



Tu A4 01

Shooting Over the Streamer Spread; a Novel Approach in Seismic Marine Acquisition and Imaging

V. Vinje* (CGG), J.E. Lie (Lundin Norway), V. Danielsen (Lundin Norway), P.E. Dhelle (Lundin Norway), R. Siliqi (CGG), C.I. Nilsen (CGG), E. Hicks (CGG), C. Walters (CGG), A. Camerer (CGG)

Summary

In this paper we present a new marine seismic acquisition technique initially developed to meet the imaging challenges of the Loppa High in the Norwegian Barents Sea. Two seismic vessels operate in tandem; one streamer vessel towing a spread of deep, densely spaced streamers, and one source vessel towing two or more sources. The source vessel is positioned on top of the seismic spread. The unique configuration facilitates acquisition of zero-offset data. This, together with the fact that both negative and positive offsets are recorded, creates a unique illumination density of the subsurface. The solution was developed and tested in close cooperation between CGG and Lundin through a comprehensive modelling and field trial program involving a series of safety and mechanical tests and also a small 3D test survey. The result is high-resolution seismic images in the shallow section and improved signal-to-noise ratio in the deeper sections.



Introduction

Conventional marine seismic surveys typically mobilize a single vessel towing two airgun source arrays in front of a spread of ten or more streamers. The resulting data are narrow-azimuth and lack near offsets due to the gap between the sources and the streamers which can be in the range of 100 to 200 m for the inner cables and up to 500 m for the outer cables. Several solutions, such as coil shooting (French, 1984; Ross, 2008) or advanced multi-vessel operations (Mandroux et al., 2013), have been proposed and deployed to improve azimuth coverage and fold. These are excellent solutions for achieving wide-azimuth data, but they are generally expensive and/or time-consuming, and none of them record zero-offset data, which are critical for imaging shallow targets. This problem is partially addressed in the P-cable solution by putting the source array close to a very narrow cable spread (Ratnett et al., 2015), but the P-cable solution lacks the necessary offset range for AVO analysis and velocity estimation and does not penetrate deep due to a very small source size.

In this paper, we present a tailored solution to this challenge that allows the recording of both zero-offset and split-spread data in an effective and safe way. We call this acquisition solution “*TopSeis*”. This solution was created in close cooperation between Lundin and CGG and is designed to deliver broadband (2.5-200 Hz) imaging of shallow to intermediate targets at depths of up to 3000 m or more.

Motivation and concept: Barents Sea imaging challenges

The Loppa High in the Barents Sea, where the Alta, Gotha and Neiden discoveries have been made, has become a new focus area for Lundin Norway. Here, the main reservoir rocks are karstified carbonates located at depths varying between 400 to 1600 meters below the seabed, as shown in Figure 1.

The Permian carbonate rocks represent a high velocity increase relative to the overlying Triassic sediments (+1500m/s). This velocity-depth setting of the Top Permian implies that the maximum offset at which the reflected energy from the prospective carbonate reservoir level is recorded on the steamers is only in the range of 800 to 2400 meters. A conventional 3D seismic spread is therefore not a suitable layout to record the narrow cone of reflected energy returning from the reservoir in this velocity-depth setting, as indicated by the green ray paths in Figure 1.

