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Unlocking AVA attributes through elastic multi-parameter full-waveform inversion

Jennifer Badry (DUG Technology), James McLeman (DUG Technology), Tom Rayment (DUG Technology), Fabio Mancini (DUG Technology)

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Summary

Elastic multi-parameter full-waveform inversion (MP-FWI) offers a powerful alternative to conventional imaging by directly estimating AVA-consistent elastic properties from minimally processed seismic data. This study presents two case studies—one from the Gulf of America using ocean-bottom nodes, and another from the Australian North-West Shelf with towed-streamer acquisition. In both cases, elastic MP-FWI delivered high-resolution models that aligned with well data. These results underscore the method's potential to streamline imaging and quantitative interpretation in complex geological settings.

Introduction

Increasing geological complexity in hydrocarbon exploration has driven the demand for advanced imaging techniques capable of delivering high-resolution amplitude-versus-angle (AVA) attributes. Traditional imaging workflows, such as reverse-time migration (RTM) and Kirchhoff depth migration (KDM), rely on the Born approximation and require extensive pre-processing to remove wavefield components (e.g., multiples) that violate this assumption. While least-squares extensions (Nemeth et al., 1999; Guitton, 2017) improve amplitude fidelity, they remain constrained in complex geological settings.

Full-waveform inversion (FWI) (Tarantola, 1984), traditionally applied to diving waves for Vp estimation, has evolved into a multi-parameter (MP-FWI) methodology that incorporates reflected energy and allows for the simultaneous estimation of elastic properties such as P-impedance and Vs/Vp ratio. MP-FWI leverages multiples as useful signal, enhancing data utilization and resolution (McLeman et al., 2023). Although early implementations often used acoustic assumptions, recent advances in high-performance computing have made 3D elastic MP-FWI (Gomes et al., 2024) feasible. This enables direct retrieval of AVA-consistent properties from raw seismic data without relying on angle stacks or conventional AVA-inversions.

This paper presents two applications of elastic MP-FWI: one from the Gulf of America using sparse OBN acquisition, and another from the Australian North-West Shelf using towed-streamer data. These contrasting examples highlight the robustness and flexibility of the method across acquisition geometries and geological settings.

Method and Results

Case Study 1: Gulf of America.

The dataset comprises sparse ocean-bottom node (OBN) acquisition in the Gulf of America, with water depths around 2 km. Initial models for anisotropy, Vs/Vp ratio, and density were built using regional geology and well constraints. Elastic MP-FWI was applied in two stages. First, Vp and P-impedance were updated with Vs/Vp held constant, followed by a joint inversion of all three parameters.

The seismic input underwent minimal pre-processing, limited to node repositioning. Only hydrophone data were used. Source signatures were modelled and refined through an inversion process within the FWI workflow. A conventional mirror migration workflow using pre-processed data was run for comparison.

Figure 1 compares the reflectivity generated from downgoing mirror RTM, acoustic MP-FWI, and elastic MP-FWI. While both FWI-derived reflectivity models outperform RTM in resolution, the elastic MP-FWI further enhances structural continuity and definition around high-impedance contrast features like salt flanks, and areas of poor illumination, as indicated by yellow arrows.

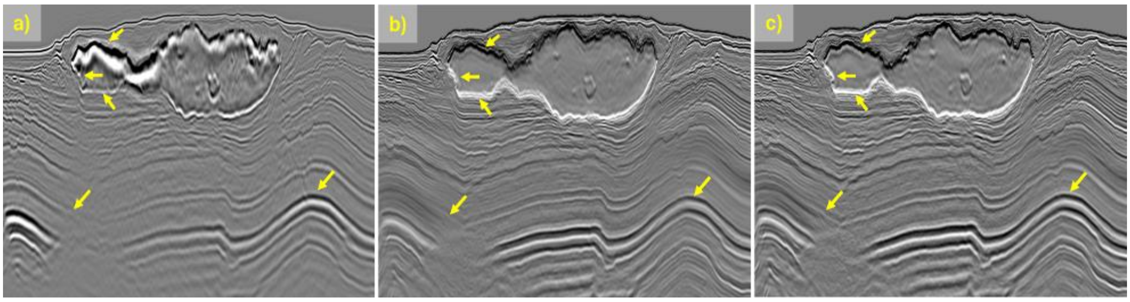

Figure 1: Downgoing mirror RTM a), acoustic MP-FWI reflectivity b), and elastic MP-FWI reflectivity c).

