Beyond Quantitative Interpretation: a Duvernay Case Study

Carmen C. Dumitrescu, Terra-IQ Ltd; Nicole Buttler, Baytex Energy; Andrew Wray, Baytex Energy; Arshad Islam, Baytex Energy

Summary

The Duvernay Formation is a well-known low-permeability unconventional resource play situated in the Western Canada Sedimentary Basin of Alberta, Canada. It is developed with horizontal wells and completed using hydraulic fractures that enhance the permeability and increase the hydrocarbon production. We focused on estimating brittleness variation within the reservoir because brittle rocks are easier to fracture and we want to achieve effective fracturing.

Geomechanical properties estimated from petrophysical analysis are the dynamic ones that were calibrated with the static ones estimated from cores. All geomechanical properties are analysed in close relation with three main facies characteristic for the Duvernay Formation: Facies F1 limestone massive to nodular (carbonate), Facies F2 organic rich shale with carbonate interbeds (organic rich shale) and facies F3 argillaceous shale (clay rich shale).

Quantitative interpretation was performed to estimate the elastic properties (compressional and shear wave velocities along with density) by integrating the wireline logs with prestack seismic data. These elastic parameters where then used to estimate geomechanical properties such as Poisson's Ratio, Young's modulus and Brittleness.

The brittleness volume was integrated with the most probable seismic facies volume to differentiate the carbonate interval non-reservoir from the organic rich shale reservoir.

Introduction and Geology

The Duvernay Formation is a well-known resource play of Alberta, Canada. The key technologies for success revolve around horizontal drilling and hydraulic fracture stimulation that enhance permeability and increase hydrocarbon production.

The full 70 m Duvernay interval is displayed in a single trough with conventional seismic data due to the combination of deep depth (2400 – 3000 m) and low frequency in zone (60 Hz). It is impossible to see within the zone seismic data variations that can be seen on log data. By using quantitative interpretation, which integrate wells and seismic data with knowledge from cores, the reservoir vertical and lateral variations of geomechanical properties and facies volumes can be estimated and mapped. In other words, quantitative interpretation allows for extension of reservoir understanding away from the wellbore where data was measured, still within the boundaries of the seismic survey, and providing more clarity for collective decision making.

The Duvernay Formation is Devonian age, more specific Upper Devonian, Frasnian of the Woodband Group. It is made of laminated organic rich shale with calcareous and argillaceous interbeds and was deposited in deep water embayment as Leduc reef complexes were developing (Figure 1). Some of the characteristics of the Duvernay Formation in the study area are: high Total Organic Content (TOC) up to 12% (typically 3 – 6%), low clay volume (< 30%) that increases brittleness and depending on maturity produces light oil to liquids rich gas to dry gas.

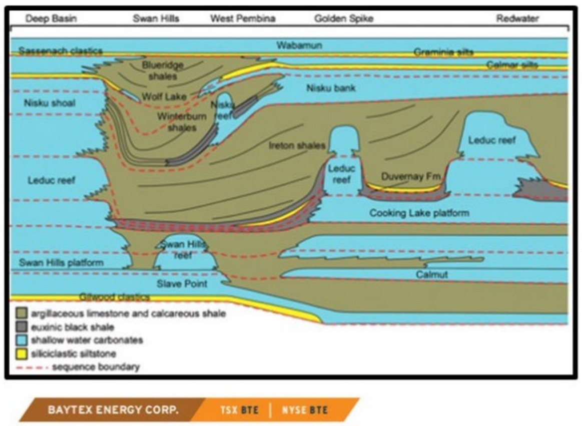

Figure 1. The Duvernay Formation geological settings

The study area location is presented in Figure 2 (modified from the National Energy Board (NEB), 2013 and Mlada, 2016) along with the approximate extent of selected low-permeability hydrocarbon resource plays in the Western Canadian Sedimentary Basin (WCSB). Most of the plays occur within the fore-deep on the western margins of the basin.