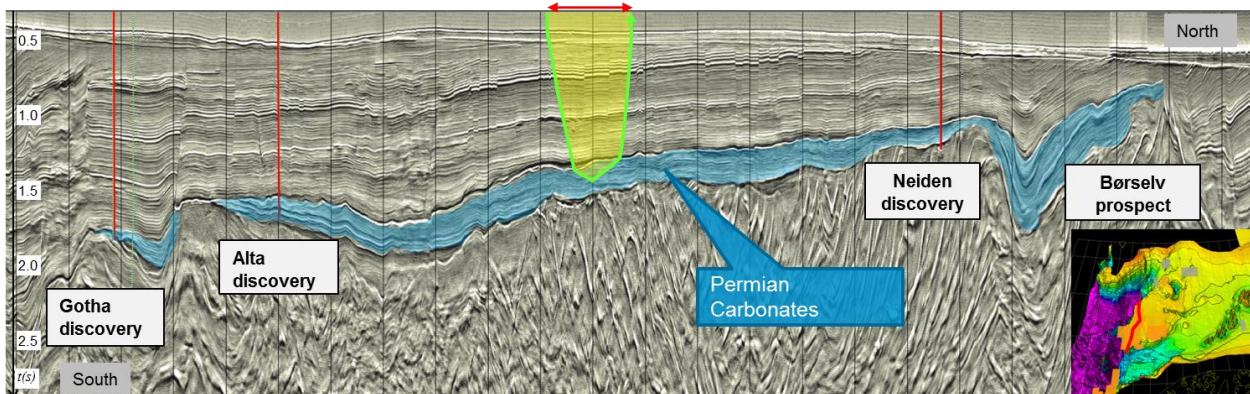


Figure 1: A 90 km regional profile over the Loppa High area in the Barents Sea with discoveries and prospects. These are located at relatively shallow depths and within high-velocity Permian carbonates which restrict the usable offsets considerably as indicated by the green ray path.

The existing "conventional" broadband seismic data in the area does not give the required resolution. In addition, seismic data from the Barents Sea suffer from severe multiple problems as hard and fast Mesozoic sediments are exposed right below the seafloor due to late tertiary tectonic uplift and erosion.

To properly address the seismic imaging issues characteristic of the Loppa High, in 2014 Lundin and CGG started to work on an ideal acquisition geometry that would give a better recording of the important near offsets and improve subsurface illumination.



The result was a split-spread, source-over-cable configuration as show in Figure 2, with a deep cable slanting upwards in both directions. We call this solution “*TopSeis*” and refer to it as SSS (Split Spread Streamer) throughout the rest of this paper.

By moving the sources so that they are positioned directly over deep towed cables we achieve a much better and denser sampling of the narrow cone of energy reflected from our target. By spreading out the sources as far as possible we improve the cross-line shot sampling without losing any acquisition efficiency. By towing the cables in a deep banana-shaped configuration with an optimum shape (Soubaras 2013) we obtain notch diversity enabling robust processing-based deghosting (Wang et al., 2013).

By reducing both cable separation and shot x-separation we achieve an even larger trace density and reduce aliasing problems in the shallow imaging.

The initial challenge was that this configuration had never been tried before and required comprehensive evaluation. Over the last two years, Lundin and CGG have jointly further developed, modelled and tested this concept.

