Triple-parameter viscoelastic MP-FWI from offshore West Africa

M. Kobylarski[1], J. Chaloner[1], K. Kraus[1], B. Chowdhury[1], M. Micu[1], T. Rayment[1]

[1] DUG Technology

Summary

In this paper we demonstrate the use of viscoelastic MP-FWI to invert for elastic properties (Vp, Vs/Vp and P-impedance) directly from field data. This method bypasses the time-consuming and highly subjective conventional processing, model-building, imaging and AVA inversion workflows. The technique was applied to a deep-water Ocean-Bottom Node (OBN) seismic survey acquired in 2024 offshore West Africa. The zone of interest is a dipping clastic reservoir beneath a regional unconformity. It displays a strong flat-spot reflection associated with a hydrocarbon-water contact. There is also a significant gas cloud in the sediments overlying the field. The viscoelastic MP-FWI simultaneously generated Vp, Vs/Vp and P-impedance models of the subsurface using the full wavefield up to a maximum frequency of 45 Hz. Generated models are detailed and accurately capture geological features. There is a good agreement with structures visible in the reflectivity. Perturbations in the gas cloud and in the deeper reservoir are reliable and the oil water contact is visible. Derived models also provided good agreement with the well logs.

Triple-parameter viscoelastic MP-FWI from offshore West Africa

Introduction

Full-waveform inversion (FWI) is now a well-established tool for deriving high-resolution earth models for seismic processing and imaging. Traditionally, FWI has focused on the inversion of P-wave velocity (Vp), but the recent development of multi-parameter inversions means that additional properties can be derived, such as Q, P-impedance and Vs/Vp, either through a single simultaneous inversion or a combination of multi-parameter inversions.

Viscoelastic MP-FWI (Badry and McLeman, 2025) is one such approach that inverts for Vp, P-impedance, and the Vs/Vp ratio. This technique is able to model and therefore use the entire recorded wavefield, which means that the conventional processing workflow of removing the effects of the source signature, ghosts and multiples is not required. Multiples, once considered noise, are now treated as usable signals which can improve the illumination of the sub-surface. The inversion for P-impedance means that a reflectivity can be derived without the need for conventional migration. Furthermore, the combination of Vp, P-impedance and Vs/Vp provides the elastic parameters required for Quantitative Interpretation (QI) without the need for conventional AVA inversion of migrated gathers. As a result, the conventional seismic processing, imaging and AVA inversion workflows are bypassed.

In this paper, we apply this technique, along with a multi-parameter inversion for Vp and Q to a deep-water Ocean-Bottom Node (OBN) seismic survey acquired in 2024 from offshore West Africa. The zone of interest is a dipping clastic reservoir beneath a regional angular unconformity. It displays a strong flat-spot reflection associated with a hydrocarbon-water contact. There is a significant gas cloud in the sediments overlying the field that exhibits strong attenuation and highly laterally variable Vp. This has significantly degraded the deeper existing image that used legacy towed-streamer data.

Method

We used viscoelastic MP-FWI to simultaneously generate Vp, Vs/Vp and P-impedance models of the subsurface using the full wavefield up to a maximum frequency of 45 Hz. Given the presence of gas bodies, it was considered important to derive an accurate Q model prior to viscoelastic MP-FWI. This was achieved through simultaneous inversion of Vp and Q using diving-waves in a frequency-stepping fashion up to a maximum frequency of 17 Hz. The input data to this and subsequent inversions was the hydrophone component of the OBN data, which had been deblended using an inversion-based deblending technique (Kumar et al., 2020). Near-field hydrophone (NFH) records were used to derive shot-by-shot source signature information. The input Vp model was a smoothed version of the existing legacy model, and anisotropy was derived using the well data and updated at the initial stage of diving-wave FWI. The extended offsets of the OBN data provide diving-wave illumination down to the regional unconformity at the top of the reservoir.

