When diagenesis calls the shots: why understanding post depositional processes is essential for understanding the Montney Formation

Noga Vaisblat*1, Nicholas B. Harris1, Korhan Ayranci1, Chris DeBhur2, David Bish3, Rick Chalaturnyk1, Federico Krause2, Tristan Euzen4, Sebastien Rhoais5, Vincent Crombez6; 1. University of Alberta, 2. University of Calgary 3. Indiana University 4. IFP Technologies (Canada) Inc. 5. IFP Energies nouvelles 6. CSIRO Australia

Background

Evaluation of reservoir quality is a key step in assessing the economic viability of hydrocarbon development and production. In this work, we investigate whether depositional or post depositional processes exerted the main control over reservoir quality (porosity, permeability and geomechanics) in the Lower Triassic Montney Formation of the West Canada Sedimentary Basin.

Sediment source, depositional environment and diagenetic processes are the main factors influencing reservoir quality in siliciclastic formations. Source terrain dictates the composition of detrital material entering the basin. Depositional environment influences the mineralogical composition and grain size of the accumulating sediment. Different lithofacies are manifestations of different depositional environments, and commonly have unique compositions and unique grain size distributions, and thus different initial porosity and permeability (Morad et al., 2010).

Porosity and permeability control fluid-flow, which can drive diagenetic processes through alteration of pore water chemistry, allow for cement precipitation and govern compaction processes. Therefore, different lithofacies in a formation can be associated with different diagenetic pathways. Much work has been conducted on the sedimentology of the Montney Formation over the years (e.g. Davies et al., 1997; Zonneveld, 2011; Playter, 2013; Davies et al., 2018; Euzen et al., 2018; Zonneveld and Moslow, 2018). Less attention has been devoted to the diagenetic history of the formation (Davies et al., 1997; Barber, 2003; Chalmers and Bustin 2012; Wust, 2018), and none of those studies related their findings to sedimentary facies. If different lithofacies in the Montney have different depositional fabric and, as a result, followed different diagenetic pathways, than identifying horizons with the best reservoir quality should be a straightforward task.

Aims and Objectives

The aim of this study is to investigate the main controls over reservoir quality in the Montney Formation are. To this end, we set the following objectives:

(1) Describe the lithostratigraphic units (lithofacies) in the Montney Formation at several locations across the basin;
(2) Identify and quantify rock composition and fabric;
(3) Identify and quantify detrital and authigenic mineralogical phases in the siltstone; and
(4) Examine and explain the relationship between the lithostratigraphic framework and reservoir quality parameters (porosity, permeability and geomechanical properties)

Geological setting:

The Montney Formation covers over 130,000 km² in central and southwestern Alberta and northeastern British Columbia (fig. 1). The formation was deposited during the Lower Triassic (Induan and Olenekian; fig. 2) (Davies et al., 1997; Utting et al., 2005; Zonneveld et al., 2010) in a foreland basin on the western margin of Pangea (Blakey, 2014; Golding et al., 2015; 2018). The Montney was deposited in a westward-dipping and deepening basin, during a time of hot and periodically arid climate with seasonal monsoons (Davies, 1997; Glokona and Ford, 2000; Preto et al., 2010; Sun et al., 2012; Zonneveld and Moslow, 2018).

Sediments composing the Montney were sourced mainly from the Laurentian continental margin, and to a lesser degree from the Innuitian orogenic wedge with a possible minor sediment contribution from a western volcanic terrain (Ross et al., 1997; Beranek et al., 2010; Crombez et al., 2016; Golding et al., 2016; Rohais et al., 2018). Burial history reconstructions show that the Montney subsided <1500 m for the first ~100 million years (Ness, 2001; Ducros, 2017; Rohais et al., 2018). The Laramide Orogeny (Early Cretaceous) initiated rapid subsidence of the formation, reaching a maximum burial depth at Ca. 57.8 Ma (Willett et al., 1997; Ness, 2001; Ducros, 2017; Rohais et al., 2018).

The Montney Formation is subdivided into an Upper, Middle, and Lower Members (Davies et al., 1997; Zonneveld and Moslow, 2018) and is bound by the Permian-Triassic unconformity from below and the Coplin and sub-Jurassic unconformities from above (fig.2). At present, the Montney deepens to the southwest, from under 1000 m at its eastern edge, to over 4000 m along the Rocky Mountains deformation front. This deepening trend dictates increasing bottom-hole temperatures (< 50°C to over 90°C) and organic matter maturity (Rₒ=0.59% to Rₒ>2%) from the northeast to the southwest (Riediger et al 1990; Ibrahimbas and Riediger, 2004; Sarmiento et al., 2016; Crombez et al., 2016; Wood and Sanei 2016).

