Advancing Imaging in the Gulf with Long-Offset OBN, Broadband Sources and Elastic FWI

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The Gulf of Mexico (America) has long been one of the most prolific petroleum provinces in the world and key to the U.S. energy supply, accounting for more than fifteen percent of domestic oil production. The basin's western deepwater provinces are dominated by thick, laterally extensive salt canopies and elaborate subsalt structures, remaining among the most technically demanding exploration environments. Geoscientists have long recognized the opportunity beneath these salt domains, yet traditional wide-azimuth towed streamer seismic surveys and conventional imaging methods have struggled to resolve the deep salt geometries and subsalt stratigraphy, limiting confident prospect evaluation.

Over the last decade, however, advances in seismic acquisition design, along with novel source technology and velocity model building workflows, have begun to change this perspective. Recent seismic surveys in the Gulf demonstrate how a coordinated methodology that integrates long-offset ocean-bottom nodes acquisition, enhanced frequency sources and elastic full-waveform inversion can address longstanding subsurface challenges. Together, these technologies are reshaping the way geoscientists interpret complex salt domains and, ultimately, how companies allocate exploration capital in the region.

Where Conventional Imaging Underperforms

Salt plays a dual role in the Gulf. Thick allochthonous bodies form highly effective traps, yet the same deposits impose severe challenges on seismic wave propagation. Large velocity contrasts with surrounding sediments distort ray paths, while complex geometries such as overhangs and welds create zones of poor illumination. Multipathing, scattering and shadowing beneath salt canopies often degrade image resolution and lead to structural mispositioning of reflectors.

Wide-azimuth towed streamer acquisition was developed to address some of these issues by recording data over a broad range of azimuths and improving subsalt illumination. Although this approach represented a significant advance in imaging the Gulf's complex salt basin, it remains constrained by streamer length, which limits achievable offsets for diving-wave coverage and compromises the ability to calibrate velocity and anisotropy in the deep section.

The imaging limitations are clearly observed in the legacy WAZ reverse-time migration image when compared to recent results (figure 2).

