Seeing through the noise: onshore subsalt updates via FWI-derived-reflectivity-driven reflection waveform inversion

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Summary

We present an onshore Louisiana case study in which FWI-Derived Reflectivity is used to drive Reflection Waveform Inversion for subsalt macro-velocity updating in a reflection-dominated setting. The workflow is fully data-driven, does not require well logs during inversion, and delivers improved subsalt velocity, seismic fit, and blind-well/ target horizon marker agreement, supporting inverted FDR as a promising future alternative to RTM-derived reflectivity inputs.

Introduction

Imaging beneath onshore salt remains challenging because strong velocity contrasts, complex wave propagation, and poor illumination degrade both velocity model building and structural interpretation. In many land subsalt settings, diving waves do not penetrate to the target depth, leaving reflection data as the primary source of information for deeper model updates. The problem is further complicated by acquisition noise, irregular spatial sampling, and limited well control, all of which increase uncertainty in the subsalt velocity model.

Previous published studies have shown that waveform-inversion-based imaging can improve subsurface characterization in challenging onshore settings and in structurally complex environments where reflections provide the dominant constraint at depth [1,2]. However, in subsalt regimes, converting reflection information into reliable macro-velocity updates remains difficult, particularly when well logs are unavailable and conventional reflectivity inputs are poorly constrained.

Although conventional Full Waveform Inversion (FWI) can recover detailed velocity structure, its application in subsalt settings is often limited by cycle-skipping, weak low-frequency content, and uncertainty in the starting model. Reflection Waveform Inversion (RWI) offers a more robust route for macro-velocity updating in these reflection-dominated regimes, but its performance depends strongly on the quality and consistency of the reflectivity model used in the inversion.

In this study, we present a workflow in which FWI-Derived Reflectivity (FDR) is used to drive RWI for macro-velocity updating in an onshore subsalt dataset from Louisiana. The approach is fully data-driven and does not rely on well logs or prior interpretive constraints. By using reflectivity estimated directly from FWI as the input to RWI, we demonstrate that subsalt velocity reconstruction can be improved without well-log conditioning and subsequently validated against a blind well log, leading to enhanced subsalt imaging in challenging land environments.

Methodology

In this land subsalt application, the ultra-deep target is illuminated primarily by reflections, so the macro-velocity update below salt must be driven by reflected energy rather than by diving-wave transmission. We therefore first estimate FWI-Derived Reflectivity (FDR) from the recorded wavefield under a zero-reflectivity residual assumption. This provides a reflectivity model recovered from the data residual itself, while reducing reliance on pre-existing inverted reflectors that may be misplaced or poorly focused in an imperfect starting model.

For RWI, the value of inverted FDR is that it is re-estimated from the reflection residual within the inversion loop. In contrast, an RTM image remains a migrated representation that can inherit structural bias, defocusing, and residual mispositioning associated with background-model error. The inverted FDR is then used as the reflectivity input to RWI, while the low-wavenumber macro-velocity update is recovered by RWI from reflection moveout residuals. In this way, the reflectivity model defines the reflected-energy response, and RWI translates the remaining reflection kinematic mismatch into subsalt velocity corrections.

Operationally, the procedure is analogous to flattening common-image gathers, but it is posed in the inversion domain through minimisation of misfit in angle- or offset-dependent FDR gathers. This allows the deeper velocity trend to be constrained directly from reflection kinematics, without requiring well-log information during the update stage.

Results

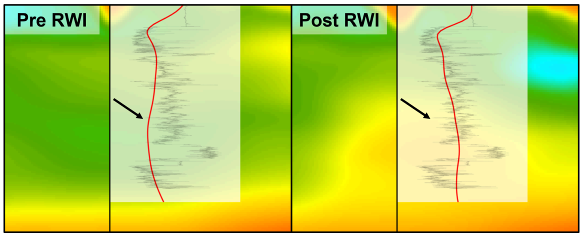

Figure 1. Blind-well sonic and marker comparison.

The FDR-driven RWI workflow delivers a meaningful subsalt macro-velocity correction in this reflection-dominated land setting as evidenced by **Figure 1**. Independent validation is provided by the blind-well comparison: the final post-RWI model gives a better match to the well sonic trend than the pre-RWI model. An example of an inverted FDR used in this inversion sequence can be seen in **Figure 2**.

A key outcome of the RWI workflow is that the update evolves iteratively and self-corrects as additional passes are applied. In the early stages, the RWI correction improves well tie mismatch but locally overshoots as indicated by **Figure 3**. Subsequent passes compensate for that overcorrection and progressively stabilise the final result. This behavior is shown clearly in **Figure 6**, where the reference horizon markers (Austin Chalk) provide a diagnostic horizon for tracking the progression from Pass 1 to Pass 2 and into the Final Pass.

