

Th_Dome3_04

Redefining High Resolution Multi-Azimuth Towed Streamer Acquisition on the Norwegian Continental Shelf

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Summary

The introduction of wide-tow multi-sources to seismic streamer vessels enables improved near offset sampling and thus the recording of near incidence angle information needed for shallow target AVO analysis. Long offset streamer tails can be added to the high-resolution acquisition set up, delivering the offsets required for FWI driven velocity model building. Combining the benefits of wide-tow sources with extra-long streamers in addition to acquiring in multiple azimuths can solve exploration challenges in areas like the North Sea. We have chosen the Viking Graben Offshore Norway for a novel high resolution multi-azimuth towed streamer acquisition project starting in 2019. The imaging challenges in the Viking Graben include isolated cemented injectites that have historically resulted in shadow zones at target levels. This case study includes the key technical advances in towed streamer acquisition and how survey design has incorporated these to solve the challenges. The application of the latest technology on a single seismic vessel enables advanced multi-azimuth acquisition at a much lower cost compared to OBN operations. We will present the acquisition concept and the imaging results from the 2019 exploration project.

Introduction

The Viking Graben, Offshore Norway has been chosen for a novel high resolution multi-azimuth towed streamer acquisition project starting in 2019. The Viking Graben is a mature exploration area with several fields and discoveries, where key exploration and field development objectives suffer from illumination and resolution challenges associated with injectites, v-brights (isolated cemented sand injection structure), and thin chalk layers deposited on top of the main reservoir targets.

This paper describes how the latest advances in towed streamer acquisition technology have been combined in a survey design to address the exploration challenges in the Viking Graben. The survey design aimed to deliver longer offsets, improved near-offset sampling, higher trace density, denser spatial sampling, and larger azimuthal coverage in a cost and time effective manner. Innovative and smart technical solutions are required to meet such objectives.

Already in 2018, a survey with a unique variable streamer length configuration was successfully acquired in the Barents Sea. The variable streamer length was tailored to deliver optimal sampling of long offsets for full waveform inversion (FWI) and at the same time dense sampling for high resolution imaging of shallow targets (Naumann et al., 2019, Widmaier et al., 2017). Building on the “two-in-one” experience from the Barents Sea, the survey in the Viking Graben was also acquired with variable streamer length. The vessel towed a 12 x 85m high-density multisensor deep-tow spread with 10 km long streamer tails. In addition, a wide-tow triple source with 225 m separation between outer source arrays was deployed to provide good coverage of the near offset. This was the widest-ever source separation towed by a single streamer vessel on a commercial project. Two azimuths were acquired on top of existing narrow azimuth multisensor data, resulting in a data set with 3 main azimuthal directions in total. Although the processing of the data is ongoing, preliminary results suggest that the acquisition solution will deliver the quality uplift in velocity model building, imaging, and quantitative interpretation the exploration program is aiming for.

Wide-tow Sources for Accurate AVO Analysis

The ongoing transition from single- and dual-source arrays to triple- and multi-source configurations has raised new focus on source separations and the position of the sources relative to the streamer spread. Wider towing of source arrays in front of streamer spreads has become operationally feasible. Modified towing solutions also enable wide-tow source arrays in close to zero distance from the streamer front ends. The geophysical motivation behind distributing multi-sources across the front of a streamer spread is to provide improved near-offset sampling (Widmaier et al., 2017). The near offset coverage is especially relevant for shallower targets, as a standard source set up in front of the center streamers may not provide the near-offset/near angle coverage required for AVO analysis. For the pilot project in the Viking Graben, a triple source with a source separation of 112.5m (i.e., a total separation of 225m) was designed and successfully deployed (Figure 1). Currently this is the widest-ever source separation delivered by a streamer vessel on a commercial project, however development is ongoing and even wider separations are possible.

In the past, the most common way to improve the near-offset coverage has been to reduce the total streamer spread width and the corresponding sail line separation. The latter reduces efficiency by increased survey turnaround and cost. Figure 2 compares the near offset distribution from a vintage survey in the Viking Graben (10 x 75m streamer spread, standard dual source) with the near offset coverage delivered by the 2019 vessel configuration (10 x 85m streamer pre-plot, wide-tow triple source). The sail line separations are 375m and 425m, respectively. The comparison shows that the 2019 pilot survey with wide-tow sources not only improves the near offset coverage but also comes with higher efficiency.



