

Quality Control of a Seismic Inversion

Introduction

Seismic inversion results suffer from uncertainty. These uncertainties are often uncharacterised, unquantified, and overlooked. This begs the question as to what measurements and observations can we make that will not only characterise and quantify the uncertainty, but will also guide the user in refining the workflow to reduce the uncertainty of the inversion at and away from well control?

We consider the case of an inversion using a single well within a 60km² seismic volume from the Gulf of Thailand. The inversion used was a simple deterministic model-based simultaneous inversion (Kemper, 2010). This inversion has a simple objective function, which allows for a reasonably clear link between parameter setting and variations in the inversion results. The seismic data used had been conditioned to reduce noise. The weights in the objective function that balance the seismic-synthetic misfits against deviations from a model were optimised and the results assessed for quality at the well and in other locations. We describe and discuss some of the variety of metrics and visual quality controls employed.

Inversion analysis at a well

It is common to assess the quality of an inversion by comparing the inverted results with the well log properties. There are various metrics that can be used to quantify the match, cross-correlation, normalised root mean square error, percentage of energy predicted amongst others. The error metrics when comparing absolute properties are often extremely high due to the influence of the low frequency model that is normally derived from the well data itself. Standard practice, therefore, is to also assess the fit within the seismic bandwidth. In the current case the cross-correlations for acoustic impedance, Vp/Vs and density fall from 0.95, 0.93 and 0.67 for absolute properties to 0.71, 0.49 and 0.51 for relative values. The low value for Vp/Vs brings into question the value of conducting a simultaneous inversion using these data. Further analysis was carried out using different frequency bands. The cross-correlations as a function of frequency are shown in Figure 1. High values at the lowest frequencies are influenced by the low frequency model that was derived from the well data and had an upper frequency range of 4 to 8 Hz. The cross-correlation for acoustic impedance decreases slightly with increasing frequency until about 80Hz, which represents the limit of the signal in the seismic data. The cross-correlations for Vp/Vs remain above 0.6 up to a frequency of about 40 Hz and then drop rapidly. Note that the regularisation for Vp/Vs in the objective function was independent of the acoustic impedance.

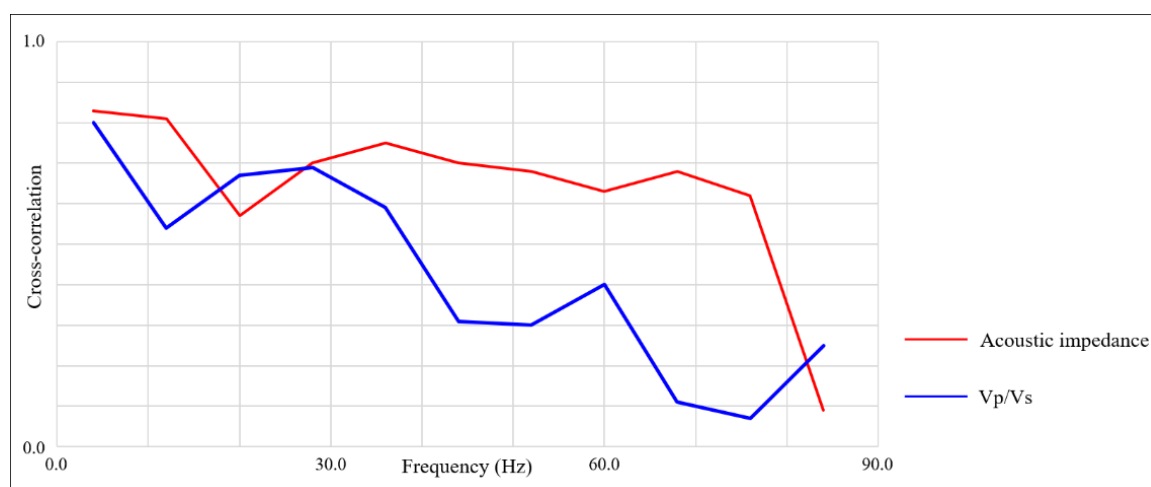


Figure 1 The cross-correlation between well log and inverted properties as a function of frequency for acoustic impedance (red) and Vp/Vs (blue).