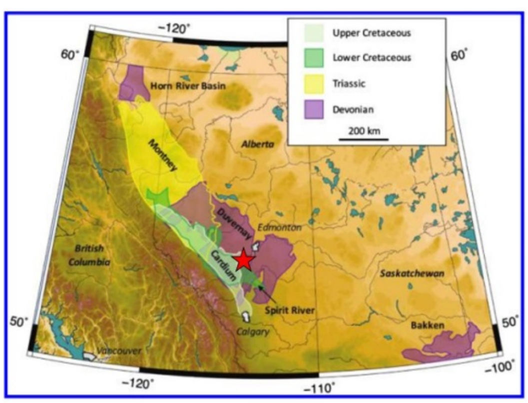

Figure 2. Location of study area (red star) and approximate extent of low-permeability hydrocarbon resource plays in the WCSB (modified from NEB, 2013 and Mlada, 2016)

The reservoir is situated at depths of 2000 to 3500 m, has the thickness of 25 to 90 m, the average porosity of 3 to 6%, the API from 33 to 45 degrees, the pressure gradient of 13 to 16 kPa/m and the recovery factor of 5 to 8%.

In Figure 3, core photos for each of the three main facies of our study are presented along with the estimated parameters. The Facies F1 Carbonate is presented at the top, F2 Organic rich shale in the middle, and F3 Clay rich shale at the bottom.

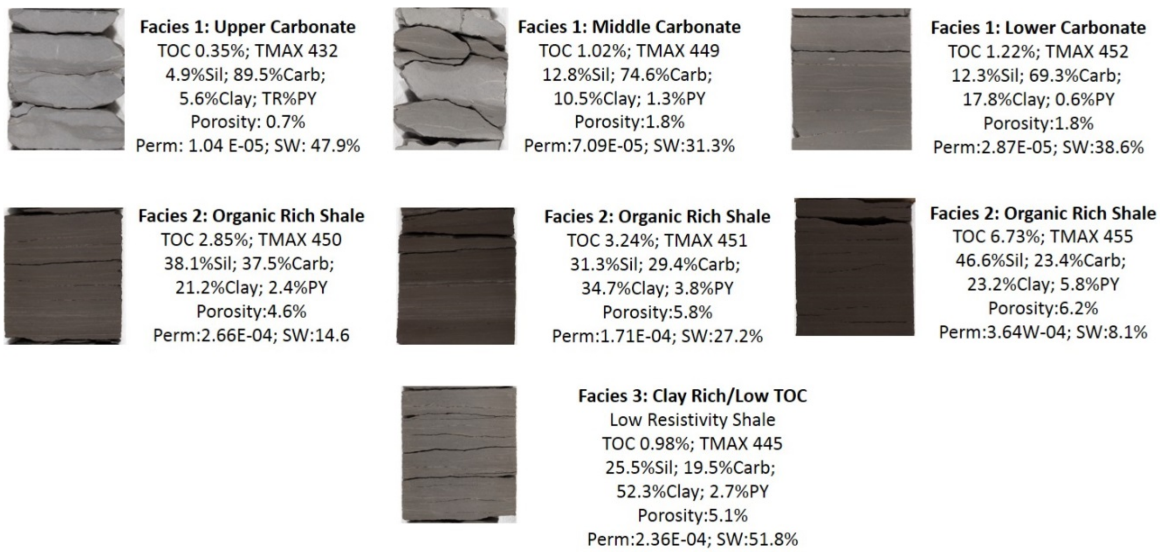

Figure 3. Core, facies data and estimated parameters

Geomechanical properties and seismic results

Poisson's Ratio and Young's modulus are referred also as elastic constants or elastic moduli for isotropic media and can be expressed in terms of P- and S-wave velocities and density as in equations 1 and 2.

$$\upsilon = \frac{v_p^2 - 2v_s^2}{2(v_p^2 - v_s^2)} \qquad (1)$$

$$E = \frac{\rho v_s^2 (3v_p^2 - 4v_s^2)}{v_p^2 - v_s^2} \qquad (2)$$

These are the equations used for estimating the dynamic moduli from petrophysical analysis as opposed to static moduli estimated from cores measurements.

