Biostratigraphic Correlation and Shale Fabric of Lower Triassic Strata, East-Central British Columbia (NTS 093I, O, P)

C.M. Henderson, Department of Geoscience, University of Calgary, Calgary, AB, charles.henderson@ucalgary.ca

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Introduction

The Montney Formation in northeastern British Columbia is a focus of considerable industry activity as a shale gas and tight gas target. Successful exploitation of this resource will require geological insights into the stratigraphic framework, distribution of organic matter and shale fabric. The latter affects mechanical rock properties and more knowledge on this topic will lead to innovative engineering techniques to efficiently exploit this resource. A sequence biostratigraphic framework in both core and outcrop to the west is needed in order to map the distribution of siltier and sandier horizons, and the potential concentration of organic matter. This preliminary study addresses the current biostratigraphic potential for the interval (latest Permian to earliest Middle Triassic) and discusses lithology and depositional rates at four different locations. The sequence biostratigraphic framework is still in progress.

Study Area and Methods

Field sites for this study are located in east-central British Columbia (BC) in the Sukunka-Kakwa area, within NTS areas 093I, O and P (Figure 1). The outcrops, located south and west of Chetwynd, BC, are part of the southeast-trending outcrop belt that represents the westernmost extent of the Western Canada Sedimentary Basin. Three outcrops were studied in August 2010, including Mount Crum, Peck Creek and Ursula Creek, and a fourth site is described based on the report by Orchard and Zonneveld (2009). Outcrops were accessed by helicopter due to the remote nature of the sites.

Lithology samples were collected for Rock Eval™ analysis and to characterize shale fabric. Conodont samples were collected to provide a biostratigraphic framework for correlation and are being processed following standard procedures.

Keywords: *conodont biostratigraphy, latest Permian, Lower Triassic, shale fabric, depositional rates*

Geological Setting

Sediments were deposited in a variety of depositional environments within the Peace River Basin from west-central Alberta to northeastern BC. Structural inversion of various tectonic elements, possibly caused by far-field effects from the Sonoma Orogeny, resulted in a complex basin that affected the distribution of depositional environments during the latest Permian to earliest Triassic transgression. The distribution of tectonic highs and lows are known at a reconnaissance level for the Upper Paleozoic succession in the area (Henderson et al., 2010; Zubin-Stathopoulos et al., 2011), but are very poorly known for the Lower Triassic in the region. Kendall (1999) demonstrated some of the effects of structural inversion at the Permian–Triassic boundary and latest Dienerian through her subsurface mapping in west-central Alberta.

Sedimentation occurred on the northwestern margin of Pangea at a paleolatitude centred about 25ºN that was, just as today, a site of very arid conditions (Davies et al., 1997). Aridity and reduced rates of chemical weathering meant that very little medium to coarse sand and very little clay were delivered to the Peace River Basin by ephemeral fluvial systems. Very fine grained sand was distributed by various processes along the coast and delivered to the basin by storms and turbidites (Moslow and Davies, 1997). Eolian processes delivered a considerable proportion of coarse silt into the basin throughout this interval (Davies et al., 1997), but the proportion of clay may have been higher during the latest Permian and earliest Triassic (Phroso Member of the Sulphur Mountain Formation) because of increased weathering associated with effects from the Late Permian extinction event (Hays et al., 2007; Algeo and Twitchett, 2010). The Late Permian extinction also affected the distribution of trace fossils (Beatty et al., 2008) and the proportion of bioclasts, both of which significantly affect reservoir characteristics.

