Integrated Sedimentology, Ichnology and Petrography of Unconventional Gas Reservoirs of the Montney Formation; Dawson Creek Region, Northeastern British Columbia, Canada

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Introduction:
The Montney Formation in northeastern BC has emerged as one of the premiere unconventional gas plays in North America. While horizontal drilling and completion technology is primarily responsible for the success of this play, the role of primary deposition and its influence on reservoir quality distribution is a subject that has received much less attention. The objective of this presentation is to interpret the depositional processes associated with the Upper Montney, through the integration of sedimentology, ichnology and petrography.

Study Area and Geological Setting:
The study area is situated in northeastern B.C. and the adjoining region of west-central Alberta. The Montney Formation is Lower Triassic in age and is an unconformity-bounded siltstone dominated succession deposited adjacent to the northwest corner of the supercontinent Pangea (Gibson and Edwards, 1990; Davies, 1997a). In the study area the Montney is over 300m thick and is subdivided into upper and lower intervals on the basis of a major regional flooding surface. The Montney comprises a continuous basin-centred gas accumulation within the study area, with prolific production associated with horizontal wells, primarily in the upper Montney interval. Key pools include Dawson, Bissette, Parkland, Sunset, Sunrise, Groundbirch and Septimus.

Stratigraphic Architecture:
The lower Montney comprises a westward tapering wedge that features three morphological elements, including a shelf-edge which separates a shelf platform that extends to the east, from a slope to the west. The thickness and distribution of the upper Montney is controlled by the topography on the lower Montney, such that the upper Montney thickens abruptly and progressively west of the lower Montney shelf-edge.

The upper Montney is comprised of at least five offlapping sub-units designated as the upper Montney A through E in ascending order. These subunits record the continued progradation and aggradation of the Montney shelf-margin through time.

Petrography:
Petrographically, the Montney is composed of fine to coarse siltstone with very minor amounts of both very fine sand and clay. The detrital grains consist mainly of quartz and feldspar, while dolomite calcite and silica are the most common cements. A distinctive feature of the upper Montney is the pervasive occurrence of organic matter or kerogen, which is primarily responsible for the characteristic dark grey appearance of the rock. Total Organic Carbon content ranges from 0.5% to 3.5% and is somewhat facies dependant with a tendency towards higher TOC values in the more distal facies. An interesting outcome of some preliminary palynological analysis, is the recognition that a significant component of the identifiable organic material is terrestrial in origin. These findings have important implications regarding the depositional processes associated with the upper Montney.
Facies Description and Interpretation:
The detailed evaluation of about a dozen cores has revealed that the upper Montney is comprised of three main facies, which are further subdivided into a number of subfacies based on subtle differences in lithological and ichnological features. Facies 1 was deposited in a shelf to prodelta fringe setting and is comprised of dark grey siltstone with rare pinstriped lamina of light grey siltstone; Facies 2 was deposited in a distal prodelta setting and is characterized by pinstripe laminated light grey and dark grey siltstone; and Facies 3 was deposited in a proximal prodelta setting and is characterized by bioturbated light grey siltstone interbedded with pin stripe laminated light and dark grey siltstone.

A core from the Dawson pool in the ARC Energy 11-4-79-14W6 well is used to examine those specific features of each facies that facilitated interpretation of the associated depositional processes. This core was chosen as it spans almost the entire section of the upper Montney and contains most of the facies encountered in the study.

Facies 1:
The dark grey siltstone of Facies 1 ranges from being essentially structureless, to containing very rare pinstriped lamina of light grey siltstone. These lamina suggest that deposition occurred by suspension fall-out, in a quiescent setting. There is no evidence of wave generated structures such as wave ripples, indicating that deposition occurred below maximum storm wave base. Soft-sediment deformation structures occur locally and are indicative of episodic rapid sedimentation.

Bioturbation is generally absent in Facies 1, with the exception of rare weakly bioturbated beds. This suggests that the paleoenvironment was generally hostile towards burrowing organisms. The overall lack of bioturbation is interpreted to reflect bottom-water anoxia in which stagnant bottom waters are depleted of oxygen by bacteria during the process of decomposition of the abundant organic matter in the substrate (Demaison, 1980; Rabouille et al, 2008).

