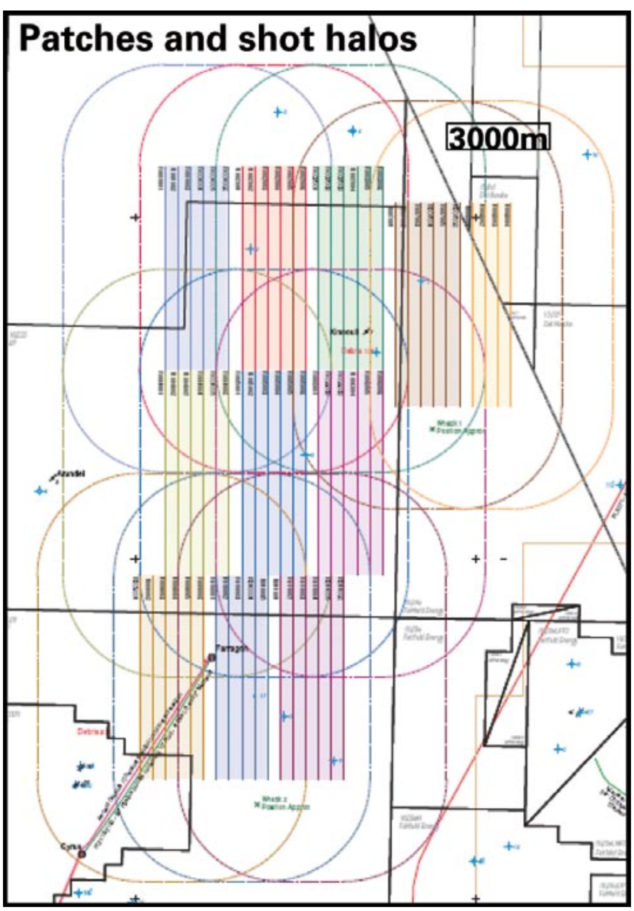

***Figure 5** Acquisition patches and shot halos. The high-density shot grid has been shot within a 3000 m halo of each receiver patch.*

A clear example of the deterioration of data quality due to the Eocene overburden channels can be seen in the Farragon Field (Figure 3). The data quality is good in the south, where there are no overburden channels. This is the part of the reservoir that is currently developed with two horizontal producers. The data quality gets poorer in the direction of North Farragon. The point where the data start to deteriorate coincides with the point where Eocene channel sands start to develop. The Kinnoull discovery is also overlain by a package of Eocene channels, typically 100 m thick, and as a result the data quality at reservoir level is poor.

Both reprocessing of the existing towed-streamer seismic data and acquisition of a new towed-streamer survey were expected to produce only small improvements in data quality. The solution to achieving a significant increase in data quality was believed to lie in a different acquisition method. Because the Eocene channels are located just above the reservoir, are widely distributed, and have no dominant spatial orientation, a conventional towed-streamer undershoot was ruled out. Given the multi-directional nature of the Eocene channels, it was thought that a wide-azimuth HDOBC survey would be the best technical solution to deliver a step change in data quality (Bouska, 2008). Acquiring a multi-azimuth (MAZ) seismic survey was also considered, for instance by shooting two additional surveys at azimuths of 60° to the existing survey. But an HDOBC survey offers a lot of additional benefits, such as much better sampling of the wavefield, multiple suppression, higher signal-to-noise ratio (SNR), and shear-wave data, and for a small area the cost was comparable to the cost of two additional towed-streamer surveys. Acquisition and processing of the P-wave data was the main objective. This would provide the Andrew Area Development Project with the best possible HDOBC seismic data to optimize well placement and thereby maximize recoverable resources, and to de-risk upside development options.

