High-resolution sequence stratigraphy of the Middle Triassic Sunset Prairie Formation, Western Canada Sedimentary Basin, Northeastern British Columbia

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ABSTRACT

The Middle Triassic Sunset Prairie Formation has been recently identified between the Lower Triassic Montney Formation and the Middle Triassic Doig Formation in the Western Canada Sedimentary Basin. Due to its recent recognition, the Sunset Prairie Formation has yet to be incorporated into sequence stratigraphic frameworks of the Triassic. Through the investigation of 25 cored wells, facies characteristics, vertical facies stacking and lateral facies distributions have been identified and described. Sequence stratigraphic surfaces were identified in core and extrapolated to geophysical wireline log signatures of 248 wells within the basin. The Sunset Prairie Formation can be divided into three, upward-coarsening parasequences that exhibit a retrogradational stacking pattern. All parasequences of the Sunset Prairie Formation are truncated at their tops by the Doig phosphate zone. The Sunset Prairie Formation truncates the underlying Montney Formation, suggesting that the stratigraphic interval is unconformity bound by sequence boundaries and their correlative conformities. The addition of the Sunset Prairie Formation reveals a discrete sequence of transgressive deposits previously unaccounted for within the Triassic sequence stratigraphic framework of the Western Canada Sedimentary Basin.
INTRODUCTION

The Middle Triassic Sunset Prairie Formation occurs in the subsurface of British Columbia within the Western Canada Sedimentary Basin. The interval consists of interbedded light gray, pervasively bioturbated sandstone and dark gray, diminutively bioturbated siltstone beds that are sedimentologically, ichnologically and palaeontologically discrete from the underlying and overlying units (Furlong et al., 2018a, b). The newly described stratal unit of the Sunset Prairie Formation sits stratigraphically between the Lower Triassic Montney Formation and the Middle Triassic Doig Formation, and has previously been informally referred to as the ‘Anisian Wedge’ prior to its formal lithostratigraphic affiliation (Zonneveld and Moslow, 2015; Zonneveld et al., 2015, 2016; Furlong et al., 2016b, 2017; Davies et al., 2018).

A number of studies have investigated the sedimentology, stratigraphy and sequence stratigraphy of the Montney and Doig formations (Davies et al., 1997; Embry, 1997; Golding et al., 2014b; Crombez et al., 2016, 2017; Davies et al., 2018; Proverbs et al., 2018). The Sunset Prairie Formation, however, was not recognized by these studies, and the interval was either included in the Montney or Doig formations (Doig phosphate zone), or straddled both. More recent publications have acknowledged the presence of the Sunset Prairie Formation (Davies et al., 2018; Euzen et al., 2018; Moslow et al., 2018; Zonneveld and Moslow, 2018), but little work has been done to integrate the interval into the overall Triassic sequence stratigraphic framework. A revised stratigraphic framework...
is needed to better understand the transition between the Montney, Sunset Prairie and Doig formations.

The objectives of this study include: 1) providing an overview of the lithofacies and facies associations present in the Sunset Prairie Formation; 2) describing facies distributions and lateral variability; 3) defining a sequence stratigraphic framework internal to the Sunset Prairie Formation; and 4) interpreting a sequence stratigraphic relationship between the Montney, Sunset Prairie and Doig formations. The purpose of this investigation is to provide a better understanding of the depositional models, stratigraphy and basin evolution of Western Canada during the Lower to Middle Triassic.

GEOLOGICAL SETTING

Lithostratigraphic Framework

The Western Canada Sedimentary Basin consists of a westward-thickening wedge of Phanerozoic strata above the Precambrian crystalline basement (Mossop and Shetsen, 1994). Triassic subsurface strata of the Western Canada Sedimentary Basin consist of the Lower Triassic Montney Formation, the Middle Triassic Sunset Prairie, Doig and Halfway formations, and the Upper Triassic Charlie Lake, Baldonnel, Pardonet and Bocock formations (Fig. 1) (Clarke, 1957; Hunt and Ratcliffe, 1959; Armitage, 1962; Furlong et al., 2018a). Throughout Alberta and British Columbia, Triassic strata sit unconformably above Permian or Carboniferous strata and are unconformably overlain by Jurassic or Lower Cretaceous strata (Edwards et al., 1994).

Stratigraphic nomenclatural discrepancies occur between Alberta and British Columbia for the Montney and Doig formations (Playter et al., 2018; Zonneveld and Moslow, 2018). Herein, the authors refer to the Montney Formation from a British Columbian perspective. Therefore, the “Montney Formation” as used in this paper, includes intervals referred to as both the Montney Formation and Basal Doig Siltstone within the Albertan stratigraphic nomenclature (Playter et al., 2018; Zonneveld and Moslow, 2018).
Palaeoenvironmental Setting

By the end of the Permian, the supercontinent of Pangea had formed from the amalgamation of the world’s major landmasses (Ziegler, 1988; Lawyer et al., 2002, 2011). On the western margin of Pangea, Triassic sediments were deposited within a large, central sub-basin, called the Peace River Embayment, and these consisted of marine and marginal-marine siliciclastic and carbonate sediments, and lesser volumes of evaporite deposits (Fig. 2) (Douglas, 1970; Barclay et al., 1990; O’Connell et al., 1990; Edwards et al., 1994; Evoy and Moslow, 1995). These deposits accumulated under arid, mid-latitudinal (~32-34°N) conditions (Wilson et al., 1991; Davies, 1997a; Davies et al., 1997; Dixon, 2000; Moslow, 2000; Golonka, 2007; Zonneveld and Moslow, 2018). During this time, Canada was rotated approximately 30° clockwise from its current orientation and the regional shoreline approximately parallels the axis of the modern-day Rocky Mountains (Golonka et al., 1994; Davies, 1997a, b; Golonka and Ford, 2000).

Many have suggested that the Triassic of Canada represents an arid coastline, mainly through evidence of aeolian dunes, regionally extensive anhydrite beds and solution-collapse breccia (resulting from evaporite dissolution) associated with latest Middle and early Upper Triassic marginal marine and non-marine strata (Gibson and Barclay, 1989; Zonneveld et al., 1997; Zonneveld, 2001). Although minimal direct evidence has been presented on the palaeoclimate of Lower to early Middle Triassic strata, palynology (e.g., taeniate bisaccate and polyplicate palynomorphs; Utting, 2001; Utting et al., 2005; Zonneveld et al., 2010b) and mineralogy (abundance of detrital dolomite, low clay proportions and reworked anhydrite nodules; Davies et al., 1997) are consistent with arid conditions.

Palaeoshoreline reconstructions and coastal facies distributions are difficult to determine during the Lower and early Middle Triassic, owing to the presence of unconformities between many of the formations that cannibalized marginal marine and terrestrial deposits.

Tectonic Setting
Multiple structural features should be taken into consideration when trying to resolve depositional dynamics of Triassic strata in the Western Canada Sedimentary Basin. Prior to the Triassic, the Peace River Arch was a basement-uplifted topographic high, which persisted from the Precambrian to Devonian and greatly controlled deposition and preservation of sediment (deMille, 1958; Cant, 1988; Stephenson et al., 1989; Barclay et al., 1990; O’Connell et al., 1990). During the Carboniferous, the Peace River Arch began to subside and collapse, which eventually formed the Dawson Creek Graben Complex (Barclay et al., 1990; Gibson and Edwards, 1990; O’Connell et al., 1990). The graben complex consists of three major elements, which comprise the Fort St. John Graben, the Hudson Hope Low, and a number of smaller satellite grabens (Hines Creek, Whitelaw and Cindy grabens) (Barclay et al., 1990; O’Connell, 1994). These features formed a system of high-angle normal faults that subsided due to syndepositional and post-depositional growth-type block faulting (Barclay et al., 1990; Edwards et al., 1994). Subsidence associated with the Peace River Arch and Dawson Creek Graben Complex significantly influenced deposition of Carboniferous, Permian and Triassic strata, and this region ultimately became the main sediment depocentre within the Peace River Embayment (Cant, 1988; Barclay et al., 1990; O’Connell et al., 1990; Wittenberg, 1992, 1993; Qi, 1995; Davies, 1997a). Other structural features influencing Triassic deposition include: the Hay River Fault Zone, Laurier Embayment, Monias High, Beaton High, Grassy High, Sukunka Uplift, and faulting associated with Devonian reef trends (Leduc Reef and Swan Hills Reef) (Richards, 1989; Davies and Majid, 1993; Henderson et al., 1994; Davies, 1997a, b).

