Identifying reservoirs through relative simultaneous inversion

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Summary

A relative simultaneous inversion study, calibrated to a regional rock physics model derived from 56 wells, was conducted over a large lateral (15,200 sq km), and vertical (up to 3 s TWT) extent of data from the Bonaparte Basin, offshore Western Australia. The objectives were to create interpretation volumes that supplement the seismic in making development decisions, reducing exploration risk, and high-grading prospects.

The complex geological evolution of the basin meant that defining single, universally applicable interpretation criteria were not feasible over the complete extent. Instead, interpretations were focused on rock property models at representative well locations. Interface reflectivity models were created for specific lithology and fluid contrasts. These were analysed to determine whether significant weighted combinations of near versus far reflectivity existed that discriminated reservoir lithology. The inferences were applied to weighted stacks (or stack rotation volumes) of elastic impedance to interpret reservoir distributions in the adjacent formation. The study revealed numerous instances of reservoir sand distributions in horst blocks. These form additional prospectivity. An interpretation of sand-filled low-stand basin slope and floor channels forms an overlooked play in the area. The study met objectives of predicting reservoir distributions, and high grading prospects.

Introduction

A quantitative interpretation (QI) study was conducted on 15,200 sq km and up to 3 s TWT of broadband PreSDM 3D seismic data in the Vulcan Sub-basin of the Bonaparte Basin, offshore Western Australia. NOVAR (NOrth Vulcan Advanced Reprocessing) MC3D is a contiguous and consistent dataset from 10 seismic surveys acquired between 1995 and 2012. The QI study comprised relative simultaneous inversion and focused interpretation calibrated to relevant local lithology contrasts from a regional rock physics model developed using 56 wells. The QI project objectives were to create interpretation volumes that supplement the seismic in making development decisions, reducing exploration risk and high-grading prospects.

The Bonaparte Basin has had a complex geological evolution with multiple phases of extension and compression from the Paleozoic into the Cenozoic. This geological complexity created considerable technical challenges. Most QI workflows require some form of prior knowledge that is used as a constraint: absolute inversion requires low frequency models; Bayesian probabilistic lithology / fluid predictions need prior estimates of probability. The complex evolution of the basin made it difficult to establish prior knowledge across the considerable areal and vertical extent of the interval of interest. A relative simultaneous inversion was therefore conducted to reduce the impact of these uncertainties. AVA stack rotation interpretations of the relative inversion results, calibrated to local wells, provided interpretations of adjacent reservoir distributions and prospectivity.

Statistical rock physics

A depth-dependent interpretation framework was built from well logs using statistical rock physics. Figure 1 summarises the workflow. End-member lithologies were picked on logs. End-member trends were defined (Figure 1.A.). At any depth, the rock property distributions were sampled to derive cross-plots of near vs far reflectivity for lithology and fluid interfaces (Figure 1.B.). The results were summarised using Probability Density Functions (PDFs) that define the likely range of AVA responses for the interface. The interface reflectivities were projected on to different angles of axis rotation (Figure 1.C.) to derive graphs of rotation angle vs reflectivity (Figure 1.D.). The rotation at an angle represents the weighted stack of the reflectivity data and is analogous to Extended Elastic Impedance (Whitcombe et al, 2002). Different weighting functions or stack rotations can be defined to optimally brighten a target interface of interest while suppressing other reflections. In the example below, a -30° rotation brightens the reflectivity of interface (b) relative to interface (a).

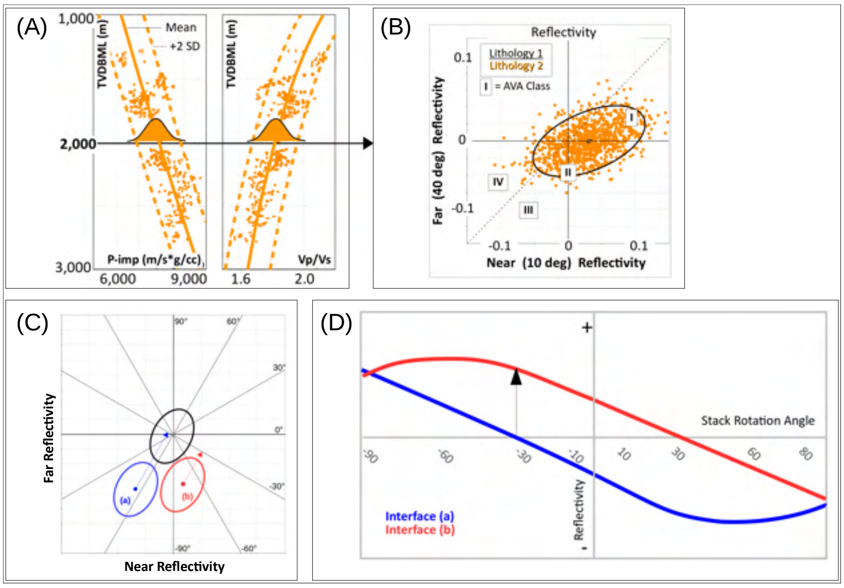

Figure 1 An interpretation framework from statistical rock physics.

