Application of Seismic Inversion Workflow Guided by Depth-dependent Rock Physics Trends – A QI Study in the Northern Malay Basin.

Fahmi, F.[1], Wei Di, G.[1], Ronghe, S.[2], Locke, A.[2], and Teng, S.[2]
[1] REPSOL Oil & Gas Malaysia Limited. [2] DownUnder GeoSolutions.

Introduction

The PM-3 Commercial Arrangement Area (CAA), is located in the north-east Malay Basin at the international border between Malaysia and Vietnam. This area is operated by Repsol Oil and Gas Malaysia Limited (REPSOL) together with its partners Petronas Carigali Sdn Bhd (PCSB) and PetroVietnam Exploration Production Corporation (PVEP).

Two main development areas in PM-3 CAA are the Northern and Southern Fields, which consist of several fields located within a development complex. This paper will focus on the development area in Northern Fields, which have hydrocarbon traps that are significantly stratigraphic in nature. Some of the geophysical challenges in this area include high seismic amplitudes that could be the result of sand, shale or coals, thin sands below seismic resolution, and several near-seabed channels that create amplitude shadows in the reservoir intervals.

In this paper we show how a depth-dependent statistical rock physics model along with constrained absolute simultaneous inversion of PreSDM seismic angle stacks were used to derive probabilistic estimates of reservoir distributions. Particular attention was given towards seismic conditioning to alleviate the effects of amplitude shadows from shallow channels; and towards incorporating formation over-pressuring in rock physics trends and in low frequency models required for absolute inversion. The probabilistic lithology interpretations have reduced the uncertainty in differentiating between sand and shale filled channels. The lithology prediction is being progressively evaluated against an ongoing drilling campaign and results so far have been encouraging.

Depth dependent statistical rock physics modelling

Data comprised three exploration wells within the targeted area, and three outside. Statistical rock physics was performed subsequent to comprehensive petrophysical evaluation of each well. The analysis involved picking end-member lithology types and establishing end-member trends (Figure 1). A total of five reservoir end-members were identified that differed in elastic properties: Sandstone, Silty Sandstone, High P-velocity Sandstone, High Porosity Sandstone and Over-pressured Sandstone. Non reservoir end-members comprised Shale, Silty Shale, High P-velocity Shale, their over-pressured counterparts, Carbonaceous Shale and Coal.

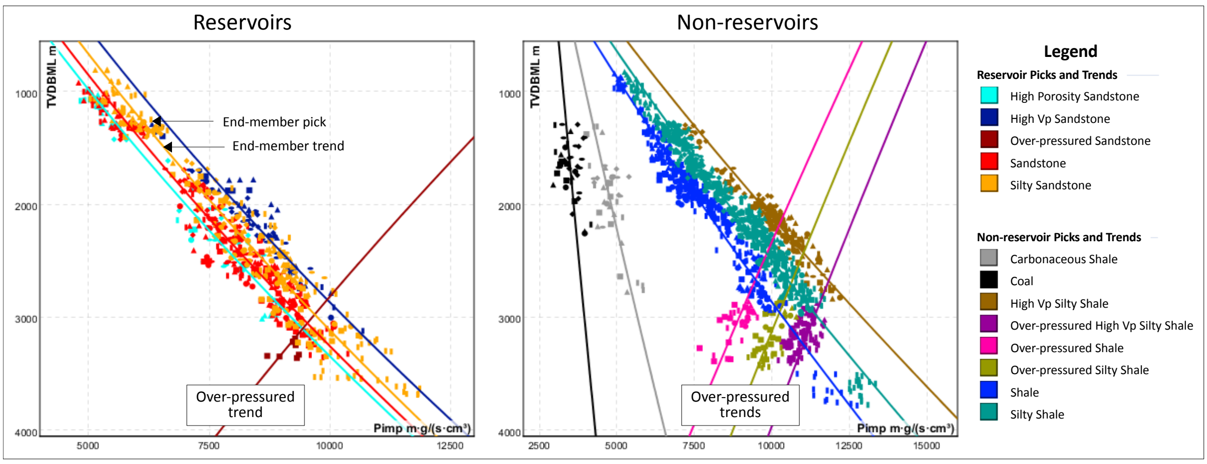

Figure 1 Reservoir and non-reservoir end-member picks and trends. While over-pressured trends are extrapolated shallow in display, they are only relevant and have been used within the depth range of the corresponding end-member picks.

Reservoir and non-reservoir end-member trends were mixed to create known and expected lithology combinations of interest. Fluid mixing and substitution by Gassmann's equations were performed for reservoirs at designated saturations. The resulting combinations were statistically sampled to derive distributions representative of the possible range of properties (population behaviour) of each lithology and fluid mixture at each relevant depth.

The distributions were cross-plotted in P-impedance vs Vp/Vs space and were characterised using probability density functions (PDFs) for each lithology and fluid mixture as function of depth (Figure 2). The results showed that different types of sands could be separated from the different types of shales. Fluid discrimination may be more uncertain due to overlapping properties, and over-pressured formation PDFs also introduced additional interpretation uncertainty.