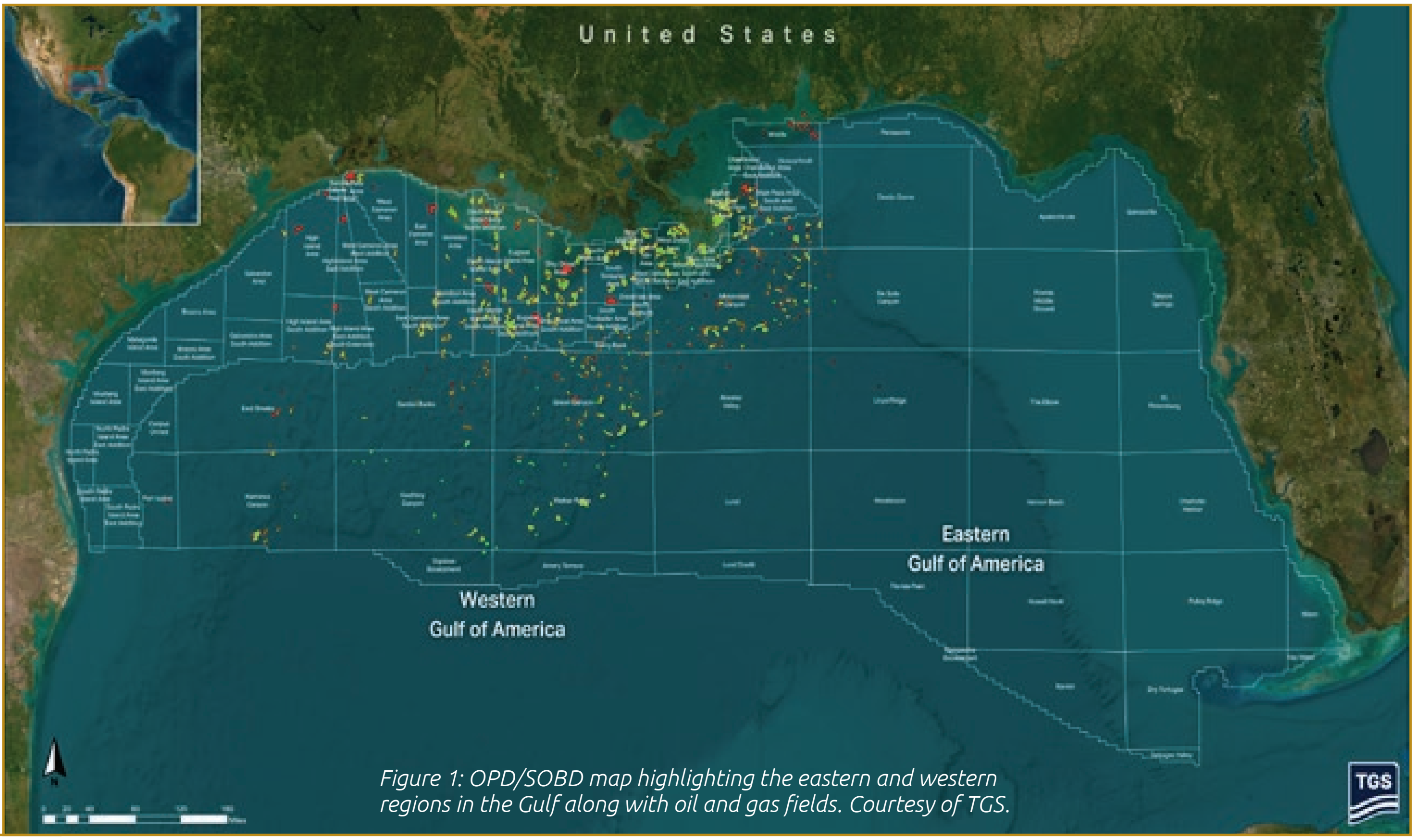

Figure 1: OPD/SOBD map highlighting the eastern and western regions in the Gulf along with oil and gas fields. Courtesy of TGS.

Lack of velocity resolution and low signal-to-noise conditions obscure the position and geometry of fault planes, basement reflectors appear poorly defined, continuity of deep carbonate horizons is disrupted and salt feeders are only partially imaged. Such shortcomings highlight the necessity for novel acquisition geometries and source technologies that extend the effective seismic aperture and provide the low-frequency content required for robust velocity model building workflows. Without such innovations, interpreters face persistent uncertainty when attempting to characterize traps and reservoirs located beneath thick salt canopies.

The Power of Long-Offset OBN

Since 2019, long-offset OBN acquisition has emerged as a leading tool for addressing