Figure 2 shows reflectivity, P-velocity, density, P-impedance, and Vs/Vp ratio derived from the elastic MP-FWI. The inversion results exhibit excellent geological consistency and reveal fine-scale detail. This strong conformity with expected stratigraphy provides qualitative evidence of the success of the elastic MP-FWI approach.

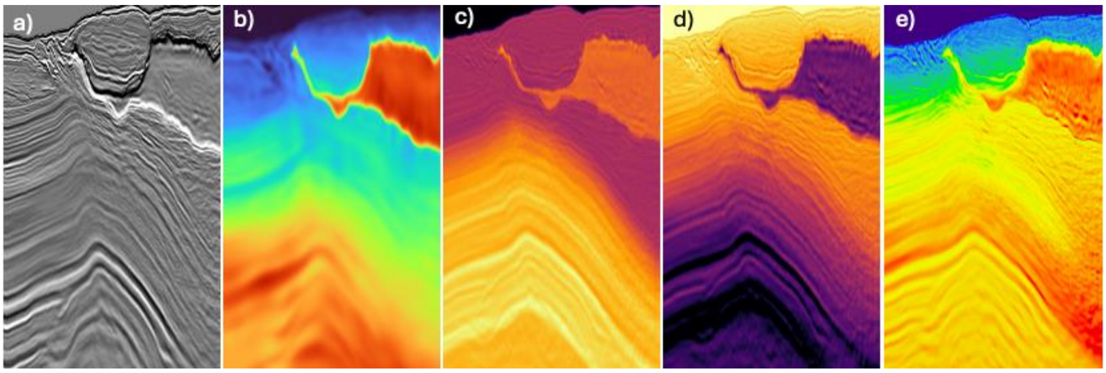

Figure 2: Outputs from elastic MP-FWI. Reflectivity a), P-velocity b), density c), P-impedance d) and Vs/Vp e).

To move from a qualitative to a quantitative assessment, Figure 3 compares the initial (red) and inverted (blue) models with the well data (black) at the well location. The elastic MP-FWI models show strong correlation with well-log trends, particularly in resolving impedance contrasts and preserving AVA-consistent behaviour.

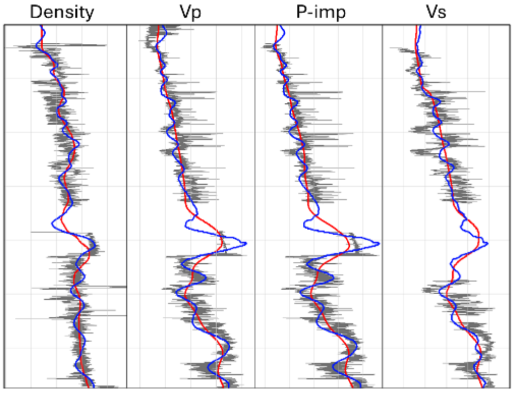

Figure 3: Comparison between the well data (black), initial models (red), and elastic MP-FWI inverted results (blue).

Case Study 2: Australian North-West Shelf.

This dataset was acquired in 2006 using a dual-source towed-streamer array northwest of Barrow Island. The area is characterized by shallow carbonate heterogeneity and complex channel features. Acquisition was performed by a towed-streamer vessel comprising eight streamers with 6 km maximum offsets.

Legacy Vp models were refined using diving-wave FWI up to 19 Hz. Initial low-frequency models for Vs/Vp, density, and anisotropy were built using well logs and regional geology. These inputs were used in a multi-stage elastic MP-FWI workflow: Vp and P-impedance were first updated at 11 Hz, 14 Hz, and 19 Hz; anisotropy was refined at 19 Hz; and a targeted single-parameter inversion further improved P-impedance using near-angle reflections. The inversion for Vp, Vs/Vp, and P-impedance followed at 19 Hz, 25 Hz, and 35 Hz. Parameter crosstalk was minimized through data partitioning and an L-BFGS optimizer with adaptive gradient preconditioning.

The input data were raw hydrophone field recordings, with wavelets modelled and iteratively updated during inversion. No near-field hydrophone data were available.

Figure 4 presents an inline comparison, showing initial models for Vp, Vs/Vp and P-impedance (top raw) and the equivalent elastic MP-FWI results (bottom raw). The updated models demonstrate increased resolution, particularly in thin layering, and successfully predict AVA trends associated with gas saturation—marked by decreasing Vp and P-impedance and increasing Vs/Vp ratio (black arrows).

