



## Fit for Purpose Seismic Reservoir Characterisation

Troy Thompson<sup>1</sup>, Matthew Lamont<sup>1</sup>, Carlo Bevilacqua<sup>2</sup>, Natasha Hendrick<sup>1</sup>

- 1. DownUnder GeoSolutions Pty Ltd
- 2. Apache Energy Limited

### 1. Introduction

Quantitative seismic interpretation utilises seismic amplitude behaviour in conjunction with well log data, petrophysics and rock physics to make quantitative predictions about lithology and fluid away from well locations. Seismic reservoir characterisation in general cannot follow a one-size-fits-all approach - it is critical to consider local geological insight. It is also essential to determine the appropriate quantitative interpretation (QI) workflow based on available seismic and well data, and the desired outcome. Together, this will ensure robust and reliable characterisation of the hydrocarbon reservoir is achieved.

Figure 1 illustrates a range of QI workflow options available for reconnaissance, exploration and reservoir-appraisal applications. This list is by no means exhaustive, but highlights the range of QI work that can be done to enhance seismic exploration given different project scenarios. Typically, reconnaissance workflows must be utilised when no wells are available within the seismic survey area. In this instance, amplitude variation with incident angle (AVA) attributes can be used to identify exploration targets.

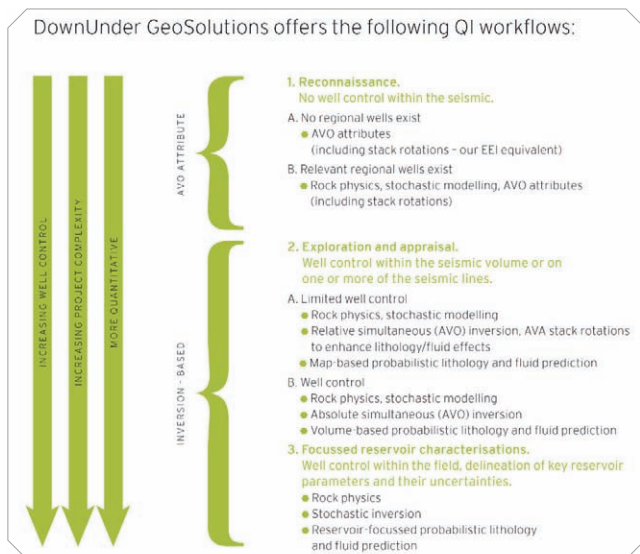


FIGURE 1 High level road map of range of QI options available for seismic reservoir characterisation.

As more well control becomes available, the QI workflows can become more sophisticated, and move from attribute-type studies to inversion-based studies. Rock physics studies should always be undertaken when well log data are available.

This paper gives an overview of the different QI workflows that are available and demonstrates how they can add value to a project, with particular emphasis on discussing a new approach to working with AVA attributes.

### 2. Rock Physics Modelling

Rock physics is the critical link between seismic data (and their derivatives) and geology. Statistical rock physics work should be undertaken to quantify the geophysical signatures of all rock and fluid types of interest any time well log data are available.

Ideally, a statistical rock physics model is constructed via a detailed petrophysical analysis that defines depth-dependent lithological end-member trends. An end member is defined as the cleanest example of a lithology, and is based on interpretation (not automated cut-offs) of available log data.

Figure 2 shows the rock physics model for two different lithologies. Once the elastic properties of end members are known, the elastic behaviour of any rock composed of different proportions of these end members can be determined.

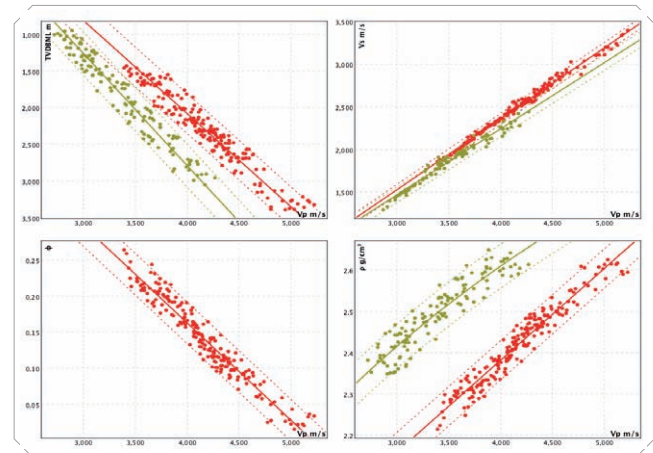
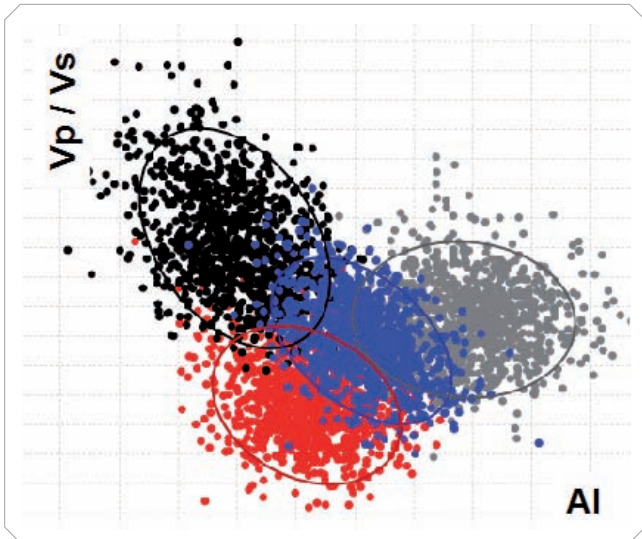