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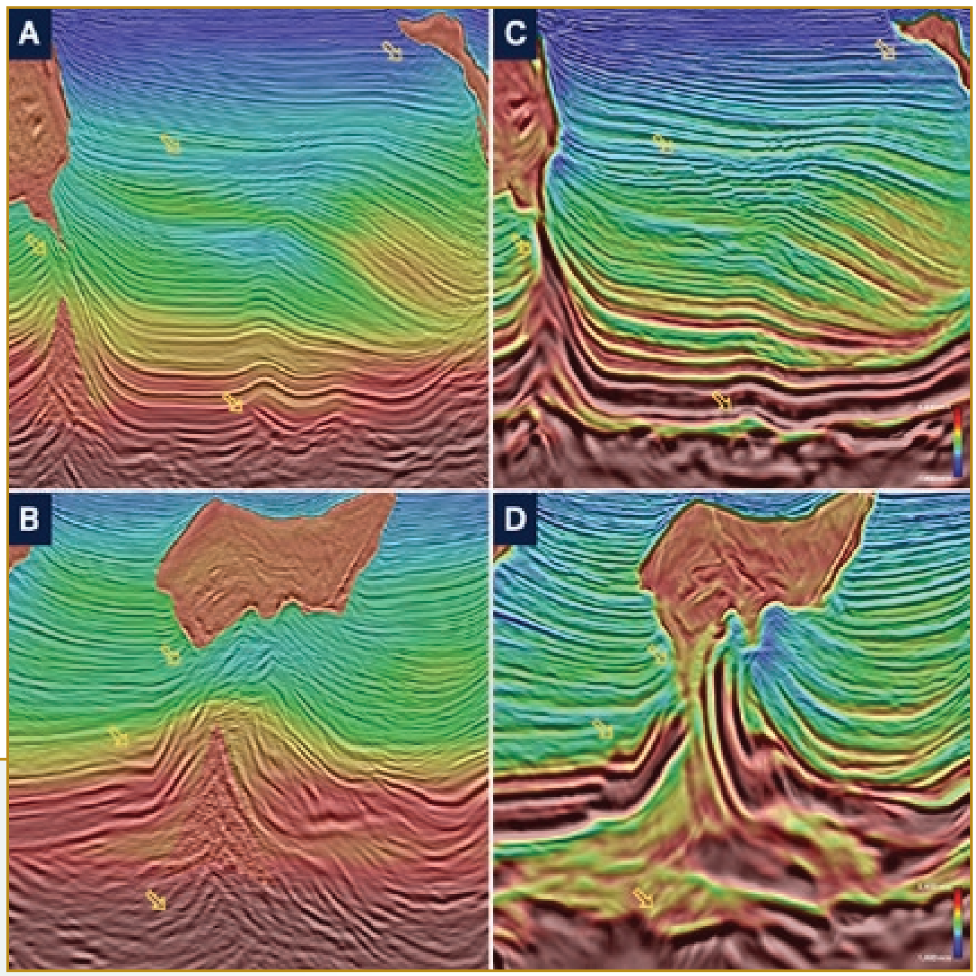
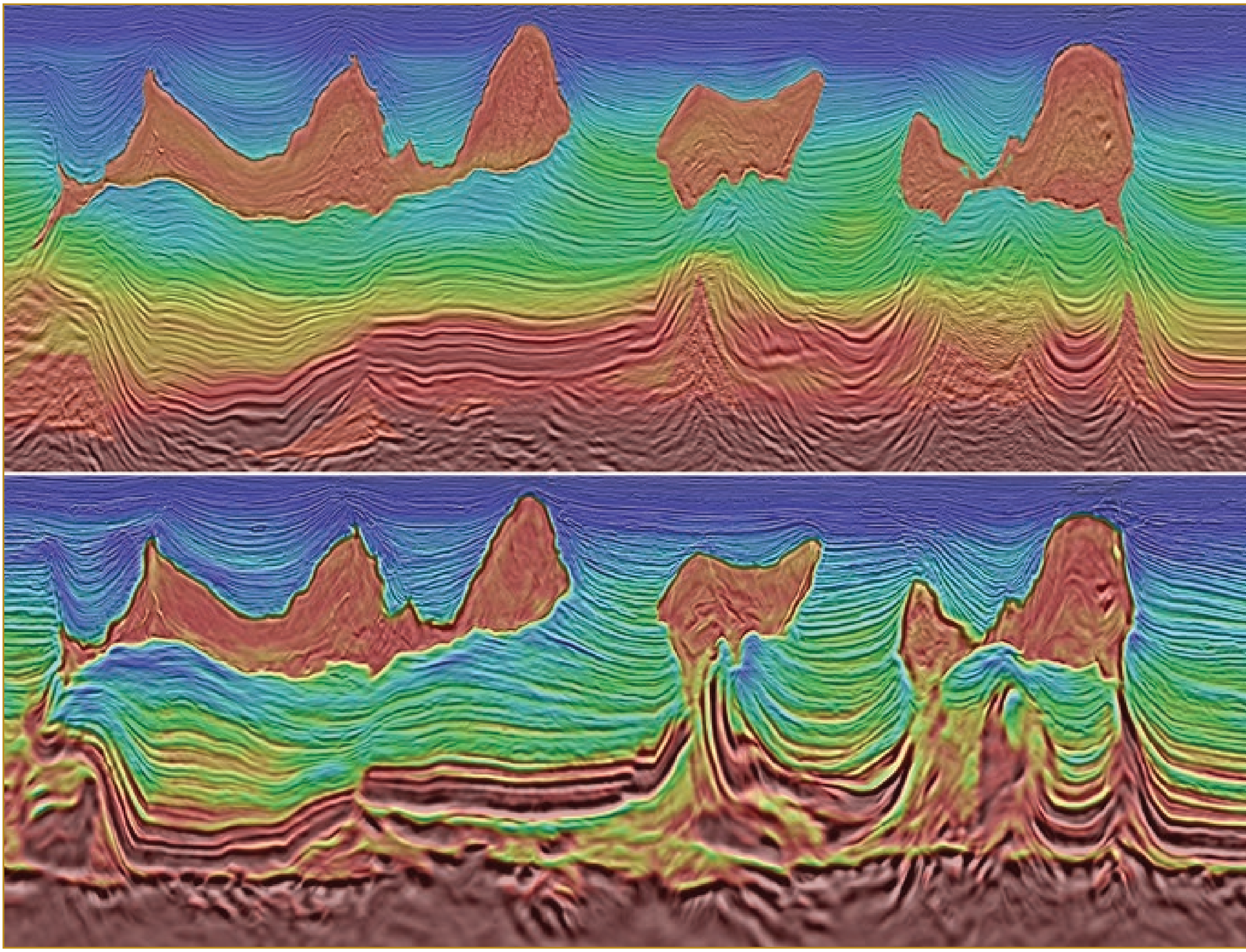


