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Elastic 1.5D Wave Equation based inversion: Theory and case studies

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Delft Inversion

Summary

Elastic 1.5D Wave-Equation-Based inversion (WEB-AVO) is a reduced-dimensional elastic full-waveform inversion method that solves the elastic wave equation in the ray-parameter domain to recover subsurface properties while explicitly accounting for multiples, mode conversions, and transmission effects. Parameterized in compressibility (κ) and shear compliance (M), it delivers rock-physics-intuitive outputs with improved stability and interpretability. Application to the a Llanos basin, field, onshore Colombia, shows that WEB-AVO can isolate reservoir responses beneath a highly compressible, scattering overburden, producing laterally coherent κ volumes with strong well ties, bandwidth extension, and low-frequency updates, demonstrating reliable recovery of physically meaningful elastic parameters in challenging settings.

Method: The Wave Equation based inversion

Elastic 1.5D Wave-Equation-Based (WEB-AVO) inversion is formulated as a reduced-dimensional elastic full-waveform inversion (eFWI), operating in the ray-parameter domain over vertically resolved stratified Earth models, see Gisolf et al. (2017). The method iteratively solves the full elastic wave equation and updates subsurface parameters by minimizing data misfit while explicitly accounting for interbed multiples, mode conversions, and transmission effects within the inversion window. The exploitation of the non-linear relationship between the properties and the seismic gathers allows the extraction of more information from the available seismic data.
The inversion is performed in the compliance domain using compressibility (κ) and shear compliance (M), which provide more rock-physics-intuitive parameters that link directly to pore-volume change and frame stiffness, Gisolf (2016) and Kelsay and Doulgeris (2024). From an observability perspective, κ typically dominates the PP seismic response and is therefore well constrained, whereas M and density contribute more weakly and through shear-sensitive scattering effects. This eFWI-1.5D formulation bridges conventional seismic reservoir characterisation wisdom with the power of eFWI, enabling stable elastic parameter recovery while preserving a clear physical interpretation of the produced elastic properties.

Case Study: Llanos basin, Onshore Colombia

This field contains an onshore Colombian reservoir characterized by moderate burial depth and a relatively soft overburden sequence. The target reservoir interval is located immediately beneath a highly compressible layer, which generates strong impedance contrasts and significant internal scattering, see Figure 1. This geological configuration poses a challenge for conventional AVO and impedance-based inversion, as overburden-related scattering distorts the apparent amplitude response at the reservoir level and reduces the reliability of linearized elastic attributes. Elastic 1.5D eFWI (WEB-AVO) was applied to raw migrated offset gathers to retrieve compressibility (κ) and shear compliance (M) within an inversion window that explicitly includes the scattering-generating overburden. By solving the elastic wave equation iteratively, the

inversion allows the reservoir response to be isolated despite its proximity to the compressible overburden. The resulting κ volume is laterally coherent and exhibits stable well ties, indicating that the dominant elastic sensitivity of the data has been successfully captured, see Figure 3.

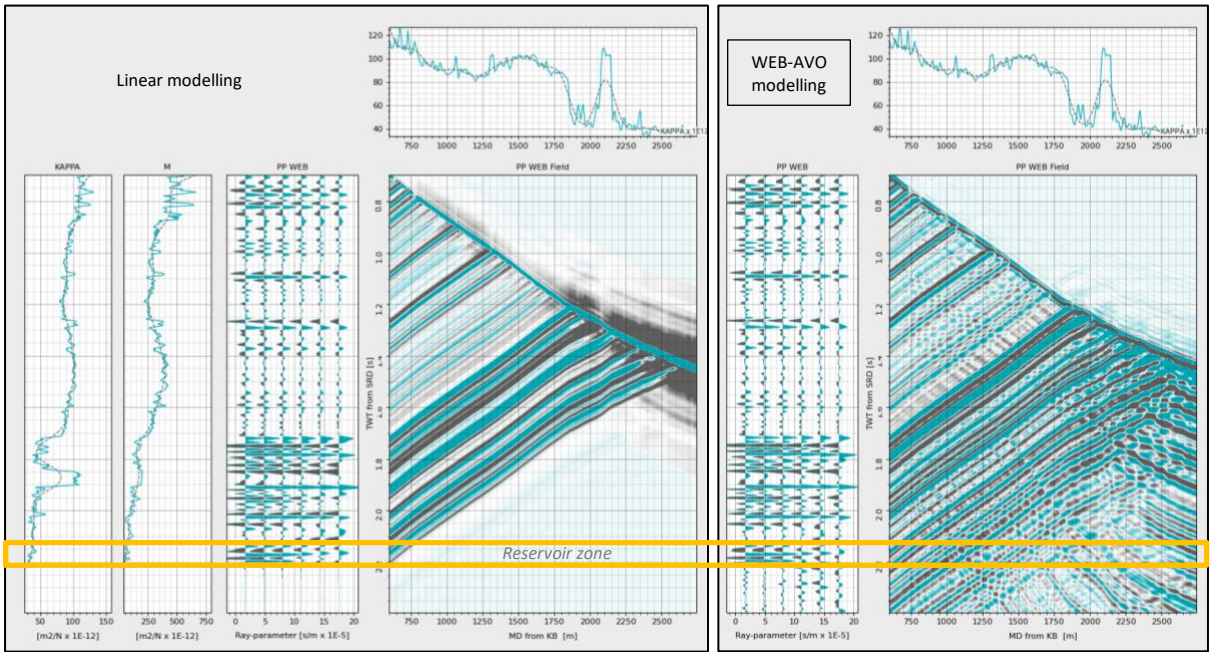


Figure 1:Synthetic VSP modeling at one of the wells showing strong scattering from the overburden.