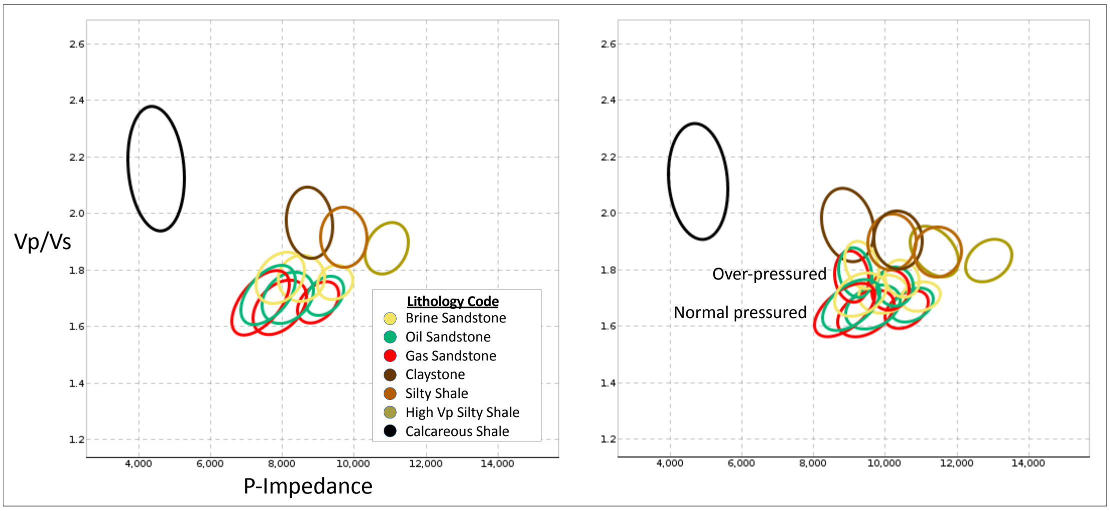

Figure 2 *PDFs for lithology and fluid mixtures at shallow (left) and deeper (right) intervals.*

Constrained absolute simultaneous inversion

The conditioned seismic angle stacks were simultaneously inverted in multiple vertical zones using extracted wavelets (as a function of angle), low frequency models and rock physics constraints to derive absolute P-impedance and absolute Vp/Vs (Figure 3). A Bayesian wavelet extraction workflow accounted for numerous uncertainties associated with the well-seismic tie including the phase of the seismic data within the zone of interest. Low frequency models were built using a combination of elastic logs and tomographic velocities that are sensitive to formation over-pressuring. The use of the velocities enabled formation overpressure characteristics to be incorporated in the low frequency models in 3D.

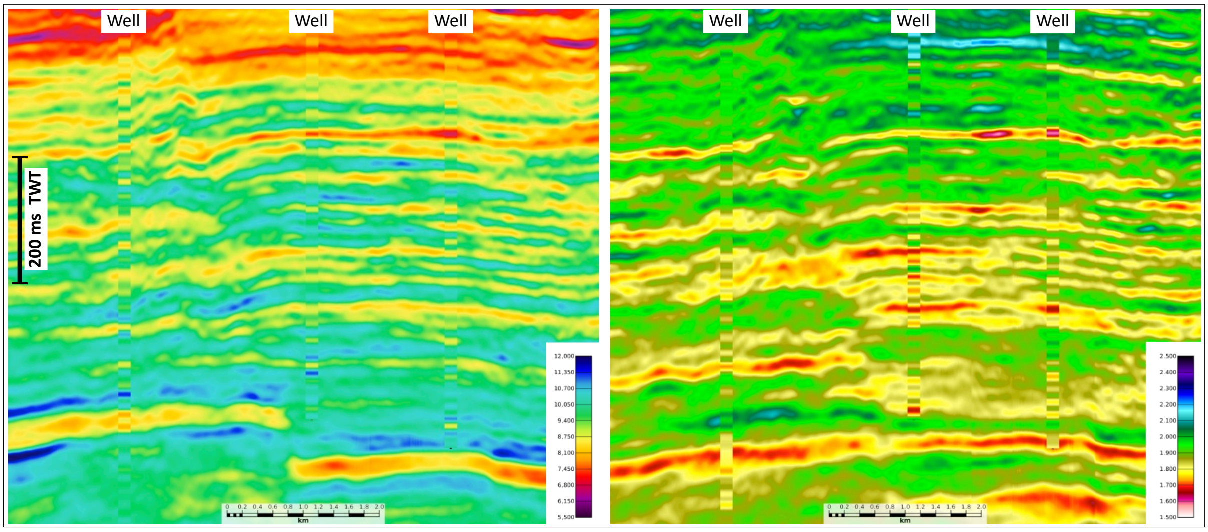

Figure 3 Absolute results from simultaneous inversion. P-impedance (left) and Vp/Vs (right). The sections are overlain by frequency filtered (45 Hz high cut) well logs.

Probabilistic lithology interpretations

Lithology and fluid probabilities were derived by comparing absolute P-impedance and Vp/Vs volume samples against the depth dependent PDFs from statistical rock physics analysis. A Bayesian classification system was used to derive individual lithology probability volumes for all lithology and fluid types. A most likely lithology type was also calculated at each sample in the volume (Figure 4).

