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Palaeogeographic evolution of the Montney in the Western Canada Sedimentary Basin

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Summary

The Lower Triassic Montney Formation was deposited during an interval of transition; transition from carbonate-dominated deposition during the Paleozoic to clastic dominated deposition during the Mesozoic; transition of invertebrate faunas from archaic Palaeozoic forms to Modern forms; and transition from a passive margin setting to a foreland basin setting. These criteria render the Montney unique amongst Phanerozoic sedimentary successions in western Canada.

Extinction considerations.— The Montney Formation records sediment accumulation on the northwestern margin of Pangaea during the first five million years after the Permian-Triassic extinction. In addition to the demise of ~95% of skeletonized marine taxa, this extinction event had a profound affect on the sedimentary framework of the Montney. Thus, echinoderm detritus, articulate brachiopods and scattered rugose corals, all of which are important grain constituents in the Upper Permian Belloy Formation, are absent in the Montney Formation.

Montney sediment.— The Montney is unusual, in that it comprises a thick (>350 metres in the west) succession dominated by dolomitic siltstone and very fine-grained sandstone with rare fine-grained sandstone intervals and even rarer silty shale intervals. The Montney's unique grain size distribution is a function of its palaeogeographic occurrence and the palaeoclimatological conditions under which it was deposited. Deposition in a shallow clastic ramp setting on an arid coastal margin severely constrained the nature of sediment delivery and redistribution, and the way in which constituent minerals were altered in the sediment source areas. In humid or temperate settings feldspar, mica and other unstable minerals in soils are in frequent contact with percolating fluids, rapidly succumb to hydrolysis and become altered to clay minerals, particularly in the presence of plant-derived organic acids (eg. Velbel, 1990; Drever, 1994). In arid settings (such as the coastal interior adjacent to the Montney coast), rainfall is rare, typically catastrophic and short-lived and the paucity of plants minimizes the presence of organic acids in soils. Thus, the affects of hydrolysis were minimal in the Montney interior and mineral breakdown was dominated by mechanical influences (grain-grain interactions). Although clay minerals do occur in fine-grained Montney strata, much of this clay is immobile (occurring within individual degraded mica or feldspar grains). Large quantities of clay occur in only a few locations in the basin, such as Pedigree, Ring and Border fields on the Alberta-British Columbia border and Dixonville field in central Alberta.

As with all desert systems, wind plays an important role in sediment transport, particularly within coast-proximal areas. Finer-grained clastics (fine silt; <20 μ) may have been carried in suspension 10s to hundreds of kilometres offshore, however medium to coarse silt and very fine-grained sand (20-125 μ) are transported primarily by saltation and are rarely transported more than a few 10s of metres in air (Nickling and Neumann, 2009; Bullard, 2009). Water, in the form of sheet floods and reactivation of ephemeral streams is the dominant sediment transport medium in desert systems (Powell, 2009). The Montney was no exception. Montney sediment delivery to the coast and broad ramp is attributed to

numerous ephemeral rivers and a very few perennial rivers flowing from the craton interior to the northwest Pangaean coastline (Zonneveld and Moslow, 2014).

Montney beginnings.—The basal Montney Formation (Griesbachian / lower Induan) comprises an overall retrogradational succession deposited as part of a regional marine transgression. Montney sediment accumulation was not uniform across the basin. Depocentres occurred in fault-influenced areas including the Peace River embayment (Fort St. John Graben, Dawson Creek graben, Webster Fault, etc…) and the Hay River Fault Zone (Ring-Pedigree fields with ~100 metres of Griesbachian sediment accumulation). A subaerially exposed ridge (Fig. 1) occurred on the western margin of the basin partially constraining basin circulation and possibly acting as a source of sediment during some intervals.

The basal Montney transgression proceeded from west towards east, onlapping progressively older Paleozoic units towards the Montney subcrop limit. During the Griesbachian the Montney Basin was constrained on the west by a regional high, referred to informally as the Meosin-Muinok high (Fig. 1; Orchard and Zonneveld, 2008; Zonneveld et al., 2015), which occurred in the same approximate location as the Permian Sukunka Uplift (*sensu* Henderson et al., 1997). Shallow marine sandstone units occur in the several parts of the basin, including on the northeast (deltaic units in the Ring-Pedigree area) and east central parts of the basin (Panek, 2000; Zonneveld et al., 2010a; 2010b). The Lower Montney Formation includes two lower order sequences, with a maximum flooding surface occurring in mid-Griesbachian strata, and another in the early Dienerian, after which the Montney shoreline started to prograde westwards. A localized occurrence with abundant thin-shelled bivalves (the '*Claraia'* zone) occurs in west-central British Columbia. The top of the Lower Montney is placed at a regional sequence boundary that approximates the Dienerian-Smithian (Induan-Olenekian) boundary (Fig. 2).

