Addressing imaging challenges in the Viking Graben with multi-azimuth acquisition, longer offsets, and wide-tow sources

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Summary

The Viking Graben is a mature exploration area on the Norwegian Continental Shelf that still suffers from illumination and resolution challenges that reprocessing alone cannot solve. In the following case study we demonstrate how those challenges were addressed by a novel towed streamer acquisition project in 2019. The multi-azimuth acquisition solution featured latest advances in towed streamer technology including variable streamer lengths and wide tow sources. The survey delivered improved near-offset sampling, higher trace density, denser spatial sampling, and larger azimuthal coverage in a cost and time effective manner. Imaging results from the ongoing processing project are presented.

Introduction

A novel high-resolution multi-azimuth towed streamer acquisition was acquired by PGS in the Viking Graben, (North Sea, Norway) at the end of the 2019 acquisition season. The Viking Graben is a mature exploration area with several producing fields and discoveries. 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.

A comprehensive survey design study addressed the exploration challenges and recommended longer offsets, improved near-offset sampling, higher trace density, denser spatial sampling, and larger azimuthal coverage compared to legacy data existing in the area. Cost and turnaround were additional constraints that the project team had to take into account during survey planning. Creative and smart acquisition and imaging solutions were required to meet this long list of expectations.

The survey design for the Viking Graben built directly on the positive "two-in-one" acquisition experience from the Barents Sea. An innovative towed streamer multi-client program with a variable streamer length configuration was successfully acquired in the Hammerfest Basin in 2018. 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).

An equivalent variable streamer length solution was then designed for the Viking Graben. The configuration towed by Ramform Vanguard comprised a 12 x 84m high-density multisensor deep-tow spread with 10 km long streamer tails. In addition, the seismic vessel deployed a wide-tow triple source with 225m separation between outer source arrays to achieve good coverage of the near offsets without compromising efficiency. This was the widest-ever source separation towed by a single streamer vessel on a commercial project. Two new survey directions were acquired on top of legacy narrow azimuth multisensor data, resulting in a multi-azimuth broadband data set with three main azimuthal directions in total. Results from the fast track processing demonstrate that the survey design meets the expectations related to velocity model building uplifts, resolution and image quality, that the exploration program is aiming for.

Wide-tow Triple Source for Shallow Imaging and AVO

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.

The more traditional way to improve the near-offset coverage is to reduce the total streamer spread width and therefore the sail line separation. Consequently, the traditional approach increases survey turnaround and cost. Figure 2 directly compares an image of the shallow overburden resulting from a vintage survey in the Viking Graben that was acquired with a 10 x 75m streamer spread and a standard dual source, with the corresponding image enabled by the 2019 novel vessel configuration (10 x 84m streamer pre-plot, wide-tow triple source). The sail line separations are 375m and 422m, respectively. i.e., the 2019 pilot survey with wide-tow sources not only improved the shallow image but also came with higher acquisition efficiency.

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

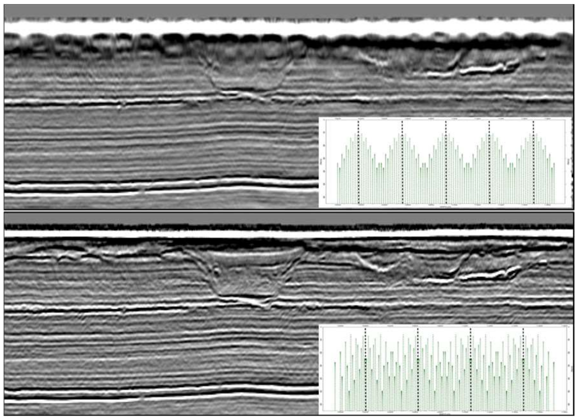

Figure 2: Raw migrated stacks of the shallow overburden overlaid with the corresponding near-offset distribution for the survey from 2011 (top, 10 x 75m streamer spread, standard dual source) and one azimuth of the newly acquired data (bottom, 10 x 84m streamer pre-plot, wide-tow triple source). The wide tow source provides an improved image of the water bottom and shallow channels. The legacy data shows the typical acquisition footprint.

Long Sparse Streamer Tails 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 (i.e., a '2 in 1' seismic acquisition solution). A variable streamer length configuration was previously used for an exploration survey in the Barents Sea in 2018 (Naumann et al., 2019; Widmaier et al., 2017).

The variable streamer configuration for the Viking Graben project comprised 12 multisensor streamers. 10 streamers had a length of 6km, in addition two streamers were towed with 10km long tails (Figure 4). The effectiveness of the variable streamer length (i.e., sparse long offsets) and its depth sensitivity was validated by a FWI feasibility study in the survey-planning phase (O'Dowd et al., 2020).