It is important to review these metrics in combination with a visual inspection of the data in order to provide an understanding of the cause of discrepancies and to provide insight as to what might be done to improve the results. Based on the observations from Figure 1, the inversion was run within two frequency bands (below and above 40 Hz), and the results are presented in Figure 2. It can be seen that many of the mismatches of the properties are at intervals where the residuals are strongest. For the lower frequencies, the residuals are dominated by events with positive moveout. This suggested a reparameterization of the Radon demultiple might be beneficial. High residuals on the farthest angle stack might question its inclusion in the inversion. The higher frequency residuals appear to be largely random noise but also have events with negative moveout/backscatter that are under sampled in the angle domain. The poor correlation for Vp/Vs at high frequencies is also affected by property mismatches where the log data indicate large variations not observed in the other logs. In this well the S-sonic was not measured, so a review of the log synthesis was indicated alongside a review of the seismic data conditioning.

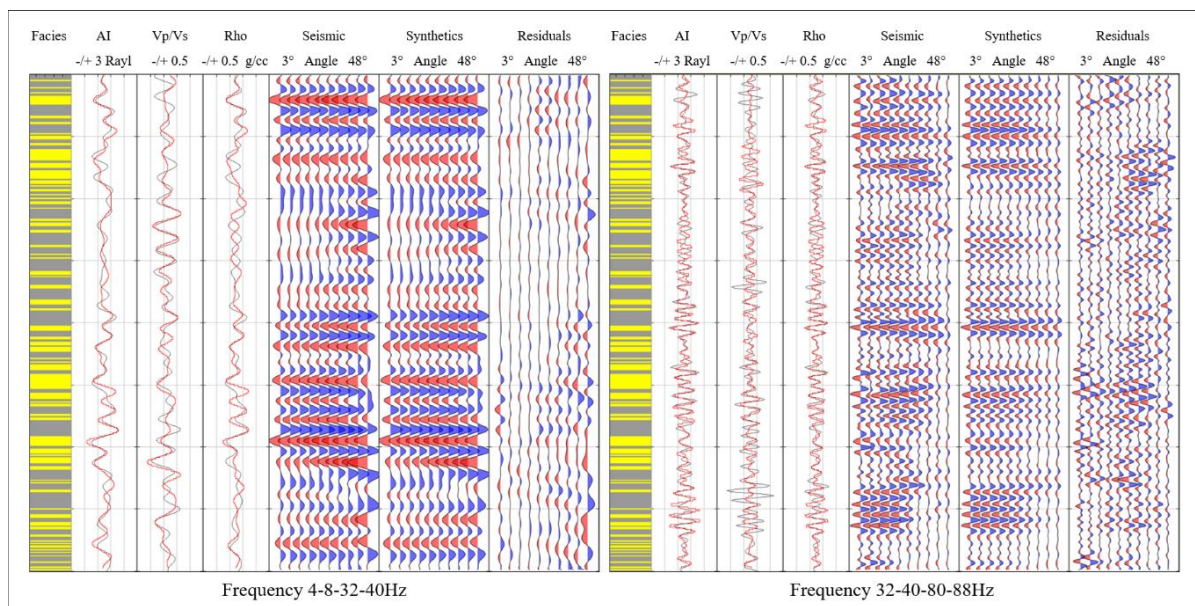


Figure 2 Inversions at a well for different frequency ranges showing from left to right (a) facies log (sand-shale) (b) acoustic impedance (c) Vp/Vs (d) density (e) seismic angle gather (f) inversion synthetic (g) residuals. For the properties red curves represent inversion results and black curves log data. The residuals are boosted by a factor of 2 for visualisation purposes.