A combination of weighted normalised Poisson's Ratio and Young's modulus define the Brittleness (Rickman et al., 2008) as presented in equation 3. Brittleness is a key indicator in unconventional plays, because defines which rocks will fracture and yet maintain sufficient strength for fracture to remain open after placement of proppant (Weir et al., 2018).

$$\mathrm{BRI} = 100 * \left(w * \frac{\upsilon_{max} - \upsilon}{\upsilon_{max} - \upsilon_{min}} + (1 - w) * \frac{E - Emin}{Emax - Emin}\right) \qquad (3)$$

The dynamic geomechanical properties for two wells (D and C) within the Duvernay Formation are reviewed in Figure 4. The first track is GR, followed by resistivity and porosity, properties connected with the dynamic geomechanical properties (tracks 4 – 6) and facies (track 7). Each estimated dynamic log is presented along with the seismic trace extracted from the corresponding volume. Last track is facies log, where blue is the F1 limestone massive to nodular, green is the F2 organic rich shale with carbonate interbeds (high level of kerogen) and brown is F3 argillaceous shale with low organic content.

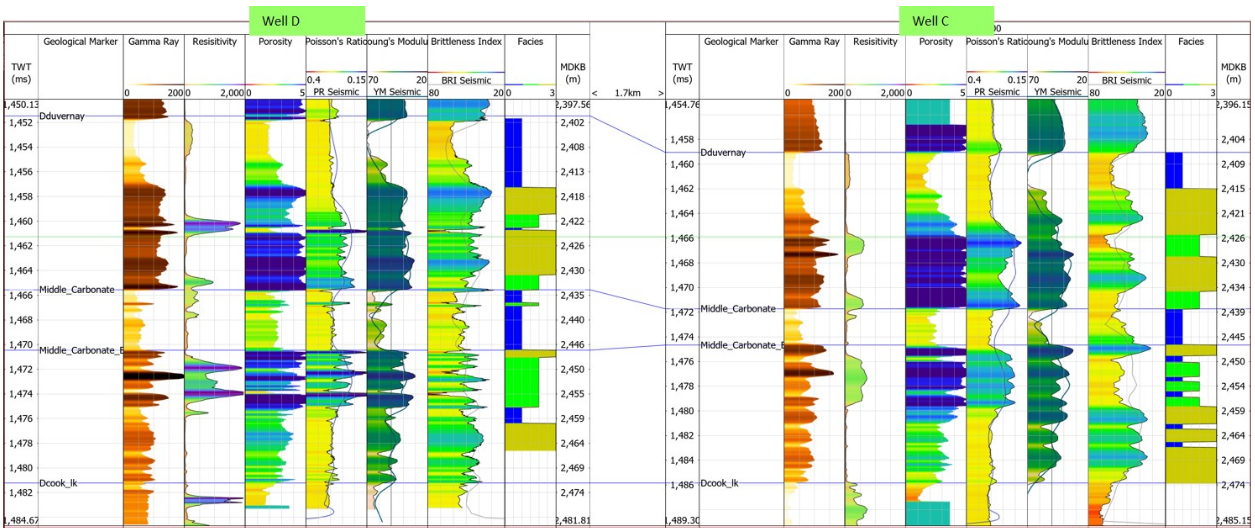

Figure 4. Log data review for geomechanics

The estimated geomechanical properties were analysed as function of facies. In Figure 5, the crossplot of dynamic Young's modulus versus Poisson's ratio is colored by facies on the left and by Brittleness on the right side. The data points are from the Duvernay Formation of 4 of the wells available (A, B, C and D).

