Uncertainty estimates on prestack inversion for a Central North Sea sandstone injectite field

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Summary

Deterministic prestack inversion results represent a minimum of a cost function in some parameter space, and in most cases, the uncertainty or variability of the inversion at this minimum is not addressed. In this study, we calculate spatially varying Cramer-Rao lower bound (CRLB) uncertainty estimates on a set of inversion results from a North Sea injectite field using a spatially varying signal to noise model. The CRLB uncertainty estimates by themselves provide a platform for interpretation of the inversion results, but using the CRLB estimates and a defined direction of interest in the inversion parameter space, we investigate the P10 and P90 percentile halfspaces along this direction. Finally we perform a lithology classification on the P10, P50 and P90 inversion results and compare the hydrocarbon bearing sands lithology probability for the three cases. This provides a range of possibilities for the extent of the hydrocarbon bearing sands within the uncertainty of the inversion results.

Introduction

Injectites are sandstone intrusions resulting from massive remobilization of unconsolidated sands. One of the many challenges of imaging these remobilized sandstone reservoirs is their variable thickness over short distances. Sand thickness in some cases borders the seismic resolution, resulting in uncertainties in their connectivity and extent (e.g. Murphy and Wood, 2011). Deterministic seismic inversion is often used to identify these reservoir intervals, making use of the differences in their elastic properties from its surroundings.

Mathematically, the deterministic inversion represents a minimum of a cost function in some parameter space (Rasmussen, 2004), however, uncertainties associated with this result are usually not addressed. In this study, we use the Cramer-Rao lower bound uncertainty estimates of the seismic inversion results from a North Sea injectite field in conjunction with a lithology classification to identify the spatial extent of the reservoir. The workflow applied is outlined as follows:

- Calculate a signal to noise model
- Calculate the Cramer-Rao lower bound uncertainty on the inversion results
- Define a direction of interest in acoustic impedance versus Poisson's ratio cross-plots
- Use the direction of interest to create percentile half spaces (e.g. P10, P50, P90) of the inversion results
- Apply the sets of probability density functions from the lithology classification to the percentile half space of the inversion results

Spatially varying signal to noise model

To obtain a signal to noise model for the uncertainty estimates, we implement a well log and seismic based methodology to derive a spatially varying model. First, using a multiple correlation approach at each well location, the multiple correlation coefficient between the log reflectivity and adjacent seismic was obtained using a sliding vertical window. Here, the applied assumption is that the noise is the part of the seismic signal that does not fit the convolutional model. Subsequently, a purely seismic driven signal to noise ratio (SNR) estimate was computed as the multiple correlation coefficient between the unfiltered seismic and horizontally filtered seismic using a sliding vertical window. Here, the applied assumption is that the noise is the horizontally incoherent seismic signal. Finally, the two estimates are combined by interpolating/extrapolating the well estimates away from the wells along interpreted seismic horizons and guided by the seismic SNR estimates using a radial basis function interpolation technique.

