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# Application of an Integrated Approach for the Characterization of Mechanical Rock Properties in the Duvernay Formation

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## Summary

An integrated approach that implements a wide variety of data types was used to geologically and geomechanically characterize the Duvernay unconventional play in Alberta, Canada (Fox and Soltanzadeh, 2015). The stratigraphic distribution of geomechanical properties in the Duvernay and Ireton formations shows a strong relationship with the geological depositional model developed from the analysis of full core from 29 wells. In addition, correlations between mechanical and mineralogical rock properties with fracture fabrics identified in core and image logs provides insight into the fracturing behaviour of the rock. The analyses also reveal the significant effect of in-situ conditions such as stresses, fluid type and content, and especially pore pressure on differences between mechanical properties derived from logs and those measured in the lab. A detailed analysis of so-called "brittleness" reveals that the commonly used indices may not be the optimal approach for understanding the mechanical behaviour of the Duvernay and Ireton Formations. Clay content seems to play a major role in the mechanical behaviour of these formations, and measures of "brittleness" based on clay content are more definitive in interpreting mechanical distinctions between stratigraphic units. In general, the study shows that approaches towards understanding rock behavior may need to be customized to suit the specific nature of a given formation.

## Introduction

The complex geomechanical behaviour of unconventional plays requires careful attention to characterization of rock mechanical properties in these reservoirs. An integrated approach towards understanding geomechanical properties in the Duvernay Formation, an emerging unconventional play in Alberta, Canada is presented here. This study illustrates how analyzing geomechanical data in the context of geology, geochemical properties, rock mineralogy and fracture fabrics leads to a better understating of rock behaviour in this highly over-pressured play and its immediate overlying formation, the Ireton.

## Methodology

*Geology and Fracture Fabrics:* In this study, the Ireton Formation was subdivided into six layers designated as A through F, but due to local variations and clinoforming of the Ireton, only D, E. and F are considered regional. The Duvernay Formation has been subdivided into three main units: A lower A Shale, a middle B Carbonate, and an upper C Shale that has been subdivided into five sub-units of C1 to C5. These subunits are interpreted to onlap onto the top of the B Carbonate eastward/northeastward, supported by the common occurrence of one or more coarse-textured lags at the B Carbonate – C Shale boundary in core (Canadian Discovery Ltd. et al., 2014). Several types of pre-existing natural fractures and induced fractures were identified during the analysis of full core from 29 wells throughout the study area. Natural fractures included high-angle fractures as well as polished slip faces (PSF) and associated cleavage (Davies, 2013). Coring-induced fractures included petal, petal-centreline and bed-parallel parting (BPP) fractures. In some cases where it was unclear from the core whether a fracture was high-angle or induced, image logs were used to differentiate between the two.

*Mechanical and Petrophysical Properties:* The available core mechanical test reports/data from 11 wells were carefully reviewed and databased. The data set provided a variety of rock properties such as static and dynamic elastic moduli, compressive strength, cohesion, angle of internal friction, tensile strength, anisotropy, brittleness and more. Given the scarcity of core tests for such a broad geographical area, compressional and shear sonic logs were another important source of rock mechanical properties. Combined with density logs, they were used to calculate parameters such as dynamic Poisson's ratio and dynamic Young's modulus. In this study, dipole sonic data from 26 wells were used to calculate these parameters in each of the Ireton and Duvernay stratigraphic units (Figure 1a-b), and where possible the calculations were compared to static and dynamic values from the core test data. Detailed petrophysical analyses including geochemical and mineralogical rock properties from 16 wells (Rahim and Watson, 2015) were incorporated into the geomechanical workflow to characterize rock properties and fracture fabrics.