In this study, a large number of end-member lithologies were defined from rock properties. These comprised 13 reservoir and 14 non-reservoir lithologies. Stack rotation curves from statistical rock physics were used to assess whether significant rotation angles occur that highlight lithologies or fluids for particular combinations under consideration. Due to the considerable vertical and lateral heterogeneity in lithologies and their properties, interpretations were focused on rock property models at representative well locations and extended into relative inversion derived stack rotation volumes to characterise analogous prospects.

Relative simultaneous inversion

Three seismic angle stack volumes were simultaneously inverted for relative p-impedance, gradient impedance and elastic impedance for each stack. The seismic data were modelled as a convolution of inverted reflection coefficient series with derived wavelets. The Aki-Richards three-term approximation was used to constrain inverted AVA coefficients and thus the resultant reflectivities and elastic parameters. At each trace, a constrained non-linear optimisation was solved (Lamont et al, 2008). No low frequency models were used in the inversion. Figure 2 displays results at a representative well. The relative inversion results are of good quality and track the correspondingly filtered logs quite well.

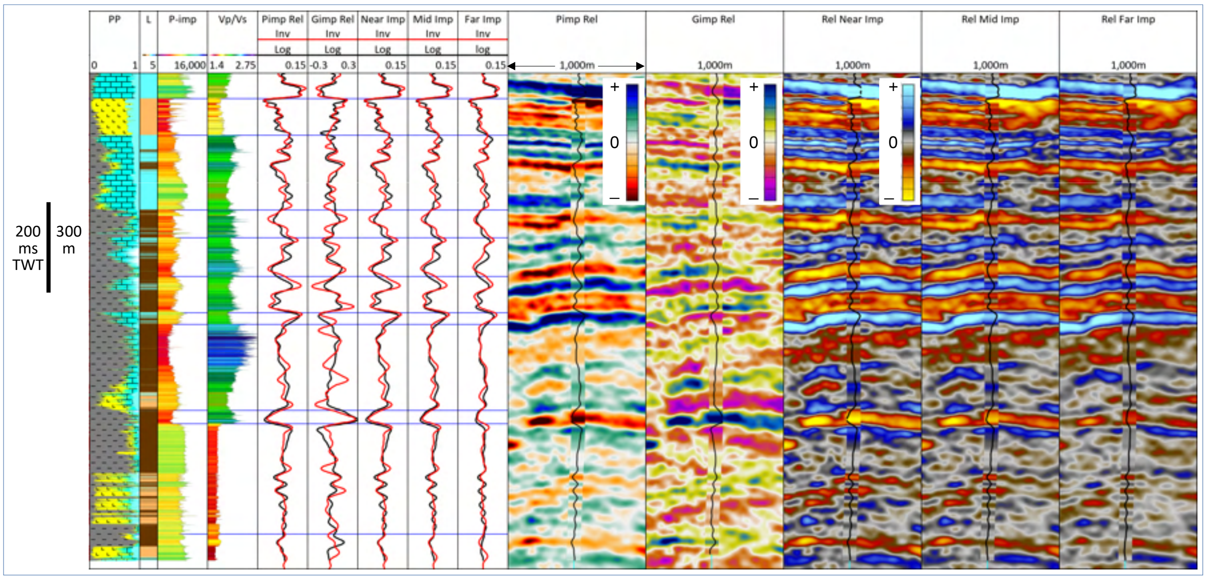

Figure 2 Relative simultaneous inversion results compared with well logs.

Interpretation of results

Stack rotation volumes were derived as weighted stacks of the near, mid and far relative impedance. The volumes were perused at significant angles of rotation calculated from the rock physics analysis for specific lithology and fluid contrasts modelled at wells, and localised interpretations were made.

