Integrated Sedimentology, Ichnology and Petrography of Unconventional Gas Reservoirs of the Montney Formation; Dawson Creek Region, Northeastern B.C.

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Introduction

Within the Dawson Creek region of northeastern BC, the informally designated upper Montney Formation has been the target of intense oil and gas industry activity during the past several years. While evolving horizontal drilling and completion practices are largely responsible for the transformational success of this unconventional play, the influence of primary deposition on the distribution of upper Montney reservoir quality has received comparatively little scrutiny. The object of this study has been to interpret the depositional processes associated with the upper Montney through integration of sedimentology, ichnology and petrography. The fundamental understanding of depositional process may ultimately lead to more robust predictive geological models that can be utilized to identify “sweet spots” in this otherwise continuous gas accumulation.

Regional Setting and Stratigraphy

The Lower Triassic Montney Formation is an unconformity bounded, siltstone dominated marine succession, deposited adjacent to the northwestern margin of the supercontinent Pangea (Gibson and Edwards, 1990; Davies, 1997a). The study area is primarily situated in northeastern BC, centred roughly on the town of Dawson Creek, and overlapping into the adjoining region of west-central Alberta. In this region the Montney Formation is interpreted to comprise a continuous, basin-centred, tight gas accumulation where prolific production is associated with hydraulically stimulated horizontal wells in pools such as Dawson, Bissette, Parkland, Groundbirch, Sunset and Sunrise.

Within the study area, the Montney Formation, which reaches thicknesses of over 300m, can be informally subdivided into upper and lower intervals on the basis of the presence of a major regional flooding surface. The upper Montney, which remains the target of most of the horizontal drilling activity, can be further subdivided into at least four sub-units, namely the upper Montney A through D, in ascending order.

Facies and Petrographic Descriptions

Detailed core evaluation has revealed that the upper Montney is dominantly comprised of three main facies, designated as Facies 1 through 3, arranged in order from most distal to most proximal in terms of depositional setting. Within each of these facies a number of subfacies have also been identified based on subtle differences in lithological and ichnological features.

Facies 1consists of dark grey siltstone, which ranges from being essentially structureless (subfacies 1A), to containing rare pinstripe lamina (subfacies1B). Small-scale, soft-sediment deformation structures range from rare (subfacies 1C), to common in occurrence (subfacies 1D). Locally, very rare, small-scale, starved, current ripples can occur (subfacies 1C). Bioturbation is generally absent, however sporadically distributed intervals of moderate to abundant bioturbation can be observed. Traces include navichnia, fugichnia, *Planolites* and *Chondrites*.

Facies 2 consists of pinstripe laminated light and dark grey siltstone. Soft-sediment deformation structures and ripples range from local in occurrence (subfacies 2A and 2B), to common (subfacies 2C). Bioturbation is mostly absent, however sporadically distributed intervals of sparse to abundant bioturbation can be observed (subfacies 2B and 2C). Traces include navichnia*, Planolites, Chondrites, Cylindrichnus* and *Phycosiphon*.

Facies 3 comprises bioturbated light grey siltstone interbedded with pinstripe laminated light and dark grey siltstone, and rare beds of structureless dark grey siltstone. Soft-sediment deformation structures are common (subfacies 3B). Bioturbation is abundant and ranges from pervasive (facies 3A), to sporadically distributed (subfacies 3B). Traces include diminutive *Phycosiphon, Teichichnus, Planolites, Cylindrichnus, Asterosoma, Zoophycus, Palaeophycus tubularis, Chondrites, Rosselia, Trichichnus* and *Diplocriterion habichi*.

Because of their fine grained nature, petrographic analysis has been applied to assist in the characterization of the rocks which comprise the three main facies. In general, each facies is composed of fine to coarse silt, typically with a small proportion of very–fine grained sand, which is commonly (but not exclusively) concentrated in the light grey lamina. The bulk of the detrital material consists of quartz, plagioclase and alkali feldspars, with the total feldspar component typically comprising approximately 30% of the rock by volume. Minor amounts of detrital muscovite are invariably present, while phosphate material is rare, occurring mainly as coated grains and pellets, and less commonly as relatively large, rounded intraclasts, or fragmented fish remains. The bulk of the detrital grains tend to be unaltered and angular or elongate, suggesting that very little physical or chemical weathering occurred prior to deposition.

Kerogen is a ubiquitous component of the upper Montney siltstone. The dark grey colour that characterizes most of the facies is directly attributed to the relatively small volume of finely disseminated organic matter, which commonly occurs as flakes and masses, draping or masking the detrital grains. Total Organic Carbon content (TOC) is typically in the range of 0.3 to 3.65% (approximately 0.6 to 7.0% by volume), but the actual amount appears to be somewhat facies dependant, with a trend towards higher TOC values in the more distal facies. Preliminary palynological analysis suggests that a significant portion of the organic matter may be terrestrial in origin (Elena Kravosky, pers. com.)

Another conspicuous aspect of the mineralogy is the lack of detrital clay. By volume, clay rarely exceeds 4%, and is overwhelmingly authigenic in origin. Other authigenic constituents consist of dolomite, calcite and silica, which occur primarily as cements.

