BGP's Marine Data Processing Capabilities

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Summary

The marine seismic environment encompassing deep water, shallow water, and the transition zone presents unique challenges. These include managing the impact of sea conditions and acquisition operations, processing broadband data influenced by the water layer, and achieving high-resolution subsurface imaging. Through continuous development, BGP has become a major player in the marine acquisition market. In parallel, our data processing capabilities have advanced significantly and are now successfully applied to projects worldwide.

Introduction

Marine seismic exploration offers inherent advantages over land operations, largely due to the more favorable source–receiver environment. This enables stable wavelet design and supports the acquisition of seismic data with a high signal-to-noise ratio. At the same time, the marine environment introduces its own set of complexities. Processing must account for the dynamic influence of sea conditions, operational factors, and water-layer effects, all while striving for sharper and more reliable subsurface imaging. To address these challenges, BGP has developed a robust, industrialized processing workflow through years of continuous innovation.

This article presents advances in seismic processing such as deblending, PTC inversion, deghosting, demultiple, near-seabed tomographic inversion, phase-driven full-waveform inversion (FWI), and FWI imaging. It concludes with case studies from around the world that demonstrate the effectiveness of these techniques.

Methods

1. Deblending

Blended acquisition and subsequent deblending is a proven technology that greatly enhances field productivity while maintaining data quality. BGP has developed advanced solutions for both efficient blended acquisition and high-fidelity deblending processing, which have been successfully applied in numerous land and marine seismic surveys.

The core processing workflow can be summarized as follows: first, 3D common receiver gathers are transformed into the FKK domain using a fast Fourier transform, with sliding windows applied to keep signal events flat in the time domain and sparse in the transform domain. Next, thresholding is employed to isolate coherent signals and predict interference noise. Finally, driven by data residuals, the signals are iteratively refined by progressively shrinking thresholds until the separation between signal and noise is fully achieved.

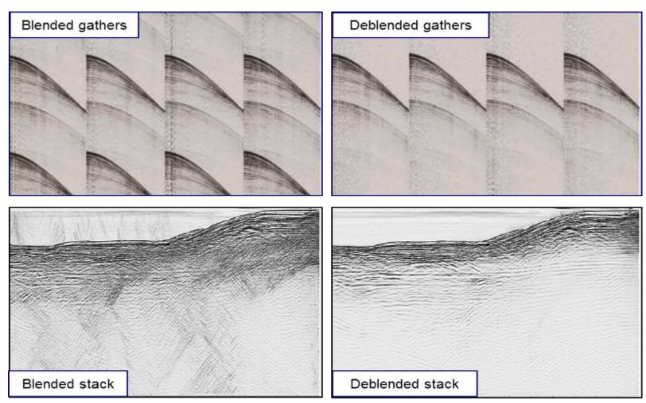

Figure1 Deblending result of towed streamer

Figure 1 and Figure 2 present the successful deblending results for towed streamer and OBN data, respectively. Both examples demonstrate how blended noise is effectively suppressed while preserving signal integrity.

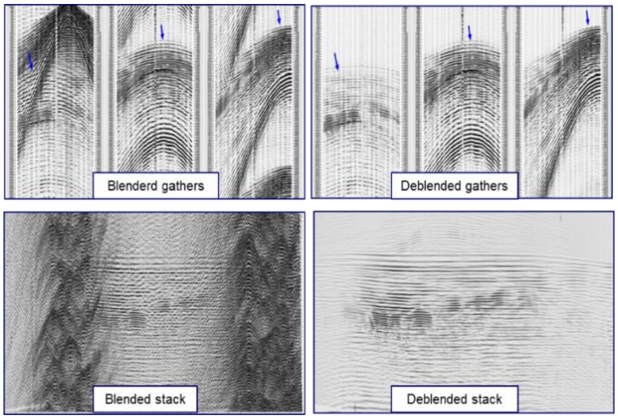

Figure2 Deblending result of OBN

2. PTC inversion

For 4D OBN data, achieving optimal results demands highly accurate timing and positioning—requirements that often exceed the capabilities of routine on-board "LMO-based" corrections. To meet this challenge, BGP has developed a PTC (Positioning, Timing, Clock) inversion method, specifically designed to deliver precise corrections for both node and shot positioning and timing.

Figure 3 presents the time-difference maps before and after PTC inversion. The results clearly show that discrepancies between the picked and theoretical first arrivals are greatly reduced and tightly clustered around zero after correction.

