# Recent advances with wide-tow multi-sources in marine seismic streamer acquisition and imaging

Martin Widmaier[1*], Rune Tønnessen[1], Julien Oukili[1] and Carine Roalkvam[1] share progress made with towing marine sources wider to enable better acquisition efficiency and improved near offset coverage for more accurate seismic images.

## Introduction

Very recently, PGS completed its sixth towed-streamer marine seismic acquisition project with a novel wide-tow multi-source configuration. The wide-tow source solutions were applied in two advanced multi-azimuth (MAZ) programmes in the North Sea, offshore Norway; in exploration surveys offshore Australia and the UK; and most recently during two high-resolution surveys in the Barents Sea. These wide-tow source acquisition programmes achieved several industry records, new geophysical benchmarks were set, and the near offset rich data built the basis for new processing approaches. This article discusses current experiences with wide-tow sources in towed streamer marine seismic acquisition, and the corresponding uplifts in seismic data quality and acquisition efficiency.

## Wide-tow sources for better near offset coverage and efficiency

Traditionally, marine seismic sources have been towed in front of the two innermost streamers of a streamer spread. The standard source separation for a typical towed-streamer seismic survey is defined by dividing the streamer separation by the number of source arrays. However, a wider separation between the source arrays can improve the near offset coverage without sacrificing survey efficiency. This is especially relevant for shallow water areas with relatively shallow targets, where good near offset or near angle coverage is required for robust AVO analysis or for effective multiple removal.

Wider tow of sources also extends the common midpoint (CMP) coverage per sail line, i.e., the so-called 'CMP-brush' becomes wider. The number of CMP lines or sublines acquired per sail line is equal to the product of the number of source arrays and the number of streamers. The separations of the source arrays and the streamers do not have a direct impact on the number of CMP lines acquired, but do control the CMP line spacing. Thus, the wider 'CMP brush' that results from a wider source separation is the result of partially sparser spatial sampling in a crossline direction, and not the outcome of acquiring additional data. It is common practice to acquire marine streamer seismic data with homogeneous fold and regular spatial sampling, although there are exceptions, such as compressive sensing-based survey design (Mosher et al., 2017), or Fresnel zone-driven configurations (Hager et al., 2015). When combining standard streamer spreads with wide-tow sources, regular sampling can be achieved by means of overlapping the CMP brushes. Ultimately, the combination of wide-tow multi-source configurations with high streamer counts enables higher acquisition efficiency without trading off near offset coverage or sacrificing regular cross line sampling (Figure 1). A detailed introduction to wide-tow sources and

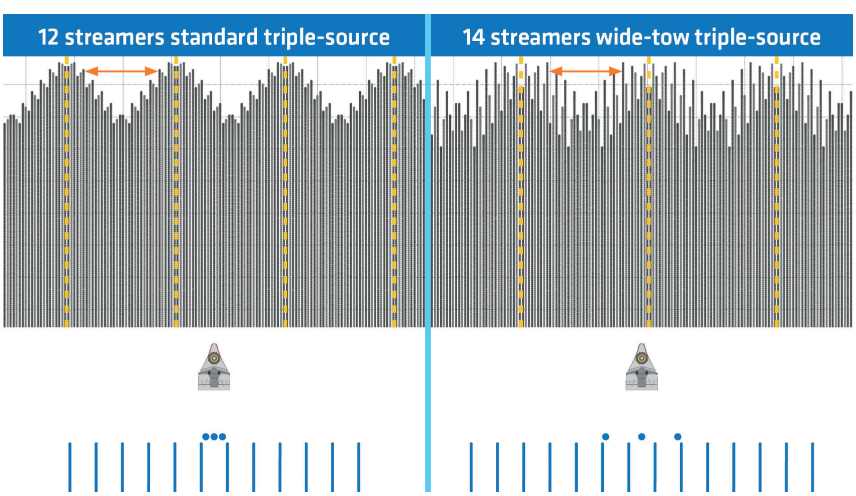


**Figure 1** CMP coverage comparison between a 12-streamer spread with a standard triple source set-up (left) and a 14-streamer spread with a wide-tow triple source set-up (right). The x-axis is crossline direction, and the y-axis is offset. The yellow dashed lines represent the sail lines. The 14-streamer solution provides 17% higher efficiency. When combined with wide-tow sources, the near offset coverage is not compromised, and in this example even slightly improved (indicated by the arrows).

