Influence of Sedimentary Facies on Geomechanical Properties in the Duvernay Formation, Fox Creek Area, AB, Canada

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Summary

The Devonian Duvernay Formation is one of Canada's most promising shale plays.
Recent works focused on the geology or the geomechanical properties of the shales and carbonates, but a comprehensive work has not been published yet.
This study shows how integrating geomechanical analyses to sedimentary facies can lead to a better understanding of the behavior of shale plays undergoing hydraulic fracturing treatment.
For this research, the 8 sedimentary facies identified in cores have been upscaled into 4 GR-based petrofacies identifiable in each vertical and horizontal well in the study area, and box plots highlighting petrophysical and geomechanical properties for each petrofacies have been built.
This study shows that the Duvernay middle carbonate member stands out in each box plot showing the highest Young's modulus, Poisson's ratio and bulk density with values typical of a limestone. On the other hand, the other 3 petrofacies showing higher Gamma Ray values mainly differ in bulk density and Young's modulus, as well as breakdown pressure of the completion stages and potential presence of natural fractures.
Completion data show that 10% higher breakdown pressure is required to frac the organic-rich facies LF3 with respect to the more organic-lean LF2. This is most likely due to the more ductile behavior of the organic-rich LF3, which requires higher pressure for matrix breakdown during hydraulic fracturing operations. LF3 is also the only facies showing several ROP readings above 60 m/hr (more than double the average for this facies), which have been interpreted as potential indicators of natural fractures in this TOC-rich facies of the Duvernay.
Each upscaled sedimentary facies has been proved to be a geomechanical facies as well, but an additional subdivision has to be made inside LF3 (LF3a vs LF3b) using a 200 API cutoff. Samples with GR > 200 API show significantly lower bulk density and Young's modulus values, and therefore represent another sedimentological and geomechanical facies. This is most likely caused by different TOC values in LF3a vs LF3b and will be further evaluated by looking at the organic-rich shales in thin sections and SEM and performing rock eval analyses on the rock samples.

Introduction

In the last decade, shales have become viable hydrocarbon reservoirs all over the world. In the Devonian Duvernay Formation, one of Canada's most promising shale plays, exploration for shale gas and liquids has been ongoing since 2010, when the first horizontal targeting the organic-rich shales was drilled in the Fox Creek area. Since that time, interest in this play rapidly grew and many papers were published focusing on the geological (e.g. Rokosh et al., 2012; Knapp et al., 2017) and engineering aspects of the Duvernay (e.g. Fox and Soltanzadeh, 2015; Soltanzadeh et al., 2015). Despite the relatively rich recent literature on the Duvernay, a comprehensive work linking geology and geomechanics has not been published yet, and would be a great aid in optimizing this shale play. Fox et al. (2015) and Soltanzadeh et al. (2015) partially addressed this issue sub-diving the Duvernay into 7 units and estimating geomechanical parameters for each unit using well logs. Their work did show high internal geological and geomechanical heterogeneity within the Duvernay formation, and was a good starting point for this research. Fox and Soltanzadeh's sub-division of the Duvernay into 7 units wasn't based on different sedimentary facies, but on different Duvernay clinoforms instead. Therefore, their 7 units reflect age-based sub-divisions of the Duvernay (assuming the top of a clinoform is a chronostratigraphic surface), rather than proper sedimentary facies.

The aim of this research is to push Fox and Soltanzadeh's research a step forward by estimating geomechanical parameters for each single sedimentary facies interpreted in the Duvernay cores and well logs, to better understand the geomechanical behavior of the different shale facies.

Theory and/or Method

Detailed observation of 2 Duvernay cores identified 8 sedimentary facies within the Duvernay Formation, which have been upscaled into 4 gamma Ray-based petrofacies (LF1a, LF1, LF2, LF3 in order of increasing GR and TOC values).

For horizontal wells, completion data were available. Once picked the different upscaled facies for the whole well length, we did the best estimation of which facies was affected by each completion stage, and we plotted breakdown pressure of the rock matrix against each different facies in box plots.

Concerning vertical wells, bulk density and dipole sonic logs were used to derive dynamic elastic parameters for each upscaled facies. Derived dynamic geomechanical parameters include, but are not limited to, Young's modulus and Poisson's ratio.

