Introduction

The lower Triassic Montney consists of thick siltstones, spreading from north-eastern British Columbia to west-central Alberta (Cui & Nassichuk, 2018). It contains tremendous hydrocarbons in place (HIP) (Beaton, et al., 2010). The size is 900,000 gross acres with more than 60 trillion ft$^3$ of reserves (PETRONAS Canada, 2019), where horizontal wells and hydraulic fracturing are vastly implemented.

Attempting to do Petrophysical evaluations without calibrations can be misleading (Quirein, et al., 2010). This case study describes the formation evaluation steps: 1) Use XRD data to establish the minerals’ model, 2) Use core TOC to calibrate the calculated kerogen, and 3) Simultaneously solved for the bulk-volume, matrix density, total porosity, permeability and water saturation (Sw), calibrate to core and elemental capture spectroscopy (ECS) logs.

Montney is a complex reservoir. It exhibits very tight properties. The biggest challenge is to select the representative minerals. Montney consists of relatively fine-grain clay-rich laminae, intercalated with layers of coarse-grain quartz and silt-rich carbonate. It has heterogeneous pore structures with wide range of pore-throat sizes; 3nm to larger than 100 nm (Cui & Nassichuk, 2018). Thus, selection of the best model is crucial (Akai & Wood, 2014). From the available ECS logs, XRD data and upon team’s agreement, 6 minerals and kerogen were selected to be in the model (quartz, plagioclase, illite, calcite, dolomite and pyrite).

Logs Characteristic

Shale is a marine sedimentary rock, rich in organics, went for a specific burial history, and the source of hydrocarbon (Lewis, et al., 2004). Due to poor properties, the reservoirs must be big in volume, and mature TOC for hydrocarbon generations. Typically, the logs’ response for unconventional shale-play are: 1) High gamma ray reading (GR of 500 – 4000 API), 2) High formation resitivity (Rt), 3) Low bulk density (RhoB of 1.0 – 1.4 g/cc), 4) High Neutron-porosity (NPhi of 50 to 65 p.u.), and 5) Low photoelectric absorption factor (PeF). These are mainly coming from the kerogen (insoluble organic) within the shale (Stankiewicz*, et al., 2015).

XRD and ECS Data

XRD is an analytical but non-continuous data. It provides the information on minerals’ composition. It can be transformed into synthetic logs (Quirein, et al., 2010). However, XRD excludes porosity and kerogen measurements. Meanwhile, ECS logs provide continuous minerals’ and TOC compositions. Based on that, matrix-density and volume-fractions are calculated, followed by porosity, permeability and Sw calculations (Glorioso & Rattia, 2012).

\[
\rho_{\text{matrix}} = \frac{\sum (w_i \times \rho_{\text{minerals}})}{\sum w_i} \quad \text{Equation 1}
\]

\[
V_{\text{mineral}} = w_i \times \frac{\rho_{\text{matrix}}}{\rho_{\text{minerals}}} \quad \text{Equation 2}
\]

where $\rho_{\text{matrix}}$ is the matrix density (g/cm$^3$), $w_i$ is the mineral weight fraction (w/w), $\rho_{\text{minerals}}$ is the mineral density (g/cm$^3$), and $V_{\text{mineral}}$ is the mineral’s fraction volume (v/v).
TOC / Kerogen Quantification

TOC computes the total organic carbon, followed by kerogen volume (Schmoker & Hester, 1983).

\[
TOC = \frac{Schmoker_A}{\rho_B} - Schmoker_B
\]

Equation 3

\[
Kerogen = \frac{TOC \times Conv \times \rho_B}{\rho_K}
\]

Equation 4

where TOC is the total organic carbon (w/w), SchmokerA is 154.5 (constant), SchmokerB is 57 (constant), Conv is 1.2 (conversion factor), \(\rho_B\) is the bulk density (g/cm\(^3\)), and \(\rho_K\) is the kerogen density (g/cm\(^3\)).