Biostratigraphy and Biochronology

Conodont biostratigraphy is summarized in Figure 2. Three M.Sc. theses under my supervision originally demonstrated the value of conodont biostratigraphy in the Montney Formation (Markhasin, 1997; Kendall, 1999;

Panek, 2000). The biozonation for the Late Permian is strongly controlled by provincialism and, as a result, there is a zonation for cool-water and warm-water (Mei and Henderson, 2001; Henderson and Mei, 2007). During the latest Permian, associated with events that resulted in Earth's greatest extinction event, this provincialism breaks down for the most part and a single standard zonation results (Figure 2), but there remain some issues associated with biofacies control, endemism and taxonomy that affect the duration of zones and presence of distinctive faunas. The ages for stage boundaries have been considerably modified in the past few years with advances in U-Pb radiometric dating and the discovery of new ash beds in sedimentary successions (Figure 2). The ages of individual zones are not known with certainty, but are proportionally calibrated within the known framework. As a result, the precision and accuracy of zonal ages for the Induan and Early Olenekian are much higher than for the Late Olenekian and Anisian. Improved taxonomy will undoubtedly lead to increased precision for the Spathian and Anisian. As a result, with this good biochronological control, it is possible to estimate rates of deposition for the Phroso, Meosin Mountain and Vega members of the Sulphur Mountain Formation, and portions of the Grayling and Toad formations.

Stratigraphy and Depositional Rates

The stratigraphic units being investigated represent the surface equivalents of the Montney Formation and include the Phroso, Meosin Mountain and Vega members of the Sulphur Mountain Formation, as well as the Grayling and Toad formations. The lithology and distribution of these units in the study area was discussed by Gibson (1975). This section discusses these units at four locations: Meosin Mountain, Mount Crum and a composite of Peck Creek and Ursula Creek (Figure 3). Very little of the succession can be referred to as pure shale and so many of the reservoir characteristics are related to the porosity and permeability distribution within siltstone and very fine grained sandstone beds. The fabric of shaly parts of the succession is characterized by variations in calcareous or dolomitic cement, physical sedimentary structures, biogenic sedimentary structures and depositional rates. Slower deposition rates result in more compacted rock fabrics that would behave in a more brittle fashion.

Meosin Mountain Section

This section description is based on Orchard and Zonneveld (2009), in which they named a new member, the