The improvement is also supported by seismic data fit and broader spatial QC. **Figure 4** shows that, relative to the pre-RWI model, the post-RWI model yields better agreement between predicted and observed data for selected shots, consistent with an improved reflection moveout fit in the subsalt section. The same figure also indicates that the update is not confined to a single location, but remains coherent over a wider area, supporting the interpretation that the recovered macro correction is geologically plausible rather than a localised inversion artifact. **Figure 5** demonstrates this match further visually when comparing predicted data with the field.

This result is important because it demonstrates that the FDR-driven RWI update is not only internally consistent with the seismic reflection data, but also consistent with independent subsurface control that was not used to condition the inversion.

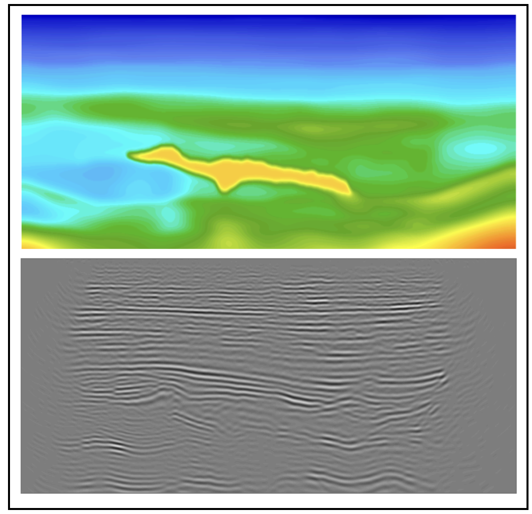

Figure 2. Initial velocity model and inverted FDR.

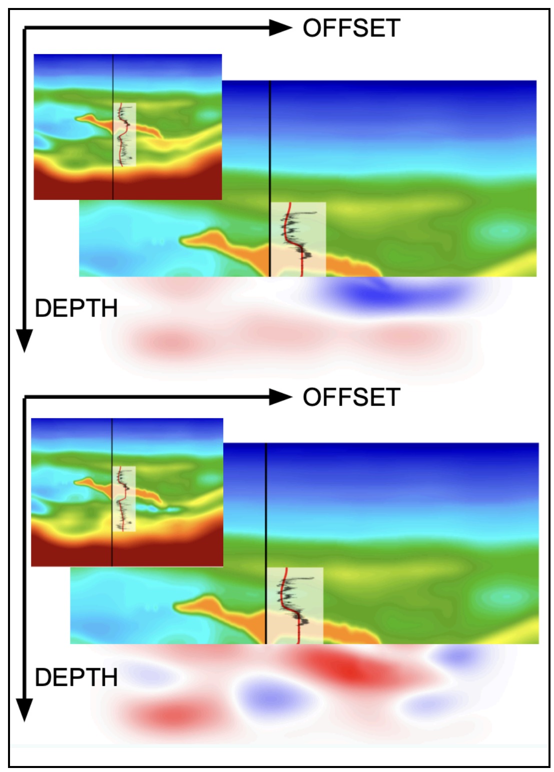

Figure 3. An example of RWI self-correction. Initial update overshoots albeit going in the right direction at the blind well for correcting the well-tie mismatch.

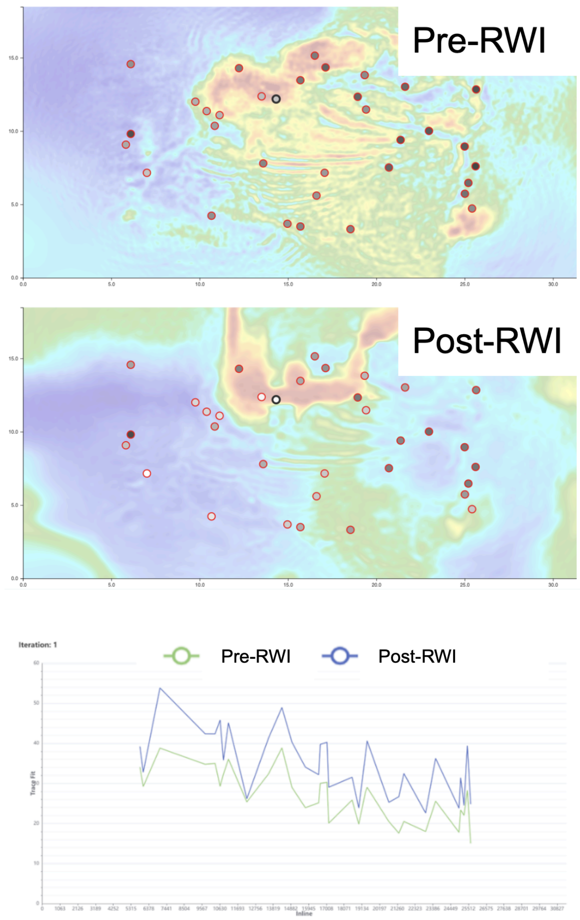

Figure 4. Tracefit correlation QCs between predicted and observed data before and after the RWI Inversion. The colourmap goes from black to white and higher values indicate better shot fit.