Acquisition parameters:

– Number of patches	11
– Receiver cables patch	4 - 7
– Receiver line length	6000m
– Receiver line spacing	375m
– Receiver group interval	25m
– Receivers per cable	240
– Receiver type	Non gimballed 4component, 3 MEMS accelerometers + hydrophone
– Sail line increment	100m
– Gun array separation	50m
– Shot point interval	25m (flip / flop)
– Gun array depth	6m
– Record length	7secs

***Figure 6** Acquisition parameters for the Andrew area HDOBC survey.*

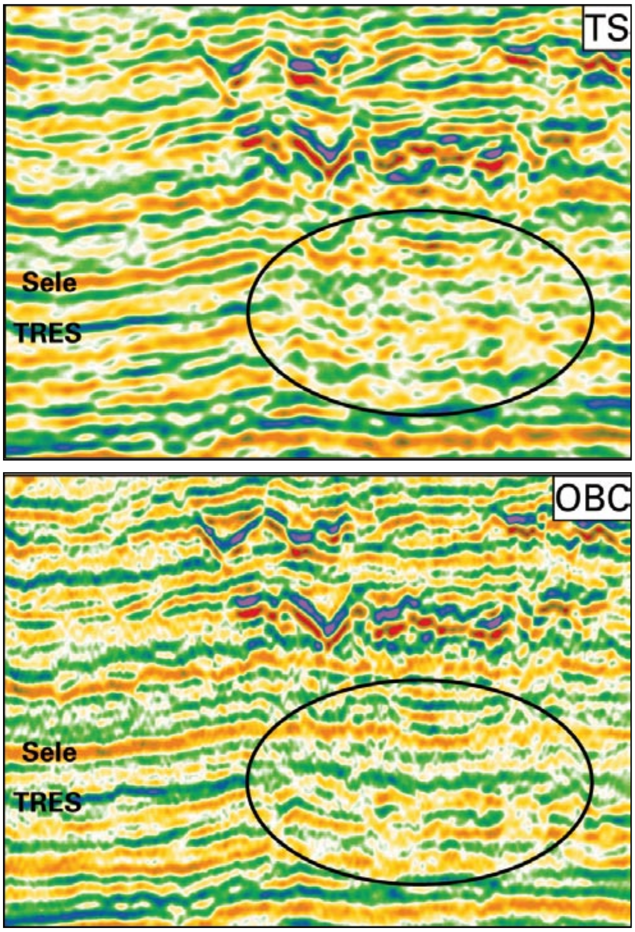

Figure 7 Seismic sections over Farragon comparing towed-streamer and HDOBC data. The HDOBC section (bottom) has improved SNR and horizon continuity at reservoir level (TRES = Top REServoir).

Acquisition

The Andrew satellites HDOBC survey was acquired from December 2008 to July 2009. Starting the acquisition in the winter months was a very important factor in being able to meet the Kinnoull development drilling schedule. The survey area was 140 km^2, and the water depth is approximately 105 m.

The survey contained 11 patches, with four to seven cables per patch (Figure 1). The cables were 6000 m long, and were laid out at 375 m spacing. The sail line increment was 100 m, and the gun array separation was 50 m. The shot point interval was 25 m, which is 50 m per flip or flop. These acquisition parameters translate into a regular 50 m × 50 m staggered grid of shots (Figure 4). Data were shot within a 3000 m halo around each patch (Figure 5). This acquisition design produces a very high fold (760 for a nominal 25 m × 25 m bin, with 3000 m notional offset acquisition). The acquisition design also provides a regular azimuthal distribution of shots with offset, and has higher fold at the far offsets, which will aid velocity analysis. The shot lines were acquired parallel to the receiver lines to minimize the number of line turns. More details of the acquisition parameters are given in Figure 6.

Processing

Of the acquired multi-component data, only the P and Z components were processed. The processing was split into two phases, to ensure that the data would be available in a timely manner to impact the planning of the Kinnoull development wells, which are on the drilling schedule for late 2010.

