Advancing Legacy Streamer Data with Elastic Dynamic Matching Full Waveform Inversion: Campos Basin

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Introduction

Many successful Full Waveform Inversion (FWI) studies rely on long-offset, low-frequency data acquired with full-azimuth geometries, which are widely regarded as key requirements for robust inversion results (Roende *et al*., 2020). In contrast, relatively few published examples address the application of FWI, particularly Elastic FWI to narrow-azimuth (NAZ) seismic data. This paper demonstrates that, despite the inherent limitations of NAZ acquisition, Elastic Dynamic Matching Full Waveform Inversion (E-DMFWI) can be successfully applied to resolve small-scale volcaniclastic features and complex structural settings. The approach mitigates many of the challenges associated with conventional tomography and interpretation driven velocity model building workflows. A direct comparison between elastic and acoustic FWI highlights the additional uplift provided by elastic physics, with elastic FWI delivering improved resolution while requiring reduced manual intervention and operating in a data-driven framework. The results indicate that NAZ seismic data in Brazilian basins contain exploitable information beyond that recovered by traditional imaging approaches, enabling more cost-effective exploration and development through the application of advanced Elastic FWI technologies.

Geological Setting

The Campos Basin, located along the southeastern continental margin of Brazil, is one of the most prolific hydrocarbon provinces in South America. It covers approximately 115,000 km² offshore the states of Rio de Janeiro and Espírito Santo, spanning water depths from the shallow continental shelf to ultra-deepwater settings exceeding 3,000 m. The basin developed during the Early Cretaceous South Atlantic rifting, evolving from a continental rift system into a passive margin. This tectonic evolution is reflected in its stratigraphic architecture, which comprises three principal depositional sequences: pre-salt, salt, and post-salt.

The pre-salt interval consists primarily of syn-rift lacustrine carbonates and siliciclastic sediments, including microbialite-dominated reservoirs, which are sealed by thick Aptian evaporites forming a regionally effective seal. Overlying the salt, the post-salt succession comprises Albian to Recent marine sediments, dominated by turbiditic sandstones and slope-channel systems that constitute important secondary reservoirs. Salt tectonics has generated significant halokinetic deformation, creating complex structural traps and migration pathways that strongly influence hydrocarbon distribution. In addition, localized volcanic bodies are present in parts of the basin, further complicating seismic imaging.

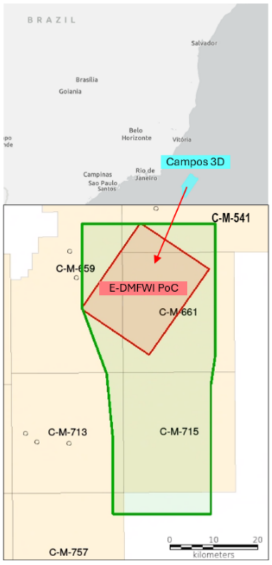
Despite its proven hydrocarbon productivity, the Campos Basin poses several technical challenges. Structural complexity associated with salt movement and thick, laterally heterogeneous evaporite layers distorts seismic wave propagation, making subsalt imaging particularly challenging. Addressing these issues requires advanced imaging and model-building techniques, including reverse time migration (RTM) and Elastic Dynamic Matching Full Waveform Inversion (E-DMFWI).

Method /Workflow

The Campos 3D survey, acquired in 2020 - 2021 in the outboard Campos Basin, covers ~14,000 km² and comprises a narrow-azimuth (NAZ) streamer geometry with a maximum offset of 10 km, 100 m cable spacing, and 25 m flip-flop shooting. Legacy depth imaging relied on iterative tomography and Acoustic Dynamic Matching FWI, producing good-quality images but required elaborate manual intervention and exhibited limitations in areas of complex salt tectonics and localized volcanics.

This study evaluates the uplift obtained using E-DMFWI through a proof-of-concept (PoC) conducted over ~500 km² in the southern survey area, covering blocks C-M-659, C-M-661, and C-M-541 (Figure 1), with water depth ranging from approximately 2,800 to 3,100 m. As with most NAZ datasets, limited azimuthal illumination and a lack of diving-wave energy and low frequencies poses challenges to FWI.

Elastic FWI better captures areas with high lithologic variability and strong impedance contrasts, such as salt bodies, carbonate build-ups, and volcanic sequences where elastic effects are significant. It offers improved amplitude and phase fidelity compared to acoustic assumption. The inversion in this PoC used minimally processed seismic data and was initialized from the legacy velocity model. Different Vp/Vs ratios were assigned to the post-salt, salt, and pre-salt intervals based on regional knowledge gathered from well information. A multi-scale inversion strategy was employed, progressing through multiple frequency bands from 4 to 18 Hz (figure 2), with data and image-domain quality controls applied between stages to ensure stable convergence and progressive model improvement.



