Application of Rock Physics to an Exploration Play: A Case Study from the Brazeau River 3D

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Introduction

The ultimate goal of any Rock Physics analysis is to gain insights into the physical properties of a reservoir. These can be bulk properties such as lithology, porosity, and permeability, or dynamic properties like fluid content or pressure. A geophysical Rock Physics analysis makes use of the measured elastic properties from seismic data to generate attributes that yield information about the reservoir rocks. There are, however, several other sources of Rock Physics information that can and should be used to assist the analyst's understanding of the study area. These other sources can be petrophysical, geophysical, and/or geological in nature. Examples include wireline logs, mudlogs, core, DST/RFT pressure and fluid analyses, VSP, and checkshot surveys. Ultimately, the more tools we use to assist in our understanding of the reservoir, the more we reduce the risk associated with an exploration/exploitation undertaking. This presentation uses a case study from the Brazeau River 3D to illustrate how the integration of a petrophysical analysis not only augmented, but actually directed the course of a successful geophysical analysis.

Model For An Ideal Petrophysical Workflow

Performing a petrophysical analysis prior to a geophysical analysis has many benefits. From wells logs we can a) determine which seismic attribute(s) are most diagnostic (sensitive) to solving our project goals; b) predict, and ultimately verify, expected seismic responses (i.e. calibration); c) perform forward modeling (e.g. Gassmann fluid substitutions); d) provide quality control by editing, reconstructing, and/or estimating well logs for seismic inversions and phase analysis; and e) understand the regional geology to design the optimum geophysical analysis workflow.

Study Area & Goals

The study area is a subset of the Brazeau River 3D Seismic Survey (Figure 1). For the Rock Physics Analysis two targets, one clastic and one carbonate, were identified. The clastic target was the Viking sand interval with the project goal to identify the fluid content. The carbonate target was the Nisku formation where lithology differentiation would be the key to success. Good well control was available in the area with wells penetrating both the Viking and Nisku intervals.

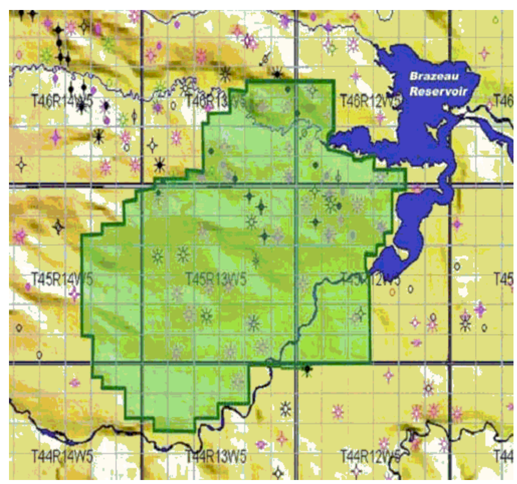

Figure 1: Brazeau River 3D

Case Study Workflow

The petrophysical analysis workflow consisted of: a) log edits and reconstructs as necessary; b) standard formation evaluation; c) lithology driven shear estimation for missing shear sonics based on local Vp/Vs trends for sand, shale, and carbonates; d) calculation of AVO and Rock Property attributes; and e) attribute interpretation. The petrophysical "feasibility" study was instrumental in providing a roadmap to focus the geophysical study. The geophysical work then proceeded with the a) extraction of the pre-stack information through various AVO methodologies; b) inversion of these AVO products to convert the reflectivity attributes into layer properties; c) calculation of Lamé parameters (LMR™) attributes; d) cross-plotting and interpretation, and e) calibration/comparison with the petrophysical results.

Petrophysical Analysis – Viking

From standard formation evaluation, the Viking interval is a silty sand package (often conglomeratic at the base) with an overall thickness of approximately 15 meters and reservoir-quality sand thicknesses often much less. We used blocked compressional velocity (Vp), shear velocity (Vs), and density logs over the target sand to create half-space, or interface models, to predict the expected seismic response. These half-space models show how the seismic amplitudes behave as a function of angle of incidence (**A**mplitude **V**ersus **O**ffset) based upon the log data (Figure 2). Introducing oil and gas into the pore space using Gassmann fluid substitution, the AVO response curves predict a subtle class I anomaly for oil-filled sand (positive intercept, negative gradient), and a class II anomaly with phase reversal for the gas case (near-zero intercept, negative gradient).

