Geology-Guided Classification of an Alberta Montney Reservoir

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Summary

Variations in geological properties, such as mineralogy and porosity, can have a significant impact on the completions and production of the low-porosity Montney. In this presentation we look at characterizing these geological changes using seismic data. The impact of geological variations on geophysical properties is first investigated to establish confident relationships. Elastic properties are then estimated from the seismic data using AVO inversion. These calculated properties are then classified based on the previously established relationships. Finally, additional information, useful for the geomechanical characterization of the reservoir, is added to the interpretation.

Introduction

The Montney is an unconventional reservoir that spans across the border of Alberta and British Columbia. There is variation in the geological properties not only over this large range, but also on a more localized scale. It is the characterization of these variations that is of significant importance for field development in the Montney.

Our analysis follows three steps to interpret geological meaning from the seismic data, specifically from calculated elastic properties:

1) In the first step, we investigate to see if geophysical attributes can be shown to relate to known geological changes. Specifically, we use well data and rock-physics modelling to investigate the effect of property variations, such as clay content, on the observed rock. The investigation of these variations and the sensitivity of different elastic properties helps to build confidence in the characterization process.

2) Once we establish how to best detect geological changes, the second step is to obtain the best estimate of the geophysical properties through prestack simultaneous inversion of the seismic data. We then use these elastic properties to classify the seismic data by geological behaviour, giving a volumetric interpretation of the data.

3) Finally, we use additional information from measured pressure data and calculated effective stress values, calibrated with geomechanical data. We layer these values on top of the geological classification to facilitate comparison with production and completion results.

Analysis

<u>1) Geological changes</u>

Mineralogy estimates are available from XRF of drill cuttings and XRD of core data. These measurements show that, in this particular field, there are four main mineral components of the reservoir: quartz, clay (illite), feldspar, and dolomite. The largest mineral variations are in clay and dolomite, which range from 0 - 30% and 5 - 35%, respectively. Porosity measurements from core analysis and petrophysical interpretation calibrated to these values are also available. The average porosities of the Montney in this data set are 3.6% (σ = 1.5%) from core and 2.8% (σ = 1.4%) from petrophysics.

Clay content is an important parameter in the characterization of the Montney, and we first investigate different elastic properties to see how they respond. We determine that Young's modulus shows some of the most significant changes with clay content. Figure 1 shows superimposed distributions of Young's modulus values for low (< 9%) and high (> 15%) values of V_{clay}. Although low and high cutoffs are shown in this figure, the data forms a continuous distribution with clay content rather than discrete cases; however, the effect on Young's modulus from clay content is apparent. Poisson's ratio and density were also identified as being useful for mineralogy and porosity identification.

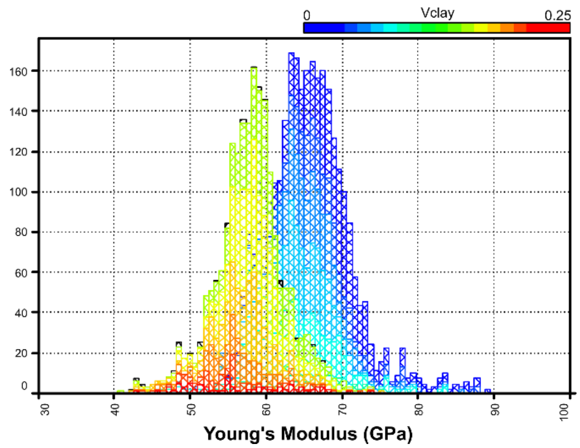

Figure 1*. Superimposed distributions of log-calculated Young's modulus for high and low clay content facies. The separation on this and other attributes show clay content can be distinguished by elastic properties.*

To further investigate the effects of different geological properties in more detail, we also create rock-physics models. A constant-cement model (Dvorkin and Nur, 1996) fits the observed well data used for calibration. To investigate the changes in the reservoir, two plausible scenarios are modelled. In the first case, a constant-quartz model looks at variations in clay content and porosity. Where clay increases, there is a corresponding decrease in dolomite. For the second case, porosity is held constant while variations are allowed for clay and quartz. Figure 2 shows the resulting rock-physics templates to be used for classification of the data. The well data suggest that the second scenario, allowing for variations in both clay and quartz, has an orientation that is more consistent with the observed clay content (point colour).

