

Finding signal in the noise: Using multiples and mode conversions to improve AVO inversion

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Summary

Seismic reservoir characterization in geologic settings with coals, anhydrites, gas clouds is known to be challenging due to transmission effects and non-primary energy noise introduced by these strong velocity contrasts. In the Western Canadian Sedimentary Basin, the problem of coals masking the amplitude response of underlying reservoirs is well known and understood to be difficult to overcome in AVO inversion workflows. In this study, we compare a standard AVO inversion workflow, which relies on standard convolutional modelling, to a new workflow that uses 1D tau-p domain wave equation as the forward model in an effort not only to more accurately model the input seismic data, but to use the short period multiples and mode conversions to improve AVO inversion results.

Theory

Conventional AVO inversion is based on the 1D vertical convolutional model combined with a single interface reflection coefficient model such as Zoeppritz or Aki & Richards. As such, it is assumed that the issues of multiple reflections, converted waves, and scattering have been removed or suppressed sufficiently in the pre-processing. However, short period multiples or mode conversions are very complex to remove from the observed seismic without significant damaging primary energy. It is therefore proposed to replace the convolution model in the AVO inversion loop with a more accurate forward seismic model that accounts for these effects. Ideally, the forward seismic model would be the full 3D wave-equation resulting in what is generally known as 3D Full Waveform Inversion (FWI). However, 3D FWI is mostly just used for inverting for a low frequency velocity model which in itself is computationally very demanding, and incorporating full AVO information is usually considered prohibitively computationally demanding.

Here, we propose to use the 1D tau-p domain wave-equation as the forward seismic model in the inversion loop. This equation assumes that the subsurface is slowly varying horizontally, but accurately models multiples, mode conversions, and can incorporate velocity dispersion. The advantages of such an approach is that it can be fitted into conventional seismic processing, including one that includes conventional 3D FWI and that it is many orders of magnitude less computationally expensive compared to 3D FWI. To reduce the number of forward and backward tau-p transformations, the comparison of synthetic and observed seismic in the inversion loop is performed entirely in the tau-p domain by transforming the observed seismic to the tau-p domain.

Results

The results for this study include an example from the North Sea in the Cygnus field, where there are sand reservoirs below an anhydrite and surrounded by coals. First, we compare forward

modelled seismic to observed, gradually increasing the complexity of the forward modelled response from standard convolution primaries only to primaries plus multiples and finally including mode conversions. The results of this comparison are shown in Figure 1. In the observed seismic, at the reservoir level we notice a sharp decrease in far angle amplitudes as well as strong polarity reversals and distortions that are not observed in standard primaries only convolution seismic. Adding multiples does not dramatically alter the forward modelled seismic, but by adding mode conversions we begin to model the complex polarity reversals and distortions that characterize the input seismic. The interpretation is that the overlying high reflectivity anhydrite is not only producing short period multiples, but more significantly a converted shear wave that significantly alters the acquired waveform.