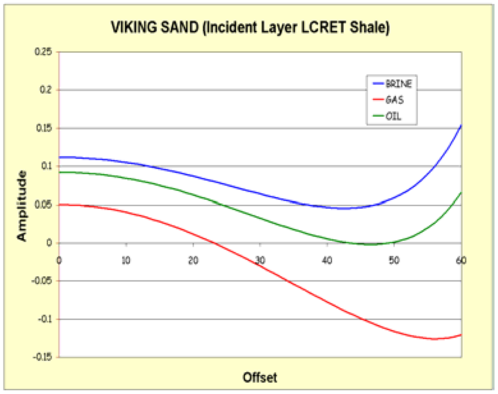

Figure 2: Interface Model

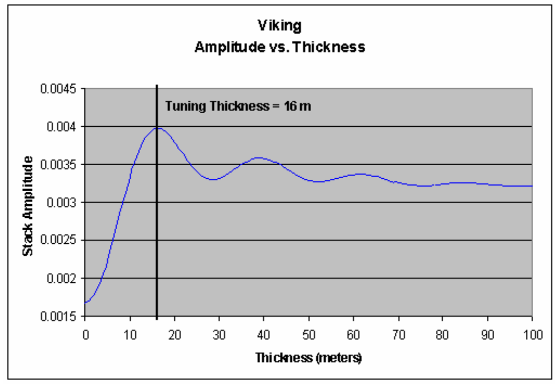

Figure 3: Tuning Curve for Viking

The next step was to move from the log-predicted offset response to an offset synthetic with the introduction of a seismic wavelet. For synthetic modeling, we used a wavelet extracted from the seismic data (P-wave reflectivity volume). The AVO response curve from the offset synthetic showed no decrease in amplitude with offset (angle). Since both interface curves should produce the same result, and given that the only change was the introduction of a wavelet, it is probable that we were dealing with a resolution issue. Figure 3 shows a tuning curve (Kallweit and Woods, 1982) for the Viking interval suggesting that for an interval of 16meters or less, we cannot trust the amplitudes to fully preserve the AVO information. Since our Viking interval is only 15m (gross thickness), the conclusion of the combined petrophysical study and geophysical modeling is that the likelihood of successfully applying AVO to the Viking sand for hydrocarbon discrimination may be limited. This is not necessarily a negative result. Valuable resources - both time and money - can be saved by performing the petrophysical analysis upfront. Also, the tuning curve demonstrates that below tuning thickness, the stack amplitude behaves linearly with thickness. As a result, we may be able to use the traditionally processed stacked seismic data for mapping the thickness of the Viking sand in the study area.

Geophysical Analysis – Viking

Based on the previous analyses, our expectations were that a geophysical AVO analysis would be largely unsuccessful because the limited bandpass frequency of the data is below resolution limits. It should be noted, however, that seismic resolvability and seismic detectability are not synonymous. Although the tuning curve predicts the limits of fully resolving the Viking sand, it says little regarding the thickness necessary to impact the seismic response and therefore, does not rule out seismic detection. For this reason and for completeness of the case study, a geophysical analysis was nevertheless preformed over the Viking interval. The results were consistent with the petrophysical/modeling predictions and we were unable to determine fluid content within the Viking formation, even within known gas producing wells.

Petrophysical Analysis – Nisku

A major problem with searching for porous dolomite in the Nisku formation is that the stacked seismic response for porous dolomites and shales are similar. The log data also illustrates this mutual decrease in acoustic impedance (AI), as seen in Figure 4. Hydrocarbon effects on the seismic amplitudes, which typically help distinguish reservoir from non-reservoir rocks, are very subtle in this hard rock environment. This is the classic carbonate problem. However, successful producing gas wells have been drilled in this area because of the good regional correlation between porosity development and the presence of hydrocarbons. Figure 5 shows the AVO crossplot of intercept vs. gradient computed from log data. The blue polygon isolates points of good porosity in the well logs while the red polygons highlight shales (refer to color track in Figure 4). It is obvious from the intercept attribute, or traditional processed stack, no separation between the two polygons/lithologies can be seen, whereas in the gradient attribute there is some differentiation. However, there remained some ambiguity discerning the mid range dolomite porosities from shales. By examining additional Rock Physics relationships, it was found that the LambdaRho vs. MuRho crossplot (Figure 6) provided superior discrimination, with discrete populations of shale and porous dolomite isolated in crossplot space.