Facies Interpretation

The rare pinstripe lamina within the relatively organic rich, dark grey siltstone of Facies 1 suggests that deposition occurred in a quiescent setting, mainly by suspension fall-out. The absence of wave-generated structures such as oscillation ripples suggests that deposition was primarily below storm wave base. Localized soft-sediment deformation suggests episodic rapid sedimentation, which is also indicated by the presence of navichnia (sediment swimming traces) implying that soupy substrates were at least intermittently common.

The overall lack of bioturbation within Facies 1 suggests that paleoenvironmental conditions were generally hostile towards burrowing organisms, possibly due to a lack of oxygen, which may have been consumed during the process of bacterial degradation of the abundant organic matter in the substrate (Demaison, 1980; Rabouille et al, 2008). The sporadically distributed intervals of moderate bioturbation suggest that environmental conditions fluctuated, while a low trace fossil diversity is evidence of paleoenvironmental stress (Bann and Fielding, 2004; MacEachern et al, 2005).

In summary, the physical and biogenic structures that characterize Facies 1 are indicative of deposition mainly by suspension fall-out below maximum storm wave base, in the quiescent setting of an anoxic shelf.

In Facies 2, pinstripe lamination of alternating light and dark grey siltstone, suggests deposition mainly from suspension, in a generally quiescent setting. The increasingly more common occurrence of wave, current and combined-flow ripples implies that the depositional environment lay above storm wave base. The rare to common occurrence of soft-sediment deformation provides evidence of intermittent periods of increased sedimentation, which is also suggested by the local occurrence of navichnia.

The general absence of bioturbation in Facies 2 is indicative of paleoenvironments that were hostile to burrowing organisms, possibly as a result of bottom water anoxia. However, local sporadically distributed intervals of moderate bioturbation suggest that conditions were periodically favourable for opportunistic organisms and some normal marine specialists.

To summarize, Facies 2 was deposited above storm wave base, in a generally quiescent setting that experienced episodic rapid sedimentation and fluctuating paleoenvironmental conditions. The physical sedimentary structures, coupled with the sporadic distribution and reduction in size and diversity of ichnogenera, suggests that Facies 2 was likely deposited in a distal prodeltaic environment (Bann and Fielding, 2004; MacEachern et al, 2005).

Facies 3 consists of alternating beds of bioturbated light grey siltstone and pin stripe laminated light and dark grey siltstone which implies that conditions alternated periodically between being hospitable to burrowing organisms and periods that were less hospitable. In subfacies 3B, sharp based laminated beds become progressively more bioturbated towards their tops, suggesting that periods of slow sedimentation and biogenic reworking of the substrate followed episodes of more rapid deposition. Common soft-sediment deformation within these interbedded intervals, provide further evidence for episodic rapid sedimentation. The laminated to scrambled intervals are interpreted as distal tempestites (Bann and Fielding, 2004; MacEachern et al, 2005). The biogenically reworked tops reflect fair-weather colonization that ensued following the passage of the storm.

The pervasive bioturbation that characterizes subfacies 3A is interpreted to reflect deposition in a slightly more distal setting than subfacies 3B, as the intervals between storm events were sufficiently long to have permitted complete biogenic reworking of the substrate.

The abundance of bioturbation in Facies 3 suggests that the depositional setting was relatively well oxygenated. Although the assemblage is relatively diverse, the diminutive size of traces is an indication that the paleoenvironment was somewhat stressed. The rare and local occurrence of isolated beds of structureless dark grey, organic rich siltstone within Facies 3A, interpreted as river derived hyperpycnal muds (Bhattacharya and MacEachern, 2009; Mulder et al, 2003), suggests that episodic fresh water influx and other deltaic conditions may have been responsible for the observed paleoenvironmental stress.

In summary, Facies 3 is interpreted to have been deposited in a relatively quiescent environment, between storm and fair-weather wave base, in a well oxygenated, proximal prodeltaic setting.

Upper Montney Core and Well Log

Well 11-4-79-14W6, located within the Dawson Montney pool, is cored over almost the entire section of the Upper Montney, and provides an opportunity to view most of the subfacies that have been described and interpreted in this study.

