ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15–18 February 2015 Perth, Western Australia

Rock physics and quantitative interpretation using Lambda-Mu-Rho in the Shipwreck Trough, Otway Basin

David Close
Origin Energy
Brisbane, Australia
david.close@originenergy.com.au

Randall Taylor
Origin Energy
Brisbane Australia
randall.taylor@originenergy.com.au

Sebastian Nixon
Origin Energy
Brisbane Australia
sebastian.nixon@originenergy.com.au

SUMMARY

A rock physics study and AVO modelling study has been completed to assist in the interpretation of seismic amplitude and AVO anomalies in the Shipwreck Trough of the offshore Otway Basin of southeastern Australia. Elastic log data, core data (both full and sidewall) and associated thin section analysis of composition and texture were available on a number of wells; and these data are important in calibrating proposed rock physics models that suggest incorporating cement is critical to understanding anomalies in seismic inversion volumes and measured log data.

Lithoprobability volumes based on conventional interpretation paradigms, such as low Vp:Vs values indicating gas presence, that do not incorporate an understanding of the rock physics lead to biased interpretations. Ratios in particular can be misleading as there is ambiguity about whether an anomalous ratio is driven by the numerator or denominator. As a classic gas indicator low Vp:Vs values are interpreted to be driven by a decrease in Vp associated with gas replacing brine in a rock. Using Lamé Impedance terms $\lambda\rho$ and $\mu\rho$, however, provides an alternative interpretation template that does not utilise ratios and can improve insight into rock properties. As in this case study, using LMR can be an important tool when shear velocity has increased relative to the compressional velocity irrespective of any pore-fluid change.

We propose that due to quartz cement in the reservoir rocks of the Shipwreck Trough both gas and brine sandstones exhibit very low Vp:Vs, creating substantial challenges to the use of a standard rock physics template. In LMR space, however, the low Vp:Vs data points are clearly characterized by a high shear rigidity – an important point to recognize and incorporate into AVO interpretation workflows.

Key words: QI, LMR, Rock Physics, Otway Basin.

INTRODUCTION

A rock physics study for the Shipwreck Trough area was undertaken to improve the understanding of amplitude anomalies in 3D seismic data and their relationship to observed log responses. The distributions of downhole measured data in a standard rock physics template (i.e. Vp:Vs vs acoustic impedance) from gas discoveries and dry holes (Figure 1) overlap sufficiently to create ambiguity about traditional interpretation paradigms; such as low Vp:Vs ratios indicating the presence of gas. The distribution overlap implies that the anomalously low Vp:Vs data measured in these wells is not purely a function of the pore-fluid.

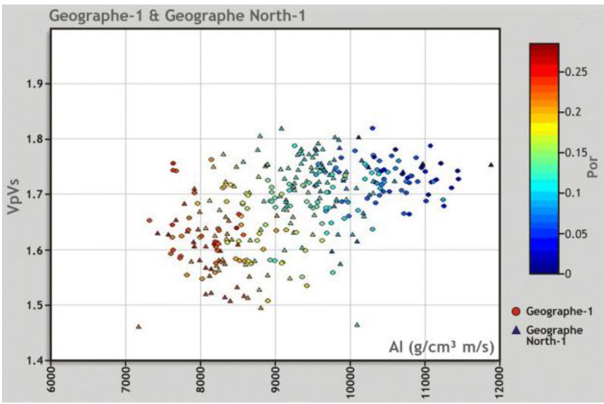

Figure 1. Data from the gas saturated Flaxman Formation at Geographe-1 and the brine saturated Flaxman Formation at Geographe North-1.

The Shipwreck Trough (Figure 2) is a structurally complex sub-basin within the offshore Otway Basin. The Trough formed during the Late Cretaceous and Early Tertiary during Gondwanan rifting between southern Australia and the East Antarctic craton. A number of gas discoveries have been made in the Shipwreck Trough since the early 1990s (e.g. Cliff et al., 2004) and a number of companies retain current exploration licenses.

Gas discoveries in the Shipwreck Trough have been characterised by strong seismic amplitude anomalies in some instances, and by a lack thereof in other instances. Seismic anomalies and AVO attributes have been used to identify a number of leads along strike from successful gas discoveries. However, many of these seismic amplitude supported leads lack structural conformance and/or flat-spot development. The absence of such direct hydrocarbon indicators could be a function of geological environment, however, it could equally indicate there are other causes of such anomalies beyond the obvious substitution of gas for brine in prospective structural closures.

