ON TOP OF THE SPREAD

Jo Firth and Vetle Vinje, CGG, explore the challenges of imaging the shallow reservoirs of the Barents Sea.

The Barents Sea is a relatively new oil region which is expected to hold large petroleum resources.[1] Traditional marine seismic acquisition using wide spreads has struggled in this area and several oil companies have searched for solutions to obtain improved imaging. Lundin Norway AS is a key player in the Barents Sea and in 2015 it initiated a close cooperation with CGG which led to a new source-over-spread acquisition and imaging solution, known as TopSeis™.

TopSeis addresses the lack of near-offset data recorded in conventional towed-streamer acquisition by enabling the recording of short- and zero-offset data with the seismic sources located above the streamers. The split-spread streamer (hereon called SSS) data increases the illumination density (number of times a specific depth point is recorded) for both shallow and deep targets.

Lundin has a detailed knowledge of the geological and geophysical challenges in the Barents Sea and knows the importance of near offsets and high illumination for obtaining better images. Lundin and CGG worked

in a symbiotic relationship with several cycles of comprehensive modelling of many survey configurations, field tests offshore Gabon and in the North Sea, and developing new processing and imaging solutions. SSS provides superior images, AVO and inversion, from the sea bottom to intermediate depths and below.

The Barents Sea challenge

Among the main reservoirs of the Barents Sea are karstified carbonates located at depths varying from 400 to 1600 m below the seabed, which require near offsets in order to be imaged successfully. The contrast in the velocity of these rocks with the overlying Triassic sediments is such that the critical angle is relatively small, meaning that the maximum offset recorded at reservoir level is in the range of 800 to 2400 m, depending on depth. Conventional narrow-azimuth towed-streamer seismic data lacks coverage at these near offsets, especially on the outer streamers, where the nearest offset may be 500 m.

Imaging in this area is further complicated by water-bottom-generated diffractions and multiples due to the hard, rugged seafloor with iceberg plough marks and pockmarks from gas seeping through the sedimentary layers. Increasing the near-offset fold is the key to improving the signal-to-noise ratio in the shallow section and to modelling the multiples accurately so that they can be removed effectively (Figure 1).[2]
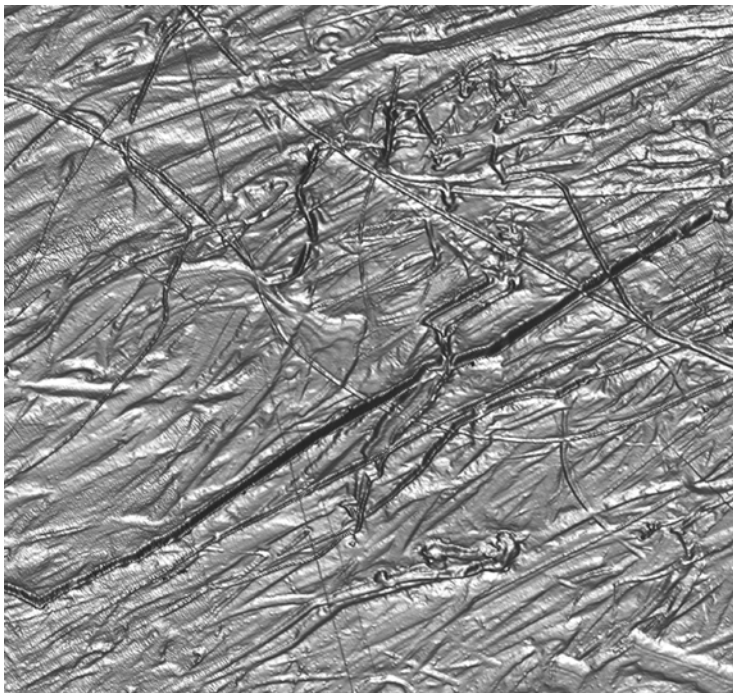
Figure 1. *Alta-Gotha water bottom, from Multi-Beam sonar (image courtesy of Lundin Norway).*
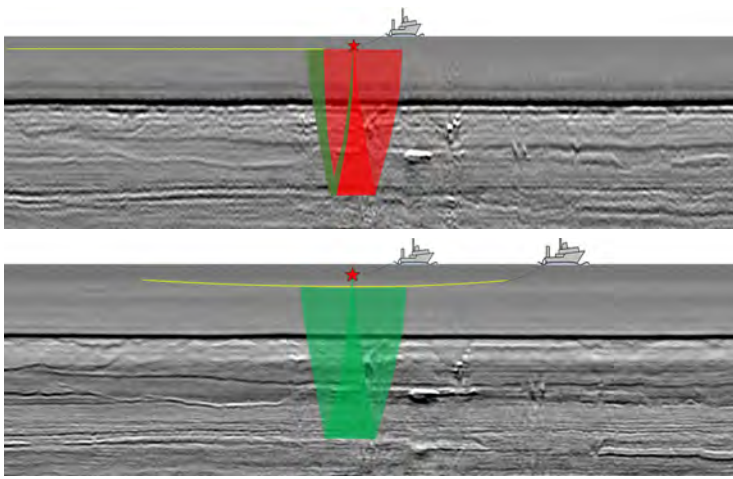
Figure 2. *In conventional acquisition (top) only a small part (in green) of the reflected energy cone is recorded, whereas with TopSeis (bottom) all the reflected energy cone is recorded.*
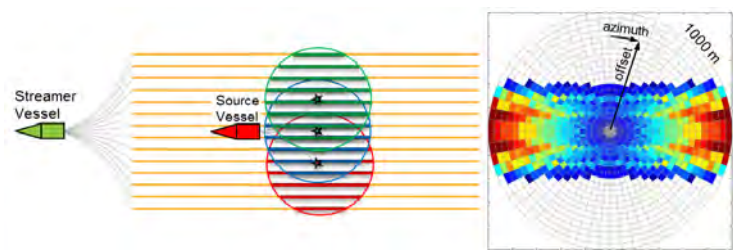
Figure 3. *TopSeis SSS marine acquisition configuration with offset/azimuth rose plot for offsets up to 1000 m.*