[1] PGS
[*] Corresponding author, E-mail: Martin.Widmaier@pgs.com
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| Count | Year | Country | Streamer Count | Streamer Separation [m] | Source Count | XL Bin Size [m] | Standard Source Sep. [m] | Wide-Tow Source Sep. [m] | Total Source Spread Width [m] |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2019 | Australia | 12 | 75.00 | 2 | 18.750 | 37.5 | 112.50 | 112.50 |
| 2 | 2019 | Norway | 12 | 84.38 | 3 | 14.063 | 28.13 | 112.50 | 225.00 |
| 3 | 2020 | Norway | 14 | 93.75 | 3 | 15.625 | 31.25 | 125.00 | 250.00 |
| 4 | 2020 | UK | 12 | 93.75 | 3 | 15.625 | 31.25 | 62.50 | 125.00 |
| 5 | 2020 | Norway | 16 | 56.25 | 3 | 9.375 | 18.75 | 93.75 | 187.50 |
| 6 | 2020 | Norway | 16 | 56.25 | 5 | 5.625 | 18.75 | 78.75 | 315.00 |

**Table 1** Overview of the six wide-tow multi-source projects acquired in 2019 and 2020. The standard source separation that normally belongs to the respective streamer spacing is listed to illustrate the source separation increase deployed in these novel case studies.

novel marine acquisition geometries can be found in articles by Widmaier et al. (2019), Widmaier et al. (2017), and Long (2017).

## Extensive experience with six wide-tow source surveys in 2019 and 2020

*Ramform Hyperion* acquired the first commercial survey with a wide-tow source operated by a streamer vessel offshore Australia in 2019 (Table 1, row 1). A dual source set-up with 112.5 m source separation was moved over the streamer front ends to acquire zero offset traces. In the same year, *Ramform Vanguard* piloted a new and novel approach to multi-azimuth streamer acquisition (Widmaier et al., 2020). The multi-azimuth survey (MAZ) was acquired in the Viking Graben, offshore Norway, and comprised both long streamer tails for full waveform inversion (FWI) based velocity model building (using refracted waves), as well as wide-tow triple source to enable both optimal near offset coverage and improved acquisition turnaround. The source separation for the triple source was 2 x 112.5 m, i.e., 225 m total separation (Table 1, row 2). In 2019, this was the widest source separation ever towed from a single streamer vessel. *Ramform Vanguard* returned to the Viking Graben earlier this year and extended the multi-client MAZ programme. This year, the triple source separation was 2 x 125 m, resulting in 250 m total separation throughout the survey (Table 1, row 3). The vessel improved her own source-tow record and acquired high quality multi-azimuth data in an innovative and cost-effective manner. Imaging results from these surveys are already available, and demonstrate the effectiveness and value generation of modern acquisition solutions (Oukili et al., 2020).

In addition, the high-capacity vessel *Ramform Tethys* has been acquiring several seismic exploration programmes with wide-tow multi-source solutions in Northern Europe this year (Table 1, row 4, 5, and 6). The first project was a survey in the East Shetlands Basin, UK, followed by two projects in the Hammerfest Basin, Norwegian Barents Sea. For the Barents Sea programmes, a high-density 16 x 56.25 m streamer spread was first combined with a triple source to provide new broadband seismic data with dense spatial sampling and a high trace density. The total separation of the triple source was 187.5 m, resulting in a source spread width wider than the span of the four innermost streamers. The wide-tow triple source was configured with only 65 m inline distance to the streamer front ends to ensure good near offset coverage both in inline and crossline directions. Again, the solution designed and deployed for the Hammerfest Basin 2020 included three long streamer tails for FWI applications. The nominal towing depth for multisensor streamer spreads with variable streamer length in Northern Europe is currently in the 25 m to 28 m depth range. The deep tow of the multisensor streamers ensures superior signal-to-noise ratio across the entire seismic bandwidth.

The ultimate milestone for wide-tow multi-source acquisition has recently been achieved in the Barents Sea. During September 2020, *Ramform Tethys* conducted a seismic survey with a penta source configuration delivering 315 m total source separation in front of the streamer spread (Figure 2).