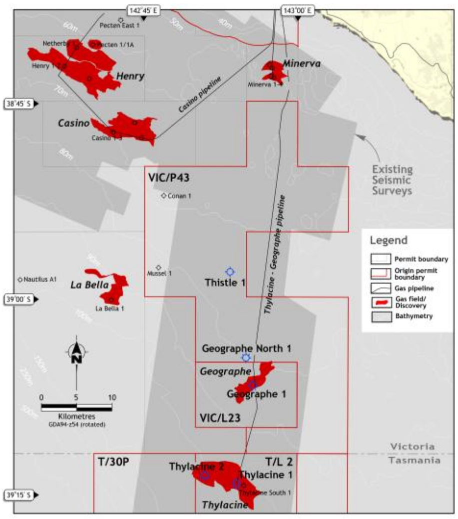

Figure 2. Location map for the Shipwreck Trough in the offshore Otway Basin.

METHOD AND RESULTS

Multiple stratigraphic intervals within the Shipwreck Trough comprise reservoir quality rocks. Reservoirs occur in the deltaic deposits and distributary channels of the Late Cretaceous Waarre Formation (Lower Turonian), Flaxman Formation (Upper Turonian), and the Thylacine Sandstone Member of the Belfast Formation (Coniacian). The Belfast Formation also provides the regional top seal for gas fields in the Shipwreck Trough. Log data are available from a number of wells through reservoir intervals in both gas discoveries (e.g. Minerva, Thylacine, Geographe) and dry holes (e.g. Geographe North). Core data and associated analyses are also available from a number of wells in the Shipwreck Trough and the greater Otway Basin.

Where compressional and shear sonic velocity log data are available, in addition to density data, elastic logs have been created for cross plotting. In addition to common elastic properties such as Poisson's Ratio, Vp:Vs and acoustic impedance, Lambda-Mu-Rho (LMR; Goodway et al., 1997) logs have also been computed.

Goodway et al. (1997) introduced the LMR method, whereby velocity and impedance are characterized in terms of the Lamé parameters of incompressibility (Lambda – λ) and rigidity (Mu – μ). The utility of these parameters is extended by creating Lamé impedances, Lambda-Rho (λρ) and Mu-Rho (μρ), which are defined as:

$$\lambda\rho = AI^2 - 2SI^2$$

$$\mu\rho = SI^2$$

Where, AI = acoustic impedance and SI = shear impedance.

λ is a function of both compressional and shear properties of a material, whereas μ is purely a function of shear properties. As μ is dependent on shear properties it is largely fluid independent. This brings advantages when crossplotting in LMR space as one axis remains fluid independent, unlike in conventional domains such as Vp:Vs vs AI where both axes are impacted by pore fluids.

To investigate the causes of the low Vp:Vs data highlighted in Figure 1, data from gas and brine saturated wells were cross plotted and compared with Rock Physics Model (RPM) templates based on Effective Media "Contact Models" (Avseth et al., 2005). RPM templates provide a means of illustrating the impact on elastic properties of varying mineral ratios, pore fluids and/or grain contact relationships or rock texture.

Data from Tertiary and very Late Cretaceous intervals in the Shipwreck Trough can be characterized by a relatively simple RPM template based on the Friable Sand model of Avseth et al. (2005) and presented in the LMR domain (Figure 3), that in this instance comprises two mineral inputs (quartz and kaolinite) in varying ratios. The data in Figure 3 clearly conform very closely to the trend lines modelled using this RPM and this mineral combination. This is in no way a unique solution, but rather a demonstration of a reasonable solution that fits the data available with relatively few assumptions and a simple mineralogical composition.

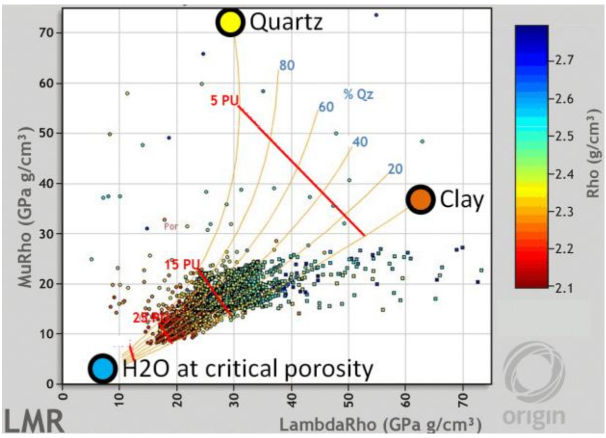

Figure 3. RPM template for a Friable Sand model incorporating varying ratios of quartz and kaolinite with data from the Late Cretaceous Paaratte Formation in the Thylacine-1 well.

