

Quick elastic attributes estimation with novel wavelet independent reflectivity inversion

Introduction

Seismic inversion projects are complex workflows that require detailed analysis of the well information such as well-log editing, time-depth conversion, and wavelet extraction. In the case of pre-stack inversion, the need for shear velocity logs (DTS) may require a detailed rock-physics analysis to ensure the quality of the resulting Vp/Vs responses for different lithologies and fluid cases. Well data preparation can be time consuming and limited to data availability and/or knowledge of the subsurface setting. The well information is assumed to be ground truth to run correlations to the seismic data and extract wavelets, which are sensitive to noise in both the seismic and logs and mis-ties between the wells and the seismic. In cases when several wells are available, it is common to observe noticeable differences on the extracted wavelets from each well, resulting in the use of average wavelets which may add lateral and vertical noise to the inversion results. Additionally, the well information is then extrapolated laterally using existing interpreted horizons to create initial elastic models. Due to seismic resolution limitations or structural or stratigraphic complexities, the used horizons can introduce errors into the models that subsequently bias the inversion result. Overall, seismic inversion is a powerful tool widely used for seismic analysis and quantitative interpretation; however, the uncertainty associated with wavelet averaging and model extrapolation is difficult to quantify away from well control.

With the objective to reduce errors associated with wavelet estimation and initial model biases, a new model and wavelet independent reflectivity inversion method, based on the Multi-Scale Fourier Transform (MSFT), is proposed as a quick alternative to produce band-limited acoustic impedance and Vp/Vs volumes from pre-stack seismic data without the need for well calibrations, wavelet extractions or initial model building. The MSFT method was first introduced by Locci et al. (2018). The method performs time-frequency analysis over a range of window lengths, capturing local and global relative amplitudes between events. Ratios of spectral amplitudes are then taken at various scales and inverted for a sparse reflectivity solution. Optimization of these spectral ratios can be accomplished by training a neural network to predict reflectivity on synthetic data with various wavelets with different amplitude spectra. Once these spectral features are identified, no additional training is required, and the problem becomes a classical geophysical inversion determining the sparse reflectivity series that matches those features via a forward model (Liu et al., 2022).

Rauch et al., 2025 and Liang et al., 2026 show examples of the application of the method on synthetic traces with good correlations to the input models. Liang et al (2026) used the method to invert for band-limited impedance in a stratigraphically complex setting, highlighting stratigraphic features observed in the wells but not clearly in the input seismic. Rauch et al. (2025) used the proposed reflectivity inversion to generate a seismic section with enhanced vertical resolution with good correlation to available well data.

The proposed reflectivity inversion is applied on partial stacks to produce band-limited acoustic impedance and Vp/Vs ratio volumes on a dataset from the Gulf of America, these results are compared to band-limited impedance and Vp/Vs estimated from a pre-stack generalized linear inversion (GLI).

Methodology

A 3D seismic survey from the Gulf of America was selected for the application of the proposed workflow. The target stratigraphic column is composed of poorly consolidated deep-water sediments. One well with measured elastic logs is available within the survey area and exhibits characteristic low impedance and low-Vp/Vs responses across three reservoir intervals. In contrast, water-bearing intervals have different elastic responses (Figure 1). Figure 2 shows the cross-plot between impedance and Vp/Vs from the well for absolute and relative properties. The relative-property cross-plot shows

that pay sands are characterized as strong negative anomalies in both band-limited impedance and V_p/V_s .

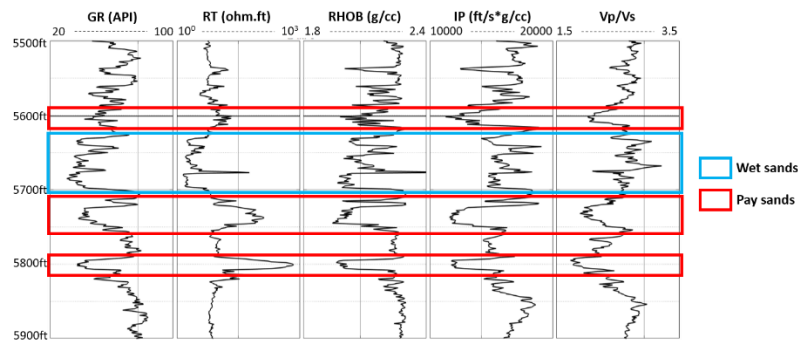


Figure 1 Electric and elastic well log responses for pay sands.