Figure 3 displays a rock physics calibrated interpretation. Figure 3.A. is a rock physics model for the lithology contrast at the top of a reservoir sand containing residual oil at 4,000 m TVDBML in the Lameroo-1 well. The interface comprises a Pre-Valanginian Shale overlying a High Vp Sandstone. For this interface, the rock physics model shows that at a stack rotation at 20°, the sand has strong positive reflectivity. There is little differentiation of fluid based on reflectivity. Figure 3.B. displays a section view of the corresponding stack rotation volume. Strong amplitudes indicate presence of reservoir in the saddle and horst structures (blue arrows) adjacent to the well.

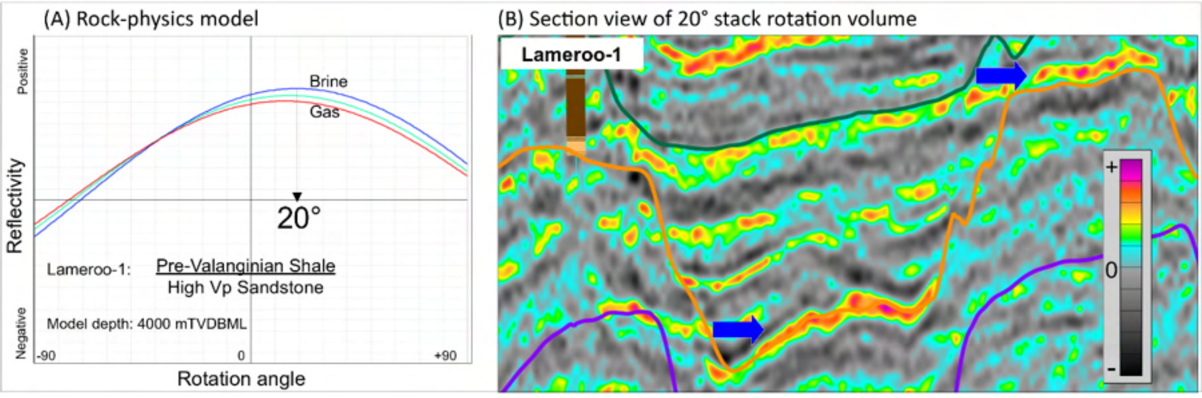

Figure 3 Rock physics calibrated stack rotation interpretation across the Lameroo-1 well.

Figure 4 is a rock physics calibrated interpretation adjacent to the Octavius-2 well. The well encountered oil and gas shows. The interface at the top of the reservoir sand is characterised by a Pre-Valanginian Shale overlying a Mid to Early Jurassic Sandstone at 3,000 m TVDBML. The stack rotation plot for this interface (Figure 4.A.) gives strong negative reflectivity for reservoir at a rotation angle of 45°. Gas filled sandstone shows higher reflectivity than oil and brine. The section view through the stack rotation volume (Figure 4.B.) shows strong amplitudes in faulted blocks downdip of the well. These may represent missed targets. The well intersected a fault, and this may explain the occurrence of only hydrocarbon shows in the sandstone encountered.

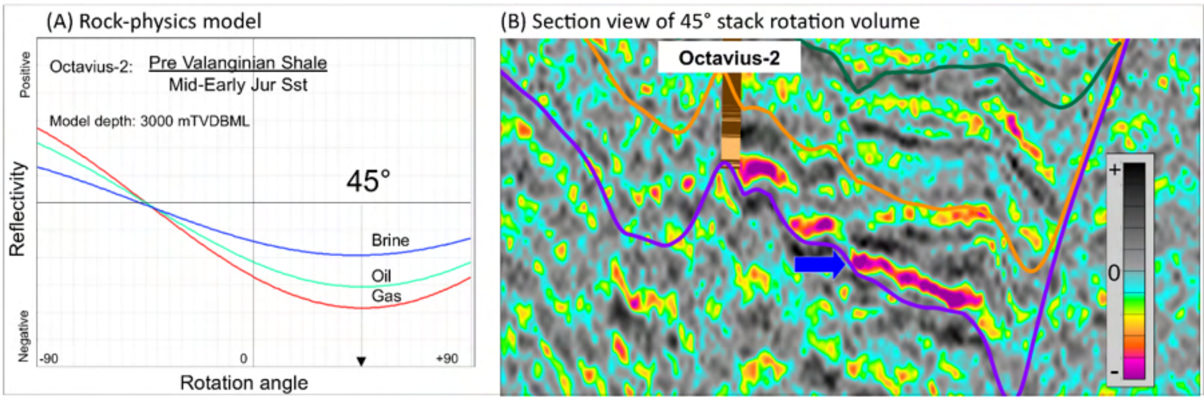

Figure 4 Rock physics calibrated stack rotation interpretation across the Octavius-2 well.