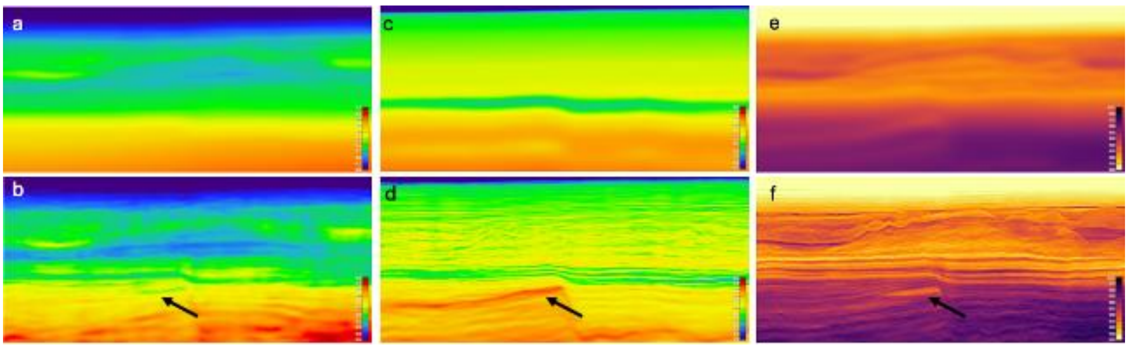

Figure 4: The initial models input to elastic MP-FWI of Vp, a), Vs/Vp c), and P-Impedance e). The elastic MP-FWI updated equivalents are shown in b), d), and f).

Figure 5 presents the results extracted at a well located at the center of the inline. Shown are the well data (black), the initial elastic MP-FWI models (red), and the final inverted results (blue). At the location marked by the orange arrow, the well indicates a drop in P-impedance primarily due to reductions in density and Vp, alongside an increase in the Vs/Vp ratio. The updated MP-FWI models accurately capture these variations, indicating successful mitigation of parameter crosstalk. Notably, well data informed only the building of the initial low-frequency models and played no role in guiding the inversion.

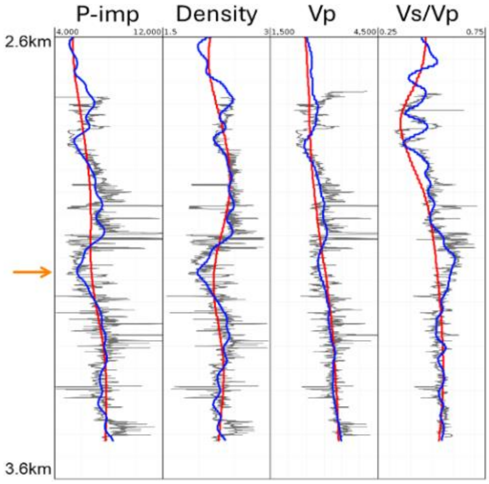

Figure 5: Comparison between the well information (black), the initial models input to elastic MP-FWI (red), and the models inverted by elastic MP-FWI (blue).

Conclusions

The presented case studies confirm the efficacy of elastic MP-FWI in directly estimating AVA-consistent elastic properties from minimally processed seismic data. The method provides high-resolution, geologically realistic models that align with well-log data. Elastic MP-FWI simplifies AVA attribute extraction by removing dependence on pre-stack angle gathers and angle stacks, offering a robust and efficient alternative for modern seismic imaging in complex environments.

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References

Gomes, A., Rocha, D., Wong, M., Perkins, C., Goh, V., Plessix, R.-E. [2024] High-resolution impedance estimation using multi-parameter visco-elastic FWI in a Gulf of Mexico setting, AAPG, Expanded Abstracts.

McLeman, J., Rayment, T., Burgess, T., Dancer, K., Hampson, G. and Pauli, A. [2023] Superior resolution through multiparameter FWI imaging: A new philosophy in seismic processing and imaging, The Leading Edge, 42(1), 34-43.

Nemeth, T., Wu, C. and Schuster, G.T. [1999] Least-squares migration of incomplete reflection data, GEOPHYSICS, 64(1), 208-221.

Tarantola, A. [1984] Inversion of seismic reflection data in the acoustic approximation, GEOPHYSICS, 49(8), 1259-1266.