An Efficency-driven Implementation of Multimeasurement Streamer Technology for High-resolution Imaging of Exploration Targets in the Flemish Pass

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Summary

This paper evaluates the proposition that a multimeasurement system that supports subsequent reconstruction of virtual cables for denser crossline sampling yields benefits in exploration settings where high-resolution data are a necessity to identify and evaluate prospects; benefits include reduced time and maximizing use of the 3D deghosted and reconstructed data sets produced real-time onboard for a large-scale acquisition program. The experiment highlights the benefits of using 12.5-m sampling in the crossline direction versus 25 m for final migrated seismic sections, spectral improvements, and geologic attributes from an interpretation system. The results achieved leverages multimeasurement wavefield reconstruction to yield solutions best suited to resolve the geological complexity of this region. It demonstrates that, utilizing this technology and approach, it is possible to very efficiently acquire data with a development type and level of data density (including the crossline component) in an exploration environment.

Introduction

Resolution limits for final migrated seismic data volumes to be utilized for interpretation depend on several factors, including usable frequency content, seismic velocities, and the spatial sampling of the input and output data. Marine towed-streamer acquisition systems are generally well-sampled in the inline direction, but poorly sampled in the cross-cable direction due to economic or operational constraints. Various methods are available that aim to improve cross-cable sampling. These include commonly used acquisition strategies, such as triple-source techniques (Langhammer and Bennion, 2015), and processing-based methods such as interpolation. Multimeasurement three-component towed-streamer systems also offer the opportunity to improve cross-cable sampling by combining different measurements of the seismic wavefield (Ozbek et al., 2010). This approach benefits from multimeasurement constrained joint interpolation and deghosting in the shot domain. It allows controlling the cross-cable sampling interval early in the processing workflow, compared to methods that operate in the common-offset or image domains.

In an exploration environment, efficient coverage of the prospect area is frequently judged to be more important than high spatial resolution. Typical acquisition geometries use streamer configurations with nominal separations of 100 m (or even more) to deliver data volumes with 25-m cross-cable common midpoint (CMP) interval after migration. However, even in these settings, denser cross-cable sampling can benefit prospect identification and evaluation so long as decision time frames are not impacted. Multimeasurement streamers support this goal by generating 3D deghosted shot records output onto a target geometry that comprises both real and virtual cables, with a smaller sampling interval for subsequent processing. We present a case study of applying this approach on a large-scale exploration survey. We evaluate the enhancements in the migrated image resolution by comparing the natural 25-m cross-cable CMP sampling versus an equivalent volume generated at 12.5-m CMP bins.

Acquisition geometry

The acquisition geometry comprised 14 cables with fan geometry starting at a 100-m cable separation in the near channels and 125-m cable separation for the farthest channel. A constant 15-m tow depth was used throughout the duration of the survey due to the presence of thermoclines in the area. A multilevel broadband source array was used in a standard 50-m flip-flop configuration. Data with a high signal-to-noise ratio was recorded on all three measurements, as indicated in Figure 1.