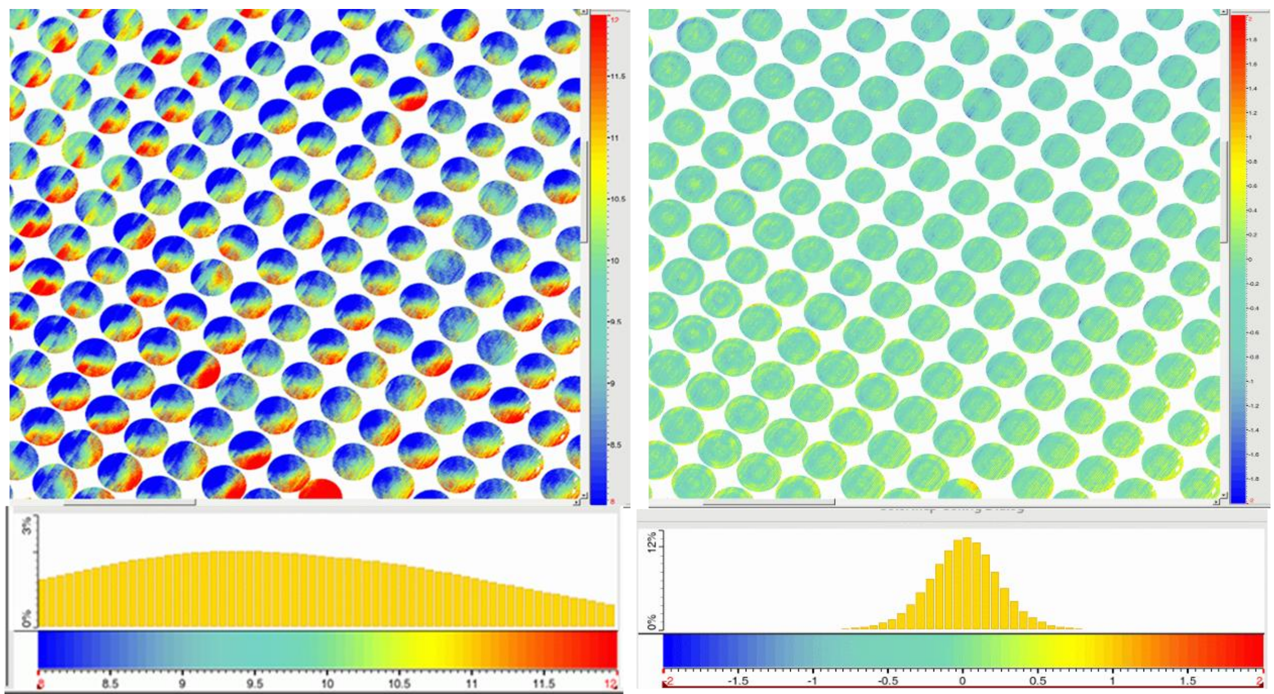

Figure3 Time difference Map before and after PTC

(Time difference = picked first arrivals - theoretical first arrivals)

3. De-ghosting

Ghosts are generated by reflections from the free surface, as illustrated in Figure 4. From an energy perspective, the recorded data can be considered as a sum of Primary + S_ghost + R_ghost + SR_ghost. The S_ghost and R_ghost components have negative polarity and are destructive, while SR_ghost has positive polarity and is constructive. However, because these components arrive at different time delays, they collectively degrade the temporal resolution of the data.

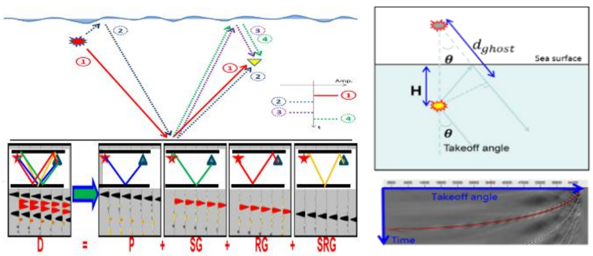

Figure4 Illustration of sea surface ghosts

(①Primary, ②Source side ghost, ③Receiver side ghost, ④Both source and receiver side ghost)

In response to the ghost effect, different frequencies (with varying wavelengths) behave differently, some are enhanced, while others are attenuated. Additionally, the takeoff angle to each receiver location plays a role: larger angles correspond to shorter ghost periods.