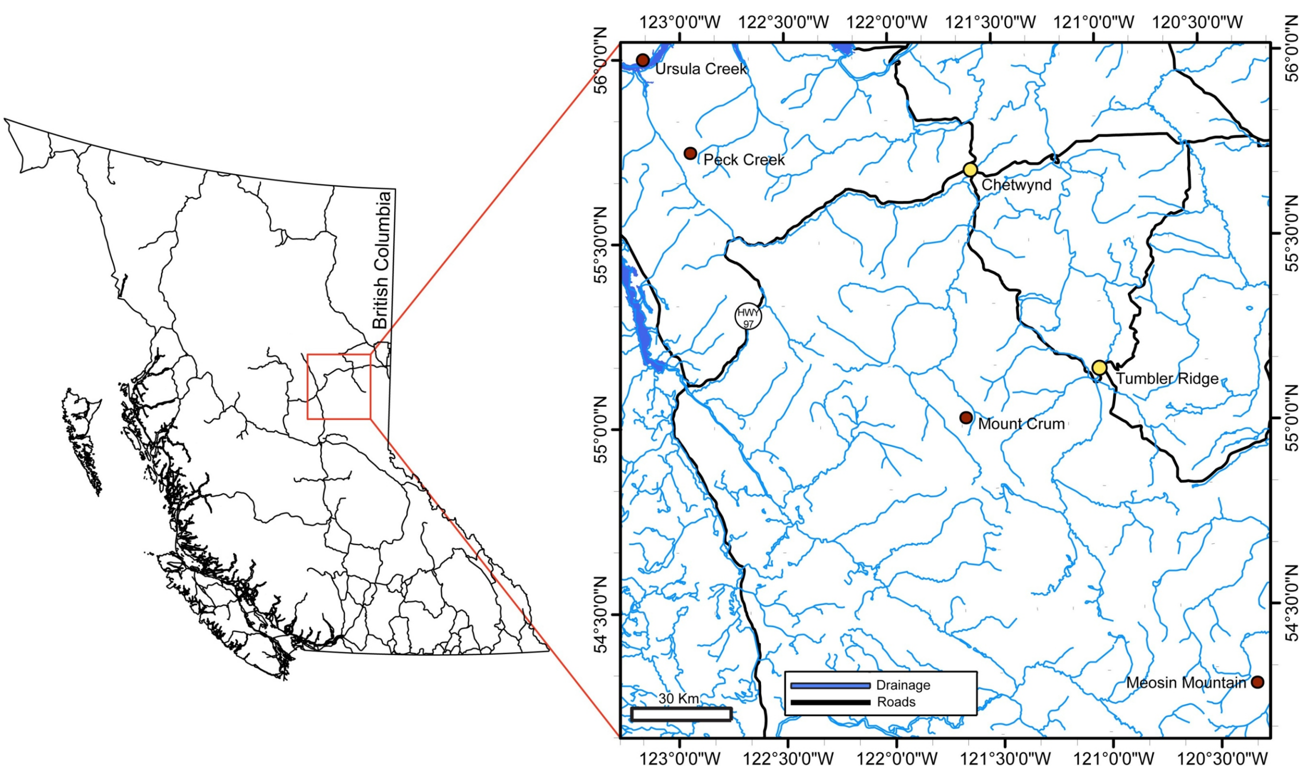

Figure 1. Study area in east-central British Columbia, showing the locations of sections (using NAD 83): Meosin Mountain, 54.28616 N, 120.32557 W; Mount Crum, 55.02541 N, 121.65057 W; Peck Creek, 55.75045 N, 122.95348 W; and Ursula Creek, 55.99312 N, 123.17426 W.

Meosin Mountain Member, for an approximately 20 m thick succession of turbidites. The Phroso Member sits unconformably on the Middle Permian Mowitch Formation, which in turn rests unconformably on the Lower Permian Belcourt Formation. The Phroso Member is 48.5 m thick at Meosin Mountain and includes a recessive, planar-laminated, organic-rich and pyritiferous silty shale succession that grades upward into ripple-laminated dolomitic siltstone and very fine grained, quartz-rich litharenite. The unit is correlated with the *Clarkina carinata* to lower *Paulella meeki* zones (Orchard and Zonneveld, 2009) and is therefore Griesbachian to mid-Smithian. The