Traditionally, the northwestern margin of Pangea during the Cambrian to the Late Triassic has been considered to be a tectonically stable, passive margin with a single northeastern-derived sediment source (Dickinson, 1977; Monger and Price, 1979; Coney et al., 1980; Gibson and Barclay, 1989; Price, 1994; Davies, 1997a). A passive margin would have fostered the development of a marine ramp/shelf setting (Edwards et al., 1994; Dixon, 2009a, b; Onoue et al., 2016). It has been suggested that subduction and collision of island arcs occurred in the Panthalassic Ocean, offshore of the margin of Pangea, with terrane accretion occurring only during the late Jurassic and early Cretaceous; thus, suggesting that the Triassic margin was passive (Gibson and Barclay, 1989; Davies, 1997a). Multidisciplinary evidence, including stratigraphic architecture, geochemical models and zircon dating suggests, however, that basin evolution, margin development and sediment provenance
are more complex than previously interpreted (Ferri and Zonneveld, 2008; Berenak et al., 2010; Golding et al., 2016; Rohais et al., 2016; Morris et al., 2018). Terrane accretion likely occurred as early as the Early Triassic (Beranek and Mortensen, 2011; Golding et al., 2016; Zonneveld and Moslow, 2018; Rohais, et al., 2018). These terranes would have provided a minor, but significant, source of sediment to the Peace River Embayment, in addition to the primary sediment source from the Laurentian craton to the east (Ferri and Zonneveld, 2008; Berenak et al., 2010; Golding et al., 2016; Morris et al., 2018). Geodynamic settings and palaeogeographic reconstructions along an active margin have led to multiple hypothesized basin models for Triassic deposition, and include a back-arc-basin (Ferri and Zonneveld, 2008; Miall and Blakey, 2008; Zonneveld et al., 2010a; Schiarizza, 2013; Morris et al., 2014, 2018), fore-arc-basin (Nelson et al., 2006; Colpron et al., 2007; Rohais et al., 2016) and early foreland basin (Golding et al., 2016; Rohais et al., 2018; Zonneveld and Moslow, 2018). The evolution of Early Triassic basin architecture in Western Canada and its implications on depositional processes, palaeoenvironmental dynamics and oceanic circulation remain debateable.

SEQUENCE STRATIGRAPHY: GENERAL CONCEPTS

Sequence stratigraphy represents a markedly different approach than lithostratigraphy. Lithostratigraphic units are mappable intervals of rocks that share similar sedimentary characteristics, where facies are correlated and boundaries between units typically represent highly diachronous contacts (Hedberg, 1976). Sequence stratigraphy is the study of cyclic sedimentation patterns that have developed in response to variations in accommodation and sedimentation conditions (Catuneanu, 2019). A relative chronostratigraphic relationship can be interpreted from the relationship between coeval stratal units and bounding surfaces, in that strata lying above the discontinuity are younger than strata lying below it (Catuneanu, 2006). The Sunset Prairie Formation is an unconformity-bound lithostratigraphic formation; however, a sequence stratigraphic framework internal to the formation can be established.

This study predominantly utilizes the Exxon model of depositional cycles defined on the basis of bounding subaerial unconformities and their correlative conformities (Posamentier et al., 1988;
Posamentier and Vail, 1988; Van Wagner et al., 1988, 1990). Stratigraphic geometries and stratal pattern relationships within the Exxon model were based on the hypothesis of eustatic controls producing systems tracts (Posamentier et al., 1988; Posamentier and Vail, 1988). For the past few decades, however, it has been increasingly recognized that sequence stratigraphic architectures are a result of ‘relative sea level,’ which is a blend of eustasy, tectonism and climate forcing functions that affect base level and therefore, accommodation space (Hunt and Tucker, 1992; Posamentier and James, 1993; Posamentier and Allen, 1999; Catuneanu, 2006; Cataneanu et al., 2009). Within the Peace River Basin, it has been suggested that there was a strong tectonic influence resulting in fault reactivation, which overprinted the higher-order eustatic signature (Embry, 1997; Kendall, 1999).

Due to the fact that sequence stratigraphic terminology is ever evolving, a brief summary of terms and concepts is outlined here. A ‘sequence’ is a package of genetically related strata that are bound by regionally extensive subaerial unconformities and their correlative conformities (Sloss, 1963; Mitchum, 1977). A sequence is the fundamental stratal unit of sequence stratigraphy and corresponds to depositional processes and products recording a full cycle of base-level change (Catuneanu, 2006; Cataneanu et al., 2009). Sequences are subdivided into systems tracts, which are defined by the types of bounding surfaces, origin of bounding surfaces, their position within a sequence, and the stacking pattern of parasequences and parasequence sets (Van Wagoner et al., 1988; Posamentier and Allen, 1999; Catuneanu, 2019). Parasequences are genetically related beds or bedsets recording progradational regression that have classically been described to be bound by marine flooding surfaces produced by an abrupt increase in water depth (Van Wagoner et al., 1988, 1990; Posamentier and Allen, 1999). The concept of a parasequence has been deemed obsolete by some (Catuneau, 2019) based on the inconsistency, ambiguity and confusion surrounding the identification and formation of flooding surfaces produced in different depositional settings. Transgression is required at the basal surface of a parasequence and it is likely that a thin transgressive package (likely <1 m thick) would be deposited at the base, which is then followed by regressive deposits; this suggests that parasequences consist of small-scale transgressive-regressive cycles with an identifiable internal maximum flooding surface and maximum regressive surface. Such small-scale (metre-scale) features, however, are difficult to reliably map using petrophysical datasets. Therefore, the authors have decided to retain the concept of parasequences within this study to represent packages of strata that
record overall progradational deposition, but may also exhibit thin transgressive deposits at the base associated with an abrupt increase in relative sea level. Genetically related parasequences can be grouped into parasequence sets, which form distinctive stacking patterns, bound by major marine flooding surfaces (Van Wagoner et al., 1988; Posamentier and Allen, 1999). The distinct stacking patterns of parasequences and parasequence sets designate subdivisions within each sequence and are described as the lowstand, transgressive, highstand and falling-stage systems tracts (Brown and Fisher, 1977; Van Wagoner et al., 1988; Catuneanu, 2006; Catuneanu et al., 2011). Three different sequence stratigraphic models have described the interplay between systems tracts and the timing of sequence boundaries (i.e. Depositional Sequence, Genetic Sequence and Transgressive-Regressive Sequence). A thorough description and discussion of the models are outlined by Catuneanu (2006, 2019) and Catuneanu et al. (2009, 2011).

