A geomechanical comparison of the Duvernay and the Montney

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Summary

This study summarizes tests on the Kakwa Montney, the Beaverhill Formation, the Allstone's Creek outcrop (a Duvernay equivalent), and the Hood Creek outcrop (a Montney equivalent). It focuses on heterogeneity, post-peak failure, microhardness, and brittleness and compares the Duvernay and Montney, mainly through the results of advanced triaxial testing. The presentation focuses on more publically available data and implications of the results for hydraulic fracturing and induced seismicity.

Introduction

Hydraulic fracturing is ubiquitous in unconventional reservoirs. It can induce seismicity and is critical to the productivity and cost competitiveness of unconventional plays. Both induced seismicity and completions are significantly influenced by geomechanics. This influence is expected to increase as wells are drilled longer with rising completion intensities.

Many operators would struggle to find similarities between the Duvernay and the Montney. The Montney is a late Triassic siltstone with low total organic carbon (TOC) and migrated hydrocarbons whereas the Duvernay is a self-sourced clay-rich and high TOC mudstone. The eleven largest Montney plays averaged a profit/investment ratio ranking of 38/100 in the *2017 Playbook* whereas the four largest Duvernay plays average a ranking of 68/100 (Bean et al. 2017). The economics of unconventional reservoirs may tend to focus on reservoir quality, reservoir pressure, and petroleum initially in place. But completion effectiveness and the avoidance of shut-ins due to induced seismicity also play a large role and are worth consideration.

This study compares the geomechanics of the Kawka area of the Montney and the Kaybob area of the Duvernay. It focuses on geomechanical tests from outcrop, subsurface cores, and publically available data with the objective of showing how geomechanical tests can be used to differentiate and compare plays.

Study Area

The geological setting of the Duvernay and Beaverhill Formations is well covered by several other papers (Dunn et al. 2012; Rivard et al. 2014). It is a laterally extensive anoxic and sulphidic Frasnian basin fill deposited contemporaneously with the Leduc reef buildup. Its significant overpressure contributes to induced seismicity and the high productivity of the play. A broad facies classification might include clay and TOC rich shale, massive or bioturbated limestone, and interbedded shale and limestone. Outcrop equivalent samples were obtained from boulders collected for the Allstone's Creek Outcrop, a laterally and vertically extensive fissile section of the Perdrix Formation. Subsurface cores were obtained from an archived well in the Kaybob area (06-30-061-21W6).

The Montney (Armitage 1962) consists of early/lower Triassic stratea deposited in a fault-driven ramp system driven by transgression and regressions (Gibson and Barclay 1989). Its facies roughly include shoreface siltstones and sandstones, offshore siltstone turbidite deposits, and distal marine muds and shales (Davies et al. 1997; Moslow 2000). Outcrop equivalent samples were obtained from drill cores into the Hood Creek Outcrop, a valley exposure of several facies of the Sulphur Mountain Formation. Plugs were obtained from archived core samples in the Kakwa area (13-28-064-05W6) (Kuppe et al. 2012; Schmitz et al. 2014).

Experimental Methods

The samples were air dried in laboratory conditions for at least three weeks prior to testing. This was considered sufficient to avoid poroelastic effects during testing. Sample volume was determined using a 14-point caliper measurement. Skeletal density (the mass of a sample divided by its solid volume including closed pores) was determined using a Micromeritics Accupyc II 1340 Gas Pycnometer with Helium (Webb 2001). The porosity could then be derived with an accuracy of ± 1%. The elemental composition of the samples was assessed using an Olympus handheld X-Ray fluorescence (XRF) analyzer after pulverization (Beckhoff et al. 2006). Microhardness, or the coefficient of restitution, was evaluated using a Proceq SA Equotip Piccolo 2 with a type 'D' impact device (ASTM 2012).

Strength and stiffness anisotropy were evaluated using unconfined compressive strength (UCS) testing (Deere and Miller, 1966) with a displacement controlled loading of 0.15 mm/min (ASTM 2014). Brazilian testing (Carneiro 1943; Akazawa 1943) was used to determine indirect tensile strength on saw-cut discs. Two loading configurations were used: a direct contact test with the sample between two steel loading platens, and a cushioned test were 6 mm plywood cushions were inserted between the platens and the sample to reduce contact stress concentrations. The cushioned method is a recommended practice by both ASTM and ISRM whereas the direct contact method is generally avoided due to the generation of large stress concentrations (a desired outcome in this study).