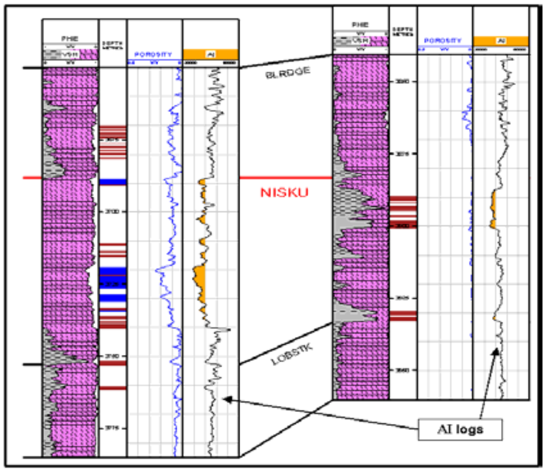

Figure 4: Porosity vs. Shale

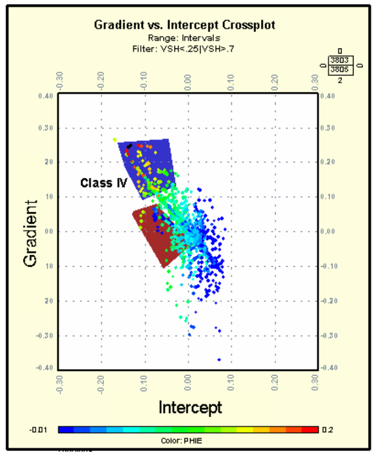

Figure 5: Intercept vs. Gradient

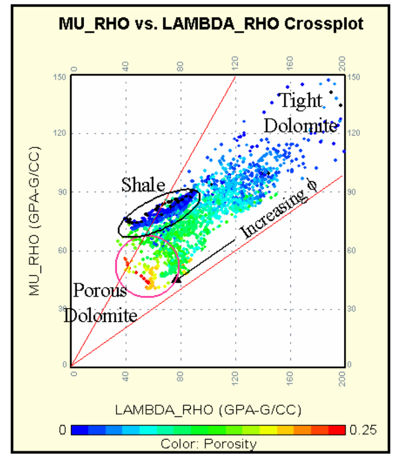

Figure 6: $\lambda\rho$ vs. $\mu\rho$

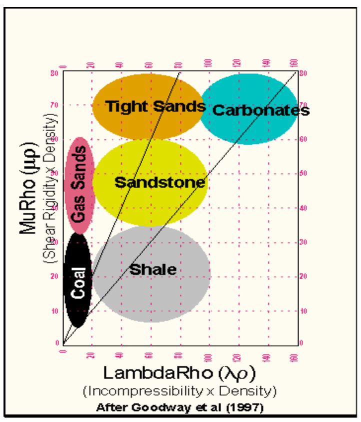

Figure 7: $\lambda\rho$ vs. $\mu\rho$

Another important observation was made from this crossplot analysis. Typically we would expect shales to have lower rigidity than carbonates as shown in Figure 7 (after Goodway et al., 1997), but in this region, the shales are so highly compacted and calcareous that they are, in fact, more rigid than dolomites. This underscores the importance of doing a petrophysical study before undertaking the interpretation of geophysical attributes. The petrophysical study allowed us to identify the geophysical attributes that could be used to achieve our project goals, and to modify our interpretation expectations to fit the local environment. AVO response curves from half-space models and from offset synthetics for the Nisku target showed class IV responses for both porous dolomite and shales, with the shales having a slightly smaller gradient (Figure 5). Because the thickness of the Nisku formation was above the threshold for resolution (>24 m) no tuning was expected or observed.

Finally, the petrophysical study revealed some anomalously high Vp/Vs data points in the log data that appeared to correspond to the porous dolomite (Figure 8). Elevated Vp/Vs ratios may indicate some form of anisotropy in the rock fabric – perhaps due to development of secondary porosity (e.g. fractures or aligned vugs). Much of the current research surrounding the detection of fractures using seismic data is based upon the theory that shear velocities are attenuated more than compressional velocities (thus giving higher Vp/Vs) through fractured zones (Ruger, 1996; Gray et al., 2003; Lynn et al. 1996). This hypothesis is supported by a direct correlation between high Vp/Vs and computed secondary porosity in the zone. Classic formation evaluation techniques use the difference between density (or neutron-density) porosity (Figure 8; blue curve) and sonic porosity (Figure 8; red curve) as an indicator for presence of secondary porosity. The geophysical analysis should explore this observation by performing an Amplitude Versus offset and Azimuth (AVAZ) analysis to search for evidence of fractures.