Figure 5 is an example across the Ludmilla-1 well. The well has oil shows. At a depth of 3,700 m TVDBML, the interface defining the top of the reservoir is characterised by a silty shale overlying a sandstone. For this interface, a 50° stack rotation creates strongest negative reflectivity, increasing from brine to oil and gas (Figure 5.A.). The corresponding impedance stack rotation volume shows strong indications of reservoir occurrence at the top of a horst block downdip of the well. This may represent additional prospectivity.

Figure 6 applies the rock physics model from a shallower depth of the Octavius-2 well to image low stand basin floor channels. At the model depth of 2,000 m TVDBML, the interface of interest is represented by a Post Valanginian shale overlying an Early Cretaceous to Late Jurassic Sandstone. For this interface, the stack rotation cross-plot shows a few significant angles at which fluids can be potentially discriminated (Figure 6.A.). The map view time-slice in Figure 6.B. at 20° through the stack rotation volume is interpreted as displaying low-stand basin slope and floor sand-filled channels that form an overlooked prospect.

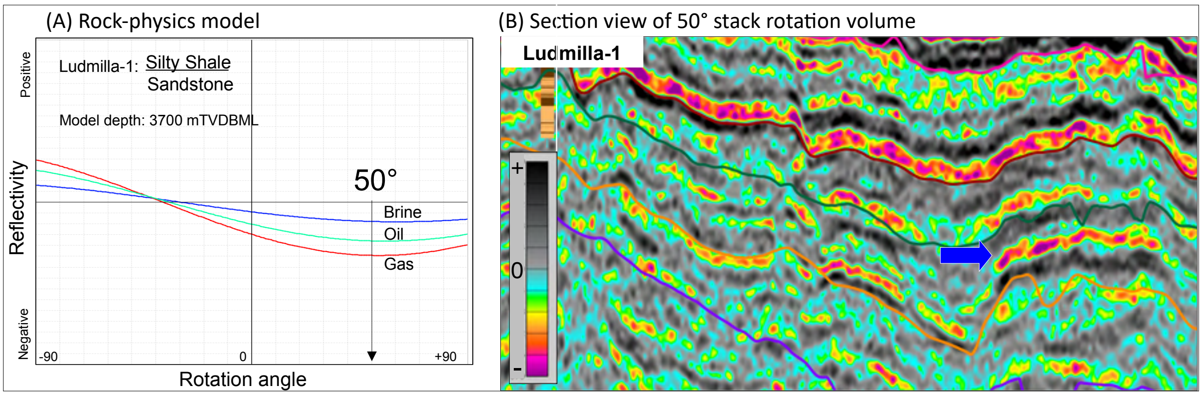

Figure 5 Rock physics calibrated interpretation across the Ludmilla-1 well.

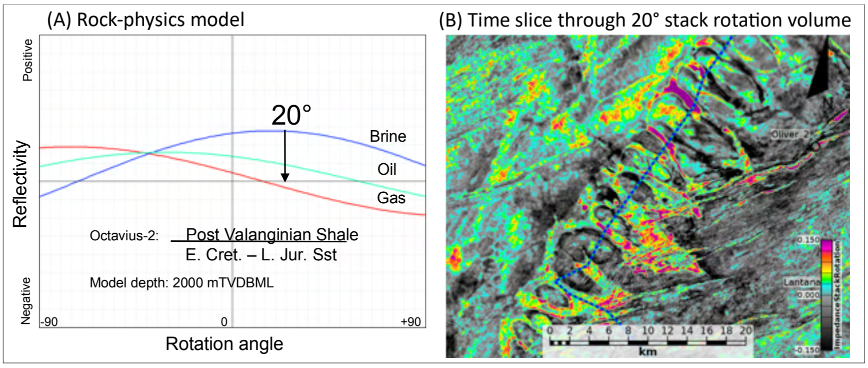

Figure 6 Rock physics model at Octavius-2 and time slice through the 20° rotation volume.

Conclusions

The geological history of the Bonaparte Basin created considerable technical challenges for QI work incorporating large lateral and vertical extents of the data. Relative simultaneous inversion was used to circumvent the complexities associated in establishing single, universally applicable models and interpretation criteria. Rock physics analysis and depth-dependent AVA stack rotations enabled interpretation of specific lithology and fluid contrasts modelled at wells to be extended into the adjacent formation using stack rotation volumes computed from the inversion products. The project met the objectives of predicting reservoir distributions and high grading prospects.

Acknowledgements

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