The depth slice comparison shown in Figure 3 demonstrates how the long streamer tails enhance the velocity model in the survey area. By increasing the offset range for diving wave based FWI from 6km to 10km (i.e., including long offset tails), the resolution and accuracy of the resulting velocity model is significantly improved. Sand bodies become much more visible in the velocity field derived.

Operational Challenges with Streamer Tails

Acquisition configurations with sparse long streamers are a smart towing solution with respect to both drag reduction and optimal utilization of a limited streamer inventory. At

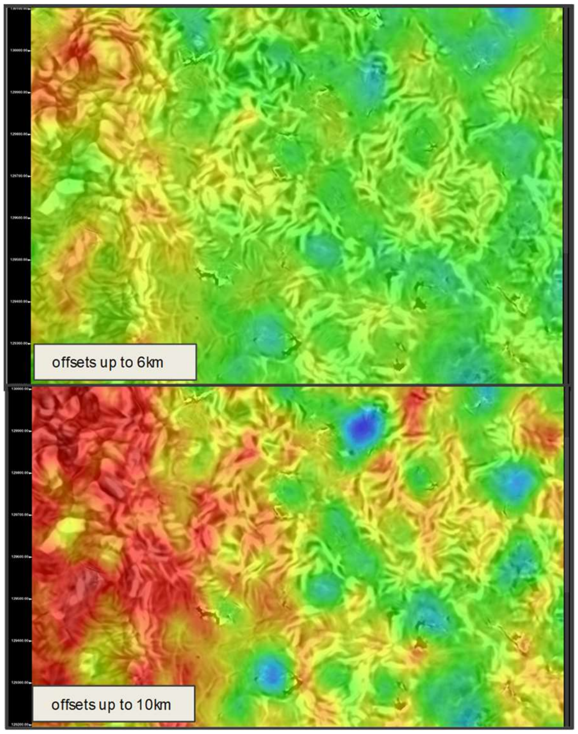

Figure 3: Depth slice at 1200m depth showing early FWI results using offsets up to 6km (top) and up to 10km (bottom). The longer offsets provide higher velolcity model resolution.

the same time, the variable streamer length (dense streamer separation in the front, much sparser separation for the long offset) meet typical geophysical sampling requirements without trading off quality. We should however not ignore the fact that operational complexity may increase compared to more standard towing arrangements. For example, line turns result in different radii for the longer streamers relative to the shorter streamers. Crossover of streamers could be a consequence.

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 times to mitigate the tangling risk. The presence of planned or unplanned differences in streamer tow depth is not an issue as the wavefield separation processing for multisensor streamers is insensitive to local variations in receiver depth. The separated up- and down-going wavefields can be propagated accurately to a common receiver datum in pre-processing.

Cost-effective and Scalable Multi-azimuth Acquisition

Multi-azimuth acquisition was chosen to address the illumination and signal-to-noise ratio related imaging challenges for the Viking Graben survey in 2019, in combination with the latest advanced source and streamer towing solutions as discussed above. It is well known from many case studies that high fold data with rich azimuth diversity can improve illumination, multiple attenuation, and the signal-to-noise ratio especially in areas with complex geological targets or complex overburden. (e.g., Keggin et al., 2007). In comparison with wide-azimuth (WAZ), rich azimuth (RAZ) or even ocean bottom seismic acquisition, multi-azimuth acquisition is in many cases the most flexible and scalable approach in marine seismic as the acquisition template is usually based on a single streamer vessel. Most other techniques (including OBN) require more complex multi-vessel operations.

For the acquisition in the Viking Graben in 2019, two new acquisition directions were acquired, complementary to the existing multisensor seismic data in the survey location (Figure 4). The three data sets combined establish the basis for a robust and efficient rich-azimuth acquisition and imaging solution. The resulting rose diagram is also shown in Figure 4. Enabled by the wide-tow source configuration, the additional azimuths were acquired with a flexible sail-line separation of either 422m or 506m optimizing between geology-driven near-offset requirements and productivity.

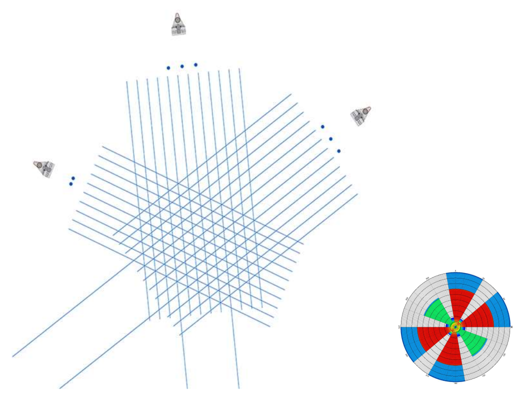

Figure 4: Three azimuth solution for the Viking Graben project: Two new azimuths were acquired in 2019 on top of a 2011 multisensor survey. The 2019 acquisition used wide tow triple sources and a variable streamer length configuration with 10km long offset tails for FWI. A standard acquisition configuraton with dual sources was used for the survey acquired in 2011. The rose diagram (with reciprocity principle applied) resulting from the three combined surveys is shown on the right.