In summary, Facies 1 was deposited by suspension, below maximum storm wave base, on an anoxic shelf that periodically experienced episodes of rapid sedimentation.

Facies 2:
Facies 2 is characterized by pinstripe laminated light grey and dark grey siltstone, which also suggests deposition from suspension in a quiescent setting. However, wave ripples and wave modified current ripples are common indicating that deposition occurred above storm wave base. Also common are soft-sediment deformation structures which are indicative of episodes of heightened sedimentation.

Bioturbation is generally absent, suggesting that paleoenvironmental conditions were inhospitable. However, local intervals display low to moderate levels characterized by a low diversity suite of tiny traces. The sporadic distribution of low diversity and diminutive traces reflect fluctuating and stressed conditions (Bann and Fielding, 2004; MacEachern et al, 2005).

To summarize, Facies 2 was deposited above storm wave base in an environment that was characterized by episodic rapid deposition as well as fluctuating and stressed conditions, which is consistent with deposition in a distal prodelta setting (Bann and Fielding, 2004; MacEachern et al, 2005).

Facies 3:
Facies 3 is characterized by bioturbated light grey siltstone interbedded with pinstripe laminated light grey and dark grey siltstone. The pinstripe laminated interbeds are commonly associated with soft sediment deformation, implying rapid sediment emplacement, possibly by storms. While the bioturbated intervals record periods of slow sedimentation reflecting the return to fair-weather conditions following the passage of the storm. These alternating laminated and bioturbated successions are referred to as lam-scram beds and are characteristic of distal storm deposits (Bann and Fielding, 2004; MacEachern et al, 2005).
The abundant bioturbation characterizing Facies 3 reflects well oxygenated bottom waters, which is consistent with more frequent wave agitation. The trace fossil assemblage is relatively diverse however, the size of the traces are small in comparison to fully marine counterparts, suggesting that the paleoenvironment was somewhat stressed. Individual traces include Phycosiphon, Planolites, Zoophycus, Teichichnus, Trichichnus, Chondrites, and others including tiny Asterosoma and Paleophycus.

The well oxygenated yet stressed paleoenvironmental conditions suggest deposition between fair-weather and storm wave base in a proximal prodeltaic setting that was influenced by storms.

**Summary of Depositional Processes:**
The assemblage of facies within the upper Montney, and the abundance of terrestrially derived organic matter, suggests that deposition occurred on a marine ramp that was influenced by deltaic and storm processes. A semi-arid climate is inferred in which previously deposited and easily eroded silts were flushed into the ocean during flash floods, triggered by seasonal heavy rainfall (Mulder et al, 2003; Fraticelli, 2006; Bhattacharya and MacEachern, 2009). These silts and associated organic matter was deposited on the proximal portion of the ramp, where storm waves, possibly associated with the heavy rains, could have resuspended the material and transported it further down-slope to the distal portions of the ramp, resulting in episodic accumulation of organic rich silts (Traykovski et al, 2000; Fan et al, 2004; Bentley, 2003; Wright et al, 1990).

During the intervening arid periods when the influx of river derived silt and organic matter was reduced, storm waves would have winnowed the substrate resulting in a dilute suspended sediment concentration, followed during fair-weather by slow settling from the water column (Fan et al, 2004). The slow sedimentation rate would have allowed for extensive biogenic reworking of the substrate, especially in the wave agitated and, consequently, well oxygenated waters of the proximal prodelta. In the stagnant bottom waters of the shelf, oxygen would have been depleted by bacteria during the decomposition of the abundant organic matter in the substrate, rendering the environment inhabitable for burrowing organisms (Rabouille et al, 2008, Demaison, 1980, Schieber, 1999).

**Conclusions:**
The integration of sedimentology, ichnology and petrography has resulted in an improved understanding of the depositional processes associated with the unconventional reservoirs of the upper Montney in the Dawson Region of northeastern B.C. This understanding may ultimately provide the basis for the development of a comprehensive and predictive geological model that can be utilized to aid in the identification of areas of greater reservoir quality.

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**References:**


