geoconvention
Virtual Event
September 21-23
2020
CSPG • CSEG • CWLS • GAC • MAC • IAH

A hybrid approach to geomechanical property prediction in the Duvernay Formation

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Summary

Unconventional plays have become the main target of exploration in North America in the last decade. Due to their very low permeability, completion techniques such as hydraulic fracturing are necessary to their viability as hydrocarbon reservoirs. Completion strategy of horizontal wells, as well as wellbore stability and well-to-well connectivity management are strongly dependent on the geomechanical properties of the reservoir, and therefore it is crucial to estimate these ahead of drilling. Geomechanical properties of unconventional reservoirs can be measured directly through laboratory testing on subsurface samples. These tests give as output the static elastic moduli of the analyzed samples, amongst other parameters of geomechanical interest. These results directly depend on the relation between stress and strain measured on core samples when undergoing mechanical testing. In parallel with lab-measured properties, petrophysical techniques based on analysis of elastic wave velocity and anisotropy may also provide dynamic mechanical moduli. Theoretically, static and dynamic elastic moduli should perfectly match, but this rarely happens due to the difference in strain between these two measurement techniques, which can be of several orders of magnitude.
Our general understanding of rock strength and rock failure mechanisms comes from laboratory testing of subsurface samples. However, since this dataset is vertically and laterally discontinuous and extensive sampling and testing is cost-prohibitive at the full scale of a resource play, most of the geomechanical problems are solved using petrophysical techniques because of their simplicity, vertical continuity and abundance of data. This strategy is geomechanically significant only after linking core-scale “real” static measurements to their well log-scale dynamic equivalents.

This talk will focus on this topic with a close-up on the Devonian Duvernay Formation, one of Alberta’s hottest unconventional plays at the present day.

In the first part of this talk we will focus on a small portion of the Kaybob sub-basin, where we compare static geomechanical measurements obtained from core testing to dynamic elastic moduli derived from wireline logs as well as PP-PS joint stack inversion of 3-D seismic. We will demonstrate that, although the values do not match due to differences in measurement technique and vertical resolution of the three methods as we expect, results from the three datasets clearly demonstrate that each unit with unique mineralogy and rock fabric shows unique mechanical properties. More specifically, 3-D seismic can resolve the sharp contrast in mechanical properties between the Duvernay reservoir and its overlying and underlying units (Ireton and Beaverhill

Lake). Cores and wireline logs may also resolve intra-Duvernay beds marking mechanical contrasts with the adjacent units due to sharp changes in mineralogy and fabric (biogenic silica-rich vs clay-rich vs carbonate-rich beds). This makes it possible to use relative values of elastic properties to integrate seismic, wireline logs and core data, but the conversion to absolute static values is extremely challenging. This is due to several factors influencing mechanical tests such as differences in testing confining pressure, stress state in the subsurface and many others. Therefore, integrating these variables is necessary to switch from dynamic to static elastic moduli thus significantly improving the fidelity of any geomechanical model. This is the main topic of the second part of the research, which integrates core-scale experiments with well logs to compare the Duvernay Formation with its underlying strata, including the non-bituminous shales of the Majeau Lake Formation and the carbonates of the Waterways Formation. Core-scale experiments including multistage triaxial, unconfined compressive strength, Brazilian, and ultrasonic pulse transmission testing are first performed on the Waterways Formation to contribute to the sparse geomechanical dataset on the formation. We combine these results with a public database of 31 cores from the Duvernay Formation and 3 cores from the Waterways and Swan Hills formations. Triaxial tests with simultaneous ultrasonic pulse transmission tests are also used to develop a statistical model that links static elastic moduli to compressional sonic velocities, with or without shear sonic velocities. This greatly increases the amount of wells that can be used for geomechanical interpretation. The statistical model is integrated with a previous study of the stresses of the Duvernay Formation in the Kaybob area to compare the Young's modulus, Poisson's ratio, and experimental brittleness of the Duvernay Formation and the underlying units which have the potential to influence induced seismicity and hydraulic fracturing.