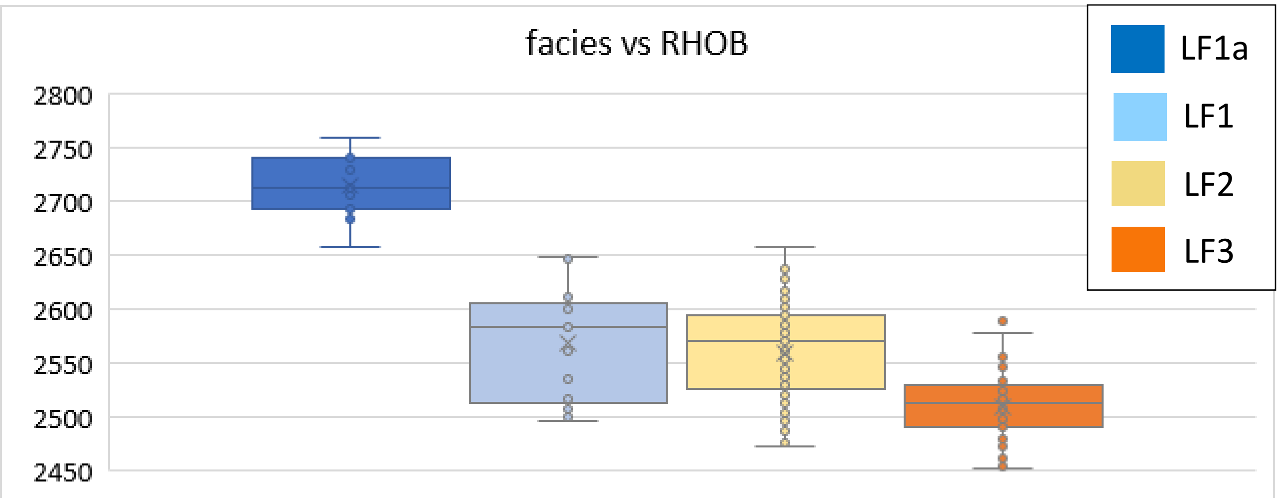
Results and Discussion

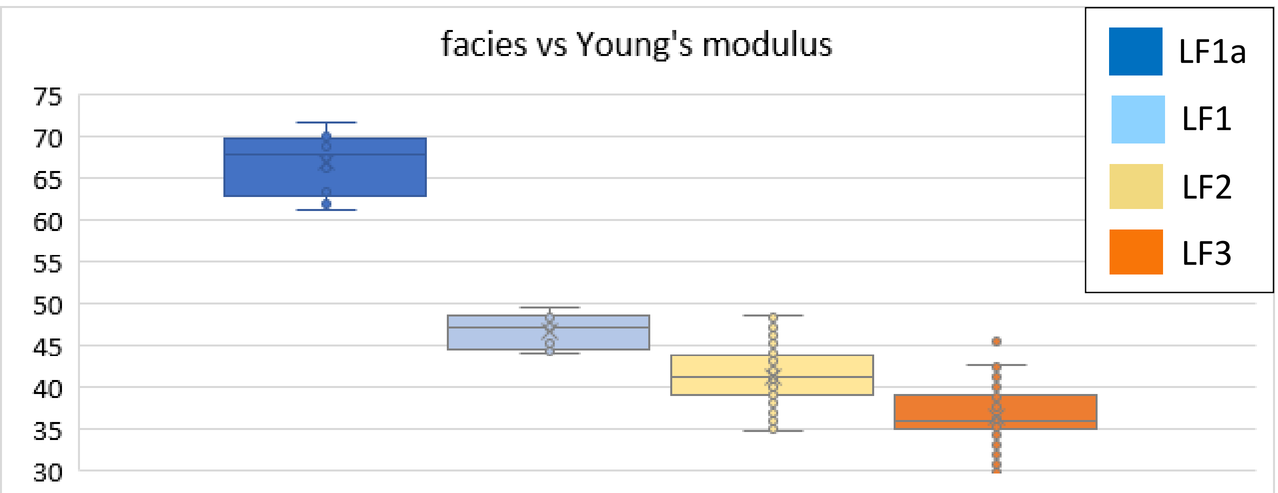
Significant variability in log-derived geomechcanical properties of the shales can be observed. In the analyzed vertical wells, going from LF1, to LF2, to LF3 we observe a clearly visible decrease in Young's modulus, showing averages of 47 MPa, 41 MPa and 37 MPa respectively. LF1a stands out having Young's modulus values in the 65-70 MPa range.