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Early Imaging Results

Early results from the ongoing processing effort confirm that the innovative acquisition solution not only delivers an improvement in velocity model building as discussed above, but also uplifts in image resolution and quality, both shallow and deep. Figure 5 shows a comparison of shallow time slices (220ms two-way travel time) derived from the 2011 survey with the traditional acquisition set up and the combined multi-azimuth data with good near offset coverage and dense sampling from the more recent survey design.

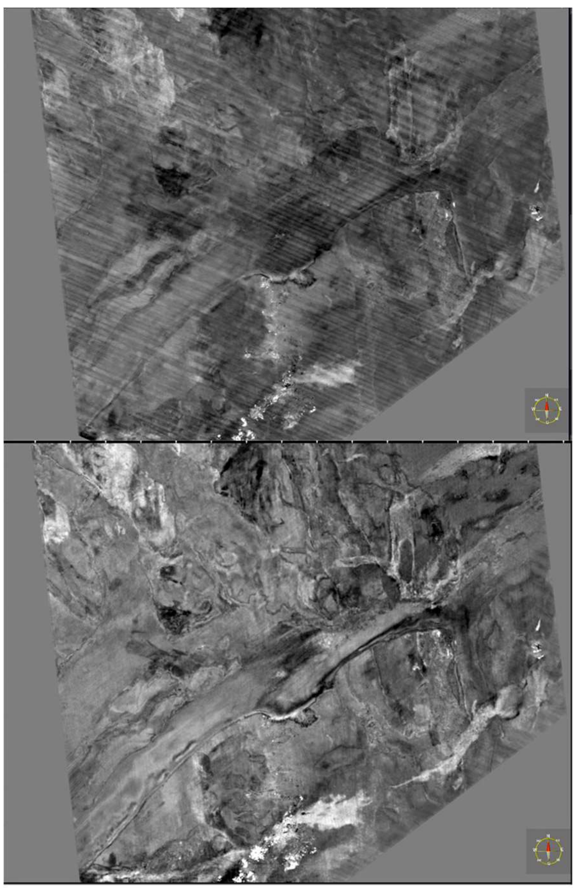

Figure 5: Fast track imaging demonstrates better resolution in the shallow overburden. Time slice at 220ms two-way travel time from the 2011 survey (top, dual source and 10 x 75m streamer spread) compared to the wide tow source multi-azimuth project (bottom).

Cross-sections from the ongoing imaging effort are compared in Figure 6. In addition to the better resolution in the overburden, one can observe improved imaging below injectites, as well as a better S/N ratio around the chalk reflector.

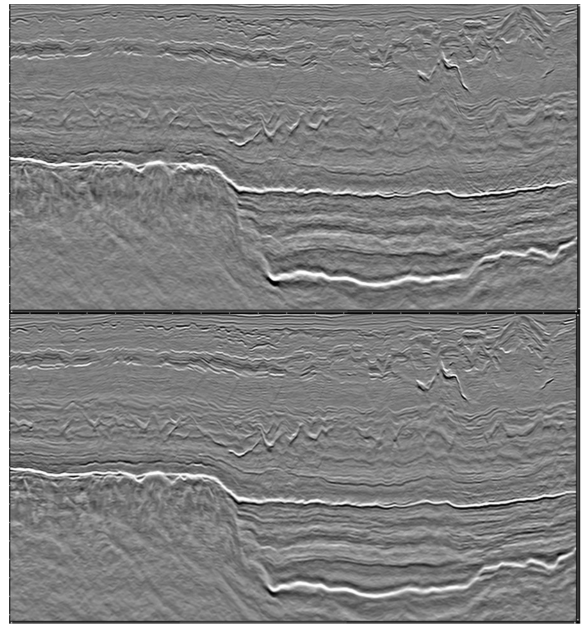

Figure 6: Early seismic imaging results show better resolution of the shallow channels, as well as below injectites and better S/N ratio around chalk. The image on top results from the vintage 2011 configuration (10 x 75m streamer spread, dual source standard tow) and the lower one the newly acquired data (10 x 84m streamer pre-plot, wide-tow triple source).

Conclusions

A unique multi-azimuth streamer survey with a wide tow triple source and variable streamer lengths was acquired in the Viking Graben Offshore Norway in 2019. The survey was designed complementary to existing multisensor data in order to solve exploration challenges in the area. Imaging is ongoing and latest results are presented at the SEG 2020 conference. This integrated and tailor-made acquisition and imaging approach is very cost-effective and enables fast turnaround especially in combination with existing seismic data. Based on proper geophysical survey planning, the concept can be tuned to address complex exploration objectives in almost any geological settings.

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