Lithofacies Prediction from Seismic, One Step at a Time: An Example from the McMurray Formation Bitumen Reservoir at Surmont

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Summary

Before drilling in situ production wells in bitumen reservoirs, we would like to be able to predict the presence of muddy intervals, even thin ones, since they can affect the propagation of steam through the reservoir, and thus production. Very-high-resolution seismic data are independent of well data and provide information about lithofacies. A linear combination of the most useful seismic attributes into a single scaled and calibrated pseudo-density 'super-attribute' substantially improves non-reservoir prediction quality when applied to the geomodel.

Introduction

Silt and mud zones, even ones less than 1 m thick, can to some degree slow the progress of steam through the Early Cretaceous McMurray Formation, a prolific bitumen reservoir. Failure to develop a uniform steam chamber above the production well pair is thought to be one of the chief causes of a high steam-oil ratio, resulting in a high cost of production. Thus, describing and predicting the spatial distribution of silt and mud zones is imperative in our interpretation and geomodelling efforts. Since very-high-resolution 3D seismic (upper frequency over 200 Hz) is almost ubiquitous on the Surmont lease, it necessarily plays a key role.

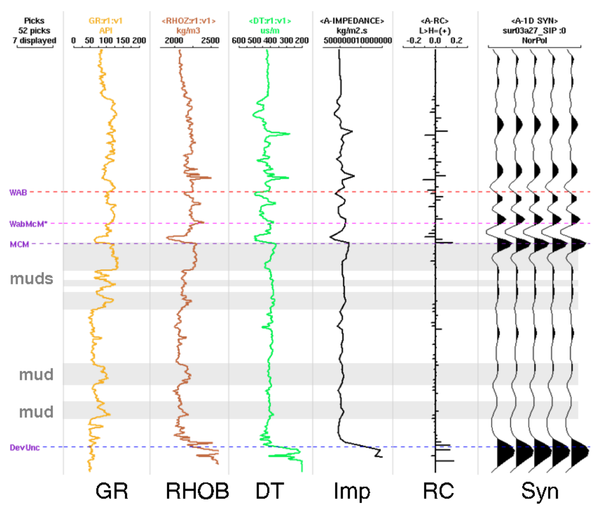

Figure 1: Synthetic seismogram showing the problem: muddy intervals tend to show small but consistent density contrasts, but inconsistent velocity contrasts. As a result, impedance and reflectivity may not be reliable indicators of lithology.

This sounds simple, but unfortunately the earth's acoustic properties are not. Figure 1 shows that thin muddy intervals, as indicated by the gamma-ray log, have a variable expression in acoustic impedance. When it comes to lithology prediction, the most reliable acoustic property is density, which is notoriously difficult to get at in seismic data.

Method

We have four concurrent lithology prediction efforts at Surmont:

1 Qualitative seismic interpretation and geomorphology. We use this methodology for qualitative exercises like delineation well planning.

2 Trace integration is a cheap, semi-quantitative seismic attribute we call pseudo-impedance. Furthermore, poststack inversion can give us an estimate of acoustic impedance. We use such products for detailed seismic interpretation, pad-placement and production well planning.

3 Log prediction by multi-linear regression of seismic attributes, using Hampson–Russell's EMERGE software. This more involved, quantitative workflow produces a scaled, seismic-bandwidth bulk density prediction at every seismic trace and is incorporated into the geomodel by sequential Gaussian simulation.

4 A suite of speculative research projects into, for example, non-linear AVO inversion for density, simultaneous 4D inversion, converted wave processing, and stochastic inversion (eg Hall 2006 and Roy et al 2008).

The purpose of this paper is to present results from the multi-linear regression approach.

Results

To date, I have performed this type of analysis four times at Surmont. In one study, the multi-linear regression procedure give the geomodel an improvement of about 11% in prediction accuracy for non-reservoir (from about 52% to about 58% accuracy), with no cost in accuracy for reservoir. To put this in perspective, the best you can do with almost total ignorance (one well, no seismic) is about 20%, the proportion of silt in the reservoir as a whole.

My best results typically come from correlating logs filtered with a 200 Hz hi-cut to a pre-stack, straight-ray Kirchhoff time migration processed with amplitude- and phase-friendly parameters. This gave superior results to other volumes, such as post-stack time migrations, and non-amplitude-friendly volumes (with, for example, spectral balance applied). It was also superior to two attempts at non-linear AVO inversion. The preferred attributes are consistently variants of the stack, the integrated trace, and a sparse-spike inversion (computed with Hampson–Russell's STRATA software). I also include a low temporal- and spatial-frequency model (few wells, 6–12 Hz hi-cut filter) to compensate for the bandlimited data. For the regression, I typically select no more than five attributes, using the validation (recursive well drop-out) error as a guide. Well tie quality did not have a strong influence on the quality of the density prediction.

Figure 2 shows an example of one of my lithology prediction efforts, in Surmont's Phase 2 development area. The difference between the Pseudo-density volume and the Amplitude volume is simply that the Pseudo-density is calibrated to the wells and scaled to appropriate units. It is also possible to quantify the mismatch with the wells and the overall magnitude of the error.

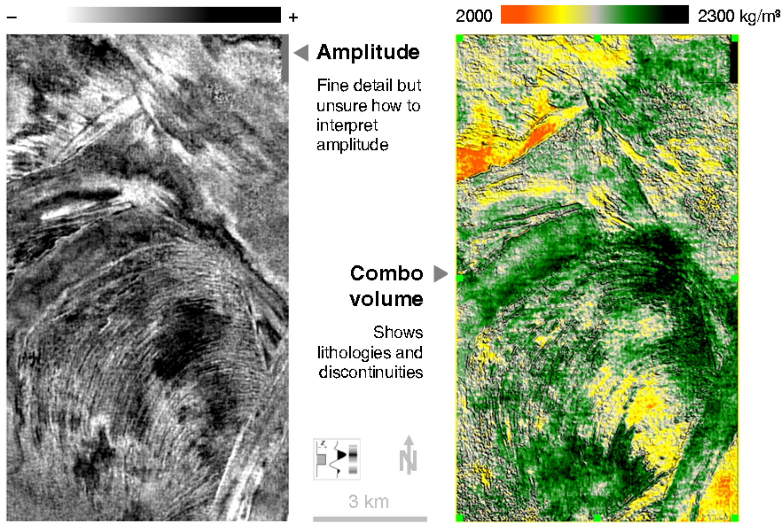

Figure 2: A timeslice from the PreSTM (left) and from the final product (right), showing the pseudo-density 'super-attribute' in colour and is shaded with Semblance, which shows discontinuities as darker shades.

Conclusions

Qualitative interpretation techniques and semi-quantitative lithology estimates from single attributes are useful planning and interpretation tools at Surmont. However, a weighted sum of various seismic attributes and inversion products, established by linear regression against density logs, provides a superior estimate. This estimate, pseudo-density, positively impacts facies predictions in the geomodel, improving our non-reservoir prediction quality from 52% to 58% in one study. For input data, we found that amplitude- and phase-friendly pre-stack time migration was worth the investment, having a more quantitative and more consistent relationship to the well logs.

Acknowledgements

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