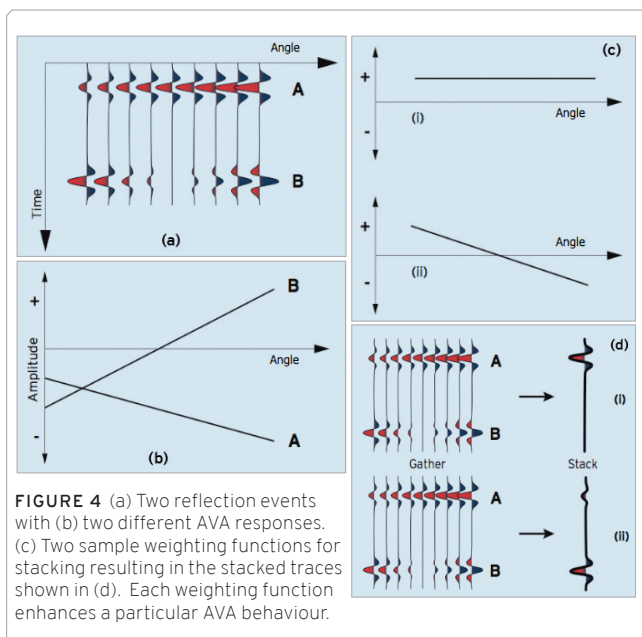
FIGURE 2 Statistical rock physics model for an end-member sand (red) and shale (green).

# Case Study



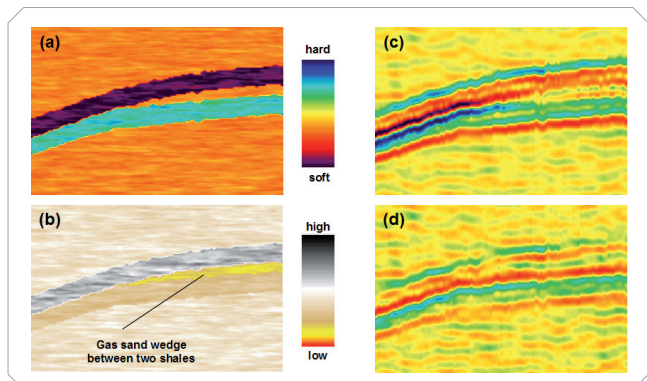
**FIGURE 3** Stochastic forward modelling results for four litho-fluid combinations at a single depth. The ellipses represent the P95 contours of the probability density functions (PDFs).

Subsequent stochastic forward modelling facilitates the understanding of how seismic responses will change as a function of key variables such as depth, fluid content, and reservoir quality. In addition to enabling the prediction of the most likely seismic response, statistical rock physics enables the prediction of the range of possible responses. Capturing this population behaviour results in a more realistic evaluation of any seismic anomalies.

