Maximizing Quality and Efficiency of Multisensor Streamer Seismic with an Ultra-wide Penta Source Configuration

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Summary

An ultra-wide penta source configuration was deployed in combination with a high-density multisensor streamer spread to address shallow exploration targets in the western part of the Norwegian Barents Sea in 2020. The total source separation was 315 m, and is the widest towed by a seismic vessel in a commercial project to date. The survey area was near the Loppa High discovery in water depths from 300 to 400 m. Target depths are as shallow as 600-700 m. The innovative acquisition configuration provided very dense spatial sampling and uniform coverage of the ultra-near offset class for high resolution imaging of shallow exploration targets and geohazards. At the same time, the improved near offset sampling was achieved without compromising acquisition efficiency.

Introduction

Imaging of the near surface in shallow or moderate water depths has traditionally been a challenge in 3D marine seismic acquisition and imaging. Standard seismic vessel configurations with source array set-ups in front of the central streamers do typically not provide the near-offset (or near angle) coverage required as the distance between the sources and the outermost streamers in a spread determines the first fully populated near offset class. This distance is a function of the streamer spread width and can be several hundred meters. The lack of near offsets results in illumination gaps and/or acquisition footprints at the sail-line boundaries in the images of the shallow overburden. The most common method to improve the near-offset coverage in marine streamer seismic is to reduce the streamer spread width and consequently the sail line separation. Reducing the sail line separation compromises however survey efficiency and increases cost. Widmaier et al. (2017) discussed new strategies for high resolution acquisition and imaging of shallow targets. One of the key technical elements was the introduction of wide-tow sources, i.e., the distribution of multi-sources across the front of a streamer spread. In this case study we demonstrate how this strategy was successfully applied in the western part of the Norwegian Barents Sea in 2020.

Source Towing Challenges

It has been common practice in marine towed streamer acquisition that seismic sources in a standard dual source configuration comprise three sub arrays per source. The two source arrays are then typically connected by a separation rope. Equivalent configuration solutions apply to triple source configurations. In the latter case, each source is often configured with two sub arrays as opposed to three.

Towing the source arrays wider apart requires overcoming towing and handling challenges compared to a standard source set up. Three parameters can be adjusted: The first one is the lateral force applied to the source to pull it wide. The second is the opposing force, generally dominated by the hydrodynamic forces acting normal to the source cables when pulled at an angle through the water. The drag of the source array plays a lesser role. The third aspect is the source lay-back. It is not very feasible to tow the source arrays out wide if they are towed close to the vessel. The source separation typically increases with lay-back for a given lateral force.

The first effort that can be made to enlarge the lateral offset of the sources is to remove the source-to-source separation ropes. Without the ropes, the relative positions of the multiple sources must be controlled by an advanced active source steering system. The force required to move the sources out laterally can be generated by deflectors. The available force is dependent on the size and shape of the deflector wings. A more detailed discussion of towing solutions based on recent wide-tow multi-source acquisition projects is provided in Widmaier et al. (2020).

Wide-tow Multi-source Project Barents Sea 2020

Most of our recent wide-tow source experience is based on modified triple source configurations. E.g., wide-tow triple sources have been key survey design elements of cost-effective multi-azimuth programs in the Viking Graben Offshore Norway in 2019 and 2020. Oukili et al. (2020) documented how the near offset rich data enabled accurate imaging of shallow quaternary channels, gas-filled sand mounds and minor scours or plough-marks.

Building on the wide-tow triple source success, the obvious next step was to increase both the number of sources and the source separation. Following a large acquisition program in the Barents Sea last year, 14 sequences were acquired after reconfiguring from a wide-tow triple source (Figure 1) to an ultra-wide penta source setup (Figure 2). The streamer spread and the nominal sail line separation were kept the same. The wide-tow penta source improved both the spatial sampling (i.e., the crossline bin size was reduced) and the near offset coverage without compromising acquisition efficiency.

The multisensor streamer spread consisted of 16 cables of 7 km length towed with a 56.25 m nominal separation, including three 10 km long streamer tails (Figure 3). This non-standard configuration with variable streamer lengths was successfully applied in the Barents Sea already in 2018 and has proven to provide optimal wavefield sampling both for high resolution imaging and for refraction full waveform inversion (FWI) based velocity model building (Naumann et al., 2019).