Low-frequency background models of density and Vs/Vp were created from rock physics analysis of available well data and regional geological understanding. Viscoelastic MP-FWI was then performed using the full wavefield in a frequency-stepping fashion, up to a maximum frequency of 45 Hz. At lower frequencies, the Vs/Vp ratio remained fixed, and only Vp and P-impedance were updated. Once these parameters were well established, Vs/Vp was included as a third parameter in the inversion. This strategy has proven useful for resolving crosstalk. This approach resulted in 45 Hz Vp, P-impedance, and Vs/Vp models with directional P-reflectivity computed by taking the derivative of P-impedance along the direction normal to the impedance contrast.

Results

Figure 1 shows the Q model derived from the joint Vp and Q diving-wave MP-FWI co-rendered with MP-FWI reflectivity. The main absorbing body in the large gas cloud is isolated, along with some smaller regions of higher attenuation that correlate with bright events that we interpret as smaller gas bodies.

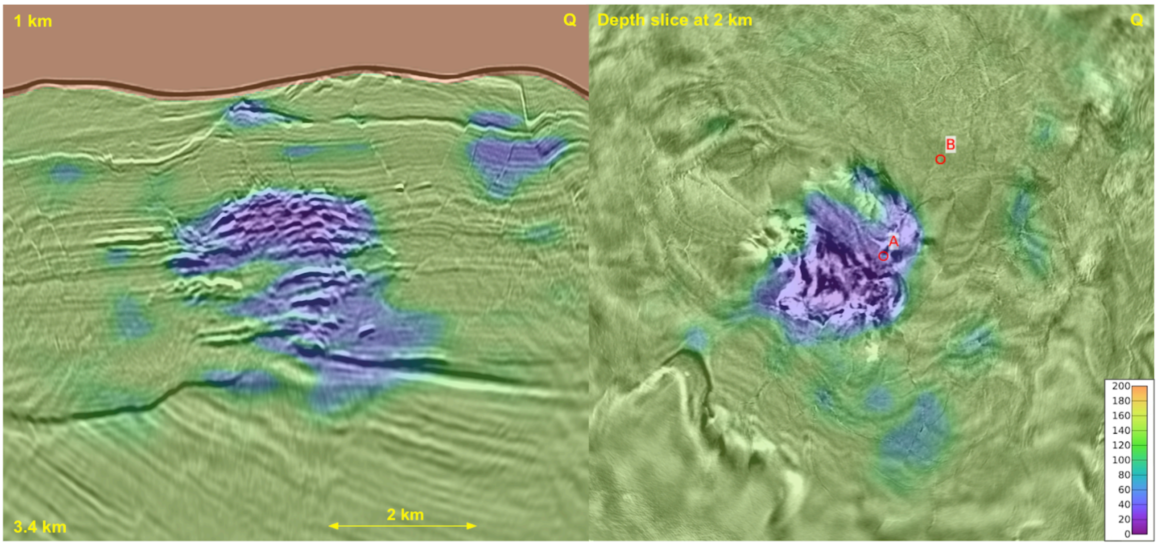

Figure 1 *Inverted Q model and MP-FWI reflectivity. Left, inline through a gas cloud, right, depth slice at 2 km. Note the correspondence of the higher attenuation with the likely presence of gas in the main gas cloud complex, as well as other locations associated with anomalously bright reflectors.*

Figure 2 shows the legacy Vp co-rendered with the legacy towed-streamer KPreSDM compared to the Vp and reflectivity derived through viscoelastic MP-FWI. The combination of MP-FWI and the newly acquired full-azimuth data from the OBN acquisition (maximum offset ~10 km) provides a significant illumination improvement over the legacy narrow-azimuth towed-streamer image (maximum offset ~4 km). The MP-FWI-derived Vp model is much more detailed, with the Vp perturbations associated with the gas cloud nicely captured. Good agreement is observed between the model and the structures visible in the reflectivity - such as the faults in the shallow (orange arrows) and at the flat spot in the reservoir (yellow arrows).