Figure 2: Suboptimal definition of fault planes, basement reflectivity as well as poor illumination of salt feeders and carbonates are some of the imaging limitations observed in the legacy WAZ streamer RTM product (A, B) compared to modern FWI-driven velocity and reflectivity (C, D).



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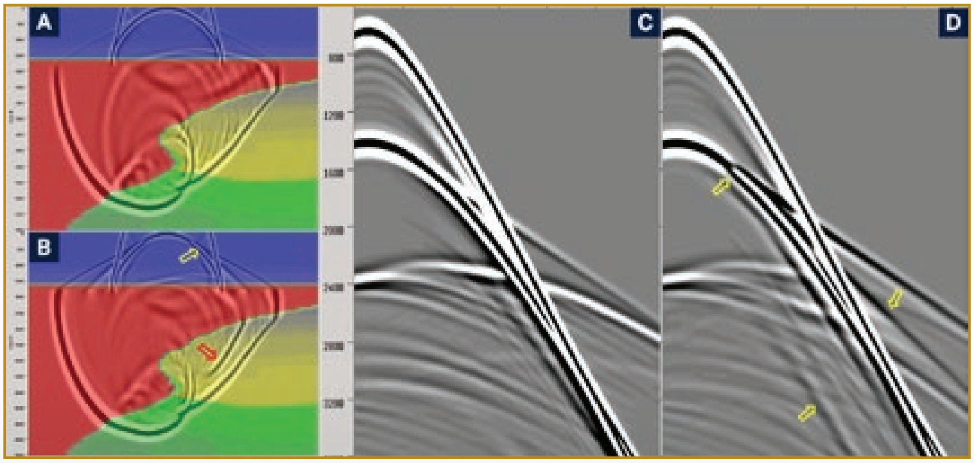
salt complexity in the Gulf. Nodes deployed on the seafloor can capture the required diving wave information to drive FWI methods at offsets well beyond those which streamers allow. The stationary placement of node systems ensures consistent geometry throughout the survey. This stability, combined with survey design flexibility, enables higher fold coverage and can provide superior signal-to-noise compared with streamer data. The result is a dataset with better low-frequency performance, superior angular coverage and improved illumination of steep salt flanks and deeper structures.

The benefits of OBN acquisition are evident in its impact on interpretation and exploration strategy. The extended aperture and azimuthal coverage provide the basis for mapping features such as fault networks, salt feeders, and deep carbonate platforms with a level of continuity not achievable from streamer data alone. As exploration shifts into areas of greater geological complexity, long-offset OBN surveys have become a strategic tool by offering both the technical foundation for advanced imaging and the confidence required to pursue opportunities in salt-influenced provinces.