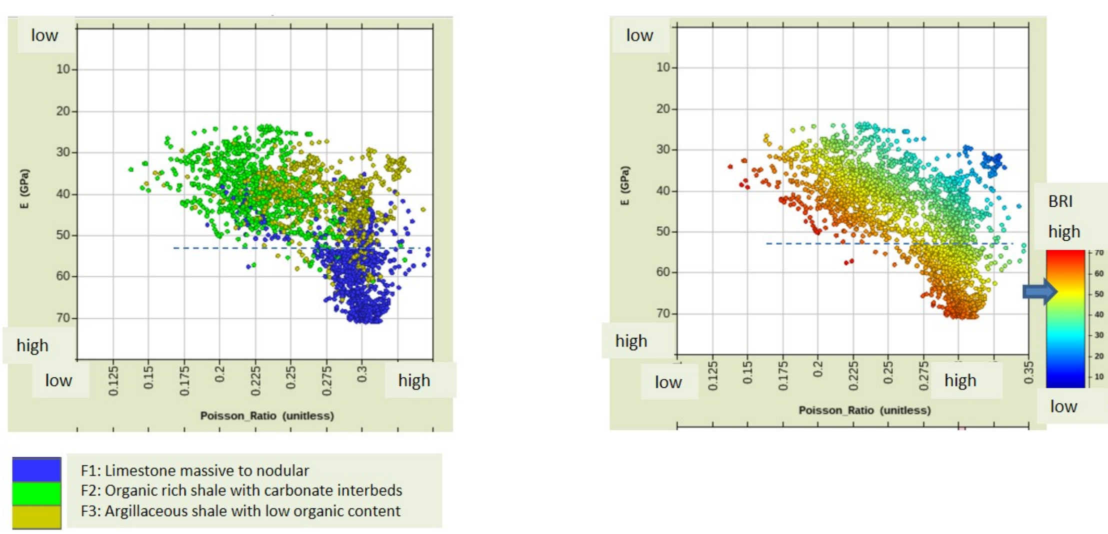

Figure 5. Crossplot of the dynamic Young's modulus and Poisson's ratio colored by facies on the left and by Brittleness on the right side

The range of values for Poisson's ratio is from 0.15 to 0.35 and the lowest values are for the facies F2, organic rich shale data points which display high brittleness. The range of Young's modulus is from 20 to 70 GPa and a line at 55 GPa separates the carbonate of F1 from shale of F2 and F3.

On the crossplot situated on the right side, there are two clusters with high brittleness separated by the E = 55 [GPa] line: the first cluster is below the line and the data points correspond to the F1 carbonate. More interesting is the second one situated above the line, where the data points correspond to the F2 organic rich and F3 clay rich shale.

Let us introduce the cut-off (about 50-55) between the ductile and the brittle shale. The higher the values of brittleness above this cut-off value, the more likely the shale will brittle. This is particularly important because it means there may be natural fractures present and the shale should respond well to hydraulic stimulation (Rickman et al., 2008). The second cluster with high brittleness is made of F2 organic rich shale with high silicates percentage as presented in Figure 6. In this figure the crossplots of Quartz volume versus brittleness are in the left side and the crossplots of Calcite volume versus brittleness are in the right side. The data points of the crossplots at the top are colored by facies and at the bottom by brittleness.