Upper Montney 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. Sediment was supplied to the proximal portions of the ramp by rivers whose suspended sediment load was dramatically increased in response to seasonal flash floods that affected a semi arid drainage basin or coastal plain (Mulder et al, 2003; Fraticelli, 2006; Bhattacharya and MacEachern, 2009). Upon deposition, storm waves, possibly associated with the heavy rainfall, could have re-suspended the previously deposited river derived silts and transported them further down-slope to the distal portions of the ramp, as a highly concentrated organic rich, near-bed suspension or fluid mud (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 silts and organic matter was lacking, the storm events 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). Slow sedimentation would have allowed for extensive biogenic reworking of the substrate, particularly in the wave agitated and well oxygenated waters of the proximal prodelta. On the shelf, relatively stagnant bottom waters were rapidly depleted of oxygen in response to bacterial degradation of organic matter in the substrate (Rabouille et al, 2008, Demaison, 1980). The corresponding reduction in biogenic activity resulted in the preservation of the observed fine-scale sedimentary structures (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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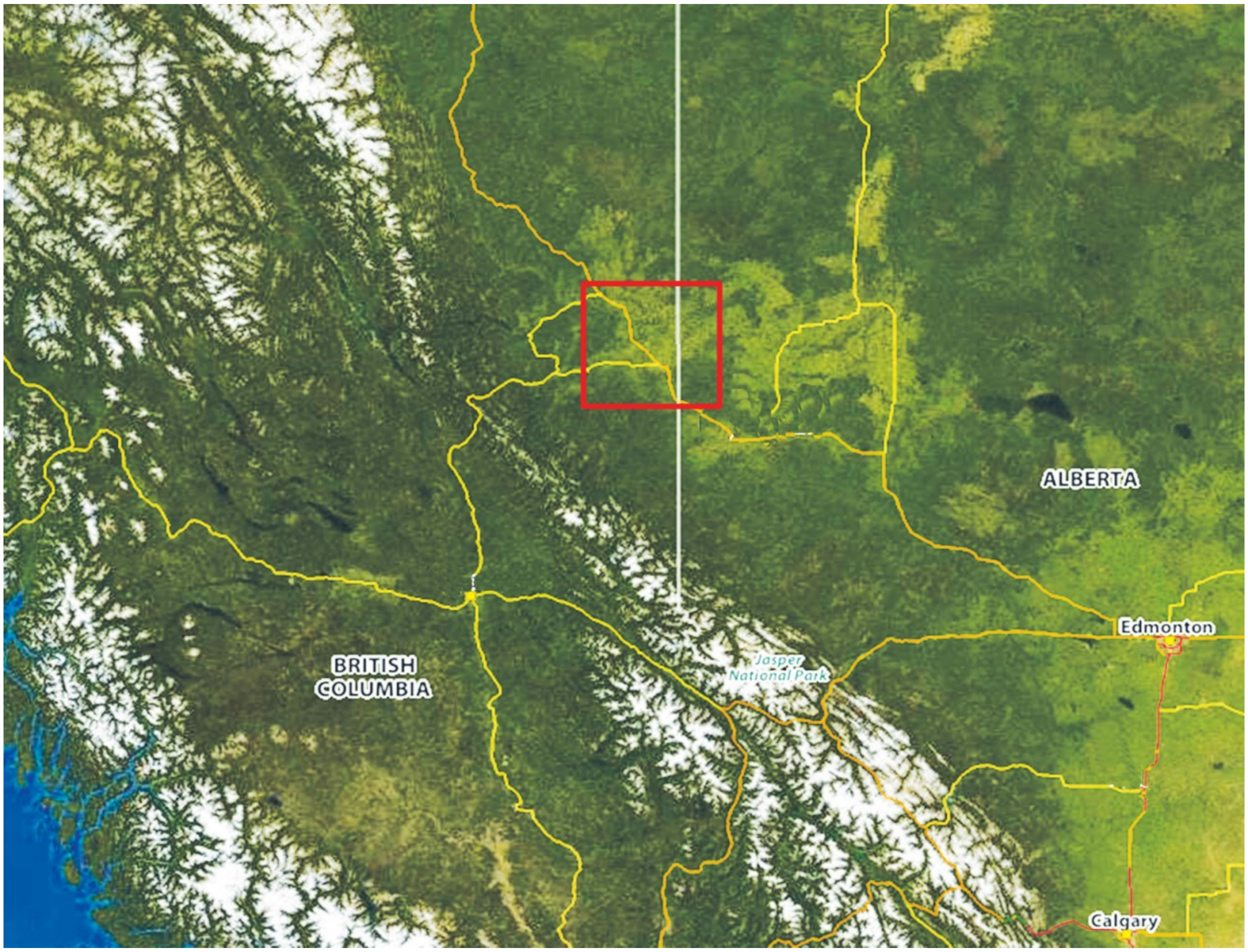