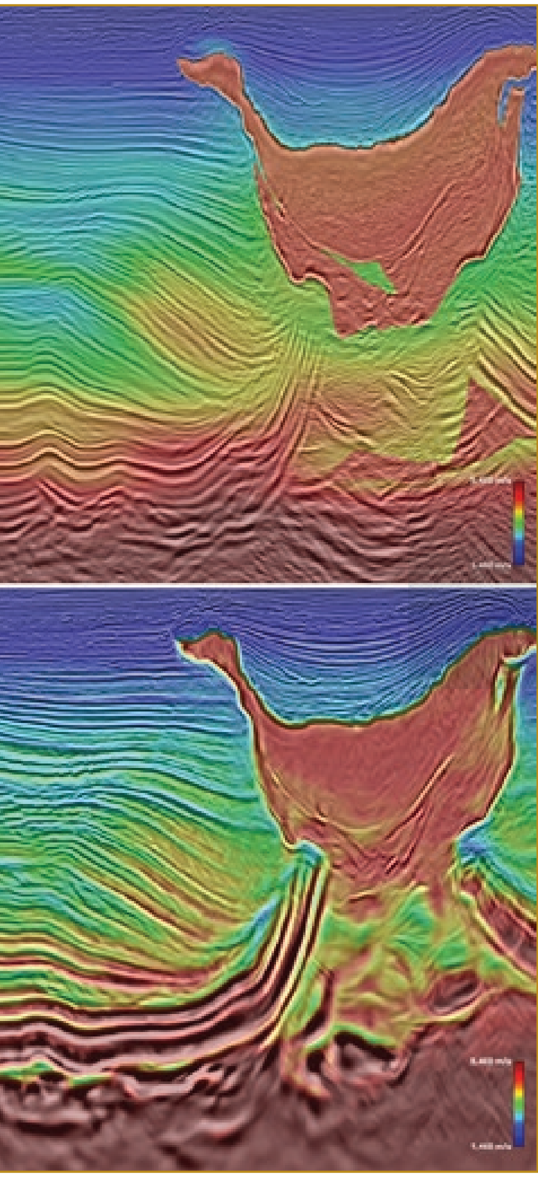
Rethinking Inversion with E-DMFWI

With the right offsets in place, the next challenge is to translate recorded data into an accurate and detailed velocity model. Full-waveform inversion has become the tool of choice for this task; however, conventional implementations might face added challenges in complex salt provinces. Acoustic FWI algorithms typically ignore the shear wave (S wave) component and only account for the impacts of P wave velocity and density, which makes them less effective in high-contrast media, such as the boundary of salt bodies. This can lead to less optimal imaging for complex underlying structures, such as faults and fractures, and inferior inversion results for reservoir properties.

Elastic dynamic matching FWI has intrinsic advantages over the acoustic version, especially in geologically complex areas. By incorporating an elastic formulation into the wavefield propagation, the method can simulate both compressional (P waves) and shear waves (S waves), as well as mode conversions, capturing more detailed information about the subsurface (figure 3). The dynamic matching objective function allows for better alignment between modeled and observed waveforms,



Above – Figure 3: A snapshot for acoustic (A) and elastic (B) wave propagation; one synthetic shot gather of acoustic (C) and elastic (D) simulation. The red arrow points to a double mode converted wave from P to S and back to P in B).



Left – Figure 4: Amendment 1 and 2 (in partnership with SLB): Legacy WAZ streamer RTM and Velocity (top) compared to E-DMFWI FDR and Velocity (bottom)

maintaining stability even when dealing with extreme contrasts. Importantly, E-DMFWI not only improves the velocity model but also produces a reflectivity volume derived directly from the inversion, commonly known in the industry as FWI-derived reflectivity. These derived images often reveal stratigraphic and structural details that migration alone cannot, giving interpreters an additional lens on the subsurface.

Lessons from Amendment 1 and 2

Recent Amendment surveys acquired by TGS and partners demonstrate the power of pairing long-offset OBN with next-generation processing techniques and E-DMFWI, delivering cleaner images that enhance structural interpretation and stratigraphic mapping compared to the legacy WAZ streamer RTM data, as observed in figure 4. The recent Amendment 1 and 2 E-DMFWI results demonstrated:

- Sharper definition of salt geometries, allowing interpreters to better understand overhangs and feeders
- Improved continuity of deep reflectors, including carbonates at the base of the Miocene
- Clearer basement imaging, providing insights into regional tectonic history and structural controls on sedimentation

These outcomes reduced uncertainty in depth imaging and provided explorers with more confidence in prospect evaluation. Just as importantly, they set a new benchmark for what could be expected from surveys in salt-heavy provinces of the Gulf.

Gemini: Supplying the Missing Frequencies

For full-waveform inversion methods to extract meaningful velocity updates from long-offset OBN data, the seismic signal must contain very low frequencies. These are the components that allow algorithms to converge on the correct long-wavelength solution and to avoid being trapped in local minima.