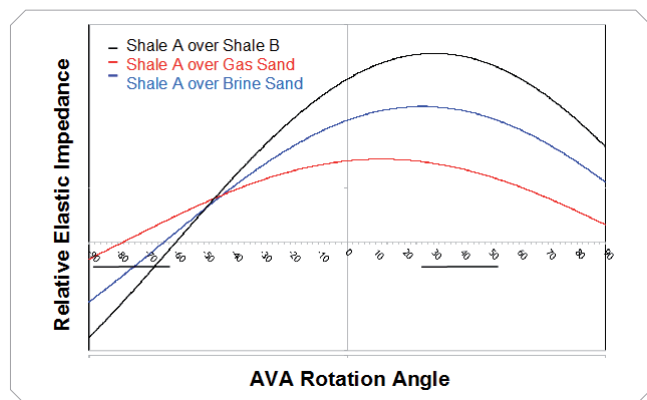


### 3. AVA Stack Rotations

AVA stack rotations are one powerful attribute that can be used to highlight potential hydrocarbon anomalies when minimal or no well log data are available within the seismic survey area. AVA stack rotations are equivalent to the well known extended elastic impedance (EEI) attribute (Whitcombe et al., 2002), and can be thought of as weighted stacks designed to enhance or suppress particular AVA responses. EEI is typically computed in intercept-gradient space, however stack rotations can also be computed using near and far (angle stack) attributes. Near and far AVA attributes have both high signal-to-noise ratios and statistical independence (Herrmann and Cambois, 2001). Figure 4 illustrates the basic concept of AVA stack rotations. In practice, a simple scan through rotation angles can be undertaken to highlight interesting anomalies.

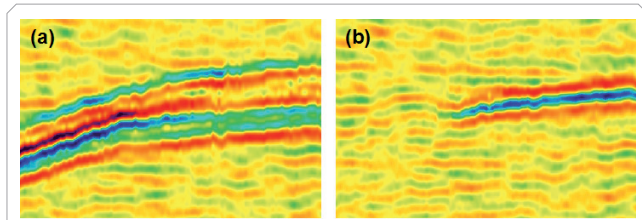


**FIGURE 5** (a) AI and (b) Vp/Vs of a synthetic earth model using properties from a real field example. (c) Near- and (d) far-angle stacks generated using a 30 Hz Ricker wavelet with -90° phase.

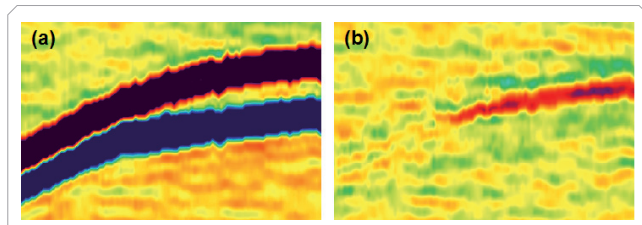


**FIGURE 6** AVA rotation angle versus relative elastic impedance for three litho-fluid interfaces. 52° is the angle at which the difference between each interface is maximised (at the same time, minimising population overlap). -62° is the angle at which gas sand has a relatively larger impedance contrast compared to the near zero impedance contrast for the brine sand and shale.

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**FIGURE 7** (a) Optimal lithology and fluid stack; (b) optimal gas sand stack.



**FIGURE 8** (a) Optimal lithology and fluid impedance; (b) optimal gas sand impedance.

With access to statistical rock physics and stochastic forward modelling results, it becomes possible to calibrate variations in AVA stack rotations to known rock and fluid properties.

Figure 5 shows a synthetic earth model and related near- and far-angle stacks. Figure 6 is a plot of the relative elastic impedance as a function of AVA rotation angle, for the three relevant litho-fluid interfaces in this example. These stochastic modelling results indicate that there is a broad range of rotation angles at which the three interfaces will have large and different relative impedance contrasts ( $\sim -20^\circ$  to  $90^\circ$ ).

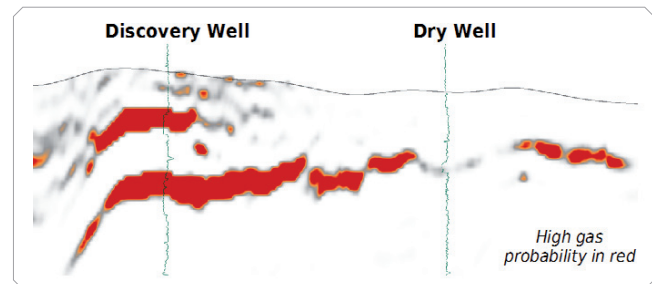
Figure 7(a) shows the optimal fluid and lithology stack, using an AVA rotation angle of  $52^\circ$ . Note however, that generating an AVA rotation stack at this angle, while maximising fluid and lithology responses, does not help differentiate between the effects of fluids and lithology. An AVA rotation angle of  $-62^\circ$  will produce a stack where the shale and brine sand impedance contrasts are almost zero compared to a relatively larger gas sand impedance contrast. Figure 7(b) shows this optimal fluid stack – the gas effects are very clearly seen in this AVA rotation stack.

#### 4. Adding Value with Seismic Inversion

Seismic inversion-based QI workflows are possible with access to well log data in the seismic survey area. Seismic-to-well ties can be made, and relative AVA inversion products can be generated. AVA stack rotation can be applied following simultaneous relative inversion – this adds value through largely removing the effect of the seismic wavelet.