In Phase I, sub-areas over Farragon and Kinnoull (Figure 1) were processed separately. A processing flow regarded as best practice was used as a starting point, and initially limited

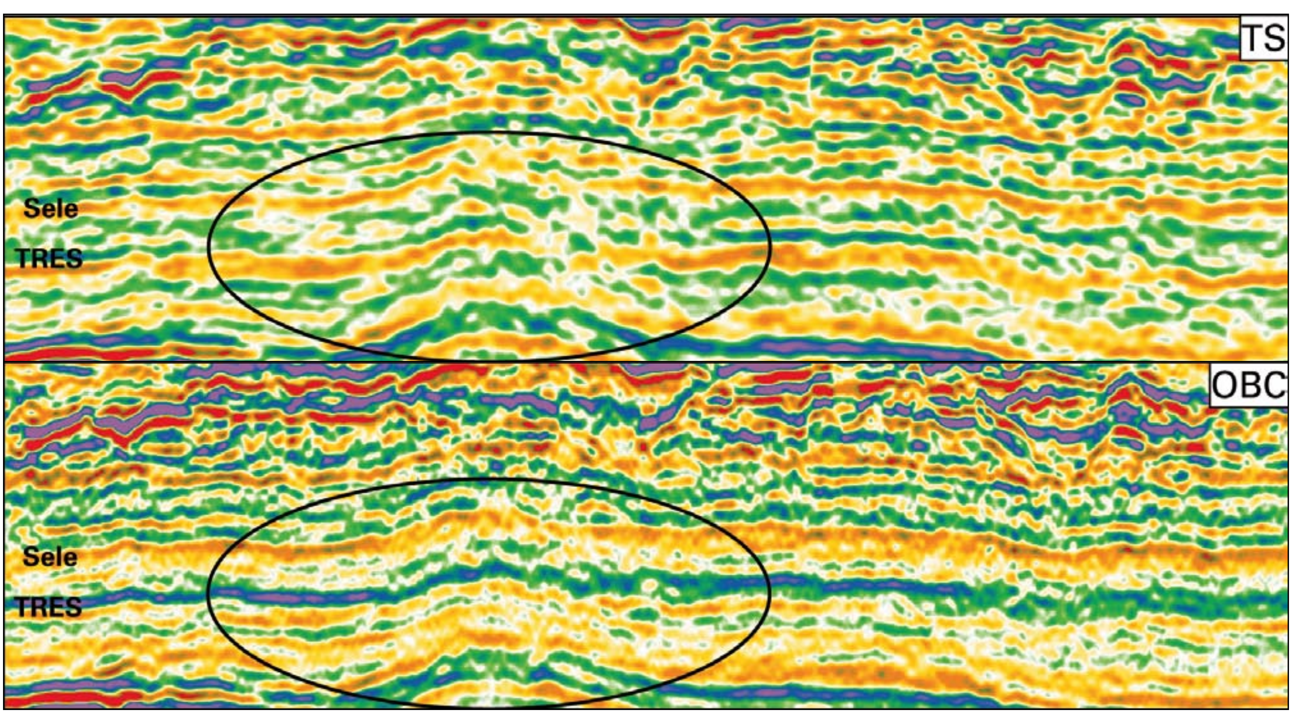

Figure 8 Seismic sections over Kinnoull comparing towed-streamer and HDOBC data. The HDOBC section (bottom) has improved SNR and horizon continuity at reservoir level.