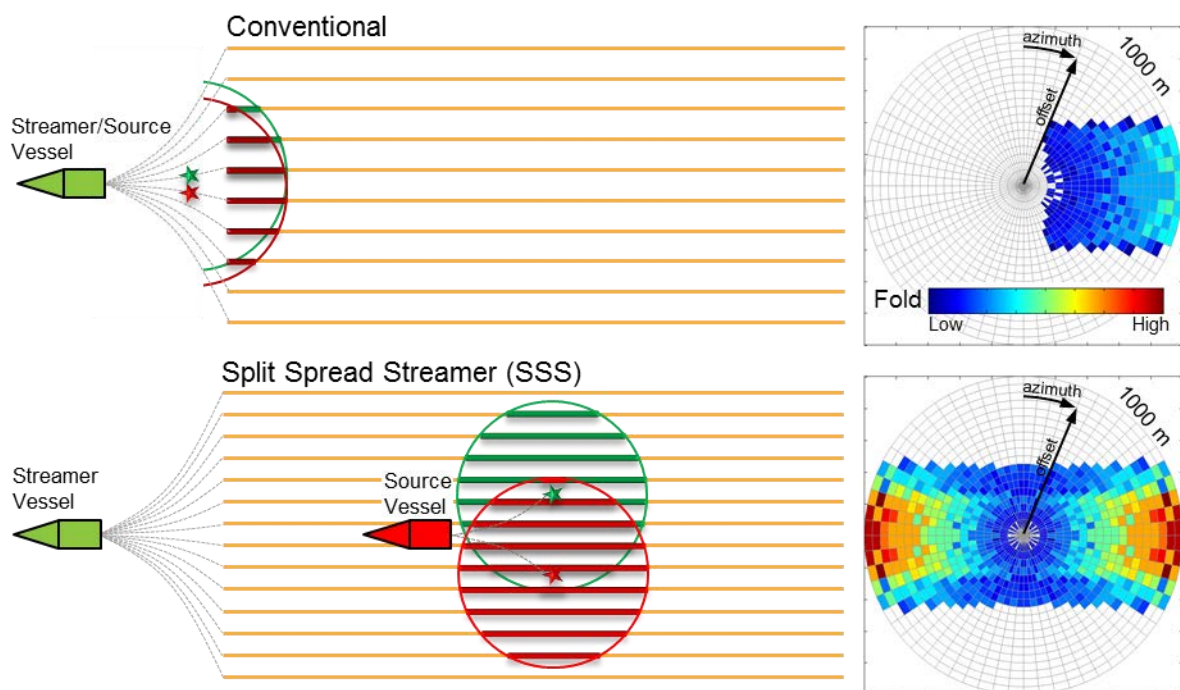


Figure 2: Conventional and SSS marine acquisition configurations with corresponding offset/azimuth rose plots with offsets of up to 1000 m. The highlighted circles show near-offset data surrounding the airgun source arrays. SSS is displayed with two sources here, but three or more sources can be deployed for even larger trace density.

Modelling studies

In order to (i) verify the feasibility of SSS processing and imaging, (ii) test various SSS configurations and (iii) quantify the uplift versus Conventional acquisition, we ran a comprehensive 3D seismic modelling program. Synthetic seismic data from a series of acquisition designs with real noise added were fed into several 3D seismic processing and imaging workflows. The synthetic data were generated by diffraction modelling in a complex reflectivity/velocity model from the Wisting field operated by OMV in the Barents Sea.

The modelling program convinced us that the processing and imaging of SSS data were feasible and provided superior results, improved AVO in the shallow, and also helped us in the detailed design of the SSS configuration.



Field tests

During the second half of 2015 several field tests were carried out to validate the key aspects of SSS: Safety and HSE, as well as navigation and equipment durability. In March 2016, a 2D test line was acquired offshore Gabon and compared with a Conventional acquisition using a BroadSeis configuration. The test confirmed the modelling results and we observed a clear improvement in signal-to-noise ratio and resolution with SSS down to 2.5 s, and especially in the very shallow section.

In June 2016, the first 3D test using SSS was conducted over the Frigg-Gamma structure in the Northern North Sea using seismic vessels acquiring data for CGG's Multi-Client & New Ventures (MCNV) group. A small, rectangular area of 15x3 km extending south-to-north was selected.

Frigg-Gamma is part of the Frigg field which includes five gas fields (now shut down). The water depth in the area is about 120 m. As described by Rykkelid (2014), hydrocarbons in the Frigg sands at a relatively shallow depth of ~2000 msec have leaked up through the apex of the Frigg Gamma structure, creating poor data quality all the way up to the sea bottom.

One month after the SSS acquisition, a new data set was acquired over the same area with high-quality state-of-the-art BroadSeis acquisition as part of CGG's MCNV program. In the following, we refer to this as the "Conventional" solution. The two data sets (SSS and Conventional) were fast-track processed through a similar workflow, including basic denoising, source signature, receiver deghosting, demultiple (SRME, MWD and Radon), regularization/binning and Pre-Stack Time Migration in a simple isotropic velocity model. Both data sets were processed at 2 msec sampling.

In Figure 3 an Inline of the full-stack of Conventional and SSS is compared. This inline is located in-between the Conventional sail lines and is therefore illuminated only by its outer streamers.

The hydrocarbon pathway stretching all the way to the surface is indicated by the red arrows. The superior illumination and zero offsets of SSS reduce noise level and improve imaging at all levels in the image.

