SBGf Conference 18-20 NOV | Rio'25

Advancing Complex Subsalt Imaging Using Elastic FWI and Sparse Ocean-Bottom Node Acquisition

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Abstract Summary

This study highlights the effectiveness of Elastic Dynamic Matching FWI (E-DMFWI) using sparse OBN data to enhance subsalt imaging in the Gulf of Mexico. Leveraging ultra-long offset, full-azimuth, and low-frequency data from Amendment Phase 1 and Phase 2, E-DMFWI accurately resolves salt feeders, carbonates, and deep Luanne salt, and improves imaging beneath complex shallow salt where illumination was previously poor with the streamer data. The approach delivers superior imaging and has the potential to greatly enhance project efficiency.

Introduction

The central U.S. Gulf of Mexico is a key area for hydrocarbon exploration, but complex salt geometries challenge subsalt imaging. Legacy multi-WAZ projects improved results using diving wave FWI and interpreter-driven salt modeling, yet subsalt uncertainties and labor-intensive workflows persisted (Dhananjay et al., 2018). Since 2019, sparse OBN surveys with ultra-long offsets—such as the two-phase Amendment project in Mississippi Canyon (Figure 1)—have been acquired to enable advanced FWI model building (Huang et al., 2020). Phase 1 used 1000×1000 m node spacing, and Phase 2 used 1200×1200 m, both with 50×100 m source spacing and ≥40 km offsets. Low-frequency sources (<2 Hz) were employed to improve deep subsalt updates.

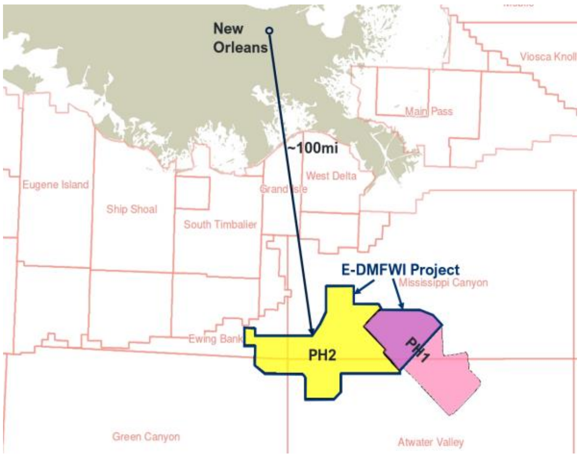

Figure 1: Amendment surveys in GOM. The dark blue polygon defines the E-DMFWI project area.

Applying acoustic dynamic matching FWI (A-DMFWI) to Amendment data highlighted the benefits of sparse, ultra-long offset OBN for subsalt imaging (Mao et al., 2020; Xing et al., 2020), but its acoustic-only approach caused artifacts like salt halos, and boundary mispositioning. Elastic dynamic matching FWI (E-DMFWI) addresses these by incorporating shear waves and density, improving wavefield realism in complex geology. Applied to all Phase 2 nodes and the northern half of Phase 1, E-DMFWI delivered higher-resolution velocity models and clearer subsalt FWI-derived reflectivity (FDR) with less interpretation effort (Wang et al., 2021), fully unlocking the potential of the Amendment acquisition for subsalt imaging.

Method

The Amendment E-DMFWI project began with a legacy 12 Hz A-DMFWI model, smoothed to remove details from shallow sediments and deep carbonates. The inversion used minimally preprocessed hydrophone data (deblending, debubble, basic denoise). E-DMFWI applies elastic wavefield propagation focused on P-wave inversion, while S-wave velocity and density are passively updated using empirical relationships from well data (Liu et al., 2025).

Results

Figures 2A and 2D show the legacy velocity model and WAZ RTM image from conventional top-down workflows, which missed key features like high-angle salt feeders and small inclusions due to limited illumination. Starting from this model, A-DMFWI improved feeder and basement imaging (Figure 2B), with its FDR (Figure 2E) showing better results in poorly illuminated zones. However, acoustic-only physics causes phase mismatches and velocity leakage. E-DMFWI (Figures 2C) provided sharper salt boundaries, clearer feeders and inclusions, and more accurate salt exit velocities. Its FDR (Figures 2F) improves imaging by incorporating the improved illuminations and focusing from more accurately simulated wavefield.