To understand the inversion behaviour, an elastic parameter contribution analysis was performed for this geological setting, see Figure 2. The analysis shows that κ provides the dominant contribution to the PP seismic response, consistent with its sensitivity to compressional compliance and pore-volume effects. In contrast, M contributes more weakly and primarily through AVO and scattering effects, which are partially masked by the overburden response. Density exhibits the lowest contribution, reflecting its secondary role in the PP reflection response under these conditions. This hierarchy of elastic contributions explains the robust recovery of κ, the reduced stability of M, and the limited resolvability of density in the inverted results.

Novel/Additive Information

The WEB-AVO inversion also delivers a measurable bandwidth extension relative to the input seismic, as demonstrated by the spectra in Figure 4. Moreover, a low-pass filter applied on the inverted results highlights the update of the low frequencies by the inversion. Inverted section views show a clear and continuous κ response across the field and a good agreement between inverted κ and log-derived trends within the seismic bandwidth. The results illustrate that, even in the presence of a highly compressible overburden, Elastic 1.5D eFWI can recover physically meaningful elastic parameters when parameter observability is properly accounted for.

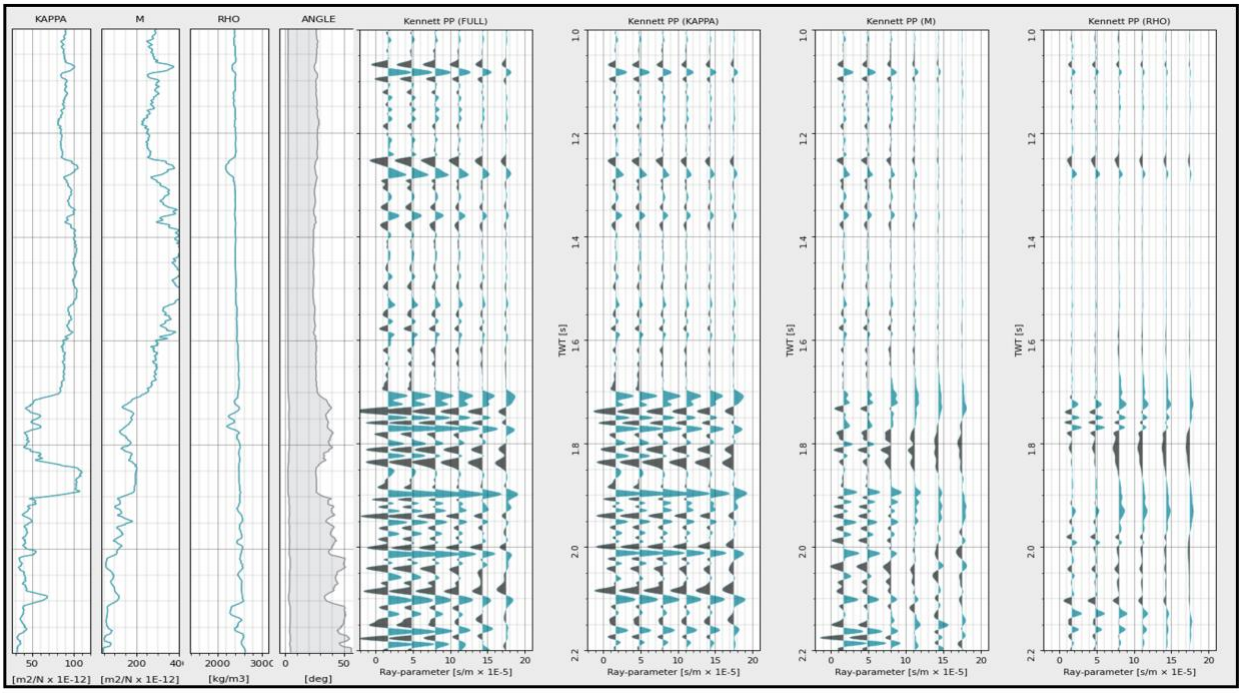


Figure 2: Contribution analysis of κ, M, and ρ at the well location. The κ contribution is dominant, whereas the M contribution is weaker and carries significant AVO and scattering effects.