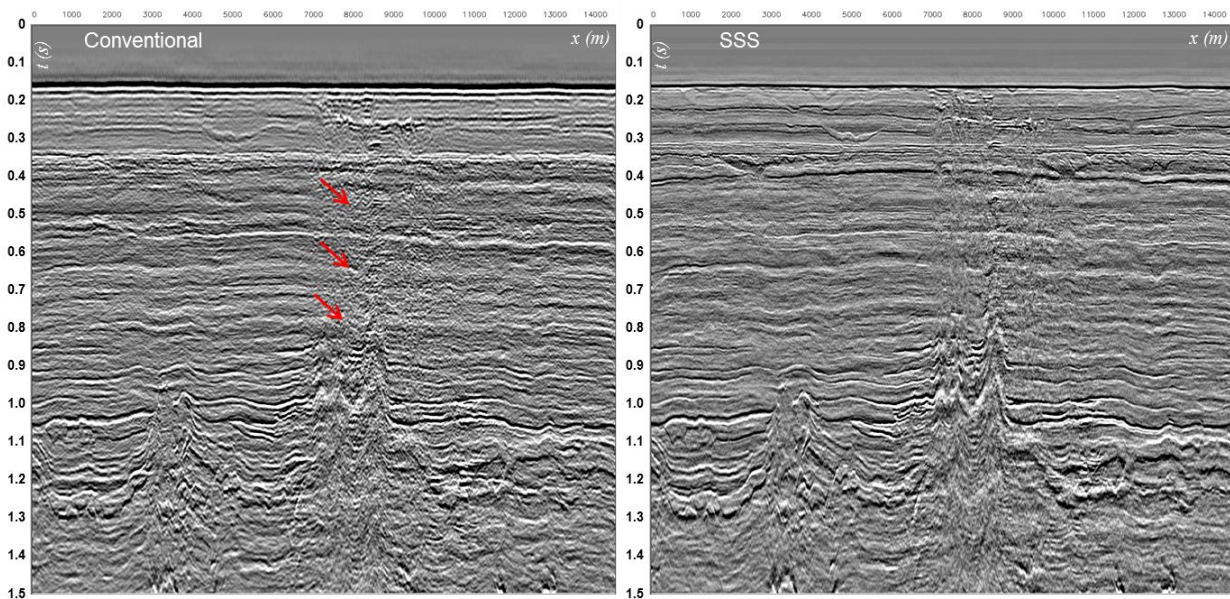


Figure 3: Stacked PSTM image comparing Conventional with SSS with the obscured area caused by the hydrocarbon pathway indicated by red arrows on Conventional. SSS is less noisy and provides better imaging.

A zoom of the shallow part of the inline in Figure 3 is shown in Figure 4.

In this shallow part of the geology there is a complex, interleaved pattern of post-glacial Neogene channels and basins, several gas pockets (soft/white tops and hard/black bases, e.g. by the white arrow) from the hydrocarbon leakage at ~2000 msec and pockmarks along the water bottom.

