Introduction

Reliable seismic data is essential for guiding drilling decisions and reducing the uncertainty associated with hydrocarbon exploration. In this context, the development of advanced seismic processing techniques, particularly Full Waveform Inversion (FWI), has enabled the generation of robust, high-fidelity, data-driven velocity models and associated FWI-Derived Reflectivity (FDR) for rapid interpretation. Recent studies have demonstrated that FWI imaging in geologically complex areas can provide superior model building and imaging results compared with conventional workflows based on migration methods, such as Reverse Time Migration (RTM) (Dias *et al*., 2023).

Additionally, the widespread adoption of Ocean Bottom Node (OBN) acquisition over the last decade has further expanded the applicability of FWI by providing the long offsets and wide azimuths required to exploit refracted and diving waves (Alcudia-Leon *et al.,* 2025). These acquisition characteristics are particularly valuable in complex pre-salt environments, where legacy streamer surveys were often limited by restricted azimuthal coverage, shorter offsets, and historical processing workflows that predated the routine application of FWI. In addition, modern 3D FWI workflows can be applied directly to minimally processed OBN datasets, reducing the need for extensive preprocessing while preserving valuable wavefield information. Combined with advances in high-performance computing (HPC), these developments enable the rapid generation of reliable subsurface models, reducing the turnaround from seismic acquisition to high-confidence imaging products, and accelerating decision-making.

In this case study, we demonstrate how the application of the Dynamic Matching FWI (DM FWI) algorithm (Mao *et al*., 2020) enabled a high-resolution 3D imaging solution in the Campos Basin under a strict four-month turnaround. By applying DM FWI directly to a minimally processed hydrophone data from a newly deployed OBN network, the project bypassed intensive preprocessing to deliver timely, high-quality imaging for imminent drilling decisions. The resulting FWI velocity model and associated FDR significantly improved structural continuity, base-of-salt definition, and subsurface interpretability, providing critical support for the evaluation and de-risking of pre-salt drilling targets.

Geological background & Methodology

Historically a prolific post-salt hydrocarbon province, the Campos Basin reached exploration maturity over the past decade for the Oligocene and Upper Cretaceous sandstone reservoirs. It is currently experiencing renewed exploration activity driven by recent pre-salt discoveries in Macabu Formation carbonates. Like the well-known fields in the Santos Basin, the overburden in Campos is highly complex, with distinctive characteristics that hinder imaging and understanding of the pre-salt interval. Among the challenges, the evaporitic section exhibits geometries shaped by stretching and thinning processes that sometimes raise doubts about seal efficiency, demanding high-resolution seismic imaging for accurate mapping. Furthermore, supra-salt Albian carbonates, due to their higher velocities compared to halite, can invert the expected polarity at the top of salt, often rendering it transparent and difficult to interpret. In this context, the juxtaposition of supra-salt carbonates and clastic sediments, halite, and sub-salt carbonates generates a complex velocity regime. The accurate delineation of these targets requires seismic imaging solutions capable of resolving strong velocity contrasts and reducing uncertainty associated with base-of-salt interpretation.

To address these challenges, a recently acquired OBN survey was processed using a fast-track (DM FWI) workflow. The full-azimuth and long-offset acquisition geometry provided the necessary wavefield coverage to exploit the kinematic sensitivity of refracted and diving waves, enabling the construction of a robust, data-driven velocity model directly from minimally processed hydrophone gathers following source deblending and debubble processing. The dynamic matching technology, combined with a multi-scale inversion strategy, mitigated cycle-skipping and convergence limitations commonly encountered in conventional FWI implementations, allowing stable model updates in the presence of complex salt and carbonate geometries (Sheng *et al*., 2020). This workflow was executed with commercially available high-performance cloud computing resources in Brazil, enabling delivery of a fast-track imaging solution within a four-month timeframe.