STUDY AREA AND DATASET

This investigation of the Sunset Prairie Formation was undertaken on a regional scale within the Western Canada Sedimentary Basin. Stratigraphic correlations between drill cores were produced using geophysical well log data from GeoScout. A total of 248 vertical wells were used to determine the stratigraphic architecture and distribution of the Sunset Prairie Formation. Geophysical data were supplemented with slabbled core from 25 wells. Cores were logged and described for sedimentological, ichnological and palaeontological characteristics. Detailed observations of lithology, grain size, nature of contacts, physical sedimentary structures, biogenic sedimentary structures and body fossils were recorded for each core. Bioturbation intensity was quantified using a bioturbation index (BI), which ranges from non-bioturbated (BI = 0) to pervasively bioturbated/completely biogenically homogenized (BI = 6) (Reineck, 1963, 1967; Taylor and Goldring, 1993). Trace fossils were identified down to the ichnogenus level. Core characteristics were categorized into facies and combined into recurring facies associations to interpret their depositional settings. The open-marine environmental subdivisions used in this study are based on Elliott (1986) and Reading and Collinson (1996), which place the offshore below storm-wave base, the offshore...
transition between storm wave base and fair-weather wave base, and the shoreface between the fair-
weather wave base and low-tide line. A thorough investigation of facies within the Sunset Prairie
Formation and their interpreted depositional palaeoenvironments has been described by Furlong et al.
(2018b).

Stratigraphic relationships within the Sunset Prairie Formation were established through the
evaluation and interpretation of facies distribution and stacking patterns. Parasequences and sequence
stratigraphic surfaces were interpreted in core and tied to geophysical well data. These surfaces were
then correlated between cored wells. A grid of depositional dip- and strike-oriented, regional cross
sections were constructed using gamma, resistivity and density porosity logs. Regional isopach maps
were produced for each parasequence of the Sunset Prairie Formation to visualize the distribution and
thickness of each package. All of the 248 vertical wells were included in the regional grid to ensure
the integrity of the depositional sequence stratigraphic framework.

INTERNAL ARCHITECTURE OF THE SUNSET PRAIRIE FORMATION

Summary of Lithofacies

Seven lithofacies were identified in the Sunset Prairie Formation and have been described in
detail by Furlong et al. (2018b). Sedimentological, ichnological and palaeontological characteristics
of each lithofacies are outlined in Figure 3. Overall, the facies can be subdivided into three categories:
1) diminutively bioturbated (Facies 1 and 2), where physical sedimentary structures are observable; 2)
pervasively bioturbated (Facies 3, 4 and 5), where burrowing organisms have homogenized the
sediment and destroyed most primary physical sedimentary structures; and 3) facies that are
associated with regional or local stratigraphic surfaces (Facies 6 = Glossifungites Ichnofacies; Facies
7 = conglomeratic lag deposit). Collectively, the facies are associated with deposition in the offshore,
offshore transition and lower shoreface environments (Furlong et al., 2018b).

Facies Associations
Facies associations record the recurrence of lithofacies in a predictable vertical distribution. Collectively, the lithofacies of the Sunset Prairie Formation are interpreted to represent deposition along a wave-dominated, shallow-marine setting, within the offshore, offshore transitions and lower shoreface. The shallowing-upward pattern of lithofacies within the facies associations suggests a small-scale regression of relative sea level (Fig. 4).

A variety of different shoreface models have been suggested over the past few decades and use slightly variable terminology for environmental subdivision (Elliott, 1986; Reading and Collinson, 1996; MacEachern and Bann, 2008; Buatois and Mangano, 2011). Within this paper, the open-marine environmental subdivisions are based on Elliott (1986) and Reading and Collinson (1996), which place the offshore below the storm-wave base, the offshore transition between the storm-wave base and the fair-weather wave base, and the shoreface between the fair-weather wave base and the low-tide line. Ichnological characteristics observed within the Sunset Prairie Formation vary slightly from those that are classically associated with shoreface successions (Reading and Collinson, 1996; Buatois and Mangano, 2011), due to the stressed marine ecosystem attributed to the end-Permian mass extinction and the faunal recovery period that followed (Benton and Twitchett, 2003; Heydari and Hassanzadeh, 2003; Black et al., 2012; Hinojaosa et al., 2012; Payne and Clapham, 2012). General trends observed in each setting are described below.

Offshore deposits (Facies 1) consist of fine-grained to coarse-grained siltstone. Sedimentary structures include faint horizontal planar-parallel laminae and horizontal wavy-parallel laminae, which are indicative of deposition within a low-energy environment. Ichnological assemblages are characterized by a low trace fossil diversity (4 ichnogenera), low trace fossil abundance (BI = 0-2), and small trace fossil size (<1 mm in diameter).

Offshore transition deposits are associated with a large range of sedimentological and ichnological characteristics. The offshore transition setting has been divided into a distal expression (lower offshore transition) and a proximal expression (upper offshore transition). The lower offshore transition is characterized by both diminutively bioturbated facies (Facies 1 and 2) and pervasively bioturbated facies (Facies 3 and 4). Lithologically, deposits consist of fine-grained to coarse-grained siltstone. Within bioturbated facies, trace fossil diversity is moderate (7 ichnogenera), trace fossil
abundance is high (BI = 4-6), and trace fossil size is variable (0.5-12 mm in diameter). Fair-weather wave deposits are mainly associated with bioturbated intervals; however, non-bioturbated intervals exhibit horizontal planar-, wavy-, and pinstripe-parallel laminae, which can also be associated with fair-weather deposition when physico-chemical stresses reduce/hinder biotic colonization. Rare low- and high-angle planar cross stratification, and asymmetric ripples are indicative of periodic increased energy, possibly associated with storm deposition. But the lack of strongly storm-influenced primary sedimentary structures and the presence of intensely bioturbated intervals within the offshore transition suggest that a sheltered coastal setting that was protected from storm erosion existed during deposition of the Sunset Prairie Formation. Deposition within the upper offshore transition (Facies 3, 4 and 5) is characterized by a moderately high trace fossil diversity (11 ichnogenera), large trace fossil sizes (up to 15 mm in diameter) and intense bioturbation (BI = 4-6). Lithologically, deposits consist of fine-grained to coarse-grained siltstone. The lack of non-bioturbated facies suggests that bioturbation rates outpaced sedimentation rates, resulting in infaunal organisms completely homogenizing the sediment.

Lower shoreface deposits (Facies 5) are associated with a moderately high trace fossil diversity (10 ichnogenera), large trace fossil sizes (up to 15 mm in diameter) and intense bioturbation (BI = 4-6). Lithologically, deposits consist of fine-grained siltstone to fine-grained sandstone. The coarse-grained sandstone material suggests that these intervals are more proximally located than the other facies of the Sunset Prairie Formation. Facies associated with more proximal settings, like the middle shoreface, upper shoreface and foreshore are not observed within the Sunset Prairie Formation and have been erosionally removed.

Distribution of Sedimentary Facies and Facies Associations

*Vertical Distribution of Facies* The reoccurring stacking pattern of facies show upward-coarsening packages that preserve deposits from distal (offshore) to proximal (lower shoreface) settings. Upward-coarsening successions have a variety of origins within the rock record. Increased hydrodynamic energy resulting from relative sea-level fall leading to depositional shallowing can generate upward-coarsening intervals (Van Wagoner *et al.*, 1990; Catuneanu *et al.*, 2009). However, when independent
indicators of palaeoshoreline position or water depth are absent, coarsening-upward successions may reflect bedsets that form without relative changes in sea level (Hampson et al., 2008). Such conditions include an increase in sand influx due to river flow, or increase in storm waves and/or currents driven by variations in climate, ocean circulation or shoreline palaeogeography (Storms and Hampson, 2005; Somme et al., 2008; Mitchell et al., 2012). Although the exact palaeoshoreline position during Sunset Prairie Formation deposition has not been preserved, it is most likely that the upward-coarsening successions are a result of changes in relative sea level due to: 1) the high bioturbation intensity suggesting prolonged periods of low intensity storms (Howard, 1975; Gani et al., 2007; Furlong et al., 2018b); 2) arid conditions during the Triassic would have fostered the development of ephemeral rivers (Zonneveld and Moslow, 2014), which would only increase sediment supply occasionally (seasonally or less frequently); and 3) spatial migration of the lower shoreface deposit capping the top of coarsening-upward packages (parasequences) through time can infer palaeoshoreline trajectory.