Cramer-Rao lower bound uncertainty estimate

Using the signal to noise model, we compute unimodal uncertainty estimates of the prestack inversion with the Cramer-Rao lower bound (CRLB) covariance matrix (Shahraeeni, 2014). The CRLB will be a function of the prior model, additive nose level (SNR), reflection angles, wavelets and the AVO model used. Therefore, when analyzing the CRLB based uncertainty estimates, one should keep in mind that there is both a seismic as well as a prior model contribution. In addition, the matrix inverse of the CRLB is the concentration or precision matrix, which is equal to the sum of the seismic and prior model precision matrices. It turns out that the seismic precision is largest for acoustic impedance when compared to any other property. This implies that the acoustic impedance is as expected the most precise property that can be estimated.
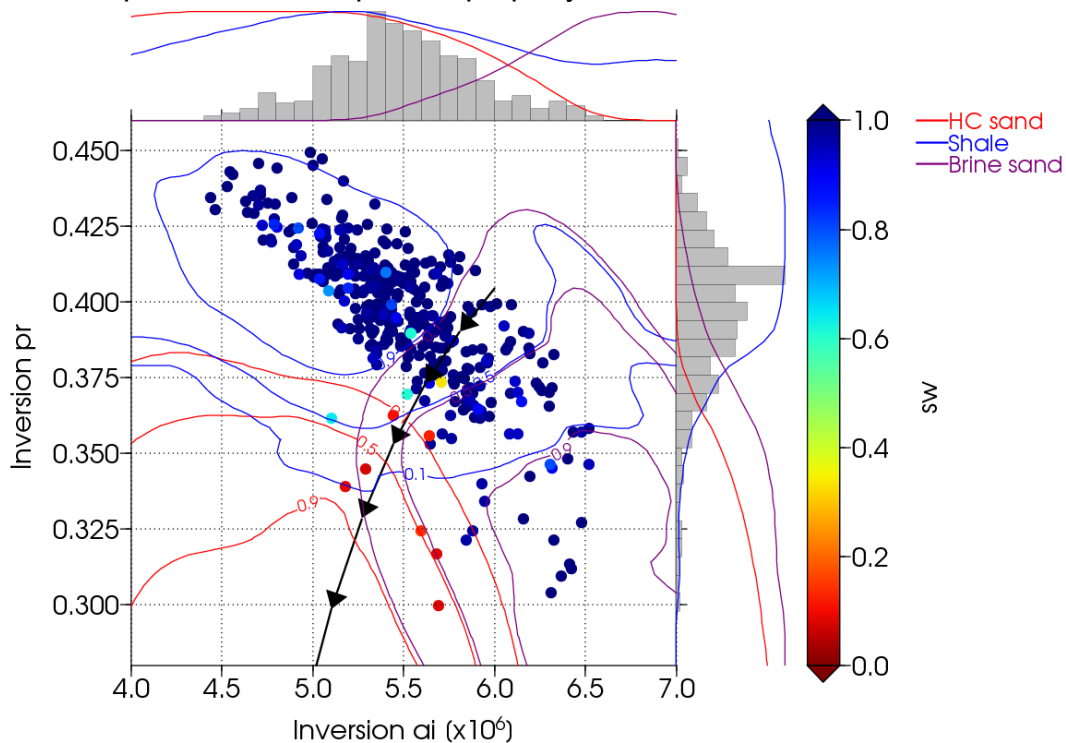

Figure 1: Absolute prestack inversion results extracted along a well path and color-coded by water saturation. The Poisson's ratio vs. acoustic impedance cross-plots has been overlain with the direction of interest vector. Additionally contour lines for probability density functions from the lithology classification have been overlain.

(a) Seismic: Near angle-stack (5-10°)

(b) Seismic: Far angle-stack (40-45°)