This is where the enhanced frequency sources enter. Designed to generate a reliable signal down to 1 hertz (figure 5), TGS' Gemini EFS gives OBN surveys the spectral bandwidth and deeper penetration needed at very long offsets for modern elastic inversion workflows. It has a point-source design that simplifies processing, while the ability to tow multiple sources from a single vessel enhances operational efficiency. Just as important, Gemini's environmental performance addresses industry concerns about source design, ensuring that operational improvements do not come at the expense of responsible practice.

A Forward Look: Amendment 4

Building on these recent achievements, the Amendment 4 survey in the Mississippi Canyon (figure 6) has been designed to take their integration a step further. It is the first large-scale program in the region to combine Gemini EFS, long-offset OBN acquisition and E-DMFWI from the outset. While results are still at early stages, the intent is clear: create a dataset that fully leverages low frequencies, extended offsets and elastic inversion to resolve the most complex salt structures in the basin.

For industry watchers, Amendment 4 represents more than another survey. It is a test case for whether the combined approach can be scaled to cover large portions of the Gulf and whether it can consistently deliver the clarity needed to de-risk multi-billion-dollar investments.

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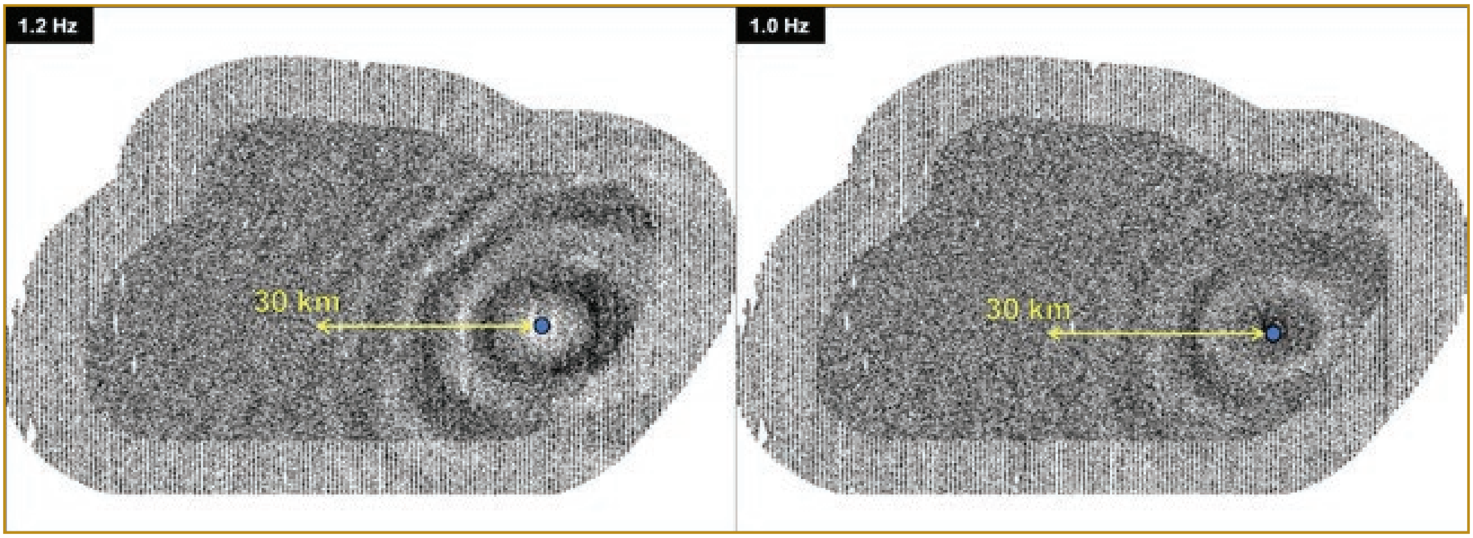

Figure 5. Gemini EFS phase rings for 1.2 and 1.0 hertz, showing wave propagation up to 30 kilometers away from the node location.

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Strategic Implications and Outlook

For decades, geoscientists in the Gulf of Mexico (America) have wrestled with the imaging challenges posed by complex salt provinces. Now, with the combined strength of long-offset OBN coverage, Gemini's extended low frequencies and E-DMFWI velocity modeling, a path is emerging toward consistently reliable subsalt images.

These advances translate into tangible strategic benefits. Companies can shorten evaluation timelines, allocate resources more effectively and avoid unnecessary wells. The ability to image underlying complex faults, salt feeders, carbonate platforms and basement features also supports broader-play fairway analysis, improving confidence at both prospect and basin scale. For operators working in a competitive leasing environment, the advantage lies in being able to act more decisively on opportunities that were once considered too high-risk.