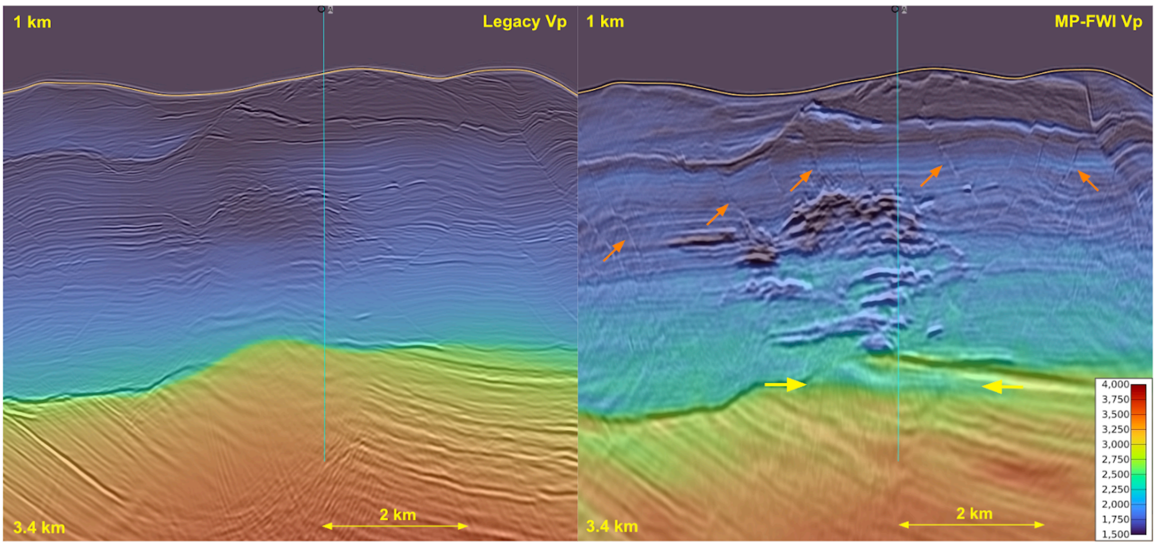

Figure 2 *Legacy velocity model and KPreSDM stack of legacy streamer data overlain (left) and viscoelastic MP-FWI Vp and reflectivity from new OBN data overlain (right).*

Figures 3 and 4 show the initial and final 45 Hz Vs/Vp and P-impedance models respectively. There is a good agreement between the inverted parameters and the underlying geology. The inverted Vs/Vp demonstrates an increase within the gas cloud (blue arrows) and a small decrease within the deeper hydrocarbon accumulation (pink arrow). P-impedance shows a significant decrease within the reservoir with a sharp increase at the level of the apparent flat-spot reflection (yellow arrows). There is also a strong reduction in impedance in the gas cloud (blue arrows) due to a reduction in both density and Vp. Figure 5 demonstrates the good agreement between the well logs and the inverted parameters.