The initial model for FWI was derived from a legacy velocity volume that had undergone considerable smoothing. In addition, high-contrast transitions present in the legacy model (e.g. carbonate structures) were removed to avoid biasing the inversion. FWI was deployed using a multiscale approach, starting at 2.5 Hz, and progressing up to 30 Hz. The early stages of FWI leveraged refracted and diving wave energy to resolve kinematic details of the background model. The general sedimentary velocity trend was refined while the high-velocity features were progressively recovered and refined with increasing frequency and iteration count. A key quality-control (QC) step through the model building incorporated the available well data. The sonic logs and geological markers were used to calibrate the model building, and to define and guide the anisotropic parameters (delta and epsilon). Well misties were progressively reduced across all frequency stages, with the final FWI model demonstrating improved structural consistency and tighter calibration to the well data throughout the section.

The final velocity model was the basis for the generation of a high-resolution 30 Hz FDR volume, enabling the rapid delivery of a high-resolution and interpretable imaging product.

Results & Discussion

The DM FWI velocity model and associated FDR volume, when compared to the legacy velocity and Kirchhoff-based imaging product, demonstrated substantial improvements in regions affected by complex salt-related illumination challenges (Figure 1). While the legacy image locally exhibits a higher-frequency character, as expected from a conventional migration workflow, the FDR volume provides a substantially more geologically consistent representation of the subsurface, characterized by improved reflector continuity, enhanced structural conformity, and a more coherent stratigraphic framework.

The most significant imaging enhancement is observed at the base of salt, where the DM FWI velocity model improves the positioning and continuity of key structural events relative to the legacy interpretation. Beneath the salt bodies, the updated velocity model enables a more reliable reconstruction of the pre-salt structural architecture, reducing uncertainty in the interpretation of fault patterns, structural closures, and reservoir geometries. The associated FDR volume reveals laterally continuous reflectors that were previously discontinuous, distorted or poorly illuminated, increasing confidence in the correlation of key stratigraphic markers across the survey area.