*Brittleness:* The concept of rock brittleness is a recent popular consideration in identifying sweet spots—parts of the rock that are deemed easier to hydraulically fracture—in unconventional plays. In this study, this concept was investigated in detail using different mechanical and mineralogical parameters. Mechanical parameters include Rickman's brittleness index (Rickman et al., 2008) and plane-strain Young's modulus (Valkó and Economides, 1995) and mineralogical parameters include dolomite based and clay based brittleness indices. The applicability of these parameters to quantify rock fracturing potential was evaluated by comparing to fracturing experience in the field and natural and induced fractures observed on the image logs and cores.

## Results

Significant stratigraphic variations were observed among both lab and log based mechanical properties manifesting the dissimilarities in geomechanical responses of different lithological zones in the study area (e.g., Figure 1). In the case of Young's modulus, strong relations between static and dynamic values measured in the lab were observed. Inconsistencies between the lab and log based data seemed to be related to sampling frequency and the difference between in situ and laboratory conditions (e.g., stress, pore pressure, temperature). Figures 1a and 1b show significant variations in log based dynamic elastic properties (particularly Poisson's ratio) in different zones especially between the Duvernay and

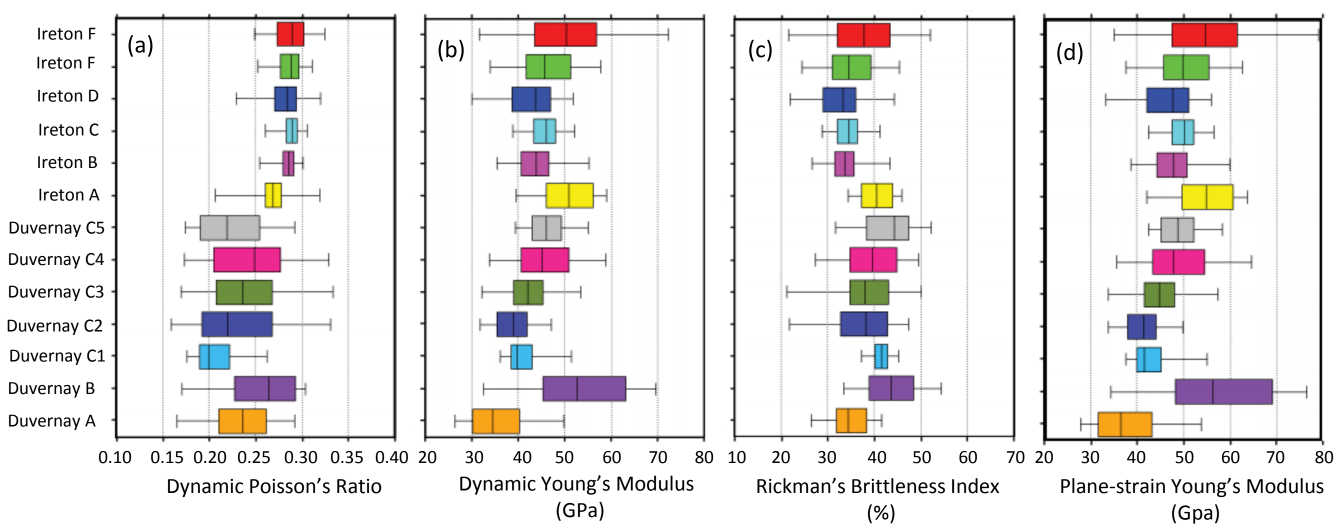


Figure 1. Mechanical properties calculated based on sonic logs for 26 wells for the Duvernay and Ireton formations: (a) dynamic Poisson's ratio, (b) dynamic Young's Modulus, (c) Rickman's brittleness Index, and (d) plane-strain Young's modulus.

Ireton formations. These variations may be related to fluid content and pore pressure difference between the Duvernay and Ireton formations (Dvorkin, 2000). Analysis of directional anisotropy in rock properties based on the log data showed little directionality in the plane of bedding, but the lab data showed significant differences between properties measured parallel versus perpendicular to bedding, confirming that both the Duvernay and Ireton may be considered transversely isotropic. As part of the study, effort was made to understand relationships between rock mechanical properties and mineralogical composition. A strong correlation was observed between Young's modulus and percentage of clay, where the modulus decreased as clay volume increased. Correlations were also observed between Poisson's ratio, quartz content and TOC (Figure 2).