To account for the variation of ghost period with takeoff angle in marine seismic data, a 3D sparse tau-p domain deghosting method has been developed. This approach improves ghost attenuation and compensates for notch frequencies.

Figure 5 illustrates the stack section before and after 3D sparse tau-p deghosting, highlighting the enhanced data quality.

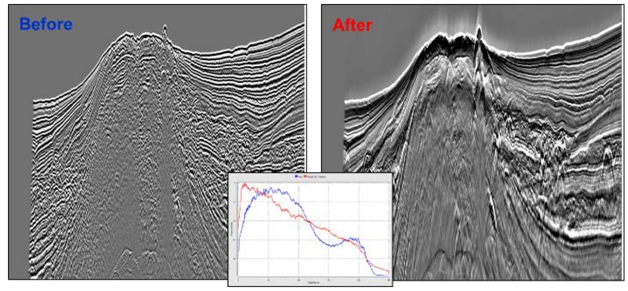

Figure5 Stacking section before and after De-ghosting

4. Demultiple

Surface-related multiples generate strong coherent noise that can obscure primary reflections and complicate seismic imaging. To address this challenge, BGP has developed a suite of dedicated suppression methods (Figure 6).

□ Surface related multiples
- 3D MWD/3D SRME
- 3D de-multiple based on de-migration
- Joint SRME (OBN & streamer)
- 3D radon transform
- UDD/DDD

□ Interbed multiples
- Extended SRME
- Inverse scattering series
- Interbed based on de-migration

□ Shallow water multiples
- EPSI (Estimation of the primaries by sparse inversion)
- 3D Tau-p deconvolution

□ Adaptive subtraction
- Least squares adaptive subtraction
- Pattern recognition adaptive subtraction
- Curvelet adaptive subtraction
- Multi-model simultaneous adaptive subtraction

Figure6 De-multiple methods

5. Near seabed model building

To address the differing datums of source and receiver points in shallow-water OBN/OBC data, an analogy analysis is performed between shallow-water OBN/OBC and land data. Given the high source-point density and low receiver-point density typical of marine OBN/OBC surveys, an observation system analogous to land acquisition is created by exchanging the roles of source and receiver points. Additionally, source and receiver points are corrected to a common plane using techniques such as water velocity correction or wavefield extrapolation. Based on this, a near-seabed velocity model is established through tomographic inversion.

Figure 7 shows the tomography-based velocity model, illustrating velocity variations. Low-velocity areas correspond to mud volcanoes, enabling clear identification of their distribution within the model. Figure 8 demonstrates the improvement in the PSDM stack section after incorporating the accurate near-seabed model. It is evident that merging the near-surface velocity model significantly enhances the imaging around and beneath the mud volcano area.