Figure 1: (a) Location of study wells. Cored wells are (2) 16-17-083-25W6 (4) 16-29-079-20W6 (6) 06-03-079-13W6 (9) 05-24-063-6W6 (15) 103/05-20-079-22W5. Full dataset includes core description, SEM and SEM-CL imaging, thin section analysis, QEMSCAN analysis on rock chips, porosity, and TOC. Map modified after Zonneveld and Moslow (2018). (b) A chronostratigraphic chart for the Triassic and Lower Jurassic in the WCSB. Location of study wells is marked at the top of the chart. UC is unconformity. Ages after Golding et al., 2016.
Materials and methods

The dataset from this study is composed of both drill-cuttings samples (3 wells) and long cores (5 wells). Completing the data set are thin sections (14) and core samples (15) from 13 additional wells in the Montney Formation. The location for all sampled wells in this study is presented in Figure 1. Four cores were logged at the cm scale to provide a detailed sedimentological characterization. The following data was used to identify lithofacies in the siltstone: lithology, grain size, sedimentary structures, trace fossil assemblages, and bioturbation intensity.

Mineralogy was determined through QEMSCAN analysis at SGS Canada, and confirmed with quantitative XRD analysis at Indiana University and the Hutton Institute. Point count analysis was performed on images obtained with a Scanning Electron Microscope equipped with a Cathodoluminescence detector (SEM-CL) at the University of Calgary. We randomly selected three (1000X magnification) areas, perpendicular to bedding, from each sample and used a 437-points grid on each image. EDS elemental maps were used to identify mineralogy and SEM-CL images were used for separating detrital from authigenic phases. We also used SEM-CL images to estimate detrital grain size by measuring the longest apparent axis of detrital grains. SEM analysis was used to examine rock fabric, identify cements, and establish the relative timing of authigenic phases.

Porosity and crushed rock permeability was measured with He-Pycnometry at AGAT, Calgary on 134 samples from the 4 long cores. For the four long cores, we calculated Young’s Modulus and Poisson’s Ratio from sonic and density well-logs. Samples with high Young’s Modulus and low Poisson’s Ratio are considered more brittle, whereas samples with low Young’s Modulus and high Poisson’s Ratio are considered more ductile and less suitable for hydraulic fracturing. Ductile rocks are associated with higher content of organic matter and soft minerals (mostly clays). Brittle rocks are associated with higher content of hard minerals (quartz, feldspars, and dolomite).

Results and discussion

Sixteen lithofacies were identified in the 4 long cores. Eight lithofacies comprise over 90% of all cores analyzed (Table 1). Major minerals identified in our samples include quartz, K-feldspar, plagioclase, micas (muscovite, biotite, and chlorite), dolomite, calcite, and clay minerals (mixed layer illite-smectite and kaolinite). Minor phases include iron oxide, sulfides, anhydrite, phosphate, fluorite, barite, and heavy minerals. Mineralogical assemblages of all wells are summarized in Figure 3. XRD analysis results are consistent with QEMSCAN results. Carbonate mineral content shows the largest variation between samples. In most wells, quartz and feldspars concentrations along the well vary antithetically to the total carbonate concentration. Clay minerals concentrations usually increases with depth.

A detailed presentation of paragenetic relationships is beyond the scope of this paper. Briefly, shallow burial diagenesis took place during the first ca. 100 Ma following deposition, under conditions of very slow burial and minor compaction. Open pore space and good hydraulic connectivity allowed for fluid flow and massive precipitation of quartz, feldspar, dolomite, and calcite cements (Figure 4). Point count analysis results indicate that shallow burial cements compose over 30% of present day rock volume. Late burial diagenesis occurred during the Laramide orogenic event, when the entire basin subsided, and the Montney was exposed to elevated temperatures. Temperature-controlled reactions characterize late burial diagenesis that include hydrocarbon maturation and pressure solution.

Results from point count analysis allowed us to calculate the detrital composition of different lithofacies in three wells (Figure 3). Detrital composition variations between lithofacies in the same well are small. Some lithofacies have similar detrital composition in different wells (G, wells 2 and 4), but others may have significantly different detrital composition in each wells (H, in wells 2 and 9). For the four logged cores, mineralogical composition is presented by lithofacies. Note that with the exception of well 15, it is impossible to distinguish one lithofacies from another based on mineralogical composition.