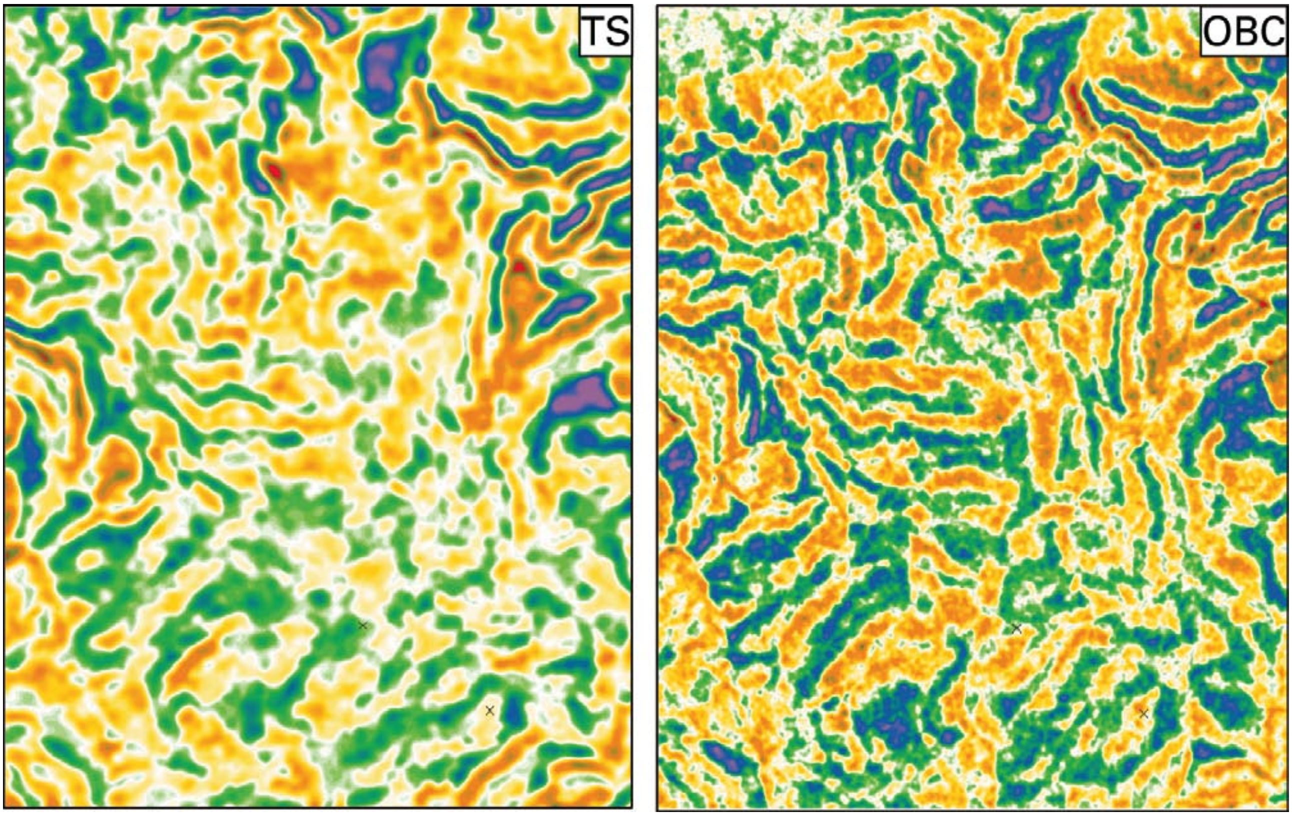

Figure 9 *Time slices over Farragon comparing towed-streamer and HDOBC data. The time slice is in the shallow section, at 1748 ms, above the Eocene interval. The HDOBC time slice (right) has improved SNR and spatial resolution.*