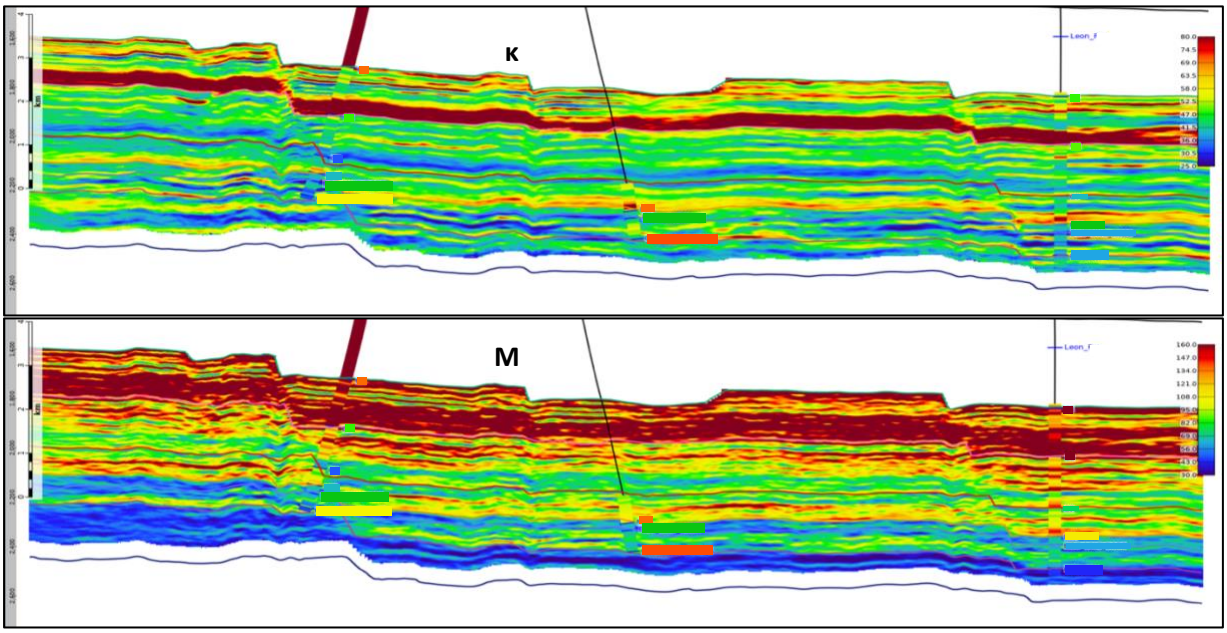


Figure 3: [Top] Compressibility and [Bottom] Shear Compliance over an arbitrary line going through 3 of the wells of the field.

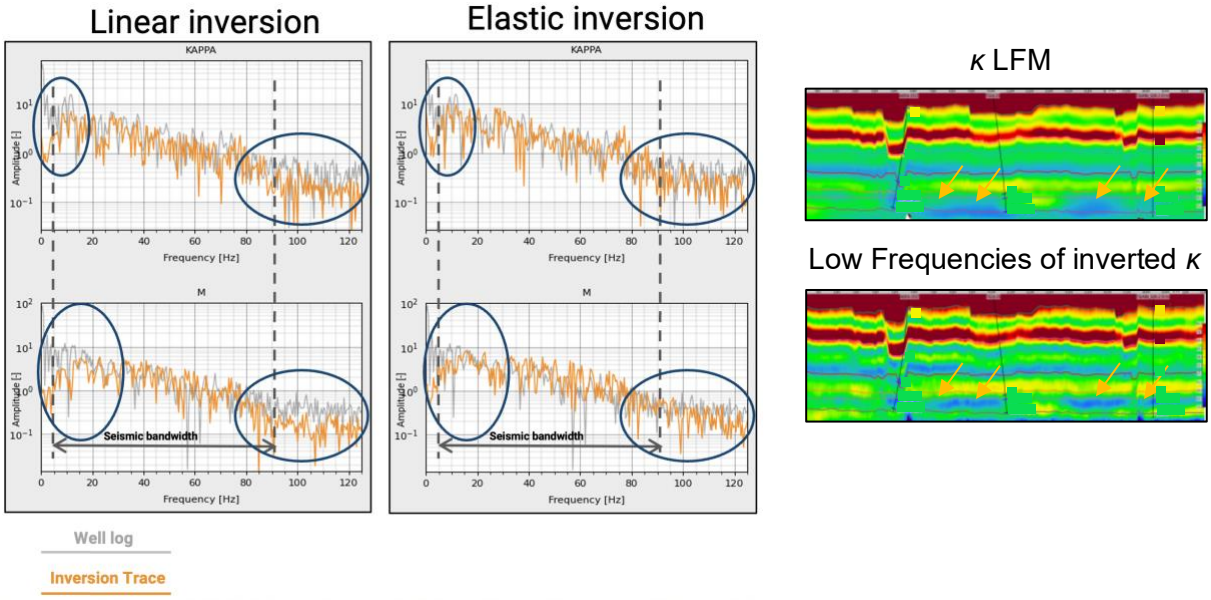


Figure 4: [Left] Comparison of spectra of retrieved elastic properties for linear (primaries only) and WEB-AVO inversion [Right] Update of low frequencies by the inversion.

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