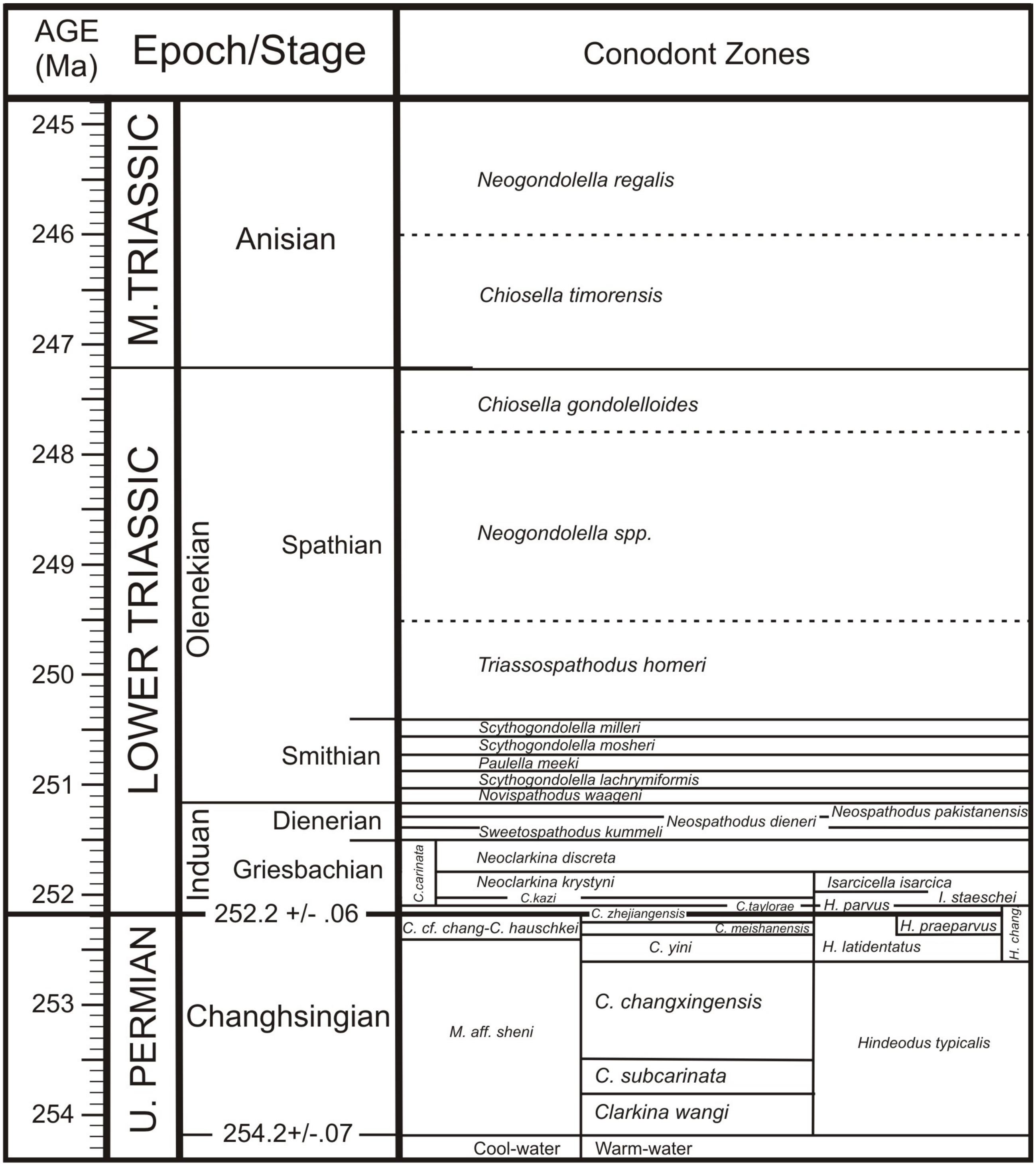

Figure 2. Distribution of conodont biozones for the Changhsingian (Late Permian) to Anisian (Middle Triassic) in the study area, east-central British Columbia. This chart is a modified summary of biozonation described in Orchard (2008, 2010) and Orchard and Zonneveld (2009). The geochronological ages are modified from Ogg (2004) based on new dates from Mundil et al. (2010) and Shen et al. (2010).