From a broader perspective, these innovations mark a transition in how salt provinces are approached. The achievements of Amendment 1 and 2 provided initial proof that the approach works. The design of Amendment 4 points toward how it will evolve further. For the industry, these efforts mark the beginning of a new era in which the geological riches of the Gulf can be pursued with greater confidence, reduced uncertainty and a clearer view of the subsurface than ever before.

Acknowledgements: The authors thank TGS for support and permission to publish this work, TGS Multi-Client and partners for images and data examples from Amendment surveys 1, 2 and 4.

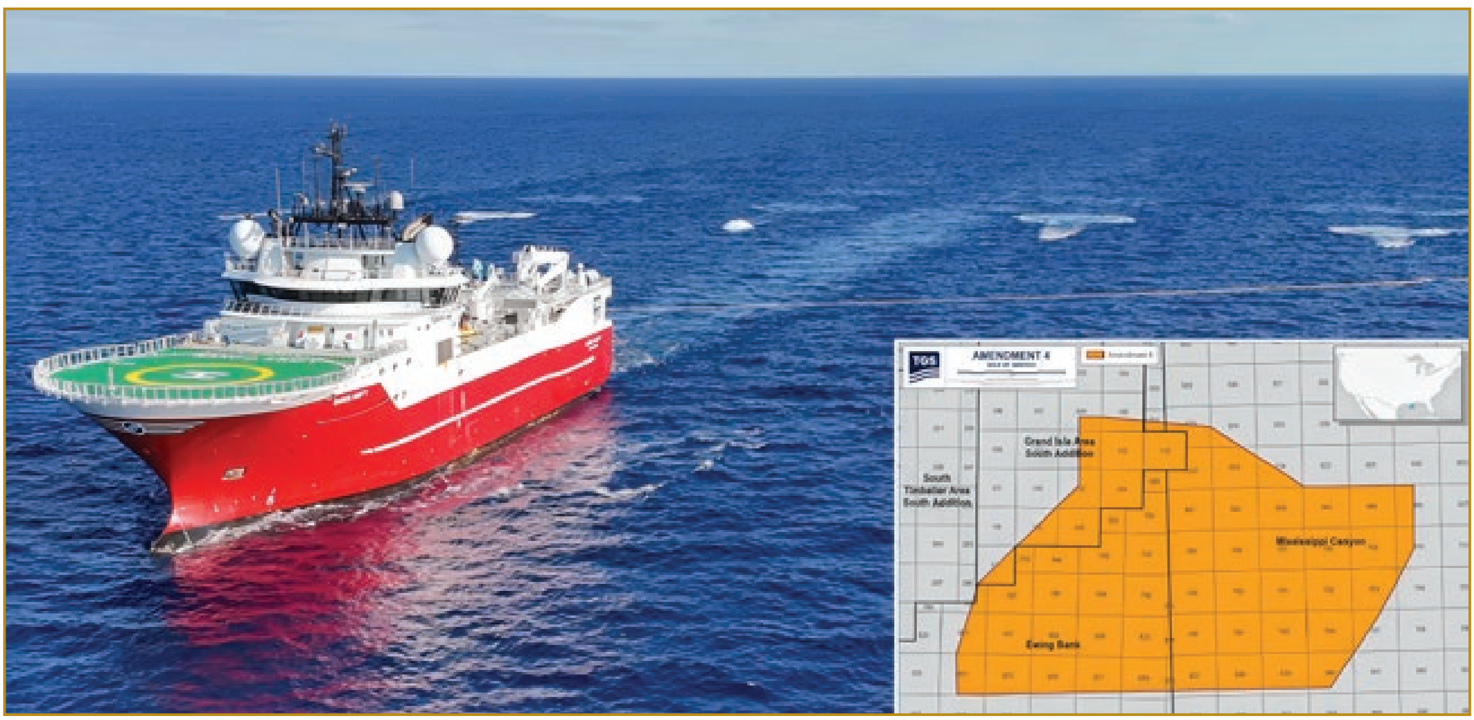

Figure 6. Amendment 4: single source vessel towing 4 Gemini sources, one per gun string during OBN acquisition.