In general, the Duvernay units show higher mechanical brittleness index than the Ireton, and therefore the Ireton would be expected to act as a barrier to hydraulic fractures initiated in the Duvernay (Figure 1c). However, experience in the area shows that the Duvernay B is a significant barrier against fracturing, an effect which is better captured by the fact that the Duvernay B has the highest values of plane-strain Young's modulus (Figure 1d). The brittleness index defined using clay shows a good correlation with plane-strain Young's modulus and effective porosity (Figure 3) while the one based on dolomite does not show a significant correlation with either of mechanical brittleness parameters.

Mechanical rock properties, along with in situ stresses and pore pressure, are expected to have critical roles in fracture formation. A detailed comparison of fracture distribution with logs, log-derived rock properties and mineralogy was performed as part of this study. The analysis revealed that the presence of fractures was restricted to rocks with intermediate ranges of both plane-strain Young's modulus and clay-based brittleness index (Figure 4). This methodology seems to be a useful tool for identifying the more fraccable zones from the zones that are either too ductile or too strong to be fractured easily. Fracture types also seemed to have strong relations to rock properties as shown in Figure 5. This figure shows that natural shear fractures, polished slip faces, and bed-parallel partings (core diskings) can be identified as functions of rock mechanical and mineralogical properties. Similar trends were observed for even more basic log types such as compressional and shear sonic or spectral gamma logs.

## Conclusion

The study shows that how integrated analysis of different sets of data from geology, lab measurements, logs, pore pressure and in-situ stresses, geochemical and petrophysical properties, fracture fabrics from core description and image logs can lead to more comprehensive understating of geomechanical behavior of unconventional plays such as the Duvernay Formation.

## Acknowledgements

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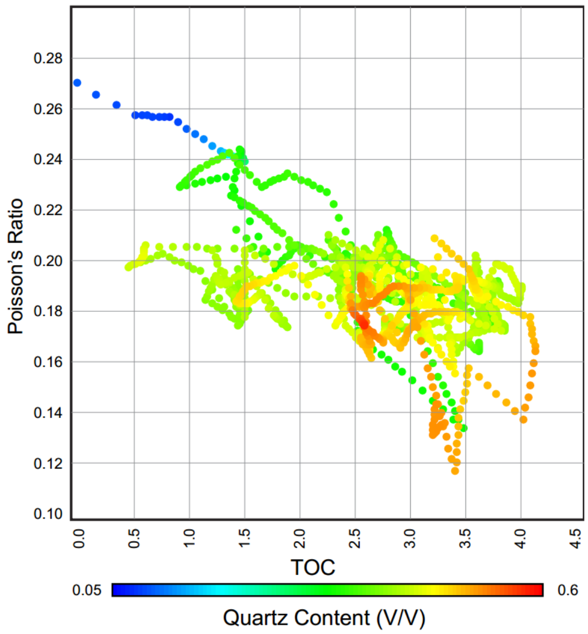


Figure 2. Variation of Poisson's ratio with total organic content (TOC) and quartz content in a well in the northwest region of the study area.