The proposed solution to this challenge was to acquire SSS data using two vessels, with the source vessel sailing behind the streamer vessel, directly over the spread.[3] Although there were some concerns about the feasibility of this option, CGG's experience with towing spreads deep and with variable profiles has delivered a wealth of operational knowledge. Further investigation revealed that it could be a practical solution if the streamers were towed deep beneath the source vessel, and that it would deliver the required fold and offset ranges (Figures 2 and 3).

Proving the concept

This solution required numerous risk analyses to be performed and operational strategies to be developed in order to ensure it was a practical, safe, efficient and operationally sound solution. In parallel with this, comprehensive 3D seismic modelling was performed to verify the processing and imaging feasibility of the concept. Various configurations, including streamer depth and profile, source vessel position and source and streamer separation, were evaluated to quantify the uplift of the proposed solution versus conventional acquisition.[3,4] This study showed that efficient acquisition of densely sampled data would be facilitated by towing the sources unusually wide and in a triple source mode (Figure 3).

One of the major operational concerns was the proximity of the source to the streamers. This required specific assessment of safe navigation procedures, the position of the source vessel, the length and towing shape of the streamer, and the effect on hardware and software of the close proximity of the streamer to the release of the pressure bubble. Following this review, an adapted emergency response plan was devised for the source and streamer vessels. Detailed analysis of the implications for processing were also required and resulted in a carefully calculated streamer shape for optimal imaging.

When all the known risks had been addressed a number of field tests were carried out to prove the concept, discover any unidentified risks and record some test data. The company's experience with deploying deep BroadSeis™ streamers[5] and operating multiple vessels in unusual configurations[6] provided the confidence to try this configuration and place the source over the spread. The aims of the initial field test were to move a source vessel over a deep-towed spread, confirm the expected response of the nearest hydrophones and record some data to use in development of the processing techniques and algorithms that would be required. Figure 4 shows an example split-spread shot record. The next tests were designed to test the towing width limits of the sources and any engineering required for stable wide-source towing over an extended period of time. The third stage of testing was to acquire a 2D line from deep to shallow water, to check the limitations of the technology with relation to water depth and to enable a direct comparison between this SSS data and a conventionally acquired broadband 2D line and so evaluate the potential of the solution.