Through our experimental results, we show that the use of dynamic elastic properties for geomechanical differentiation is fraught with difficulty, and that consideration of rock fabric and stress conditions are essential for geomechanical analysis. We also demonstrate the importance of bedding-plane slip as a dominant failure mechanism. A statistical model is then developed from the public database of testing data. We show that the inclusion of bulk density and estimated stress conditions greatly improves the model's predictive capacity. The model is also able to estimate the observed experimental brittleness of the geomechanical tests, which we consider as the most representative measure of rock brittleness at failure. It is also able to make robust predictions without the need for shear sonic data, greatly increasing the well control available for geostatistical analysis. Integration of this model with geostatistical simulations of stress conditions, density, and sonic velocities allows us to differentiate geomechanical regimes, showing significant differences between near-reef areas and the central part of the Kaybob area. The integration of these approaches highlights major differences between the Duvernay, Majeau Lake, and Waterways formations that influence our understanding of hydraulic fracturing and induced seismicity.

The model is reviewed and interpreted using a standard machine learning approach – a cross-validated pipeline is used to train the model, followed by a test set. An interpretable machine learning framework using partial dependence plot and feature importance is used to investigate the influence of each input on the results and validate the statistical approach.

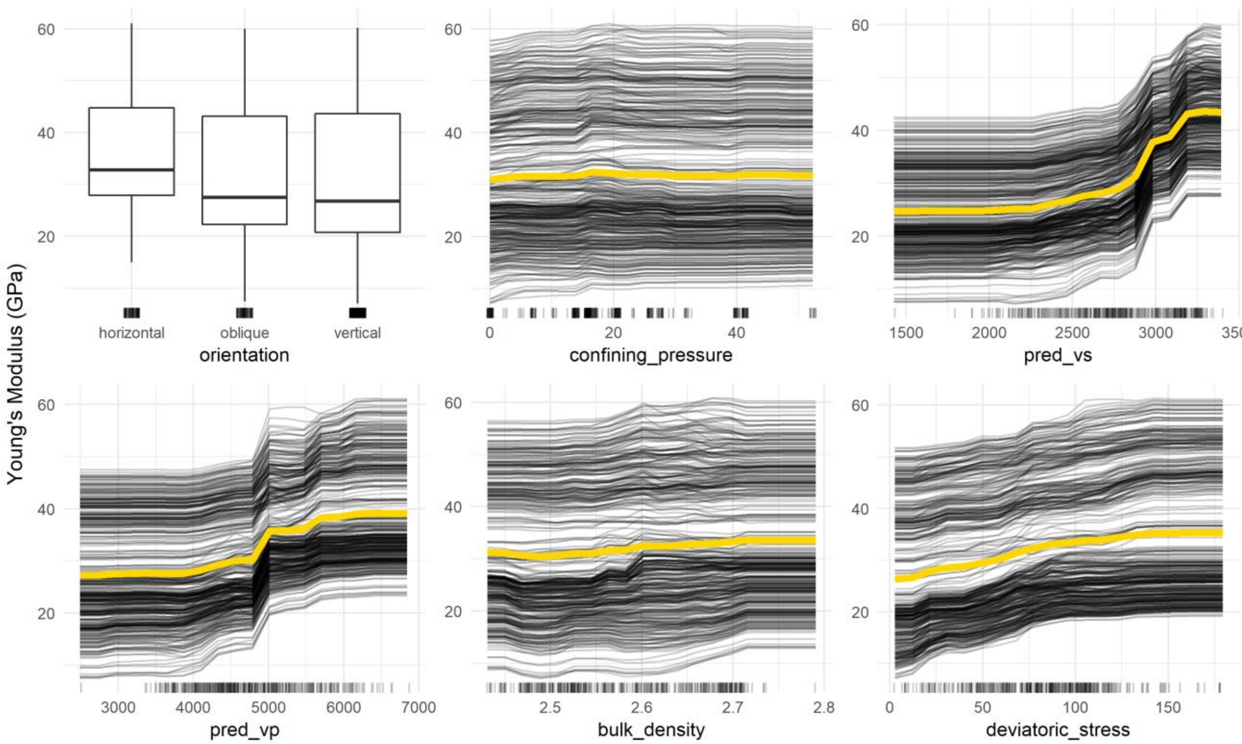

Fig.1: A partial dependence plot for Young's Modulus generated using a random forest model. The yellow line depicts the mean individual conditional expectation line (i.e. the partial dependence line) and the black lines show individual conditional expectations. The box plots similarly represent the mean and individual effects of the categorical orientation parameter.

