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Origin and Evolution of Clay Mineralogy in the Montney Formation

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Summary

Clays in unconventional reservoirs, including the Montney Formation, are significant to understanding petrophysical properties (porosity, permeability, and water saturation) and geomechanical properties. Consequently, the quantity, type and distribution of clays affect reserve estimates, well completions and well performance. Clay content, composition and distribution are dictated by the sediment source type, climate at the sediment source and at the site of deposition, the depositional environment, and diagenetic processes (burial and temperature history and water-rock interaction). Understanding the conditions under which the sediment was deposited and the evolution of the mineralogical composition of the rock may enhance our ability to target higher quality reservoir intervals.

The Montney Formation is a tight siltstone reservoir, deposited on the western margins of the North American continent during the Lower Triassic. Sediments composing the Montney Formation were primarily sourced from the felsic terrain of the Canadian Shield, and transported into the basin during a period of hot and arid climate, with seasonal monsoons. Sediments were finally deposited in the hot, acidic and intermittently anoxic Triassic ocean. These factors combined to determine the composition of the deposited sediment, which mainly included quartz, chert, feldspars, dolomite, and mixed layer illite-smectite (MLIS) clays.

Whether clay minerals exist in any significant quantity in the Montney Formation has been a controversial topic for the past several years. Our results show unequivocally that clays are a significant component in the Montney siltstone, and are affecting reservoir quality properties.

Methods

Our study of clay minerals in the Montney Formation is part of a larger diagenetic study of the formation that includes a total of 16 wells. Four long cores were logged and sampled at constant intervals, and three wells were characterized through cuttings samples. Thin sections and core samples obtained from additional ten wells provided further information and completed the data set.

Quantitative mineralogical composition for all samples was determined by QEMSCAN analysis at SGS Canada laboratories. In addition, 26 samples were analyzed for quantitative whole rock and clay fraction XRD at the James Hutton Institute, and the Mineralogy Facility at the Indiana University in Bloomington. Cathodoluminescence (CL) optical microscopy, as well as Scanning Electron Microscopy (SEM) and SEM-CL analyses were used to distinguish detrital grains from cements, and establish cross-cutting relationships between the different authigenic phases. Point count analysis (1,300 points/sample) on SEM and SEM-CL images provided quantitative information on the volume of different detrital and authigenic phases. Elemental composition was obtained by ICP-MS analysis at ACME lab, Vancouver. The information obtained from all analyses was then integrated into a paragenetic sequence that can be explained in terms of sediment source material, climate and oceanic conditions at the time of deposition, compaction rates, and the thermal history of the formation.

Results and discussion

Shallow burial diagenesis is characterized by massive precipitation of quartz, feldspar, dolomite, and calcite cements that comprised over 30% of present-day rock volume. Massive cementation was made possible due to very slow burial rate over the first ~100 million years, when minor compaction allowed for good hydraulic connectivity and high volume fluid-flow through the open pore system. Late, deep burial diagenesis occurred during the Laramide orogenic event, when the entire basin subsided and the Montney was exposed to elevated temperatures. Late burial diagenesis is characterized by temperature-dependent reactions, including hydrocarbon maturation, pressure solution of all mineralogical phases, and illitization of smectite, which is the reaction on which the following discussion will focus.

QEMSCAN and quantitative XRD analysis results are consistent and show that clay minerals concentrations in the Montney vary across the basin from just under 1.5 wt.% to 37 wt.%, with an average of 14 wt.%. Clay concentration, as obtained from XRD and QEMSCAN analyses is also consistent with ICP-MS aluminum oxide (Al_2O_3) content. These results indicate a much greater concentration of clay minerals in the Montney Formation than previously estimated. The main clay mineral in the Montney Formation is MLIS, but minor amounts of authigenic kaolinite (1 wt.% on average; Fig. 1a) and some fibrous illite (Fig. 1b) were also identified.