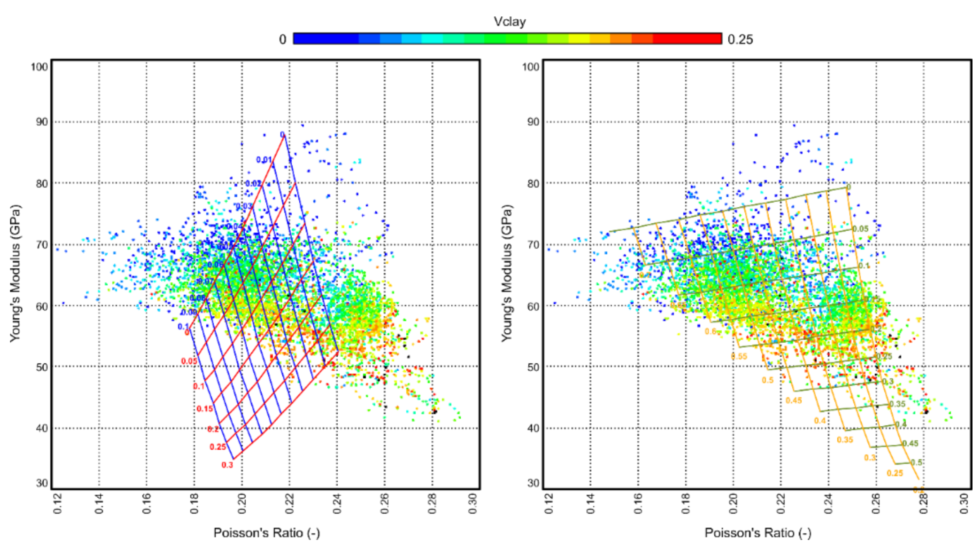

Figure 2*. Rock-physics templates for a constant-quartz model (left) and a constant-porosity model (right). The well data are shown coloured by clay content, and the orientation of the second template is more consistent with the observed data.*

<u>2) Elastic properties</u>

We obtain the elastic properties for the Montney reservoir from a prestack simultaneous inversion (Hampson et al., 2005). This first involves preconditioning of the gathers to ensure appropriate phase and amplitudes, reduce random and coherent noise, and correct for residual moveout. Testing of preconditioning workflows, angle ranges, and inversion parameters helps to optimize the fit between the inverted properties and the observed log data. Twenty-seven wells are used for the initial models.

After obtaining the elastic properties, we perform a geological classification using two steps. The first step is to isolate the Montney from surrounding formations to the extent possible. The second step is to subdivide the reservoir interval based on geological properties. We use successive crossplots for these steps, the isolation being performed on a crossplot of v_P:v_S versus I_P and the reservoir subdivision on a crossplot of Young's modulus versus Poisson's ratio. Figure 3 shows the second crossplot along with the geologically classified data.

As seen with the well data, the seismic data also more closely follow the orientation of the variable mineralogy rock-physics template. The variations in clay content known to exist in the reservoir cause the data to run virtually parallel to the constant-clay lines on this second template option. Cutoffs are applied to identify facies with high and low clay content, with a medium clay-content transition. The low clay-content facies is further subdivided into low, medium, and high quartz content.

<u>3) Additional Data</u>

In addition to the geological characterization of the Montney, seismic and other data can be used to provide inputs for geomechanical characterization. The non-seismic data used includes: a 3D