In the wide-tow triple source case (Figure 1), the separation between adjacent arrays was 93.75 m. The total source separation was 187.5 m. The nominal common midpoint gather (CMP) acquisition grid was 6.25 m x 9.375 m. The inline offset between the sources and the streamer front-end was as little as 65 m.

In the wide-tow penta source case (Figure 2), the separation between adjacent source arrays was 78.75 m, resulting in a total source spread width of 315 m. The corresponding CMP grid was 6.25 m x 5.625 m. The unusual nominal crossline bin size of 5.625 m was a result of not changing the streamer separation in correspondence with the new source setup. A symmetric 6.25 m x 6.25 m grid size is used in processing.

The penta source configuration comprised only one source sub array for sources 1, 2, 4, and 5. However, the center source was configured with two sub arrays (Figure 2). This design was chosen for practical reasons as arrays pull slightly to the side. Connecting the two center sub arrays was the easiest way to make the center source stay in the middle. It also enabled the possibility of emitting more source energy for every 5th shot, which was considered beneficial for refraction FWI as offsets up to 10km were recorded.

The wide tow source solutions led to enhanced near offset coverage. Figure 4 compares the population of the offset class 0 – 100 m (which is seldomly populated in a traditional towed streamer survey) between the wide-tow triple source and the adjacent wide-tow penta source survey using the real navigation data. The ultra-wide penta source provides almost uniform coverage for offsets smaller than 100 m. The typical lack-of-near-offset footprint at sail-line boundaries is no longer present.

Pop-interval and Deblending

While the penta source geometry solved the near offset challenge in crossline direction, shot point sampling in inline direction and fold needed to be addressed too. The pop-interval was consequently reduced from 12.5 m (triple source part of the survey) to 7.5 m for the penta source. The average firing interval for the penta source acquisition consequently became 3 s (Figure 5). In addition, dithering was introduced to allow for deblending and thus imaging for

Figure 1: Ramform Tethys with a wide-tow triple source in the Barents Sea 2020. The separation between adjacent sources arrays was 93.75 m, resulting in 187.5 m total source separation.

Figure 2: Drone picture showing the ultra-wide penta source configuration with 78.75 m source separation and 315 m total source separation, in combination with a high density 16-streamer spread. Note that the source separation is signficantly wider than the streamer separation. For practical reasons, the center source consisted of two source sub arrays.

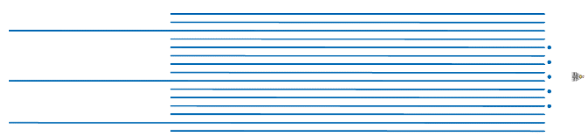

Figure 3: Schematic drawing showing the vessel configuration with the ultra-wide penta source and the 16 x 56.25 m x 7000 m streamer spread. The acquisition solution also included 3 long streamer tails (10km length) for refraction FWI based velocity model building.

deeper exploration targets. An iterative multi-domain approach that simultaneously estimates the signals of all previous and subsequent shots present in the desired output record length was used for the deblending of the overlapping shots. Deblending results are shown in (Figure 6).

Imaging and Results

The imaging workflow beyond deblending was kept simple for a fast-track delivery in early 2021. Denoise, wavefield separation, source deghosting and designature were applied

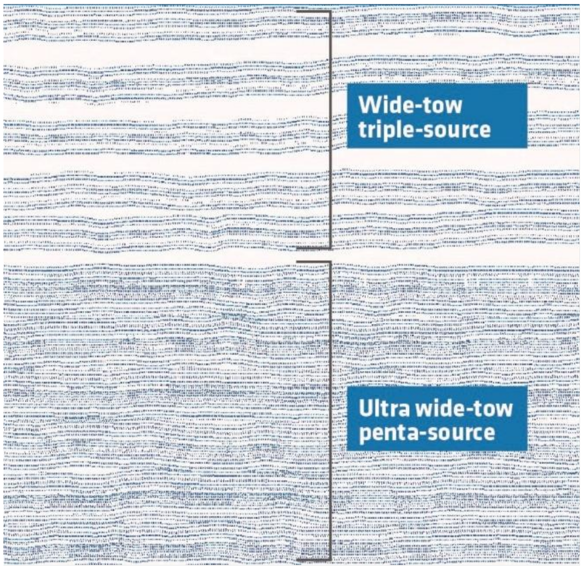

Figure 4: Coverage map for the ultra-near 0-100 m offset class based on the navigation data. While the wide-tow triple source already delivered good ultra-near offset coverage (top), the penta source solution enable uniform near offset sampling with gaps at the sail-line boundary (bottom).