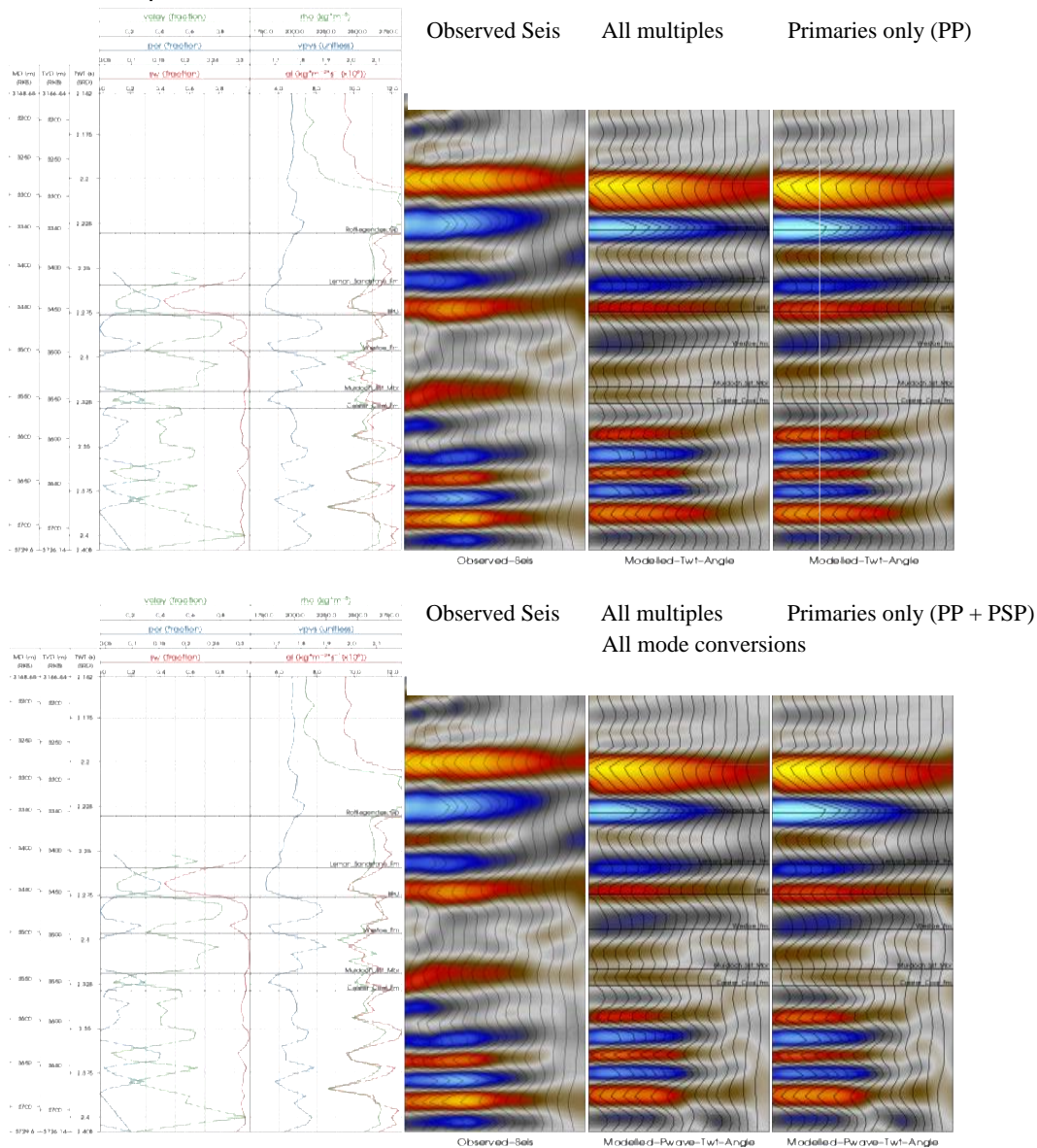


Figure 1: Forward modelled vs observed seismic comparison at a well location. Comparison includes PP only modelling (top) and PP and PSP modelling (bottom).

This modelling demonstrates that we have significant noise in the observed seismic in the form of converted PP-PS-PP. The proposed solution is to invert the data using a 1D tau-p wave equation. The results of the inversion at the same well location are shown in Figure 2. Here, we observe a significant uplift in the Vp/Vs inversion at the target sand level. In the standard AVO inversion, we see the Vp/Vs struggle to find the low at the sand, but the resolution of the low Vp/Vs of the sand is clearly evident in the results of the Tau-P inversion.

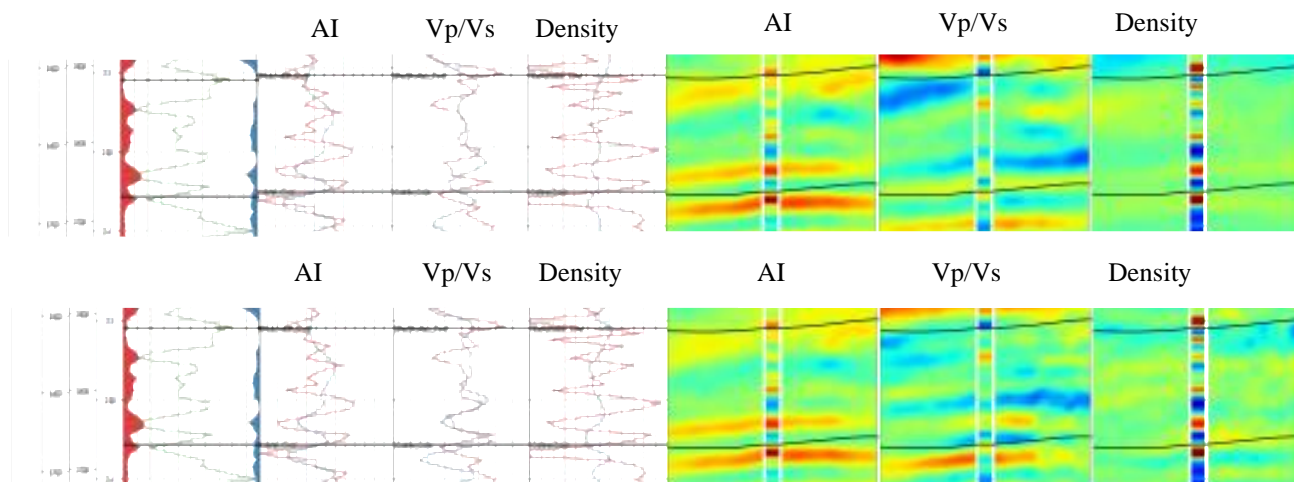


Figure 2: Inversion results using a standard AVO inversion algorithm (top) and a tau-p waveform inversion accounting for mode conversions (bottom).

Conclusion

This paper introduces a method for AVO inversion that inverts the whole recorded waveform including multiples and mode conversions. The method seeks to address shortcomings of the standard convolutional model in settings such as coals, anhydrite stringers and other potential high reflectivity boundaries. In the North Sea example shown, we demonstrate first with forward modelling and subsequently with an inversion comparison how accounting for these phenomena in our seismic model can dramatically improve our understanding of the observed seismic and improve the accuracy of inverted properties.