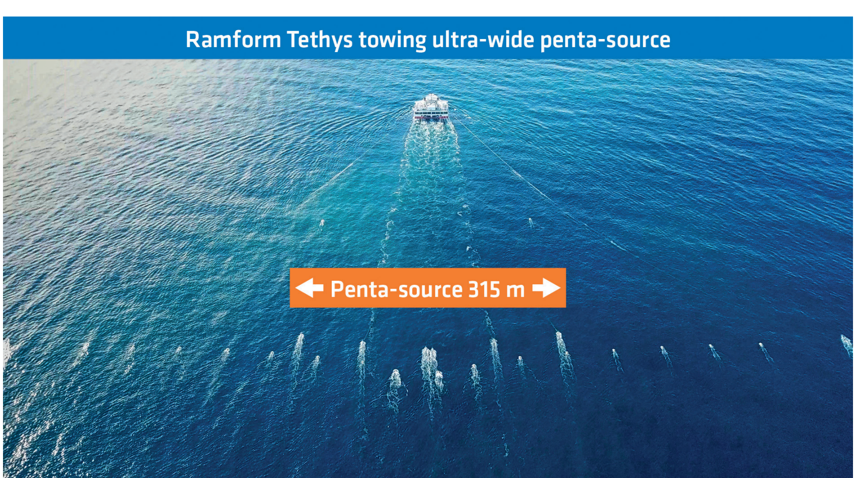


**Figure 2** Wide-tow penta source configuration with 78.75 m source separation and 315 m total source separation in combination with a high density 16-streamer spread.

## Towing and handling challenges

Traditionally, seismic sources have comprised three sub arrays connected by separation ropes. The two source arrays in a dual-source configuration would then normally be connected by a separation rope. For the sake of source steering, the two connected sources are most often considered one body, aiming to position the midpoint of the two sources at desired pre-plot source locations. The same configuration principles are generally applied for triple-source configurations, but then each source is often two sub (i.e., two sub arrays instead of two source arrays) arrays as opposed to three.

To achieve the desired aim of towing the sources wider apart, there are three parameters that can be adjusted. The first, and most obvious, 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; essentially how far the source is towed behind the vessel. In general, the source separation gets wider the longer the lay-back.

## Implementing wide-tow source steering

The first and most obvious effort made to increase the lateral offset of the sources is to remove the source-to-source separation ropes that act contrary to the lateral deflection forces. However, by doing this there is no means of controlling the separation between the sources. To mitigate this, we have further developed our source steering system to enable steering of multiple sources and control of their relative positions. Towing wider most often means more sources. As most seismic vessels are equipped with six source arrays, this will ultimately lead to a limit of one sub array per source for a six source wide-tow configuration. However, during acquisition of the penta-source survey, the centre source comprised two arrays; primarily for practical reasons since arrays pull slightly to the side, and connecting the two centre arrays together was the easiest way to make the centre source stay in the centre (Figure 2). It also enabled the possibility of emitting a larger volume shot for every 5$^{th}$ shot, which was considered beneficial for FWI.

## Adjustments needed to source umbilicals and deflectors

Source cables are not normally specified and built to be pulled at a significant angle through the water, unlike, for example, streamer lead-in cables. When moving at an angle through the water the cables will be exposed to vortex induced vibrations (VIV) that take place when the frequency of the water vortices that are generated behind the cable match the Eigen-frequency of the cable itself, hence triggering a resonance response. These vibrations may be quite violent and a means of suppressing the vibrations should be considered, both for minimizing cable fatigue and also as a means of minimizing the hydrodynamic cross-flow force. The cross-flow force on a cable exposed to VIV may easily reach two to three times that of a non-vibrating cable. Furthermore, source cables used in wide source towing will be subject to higher tension than they experience in narrow source towing. Not only does the static tension increase, but the tension response as a result of wave dynamic loading from sea waves becomes larger when the mean tension is higher. An operational consequence of this may require a trade-off between vessel speed (which affects the loading) and sea-state.

Different operators have used alternative approaches to deflect the sources laterally. Separation lines between the source and a streamer lead-in have been used by some. Rigid source arrays have been towed at an angle relative to the sail line generating a side force and some operators have implemented deflectors on the source arrays. The deflectors generate a lateral force bringing the source out laterally. Obviously, the available force is dependent on the size and shape of the deflector wings. As the deflectors are also used as part of a closed loop control system, it is important to leave some steering capacity to the control part, and not spend all the capacity on getting the source out to the desired nominal lateral position. One important point is that a deflector system applied to source arrays on a streamer vessel must be able to go to zero force. The reason is, during the deployment and recovery phase, the source arrays need to be towed straight behind the vessel in order to be able to pass the opening between where the lead-ins adjacent to the gun slip enters the sea without colliding with the lead-ins.