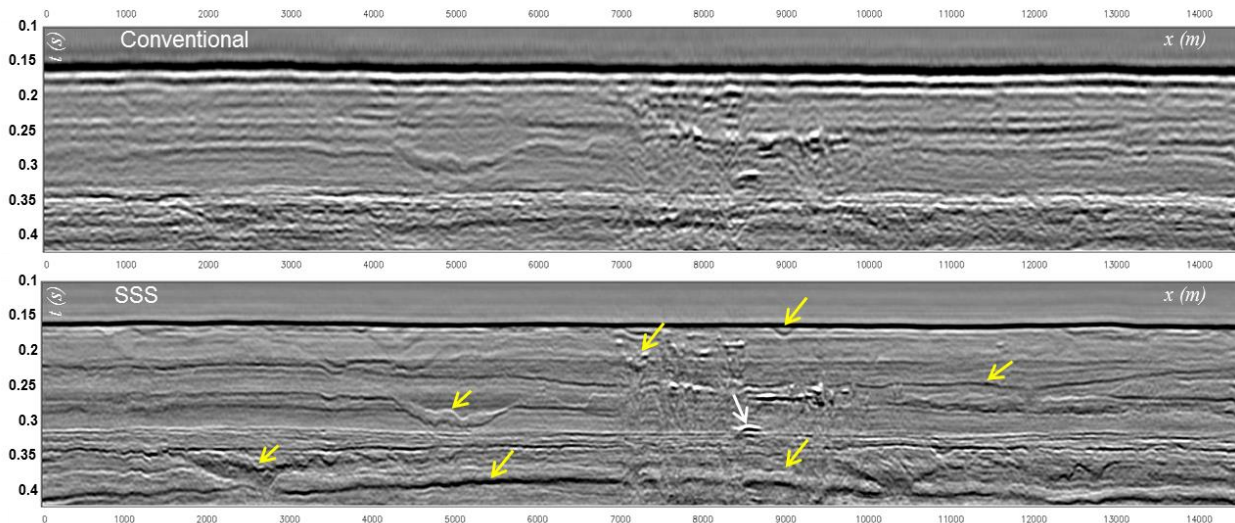


Figure 4: Zoom in the upper 400 msec of the stacked PSTM image comparing Conventional with SSS. The Conventional stack is affected by the lack of near offsets and loses a lot of detail.

The lack of near offsets and poor illumination in the Conventional makes the detailed mapping of these structures very difficult, while SSS brings them out, as indicated by the yellow arrows. The shallow seismic reflectors, including the water bottom at ~162 msec (~122 m), are more stretched in the Conventional than SSS due to the extra zero- and near offsets in SSS.

Conclusions

SSS is a novel marine acquisition and imaging solution where the seismic sources are deployed over the streamer spread with dense cable and source spacing, resulting in improved illumination compared to Conventional systems, especially in the shallow. This is a benefit for both the processing and imaging of the data. Field tests and a comprehensive modelling program have verified that SSS is superior to Conventional marine streamer acquisition with respect to the signal-to-noise ratio of the data, resolution, and AVO, especially in the shallow part of the subsurface. Imaging of deeper targets, down to roughly half the cable length, will also benefit from the superior illumination of SSS.

Acknowledgements

The authors are very grateful to a large number of people who have contributed to this new technology, including the crews on the CGG vessels involved in the SSS tests: *Oceanic Endeavour*, *Geowave Voyager*, *Oceanic Champion* and *Geo Caspian*. We would also like to thank CGG Multi-Client & New Ventures for allowing us to show the 2D and 3D SSS and BroadSeis data sets. Our special thanks go to OMV (Norge) AS for the synthetic Barents Sea model and the fruitful cooperation in developing a modeling approach and learning process that eventually led to the development of SSS.

References

- French, W. [1984] Circular Seismic Acquisition System. *US Patent No. 4,486, 863*.
- Mandroux, F., Ting, C., Montgomery, B., and Lenart, A., [2013] Staggered marine acquisition design for complex imaging. *SEG Technical Program Expanded Abstracts*.
- Ross, R., [2008] Full azimuth imaging using Coil Shooting acquisition. *First Break*, 26.
- Rykkelid, E., and Rundberg, Y. [2014], Seismic Signature of Hydrocarbon Leakage from a Frigg Structure in the North Sea. *EAGE Technical program Expanded Abstracts*
- Ratnett, N.D., Cox, P., Adeloje, G., and T. Travis, T., [2015], "Broadband Processing of P-Cable Data in the Barents Sea", *EAGE Technical program*
- Soubaras, R., [2013] Device and method to determine shape of streamer. *US Patent EP2573593 A2*.
- Wang, P., Ray, S., Peng, C., Li, Y., and Poole, G., [2013] Premigration deghosting for marine streamer data using a bootstrap approach in Tau-P domain. *SEG Technical Program Expanded Abstracts*.