Facies stacking patterns within the Sunset Prairie Formation preserve shoaling-upward successions, which are interpreted here as parasequences. The base of the parasequence is marked by a series of conglomerate lag deposits (Facies 7), which are interpreted to represent transgressive lags. These surfaces are allogenic and can be mapped across the basin. Burrowed firmgrounds of the *Glossifungites* Ichnofacies (Facies 6) are also commonly associated with the boundaries of parasequences, but can also be interformational, suggesting both autogenic and allogenic origins. Overlying the transgressive lag deposits is a shoaling upward succession, which records offshore deposits overlain by offshore transition deposits, which are then capped by lower shoreface deposits (Figs 4 and 5). Parasequences coarsen upward in grain size from fine-grained silt to very fine-grained sand and bioturbation increases upwards. Small-scale interbedding of diminutively bioturbated facies and pervasively bioturbated facies occur throughout the parasequence, but an overall shoaling upward trend occurs. Up to three parasequences are observed within the Sunset Prairie Formation.

*Lateral Distribution of Facies.*—The Sunset Prairie Formation total thickness increases to the west and thins to an erosional edge to the east (Figs 6 and 7). Eastern-located wells do not preserve all three parasequences, and commonly only preserve one or two of the lower parasequences in thinned accumulations. The parasequences commonly exhibit more proximal facies associated with the upper
offshore transition and lower shoreface, and contain abundant coarse-grained lag deposits (Figs 5 and 6). The decrease in total number and thickness of parasequences (Fig. 6) is likely a result of autogenic erosion associated with shallow-marine conditions redistributing sediment due to the lack of accommodation space.

Wells located in western or distal locations within the basin preserve thicker successions of all three parasequences, which preserve offshore, offshore transition, and lower shoreface deposits. Over-thickening in some regions might be due to structural features. The formation is thickest (66.5 m in the 03-06-078-22W6 cored well), within the Fort St. John Graben system and the Hudson Hope Low, in the western region of the study area (Fig. 6). The interval thins across the Hudson-Monias High, where the formation is <25 m in total thickness (Fig. 6). In the Laurier Embayment, in the northern portion of the study area, the formation thickens to approximately 30 m. Localized, detailed studies would provide a better understanding of how facies, facies associations and parasequence distributions change across these structural features.

Parasequence Geometry

Regional correlation suggests that three upward-coarsening parasequences are recognized within the Sunset Prairie Formation throughout the basin in core and geophysical wireline data (Figs 6, 7 and 8). Commonly, the base of the parasequence is identifiable by high, commonly off-scale, gamma ray log deflections, which are frequently associated with a lag deposit (Facies 7) and/or Glossifungites Ichnofacies-demarcated discontinuity surface (Facies 6) (Fig. 5; Furlong et al., 2018a, figs 5 through 7). Where a lag deposit or Glossifungites Ichnofacies-demarcated discontinuity surface is not present, an abrupt change from proximal facies overlain by distal facies is observed in core; this corresponds to a sharp decrease in gamma ray log signature, which may or may not be off-scale. Additionally, in more westward locations where the Sunset Prairie Formation is at its thickest, a correlative conformity can be interpreted when a subtle change in facies occurs (Fig. 5).

Spatial distribution of the three parasequences is shown in the isopach maps of Figure 7. The first parasequence (P1) extends across the entire area where the formation is preserved. Compared to P1,
Parasequence 2 (P2) is preserved in a more distal/western location. Parasequence 3 (P3) is preserved in the most western location when compared to the other two parasequences.

All parasequences are observed to thicken to the west and are erosionally removed to the east (Figs 7 and 8). Although there is a westward migration of the preserved parasequences, which would lead one to interpret progradation, facies associations within the parasequences exhibit a back-stepping stacking pattern and each subsequent parasequence preserves relatively less proximal associated facies (lower shoreface) at their tops (Fig. 5). Significant erosion would have been needed to truncate the Sunset Prairie Formation and remove the eastern parts of the parasequences. Therefore, the top of the Sunset Prairie is interpreted to represent an unconformity associated with a transgressively modified sequence boundary (FS/SB).

Sequence Stratigraphic Models for the Sunset Prairie Formation

The Sunset Prairie Formation has been interpreted as representing a variety of different sequence stratigraphic systems tracts. The interval has previously been interpreted to represent deposition under falling stage and lowstand conditions (Proverbs et al., 2018) and a shelf-margin wedge building out from the underlying highstand unit of the Montney Formation (Davies et al., 2018). The sedimentological characteristics of the interval provide evidence supporting different sequence stratigraphic frameworks, leading to complex interpretations of stratal relationship with the Montney and Doig formations. Here, two different sequence stratigraphic interpretations are made for the Sunset Prairie Formation.

Transgressive Systems Tract.—Based on facies associations, parasequence stacking patterns, sequence and stratal boundaries, the Sunset Prairie Formation can be interpreted as a transgressive systems tract. Each parasequence exhibits a back-stepping or retrogradational stacking pattern with respect to the underlying parasequence (Figs 7 and 9). The thickest packages of the most proximal facies (lower shoreface deposits) are preserved at the base of the Sunset Prairie Formation (in the first parasequence), and progressively thin in succeeding parasequences (Figs 5 and 6). Additionally, the average grain size of each parasequence decreases moving stratigraphically upward.
The base and top of the Sunset Prairie Formation are unconformities that are interpreted as transgressively modified sequence boundaries (FS/SB) due to the unconformity truncating the underlying formation (Furlong et al., 2018a, b). Little or no sedimentological evidence (e.g. root casts, palaeosols, karsting, etc.) has been observed at the boundary between the Montney Formation and the Sunset Prairie Formation to suggest prolonged subaerial exposure; however, transgressive modification would have been capable of eliminating evidence of subaerial exposure along the surface. Subaerial erosion of the underlying Montney Formation would have also been amplified by regional tectonic uplift.

In this scenario, the lowstand systems tract would be predicted to be spatially detached and the boundary between the Montney Formation and Sunset Prairie Formation would represent a significant drop in relative sea level with subsequent base-level rise. However, no observations have yet to suggest that detached, distally located lowstand deposits occur in the Rocky Mountain outcrop belt (see Orchard and Zonneveld, 2009 for descriptions of outcrop facies). The stratal relationship between the Sunset Prairie Formation and the Doig phosphate zone would also suggest that a lowstand systems tract and a highstand systems tract would be predicted in a basinward position. These deposits have yet to be recognized within the outcrop belt. Further investigations of the Rocky Mountain outcrop belt can provide a better understanding of sea-level fluctuations through the Triassic. The recognition of the lowstand systems tracts below the Sunset Prairie Formation and lowstand and highstand systems tract above the Sunset Prairie Formation remains unresolved.