Because quartz is the mineral least susceptible to dissolution in the Montney Formation, we used grain size of detrital quartz measured on SEM-CL images as a proxy for detrital material grain size (Figure 5a). All detrital grains in our samples are silt-size, but some variation between lithofacies is apparent. Lithofacies F, G, H, and K are medium silt or finer, while lithofacies B, N, and O are medium silt or coarser. The small variation in grain size in the Montney Formation is attributed to the limited f grain size range of the sediments that entered the basin (Davies et al., 1997; Zonneveld and Moslow, 2017).
Figure 3: QEMSCAN analysis results in wt%. QFM is the sum of quartz, K-feldspar, Na-feldspar and micaceous minerals. Clay minerals include MLIS and kaolinite, and carbonate minerals include calcite, dolomite and Fe-rich dolomite. Mean composition of each well is marked with a light blue circle. Gray areas are calculated detrital composition. Compositional variations between samples of different lithofacies (color coded) are presented for the four Montney cores logged. Note the large variations in carbonate minerals content. With the exception of well 15, lithofacies are compositionally indistinct from one another.

Figure 4: SEM-EDS (a) and SEM-CL (b) of the same sample, showing detrital grains and authigenic cements. Nasp is Na-feldspar, Ksp is K-feldspar, Qz is quartz, Dol is dolomite, Cal is calcite, Py is pyrite, and Ti is titanite. On the SEM-CL image (b), d suffix stands for detrital grain, while c suffix is for cement. Core 2, sample 3AJ, 2653 m.
We next examined the geomechanical properties of each lithofacies, calculated from well-logs. Several studies of fine-grained formations established that different lithofacies can have distinct mechanical behavior (Dong et al., 2017; Moghadam et al., 2019). However, in the Montney Formation, we see no clear distinction in the geomechanical properties of different lithofacies (Figure 5b). With one exception in well 15, it is impossible to distinguish any lithofacies from another based on their Young’s Modulus and Poisson’s Ratio values. Moreover, the same lithofacies can have very different values in different wells, and variations in the geomechanical properties are more a function of well location than the lithofacies themselves.

Figure 5: Lithofacies-dependent properties (a) detrital quartz grain size range for five lithofacies in the study area. Range of values is 5-95 percentile. Outliers (dots) are upper and lower 5%. Although there are little variation in grain size range, two grain size groups are notable (1) facies F, G, and H with a slightly smaller median grain size, and (2) facies O and B with a slightly larger median grain size. (b) Median value and range of calculated dynamic Young’s Modulus and dynamic Poisson’s Ratio for the 8 major lithofacies. Note that with one exceptions in well 15, it is impossible to distinguish one lithofacies from another based on their Young’s Modulus and Poisson’s ratio values, and that the same lithofacies may exhibit a very different range of Young’s Modulus and Poisson’s ratio values in different wells (for example lithofacies H). Porosity (c) and matrix permeability (d) for the eight major lithofacies. Note that porosity and permeability values of the lithofacies can be significantly different between wells, and different lithofacies in the same well have similar porosity and permeability ranges.
Similar to geomechanical properties, porosity (Figure 5c) and permeability (Figure 5d) in all four wells are also not dependent on lithofacies. Porosity and permeability values for any given lithofacies can be dramatically different between wells, and different lithofacies in the same well show very similar porosity and permeability ranges. Here too, reservoir quality properties seem to be controlled more by the location of the well than by rock fabric.

The data we present demonstrate that the Montney Formation siltstone is relatively homogeneous in terms of grain size and composition. Petrophysical and geomechanical properties vary with well location. Almost none of the lithofacies described in the study has its own unique reservoir properties, and many lithofacies have different properties in different wells. We attribute some of the composition homogeneity to the small variations in detrital grain size and composition between different depositional environments. We suggest that the massive shallow cementation event that accounts for more than 30% of present day rock volume, further homogenized rock composition and grain size in the Montney Formation and overprinted any differences in rock fabric that may existed at the time of deposition. This can explain why geomechanical and petrophysical properties are not distinctly different between lithofacies in the same core.

Conclusions

The data we present here demonstrate that reservoir quality in the Montney Formation is primarily controlled by post-depositional processes rather than rock fabric. Detailed, quantitative pool-scale diagenetic studies are required to identify sweet spots in the Montney siltstone reservoir.

References


Davies, G.R., Watson, N., Moslow, T.F., and Maceachern, J.A., 2018. Regional subdivisions, sequences,