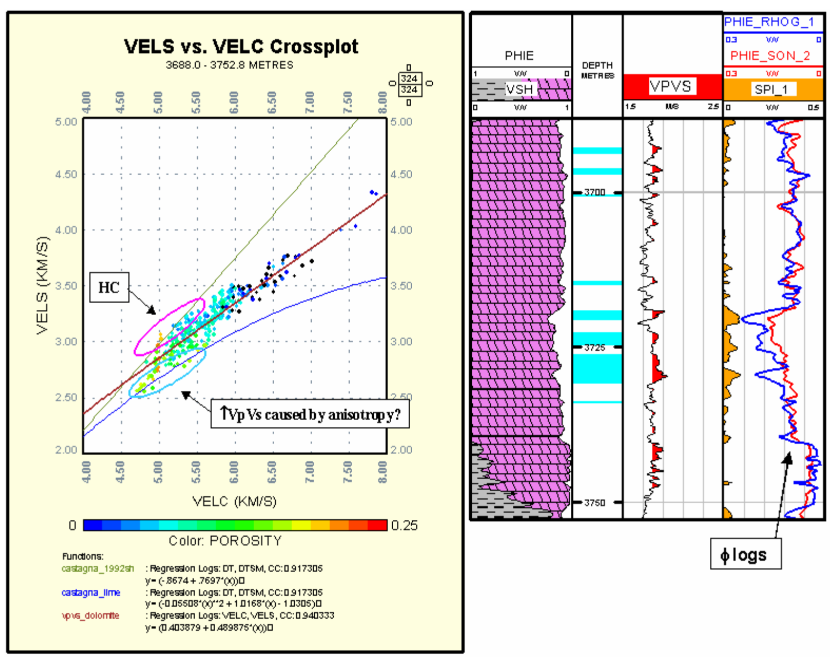

Figure 8: Secondary Porosity Indicator

Geophysical Analysis – Nisku

Equipped with a better understanding of the regional geology and rock physics characteristics in the Nisku, we were able to focus our geophysical workflow and interpretation. Figure 9 shows the seismic stack response at a time slice in the Nisku formation. The question posed is: Is the amplitude anomaly a shale plug or porous dolomite (perhaps reef)? AVO attribute extraction using the Gidlow et al. (1992) methodology was performed to generate P-wave and S-wave Reflectivities (Rp & Rs). The crossploting of these attributes, shown in figure 10, highlighted the same class IV AVO amplitudes seen in the petrophysical analysis[1].