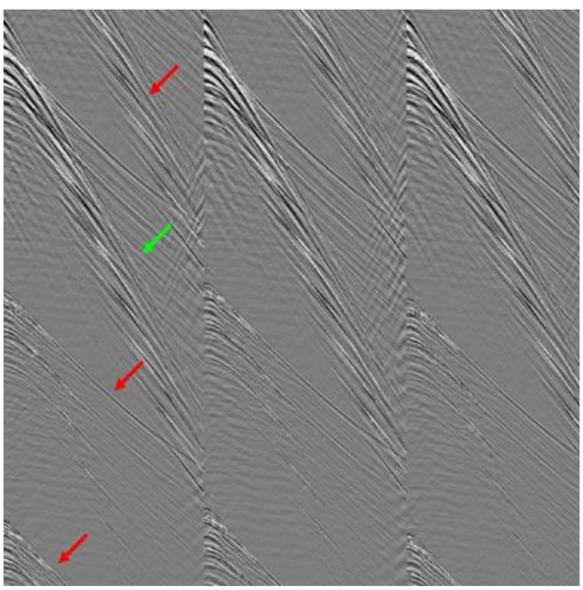

Figure 5: Seismic shot gathers from the wide-tow penta source survey. The record length shown is 7 seconds. Energy from three overlapping shots (indicated by red arrows) in addition to the main signal (green arrow) can be seen. The average pop interval was 3 seconds.

in pre-processing. The preliminary velocity model used for migration was derived with reflection tomography. The rich near offset sampling and the dense source point coverage were beneficial to surface related multiple prediction and suppression, thus providing relatively high quality for a fast-track sequence.

High resolution imaging of the shallow sub surface is critical in the Barents Sea, both with shallow exploration targets and deeper geological structures in mind. The shallow subsurface can typically be characterized by a rough seabed with very high impedance contrasts and complex and strong reflectivity just beneath it. Processing of the wide-tow multi source data delivered high resolution shallow images without the typical acquisition footprint (Figure 7).

Note that the penta source survey was acquired with relatively small source volumes. The penta source was based on single sub arrays with a volume of 1220 cu. in. per source, compared to 3280 cu. in. for the triple source. Consequently, the raw signal of the penta source data is weaker at single trace level, but so is the shot generated noise. In addition, the increased shot effort and the resulting higher trace density combined with spatial sampling however ensure a good signal-to-noise ratio, even for a weaker source.

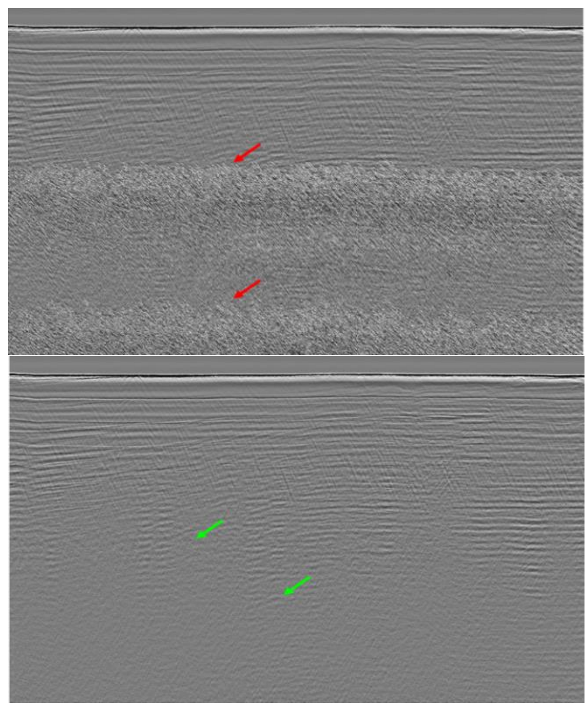

Figure 6: QC stacks before (top) and after (bottom) deblending. The QC stacks have a record length of 7 seconds. The overlapping energy (red arrows) is effectively suppressed, and primary and multiple energy uncovered (green arrows).