Porosity and Permeability

PhiT is calculated from \(\rho_B\), while permeability is calculated by using K-Lambda equation (Herron, Johnson, & Schwartz, 1998).

\[
\Phi_{Total} = \frac{\rho_{ma} - \rho_{log}}{\rho_{ma} - \rho_{fluid}}
\]

Equation 5

\[
K_L = \frac{Z \times m^* + 2 \times \pi W_i \times S_{oi}}{\rho^2 \times (1 - \Phi)^2 \times (\sum W_i \times S_{oi})^2}
\]

Equation 6

where \(\Phi_{Total}\) is the PhiT (v/v), \(\rho_{ma}\) is the matrix-density (g/cm\(^3\)), \(\rho_{log}\) is the log-density (g/cm\(^3\)), \(\rho_{fluid}\) is the fluid density (g/cm\(^3\)), \(K_L\) is the permeability (mD), \(Z\) is 200,000 (constant), \(\Phi\) is the PhiT (v/v), \(m^*\) is the clay corrected cementation factor, \(\rho\) is the grain-density (g/cm\(^3\)), \(W_i\) is the mineral’s weight-fraction (w/w), and \(S_{oi}\) is the mineral’s specific surface area (m\(^2\)/g). When the initial estimate-permeability is less than 100 mD (majority case), the calculated permeability is modified:
\[ K_{L_{\text{final}}} = 0.034325 \times K_L^{0.714} \]

**Equation 7**

**Water-Saturation**

The electrical properties used to calculate \( S_w \) in Montney are tortuosity (\( a \)) of 1, cementation factor (\( m \)) and saturation exponent (\( n \)) of 2. Water resistivity (\( R_w \)) of 0.04 ohm.m at 24°C is used. This translates into 229K ppm (NaCl equivalent). While Archie’s describes the electrical conductivity of shale-free environments, Waxman-Smits’s accounts for the dual-conductivity formed by pore-brine and clay mineral exchange cations in shaly-environments (Onovughe & Sofolabo, 2016). However, the low presence of illite causing the \( S_w \) calculated from both equations to be the same.

\[ S_{w-Archie} = \frac{R_w}{R_t} \times \frac{1}{\phi^m} \]

**Equation 8**

\[ S_{w-Waxman\ Smits} : \frac{R_w}{S_{w-WS} \times \phi^m} \left( 1 + \frac{B \cdot Q_v}{S_{w-WS}} \right) = R_t \]

**Equation 9**

where \( R_t \) is the formation resistivity (ohm.m), \( R_w \) is the water resistivity (ohm.m), \( B \) is the specific cation conductance (mL/ohm.m meq), \( Q_v \) is the volumetric CEC (eq/L), \( n \) is the saturation exponent, \( n^* \) is the clay corrected saturation exponent, \( m \) is the cementation factor, \( m^* \) is the clay corrected cementation factor, \( \phi \) is the porosity (v/v), and \( S_w \) is the water saturation (v/v).

**Result**

The above described steps are applied to Well-1. Figure 2 consists of 15 tracks. The first three tracks are the raw logs, while the rest are showing the calculated results. The log interpretation was done with the software Techlog 2017.2.

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**Figure 2:** The interpreted result for Well-1. Track 2 to 4 show raw logs of caliper, GR, Rs, Rt, PeF, NP\( \phi \)i, RhoB; track 5 shows the matrix-density; track 6 shows the PhiT, Phi-effective; track 7 shows K-Lambda; track 8 shows the lithologies; track 9 to 16 show the interpreted \( S_w \), quartz, illite, calcite, dolomite, plagioclase, pyrite, TOC, and kerogen, calibrated to core (red dots).
Conclusions

This paper outlines the steps used for formation evaluation in Montney. The process requires integration between cores and logs data: 1) RCA and special core analysis (SCAL) provide information on the minerals present, reservoir properties and Sw, and 2) Standard and geochemical logs provide continuous reservoir information (independently). Without them, one might produce misleading results. This workflow had produced a well calibrated interpretation (cores vs. ECS logs). Core XRD data has demonstrated to be a good calibration point during the evaluation works.

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References