Triaxial testing represents the most import test in this study due to its ability to replicate reservoir stresses (Fjaer et al. 2008). The multiple failure state (MFS) procedure (Kovari et al. 1983) was used to overcome the rarity of representative samples in unconventional reservoirs). It relies on the experimenter recognizing the peak stress during loading and thereby unloading the axial stress (Cain et al. 1987; Crawford and Wylie 1987) prior to the next stage of testing being carried out. Deformation was measured using linear variable differential transformers (LVDTs) and corrected for platen stiffness and membrane compliance through a series of calibration trials. Confining pressure was applied at 0.1 MPa/s during each stage. A fast deviatoric loading, up to 60% of the estimated UCS, was applied suing a strain rate of 0.05%/min. Then, a slow deviatoric loading was applied using a ramp and dwell procedure where radial strain was increased by 0.010% over 200 seconds, followed by a 30 s dwell period. This procedure, illustrated as Figure 1, was used to dissipate stored elastic strain energy close to failure and provide a negative feedback loop for unstable failure through the use of radial strain control. Elastic constants were determined using three methods: a tangent stiffness, a secant stiffness, and a linear least squares fit measured through 50% peak stress.

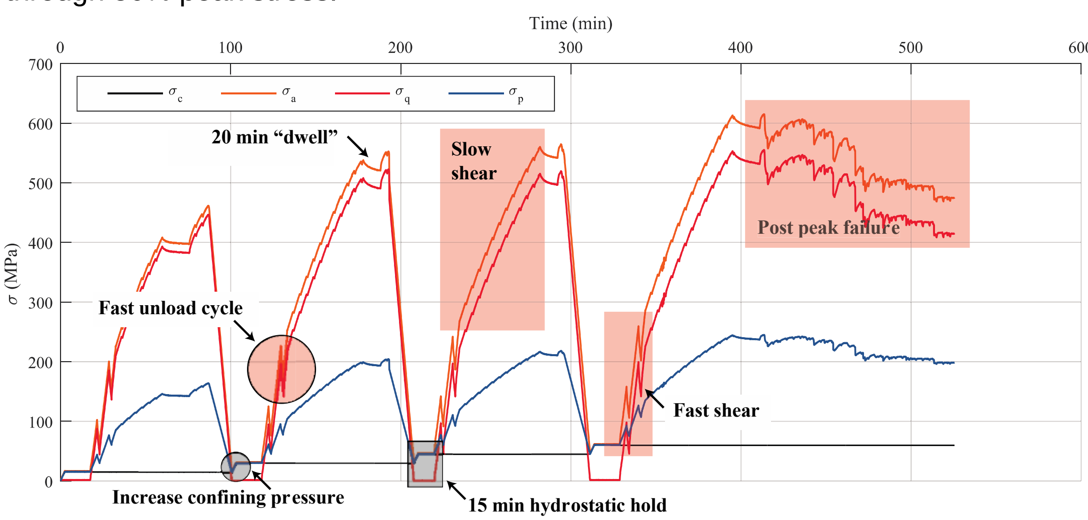

Figure 1. Illustration of the MFS triaxial procedure showing the increase in confining pressure and dwell period (black line), the fast and slow shear stages illustrated by the deviatoric (red line) and axial (orange line) stresses. Manual 20-minute dwell and post-peak failure portions of the test are also illustrated.

Results and Discussion

The experimental results showed that porosity and heterogeneity seemed to be good predictors of brittleness, strength, and the overall mechanical behavior of the samples. The Hood Creek samples were by far the stiffest and most brittle, followed by the Kakwa and Allstone's Creek samples, and then the Beaverhill samples. The post-peak failure of four samples at an effective stress of 60 MPa is presented as Figure 2 for comparison.