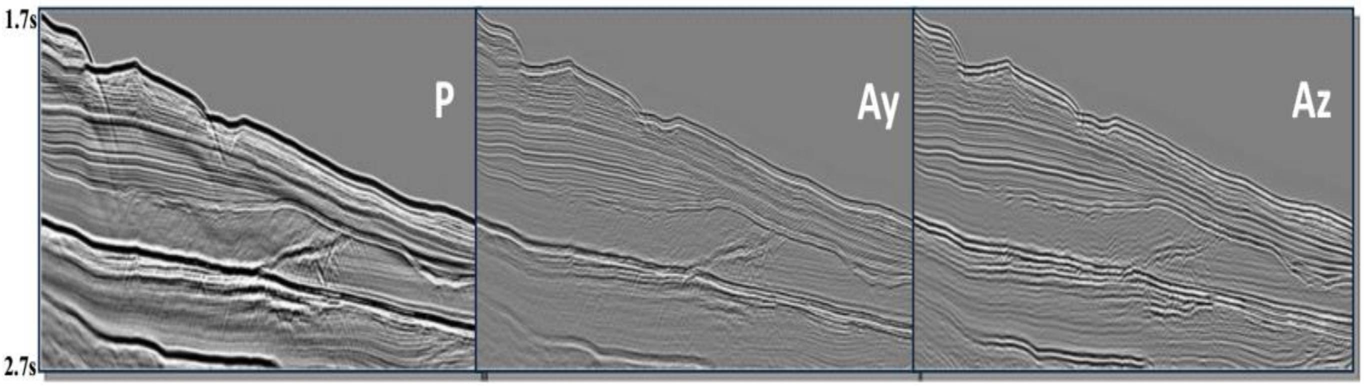

Figure 1: *Stacks of pressure (P), horizontal gradient (Ay), and vertical gradient (Az) data as input to the joint interpolation and 3D deghosting process.*

Methodology

Özbek et al. (2010) describe the process of wavefield reconstruction using a generalized matching pursuit (GMP) algorithm to perform joint interpolation and 3D deghosting. An important feature of GMP is its ability to reconstruct and deghost severely aliased wavefields. The method derives a representation of the upgoing pressure wavefield that is consistent with the three measurements (P, Az, and Ay) recorded along each streamer. The deghosted wavefield can subsequently be output at any desired location within the confines of the seismic spread – enabling interpolation to any desired target geometry.

As described in the introduction, the geometry used in this survey yields a nominal 25-m cross-cable CMP bin. Simple inspection of geometry shows that multimeasurement interpolation of a virtual streamer at the midpoint between real streamers doubles fold, but does not reduce the cross-cable sample interval. Subsurface lines generated in this fashion overlay those generated from the real streamers. This problem is overcome by generating virtual streamers at a constant distance from the real streamers, corresponding to 25% of the streamer separation. Figure 2 illustrates the concept, the flip-flop sources generate subsurface lines with standard interleaving, whilst interpolating target virtual streamers using the "¼ distance approach" result in further interleaving and the desired 12.5-m cross-cable CMP interval

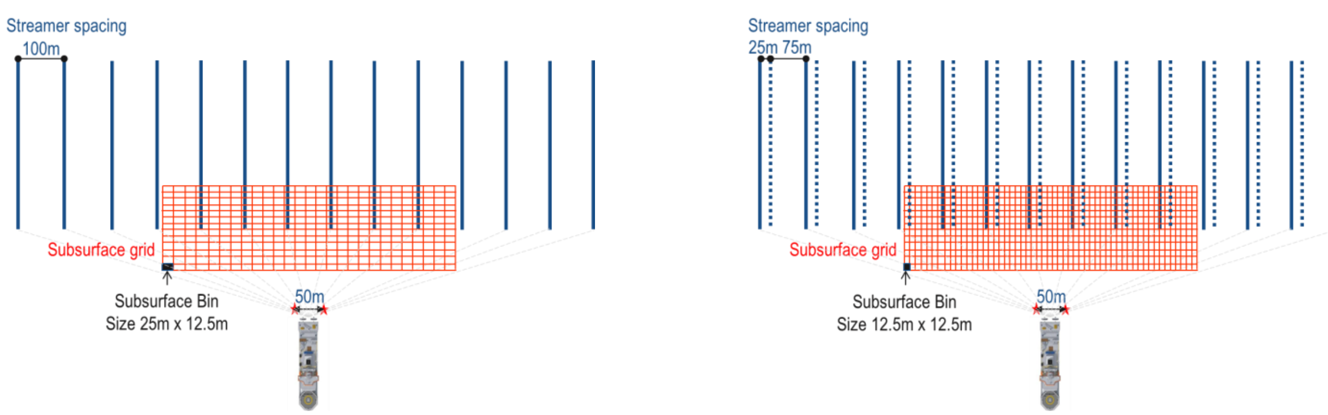

Figure 2 *(left) Subsurface grid generated for two consecutive flip-flop shots with 100-m streamer separation yields a 25-m cross-cable CMP interval. (right) Equivalent display incorporating additional subsurface lines introduced using "¼ distance strategy", and demonstrating halving of the cross-cable CMP interval to 12.5m.*

The denser cross-cable sampling, performed in the shot domain and early in the processing workflow, yields several benefits. Noise attenuation and demultiple techniques are improved with well-sampled input data. Migration resolution and aliasing protection also improves (subject to the limitations of the Fresnel zone radius and recoverable frequency content). Finally, increased data density can improve coverage statistics and reduce the reliance on interpolation later in the processing workflow.