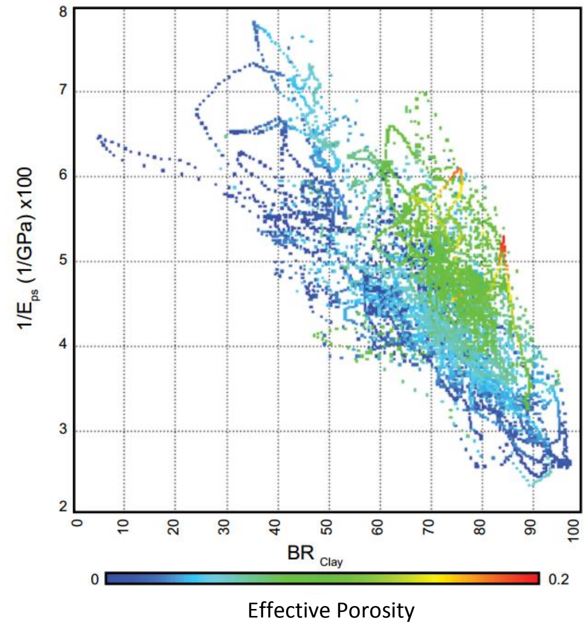


Figure 3. Variation of the inverse of plane-strain Young's modulus ($E_{ps}$) versus clay-based mineralogical brittleness index ($BR_{Clay}$) and effective porosity for 16 wells throughout the study area.

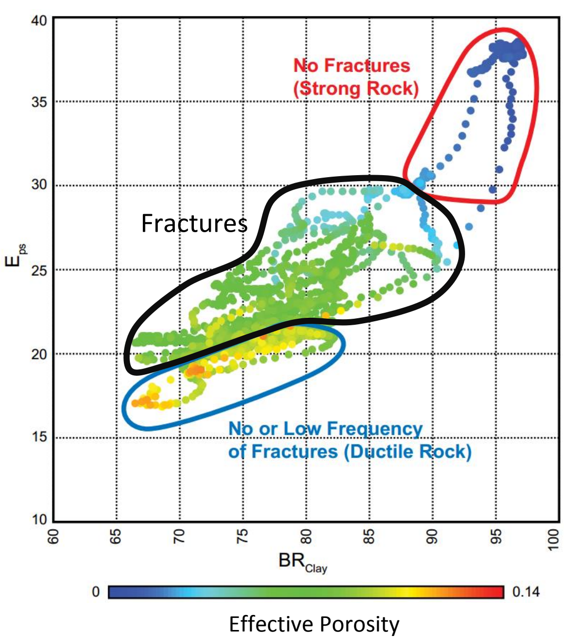


Figure 4. Fracture occurrence shown in a cross-plot between plane-strain Young's modulus ($E_{ps}$) versus clay-based mineralogical brittleness index ($BR_{Clay}$) for a well in the Kaybob region of the study area.

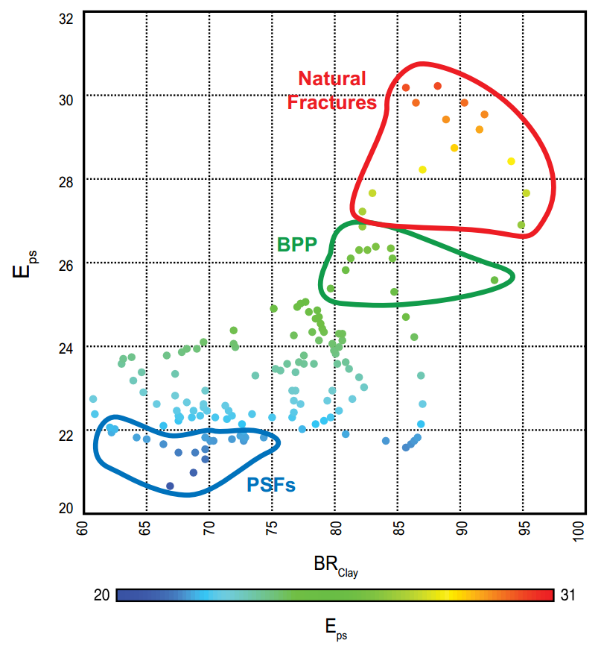


Figure 5. Various fracture fabrics identified on the cross-plot between plane-strain Young's modulus ($E_{ps}$) versus clay-based mineralogical brittleness index ($BR_{Clay}$) for a well in the northwest region of the study area.