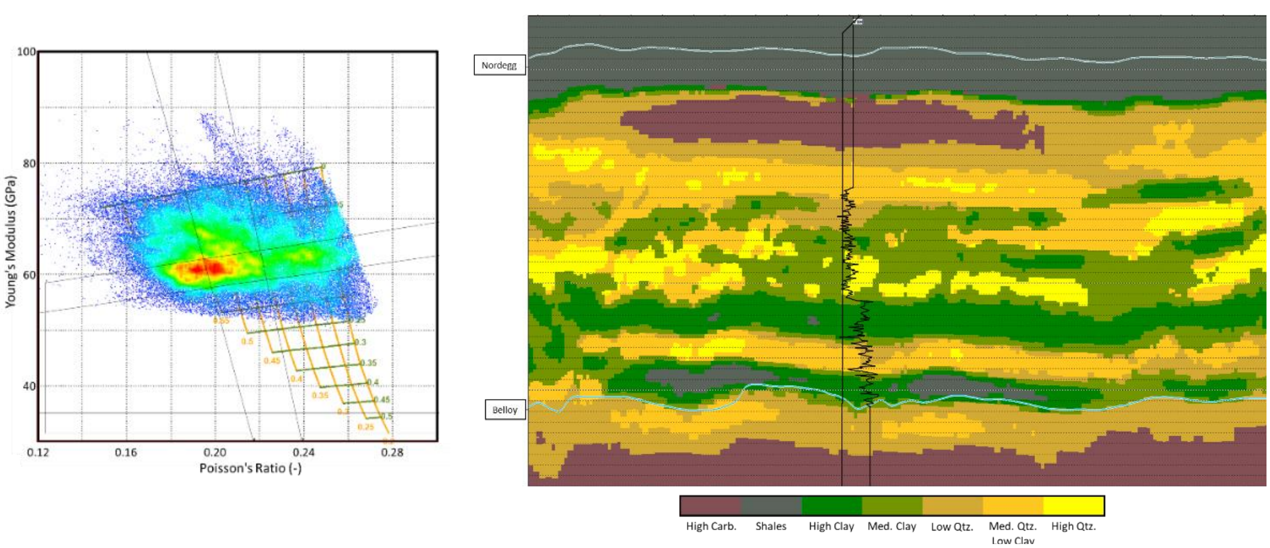

Figure 3. *Classification of elastic properties from seismic inversion. The data orient consistently with the constant-porosity rock-physics template (left). Cutoffs for high and medium clay content isolate the lowest clay facies, which are further subdivided by quartz content. The resulting classified data (right) matches well with the observed transitions in clay content, as indicated by the* V_{shale} *log.*

pressure model provided from extensive pressure data; DFIT measurements of closure stress; and triaxial test measurements on core. To incorporate the pressure data, we first calculate the hydrostatic pressure with rock-physics corrections for salinity, temperature, and pressure. This allows us to identify areas of normal versus overpressure in the reservoir facies.

Further investigating the seismic data, we start by depth converting the inverted volumes using a velocity model that makes use of both well data and seismic velocities. With the volumes in depth, we then calculate of total vertical stress from the vertical integration of the density volume. Next, we apply the triaxial test relationships for the dynamic to static and vertical to horizontal Young's modulus and Poisson's ratio. With a uniaxial strain assumption, these relationships allow us to estimate the total horizontal stresses with either isotropic assumptions $\sigma_{h(iso)}$ (Sayers, 2010) or with a VTI anisotropy correction $\sigma_{h(VTI)}$ (Shoemaker et al., 2019):

$$\sigma_{h(iso)} = \frac{\nu}{1-\nu}\left(\sigma_v - \alpha P_p\right) + \alpha P_p$$

and

$$\sigma_{h(VTI)} = \frac{E_{sh}}{E_{sv}} \frac{\nu_{sv}}{1-\nu_{sh}}\left(\sigma_v - \alpha P_p\right) + \alpha P_p.$$

Here, ν is Poisson’s ratio, E is Young's modulus (with subscripts $_{sv}$ and $_{sh}$ referring to the static values in the vertical and horizontal directions, respectively), P_P is the formation pore pressure, σ_V is the total vertical stress, and α is the Biot-Willis coefficient.

To determine the suitability of the horizontal stress calculations and the inherent assumptions, we compare the calculated stress with the DFIT measurements, as an approximation to the minimum horizontal stress. We find that over 47 points of comparison there is a very close match, with a mean discrepancy of 0.68 MPa and a standard deviation of 2.56 MPa or approximately 5% of the measured values.

Finally, we integrate information from azimuthal velocity changes to indicate the presence of azimuthal anisotropy in the reservoir. The result of these additional measurements is that we are then able to further classify reservoir-quality facies by important engineering considerations such as overpressure, stress changes, or anisotropy.

Conclusions

Elastic properties obtained from seismic data are valuable information. However, the most benefit from these properties comes when they can be given a geological or engineering context to help make informed decisions on field development. Investigating the effect of geological variations on elastic properties provides the information to map facies changes to the seismic data. Additional calculations, with input from geomechanical data, then helps to rank the occurrence of these facies by desired engineering outcomes.

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References

Hampson, D.P., B.H. Russell, and B. Bankhead, 2005, Simultaneous inversion of pre-stack seismic data: 75th Annual Meeting, SEG, 1633-1637.

Dvorkin, J., and A. Nur, 1996, Elasticity of high-porosity sandstones: Theory for two North Sea data sets: Geophysics, **61**, 1363-1370.

Sayers, C.M., 2010, Geophysics under stress: Geomechanical applications of seismic and borehole acoustic waves: 2010 Distinguished Instructor Short Course: Distinguished Instructor Series 13.

Shoemaker, M., S. Narasimhan, S. Quimby, and J. Hawkins, 2019, Calculating far-field anisotropic stress from 3D seismic in the Permian Basin: The Leading Edge, **38**, 96-105.