New operational procedures were developed for line turns, escape route and emergency protocols as well as communication and navigation procedures. Additional crew members were placed on the bridge and on the navigation desk to ensure vigilance at all times, with visual displays set up on both seismic and support vessels so that all could

see their relative positions and the shape of the streamers in the water. The final proof of concept was a 3D field trial over the Frigg-Gamma field, where the geology demonstrates similar challenges to those of the Barents Sea.[3]

Loppa High survey

Following this 3D field test, only minor adjustments were made prior to the full-scale 3D survey acquired for Lundin Norway in the Barents Sea. This approximately 2000 km[2] survey was acquired between July and September 2017 with no recordable HSE incidents and only 1% technical downtime, justifying the planning effort involved.[7]

The use of 14 densely spaced streamers and triple sources towed wide delivered a crossline bin size of only 8.33 m with a sail line separation in line with a conventional survey. The use of blended source technology enabled the sources to be activated at 8.33 m intervals (25 m per source) and combined with placement of the sources over the deep-towed streamers resulted in excellent near- and zero-offset coverage with ultra-high fold. The illumination density was a maximum of 17 times higher in the shallow part of the section than achieved by a conventional configuration, decreasing to five times higher at depth. Figure 5 shows the trace distribution benefit of wide-spread sources over the streamers compared to a conventional survey.

Processing of this data set is still ongoing, but already many of the expected benefits are becoming apparent. Recording of the complete direct arrival enabled accurate positioning of the source and receivers and this, combined with the carefully designed slanted streamer shape and dense streamer separation, delivered good notch diversity for deghosting. The deep-towed near offsets resulted in less swell-noise and generally improved signal-to-noise ratios. Split-spread offset distribution including negative offsets, combined with near- and zero-offset coverage, smaller bins and high fold, delivered higher-definition multiple models including diffracted multiples, which, in turn, deliver improved multiple attenuation.[8] Velocity and anisotropy model building has been improved by full 3D recording of the curvature of seismic events, which should provide better imaging. The results from this survey, with small bins and high fold, are already showing a higher degree of both spatial and temporal detail and resolution than the conventional data, as shown in Figures 6 and 7.

Wisting survey

Following the acquisition of the Lundin survey, a small 24 x 3 km area was acquired over the Wisting field in the northern part of the Barents Sea for further evaluation of the technology, and to test additional acquisition parameters. The imaging challenges at the Wisting field are due to the very shallow Jurassic reservoir at approximately 250 m below the seabed. This area covers three wells, with the Central Well (7324/8-1, where the Wisting discovery was made) being located in the centre of the test area. This well was used in evaluation of the AVO of the SSS data. The synthetic data set used in the original source-over-spread modelling tests in 2015 was based on the geology of this area.

As in the Lundin survey, the initial results over Wisting are also encouraging (Figure 8). The vintage line is not coincident with the SSS line, but they intersect at the Central Well. Again, the SSS data shows greater resolution and improved S/N, providing details in the reservoir not

visible on the vintage (2009) data. Notice that the 2009 data has subsequently been re-processed, resulting in improved imaging so the detailed comparisons on this field are still ongoing.

Having observed a considerable improvement in imaging in the shallow targets on Wisting, AVO analysis was performed on the SSS data set to investigate the improvements obtained by the good angle range recorded. Four angle stacks, (0 - 10, 10 - 20, 20 - 30 and 30 - 40˚), were the input to the AVO analysis. As expected, AVO prediction was improved by the increased fold and the direct measurement of the intercept from recording zero-offset data. The SSS data showed a good match to the well data and also gave consistent AVO results, with both the seismic and well data showing negative intercepts and gradients. This creates a positive AVO product (intercept x gradient), indicating a Type 3 AVO response, which may indicate hydrocarbons, although other lithologies can also give this response.