## The role of source lay-back

Source lay-back is also important. Obviously, it is very difficult to tow the source arrays out wide if they are towed very close to the vessel. Normally, for a given lateral force, the source separation increases with lay-back until it reaches a maximum, beyond which the source separation starts to decrease again. The available source cable length can sometimes be a limitation. Another limiting factor is buoyancy of the source array as the source cables are normally quite heavy and deploying too much cable may cause the arrays to sink.

The wide source requirement is often accompanied by a strict requirement on inline seismic offset, with a desire to



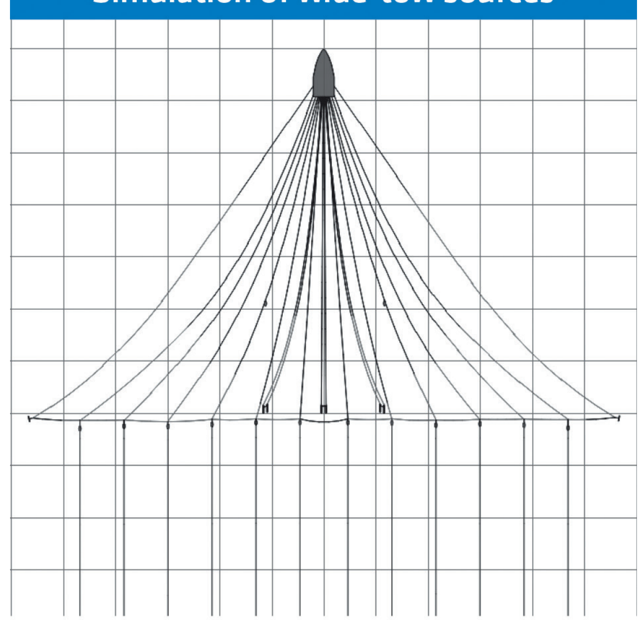

**Figure 3** Dynamic streamer array towing simulation of the wide-tow triple source configuration applied in the 2019 Viking Graben survey (Table 1, row 2). Triple source with 112.5 m source separation and 65 m inline offset.

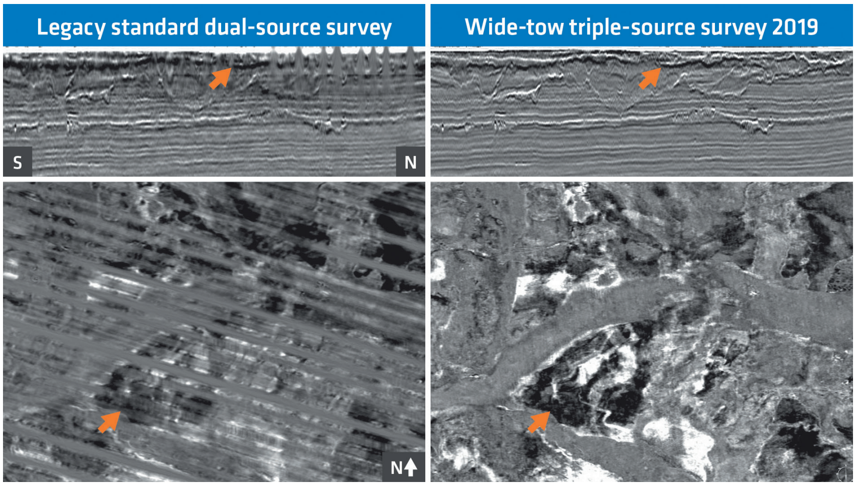


**Figure 4**: Comparison of time slices at ca.200 ms two-way traveltime and (inset) shallow seismic cross sections. The example that shows significant footprints and illumination gaps (left) was acquired with a standard dual source and a 10 x 75 m streamer spread in 2011. The wide-tow triple source configuration used in the same area in 2019 (Table 1, row 2) enabled seamless shallow imaging and higher efficiency. The orange arrows indicate the respective positions of the slices and the cross-sections.

achieve as close to zero offset as possible. This requires towing the source arrays very close to the streamer fronts and matching the lay-back of the streamer front ends with that of the source, while at the same time achieving as long a source lay-back as possible to facilitate wide source towing. To achieve this, good towing simulation tools are needed together with well validated input data for the deflectors applied to the streamer spread (Figure 3).