Figure 1 The multi-azimuth acquisition project in the Viking Graben used the widest source separation towed by a single streamer vessel on a commercial project to date.

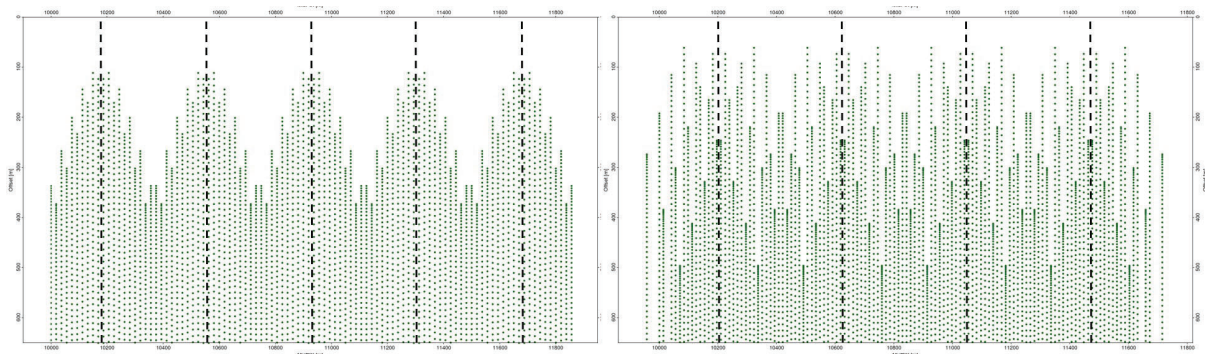


Figure 2 Near-offset distribution for the vintage configuration (left, 10 x 75m streamer spread, dual source standard tow) and the newly acquired data in the Viking Graben (right, 10 x 85m streamer pre-plot, wide-tow triple source). The black dashed lines indicate the centre of each sail line. CMP-X positions are along the x-axis, and the source-receiver offsets are along the y-axis. The wide source configuration provides an improved near offset coverage for shallow AVO analysis.

Longer Offsets for Velocity Model Building

Accurate imaging of the sub surface highly depends on accurate velocity models. The imaging, illumination and resolution challenges in the survey area in the Viking Graben are associated with injectites, v-brights, and thin chalk layers deposited on top of the main reservoir targets. One of the key survey design objectives was to tailor the configuration for full waveform inversion based velocity model building. It is well known that refracted energy and diving waves are recorded at larger offsets than the corresponding reflections from the same geological structures. Recently so called velocity surveys have been introduced (e.g., via OBN acquisition) which are mainly designed to acquire sparse long offset data in order to improve velocity models in complex areas. Imaging can then be done with existing seismic data acquired for imaging purposes. With a variable streamer length configuration, the acquisition of high-density data for imaging can be combined with a velocity survey for full-waveform inversion. A variable streamer length solution was already introduced for an exploration survey in the Barents Sea in 2018 (Naumann et al., 2019, Widmaier et al., 2017).

The variable streamer configuration design for the Viking Graben project comprised 12 streamers. 10 streamers had a length of 6km, in addition 2 streamers were towed with 10km long tails (Figure 3). The variable streamer length was validated by an FWI feasibility study in the survey planning phase. Figure 4 compares the depth sensitivity of the FWI for a vintage velocity model in the area for two different maximum offsets. First results confirm refraction-based FWI provides velocity updates down to reservoir level and below when using offsets up to 10km, thereby enhancing the velocity model.

Streamer spreads with variable cable length are a smart towing solution both with respect to using the streamer inventory with minimum drag while also optimizing the relevant sampling requirements.