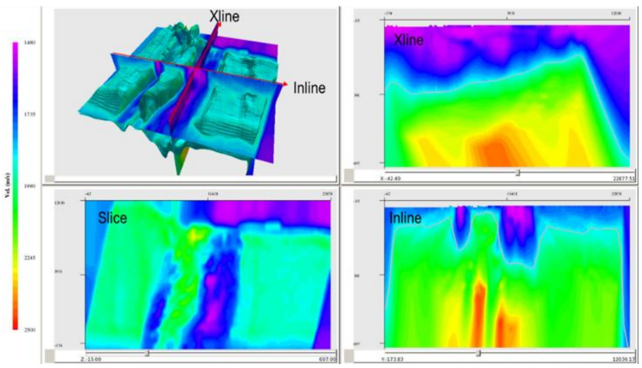

Figure 7 Near sea-bed model

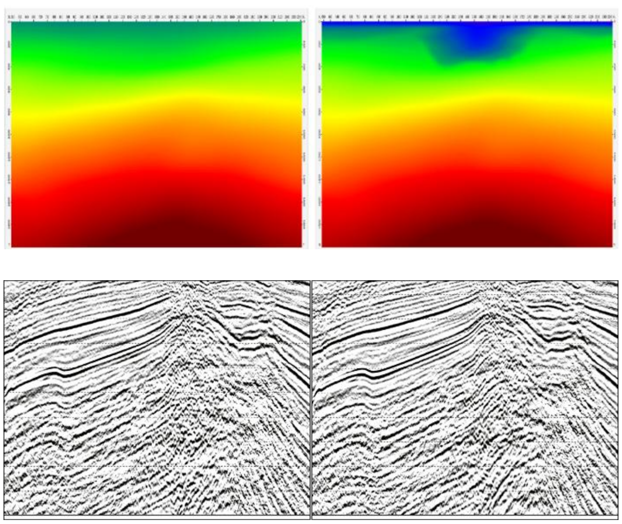

Figure 8 PSDM section with near seabed velocity model

6. Phase Driven Full Waveform Inversion

Full Waveform Inversion (FWI) estimates subsurface velocity models by iteratively minimizing the misfit between observed and synthetic seismic data. However, its inherent nonlinearity makes it susceptible to cycle skipping. To address this, Phase-Driven FWI (PDFWI) was developed. Figure 9 illustrates the successful application of PD-FWI in a pre-salt setting.

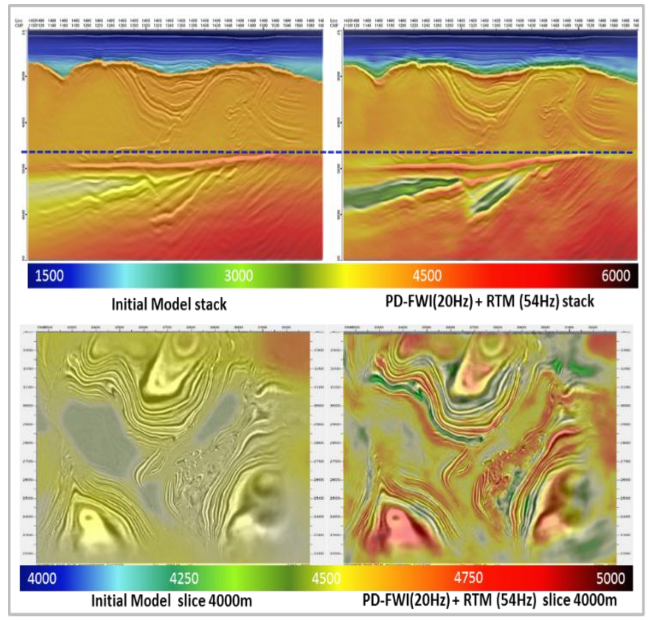

Figure 9 PDFWI result

7. Full Waveform Impedance Inversion(FWII)

FWII (Full Waveform Impedance Inversion) is based on true-amplitude migration and simultaneously inverts for both velocity and impedance.

Figure 10 shows a shallow Ocean Bottom Node (OBN) example. The 60 Hz FWII stack section effectively removes multiples compared to the Reverse Time Migration (RTM) result, demonstrating that FWII is largely unaffected by multiple reflections.

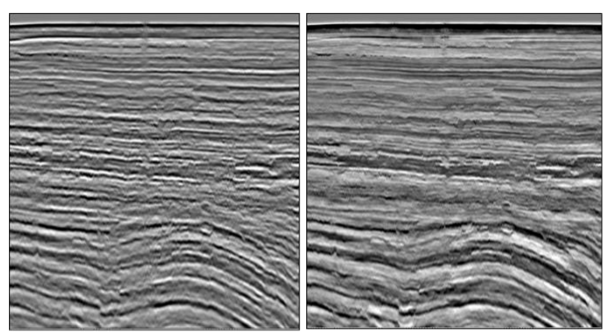

Figure 10 60Hz RTM(left) vs 60Hz FWII(right)

Case studies

1. Streamer reprocessing

This reprocessing case study focuses on a streamer survey in the Niger Delta, with water depths ranging from

570 m to 1600 m. Despite undergoing five previous reprocessing cycles, the legacy data remained insufficient for interpretation due to complex multiples. BGP successfully achieved high-resolution imaging by implementing a comprehensive workflow that includes robust multiple suppression, high-precision velocity modeling with FWI, and Q-compensated migration.