Although interpreting the Sunset Prairie Formation as a transgressive systems tract follows classic sequence stratigraphic concepts, this interpretation does face some challenges. First, the Sunset Prairie Formation consists of more proximal facies (lower shoreface) with coarser-grained material (fine-grained sandstone) than the underlying Montney Formation (siltstone deposited within the offshore transition; Crombez et al., 2016). Although these changes are subtle, the transgressive systems tract has commonly been described as exhibiting the finest grained material in the system (Catuneanu, 2006). Using classic sequence stratigraphic models, the location of the lowstand systems tract below the Sunset Prairie Formation and a lowstand and highstand system tract above the Sunset Prairie Formation are predicted to be located more distally, or basinward. However, more evidence has suggested an active margin during Early Triassic deposition, which would influence the deposition of
lowstand and highstand deposits. Back-arc-basin, fore-arc-basin and early foreland basin types have been previously ascribed to the Montney Formation (Ferri and Zonneveld, 2008; Morris et al., 2014, 2018; Rohais et al., 2016, 2018). If these basin types persisted through deposition of the Sunset Prairie Formation, then the positioning of these island arcs would have influenced the distribution of accommodation space and areas of exposure. The basal or top boundaries of the Sunset Prairie Formation do not exhibit direct evidence supporting subaerial exposure or nonmarine deposition. Although transgression could cannibalize these deposits, the subtle changes in facies at the boundaries above and below the Sunset Prairie Formation may be more reflective of diastems (short interruption in sedimentation) associated with a correlative conformity and would reduce the amount of geologic time attributed to those surfaces. Understanding the evolution of the basin, proximity of the island arcs/accreted terranes to the continent and available accommodation of the unaccounted systems tracts would better render a more complete sequence stratigraphic model. Although these ideas are speculative, the complex contributions and effects of tectonic controls undoubtedly influence deposition of Early and Middle Triassic deposits.

*Alternative Interpretation: Falling Stage/Lowstand Systems Tract and Transgressive Systems Tract.*—Due to some pitfalls in the previous interpretation, a secondary interpretation is provided as an alternative means to deposit and preserve the Sunset Prairie Formation. Within the previous interpretation, the lowstand systems tract (and falling stage systems tract) is not accounted for within the cored dataset and is interpreted to be located more basinward. The proposed alternative sequence stratigraphic model interprets the Sunset Prairie Formation as a falling stage/lowstand systems tract (preserved as parasequence 1) and a transgressive systems tract (preserved as parasequence 2 and 3) (Fig. 10). Parasequence 1 exhibits the thickest accumulation of proximal (lower shoreface) facies (Fig. 5). These facies are more proximal and consist of coarser-grained material (up to very fine-grained sandstone) than the underlying Upper Montney Formation facies, which mainly consist of siltstone interpreted as offshore transition deposits (Zonneveld and Moslow, 2018). A decrease in relative sea level cut the unconformity and led to a slight basin shift in facies, supplying fine-grained sand to lower shoreface environments. Wave reworking produced an erosional surface at the base of the Sunset Prairie Formation as sea-level fell, producing a regressive surface of marine erosion.
(RSME). Distal locations would preserve a basal surface of marine regression (BSMR), or the correlative conformity. A regressive stacking pattern of parasequences within the falling stage/lowstand systems tract cannot be determined due to the systems tract being composed of a single parasequence, rendering the interpretation of both falling stage and lowstand systems tracts for the basal parasequence. Capping parasequence 1 is a transgressive surface of erosion (or regressive surface of marine erosion), which records the most basinward migration of the lower shoreface and marks the onset of transgression. The transgressive systems tract consists of the upper two parasequences, each showing an increased abundance in distal facies (offshore transition) compared to the first parasequence and an overall back-stepping of the palaeoshoreline. All three parasequences are truncated by an overlying coplanar sequence boundary and transgressive surface of erosion associated with the base of the Doig phosphate zone. Although the alternative sequence stratigraphic interpretation of the Sunset Prairie Formation consisting of falling stage/lowstand and transgressive deposits is more speculative, the absence of the lowstand systems tract down-dip and the occurrence of sharp, erosionally based coarse-grained (fine-grained sandstone) lower shoreface deposits located in a more distal locations, compared to underlying Montney Formation lithology, make this interpretation plausible.

DISCUSSION

Stratigraphic Architecture and Sequence Stratigraphy of the Lower and Middle Triassic of Western Canada

Many workers agree that the Montney Formation is composed of three unconformity-bound, third-order depositional sequences, corresponding to the Lower Montney (Griesbachian to Dienerian age), Middle Montney (Smithian-age) and Upper Montney (Spathian-age) (Embry and Gibson, 1995; Davies et al., 1997; Embry, 1997; Golding et al., 2014a, 2015; Henderson and Schoepfer, 2017; Davies et al., 2018; Henderson et al., 2018). However, internal sequence stratigraphic frameworks vary greatly between workers (Fig. 11). The majority of studies have focused on the proximal parts of the formation (Davies et al., 1997; Moslow and Davies 1997; Moslow 2000; Markhasin, 1997;
Kendall, 1999; Panek, 2000), isolated to localized spatial areas (Evoy and Moslow, 1995; Evoy, 1997; Harris, 2000; Dixon, 2002, 2007, 2010, 2011; Golding et al., 2014b; Proverbs et al., 2018; Moslow et al., 2018; Zonneveld and Moslow, 2018), or isolated stratigraphic intervals (Euzen et al., 2018; Prenoslo et al., 2018), with only a few studies looking at sequence stratigraphic correlations on a larger, basin-wide scale (Davies and Humes, 2016; Crombez et al., 2016, 2017; Davies et al., 2018). Although the scope of each publication differs, no unanimous sequence stratigraphic framework has emerged for the Lower and Middle Triassic, and the sequence stratigraphic surfaces identified are varied (Fig. 11).

To provide evidence for how the Sunset Prairie Formation ties into the sequence stratigraphic architecture of the Lower to Middle Triassic, stratigraphic surfaces were identified in the Upper Montney Formation, Sunset Prairie Formation and Doig phosphate zone in the Fort St. John Graben system. This area was chosen because it corresponds to the region where the Sunset Prairie Formation is most thickly preserved. Facies and stratigraphic surfaces were interpreted by the author in core and correlated across the area using petrophysical wireline data. Detailed description of facies, facies associations and basin-scale correlation of parasequences within the Upper Montney Formation and Doig phosphate zone were outside the scope of this paper.

Within the Fort St. John Graben system, the Upper Montney Formation consists of a lowstand systems tract at the base, with a thin (<5 m thick) transgressive systems tract overlying it (Fig. 12). The highstand systems tract makes up the majority of the Upper Montney Formation. Three parasequences were identified in the lowstand systems tract, one parasequence in the transgressive systems tract, and up to eight parasequences are identified in the highstand systems tract. Thickness of parasequences in the topset and bottomset areas are typically 10 m or less, whereas foreset thicknesses can reach up to 55 m. Similar results were obtained by Euzen et al. (2018) when mapping the Upper Montney basin wide. They, however, described the packages as parasequence sets, instead of parasequences. They suggested that the parasequence sets were made up of multiple coarsening-upward parasequences but lack further description of facies distributions in the parasequences themselves, or the distribution of the parasequences within the parasequence sets. Here the packages are considered to be more representative of parasequences and to record a single, overall shallowing of relative sea level.
The top of the Montney Formation was truncated by the unconformity underlying the Sunset Prairie Formation. The Sunset Prairie Formation was deposited as a transgressive systems tract. The overlying Doig phosphate zone is classically considered a transgressive, condensed section (Gibson and Barclay, 1989). Within the Fort St. John Graben system, the Doig phosphate zone erosionally truncates and onlaps the top of the Sunset Prairie Formation, which suggests that the Sunset Prairie-Doig boundary is a coplanar sequence boundary and transgressive surface of erosion. Figure 9 provides a schematic depicting the interplay between relative sea-level change and the deposition of the Upper Montney Formation, Sunset Prairie Formation and the Doig phosphate zone.

With the identification of the Sunset Prairie Formation in the Triassic strata of western Canada, the presence of another unconformity-bound sequence must be accommodated. The Montney Formation exhibits three third-order sequences (Douglas, 1970; Barclay et al., 1990; O’Connell et al., 1990; Edwards et al., 1994; Evoy and Moslow, 1995), and the Sunset Prairie Formation constitutes a portion of a fourth Triassic third-order sequence. The addition of another third-order sequence modifies the timing and processes associated with the evolution of the basin.