(c) Inversion: acoustic impedance

(d) Inversion: Poisson's ratio

(e) Lithology class.: P50 HC-sands probability

(f) Lithology class.: P10 HC-sands probability
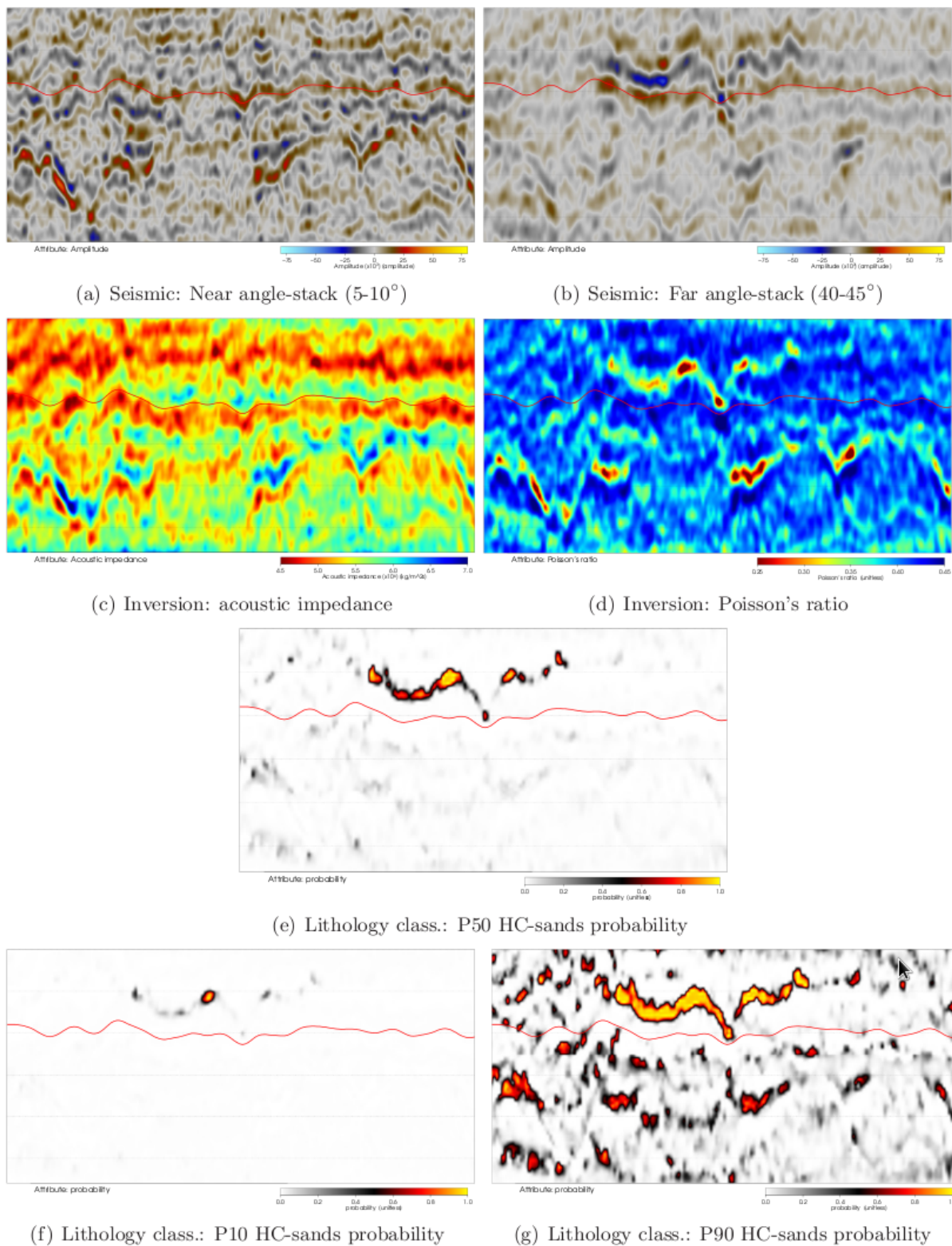
(g) Lithology class.: P90 HC-sands probability

Figure 2: Near (a) and far (b) seismic angle-stacks used in the inversion, inverted acoustic impedance (c) and Poisson's ratio (d) and the probability of encountering the hydrocarbon sand based on the lithology classification for the 10th (e), 50th (f) and 90th (g) percentiles.

Percentile half spaces

In computing the percentile half spaces, we need to define a direction of interest in acoustic impedance versus Poisson's ratio cross-plot space. We achieve this by analyzing rock physics trends and define a direction based on an increase in porosity and a decrease in water saturation (increase in hydrocarbon content). This is illustrated in Figure 1 where the cross-plot shows the inversion results color-coded by water saturation and the direction of interest points in the direction of decreasing water saturation. The resulting solutions for the P10 and P90 cases then correspond to a translation of the original inversion results (P50) to the appropriate location in the cross-plot space according to the CRLB results.

Lithology classification with uncertainties

Figure 2 illustrates the results of the study where the near (a) and far (b) input seismic anglestacks, inverted acoustic impedance (c) and Poisson's ratio (d), and the P50 (e), P10 (f) and P90 (g) cases of the lithology classification are shown. The probability density functions used for the lithology classification are shown by the contour lines in Figure 1 where three lithologies were identified.

Note that the reservoir events are visible, but hard to interpret on the seismic anglestacks (Figure 2a and b). After the inversion, these features are more apparent especially in the Poisson's ratio inversion result where several anomalies can be seen (Figure 2c and d). In the lithology classification, only some of the anomalies from the inversion are classified as hydrocarbon bearing sands with the P10 and P90 solutions illustrating the variability of the lithology classification within the uncertainties (Figure 2e, f and g).

As can be seen, the P10 case is very conservative and the P90 case is more optimistic. Note that in the P50 case, the connectivity of the left wing is questionable. However, the more optimistic result as shown by the P90 case demonstrates a connected reservoir that is within the uncertainty of the inversion results.

Conclusions

The limited resolution of seismic data presents challenges in determining the spatial extent of a North Sea injectite reservoir. By applying a Cramer-Rao lower bound uncertainty estimate on a deterministic prestack inversion, we were able to obtain a P10 and P90 case for a lithology classification. Using these results, the connectivity of the reservoir was determined to be within the uncertainty of the seismic inversion results.

Acknowledgements

References

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