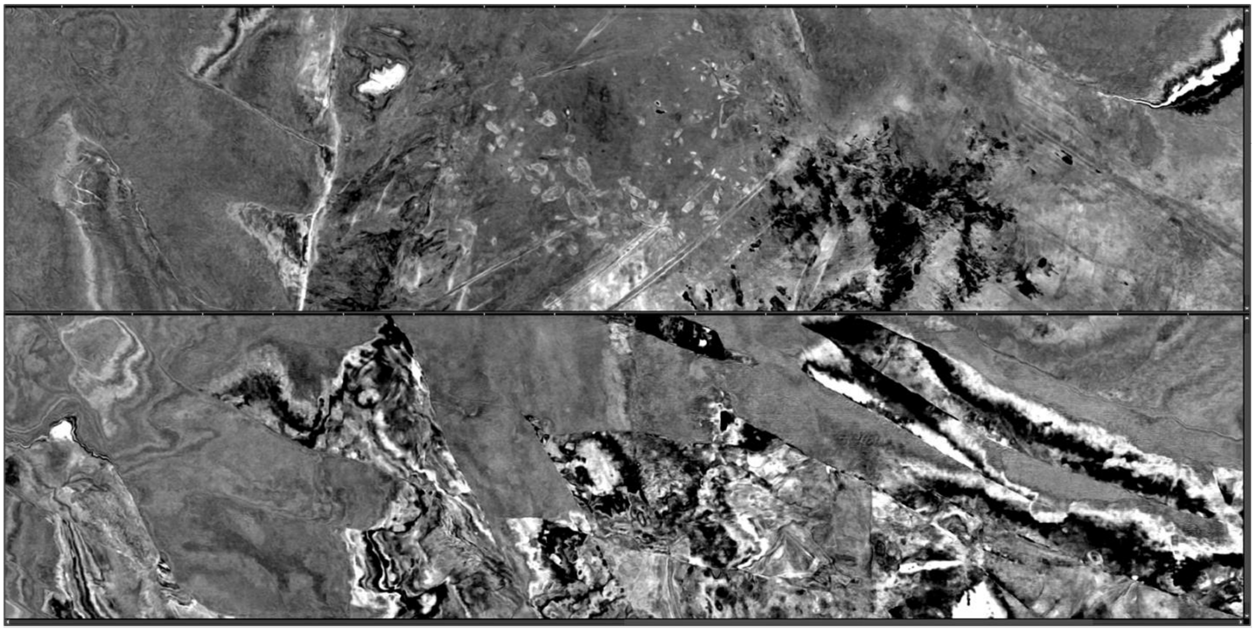

Figure 7: The novel acquisition configuration enabled a processing bin size of 6.25m x 6.25m, uniform coverage of the ultra-near offsets, and high resolution near surface imaging without the typical near-offset gaps at sail-line boundaries. The depth slices above are from 410 m and 468 m below main sea level. Water depth ranges from 300 m to 400 m in the area. The surface dimensions of the depth slices are 21.9 km x 5.3 km.

Naturally, the very dense 6.25 m x 6.25 m spatial grid is not required for imaging of deeper targets. Relaxing the grid dimensions results in increased fold and thus can maintain a high signal to noise ratio for larger depths. Full integrity processing for the penta source and adjacent triple source survey is ongoing and expected to complete later this year. Final processing results will allow direct quantitative comparisons of image and velocity model quality from shallow to deep.

Alternative Applications

The combination of wide-tow multi-source configurations with high density streamer spreads (including long offset tails) enable accurate imaging from very shallow targets and geohazards to deep geological structures. The acquisition configuration can also be tailored (i.e., scaled down) towards specialized near surface high resolution 3D studies such as deep-sea mineral exploration or offshore wind farm site surveying. Near offset, long offset, and 3D spatial sampling requirements will depend on water depth and resolution requirements.

Conclusions

A novel high-resolution survey was acquired by combining a high-density multisensor streamer spread with an ultra-wide penta source in the Barents Sea in 2020. The resulting data has dense spatial sampling and uniform coverage of the very near offsets. The wide-tow multi-source set up enabled the acquisition of the data without compromising efficiency compared to a triple source survey. Processing of the data resulted in high-quality images of shallow targets below the seabed without the typical acquisition footprint. Although the survey was acquired with relatively small source volumes, the high trace density and good spatial sampling ensured excellent signal-to-noise ratio.

The wide-tow penta source with 315 m total source separation remains the widest source set up towed by a streamer vessel on a commercial project to date. Further development of these smart and cost effective advanced marine acquisition solutions and the corresponding imaging technology is ongoing.

Acknowledgements

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