Structural Influences on Triassic Deposition

The Fort St. John Graben system and the Monias High are two regional structural features that have influenced deposition of both the Montney and Sunset Prairie formations. Studies of the Montney Formation have suggested that differential subsidence across the basin due to tectonic movement and/or differential compaction of pre-Triassic sedimentary successions produced depositional palaeorelief, which influenced and switched the position of preserved thick intervals (Davies et al., 2018; Euzen et al., 2018; Rohais et al., 2018). The Hudson Hope Low experienced subsidence beginning in the Devonian and continued to be a palaeolow throughout the Triassic (Barclay et al., 1990). The Monias High was a palaeohigh, which can be seen in Belloy Formation structures map (Dunn, 2003; Davies et al., 2018). Within the Montney, regions that exhibit thinned intervals generally correspond to zones where clinoforms (parasequences) change orientation as a result of being deflected around syndepositional highs (Euzen et al., 2018).
Evidence for syndepositional tectonism is present within the Sunset Prairie Formation. The strike-oriented cross section (Fig. 6; cross section D-D’) suggests that structural elements correlate to and likely influenced parasequence set thicknesses. Note that the cross section intersects the major palaeohighs and palaeolows, which impact parasequence distributions and stratigraphic architectures (Fig. 6). The Hudson Hope Low within the Fort St. John Graben system preserves the thickest interval of the Sunset Prairie Formation. Thickening that is wider than the area of the Fort St. John Graben system, as described by Davies (1997a, b) and Davies et al. (1997), is likely due to the graben being active during deposition of the Sunset Prairie Formation. Thinning across the Monias High suggests that the structure remained a palaeohigh during the Middle Triassic.

Other structural features have been identified and discussed within the Western Canada Sedimentary Basin to have influenced Triassic deposition (Barclay et al., 1990; Davies et al., 2018; Euzen et al., 2018; Rohais et al., 2018). Many of the small-scale features occur east of the erosional edge of the Sunset Prairie Formation and are located outside of the study area and/or are of too small a scale to resolve at the scale of this study.

The active margin associated with the western edge of Pangea during Sunset Prairie Formation deposition likely controlled the reactivation and displacement of structural features. The fluctuations in relative sea level, which formed the parasequences, may have a strong correlation with the tectonic pulses associated with the movement of the island arcs along the coast. More research is needed to assess the structural controls on this and other Triassic strata.

Reservoir Distribution of the Sunset Prairie Formation

Understanding the sequence stratigraphic framework for the Sunset Prairie Formation and its stratigraphic relationship with underlying and overlying formations can lead to a better prediction of reservoir targets. Generally speaking, the pervasively bioturbated, very fine-grained sandstone facies have core permeability measurements that are an order of magnitude higher than the minimally bioturbated siltstone-rich facies (Furlong et al., 2015, 2016a, b). Porosity doubles between non-bioturbated facies (1-3%) to bioturbated facies (4-6%), regionally. This difference in permeability and porosity in facies is based on the complex interplay between grain size variability, diagenetic features
(e.g., secondary porosity, cementation) and biogenic modification of grain distribution. This study does not elaborate on petrographic observations (e.g., grain size, diagenetic features) or specific reservoir properties (e.g., permeability, porosity, TOC distribution) due to the local variability of these characteristics; however, the discussion herein provides an overview of lithological distribution related to net-to-gross sand ratios to better predict where sand-rich reservoir intervals would be located.

Due to the retrogradational nature of the parasequences, the lowermost parasequence is where the thickest packages (up to 7 m) of pervasively bioturbated, very-fine grained sandstone intervals would be observed. Fine-grained sand content, thickness of coarse-grained beds and bioturbation intensity decrease with each following parasequence. The highest ratio of net-to-gross sand is observed at the base of the Sunset Prairie Formation and decreases stratigraphically upwards (Fig. 9; also see lithologs from Furlong et al., 2018a, figs 4-7).

If the Sunset Prairie Formation were actually a continuation of the highstand systems tract associated with the uppermost part of the Upper Montney Formation, facies distribution and stratigraphic architecture would appear differently. Within the highstand systems tract, progradation of parasequences produce coarsening-upward parasequence sets, with the most proximal, coarse-grained facies being observed stratigraphically at the top of the formation (Catuneanu, 2006, Catuneanu et al., 2009). This is the opposite of what is observed in the Sunset Prairie Formation. Additionally, the Sunset Prairie Formation truncates the underlying Montney Formation (Fig. 9), which would further suggest against the Sunset Prairie Formation being deposited during the highstand conditions associated with Montney Formation deposition.

This basin wide study provides the overall facies distribution and sequence stratigraphic architecture of the Sunset Prairie Formation, and suggests that the highest net-to-gross sand ratios are observed at the base of the formation. These intervals have the potential to be favourable reservoir targets, when other reservoir characteristics are optimal. Localized studies and detailed hydrocarbon investigations will provide more insight into reservoir characterization of the Sunset Prairie Formation and its potential producibility.
CONCLUSIONS

This study contributes to the sequence stratigraphic framework of the Lower to Middle Triassic of Western Canada by characterizing the stratigraphic architecture of the Sunset Prairie Formation. Through the facies analysis and correlation of parasequences in 25 cored wells and petrophysical well logs of 248 wells, a basin wide sequence stratigraphic model is proposed for the Sunset Prairie Formation.

Seven facies were identified in the Sunset Prairie Formation, consisting of two diminutively bioturbated facies (Facies 1 and 2), three pervasively bioturbated facies (Facies 3, 4 and 5), and facies associated with regional or local stratigraphic surfaces (Facies 6 and 7). These facies have been interpreted to represent deposition in the offshore, offshore transition and lower shoreface. Facies stacking patterns suggest that up to three upward-coarsening successions, or parasequences, can be observed in the formation. Each parasequence preserves lower shoreface deposits at their tops; however, the lowermost parasequence preserves the thickest interval of facies associated with proximal depositional settings (lower shoreface setting), whereas the two overlying parasequences preserve thinner beds of proximal facies and thicker intervals of distal facies (offshore transition to offshore deposits).

The stratigraphic architecture of the Sunset Prairie Formation consists of three parasequences constituting the transgressive systems tract. These parasequences are retrogradational and suggest that the palaeoshoreline moved eastward during deposition of the formation as a transgressive systems tract. Parasequences are truncated by the overlying Doig phosphate zone, indicating that the boundary represents a transgressively modified sequence boundary (FS/SB). The Sunset Prairie Formation directly overlies an unconformity that truncates the underlying Montney Formation, suggesting a transgressively modified sequence boundary (FS/SB) at the contact. Correspondingly, the Sunset Prairie Formation is an unconformity-bound sequence discrete from sequences of the underlying Montney Formation and those in the overlying Doig Formation. With the addition of the Sunset Prairie Formation into the Western Canada Sedimentary Basin, a revision of the sequence stratigraphic model associated with Triassic deposits is necessary.
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CONFLICT OF INTEREST

The authors report no conflict of interest.

DATA AVAILABILITY STATEMENT

All data is from public sources.

REFERENCES

Barclay, J.E., Krause, F.F., Campbell, R.I. and Utting, J. (1990) Dynamic casting and growth faulting: Dawson Creek Graben Complex, Carboniferous-Permian Peach River Embayment, Western Canada. Bulletin of Canadian Petroleum Geology, 38A, 115-145.

Benton, M.J. and Twitchett, R.J. (2003) How to kill (almost) all life: The end-Permian extinction event. Trends in Ecology and Evolution, 28, 358-365.

Beranek, L. P. and Mortensen, J. K. (2011) The timing and provenance record of the Lake Permian Klondike orogeny in northwestern Canada and arc-continent collision along western North America. Tectonics, 30, 1-23.