## Wide-tow sources improve image quality and consistency

Thanks to the increasing flexibility of towing solutions, and the increase in the number of sources and the total source spread width, the imaging of the very shallow subsurface is now possible during 3D exploration grade surveys. Optimizing near offset sampling has obvious benefits for resolving illumination and resolution challenges; particularly in areas where the impedance contrast at the seafloor limits the amount of sub-critical reflection energy. Processes such as demultiple, velocity estimation, and quality control (QC), directly benefit, and thereby enhance the seismic imaging quality at greater depths.

Processing of wide-tow source data is for the most part unchanged, if the relevant signal processing algorithms take into account the real position of the sources relative to the streamer spread, as is the case in the examples shown here. With adequate data preparation, another benefit of the wide-tow sources is the richer azimuth distribution obtained with a single vessel pass; which implicitly can provide greater illumination of complex subsurface environments. Likewise, it yields a better lateral distribution of source lines; which typically reduces the risk of introducing footprints in seismic attributes maps.

## Case study examples from offshore Norway

The first series of examples illustrate the case of the multi-azimuth solutions mentioned earlier (Viking Graben 2019 and 2020) where wide-tow triple source solutions were employed to resolve targets from shallow to deep. Figure 4 illustrates the results of the 2019 set-up, with significant uplifts in near surface illumination from the wide-tow solution compared to a standard narrow-tow configuration. The wide tow image exhibits a number of small-scale features which could not be recovered by data interpolation with the legacy dataset.

The multi-azimuth programme continued with a set-up providing even higher acquisition efficiency in 2020 (Table 1, row 3). As illustrated in Figure 5, imaging of the water bottom and very shallow overburden reveals several structural details as well as possible shallow gas. Although good near offset coverage may be expected from a single survey direction acquired with wide-tow sources, using all the azimuths in processing proves to be robust, and produces an image practically free of acquisition footprint. The data are processed and migrated at a 2 ms sampling interval and output on a 6.25 m x 6.25 m grid. Although this area has no prospectivity in the upper several hundred metres, the information is essential for future field development, as shallow hazard identification is a prerequisite prior to drilling operations. In addition, interpreters benefit from a full 3D image as opposed to 2D site survey investigations, thus saving time, money and providing more reliable attributes.

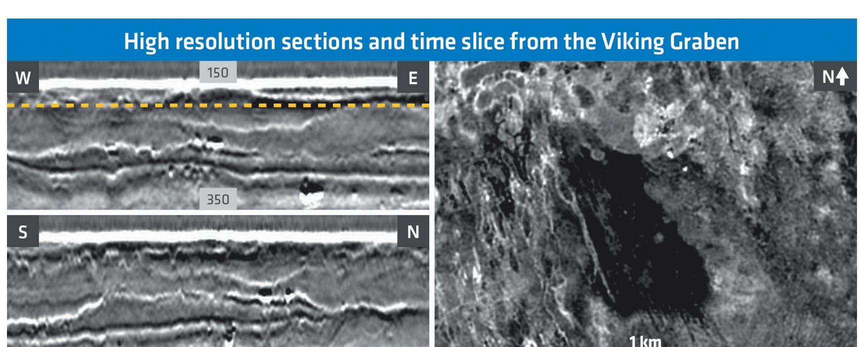


**Figure 5** High-resolution shallow images generated from a multi-azimuth programme in 2020 using wide-tow triple sources (Table 1, row 3). The imaging bin size is 6.25 m x 6.25 m. The dashed yellow line (top left section) indicates the position of the time slice. The image is free of distortions related to missing near offset information, which are often found in standard dual-source data.