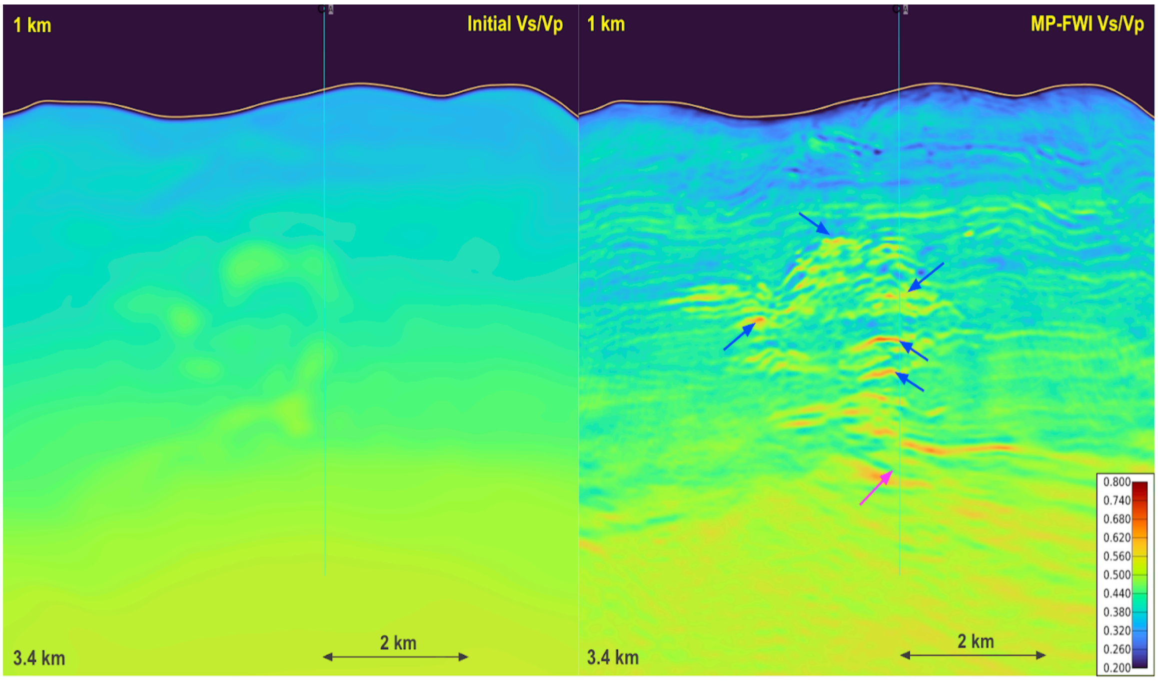

Figure 3 *Initial (left) and viscoelastic MP-FWI (right) Vs/Vp models.*

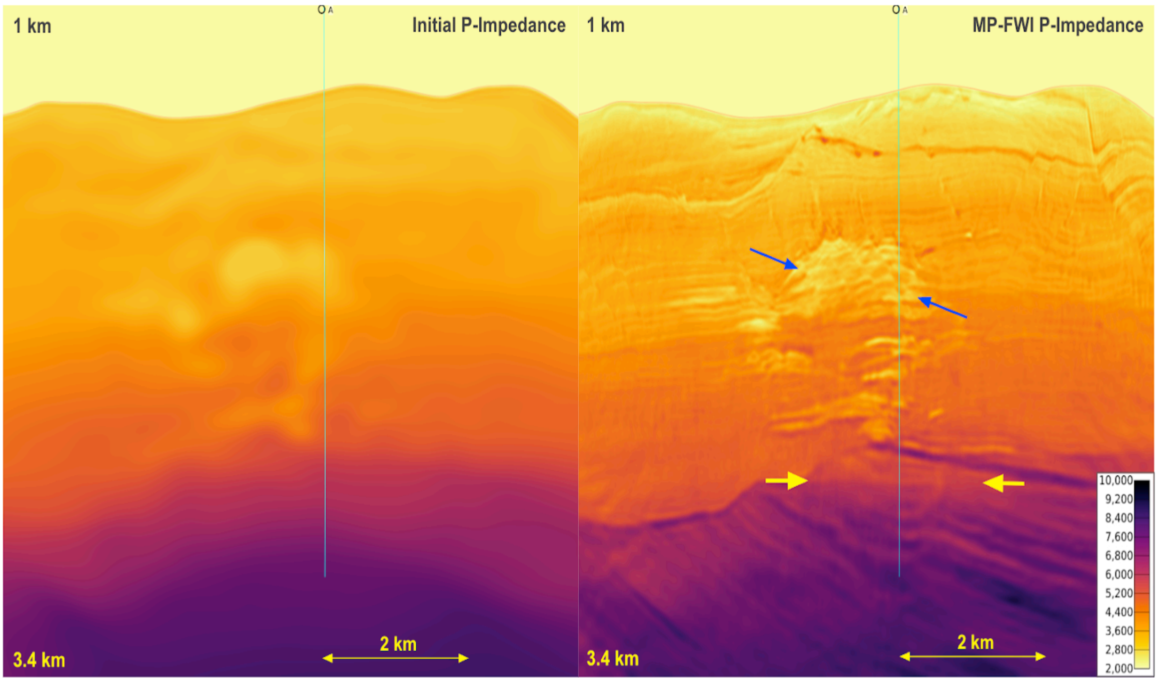

Figure 4 *Initial (left) and viscoelastic MP-FWI (right) P-impedance models.*

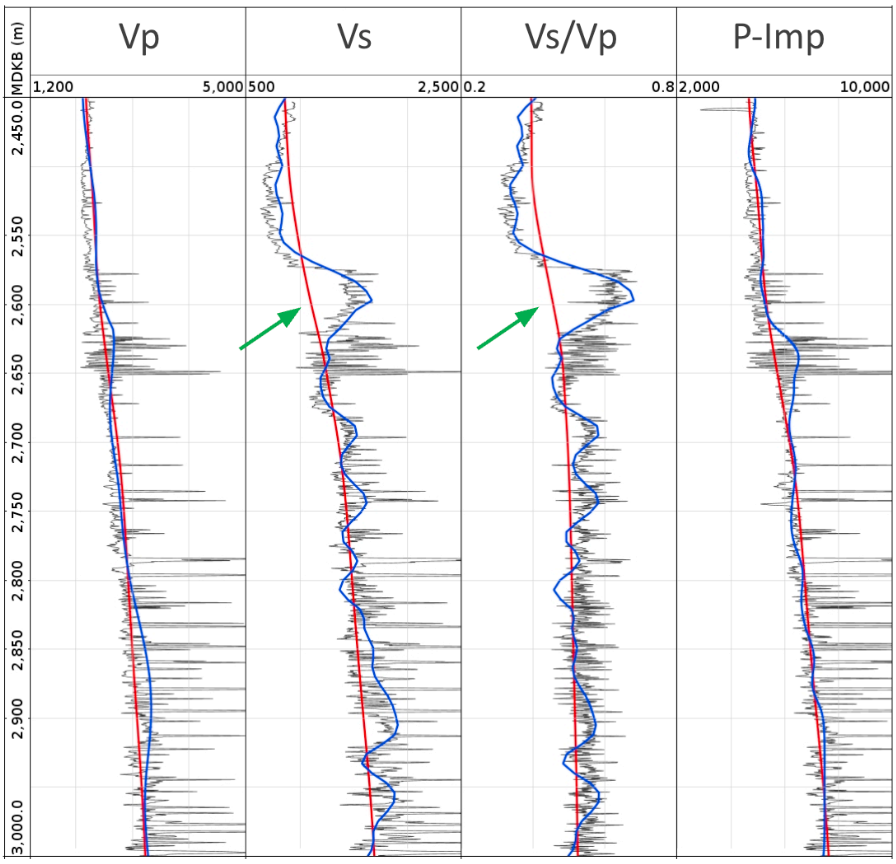

Figure 5 *Vp, Vs, Vs/Vp and P-impedance well logs (black), initial models (red) and final inverted models (blue).*

Conclusions

In this case study we demonstrated the use of multi-parameter simultaneous inversions, using viscoelastic MP-FWI to invert for Q, Vp, P-impedance and Vs/Vp directly from field data in the presence of a significant gas body.

The combination of improved illumination from OBN acquisition and the more accurate physics of viscoelastic MP-FWI provided a significant imaging improvement over the legacy towed-streamer image. The triple inversion produced elastic parameters which are geologically conformable and show good agreement with the well information. These parameters were derived without the need for the conventional processing, imaging and AVA inversion workflow.

Acknowledgements

We thank DUG Technology for permission to present this work.

References

Badry, J. and McLeman, J. [2025] Unlocking rock properties using elastic multi-parameter FWI. *International Meeting for Applied Geoscience & Energy, SEG/AAPG*, Expanded Abstracts.

Kumar, A., Hampson, G., Vice, N. and Thompson, T., [2020], Inversion-Based Deblending Using Iterative Thresholding. *EAGE 2020 Annual Conference & Exhibition*, 2214-4609.