Plotting data from the Flaxman Formation (Figure 4) against the Friable Sand RPM template illustrates that this template is not adequate for the deeper, reservoir rocks in the Shipwreck Trough. The data shown in Figure 4a are from the brine saturated Geographe North-1 well. As there is no gas in this well, the shift towards low λρ (or high μρ) is not a function of gas – although the apparent shift in LMR space towards low λρ is characteristic of gas saturated rocks (Goodway et al., 1997). The data from the offset Geogrpahe-1 well (Figure 4b), which encountered a gas column of over 200 m and is gas saturated in the Flaxman Formation, plot in an almost identical space to the Geographe North-1 data. This pattern is repeated in the underlying Waarre Formation, which similarly to the Flaxman Formation is an excellent quality sandstone reservoir with porosities of up to 25%.

The consistency of data from Flaxman and Waarre Formations, in both gas discovery wells and non-commercial brine wells, suggests a geological basis beyond a simple pore-fluid change. This interpretation is far clearer in the LMR domain than the standard rock physics template domain (i.e. VpVs vs AI).

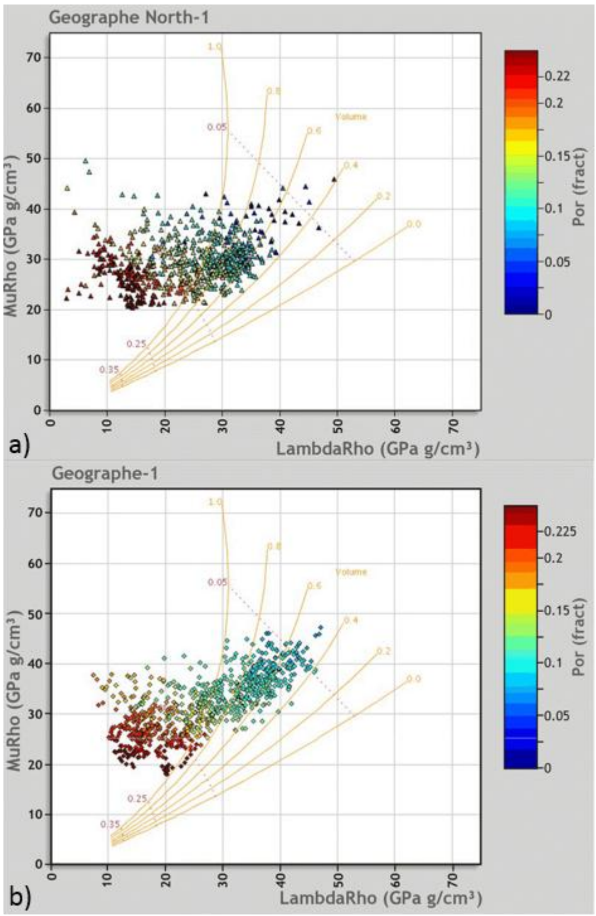

Figure 4. Data from the Flaxman Formation in the a) brine saturated Geographe North-1 well and b) the gas saturated Geographe-1 well, plot outside of the bounds of the Friable Sand RPM template.

We are fortunate to benefit from abundant geological data from full core and sidewall core in this area, which provide critical textural information about the reservoir rocks. Core photomicrographs illustrate that quartz overgrowths and quartz grain suturing are common in the reservoir rocks of both Geographe-1 and Thylacine-1 (Figure 5). Quartz overgrowths are interpreted to post-date all other major diagenetic events based on the relationships of the various diagenetic minerals. This timing is significant as it allows stiff quartz to overgrow softer clay minerals, and this is the stiffest way to mix quartz and clay (at least conceptually), as there is the potential for the quartz to encase authigenic clays (as shown in Figure 5b) – this scenario is similar to the upper bound of Hashin-Shtrikman mixing.