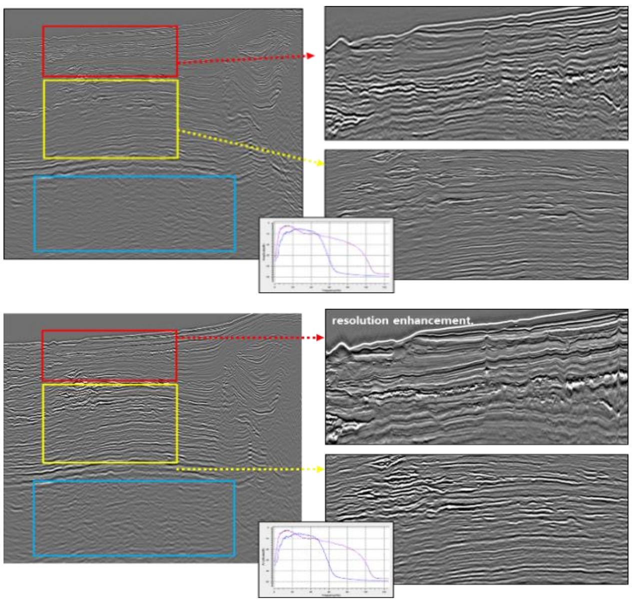

Figure 11 Legacy result(top) vs BGP reprocessing (bottom)

Figure 11 compares a seismic section from the BGP reprocessing with the legacy result from the fifth reprocessing. The comparison highlights significant improvements in the reprocessed data: the frequency bandwidth is broader, and the overall image quality is markedly enhanced. In particular, the shallow section shows higher resolution, while the deep section, previously devoid of interpretable signal, now reveals clear structural features.

2. Shallow OBN processing

The Cheleken PSA Area comprises two offshore oil and gas fields, Dzheitune (Lam) and Dzhygalybeg (Zhdanov), located in the eastern Caspian Sea, offshore Turkmenistan. It represents Turkmenistan's largest oil production asset, with a gross output of approximately 80,000 b/d in 2019–2020. Covering 950 km², the area is operated by Dragon Oil under a production sharing agreement (PSA) signed with the State Agency of Turkmenistan in 1999 and effective from May 2000.

The tectonic setting of the eastern South Caspian Basin is dominated by the active collision between the Arabian and Eurasian plates. Most of the convergent plate motion is accommodated by northward-directed subduction. Hollingsworth et al. show that plate motion in the South Caspian is partitioned, resulting in a westward-extruding block bounded by strike-slip zones. Consequently, the major structural trend in the Dome field is a dextral transgression oriented NW–SE.

BGP's advanced preprocessing, combined with near-seabed model building and full-waveform inversion, has achieved unprecedented resolution of subsurface features. Figure 12 illustrates clear fault delineation in intermediate and deep layers, accurate positioning of areas influenced by mud volcanoes, and overall improvement in imaging quality, providing geologists with enhanced structural clarity and a stronger basis for further reservoir research.

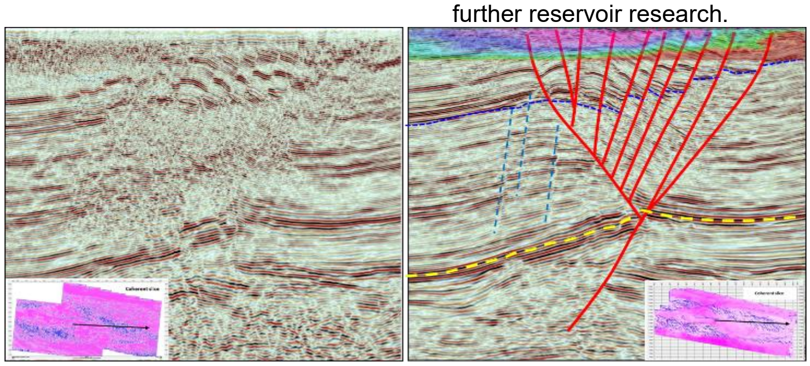

Figure 12 Legacy result(left) vs BGP OBN result (right)

3. TZ OBN processing

The offshore environment of Abu Dhabi is characterized by ultra-shallow waters and thinly layered carbonate formations, which generate complex seismic wavefields contaminated by noise and multiples. Offshore data are dominated by mud-roll and guided waves, while onshore data are affected by ground-roll and ambient noise. The intertidal zone poses an additional challenge, as weak signals are often obscured by high surface noise.

Using an integrated OBN acquisition and processing workflow, including Up and Down-going Wavefield Deconvolution (UDD), consistent processing, Full-Waveform Inversion (FWI), and QPSDM, the latest results demonstrate significant improvements. These include sharper wavelets, more effective multiple suppression, and clearer imaging of minor faults (Figure 13).