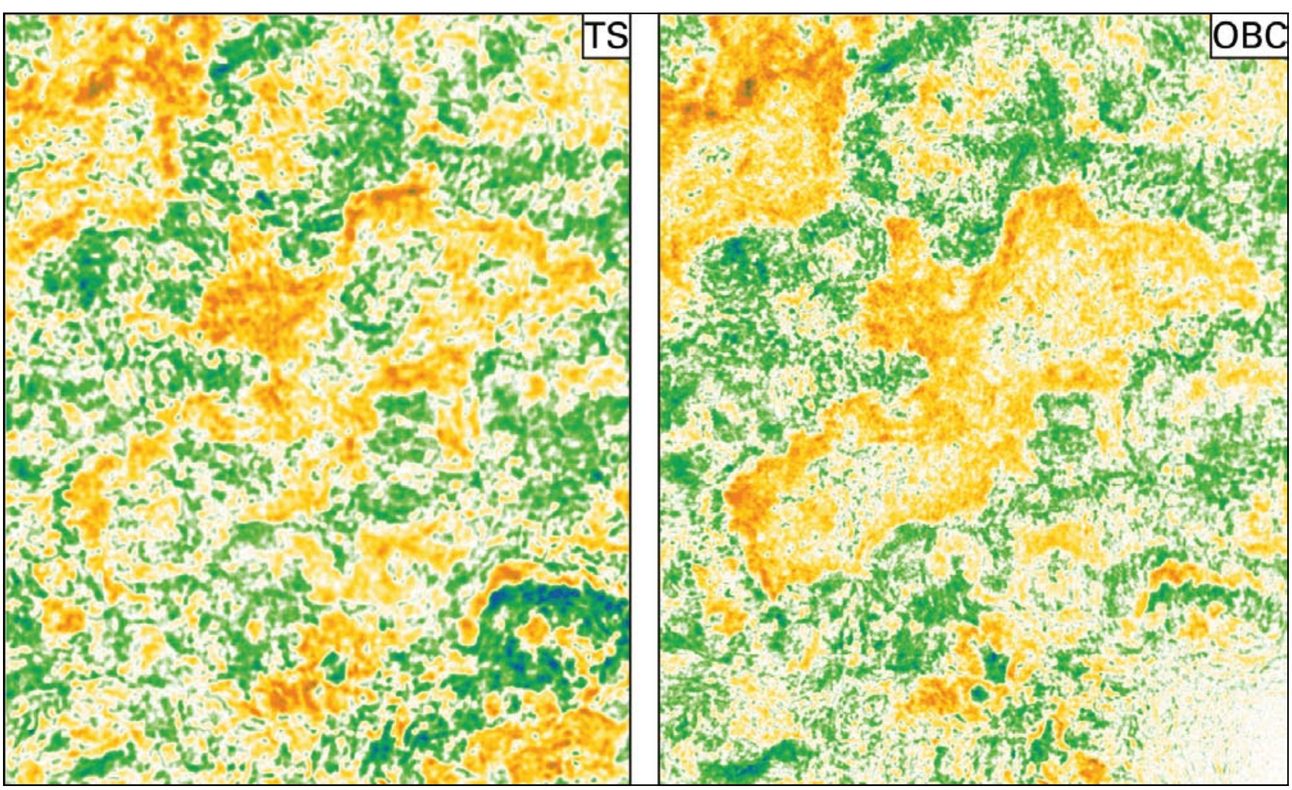

Figure 10 *Time slices over Kinnoull comparing towed-streamer and HDOBC data. The slice is at 2336 ms, at Sele level in the Palaeocene. The HDOBC time slice (right) has improved SNR and spatial resolution.*

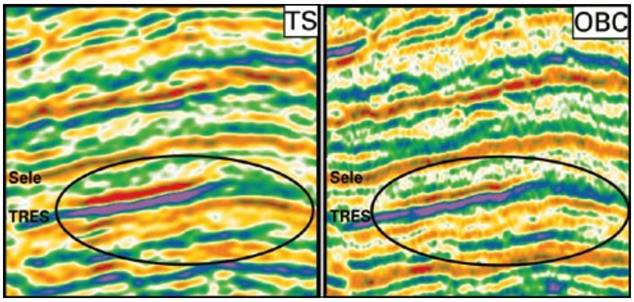

Figure 11 *Zoomed in seismic section over the south of Farragon, where there are no Eocene channels in the overburden. The HDOBC data (right) shows improved SNR and resolution.*