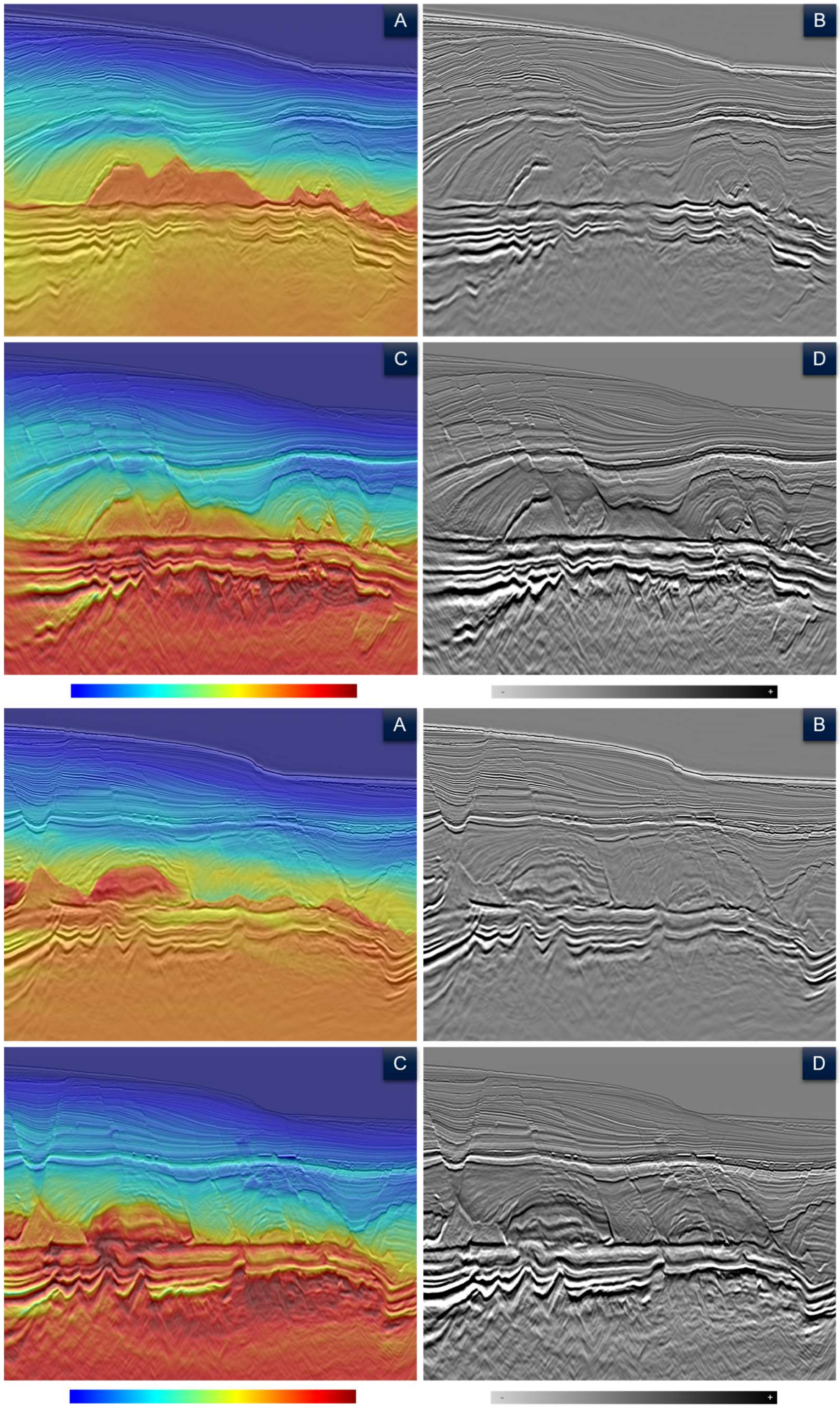

Figure 1 *Images A present the legacy Kirchhoff Depth Migration Streamer Stack with Legacy Velocity overlaid; Images B present the legacy Kirchhoff Depth Migration Streamer Stack; Images C present the 30Hz FWI Derived Reflectivity with OBN 30Hz FWI Velocity overlaid; Images D present the 30Hz FWI Derived Reflectivity dataset.*

These improvements translate directly into enhanced geological understanding of the pre-salt carbonate section. The improved continuity and structural consistency facilitate a more reliable delineation of potential reservoir intervals, trapping configurations, and compartmentalization patterns. In addition, the enhanced imaging of both post-salt and pre-salt intervals reduces uncertainty in prospect evaluation and supports a more confident assessment of drilling targets. In several cases, the improved definition of reservoir geometries and structural closures provided critical insights for the optimization and repositioning of planned well trajectories prior to drilling.

Conclusions

This study demonstrates the successful application of a fast-track 30 Hz DM FWI workflow to image the complex pre-salt section of the Campos Basin using long-offset, full-azimuth OBN data.

The resulting velocity model and its associated FDR volume provided improved base-of-salt definition, enhanced event continuity, and a more geologically consistent representation of the subsurface compared with legacy imaging products. These improvements reduced uncertainty in both post-salt and pre-salt intervals and supported a more confident structural interpretation.

Delivered within a four-month turnaround, the workflow provided timely subsurface insights that directly contributed to the optimization of planned well trajectories. This case study demonstrates the value of DM FWI as a practical imaging solution for rapidly delivering high-fidelity subsurface models that support drilling decisions in complex salt-related settings.

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References

Alcudia-Leon, A., F. Sotero, A. Sosa, V. Oliveira, J. Santos, J. Burren, B.M. Bastos, F.S. Duarte, E. E. Barbosa and J. D. M. Quintiliano, 2025, Mitigating Structural Uncertainty: Early Insights from OBN FWI Imaging - A Santos Basin Case Study: Proc. 19th Int. Congr. Brazilian Geophysical Society, Rio de Janeiro, Brazil.

Dias, B. P., P. Bertussi, A. Bulcão, and G. C. Alves, 2023, New insights on the better focusing of FWI derived images: Proc. 18th Int. Congr. Brazilian Geophys. Soc., Rio de Janeiro, Brazil.

Mao, J., J. Sheng, Y. Huang, F. Hao, and F. Liu, 2020, Multi-channel dynamic matching full-waveform inversion: SEG Technical Program Expanded Abstracts, 666–670. https://doi.org/10.1190/segam2020-3427610.1

Sheng, J., J. Mao, Y. Huang, F. Hao, and F. Liu, 2020, Dynamic matching FWI—Focusing on kinematics: 82nd EAGE Annual Conference and Exhibition, Volume 2020, 1–5. https://doi.org/10.3997/2214-4609.202010784