This observation, based on geological data acquired from multiple wells, suggests that a RPM that incorporates cement is likely more appropriate for modelling data from the Shipwreck Trough than the simple friable sand model discussed above. The Contact Cement and Constant Cement RPMs describe the velocity-porosity behaviour of Contact Models that are influenced by cement (Avseth et al., 2005). In these models cement increases the stiffness of the rock with relatively little reduction in porosity. Both models are geologically defensible as there is abundant evidence from thin section microphotography that the suturing of quartz grains occurs along crack like pores between grains and that quartz overgrowths do not occlude substantial porosity but do increase the number of contact points between quartz grains. Figure 6 illustrates the relationship between the Friable Sand RPM considered previously and both the Constant Cement and Contact Cement RPMs. The Voight Upper Bound, which is a theoretical maximum stiffness, is also plotted and demonstrates that the Contact Cement RPM is close to being the stiffest way of combining these minerals.

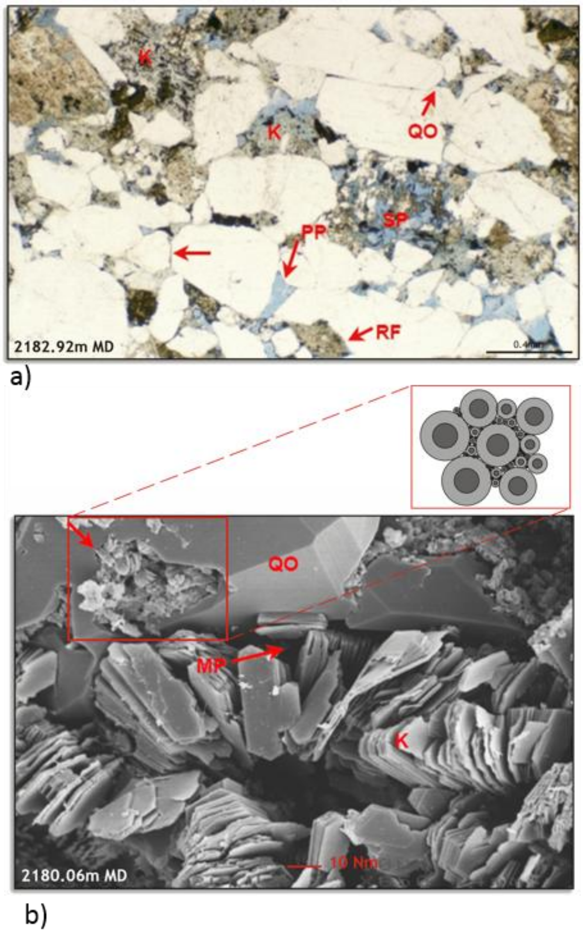

Figure 5. Images from core over the Flaxman Formation in the Thylacine-1 well. a) A photomicrograph of a thin-section that shows the extent of quartz overgrowth (QO) cement and quartz grain suturing (red arrows); PP = primary porosity, SP = secondary K-feldspar dissolution porosity, K = kaolinite, RF = rock fragment; and b) A Scanning Electron Microscope (SEM) image that shows authigenic kaolinite encased by a later quartz overgrowth.

Plotting data from the Upper Waarre Formation in Geographe-1 and Geographe North-1 (where the Upper Waarre is brine saturated in each of these wells) with the cement inclusive RPMs (Figure 6) illustrates that these data consistently plot between the Friable Sand and Constant Cement RPMs. The Constant Cement RPM is considered the most appropriate model for the quartz rich sandstones of the Flaxman and Upper Waarre formation. The important result of this interpretation is that very low Vp:Vs values can be modelled without the introduction of gas, rather these low values simply represent the stiffening effects of cement. The validity of this hypothesis can be tested, but not proven, via forward modelling.

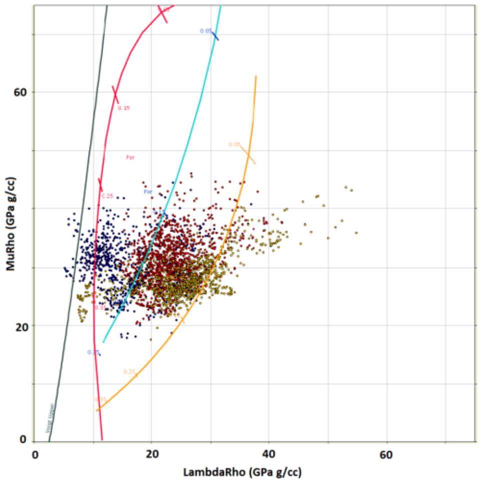

Figure 6. A Comparison of different cement influenced Contact Model RPMs for the same mineral mixture (80% quartz and 20% kaolinite). Orange = Friable Sand Model, Cyan = Constant Cement Model, Red = Contact Cement Model, Black = Voight Upper Bound; and data from the Upper Waarre Sandstones in Geographe-1 (red), Geographe North-1 (blue) and Thylacine-1 (orange) wells.