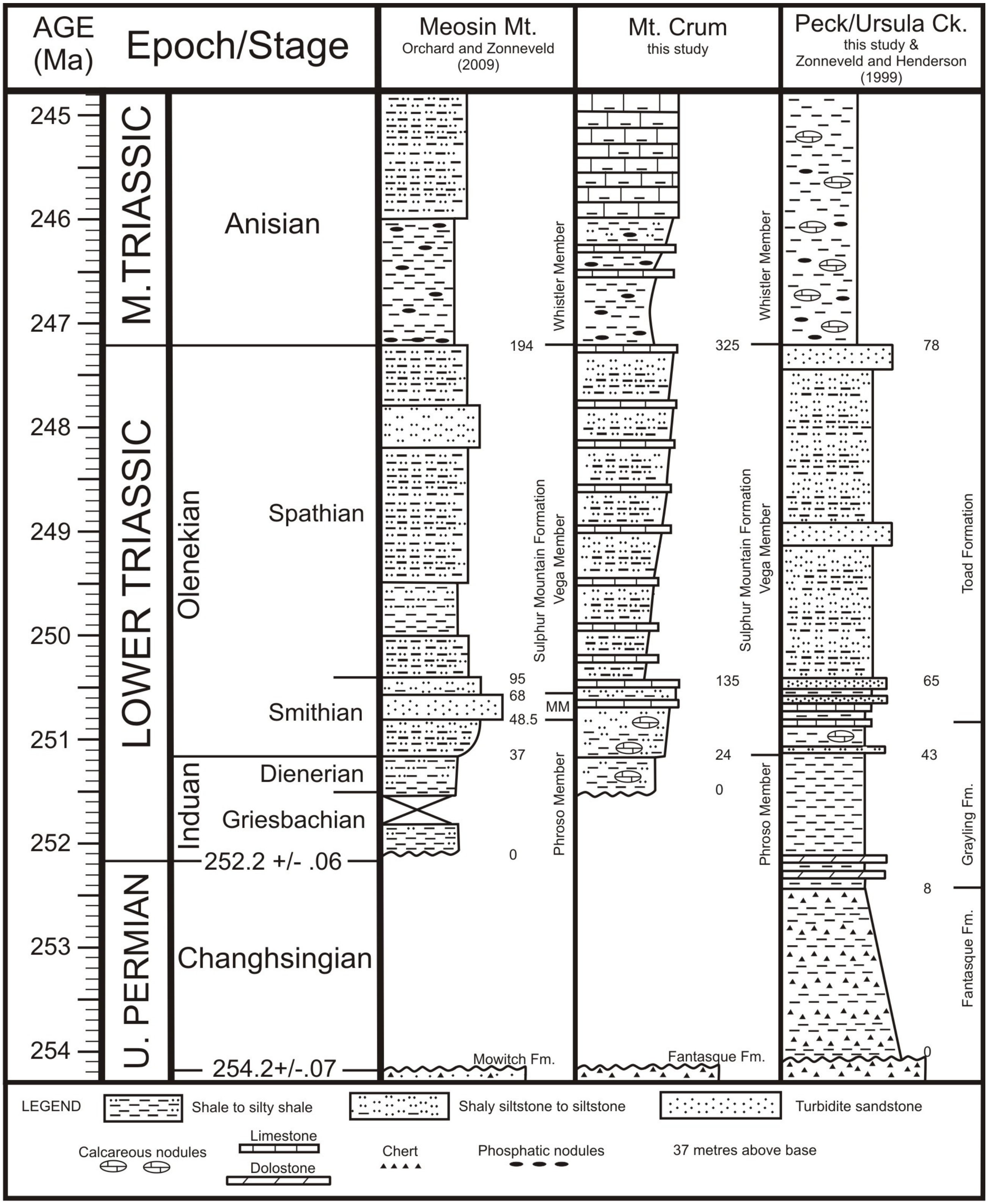

Figure 3. Lithology for Meosin Mountain, Mount Crum and the Peck Creek and Ursula Creek composite, east-central British Columbia. Stratigraphic units are arranged according to time, and measurements above base in metres are provided at key points. MM, Meosin Mountain Member.

Griesbachian (but not earliest Griesbachian) to Dienerian interval of 37 m indicates a depositional rate of 0.04 m per 1000 years, which seems to represent a general background rate of deposition for much of the Sulphur Mountain and equivalent Grayling and Toad formations in the region. This unit is sharply overlain by the Meosin Mountain Member, which is represented by 19.5 m of amalgamated, distinct, very fine grained sandstone beds that are interpreted to be the product of turbidite deposition. Orchard and Zonneveld (2009) showed that this member was deposited during the upper half of the *P. meeki* zone and lower *Scythogondolella mosheri* zone, an interval estimated at 200 000 years based on equal distribution of zones in the Smithian. This would translate into an average depositional rate of 0.10 m per 1000 years. These turbidites are younger and probably unrelated to the lowermost Smithian turbidites that characterize the Valhalla–La Glace–Knopcik succession in west-central Alberta (Kendall, 1999). The overlying Vega Member is 126 m thick and consists of mostly quartz-rich shaly siltstone and variably calcareous, very fine grained sandstone. The depositional rate is estimated at 0.04 m per 1000 years. The upper contact with the Whistler Member (equivalent to the basal Doig Formation in subsurface) is sharp and marked by a phosphate-rich shale and siltstone interval with a phosphate-granule layer at the erosional base.