A full deterministic elastic inversion of the four angle stacks was also performed, using amplitude-filtered well logs as an initial model. The outputs from this seismic inversion are 3D acoustic and elastic impedance volumes which should reflect the rock physics properties of the target sands. A high correlation between the inverted attributes and well logs at both exploration wells was observed. In addition, a distinct lateral variation in absolute Vp/Vs ratio amplitudes (from high to low values) is observed when moving towards the structural highs on the Top Stø formation (Figure 9). This is believed to be an indication of the transition from oil to gas in the reservoir. Several smaller prospective anomalies, as indicated by the red arrows, can also be observed, which should help in the positioning of future development wells.
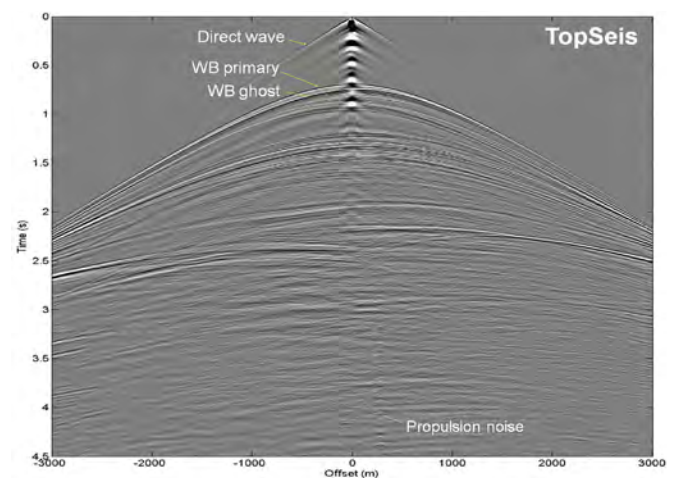

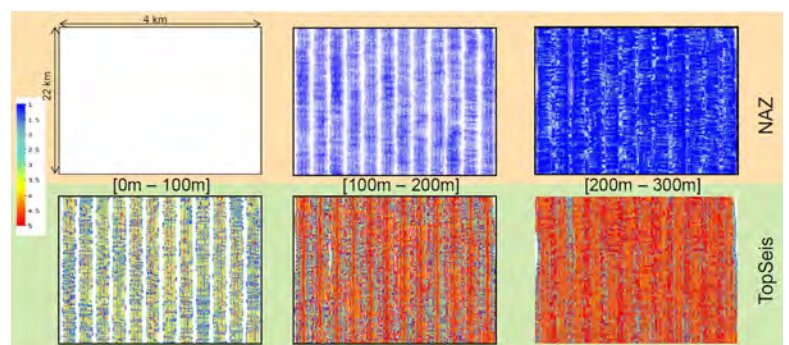**Figure 4.** *TopSeis split-spread shot showing direct wave and receiver ghost.*

Figure 5. *Near-offset distribution for a conventional survey (top) compared to an SSS survey (bottom).*
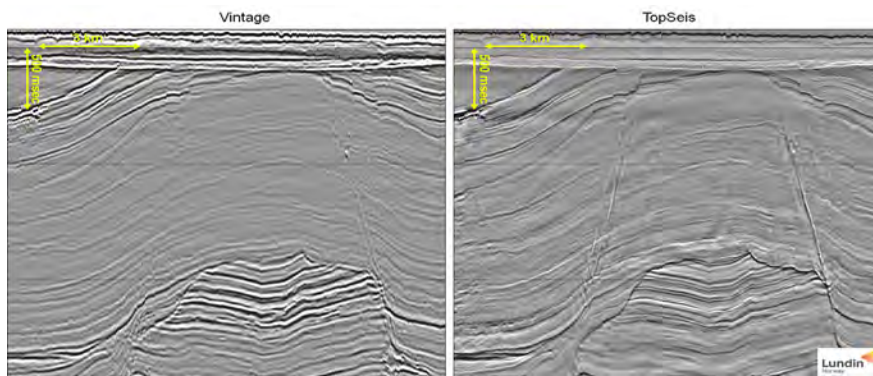
Figure 6. *SSS versus legacy comparison over Loppa High (data courtesy of Lundin Norway).*
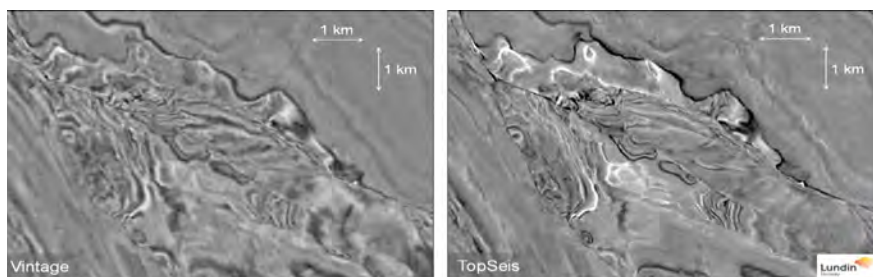