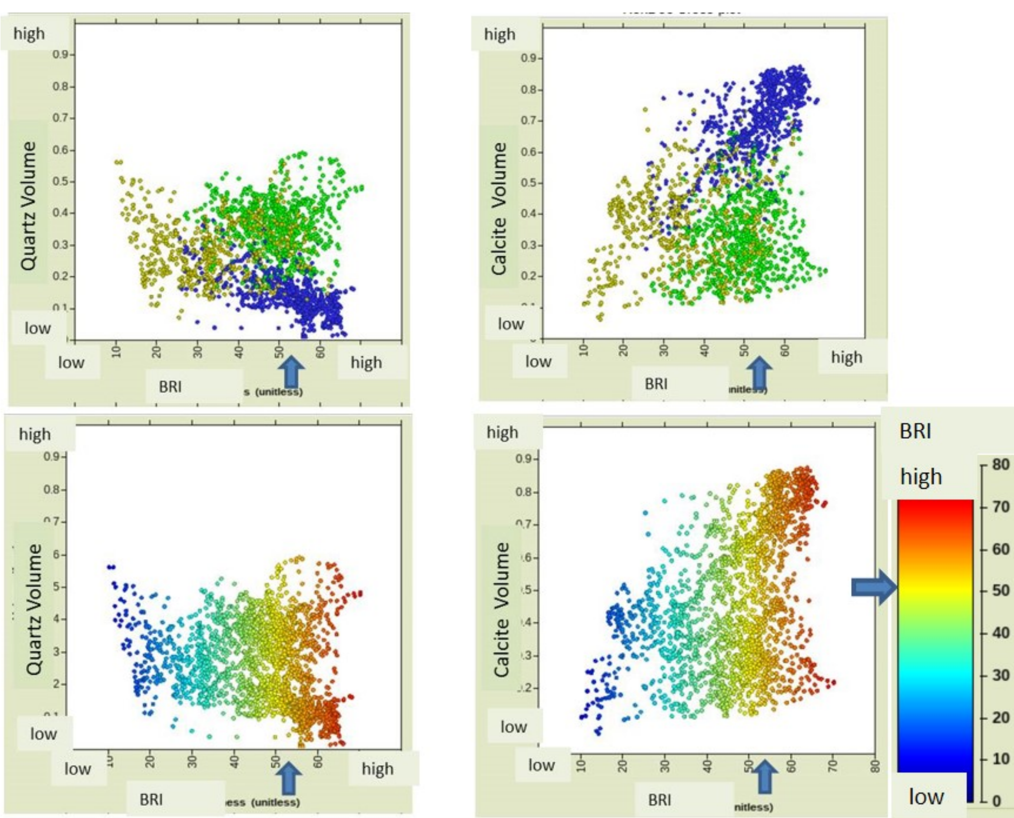

Figure 6. Crossplot of the Quartz volume (left) and Calcite volume (right) versus Brittleness colored by facies (top) and by brittleness (bottom). The facies color bar is the same as in Figure 5

Quartz is the main component of silicates which also include smaller percentage of plagioclase and feldspar. The cluster of F2 datapoints with brittleness above the cut-off value, are characterised by high quartz volume (40 - 60%) and low calcite volume (20 -30%).

Quantitative interpretation was used to estimate first the elastic parameters (P- and S-wave velocity along with Density) and then the geomechanical properties: Poisson's ratio, Young's modulus and Brittleness.

We present only the brittleness seismic results, in figure 7. On the left side, is a vertical time section of the arbitrary line through the wells D and C presented here with the corresponding Brittleness logs inserted in color. The seismic volume was flattened at the Cook Lake situated at the base of the Duvernay Formation. Low values are in dark blue and high values are in red. The black horizontal line situated within the Middle Carbonates, indicates the location of the time slice presented on the right side. In this slice we observe mid-to-high range of values of Brittleness.

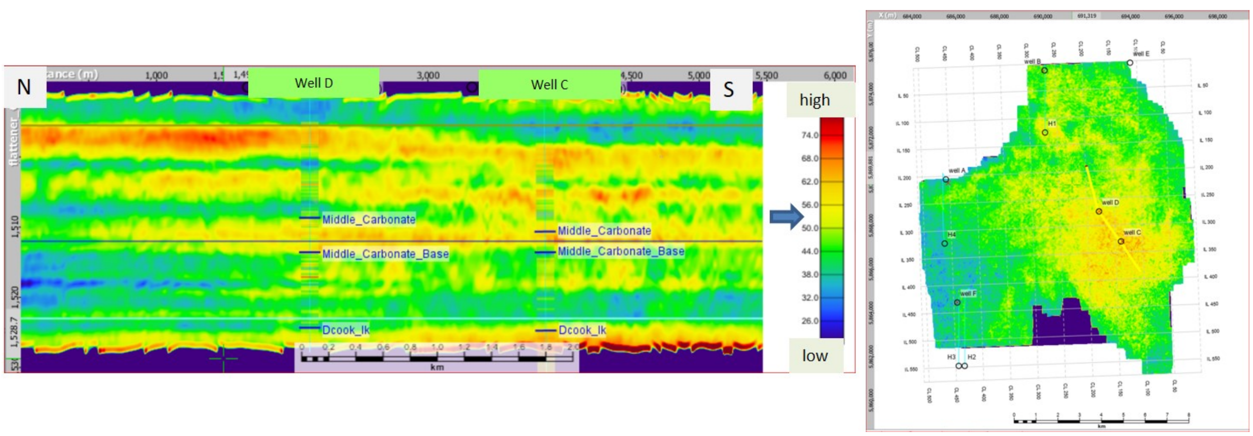

Figure 7. Seismic Brittleness: (Left) Vertical time section of the arbitrary line through the wells D and C; (Right) Time slice at 1512 ms on the seismic flattened at the Cooking Lake

Similar with what we have seen in the logs, in this seismic data there are two zones with brittleness above the cut-off value and presented in yellow-red colors: one is within the carbonates and the other one within the organic rich shale above the carbonate, and represent potential for drilling.

Conclusions

This paper presents how we can integrate wells with seismic to deliver the geomechanical properties to the team of geoscientists and engineers. Here are our conclusions:

1. Quantitative interpretation can be used to successfully estimate elastic properties: P- and S-wave velocity and density allowing for reduced number of pilots and better mapping of the mid carbonate that could be a frac barrier.

2. Young's modulus, Poisson's ratio and brittleness can be estimated from elastic properties and major changes in rock properties can be mapped, helping with completion/stimulation process, and reducing drilling risk.

References

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