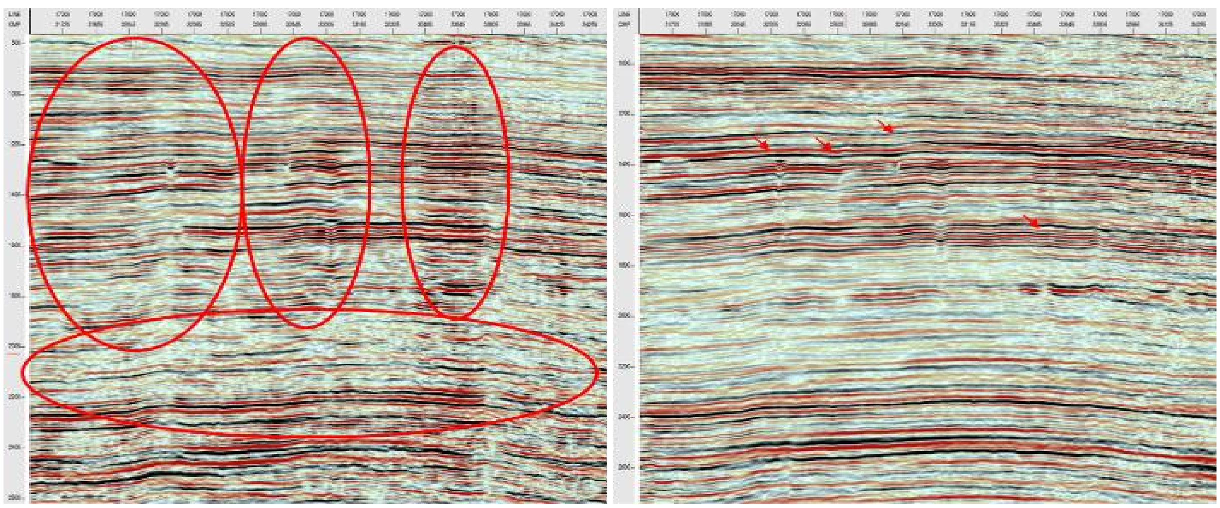

Figure 13 Legacy result(left) vs BGP OBN result (right)

4 Deep OBN processing

Since the discovery of pre-salt oil fields offshore Brazil two decades ago, the Santos Basin has shifted from an exploratory to a development phase. In this new stage, the primary objective is to gain comprehensive knowledge of the reservoir and its surroundings. Advances in seismic imaging technologies continue to provide deeper insights to improve reservoir understanding.

This study focuses on a 2015 OBN acquisition covering 110 km² over the Tupi field, located 250 km south of Rio de Janeiro in the Santos Basin. Data were acquired using a node carpet spread on a 375 m × 325 m staggered grid, with shot intervals of 50 m × 50 m, providing a maximum offset of 16 km. Water depth is approximately 2100 m, and the area is overlain by a stratified salt layer 1800–2000 m thick. The reservoir lies in the pre-salt section at a depth of 5000 m, characterized by fast carbonates, the slower Piçarras formation, and volcanic layers within a large faulted-block system.

BGP delivers high-resolution imaging through a bespoke, advanced workflow designed to suppress false structures and maximize seismic fidelity. This workflow integrates key techniques, including Sparse Tau-P deghosting, Up- and Down-going Wavefield Deconvolution (UDD and DDD), Phase-Driven FWI, and Reverse Time Migration (RTM).

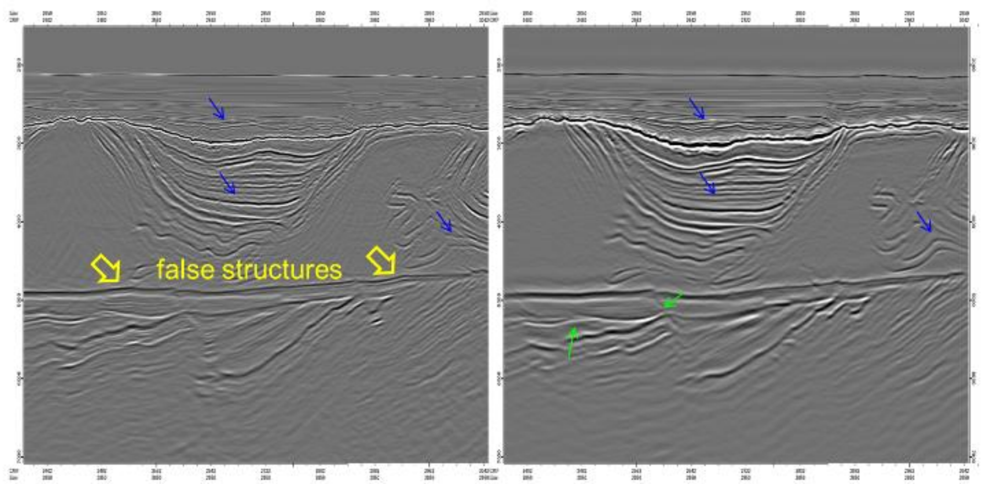

Figure 14 Legacy streamer result(left) vs BGP OBN result (right)