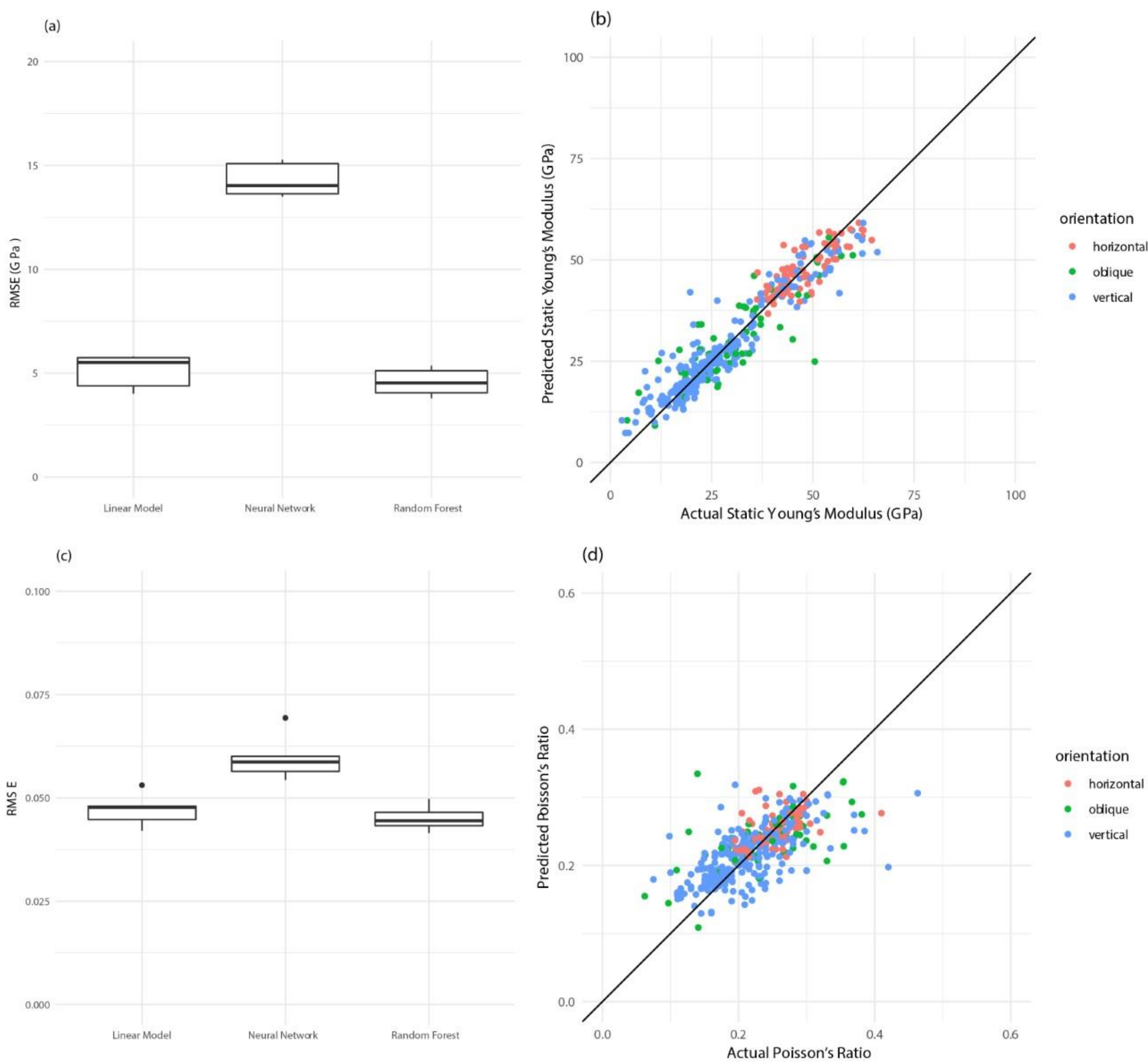

Fig.2: Benchmark and residual plot of the statistical models of Young's modulus (a,b) and Poisson's ratio (c,d). The benchmark plots (left) show the variability of multivariate linear regression, single layer neural network, and random forest models. The residual plots (right) show the predicted values (ordinate) and the actual values (abscissa).

Acknowledgements

This research was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC). The authors would also like to thank the University of Calgary Global Research Initiative (GRI), geoLOGIC Systems for allowing access to their geoSCOUT well database and QFind module and Schlumberger for allowing access to the Petrel and Techlog platforms.