High-Resolution Biostratigraphic and XRF-Geochemical Correlation of the Montney Formation, NEBC

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Introduction

There are at least 18 conodont zones that subdivide the 4.8 million years of the Lower Triassic, based on species of the following genera: *Hindeodus*, *Clarkina*, *Neoclarkina*, *Sweetospathodus*, *Neospathodus*, *Novispathodus*, *Scythogondolella*, *Paulella*, *Triassospathodus*, *Chiosella*,and *Neogondolella*. Not all of these zones are currently recognized in Montney Formation cores from west-central Alberta to northeast British Columbia, but sufficient paleontologic study has been completed to establish a sequence-biostratigraphic framework for the Montney Formation. This work then provides the template in which to correlate geochemical signatures that point to secular changes in redox conditions, circulation, weathering rates and paleoproductivity. In this paper, we show these oceanographic changes as interpreted from a basinal location in the c-65-F 94-B-8 wellsite based on data collected from a 395 metre continuous core.

Sequence-Biostratigraphic Framework

Globally, the Lower Triassic comprises three 3rd-order depositional sequences, and the Montney Formation is no exception. In contrast, the Geologic Time Scale recognizes two stages; the Induan and Olenekian. Many workers continue to use as substages, the informal stages Griesbachian, Dienerian, Smithian and Spathian, first determined by Tim Tozer (GSC) in the Canadian Arctic and Western Canada. We use both sets of terminology (Figure 1), with the Induan essentially equal to the Griesbachian and Dienerian, and the Olenekian more-or-less equal to the Smithian and Spathian.

The Lower Montney (latest Permian to Induan) includes numerous progradational parasequences that are truncated by a major sequence boundary and flooding surface. The Middle Montney (lower Olenekian) overlies this sequence boundary and numerous conventional plays are established in west-central Alberta in proximity to this sequence boundary including the Coquina Dolomite Unit and a lowstand turbidite play. Biostratigraphy has revealed that turbidite units are regionally diachronous pointing to stratigraphic architectural complexity. This sequence boundary represents the mid-Montney sequence boundary in Alberta, but not in BC. Proximal lithofacies of the lower-Middle Montney are distinctive and best represented in west-central Alberta. Distal units are relatively condensed in NEBC, and comprise important unconventional units recognized by organic carbon richness and mechanically frackable lithologies.

A sequence boundary separates the Middle Montney from the Upper Montney (upper Olenekian). The upper Montney is represented in west-central Alberta by a wedge of sandstone that is thin because of stratigraphic onlap and truncation and is sometimes referred to as the “basal Doig”. The Upper Montney however includes numerous progradational parasequences that comprise a very thick succession in east-central to NE British Columbia. There are important unconventional reservoirs in this succession. The Anisian Doig Formation sits unconformably on the upper Montney.

The definitions of the stages and biozones of the Lower Triassic continue to be refined by international biostratigraphic studies. We are continuing to recover more biostratigraphic data from the Lower Triassic Peace River Basin that can be linked to these international studies, but at the same time, provide a detailed framework of correlation for Western Canada.

Geochemistry

The geochemistry of core c-65-F has been measured at centimetre resolution using an ITRAX energy dispersive XRF core scanner. While only semi-quantitative, the unprecedented resolution of this dataset (almost 40 thousand individual measurements of 30 elements = ~1.2 million data points) provides the opportunity to study the Early Triassic at a level of detail never before possible. In combination with biostratigraphic data, this geochemical dataset allows us to draw a number of conclusions about the distal Montney depositional environment.

Variations in sulfur and arsenic, which likely reflect pyrite content, suggest that euxinic conditions were common in the lower Induan (Griesbachian) and decreased in the upper Induan (Dienerian), before becoming acute again in the lower Olenekian (Smithian), and then improving once more in the upper Olenekian (Spathian). This pattern is comparable to that seen in Early Triassic sections in southern China, suggesting global climatic control of redox conditions.

The upper Olenekian (Spathian) interval shows numerous fluctuations in redox sensitive elements such as vanadium and zinc, which are independent of variations in pyrite content, but show an interesting correspondence with interpreted water depth. Intervals of vanadium and zinc enrichment are terminated by marine flooding surfaces, potentially indicating that they represent local anoxia caused by restricted water circulation. These redox fluctuations begin shortly after a brief, marked increase in the Cr/Al ratio, indicating the introduction of a more mafic sedimentary component; we suggest this represents reactivation of an offshore arc that restricted communication between the Montney depositional setting and the open ocean when sea level was relatively low. Prior to this reactivation, high phosphorus content suggests that coastal upwelling may have resumed in the Spathian, but this is not evident after the reactivation event.

Carbonate is essentially absent during the Griesbachian, and first reappears in the early Dienerian in the form of pavements (biostromes?) of the bivalve *Claraia*. After this initial resumption of carbonate deposition, algal dolostone begins to appear at intervals of roughly three metres, likely controlled by climate variation due to orbital Milankovitch cycles. These cycles occur throughout the remainder of the Early Triassic, though their spacing changes over time, and in places they are obscured by carbonate turbidites. Calculations based on interpolated sedimentation rates suggest that these may represent 21 kyr precessional cycles that offers high-resolution correlation potential.

Longer term cycles can be seen in Rb/(Rb+K), a proxy for weathering intensity. These are most evident in the upper Olenekian (Spathian), where seven cycles can be seen. While the duration of the Spathian is not fully resolved, these likely represent short (~100 kyr) or long (~400 kyr) eccentricity cycles. In the lower Montney, this proxy increases throughout the Griesbachian and into the early Dienerian, suggesting a greater intensity of chemical weathering. This may reflect the re-establishment of land plant communities and rising sea level, both of which would lengthen the transport history of sediments prior to deposition.

Conclusions

A Lower Triassic sequence biostratigraphic framework for Western Canada provides a template to consider the spatial and temporal variations of oceanographic conditions associated with deposition of three 3^{rd}-order sequences of the Montney Formation. High-resolution geochemical analyses point to complex secular changes in climate and tectonics. When fully integrated, these two techniques will improve the predictability of unconventional resources.

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Figure 1. Uppermost Permian, Lower Triassic and Anisian conodont zones and ages (work in progress) and schematic stratigraphy (white = rocks; grey = gaps). Stage boundary ages are based on GTS 2012 (Gradstein et al., 2012 (eds). The Geologic Time Scale 2012, Elsevier). These ages show roughly equal duration zones, but it is important to note that other age models have been suggested for the Triassic stages with the base-Olenekian at 251.2 Ma and base Spathian at 250.6 Ma. *chang.* = *changxingensis*; MRS (dashed line) = Maximum Regressive Surface; SB/FS = Sequence Boundary/Flooding Surface; and 1 = mid-Montney in Alberta; 2 = mid-Montney as used in BC; 3. so-called “basal Doig” in Alberta.