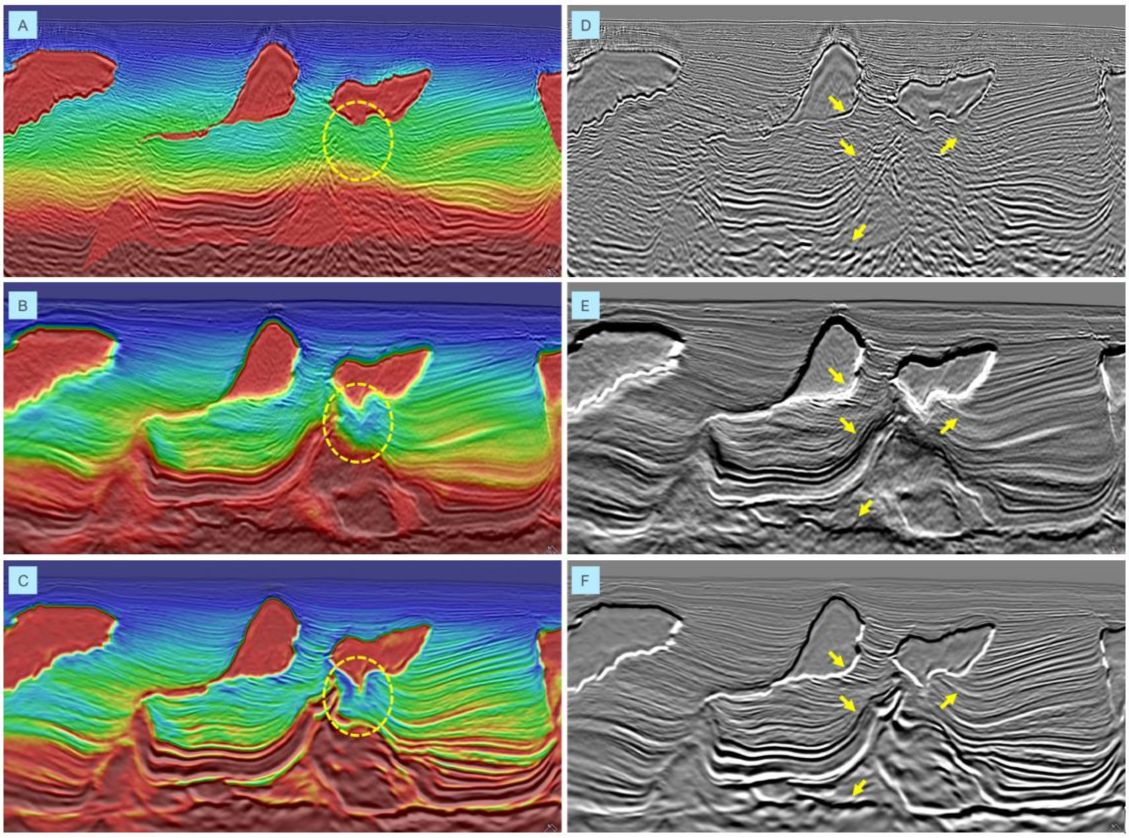

Figure 2: A) The legacy velocity model; B) Velocity model from 14Hz A-DMFWI; C) Velocity model from 14Hz E-DMFWI; D) The legacy RTM image; E). FDR from 14Hz A-DMFWI; F) FDR from 14Hz E-DMFWI. The arrows highlight significant improvements from conventional top-down model building flow to A-DMFWI model building and to current E-DMFWI model building.

The improved imaging makes the FDR a useful interpretation tool for Explorationists. Figures 3A and B highlight this by comparing 14 Hz FDR and 20 Hz WAZ data. Observed onlaps in the basin, are interpreted on the FDR. This stratigraphic relationship is more difficult to interpret on the Legacy RTM. The interpretation using FDR gives the prospect geologist higher confidence in their estimation of risk for prospect elements such as reservoir, trap and seal presence.

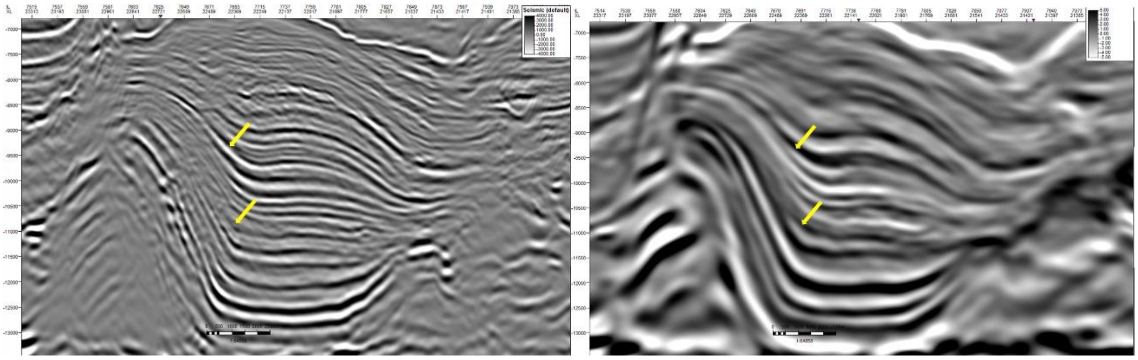

Figure 3: A) Legacy 20Hz WAZ RTM; B) 14Hz Elastic DMFWI FDR

Conclusions

The integration of sparse Ocean Bottom Node (OBN) acquisition with Elastic Full-Waveform Inversion (EFWI) markedly improves subsalt imaging in the Gulf of Mexico. This combined approach offers accurate salt geometry inversion, detailed mapping of sediment truncation to salt feeder zones, enhanced illumination, providing valuable insights for subsalt exploration and development. The Amendment Phase 1 and Phase 2 surveys exemplify how advanced acquisition and processing techniques can overcome challenges posed by complex subsalt geology and significantly reduce project turnaround time.

Acknowledgments

We thank TGS and its partner SLB for their permission to publish these results and TGS multiclient for allowing us to use the Amendment data.

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