5 Hybrid Streamer + OBN

A hybrid towed streamer and ocean bottom node (OBN) survey was acquired in the summer of 2020 over the Quad 35 block offshore Norway in ~ 400m water depths. The nodes were located on a 900m x 900m square grid with infills to a 300m x 300m square grid over the Aurora and Nova fields. The streamer data were acquired with triple source, partially blended, to produce an ultra-high density streamer 3D dataset. The nodes deployed prior to the first streamer shot, recorded data continuously throughout the streamer survey, capturing data with offsets of more than 30 km. The streamer/source geometry employed was 10 x 56.25m x 8000m/3 x 75m x 10.416m generating 128-fold data in 9.375m x 6.25m bins.

Compared to the OBN data, the streamer data have the advantage of the near uniform near-to-mid offset coverage, which is important for broadband imaging of the shallow section. On the other hand, the OBN data have the advantage of long offset and full azimuth coverage, as well as the advantages of the seabed recording environment, which facilitates the multi-component recording of low noise, ghost-separable data, rich in low frequencies. The hybrid image, combining the OBN FWI image with the streamer PSDM image, retains the strengths of both data types (Figure 15) Compared to the streamer image, the hybrid image displays improved image sparseness, seismic character and event continuity, without any loss in resolution.

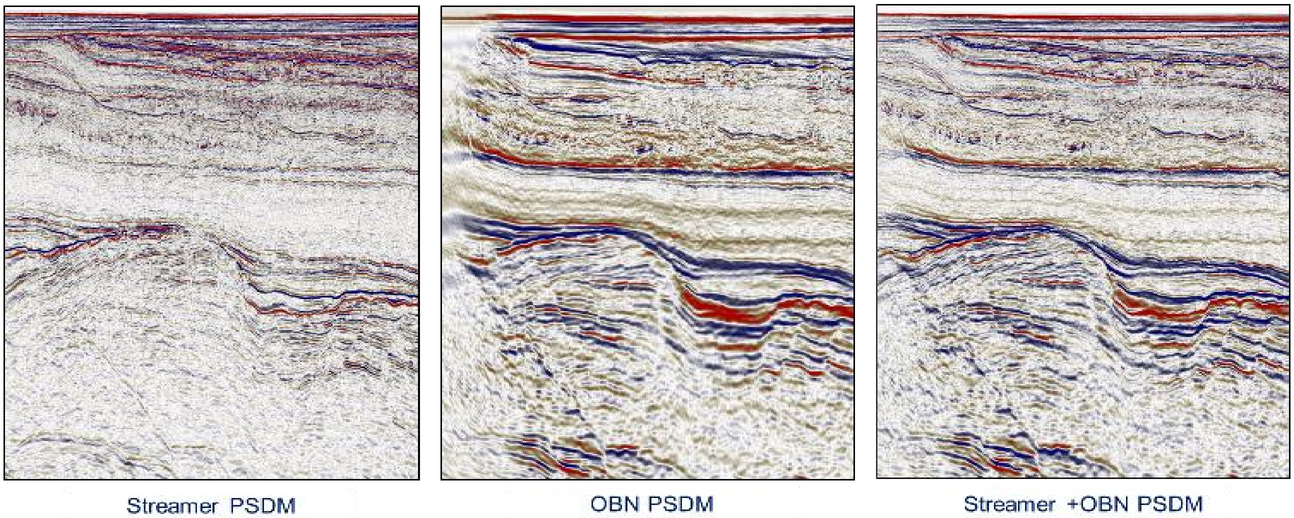

Figure 15 merging processing result

Conclusions

BGP is committed to delivering advanced subsurface imaging solutions, combining integrated geoscience services with robust support from R&D.

Leveraging a comprehensive portfolio of proprietary techniques and extensive project experience, BGP provides cutting-edge marine data processing services.

Acknowledgments

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