MLIS is at present ~95% illitized throughout most of the basin and thus have insignificant swelling potential. The presence of swelling clays in the Montney was previously reported exclusively in the Ring-Border and Dixonville fields, on the northeastern edge of the Montney (Edwards et al., 1994; Zonneveld and Moslow, 2014; 2018). Quantitative clay XRD analyses confirmed the presence of MLIS with swelling potential of 20% in the Dixonville field.

Edwards et al. (1994) proposed an active volcanic arc to the west as the source for those swelling clays, but both the Dixonville and Ring-Border areas were later interpreted as wave-dominated deltaic systems, draining sediments into the basin from the east (Zonneveld and Moslow, 2014; 2018). Zonneveld and Moslow (2014) suggested that swelling clay precipitated as a result of feldspar dissolution in perennial rivers, and that swelling clays were trapped in deltas due to rapid flocculation induced by salinity changes at the delta front (Zonneveld and Moslow, 2018). Although feldspars tend to dissolve when continuously exposed to fresh water, feldspar dissolution cannot provide the iron and magnesium required for precipitation of swelling clays. Moreover, flocculation in modern systems does not trap clay minerals exclusively in deltas; instead, some clays - particularly true of the mixed layer clays - are transported farther into basins, which is consistent with our observations of detrital clay in the deep Montney (Fig.1c).

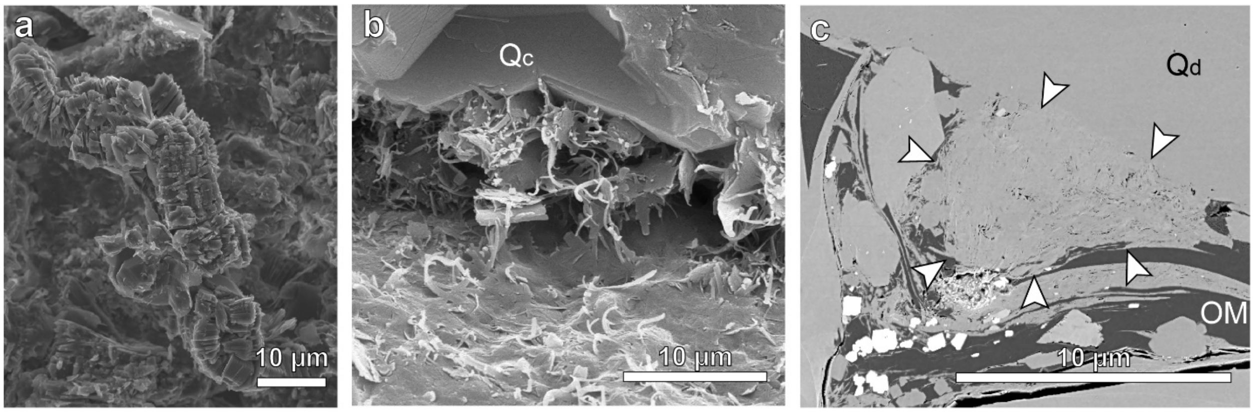

Figure 1: Clay minerals in the Montney formation (a) authigenic kaolinite (b) authigenic fibrous illite. Note quartz cement (Qc) at the top of the image (c) clay colloid (white arrows) in the distal section of the Montney near a detrital quartz grain (Qd).

Novel/Additive Interpretation

We propose that MLIS clays were generated through weathering of micas (chlorite, biotite, and muscovite) in felsic terrain under arid climate, and delivered into the basin with swelling potential of 20%. Since illitization of smectite is a temperature-controlled process, initiating at approximately 90°C, we submit that the entire Montney Formation, except near the north-eastern edge of the present-day subcrop, was exposed to elevated temperatures during burial, leading to illitization of smectite and reduction in the swelling potential of the clays. Our model is supported by an apatite fission track study that interpreted elevated temperatures (>80°C) close to the Triassic subcrop edge (Willett et al., 1997) and by the presence of late quartz cement and albitization of K-feldspar, which both are commonly associated with smectite-to-illitize reaction (Milliken, 1989).

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