Fig 1 a). Location Map

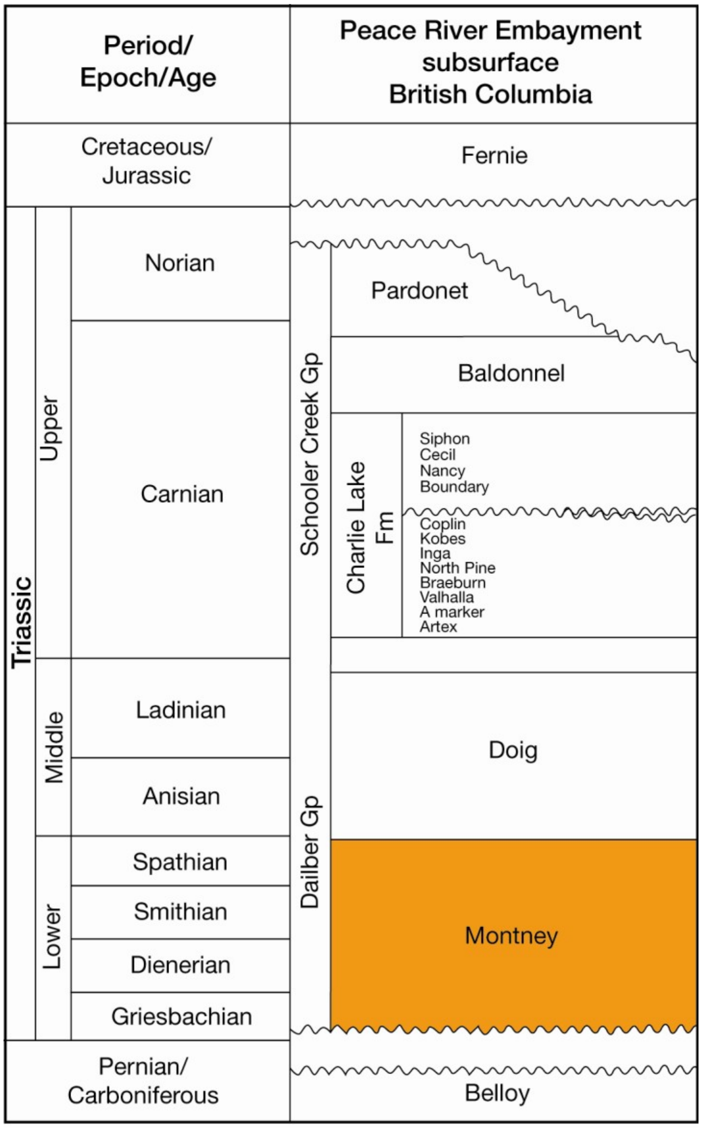


Fig 1 b). Stratigraphic Chart. Modified after Gibson and Edwards (1990).