Mount Crum Section

This section differs in many respects from that at Meosin Mountain. The succession begins with 24 m of silty black shale with disseminated pyrite and calcareous concretions belonging to the Phroso Member, which is restricted to the Dienerian. The Griesbachian is missing at this location, probably because this site was high through much of the Late Paleozoic (Henderson et al., 2010) and earliest Triassic; 1 m of phosphatic sandstone and chert, correlated with the Middle Permian Fantasque Formation, sits unconformably on Mississippian carbonate of the Visean Mount Head Formation. The Phroso Member is conformably overlain by platy, orange- to grey-weathering, calcareous siltstone and shaly siltstone with concretions and bivalve-rich bioclastic limestone beds, correlated with the Smithian part of the Vega Member. Depositional rates of 0.08 and 0.14 metres per 1000 years for the Dienerian and Smithian, respectively, are some of the highest estimated in the region (Table 1). This may be a function of increased subsidence following structural inversion of a Late Paleozoic high during the Early Triassic and the increased proportion of bioclastic carbonate. In addition, there are no turbiditic sandstone units within any part of the succession at Mount Crum. The Spathian at Mount Crum is about 190 m thick and consists of grey-weathering, interbedded calcareous silty shale and bioclastic limestone. The depositional rate is estimated at 0.06 m per 1000 years. The Vega is overlain by phosphatic shale and limestone of the Whistler Member. The increased proportion of carbonate at this section might suggest that these units would be better attributed to the Grayling and Toad formations (see Gibson, 1975).

Peck Creek and Ursula Creek Composite Section

The Peck Creek section was measured in detail during August 2010 and conodont work is still pending. However, correlations can be made directly to the section at Ursula Creek (Henderson, 1997; Zonneveld and Henderson, 1999). As a result, the section depicted in Figure 3 is a composite of the two sites. In general, depositional rates at these two sections are much lower than at the other described sites, owing largely to the more distal depositional setting. At both locations, the Grayling Formation sits conformably on a recessive upper member of the Fantasque Formation that consists of interbedded fissile shale and thin beds of dark grey to black chert. There is no erosional lag and the formation contact appears sharp only because of the degree of silicification. The source of silica is sponge spicules that are missing in the Grayling Formation after the Late Permian extinction. The basal Grayling consists of silty shale and dolomicrite (Wignall and Newton, 2003) that grades upward into laminated black shale deposited in a deep basinal setting. The Grayling-Toad formational contact is marked by the increase in bioclastic limestone interbedded with black silty shale. Intercalated laminated black silty shale and dark grey siltstone characterize the succession a little higher in the Toad Formation. These beds are attributed to distal turbidites displaying amalgamated D-E and C-D-E Bouma sequences in an outer turbidite fan to turbidite fan fringe setting (Zonneveld and Henderson, 1999). These turbidites are correlated with the Upper Smithian and Spathian and, although they may overlap in age with turbidites at Meosin Mountain, most of them are younger and seemingly unrelated to that succession or to the succession in west-central Alberta mentioned previously. The turbidite succession is overlain by phosphatic silty black shale with bioclastic calcareous concretions that are dated as Anisian on the basis of conodonts. Ages are poorly constrained for the Lower Triassic interval (see Zonneveld and Henderson, 1999), but depositional rates

Table 1. Estimated depositional rates for the studied sections, expressed as metres per 1000 years.

Stage \ Section	Meosin Mountain	Mount Crum	Peck Creek Ursula Creek
Smithian Spathian	0.04	0.08	0.01
Spathian	0.03	0.06	0.004
Smithian	0.07	0.14	0.03
Dienerian only		0.08	
Griesbachian Dienerian	0.04		0.03

are estimated at 0.03 m per 1000 years for the Griesbachian to Smithian and as low as 0.004 m per 1000 years for the Spathian, although rates must have been higher during deposition of the turbidite intervals.

Conclusions

Lithology and depositional rates for the Lower Triassic succession of east-central and northeastern BC vary significantly across the region, pointing to the need for a well-developed sequence biostratigraphic framework in order to best assess the overall potential for shale gas and tight gas in the region.

Acknowledgments

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