This article is protected by copyright. All rights reserved
Beranek, L. P., Mortensen, J. K., Orchard, M. J., and Ullrich, T. (2010) Provenance of North American Triassic strata from west-central and southeastern Yukon: correlations with coeval strata in the Western Canada Sedimentary Basin and Canadian Arctic Islands. Canadian Journal of Earth Sciences, 47, 53-73.

Berger, Z. (2005) Aeromag/tectonic study of Northeast British Columbia, summary tectonic map. Image interpretation Technologies Inc. (IITech.)

Berger, Z., Boast, M. and Mushayandebvu, M. (2009) Basement structures control on the development of the Peace River Arch’s Montney/Doig resource plays. Reservoir, Canadian Society of Petroleum Geologists, 36, 40-45.

Brown, L.F. Jr. and Fisher, W.L. (1977) Seismic stratigraphy interpretation of depositional systems: examples from Brazilian rift and pull apart basins. In: Seismic stratigraphy – applications to hydrocarbon exploration (Eds C.E. Payton, C.E.), American Association of Petroleum Geologists Memoir, 26, 213-248.

Black, B.A., Elkins-Tanton, L.T., Rowe, M.C. and Peate, I.U. (2012) Magnitude and consequences of volatile release from the Siberian Traps. Earth and Planetary Science Letters, 318, 361-373.

Buatois, L.A. and Mángano, M.G. (2011) Ichnology: Organism-Substrate interactions in space and time. Cambridge University Press, 358 p.

Cant, D.J. (1988) Regional structure and development of the Peace River Arch, Alberta: a Palaeozoic failed-rift system? Bulletin of Canadian Petroleum Geology, 36, 284-295.

Catuneanu, O. (2006) Principles of Sequence Stratigraphy. Pp. 375. Elsevier Science.

Catuneanu, O., Abreu, V., Bhattacharya, J.P., Blum, M.D., Dalrymple, R.W., Eriksson, P.G., Fielding, C.R., Fisher, W.L., Galloway, W.E., Gibling, M.R., Giles, M.R, Holbrook, J.M., Jordan, R., Kendall, C.G.St.C, Macurda, B., Martinsen, O.J., Miall, A.D., Neal, J.E., Nummedal, D., Pomar, L., Posamentier, H.W., Pratt, B.R., Sarg, J.F., Shanley, K.W., Steel, R.J., Strasser, A., Tucker, M.E. and Winker, C. (2009) Towards the standardization of sequence stratigraphy. Earth Science Review, 92, 1-33.

Catuneanu, O., Galloway, W.E., Kendall, C.G.St.C., Miall, A.D., Posamentier, H.W., Strasser, A. and Tucker, M.E. (2011) Sequence stratigraphy: Methodology and nomenclature. Newsletters on Stratigraphy, v. 44, p. 173-245.
Clark, L.M. (1957) Fort St. John sets pace for Peace River gas fields. *Oil and Gas Journal*, **55**, 132-144.

Coney, P. J., Jones, D. L. and Monger, J. W. H. (1980) Cordilleran suspect terranes. *Nature*, **288**, 329-333.

Colpron, M., Nelson, J.L. and Murphy, D.C. (2007) Northern Cordilleran terranes and their interactions through time. *Geological Society of America Today*, **17**, 4-10.

Crombez, V., Rohais, S., Baudin, F. and Euzen, T. (2016) Facies, well-log patterns, geometries and sequence stratigraphy of a wave-dominated margin: insight from the Montney Formation (Alberta, British Columbia, Canada). *Bulletin of Canadian Petroleum Geology*, **64**, 516-537.

Crombez, V., Baudin, F., Rohais, S., Riquier, L., Euzen, T., Pauthier, S., Ducros, M., Caron, B. and Vaisblat, N. (2017) Basin scale distribution of organic matter in marine fine-grained sedimentary rocks: Insight from sequence stratigraphy and multi-proxies analysis in the Montney and Doig Formations. *Marine and Petroleum Geology*, **83**, 382-401.

Davies, G.R. (1997a) The Triassic of the Western Canadian Sedimentary Basin: Tectonic and stratigraphic framework, palaeogeography, palaeoclimate and biota. *Bulletin of Canadian Petroleum Geology*, **45**, 434-460.

Davies, G.R. (1997b) The Upper Triassic Baldonnel and Pardonet Formations, Western Canada Sedimentary Basin. *Bulletin of Canadian Petroleum Geology*, **45**, 645-674.

Davies G.R. and Majid, H. (1993) “Grassy High”, northeastern British Columbia: a structural high with eroded Upper Triassic section coincident with optimum Mississippi hydrothermal dolomite reservoir development. *Canadian Society of Petroleum Geologists, Pangea Conference, Programs and Abstracts*, pp. 70.

Davies, G.R. and Hume, D. (2016) Lowstand/Slope-onlap Wedge in the Montney: Stratigraphic and Sequence Framework, Reservoir Significance. *GeoConvention 2016, Abstract*, pp. 4.

Davies, G.R., Moslow, T.F. and Sherwin, M.D. (1997) The Lower Triassic Montney Formation, west central Alberta. *Bulletin of Canadian Petroleum Geology*, **45**, 474-505.

Davies, G.R., Watson, N., Moslow, T.F. and MacEachern, J.A. (2018) Regional subdivisions, sequences, correlations and facies relationships of the Lower Triassic Montney Formation, west-
central Alberta to northeastern British Columbia, Canada – with emphasis on role of palaeostructure. *Bulletin of Canadian Petroleum Geology*, 66, 23-92.

deMille, G. (1958) Pre-Mississippian history of the Peach River Arch. *Journal of Alberta Society of Petroleum Geologists*, 6, 61-68.

Dickinson, W. R. (1977) Palaeozoic plate tectonics and the evolution of the Cordilleran continental margin. In: *Palaeozoic palaeogeography of the western United States* Eds J.H. Stewari, C.H. Stevens and A.E. Fritsche *Pacific Section, Society of Economic Palaeontologists and Mineralogists Pacific Coast Palaeogeography Symposium*, 1, 137-155.

Dixon, J. (2000) Regional lithostratigraphic units in the Triassic Montney Formation of western Canada. *Bulletin of Canadian Petroleum Geology*, 48, 80-83.

Dixon, J. (2002) A modification of Wittenberg’s model for the deposition of thick sandstone bodies in the Triassic Doig Formation, Wembley area, west-central Alberta. *Bulletin of Canadian Petroleum Geology*, 50, 393-406.

Dixon, J. (2007) Correlation of Middle and Upper Triassic strata in the Wembley area of west-central Alberta. *Geological Survey of Canada*, Open File 5665, CD-ROM.

Dixon, J. (2009a) The Lower Triassic Shale member of the Montney Formation in the subsurface of northeast British Columbia. *Geological Survey of Canada*, Open File 6274, p. 9.

Dixon, J. (2009b) Triassic stratigraphy in the subsurface of the plains area of Dawson Creek (93P) and Charlie Lake map areas (94A), northeast British Columbia. *Geological Survey of Canada Bulletin*, 595, 1-78.

Dixon, J. (2010). Character and origin of thick sandstone bodies in the Middle Triassic of Western Canada. *Geological Survey of Canada*, Open File 6431, CD-ROM.

Dixon, J. (2011). A review of the character and interpreted origins of thick, mudstone-encased sandstone bodies in the Middle Triassic Doig Formation of Western Canada. *Bulletin of Canadian Petroleum Geology*, 59, 261-276.

Douglas, R.J.W. (1970) Geology of western Canada. In: *Geology and Economic Minerals of Canada* (Ed R.J.W. Douglas), *Geological Survey of Canada, Economic Geology Report*, 1, 367-488.

This article is protected by copyright. All rights reserved
Dunn, L.A. (2003). Sequence biostratigraphy and depositional modelling of the Pennsylvanian to Permian Belloy Formation northwest Alberta and northeast British Columbia. Unpublished Ph.D. Thesis, University of Calgary, Calgary, Alberta.