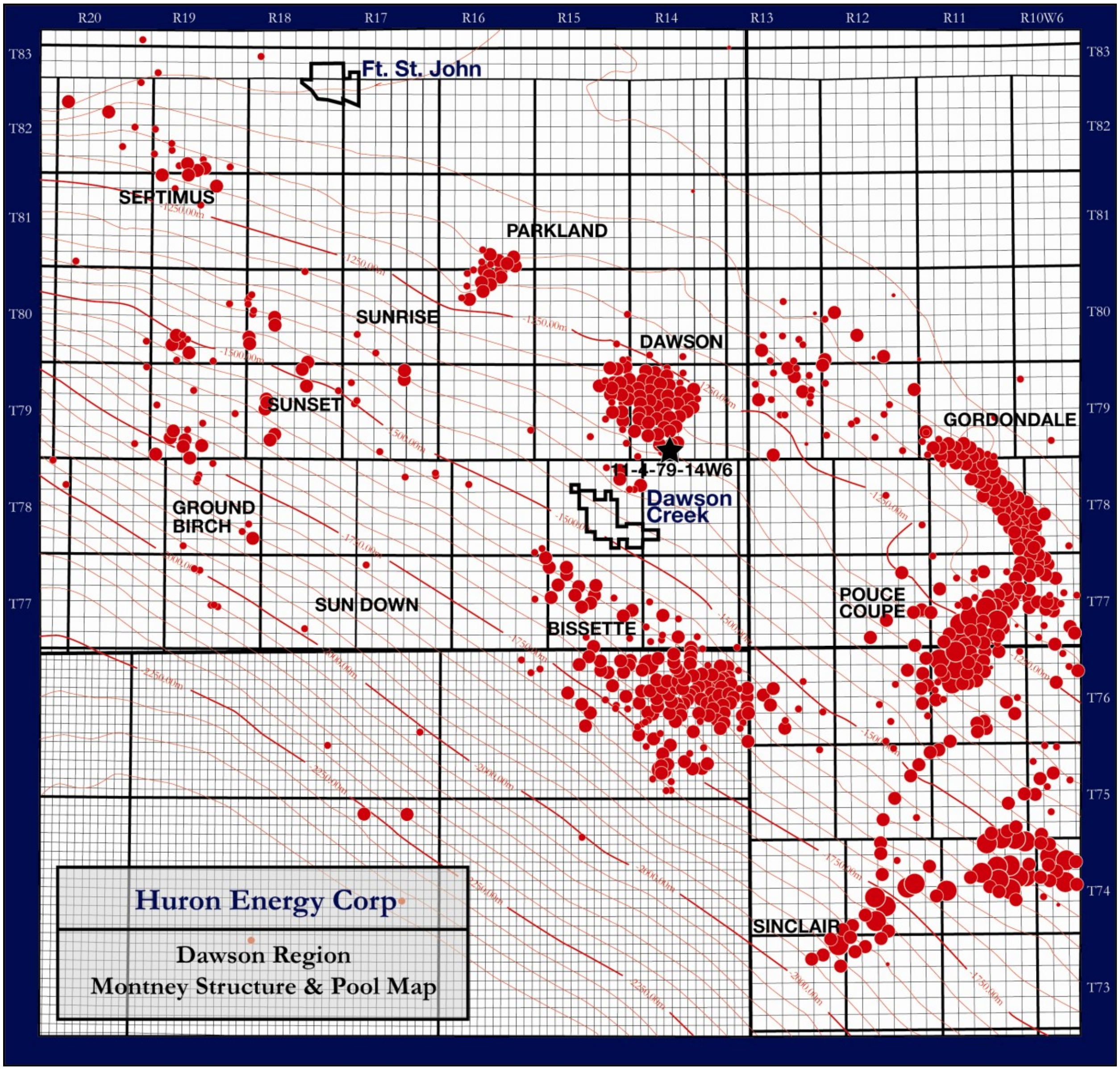


Fig 1 c). Study Area Map

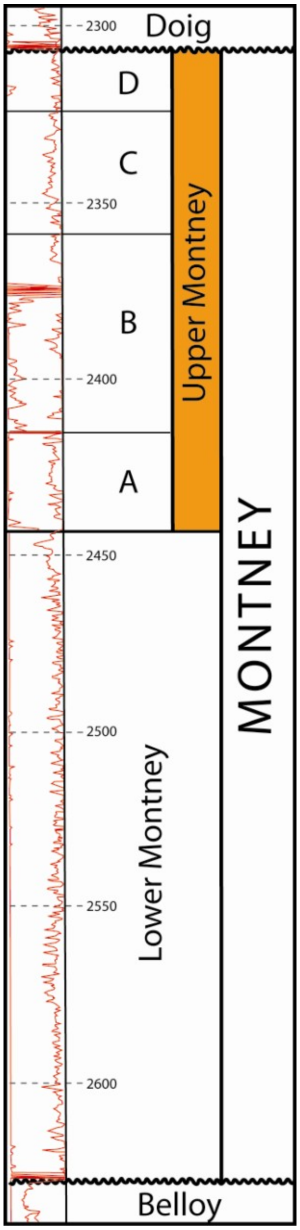