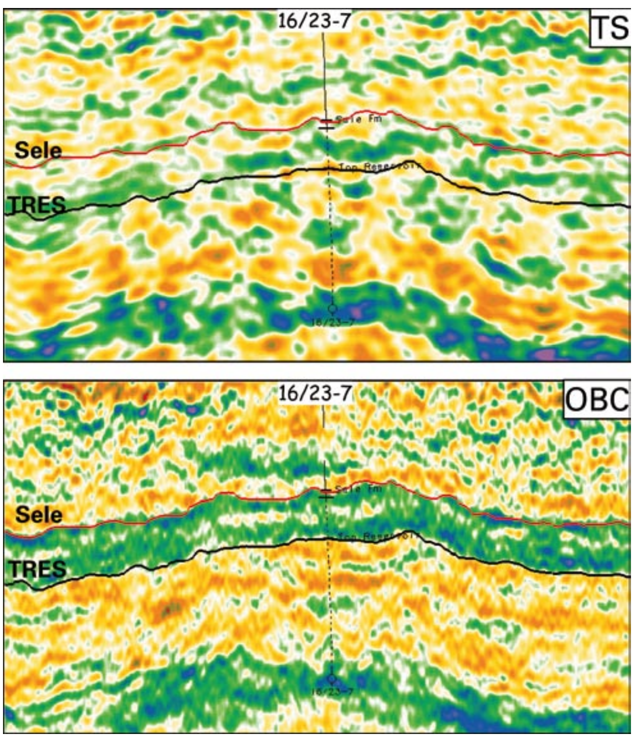

Figure 12 *Gradient impedance sections through the Kinnoull discovery well (16/23-7) comparing towed-streamer and HDOBC data. The HDOBC section (bottom) clearly images the top reservoir event. Horizons were picked on the HDOBC data, and posted on the TS data.*

parameter testing was envisaged. The data were migrated with PSDM, using the existing 2008 PSDM isotropic velocity model. Processing of both sub-areas finished in December 2009. Much more testing was done in this phase than first anticipated.

In Phase II, the entire area will be processed as one volume. This work started in December 2009 and was due to be completed in June 2010. This processing phase is intended to be optimum with current technology, and includes more extensive parameter testing, with more attention on demultiple. Full waveform inversion will be tested, and the key difference from Phase I is the rebuilding of a high-density anisotropic velocity model.

Most of the data quality improvement compared to the towed-streamer data was expected in Phase I, with the Phase II data providing an incremental uplift on the Phase I product. Reinterpretation and planning of the development wells on the new HDOBC data was started in January 2010. The Phase II data will be used to apply final corrections to the well trajectories, before the development drilling starts.

The HDOBC patches covering Farragon were acquired first, allowing the processing to begin on these data. It was decided to start the processing on Farragon because it would be easiest to see the improvement in imaging and to test parameters, given that there are areas with and without overburden channels. Most of the parameter testing has taken place on Farragon, and with minimal changes the resulting processing flow was applied to the Kinnoull data. The processing flow included prestack noise attenuation, P/Z summation, demultiple, Kirchhoff PSDM, another step of demultiple, and post-stack noise attenuation.

The comparisons in this article between the reprocessed data from the towed-streamer surveys and the Phase I processing results from the HDOBC survey show the data as delivered by the processing contractor, without additional proprietary data enhancements. Both the 2008 towed-streamer reprocessing and the HDOBC processing were done by the same processing contractor, using the same isotropic velocity model for the Kirchhoff PSDM.

Results

The HDOBC survey has been very successful in improving the imaging under the Eocene channels. It has improved the illumination of the reservoir, and been effective in suppressing the multiples generated by the Eocene channels. We can clearly see both these effects in the Farragon area, where the seismic quality under the channels in the north is now comparable to the quality away from the overburden channels in the south (Figure 7). Data quality over Kinnoull shows the same level of improvement (Figure 8). The SNR has improved, and the reservoir horizons are more continuous. As a result, the top reservoir reflection can be interpreted with a lot more confidence.

Timeslices show that the HDOBC data have higher spatial resolution than the towed-streamer data, as can be observed in the shallow section, above the Eocene channels (Figure 9), and at reservoir level, below the Eocene channels (Figure 10). The HDOBC data have much higher SNR, and consequently look much crisper. The data quality has also improved in areas without overburden channels. We can see this improvement over the south of Farragon, where both the SNR and resolution have improved (Figure 11).

The much cleaner HDOBC seismic gathers have allowed a better estimation of the zero-offset and gradient AVO products. 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. Figure 12 shows this, with a line through the Kinnoull 16/23-7 discovery well. The ability to use the gradient impedance product is also key to reducing the reservoir presence risk. Amplitude extractions on this data over Kinnoull now clearly show the sediment fairway (Figure 13). The observed fairway