Forward modelling takes basic mineralogical inputs, such as a shale volume (VSh) curve, along with the elastic moduli of the minerals, and porosity and saturation estimates and uses a selected RPM to predict elastic properties such as Vp, Vs and density. This method is relatively unbiased, particularly if the shale volume curve is created from data that are independently measured and not generally used to constrain any other parts of the RPM workflow (e.g. gamma ray log data).

In Figure 7 a comparison of forward modelled curves, using both the Friable Sand RPM and the Constant Cement RPM, is presented. The inputs to both models are identical, with the exception of the RPM selected. This is a clear graphical illustration of the validity of the Constant Cement RPM, which accurately predicts Vp and Vs (and, therefore, of course K and Mu) through the Flaxman and Waarre Formations. The Vp and Vs estimates, however, for the Friable Sand RPM are poor, typically underpredicting the velocity magnitude substantially.

CONCLUSIONS

Reservoir sandstones in the Shipwreck Trough that are substantially stiffened by quartz cement (e.g. Flaxman and Waarre Formations) are relatively unaffected by pore fluid changes and exhibit low Vp:Vs in the absence of gas due to increases in shear impedance associated with quartz cement. In contrast the younger, less quartz rich and less cemented Thylacine Member remains sensitive to pore fluid changes. Accordingly, seismic amplitude and AVO anomalies are likely to be subtle or absent in the deeper reservoirs, whereas they should remain an important part of the exploration toolkit for shallower and/or younger targets in less cemented strata.

ACKNOWLEDGMENTS

The authors acknowledge Origin Energy and the JV partners in Permits VIC/P43 and T/30P for allowing the publication of this abstract; and also thank the many colleagues that have contributed to this work. Thin section analyses and photomicrography by Julian Baker (Geosolutions).

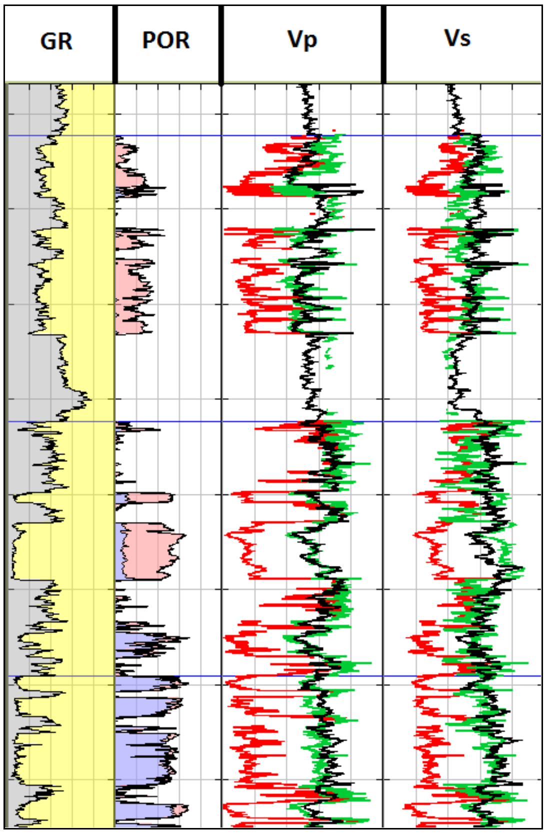

Figure 7. RPM forward modelling using porosity, saturation, shale volume and mineral moduli as inputs for a Friable Sand RPM (red curves) and a Constant Cement RPM (green curves) that incorporates 9% cement. Measured curves are in black. Depth increments = 50 m.

REFERENCES

Avseth, P., Mukerji, T. and Mavko, G., 2005, Quantitative Seismic Interpretation: Applying Rock Physics Tools to Reduce Interpretation Risk: Cambridge University Press.

Goodway, W., Chen, T. and Downton, J., 1997, Improved AVO fluid detection and lithology discrimination using Lamé parameters; lr, mr and l/m fluid stack from P and S inversions: CSEG National Convention Expanded Abstracts, 148-151.