Fig 1 d). Local Stratigraphy

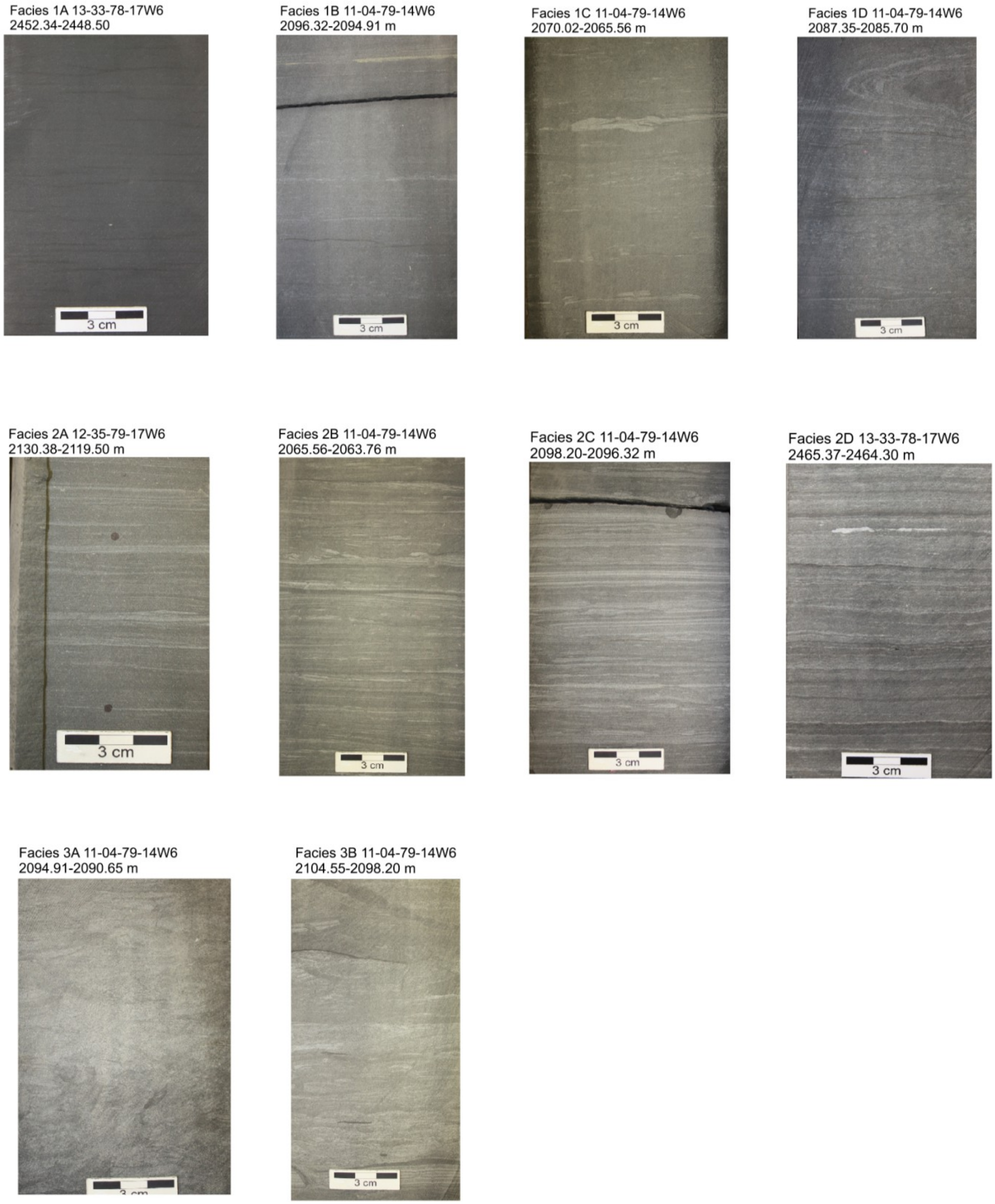
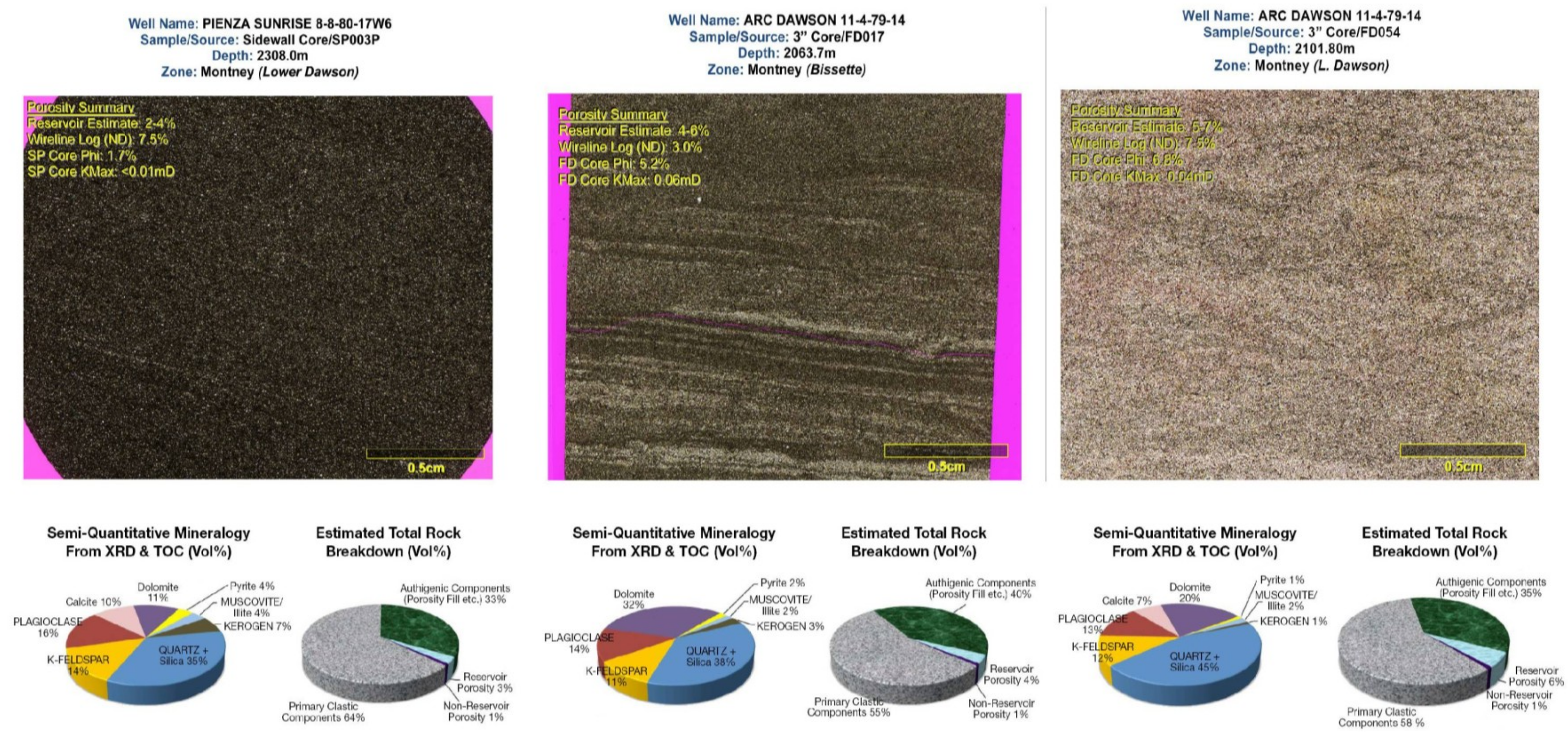