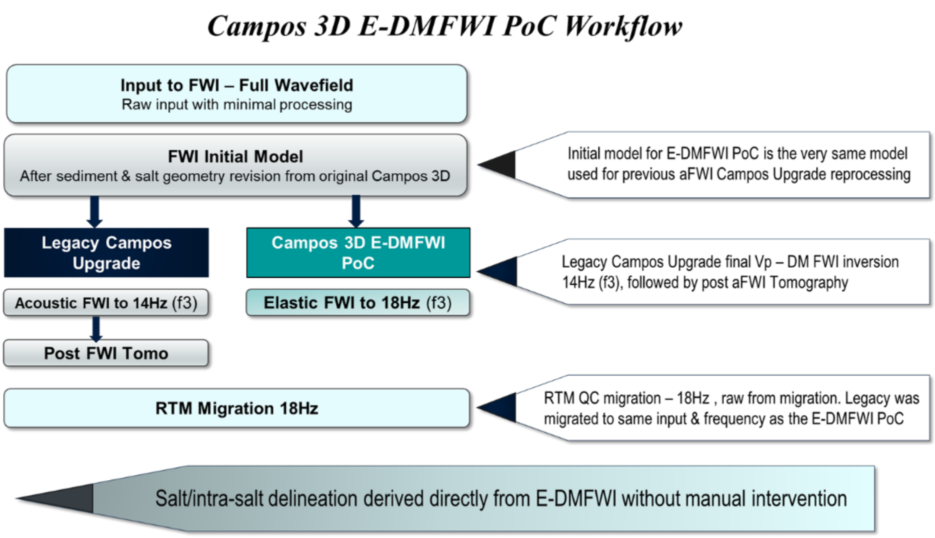


Figure 1 *(Left) Location map of Campos 3D E-DMFWI PoC. The study area outlined in red.*
Figure 2 *(Right) E-DMFWI PoC Workflow.*

Results & Observations

The proof of concept (PoC) demonstrated that Elastic Full Waveform Inversion (EFWI) significantly enhanced imaging quality across the entire section. One of the most notable observations was the improved resolution and structural details in the post-salt interval, where conventional workflows often struggle due to complex velocity variations. The E- DMFWI approach delivered sharper salt delineation and clearer stratigraphic features, extending benefits from the shallow section through to deeper targets (see figure 3 -6 illustrating the results)

A key strength of the workflow was its data-driven nature. The process required minimal manual intervention or velocity model manipulation, starting from the same initial model and seismic data as conventional and acoustic methods. This autonomy underscores the robustness of E-DMFWI technology and its potential to streamline velocity model building while reducing human bias. The PoC also highlighted the capability of E-DMFWI to improve gather flatness and image quality even in challenging pre-salt environments. However, one challenge encountered was the generation of anomalously high velocities in the pre-salt reservoir. While initially unexpected, subsequent analysis confirmed that these velocities contributed to better gather consistency and enhanced imaging of deep faults, suggesting that the inversion was capturing real geological complexity rather than artifacts.

Overall, the elastic inversion results demonstrate clear improvements in resolution and continuity throughout the section, validating the effectiveness of advanced E-DMFWI techniques for complex salt provinces. Future work should focus on refining pre-salt velocity estimation and integrating rock physics constraints to further reduce uncertainty.