Operational complexity increases however relative to standard towing arrangements. For example, line turns result in different radii for the longer streamers relative to the shorter streamers, a consequence of which could be crossover of streamers. In the Viking Graben project, the nominal streamer depth for the shorter streamers was 25 m (to record broadband data with a high signal-to-noise ratio of the low frequencies for FWI and quantitative interpretation) while the longer streamers were kept at 28m – 30m depth at all time to mitigate the tangling risk. The introduction of slight differences in streamer tow depth is not an issue as wavefield separation processing for multisensor streamers is insensitive to local variations in receiver depth.

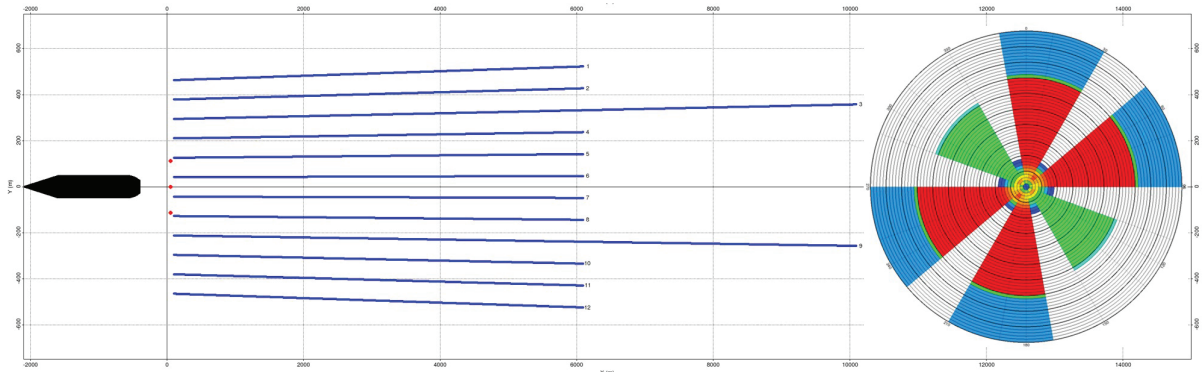


Figure 3 The ‘2 in 1’ configuration for the Viking Graben project provides high density data for imaging and is at the same time a velocity survey. It comprises a 12x85m streamer spread with variable streamer length. Two out of the 12 streamers were deployed with 10km long ‘tails’ for FWI. The figure also shows the wide-tow triple source with 225m total source separation.

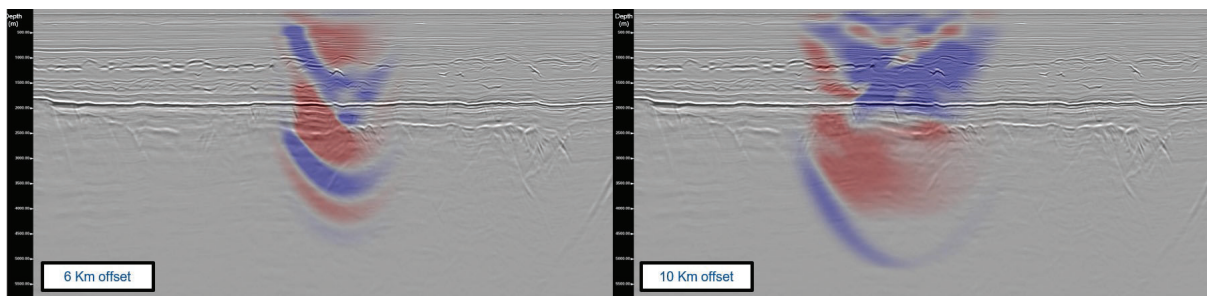


Figure 4 First FWI tests show that refraction-based FWI provides velocity updates to at least 3km depth when using offsets up to 10km.

Cost-effective and Scalable Multi-azimuth Acquisition

Multi-, wide-, and full-azimuth seismic are well-known technologies with applications to areas with increasingly complex geological targets. High fold data with rich azimuth diversity can improve illumination, multiple attenuation, and the signal-to-noise ratio as numerous case histories have demonstrated (e.g., Keggin et al., 2007). Multi-azimuth is in many cases the most flexible and scalable approach in marine seismic as the acquisition template is usually based on a single vessel while most other techniques (including OBN) require more complex multi-vessel operations.