Figure 2. Photos display the subtle differences in lithological and ichnological features that define the various subfacies identified in the study.



3A

3B

3C

Fig. 3. Petrographic characteristics of a) Facies 1, b) Facies 2, and c) Facies 3.

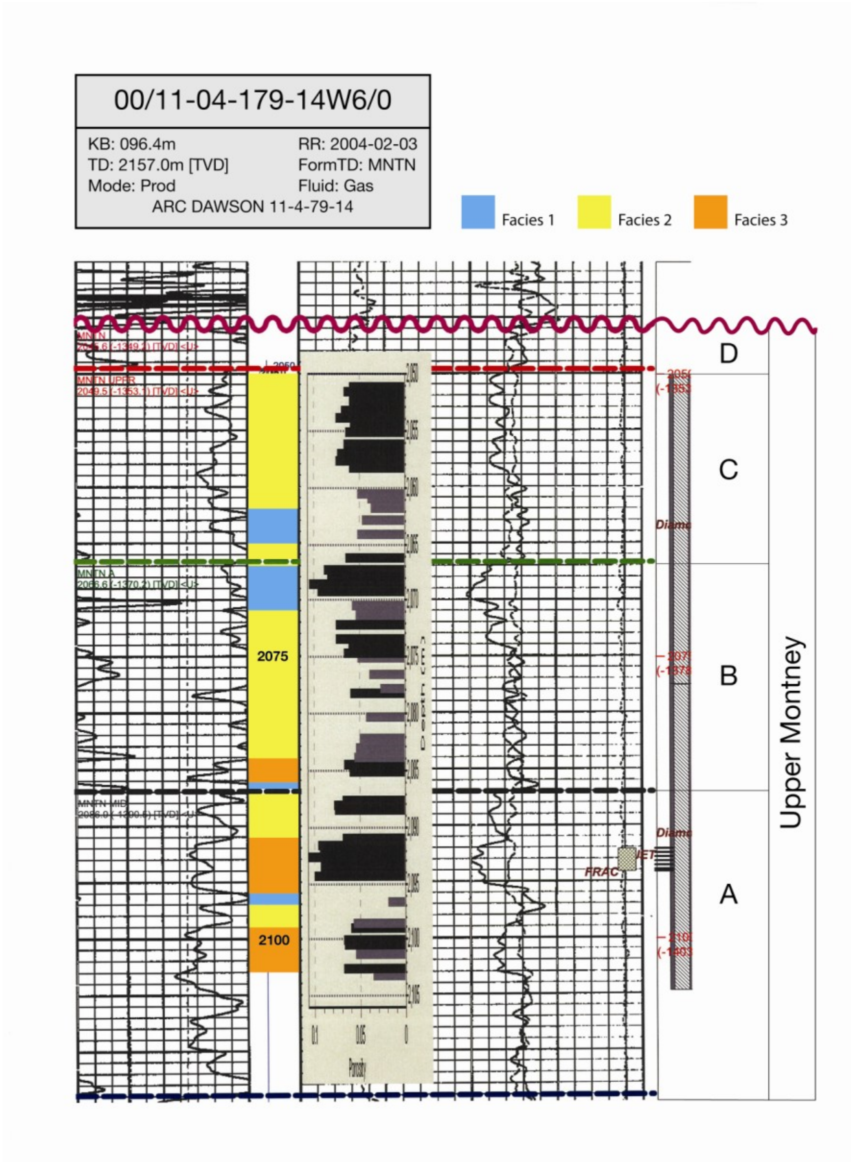


Figure 4 a). Well log for 11-4-79-14W6

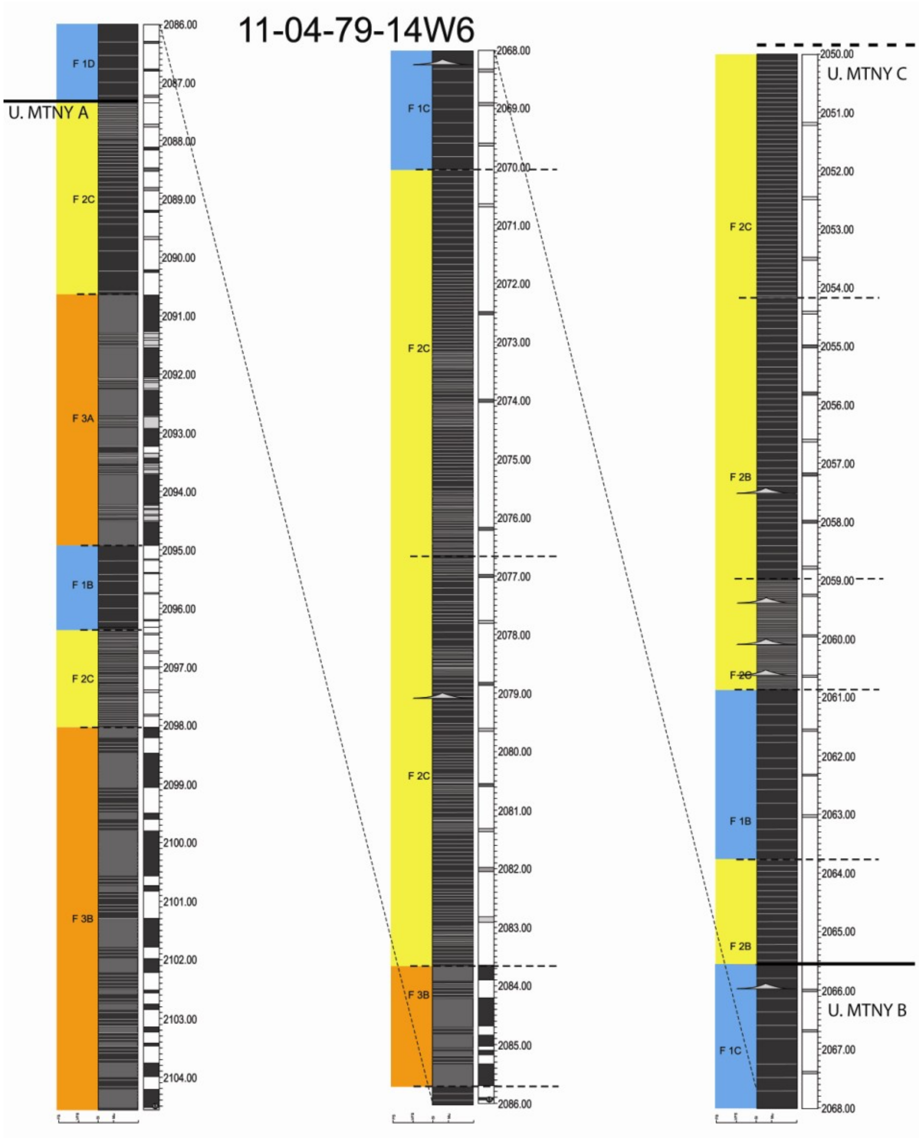


Figure 4 b). Core Description for 11-4-79-14W6.