Results

The wavefield reconstruction strategy, using the “¼ distance interpolation approach”, was completed onboard the vessel during acquisition. One QC criteria for multimeasurement-constrained interpolation is to ensure that the amplitude difference in the deghosted upgoing wavefield between real and virtual cables is small. Figure 3 makes this comparison on a stack line, including a virtual cable at the midpoint location as well as the “¼ distance position”.

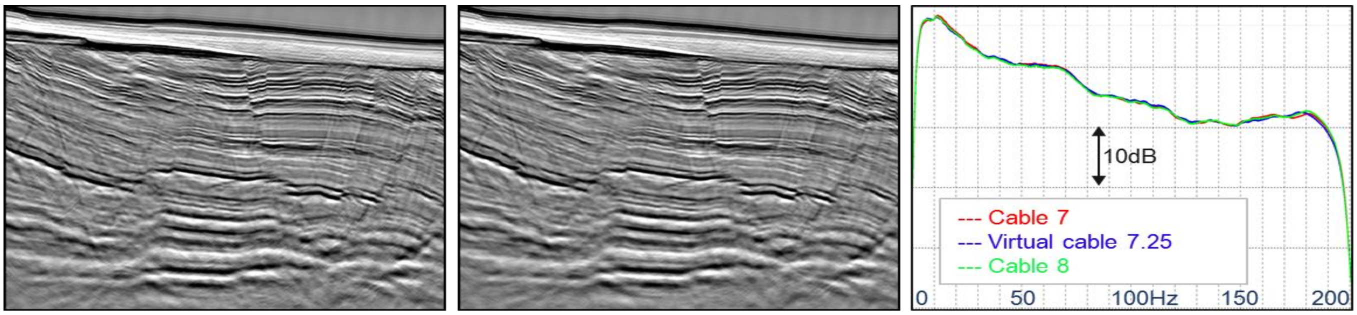

Figure 3: *Real cable after migration (left) versus reconstructed virtual cable (25 m away) (center). Fault truncations are clearly resolved on both, although slight differences in positioning are expected due to the differences in raypaths between real and virtual cables. Amplitude spectra (right) shows differences less than 1 dB.*

The data were processed in two phases, i) Processing original cables with prestack time migration as an early deliverable following acquisition. ii) Processing original and “¼ cables” with prestack VTI time and prestack transverse tilted isotropy depth migration. Figure 4 shows a comparison of prestack time migrations, where the 2nd phase processing workflow benefited from improved sampling in the shot domain and yielded improved demultiple and noise attenuation, in addition to improved resolution resulting from the denser sampling in the cross-cable direction (12.5 m versus the original 25 m). Furthermore, Figure 5 shows that the final image has a broad temporal bandwidth at the reservoir level with thin sand beds resolvable >64 Hz.