This analysis was supported by calculating the reflection coefficients for acoustic impedance and Vp/Vs. The spectra of these products were compared between the inverted data and the well log data from the one well used for the inversion and a number of offset wells that penetrated the same sequences but lay outside of the seismic area (Figure 3). The spectra of the well log data are generally consistent (grey/red). The spectra of the inverted data follow the same trend up to a point (blue). In the case of acoustic impedance, the spectra of the inverted data falls off at around 70Hz indicating the limit of the reliability even though correlations remain high for higher frequencies. The spectra of the inverted Vp/Vs diverges from the well trend at a lower frequency but suggests that inversion results may be reliable up to about 60 Hz. Closing the gap at the high frequencies for Vp/Vs reflectivity might be achieved through further conditioning of the data or through the use of a facies based inversion where strong relationships between acoustic impedance and Vp/Vs can be imposed with some confidence.

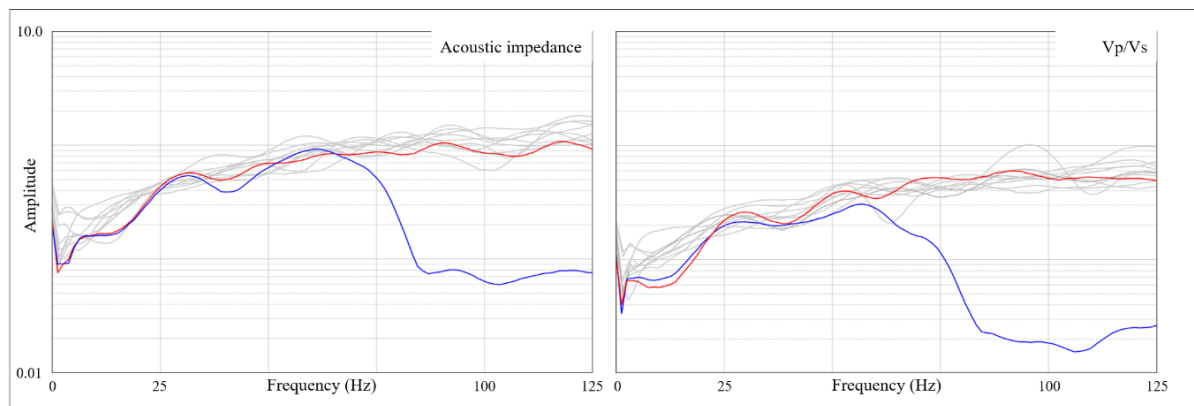


Figure 3 The frequency spectra for the acoustic impedance and V_p/V_s reflectivity from a series of offset wells outside the seismic area in grey, the well log data in red and the inverted data at the well in blue.

Seismic inversion is most often embedded within a Quantitative Interpretation (QI) workflow where rock physics is used to integrate geological and geophysical data to address questions of technical and commercial value. The quality of a seismic inversion should therefore be judged with respect to how well it helps to achieve the QI objectives. In this case, the objectives included the prediction of the distribution of reservoir sands and fluids. Facies can be predicted from the inversion properties in various ways. Here the most likely facies were predicted through a polygon capture of the inverted absolute acoustic impedance and V_p/V_s . At the well, the quality of the prediction was quantified through a confusion matrix. Variations in inversion parametrisation, wavelet estimation and seismic data conditioning were assessed through improvements to the confusion matrix in addition to previously mentioned metrics. Away from well control few of these metrics are available.

Inversion analysis away from a well

Away from a well location, the assessment of the quality of an inversion is often more subjective. For example, the strength and type of seismic data conditioning to apply prior to inversion may be based more on qualitative considerations, such as how the predicted facies distribution matches geologic expectation. The value of the objective function obtained by the inversion, which is output at each trace location, is a quantitative indicator of how consistent the seismic data are with the chosen model/constraints. The variation of the objective function along a cross-section passing through the well location is shown in Figure 4. We noted that the well lies in an area where the objective function is low. At the well, more than 80% of sands and shales are correctly predicted. The increase in the objective function away from the well location suggests that the nature or scale of the noise in the seismic is changing and the confidence in the facies prediction is reduced, but it is not clear by how much. This rise in objective function correlates with the prediction of oil in the shallow sands, where no oil is expected. These false positives were investigated by examining the residuals within different frequency bands and the dynamic ranges of the relative elastic properties. In these zones we found that the elastic property dynamic ranges were exaggerated compared with the well data. The lateral variation in the spectra of the reflectivity as shown in Figure 3 were extracted at different locations and also indicated that seismic scaling might be an issue. It is challenging, however, to quantify the variation in the uncertainty of facies prediction resulting from the variations in the objective function as there is no control away from the well.