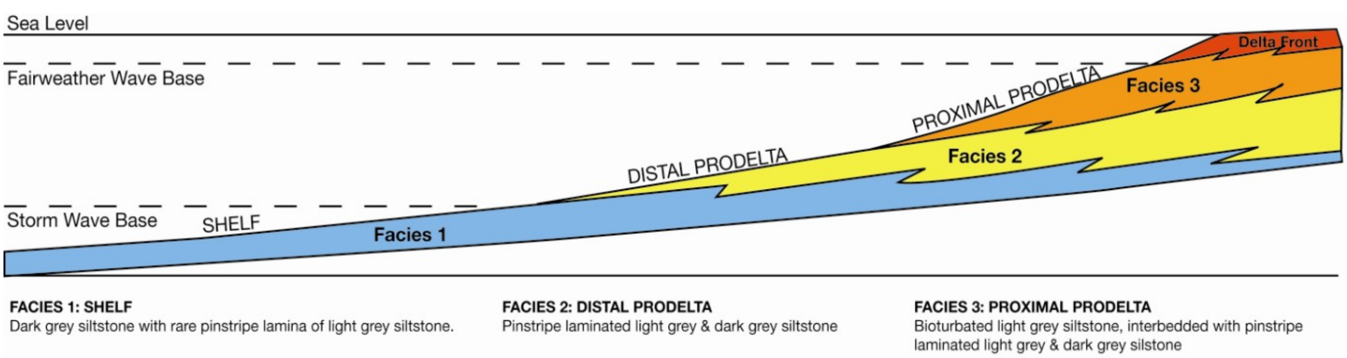


Fig 4 c). Upper Montney depositional setting. The delta front facies is not presented in the study area.

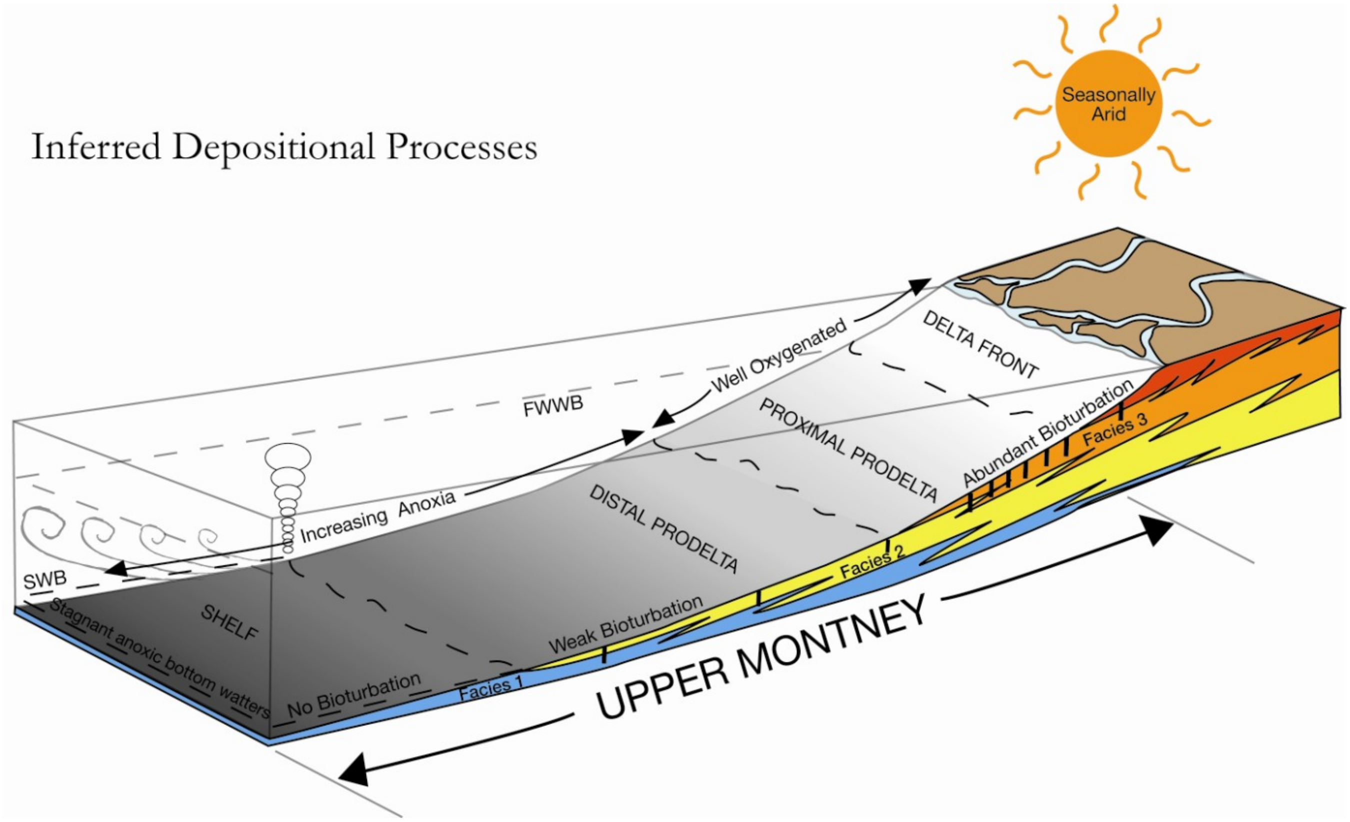


Fig 5. Summary of inferred upper Montney depositional processes.