For the acquisition in the Viking Graben in 2019, the multi-azimuth concept was chosen to address the illumination challenge and to enable more advanced velocity model building. The novel approach combined multi-azimuth surveying with the latest acquisition solutions discussed above (wide-tow sources, multi-sources, and long offset tails). Two acquisition directions were acquired, complementary to the existing multisensor seismic data in the survey location. The three data sets combined form the basis for a robust and efficient rich-azimuth acquisition and imaging solution. The resulting rose diagram is shown in Figure 3. Enabled by the wide-tow source configuration, the additional azimuths were acquired with a flexible sail-line separation optimizing between geology-driven near-offset requirements and productivity.

Preliminary beam migration results (Figure 5) using vintage migration velocities show imaging differences for the three azimuths under a v-bright. The biggest image distortion is observed on the azimuth parallel to the v-bright while no distortion is observed on the azimuth perpendicular to it. This indicates that the long offset multi-azimuth data will help to refine the velocities and the image.

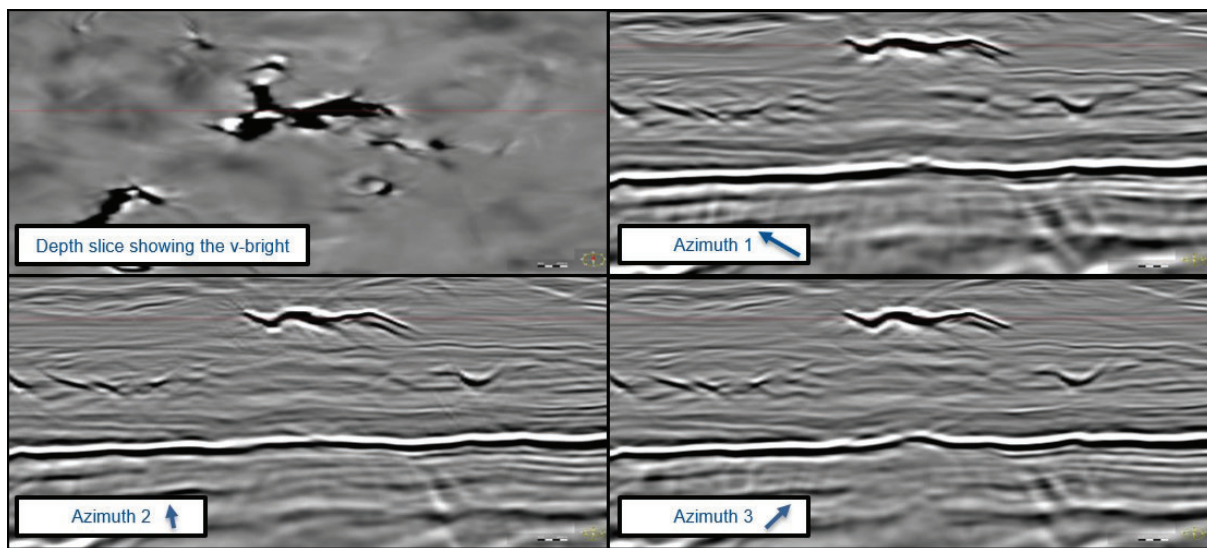


Figure 5 Initial beam results show imaging differences for the three main azimuths under a v-bright. This indicates that multi azimuth illumination will improve the accuracy of the image at target level.

Conclusions

A novel multi-azimuth streamer survey was designed to solve exploration challenges in the Viking Graben and acquired in 2019. The solution included deployment of a wide-tow triple source to address near offset and spatial sampling requirements. In addition, 10km long streamer tails were deployed on two streamers to enable FWI updates at greater depth. Imaging is ongoing and results will be presented at the EAGE 2020 conference. The integrated acquisition and imaging concept can be considered to be a more cost-effective and more efficient route to improved reservoir illumination than via nodes. The concept can be tailored to meet sampling, azimuth and long offset requirements for almost any geological regime. When acquired over legacy surveys, these strategies can significantly upgrade the quality of existing exploration data at moderate cost.

Acknowledgements

The authors thank PGS for permission to publish this paper. A special thanks goes to the Ramform Vanguard crew, the Engineering, Imaging and New Ventures departments for all their hard work on this project.

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