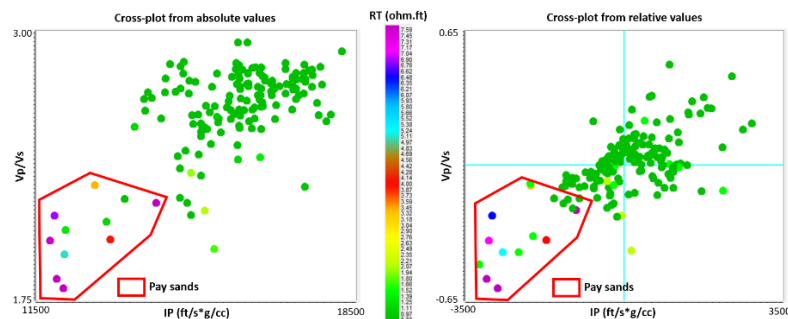


Figure 2 Cross-plot from band-limited acoustic impedance and V_p/V_s from the well as absolute (left) and relative (right) properties.

PSTM gathers were conditioned using an amplitude preserving sequence designed to attenuate random noise, coherent noise, and long-period multiples, while preserving the AVO behaviour. From the conditioned gathers, three partial stacks with angle ranges of 0-10°, 10-20° and 20-30° were calculated. Figure 3 shows the well tie against the near stack. The well tie indicates that the reservoir sands are below tuning yet still generate observable seismic anomalies.

The available well was used as calibration, wavelet extraction and model building in the pre-stack GLI workflow. For the reflectivity inversion, the well was used only for post-inversion QC and correlation analysis. The three partial stacks were used as input for both pre-stack GLI and the proposed reflectivity inversion. For a fair comparison of results, the initial models were removed from the pre-stack GLI results to generate band-limited impedance and V_p/V_s volumes.

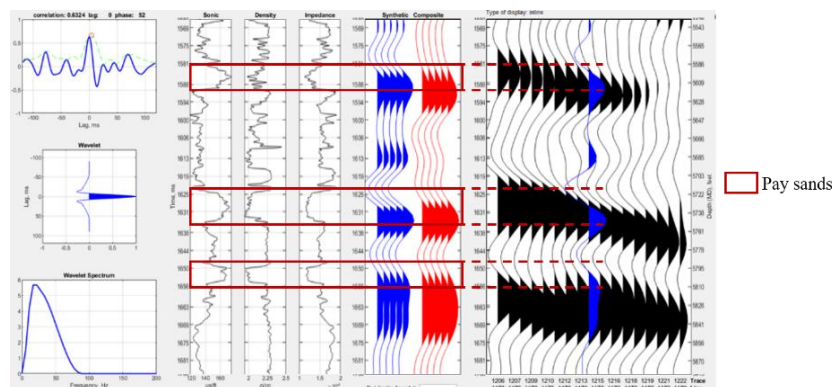


Figure 3 Well tie to conditioned near stack. Correlation coefficient is 63%.

Results

Figure 4 shows a mosaic with comparisons of the band-limited inversion results from both methods including the corresponding log inserted as colour and filtered to a bandwidth representative of the frequency content in the inversion results. Figure 4a shows the band-limited impedance from pre-stack GLI, while Figure 4f shows the equivalent from the reflectivity inversion, both sections include the filtered impedance log as colour overlay. The white arrows show the location of the pay sands at the well. The pre-stack generalized linear inversion is good at resolving the bottom sands, but it is suffering from resolution limitations at the top sand. On the other hand, the impedance result from the reflectivity inversion shows improved delineation of all three pay sands.