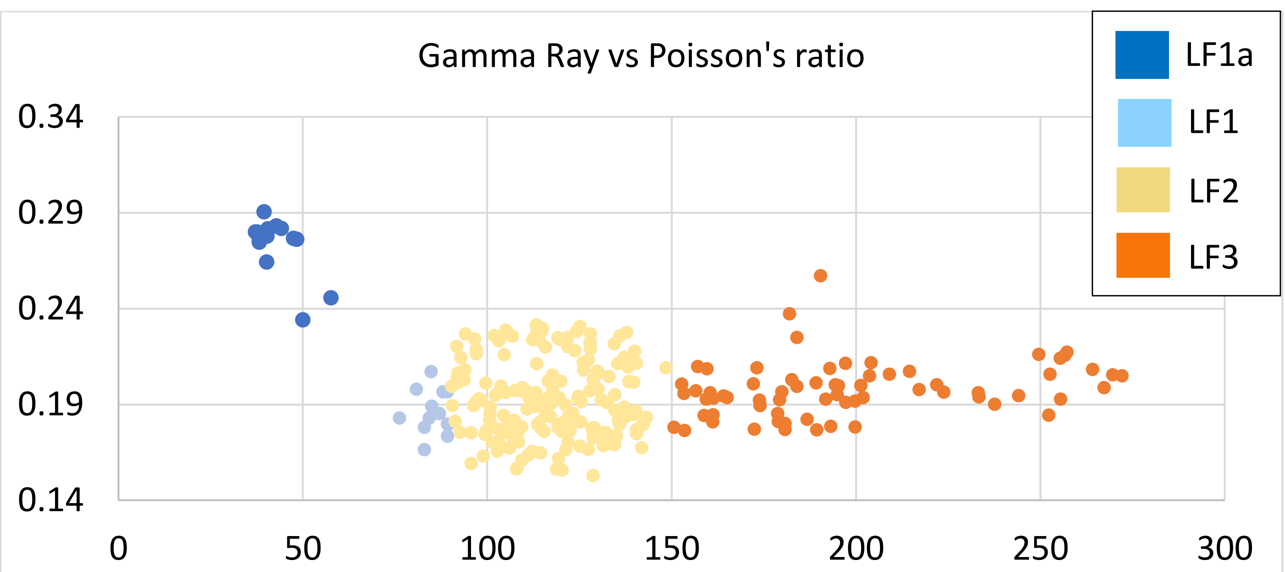
The difference in Young's modulus among the different facies is in part reflected by the same trend in bulk density. Density of LF1 and LF2 is comparable, whereas LF3 exhibits significantly lower values. LF1a shows the highest density values, with an average of 2.71 g/cm^3, close to the one of a pure carbonate.

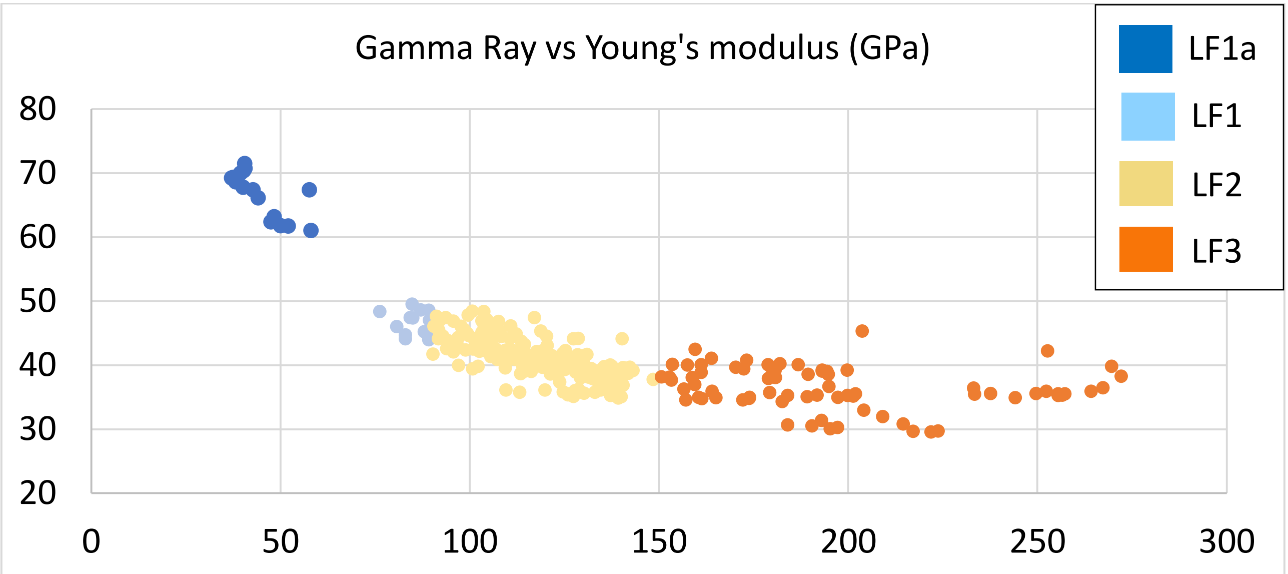
GR vs geomechcnical parameters cross-plots built based on data derived from a vertical well show that another geomechanical boundary exists within LF3, as 200 API acts as a geomechanical boundary as well. This boundary most likely reflect a difference in organic matter content between shales showing GR > 200

(LF3b) and < 200 (LF3a). This is also suggested by the lower bulk density value of LF3b with respect to LF3a.









Analyses of completion data from 4 horizontal wells show that completions in the organic-rich LF3 petrofacies require 10% higher breakdown pressure than completions in the more organic-lean LF2. This matches with LF3 having lower Young's modulus and lower brittleness index than LF2.
LF2 and LF3 also differ in natural fracture characteristics. ROP ranges for LF2 show a 10 to 48 m/hr range, whereas the range is 10 to 200 m/hr for LF3. ROP readings above 60 m/hr (more than double the average for LF3) have been interpreted as potential indicators of natural fractures in this TOC-rich facies of the Duvernay.

Conclusions

This work shows how sedimentary facies play a major role in defining the geomechanical characteristics of the Duvernay Formation. The integration of geology, geomechanics and petrophysics can effectively lead to a better understanding of the behaviour of unconventional plays undergoing hydraulic fracturing treatment.

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