Mid-Montney sequence boundary I.— The late Dienerian heralded the maximum westward progradation of the lower Montney shoreline. These shorelines are characterized by very fine- to fine-grained sandstone and bioclastic packstone / grainstone (Coquinal dolomite middle member) in the southeastern part of the basin (Markhasin, 1994; Mederos, 1995; Davies et al., 1997). Maximum progradation, and the Lower-Montney - Middle Montney sequence boundary occurred at the Dienerian-Smithian (Induan-Olenekian) boundary. This sequence boundary is most easily resolvable in the eastern Alberta subsurface, and in the Peace River embayment area where the Montney Turbidite Zone (occurs). It correlates with a basinward correlative conformity in the western subsurface. This boundary coincides with early collision of Pericratonic terranes with the North American autochthon (Beranek and Mortensen, 2011). The early Smithian interval (earliest Olenekian) was characterized by marine transgression and retrogradation of Montney shorelines towards the east. Maximum transgression occurred during the mid-Smithian. The upper Smithian is characterized by strong progradation of the Montney shoreline towards the west. Indeed, during this interval the shoreline prograded further westwards than during the earlier Dienerian progradation. The upper Smithian also saw the occurrence of an interval of abundant sharp-based bioclastic grainstone beds within a siltstone matrix. This unit, informally referred to as the 'Altares member', is younger than other bioclastic intervals in the Montney Formation. Taphonomic and sedimentological criteria indicate some degree of transport in the genesis of this unit. A lack of bioclastic beds in temporally equivalent units in shallower settings suggests that the transport may have been local rather than regional.

Mid-Montney sequence boundary II.— A second, major intraformational unconformity has been shown by numerous authors (eg. Golding et al., 2014; Davies and Hume, 2016) to approximate the Smithian-Spathian boundary. This boundary has been identified throughout the basin, from outcrop in Kananaskis to the western subcrop in British Columbia. A phosphate pebble lag commonly occurs at the sequence boundary in southern and eastern sections, typically in association with a low-diversity *Glossifungites*-demarcated discontinuity surface. In western and northern sections, this surface is informally referred to as the 'Montney shoulder' due to its appearance on well logs. It is demarcated in the western subsurface by a shift from interbedded bioclastic packstone / grainstone and siltstone in the Middle Montney to laminated phosphate-rich siltstone in the Upper Montney.

Montney endings.— Overlying the laminated siltstone beds in the lower part of the upper Montney Formation, the unit grades upwards to interbedded wave-rippled and bioturbated siltstone. It is strongly progradational and interpreted to be a low-angle clastic ramp succession. The Upper Montney is erosionally overlain by younger, dominantly Middle Triassic (Anisian), strata. Commonly, the overlying strata are phosphate granule and gravel-rich strata of the Doig Phosphate Zone. Recent work has shown that in some parts of the basin, a distinctive unit of interbedded highly bioturbated and non-bioturbated sediment occurs between the Montney Formation and the Doig Phosphate Zone (Zonneveld and Moslow, 2015; Zonneveld et al., 2015; 2016; Furlong et al., 2016; Davies and Hume, 2016). This unit, informally referred to as the 'Anisian wedge' is not allied with either unit but comprises a distinct stratigraphic interval on its own (Zonneveld and Moslow, 2015; Zonneveld et al., 2015; 2016; Furlong et al., 2016).

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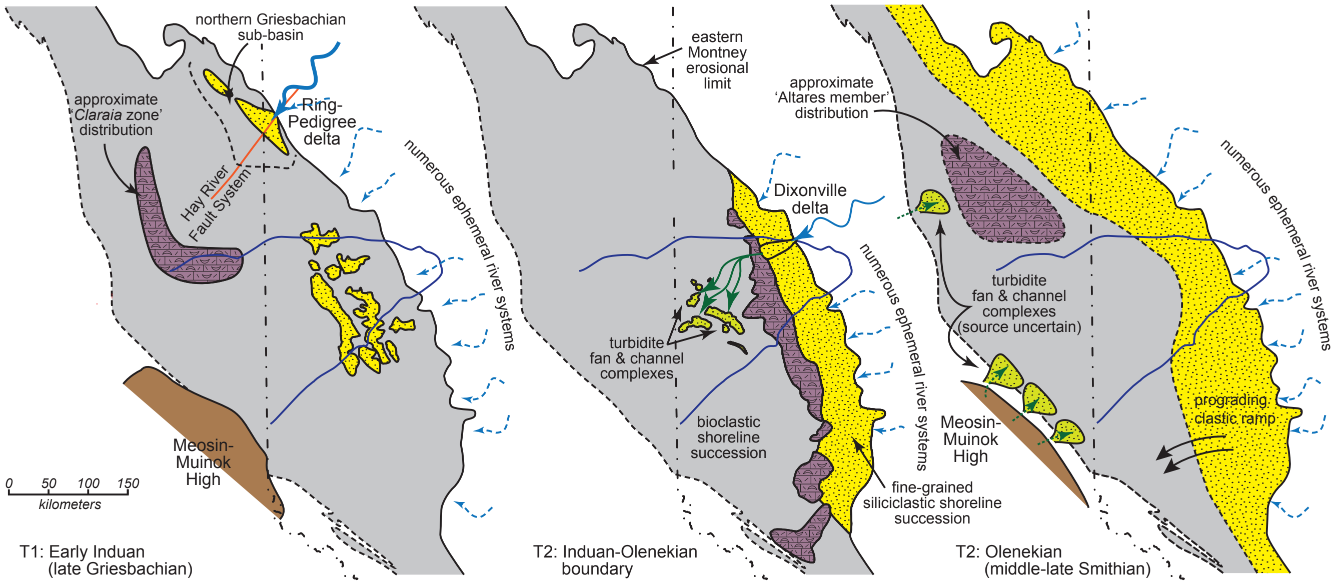