Conclusions

This study shows that FWI-Derived Reflectivity (FDR) can be used effectively as the reflectivity input for Reflection Waveform Inversion (RWI) in a land subsalt setting where the ultra-deep target is illuminated primarily by reflections. In this reflection-dominated regime, the workflow provides a practical route for recovering subsalt macro-velocity updates without requiring well-log information during inversion.

The results indicate that the FDR-driven RWI updates improve the deep velocity trend, remain spatially coherent, and lead to better agreement with both the seismic data and independent well control. The pass-by-pass behavior further shows that the inversion can iteratively correct early overupdates and converge toward a more balanced subsalt model. Validation against the blind well sonic and well markers supports the conclusion that the recovered update is not only kinematically consistent, but also geologically

meaningful.

More broadly, the study demonstrates that inversion-derived reflectivity is a viable alternative to conventional migrated reflectivity inputs for reflection-driven model building. Inverted FDR therefore offers a more suitable reflectivity input for reflection-driven velocity updating and represents a promising path toward replacing RTM-style reflectivity products in future model-building workflows.

Acknowledgements

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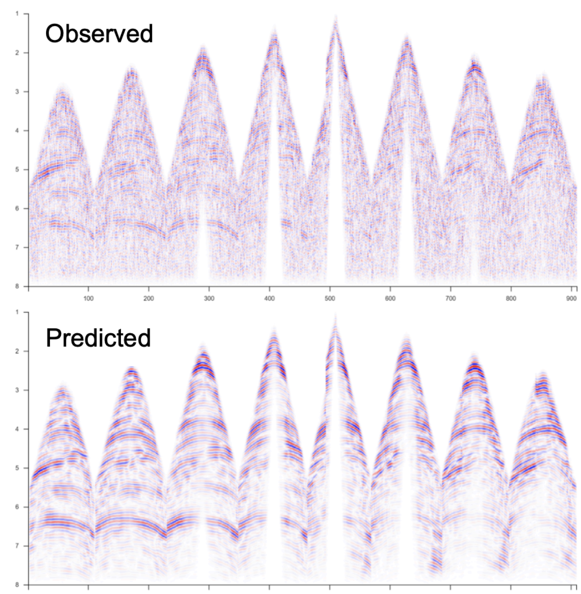

Figure 5. Observed data compared against the predicted data obtained from the final RWI model.

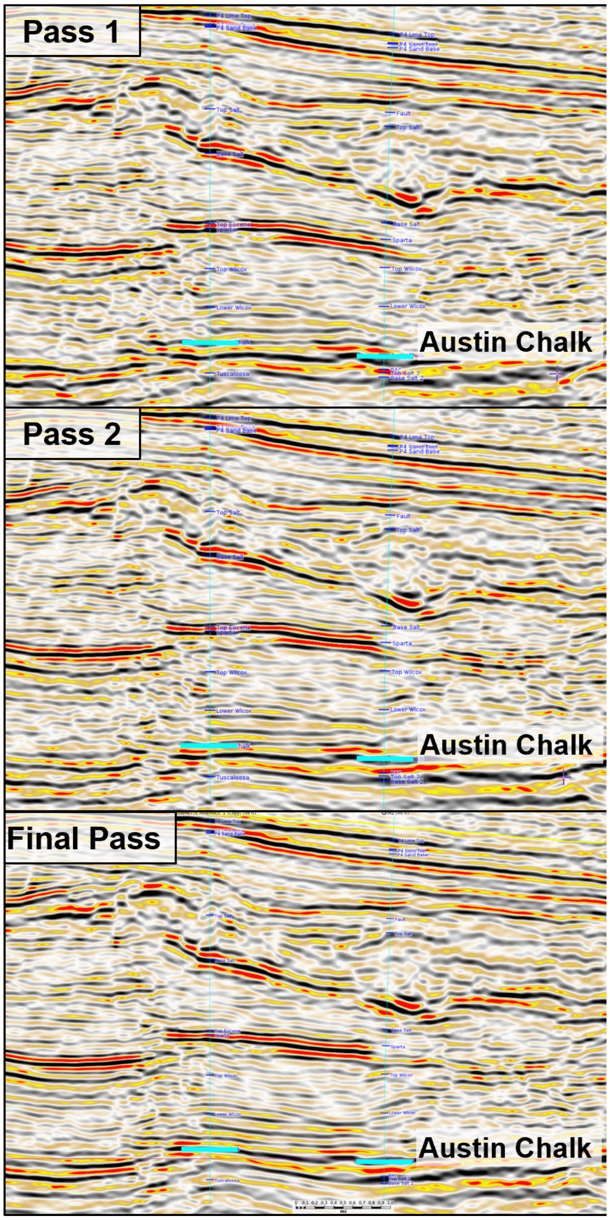

Figure 6. Pass 1, Pass 2, and Final Pass marker mistie comparison around the Austin Chalk reflector horizon.