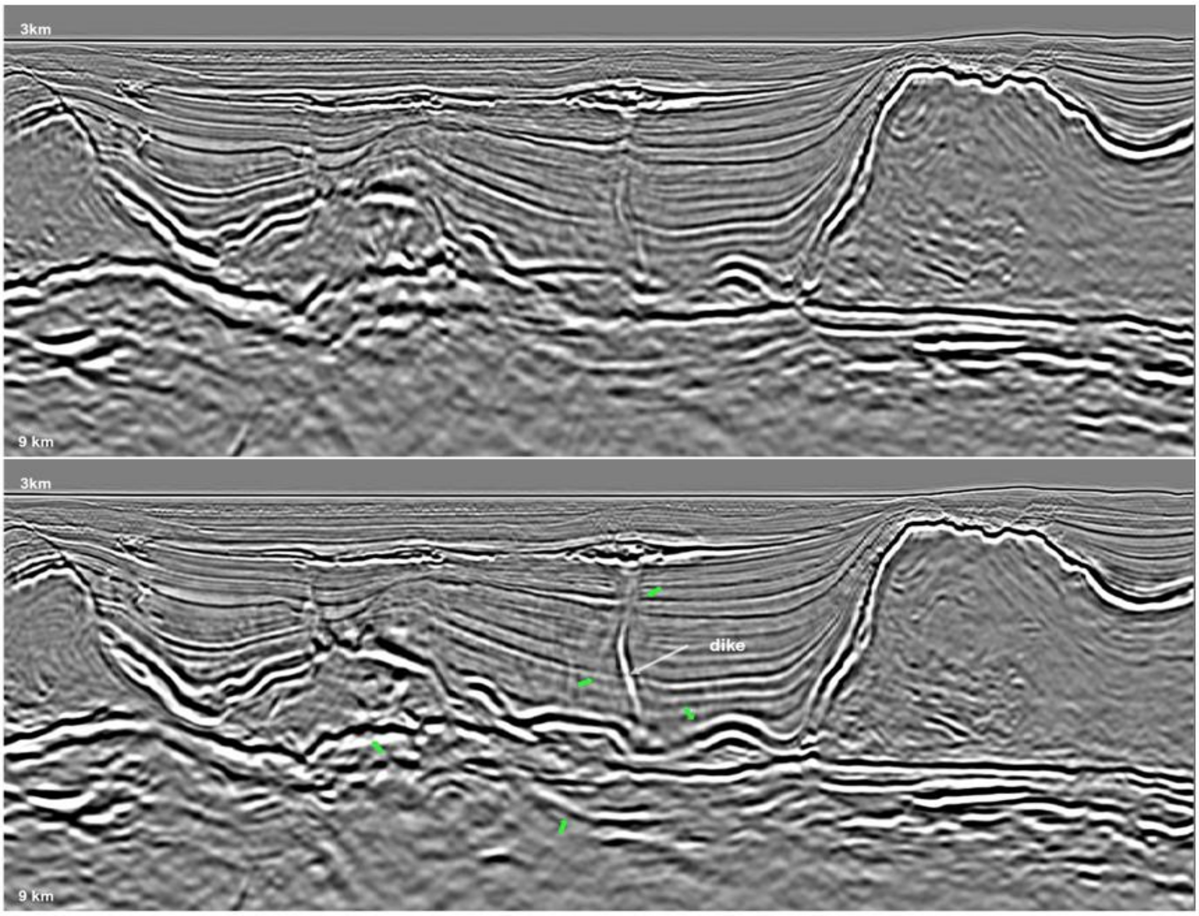


Figure 3: *(Top) Legacy 18 Hz RTM image. (Bottom) 18 Hz RTM image using the E-DMFWI velocity model, showing improved delineation of the dike feature, enhanced post-salt imaging, and reduced structural complexity in the pre-salt section*

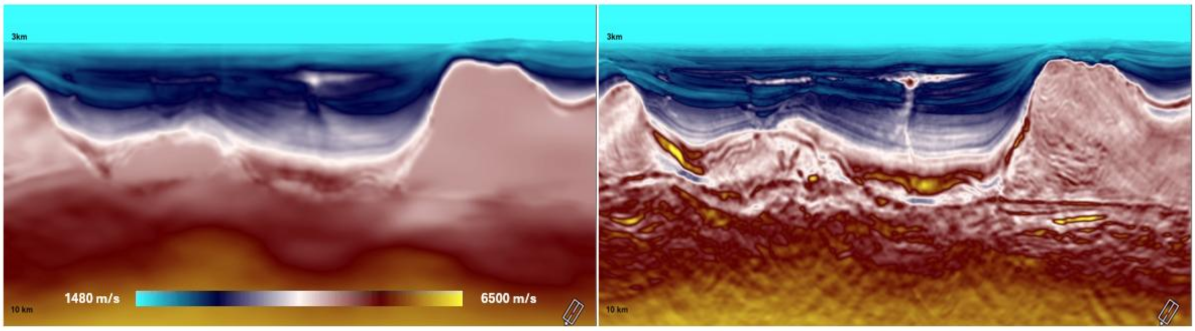


Figure 4*: (Left) Legacy acoustic DM FWI velocity model. (Right) 18 Hz elastic DM FWI velocity model*