Figure 8 shows the same AVA stack rotations as seen in Figure 7, but applied after simultaneous relative inversion. The individual sand and shale units are now obvious in Figure 8(a), and the gas-saturated sand wedge can be seen in Figure 8(b). Note that, it is important to appreciate that stack rotation angles are depth dependent. For example, AVA responses can change with depth as a function of different compaction gradients between sands and shales. It is necessary to take this into consideration when doing reservoir characterisation over large time windows.

Where well control is sufficient, it becomes possible to construct low-frequency models and generate absolute rock property derivatives. These inverted rock properties can then be integrated with depth-dependent, stochastic rock physics models using a Bayesian classification scheme to make quantitative predictions about lithology and fluids away from well locations (Lamont, et al., 2008).



**FIGURE 9** Gas-sand probability volume derived from simultaneous absolute inversion and prediction of fluids using the depth-dependent, stochastic rock physics model and a Bayesian classification scheme.

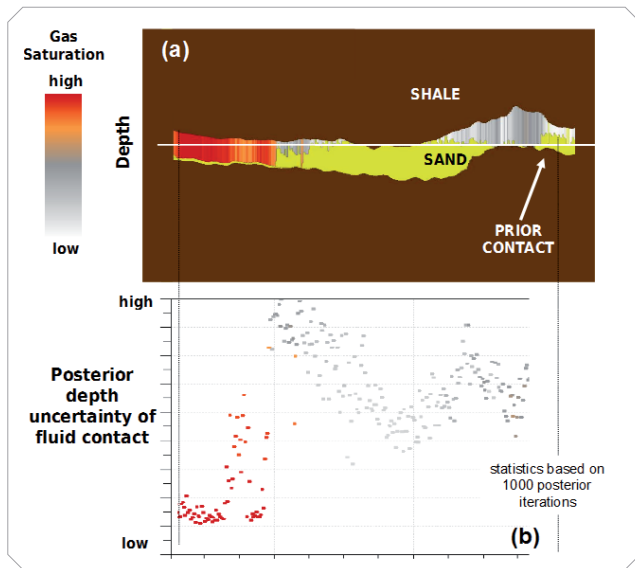
Figure 9 shows a gas-sand probability volume derived using this methodology. In this example, seismic inversion added significant value to the field as a result of the QI results providing confidence to drill down-dip of a dry hole to make a gas discovery. This was the first of around a dozen successful new discovery and appraisal wells drilled on this seismic inversion product. When multiple wells have penetrated a known reservoir, more focused reservoir characterisation is possible, and stochastic inversion can be utilised to understand key characteristics and uncertainties in important reservoir parameters such as net sand, porosity, fluid saturation etc (Glinsky et al., 2005).

Figure 10 shows an example of how stochastic inversion was used to add value to a project by clarifying why a gas-sand probability volume was showing a GWC below the known fluid contact depth (derived via drilling).

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Model-based stochastic inversion was used to specifically invert for the fluid contact depth. The prior model was built with the known contact depth, however uncertainty was placed on the contact to allow the inversion to move the contact if required to fit the seismic data.



**FIGURE 10** (a) Most likely posterior reservoir model derived via stochastic inversion, showing gas saturated sand; and (b) posterior uncertainty in the depth of the fluid contact.

The most likely post inversion model is shown in Figure 10(a) - the inversion did move the contact deeper to fit the seismic observations. Figure 10(b) shows the posterior uncertainty of the contact is minimal where the contact was moved deeper. Subsequent depth conversion work demonstrated that both the simultaneous inversion and stochastic inversion were correct - there was gas in the sand under question; but an erroneous depth conversion model was pushing the anomaly below the physical fluid contact.

## 5. Summary

The most effective integrated QI studies for reservoir delineation and characterisation are fit-for-purpose. Appropriate QI workflows should be designed on a case-by-case basis, according to the geological and geophysical information that is available.

Statistical rock physics models derived from well log data are important for understanding seismic responses and their uncertainty, and should always be derived as part of a QI workflow whenever log data are available.

AVA attributes are a powerful tool for gaining insight into the hydrocarbon reservoir even when wells are not present in the seismic survey area. A modified approach to AVA stack rotations presented here works in the near versus far space, and can take advantage of any statistical rock physics information to optimise the discrimination between fluid- and lithology-related seismic amplitude anomalies.

When well log data are available, seismic inversion can be performed. Relative or absolute inversion products can be generated, dependent on well control, and can be integrated with rock physics models to predict lithology and fluids away from well locations.

## 6. References

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