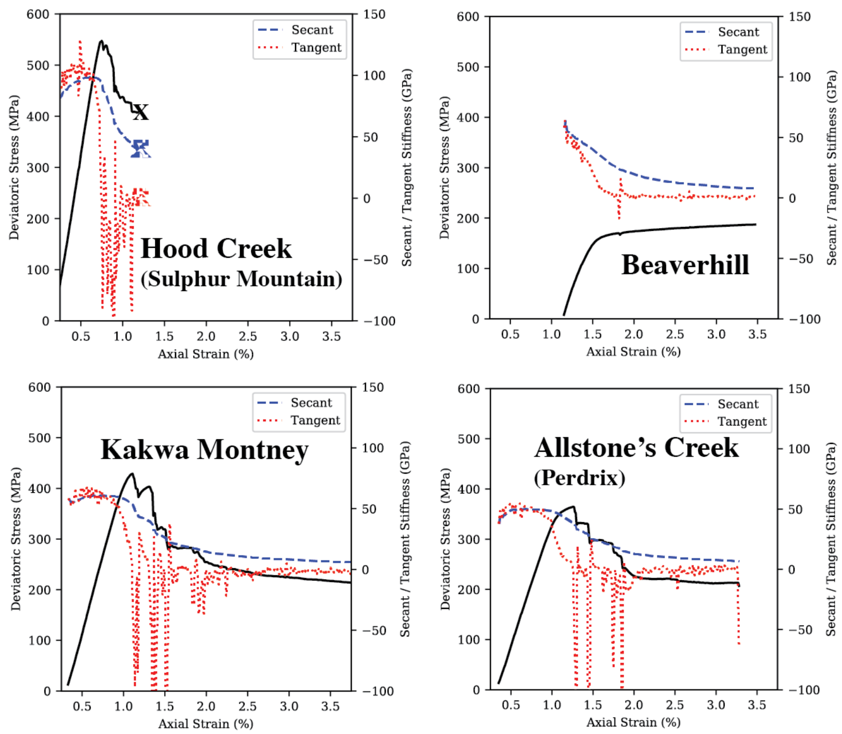

Figure 2. Comparison of post-peak behavior against axial stress from Hood Creek (upper left), Beaverhill (upper right), Kakwa Montney (lower left), and Allstone's Creek (lower right) samples. The black curve shows the deviatoric stress, the blue curve shows the secant stiffness, and the red curve shows the tangent stiffness. The tangent curve shows the instability during the failure process as the testing machine servo controls fight against unstable shear band propagation. The majority post-peak failures occurred in a series of stick-slip events followed by stable residual behavior, other than the Beaverhill samples, which failed in ductile fashion and strain hardened to the limits of the testing equipment.

The microhardness results showed similar trends to those observed during triaxial testing. Microhardness is a low cost tool that can be used during core logging and that may have the ability to distinguish geomechanical facies and provide a first-order indicator of mechanical behavior. Another index test that showed promise was the Brazilian test, despite the difficulties in its interpretation. The failure patterns of Hood Creek and Allstone's Creek provided ample evidence of bed-parallel failure and a high strength anisotropy. The Brazilian test has ability to measure elastic moduli and estimate tensile strength in laminated formations where core may 'poker chip' and limit plug availability. For example, the Brazilian tests in this study showed a very weak tensile strength for the Beaverhill Formation, another predictor of ductile behavior. This behavior may not be predictable by simply investigating the Young's Modulus (E) and Poisson's ratio (v) through UCS tests (e.g. both Allstone's Creek and Beaverhill samples had a pre-failure E of 50 GPa). Yet, there was a decent correlation between the static brittleness index and the observed behavior. Hood Creek had a mean E/v of 290 GPa, Allstone's Creek and Montney samples had a mean E/v of 120 GPa, and Beaverhill samples had a mean E/v of 75 GPa.

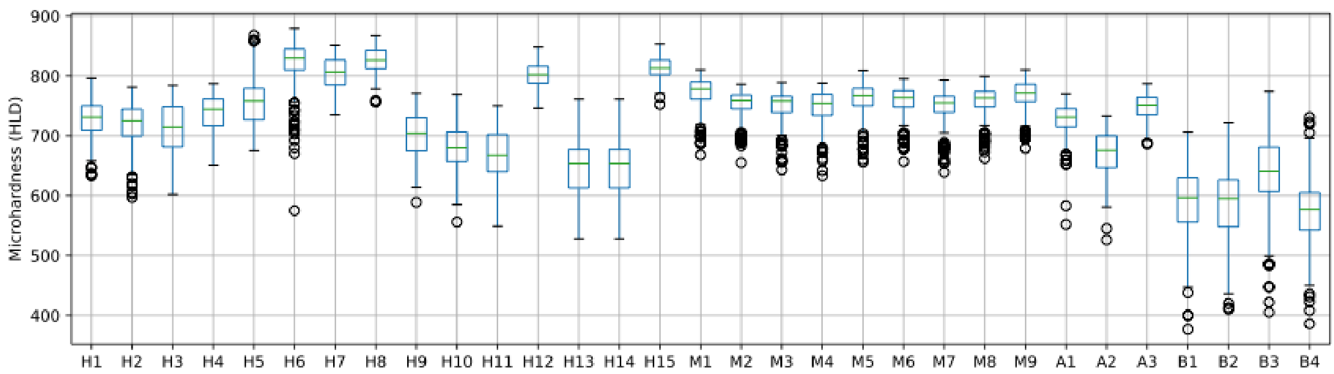

Figure 3. Microhardness results from Hood Creek (H), Kawka Montney (M), Allstone's Creek (A), and Beaverhill (B) samples. Note the low mean and high variability of the Beaverhill samples relative to the other formations. Also note the large amount of heterogeneity in Hood Creek relative to the Montney samples, a possible contributor to unstable fracture propagation.

Conclusions

There are massive compositional differences between the Devonian (i.e. Duvernay/Beaverhill Lake) carbonates and the Triassic Montney clastics. Yet, this study shows that these differences may be less pronounced than commonly thought relative to the variability in geomechanical facies across the basin. The triaxial samples from this study were collected from Duvernay equivalent outcrop because it is difficult to obtain representative samples from core. Even when samples are available, data is biased towards the strongest units (which are usually not the ones targeted for completions). There was a good correlation between Brazilian and microhardness results and the observed mechanical behavior in the tests, which indicates that these tests, while crude, may provide better information for basin scale comparisons than a series of triaxial tests that are biased towards stronger facies.

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