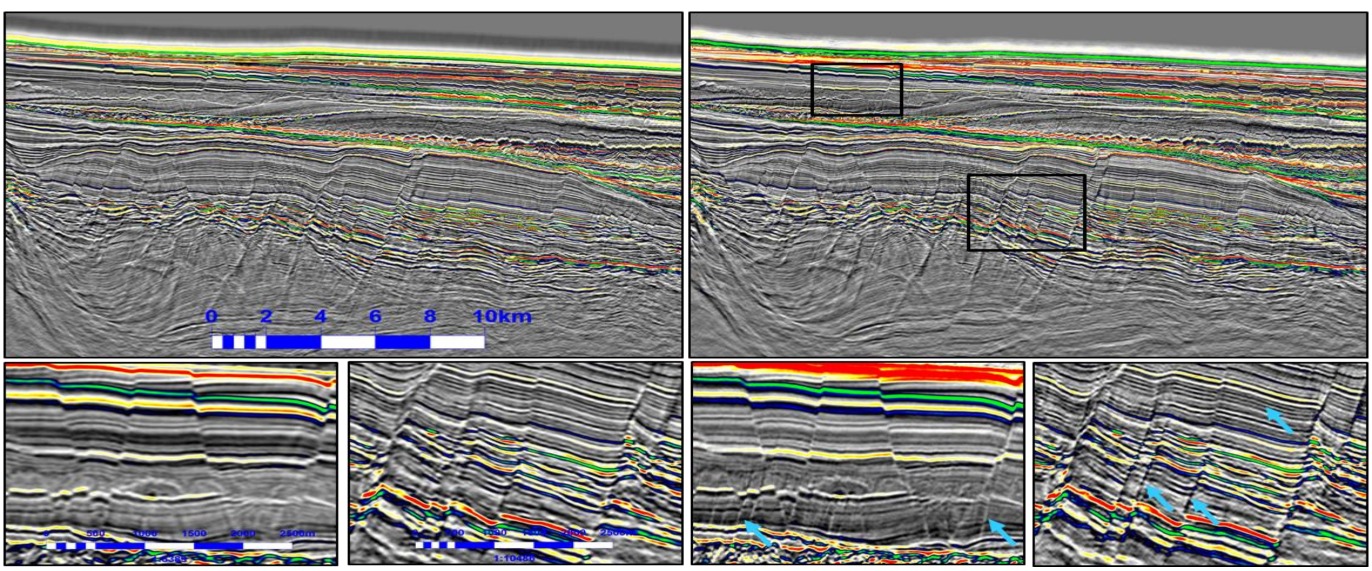

Figure 4: *Prestack time migration sections comparing original geometry and early deliverable processing (25-m cross-cable CMP bins (left) versus reconstructed geometry and final processing (12.5-m bins – right). Improved image resolution is observed at both Jurassic and Cretaceous target levels using the reconstructed data.*

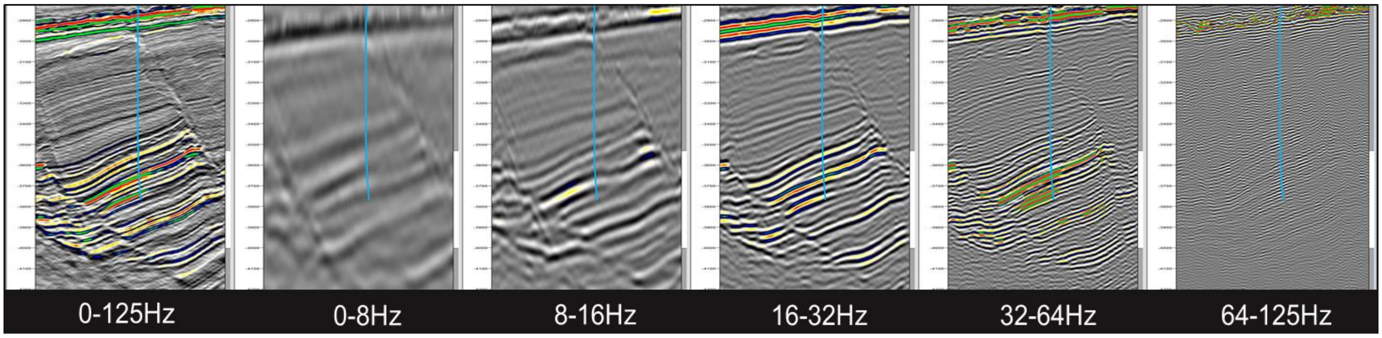

Figure 5: *Final prestack time migration; the image is zoomed to an existing discovery and then decomposed into discreet frequency ranges. The image is rich in both low frequencies (<8 Hz) and high frequencies (>64 Hz) that contribute to imaging both tilted fault blocks and thin reservoir sands.*