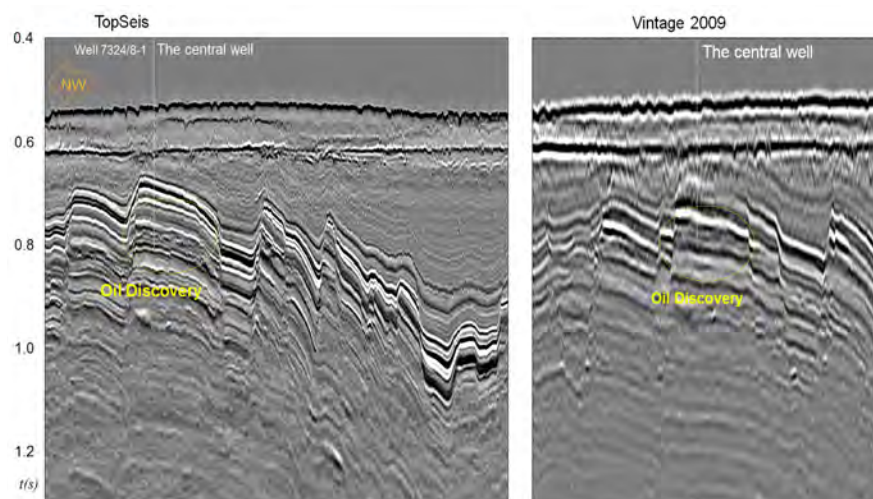**Figure 7.** *Comparison of timeslices at 1450 msec (image courtesy of Lundin Norway).*

Figure 8. *Comparison of TopSeis with existing vintage data over the central well on Wisting (image courtesy of OMV and CGG Multi-Client & New Ventures).*
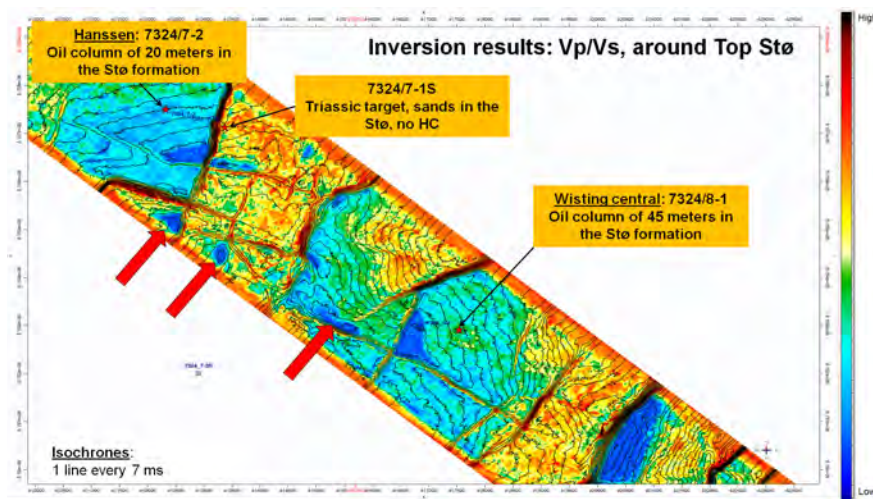

Figure 9. *Elastic inversion result, Vp/Vs around the Top Stø formation (Image courtesy of CGG Multi-Client & New Ventures).*

Conclusion

Initial results in the Barents Sea using the source-over-spread solution have been shown to be very promising, delivering the hoped-for improvements in resolution and illumination as well as clear and credible AVO and inversion results, consistent with the geology. Although designed for the Barents Sea, this solution will have applications in many other areas of the world, where improved near-offset coverage and high spatial resolution is required. The improvements are not restricted to the shallow section, but also extend down to at least 3 sec. Where long offsets are required in addition to the short and zero offsets, sources can also be deployed on the streamer vessel. This might be useful, for example, in areas where short offsets are required for demultiple, at the same time as long offsets are required for imaging deeper targets and for Full Waveform Inversion.

Seismic modelling prior to acquisition enables the optimisation of acquisition parameters required for the imaging challenge at hand, and ensures the correct solution and the best possible subsurface images and data for reservoir characterisation. Close collaboration between geologists, geophysicists and operational experts, combined with the continuous improvement process of modelling, risk assessment and testing, is also fundamental to obtaining successful results. ◼

Acknowledgements

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