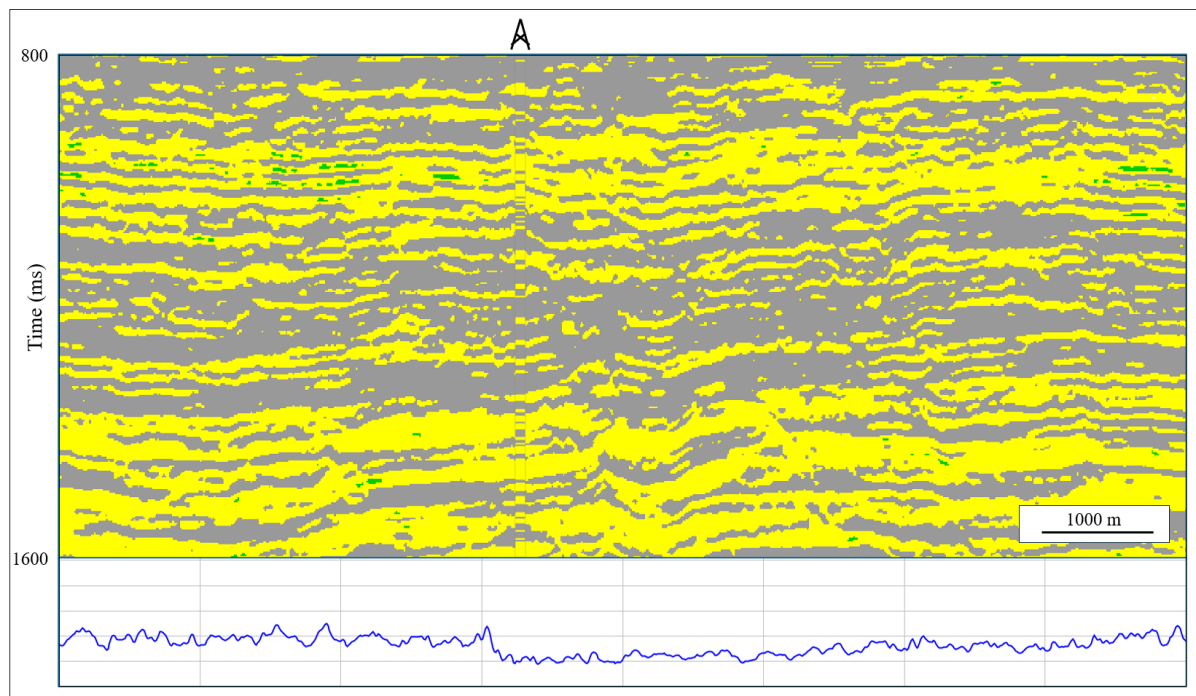


Figure 4 Facies classification from a polygon capture of inverted absolute acoustic impedance and V_p/V_s . The well log facies (based on petrophysics) is overlain. Shales are grey, wet sands are yellow, and oil sands are green. The value of the objective function obtained by the inversion is shown as a blue line.

Conclusions

Quality control of a seismic inversion is necessary to provide confidence levels in the inversion results and derivative products (such as facies). There are a variety of metrics available when inverting at a well. We recommend that metrics such as the cross-correlation between log and inverted properties are made at a range of frequencies, and include visualization of the seismic, synthetics and residuals at different frequencies. Analysis of the variations with frequency can be supported by comparing spectra of the reflectivity of inverted and well log properties. A quantitative assessment should also be made focused on the objectives of the QI workflow in which the inversion is embedded. Away from well control, where fewer metrics are available, the value of the objective function provides a quantitative measure of the conflict between the seismic data and the underlying prior model constraints, but translating that into a quantitative estimate of the uncertainty of a facies prediction remains a challenge. Additional analysis is required to incorporate the uncertainties in constructing a low frequency model away from well control and its impact on the Quantitative Interpretation.

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References

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