Laake et al. (2017) combine image processing the isometrically sampled seismic 3D data with horizon texturing to produce high-resolution images that are indicative of depositional environments. Figure 6 shows polygonal fault patterns and their changes that depend on the distance from the sediment source. Those changes can be interpreted for lateral modifications in sediment composition when associating the fault density with the overpressure generated by the dewatering process during compaction. This shows the absolute accuracy of mapping the data due to the vertical resolution and focusing. This enables more accurate reservoir characterization and can serve to reduce the overall uncertainty of the seismic measurements.

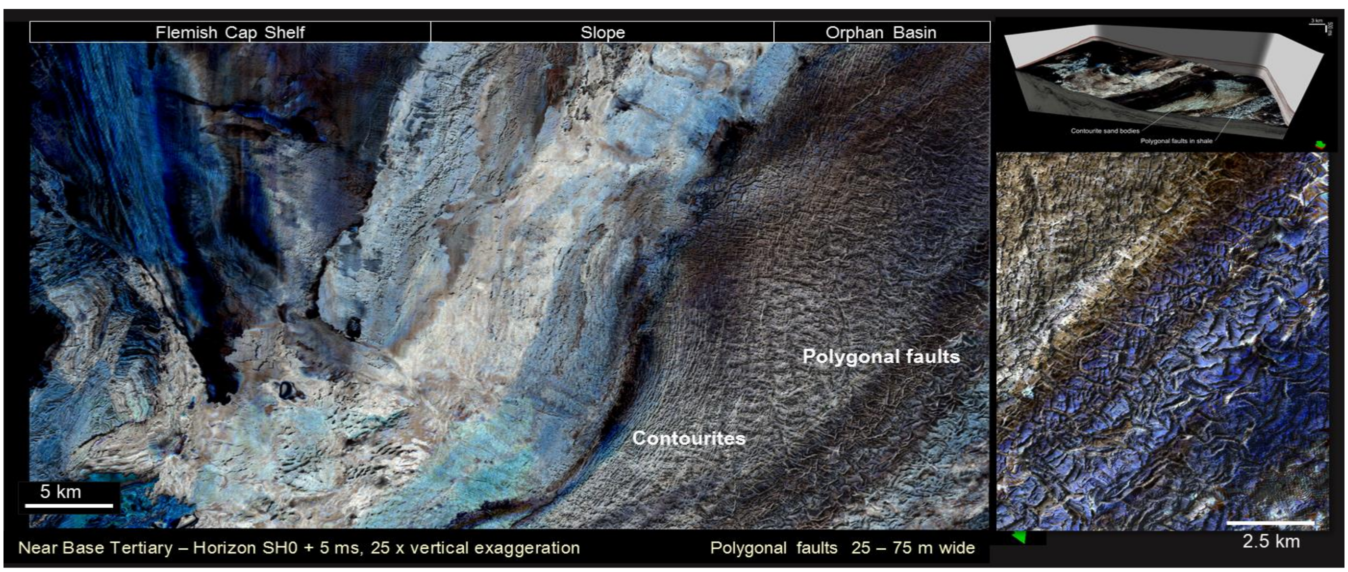

Figure 6: *Shelf, slope, and basin deposition with post-depositional polygonal fault overprint as a result of dewatering.*

Conclusions

Multimeasurement constrained joint interpolation and 3D deghosting enables cross cable sampling to be improved in the shot domain and early in the processing workflow. In this example from offshore Canada, a “¼ distance” reconstruction strategy halves the cross-cable CMP bin size. The reconstruction and pre-demultiple processing was performed onboard the vessel during acquisition with no impact on the turnaround time despite the increase in data volume. The results of the final processing combined with image processing demonstrate that streamer geometries appropriate for exploration-scale coverage can still support the higher spatial resolution required in complex geological environments for unmasking original and post-depositional lithology.

Acknowledgements

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