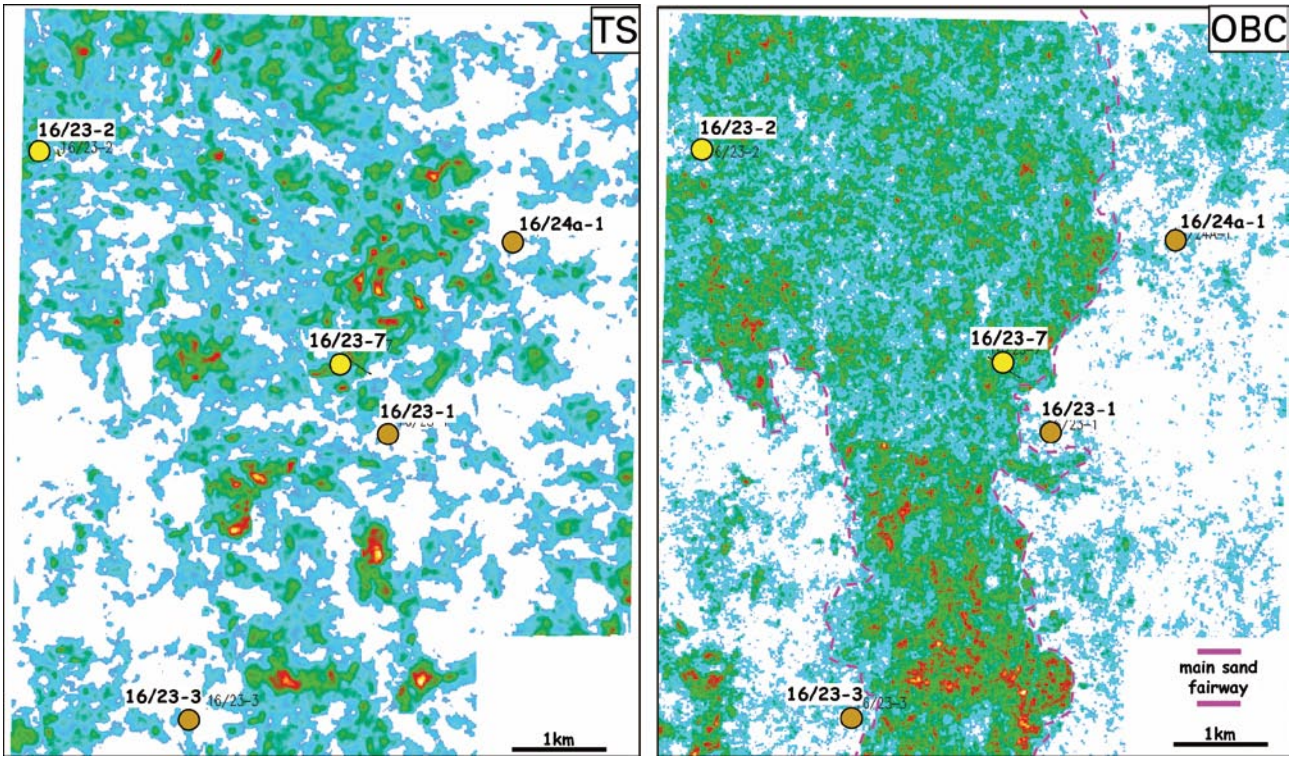

***Figure 13** Amplitude maps extracted on the gradient impedance volume over Kinnoull, comparing towed-streamer and HDOBC data. The towed-streamer map (left) is very noisy. The HDOBC map (right) clearly shows the sediment fairway, the outline of which ties very well to the well data.*

ties the well data, with the wells in the fairway having high net-to-gross and the wells outside the fairway having very low net-to-gross.

Conclusions

The wide-azimuth HDOBC seismic survey has been very effective in addressing the imaging issues caused by Eocene channels that overlie the Andrew satellite fields. It has improved the illumination of the reservoir, and been effective at suppressing Eocene multiples. The reservoir image has been significantly enhanced, resulting in seismic reflections that can be interpreted with a lot more confidence. The improvement in data quality has been such that the imaging under the Eocene channels is now comparable to areas without overburden channels. The HDOBC data have also enhanced image quality in areas without overburden channels, where SNR and resolution have increased. The much cleaner HDOBC seismic gathers have enabled a better estimation of the seismic AVO gradient. This reduces the risk on reservoir presence, since the gradient is a lithology indicator for the Palaeocene reservoirs in the Andrew area. The improved seismic data quality will play an important role in optimizing well trajectories, and help de-risk upside development options.

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