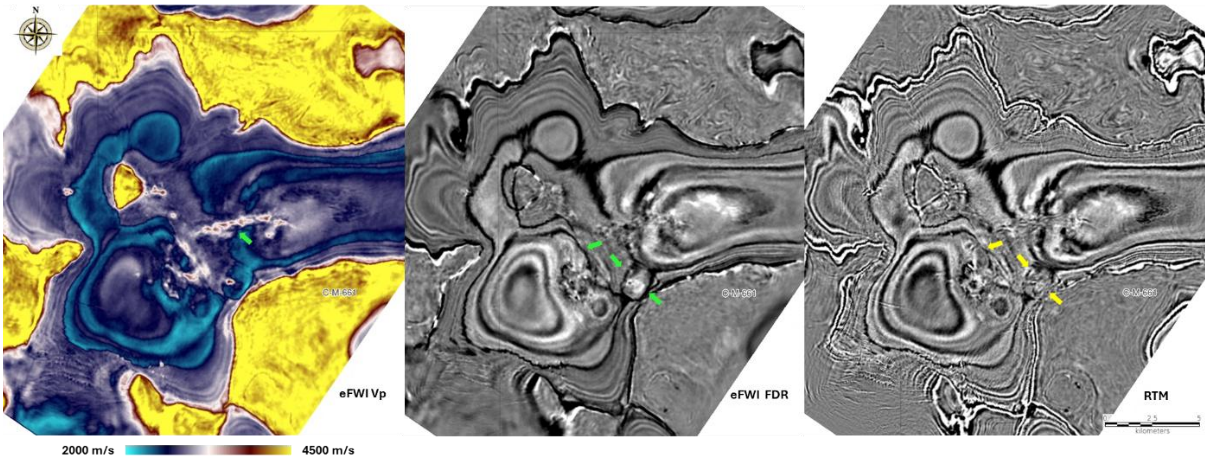


Figure 5: *Depth slice at 4400m-18 Hz E-DMFWI velocity model (left), E-DMFWI FDR (middle), and RTM image migrated with the corresponding model (right). E-DMFWI resolves dike features, while the FDR enhances structural continuity that appears less visible & more chaotic in the RTM image.*

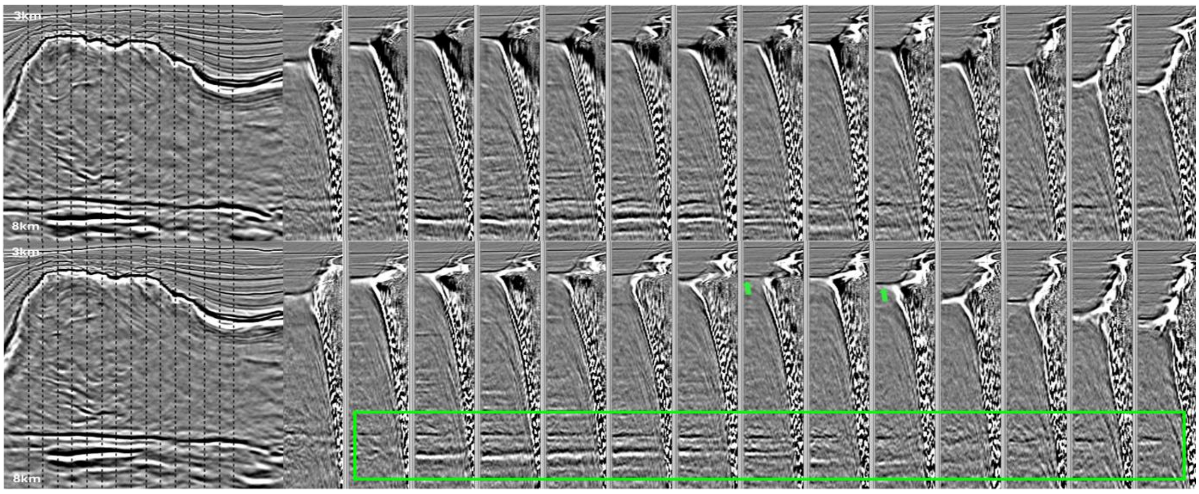


Figure 6: *Kirchhoff gathers with E-DMFWI showing improved ToS, BoS & pre-salt gather flatness as E-DMFWI is more effective in sharpening salt halo compared to legacy acoustic DM FWI*

Conclusions

Elastic DM FWI offers clear advantages over conventional workflows, delivering geologically conformable models and reducing manual interpretation time. Starting from the same initial model, the approach improved salt geometry, simplified pre-salt complexity, and delineated volcanic geobodies, unlocking additional hydrocarbon potential. While computationally demanding, cloud-based resources enable practical implementation. This study confirms that existing NAZ data contains raw measurements that have not been imaged previously. The NAZ data can now be fully leveraged using E-DMFWI for cost-effective exploration and development in Brazilian basins.

Acknowledgements

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References

Roende, H., D. Bate, J. Mao, Y. Huang, and D. Chaikin, 2020, New node acquisition design delivers unprecedented results with dynamic matching FWI — Case study from the Gulf of Mexico: First Break,38, no. 9, 73–78, https://doi.org/10.3997/1365-2397.fb2020068