The top and base of the over-pressured zone were mapped on the velocity volume and this enabled statistical rock physics models from the over-pressured intervals to be correspondingly applied to the inversion volumes for the probabilistic lithology interpretation.

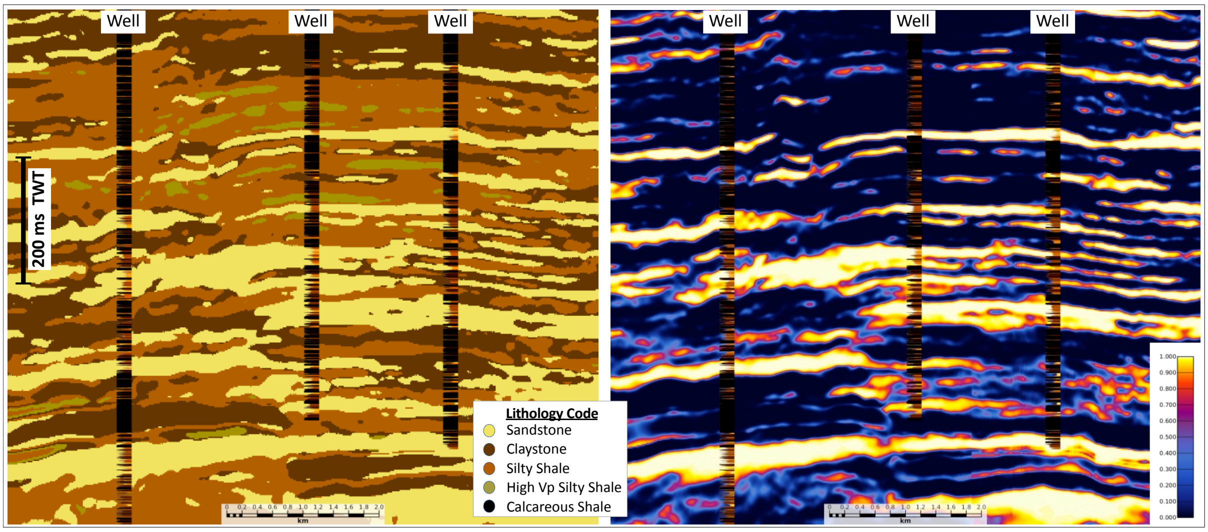

Figure 4 Lithology interpretation showing most likely lithology (left) and sand probability (right). The sections are overlain by Vsand logs. All sand types are collected into one type for clarity in the most likely lithology section.

Figure 5 compares map view slices through absolute P-impedance, absolute Vp/Vs and sand probability at a depth of interest. Channels are apparent in the P-impedance map. However, P-impedance alone cannot differentiate between sand-filled and shale-filled channels. Vp/Vs is sensitive to lithology in this data set, and a joint depth-dependent probabilistic interpretation using both properties is used to map the sand channel distributions.

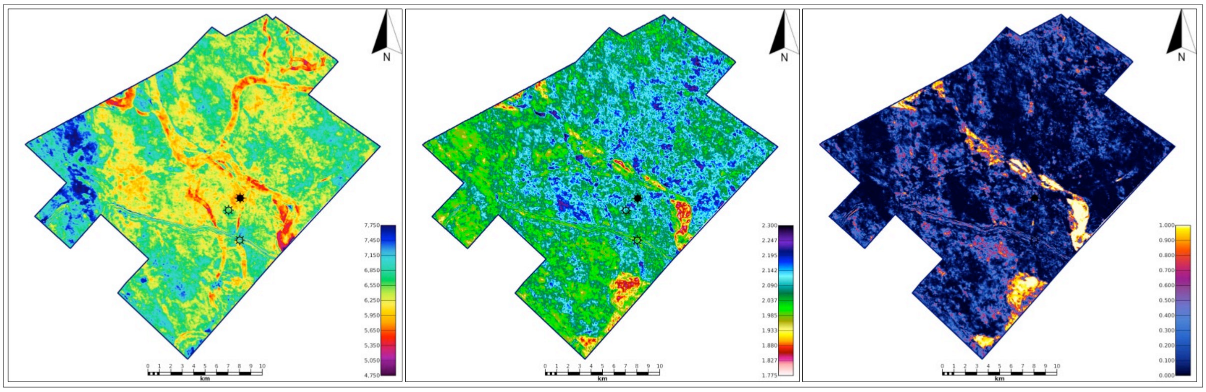

Figure 5 *An example of results and interpretation. Slices through P-impedance (left), Vp/Vs (middle) and sand probability (right).*

Conclusion

A constrained absolute simultaneous inversion followed by probabilistic lithology prediction calibrated to a depth dependent statistical rock physics model has overcome some of the exploration and field development challenges in the field through the derivation of sand probability volumes that can be used to map the distribution of reservoir in the area. Fluid prediction currently remains less reliable due to overlapping elastic properties and noise in the Vp/Vs, but more work is planned to further improve the results. The results of this QI workflow are being evaluated against the current drilling program, with encouraging results.