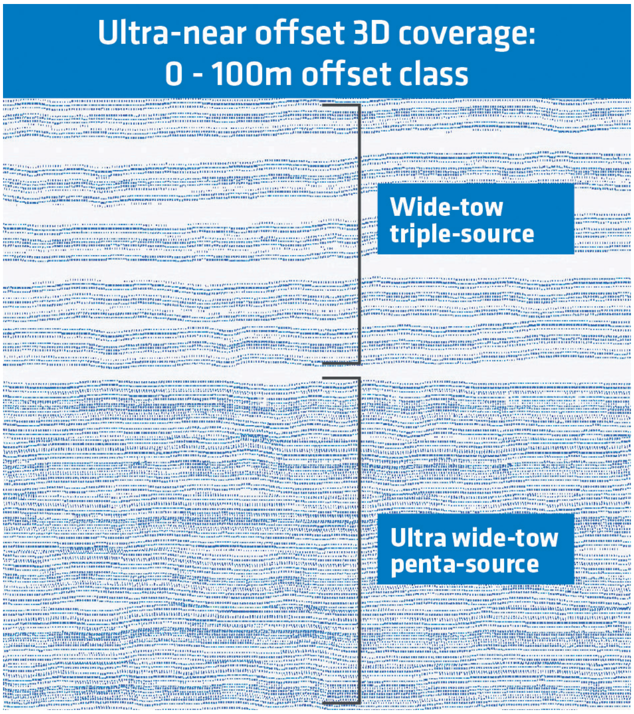


**Figure 6** Ultra-near offset coverage calculated from the navigation data belonging to two adjacent wide-tow source surveys in the Barents Sea in 2020 (Table 1, row 5 and 6). The ultra-wide tow penta-source solution delivers almost gap-free coverage of the first offset class, while keeping the same efficiency.

In the examples from two surveys in the Barents Sea (Table 1, row 5 and 6), reservoir targets can be found above the first water bottom multiples. Near offset information is critical for accurately delineating prospects and to conduct AVO studies. Figure 6 illustrates the gain in ultra-near offset coverage achieved with the respective wide-tow triple and penta-source configurations. The ultra-wide penta-source solution demonstrates excellent coverage which is free of gaps between sail lines. Details of the shallow complex geology are revealed both on time slices and cross sections, including diffractions (Figure 7). The comparison exemplifies how modern towed-streamer acquisition can be tailored to meet the geophysical and geological challenges in a time and cost-effective manner. The processing and velocity model building have started and the first imaging results are expected by the end of 2020.

## Conclusions

Wide-tow multi-sources have been successfully introduced to marine towed-streamer seismic acquisition, with six commercial projects conducted during the last two years. The transition from standard source configurations to wider separations has been enabled by modified towing solutions for seismic source arrays. The benefits of wide-tow source configurations are two-fold: Wide-tow sources enable higher streamer counts, and thus higher acquisition efficiency without comprising the near offset coverage.

If the streamer spread is kept constant and the sources are spread out, the near offset coverage can be improved without sacrificing efficiency and increasing cost. Imaging workflows and products benefit from modern data with rich near offset coverage.

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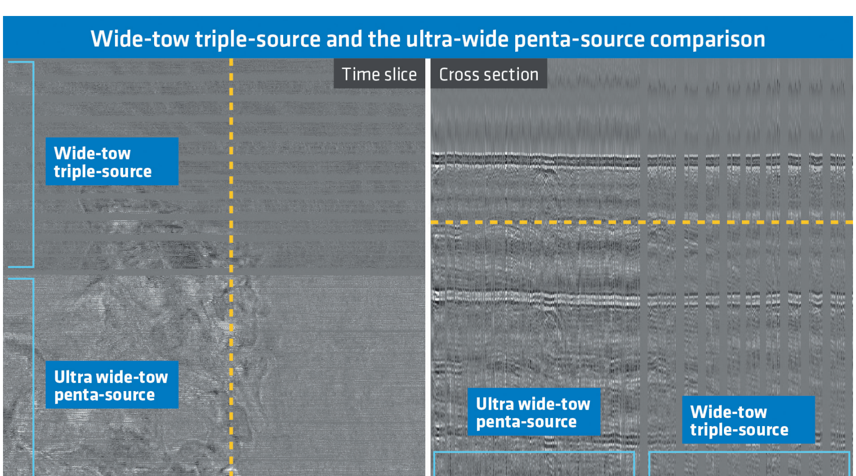


**Figure 7** Time slice and cross section extracted from the ultra-near offsets acquired by wide-tow triple source and the ultra-wide penta source as shown in Figure 6. The water depth is about 400 m and targets are expected as shallow as 600 m. The data in these examples are raw and still show multiples and source bubble energy. Sail line boundaries are no longer visible in the area acquired with the penta-source.