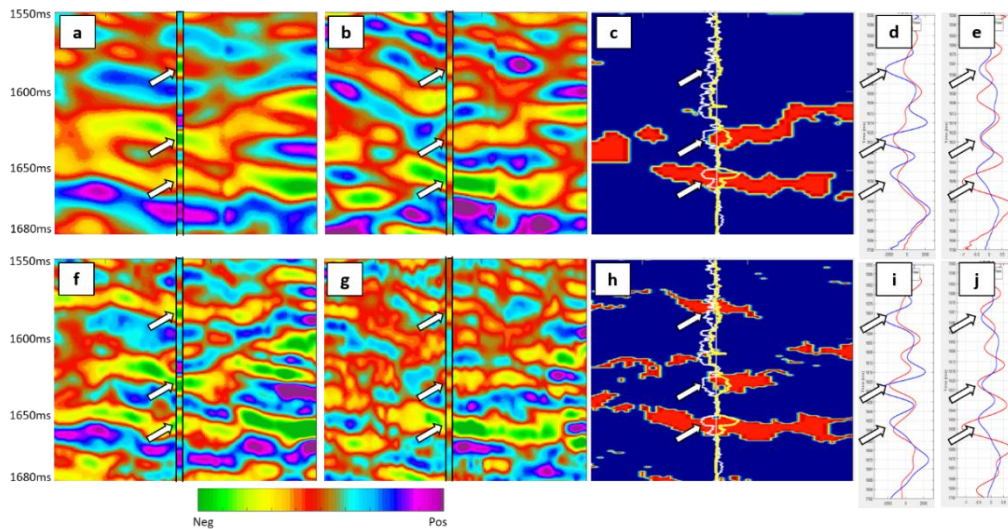


Figure 4 Comparison of inversion results from pre-stack GLI: a) relative impedance, b) relative V_p/V_s , c) facies classification, d) overlay of inverted (red) and impedance log (blue), e) overlay of inverted (red) and V_p/V_s log (blue); against results from MSFT based reflectivity inversion: f) relative impedance, g) relative V_p/V_s , h) facies classification, i) overlay of inverted (red) and impedance log (blue), j) overlay of inverted (red) and V_p/V_s log (blue). Facies determined as strong negative anomalies in band-limited impedance and V_p/V_s from both inversion methods.

Figures 4b and 4g show the corresponding band-limited V_p/V_s sections from pre-stack GLI and reflectivity inversions, respectively. In this case, the filtered V_p/V_s log is shown as colour insert. The same observations can be made on the three reservoir sands as on the impedance sections for both inversions. Additionally, a strong low- V_p/V_s layer is observed below the upper sand, this layer does not exist at the well and it is believed to be associated to noise in the far traces. This layer shows a significantly reduced V_p/V_s anomaly in the reflectivity inversion result. A possible explanation for this improvement could be associated to possible wavelet deficiencies in the V_p/V_s estimation from the pre-stack generalized linear inversion, suggesting that the use of MSFT in the reflectivity inversion decreases the sensitivity to wavelet uncertainties.

A simple facies classification was done based on band-limited impedance and V_p/V_s cross-plots from both inversions to capture the strong negative impedance and V_p/V_s values as shown on the right side of Figure 2. The resulting facies volumes from each inversion method are shown in Figure 4c and 4h with inserted Gamma Ray (white) and Resistivity (yellow) logs. The pre-stack GLI facies volume (Figure 4c) clearly highlights the bottom sands but fails to identify the top sand. The facies result from the reflectivity inversion (Figure 4h) captures all three sands and suggest the presence of an extremely thin pay sand above the middle reservoir. Overlays between the inverted traces (red) at the well location and property logs (blue) are shown in Figures 4d and 4e for impedance and V_p/V_s , respectively, from the pre-stack generalized linear inversion, and Figure 4i and 4j from the reflectivity inversion.

As a quantitative analysis and comparison of the results, statistical measures and information theory metrics (Castagna et al., 2026a,b) were calculated on band-limited impedance and Vp/Vs results from both inversion methods assuming that the well logs are correct. Table 1 shows the metrics. Although the pre-stack GLI impedance exhibits slightly higher correlation and metrics, the differences are small and may be influenced by its stronger low-frequency content. The Vp/Vs estimation from the reflectivity inversion shows better metrics overall, with F-Statistics and channel capacity showing values almost twice as large compared to the pre-stack GLI Vp/Vs. P-value is expected to decrease for better statistical significance and is significantly better for Vp/Vs from reflectivity inversion.

Table 1 Comparison of statistical and information theory measures between band-limited inversion results.

Inversion result	Correlation Coefficient (%)	F-Statistics	P-value	Channel Capacity (bits/s)
Impedance from pre-stack GLI	68.7	133	10^{-22}	36
Impedance from reflectivity inversion	65.9	114	10^{-20}	32
Vp/Vs from pre-stack GLI	53.1	39	10^{-9}	13
Vp/Vs from reflectivity inversion	58.6	78	10^{-15}	24

Conclusions

Multi-Scale Fourier Transform based reflectivity inversion was applied on partial stacks from a real dataset in the Gulf of America, producing band-limited impedance and Vp/Vs results with comparable reservoir layer detection to results from a pre-stack generalized linear inversion. Statistical and information theory metrics show similar values for both inverted band-limited impedances while the Vp/Vs derived from the reflectivity inversion exhibit F-statistics and channel capacity metrics nearly twice those obtained from the pre-stack GLI Vp/Vs. The wavelet independent nature of the reflectivity inversion may reduce sensitivity to uncertainties associated with angle dependent wavelet estimation and initial models, potentially enabling a more robust estimation of sparse subsurface reflectivity from the seismic. The similarity of the results from both inversions shows the applicability of the reflectivity inversion as a quick pre-stack inversion method without the need of extensive work for well ties, wavelet estimation and inversion model building, resulting in considerably shorter execution times for band-limited inversion workflows, making the methodology attractive for application in areas with limited or no well control.

References

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