Figure 1. Evolving Montney Palaeogeography. Note the occurrence of rare perennial fluvial feeder systems (Ring-Pedigree and Dixonville deltas) as well as numerous, seasonally / periodically active ephemeral feeder systems. Note the occurrence of the Griesbachian '*Claraia* zone', the Dienerian-Smithian Coquinal Dolomite middle member and the late Smithian 'Altares' member. These three units comprise the main bioclastic horizons in the Montney Formation. Based on numerous source's cited in text.

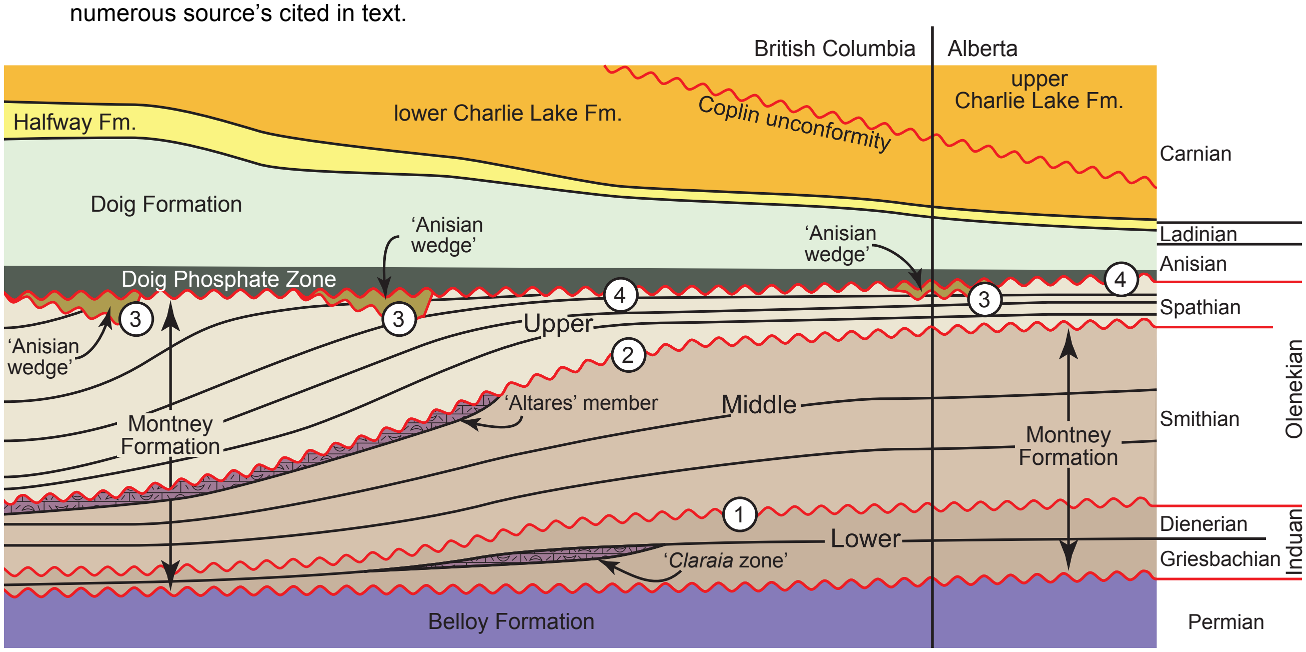

Figure 2. Montney Stratigraphy, western Alberta to the subcrop limit, British Columbia. Unconformity 1 approximates the Dienerian-Smithian (Induan-Olenekian) boundary and is a major Montney subdivision in Alberta. Unconformity 2 approximates the Smithian-Spathian boundary and is easily recognized throughout western Alberta and northeastern British Columbia. Unconformity 4 separates the Montney Formation from the Doig Phosphate Zone. Erosional outliers of the "Anisian wedge" erosionally overlie the Montney Formation (unconformity 3) and are erosionally overlain by the Doig Phosphate Zone (unconformity 4). Note the occurrence of the bioclastic packstone and grainstone beds of the '*Claraia* Zone' and 'Altares' member.