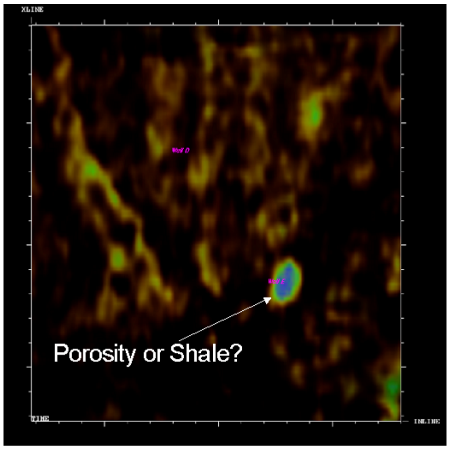

Figure 9: Stack Time slice

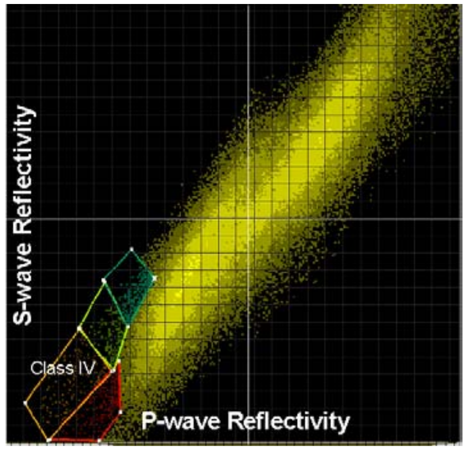

Figure 10: Rp vs. Rs

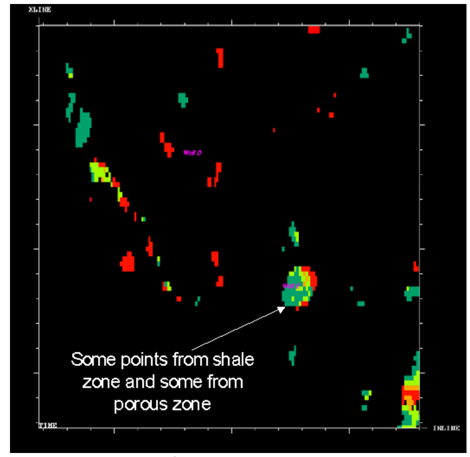

Figure 11: Crossplot Polygons

The class IV polygon data points highlight the amplitude anomaly, shown in figure 11, but there was still some overlap present, as predicted by the petrophysical study. The Rp and Rs attributes were then inverted into impedances and rock property calculations were used to generate LMR™ volumes. In figure 12, the petrophysically-guided polygons, which discriminate shales and dolomites, were applied to the seismic data. The resulting populations were mapped onto the time slice in Figure 13. The red polygon, associated with porous dolomite now indicates that the amplitude anomaly seen in the seismic stack consists of porous dolomite, not shale. There is also some evidence of dolomitization along the fault to the northwest. Following up on our hypothesis that fractures may exist in areas of porous dolomite, an AVAZ analysis was performed. The variation in azimuthal AVO gradient did indeed indicate regional anisotropy, likely fractures, corresponding to the Nisku amplitude anomaly. Figure 14 shows areas of high fracture density and may highlight other potential targets. Knowledge of fracture distribution can be critical for successful drilling and production since fractures increase reservoir permeability.

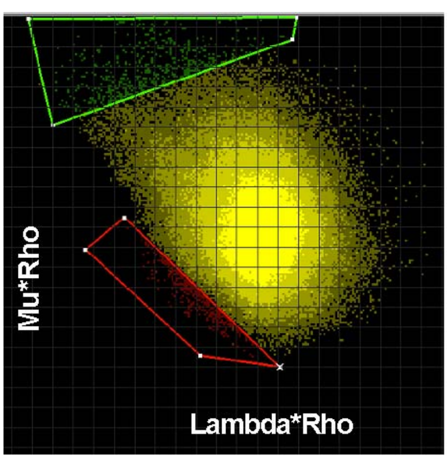

Figure 12: $\lambda\rho$ vs. $\mu\rho$

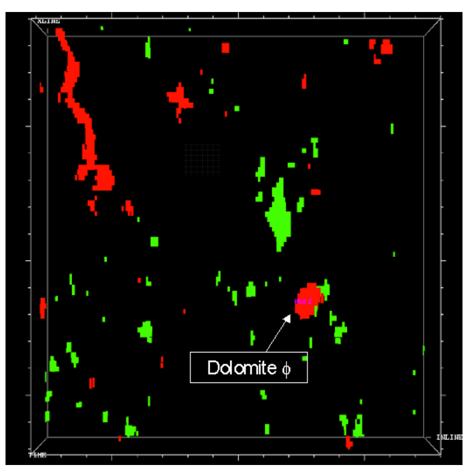

Figure 13: Crossplot Polygons

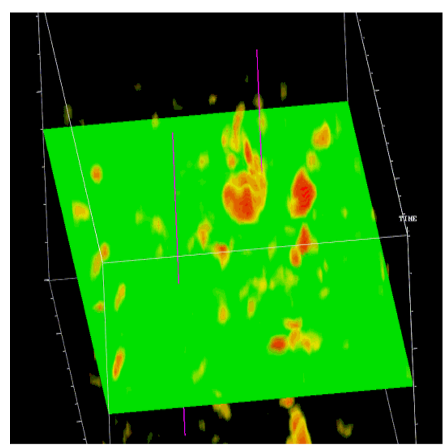

Figure 14: Nisku Fracture Swarms

[1] The petrophysical analysis used the Gradient attribute instead of the S-Wave attribute in the crossplot analysis. A rotation around the x-axis {G ~ (-Rs)} equate the two.

Conclusions

All available data should be used to gain understanding and reduce risk when carrying out a geophysical prospect evaluation. Making full use of wireline logs and available core data is particularly important and beneficial. A good petrophysical analysis – one which incorporates formation evaluation as well as rock properties – is critical for interpreting geophysical attributes and calibrating them to insitu geology. For the Viking, it saved us valuable economic resources by showing AVO was not likely to work. Results from our petrophysical work in the Nisku helped outline the best workflow for Nisku lithology identification, saving valuable time. Also, we were able to adjust our interpretations to reflect the local geologic conditions and identify a dolomite reef which has been tested and is a producing gas well.

Acknowledgements

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