Edwards, D.E., Barclay, J.E., Gibson, D.W., Kvill, G.E. and Halton, E. (1994) Triassic strata of the Western Canadian Sedimentary Basin. In: Geological atlas of the Western Canada Sedimentary Basin (G. Mossop, and I. Shetsen, I), Canadian Society of Petroleum Geologists and Alberta Research Council, Special Report 4, 159-275.

Elliott, T. (1986) Siliciclastic shorelines. In: Sedimentary Environments and Facies (Ed H.G. Reading) 2nd edn, pp. 155-188. Blackwell Science, Oxford.

Embry, A.F. (1997) Global sequence boundaries of the Triassic and their identification in the Western Canada Sedimentary Basin. Bulletin of Canadian Petroleum Geology, 45, 415-433.

Embry, A.F and Gibson D.W. (1995) T-R sequence analysis of the Triassic succession of the Western Canada Sedimentary Basin. In: Proceedings of the Oil and Gas Forum '95 – Energy from Sediments (Eds J.S. Bell, T.D. Bird, T.I. Hillier and E.I. Greener), Geological Survey of Canada, Open File 3058, 25-32.

Euzen, T., Moslow, T.F., Crombez, V. and Rohais S. (2018) Regional stratigraphic architecture of the Spathian deposits in Western Canada – Implication for the Montney resource play. Bulletin of Canadian Petroleum Geology, 66, 175-192.

Evoy, R.W. (1997) Lowstand shorefaces in the Middle Triassic Doig Formation: Implications for hydrocarbon exploration in Fort St. John area, northeastern British Columbia. Bulletin of Canadian Petroleum Geology, 45, 537-552.

Evoy, R.W. and Moslow, T.M. (1995) Lithofacies associations and depositional environments in the Middle Triassic Doig Formation, Buick Creek Field, northeastern British Columbia. Bulletin of Canadian Petroleum Geology, 43, 461-475.

Ferri, F. and Zonneveld, J-P. (2008) Were Triassic rocks of the Western Canada Sedimentary Basin deposited in a foreland? Canadian Society of Petroleum Geologists Reservoir, 35, 12-14.

Furlong, C.M., Alexander, F., LaGrange Rao, M., Wu, A. and Zonneveld, J-P. (2015) Bioturbation influence on reservoir quality: A case study from the Lower Triassic Montney
Formation of the Western Canadian Sedimentary Basin. *Geological Society of America Annual Meeting, Abstracts with Programs*, v. 76, no. 7.

Furlong, C.M., Alexander, F., Gegloick, A., Gingras, M.K., Prenoslo, D., Sanders, S.C. and Zonneveld, J-P. (2016a) Bioturbation Influence on Permeability Distribution within the Lower Triassic Montney Formation in the Western Canada Sedimentary Basin. *American Association of Petroleum Geologists, Abstracts*.

Furlong, C.M., Gingras, M.K. and Zonneveld, J-P. (2016b) Bioturbation influence on reservoir quality: A case study from the “Anisian Wedge” of the Lower Triassic Montney Formation. *British Columbia Unconventional Gas Technical Forum Abstracts, BC Oil and Gas Commission*.

Furlong, C.M., Gingras, M.K. and Zonneveld, J-P. (2017) The ‘Anisian Wedge’: Insight on the complexity of the Montney-Doig Boundary. *GeoConvention 2017 Abstracts. Geological Association of Canada*.

Furlong, C.M., Gingras, M.K. Moslow, T. and Zonneveld, J-P. (2018a) The Sunset Prairie Formation: Designation of a new Middle Triassic formation between the Lower Triassic Montney Formation and Middle Triassic Doig Formation in the Western Canada Sedimentary Basin. *Bulletin of Canadian Petroleum Geology*, 66, 193-214.

Furlong, C.M., Gegolick, A., Gingras, M.K., Hernandez, P., Moslow, T., Prenoslo, D, Playter, T. and Zonneveld, J-P. (2018b) Sedimentology and Ichnology of the Middle Triassic (Anisian) Sunset Prairie Formation of the Western Canada Sedimentary Basin. *Bulletin of Canadian Petroleum Geology*, 66, 215-236.

Gani, M.R., Bhattacharya, J-P. and MacEachern, J.A. (2007) Using ichnology to determine relative influence of waves, storms, tides and rics in deltaic deposits: Examples from Cretaceous Western Interior Seaway, Wyoming-Utah, USA. In: *Applied Ichnology* (Eds J.A. MacEachern, K.L. Bann, M.K. Gingras and S.G. Pemberton), *SEPM Shore Course Notes*, 52, 209-225.

Gibson, D.W. and Barclay, J.E. (1989) Middle Absaroka Sequence – the Triassic stable craton. In: *Western Canada Sedimentary Basin – a Case History* (Ed B.D. Ricketts), Canadian Society of Petroleum Geologists, Special Publication, v. 30, p. 219-232.

Gibson, D.W. and Edwards, D.E. (1990) An overview of Triassic stratigraphy and depositional environments in the Rocky Mountain Foothills and western Interior Plains, Peace River Arch area,
northeastern British Columbia. In: *Geology of the Peace River Arch* (Eds S.C. O'Connell and J.S. Bell). *Bulletin of Canadian Petroleum Geology*, 38A, 146-158.

Golding, M.L., Orchard, M.J. and Zonneveld, J-P. (2014a) A summary of new conodont biostratigraphy and correlation of the Anisian (Middle Triassic) strata in British Columbia, Canada. *Albertiana*, 42, 33-40.

Golding, M.L., Orchard, M.J. Zonneveld, J-P., Henderson, C.M. and Dunn, L. (2014b) An exceptional record of the sedimentological and biostratigraphy of the Montney and Doig formations in British Columbia. *Bulletin of Canadian Petroleum Geology*, 62, 157-176.

Golding, M.L., Orchard, M.J., Zonneveld, J-P. and Wilson, N.S.F. (2015) Determining the age and depositional model of the Doig Phosphate Zone in northeastern British Columbia using conodont biostratigraphy. *Bulletin of Canadian Petroleum Geology*, 63, 143-170.

Golding, M.L., Mortensen, F, Ferri, F, Zonneveld, J-P. and Orchard, M.J. (2016) Determining the provenance of Triassic sedimentary rocks in northeastern British Columbia and western Alberta using detrital zircon geochronology, with implications for regional tectonics. *Canadian Journal of Earth Science*, 53, 140-155.

Golonka, J. (2007) Late Triassic and Early Jurassic palaeogeography of the world. *Palaeogeography Palaeoclimatology Palaeoecology*, 244, 297-307.

Golonka, J. and Ford, D. (2000) Pangean (Late Carboniferous-Middle Jurassic) palaeoenvironment and lithofacies. *Palaeogeography Palaeoclimatology Palaeoecology*, 161, 1-34.

Golonka, J., Ross, M.I. and Scotese, C.R. (1994) Phanerozoic palaeogeographic and palaeoclimatic modeling maps. In: Pangea: Global Environment and Resources (Eds A.F. Embry, B. Beauchamp and D.J. Glass), *CSPG Memoir*, 17, 1-47.

Hampson, G.J., Rodriguez, A.B., Storms, J.E.A., Johnson, H.D. and Meyer, G.T. (2008) Geomorphology and high resolution stratigraphy of progradational wave-dominated shoreline deposits: Impact on reservoir-scale facies architecture. In. Recent advances in models of siliciclastic shallow-marine stratigraphy (Eds G.J. Hampson, R.J. Steel, P.M. Burgess and R.W. Dalrymple), *SEPM Special Publication*, 90, 117-142.
Harris, R.G. (2000) Triassic Doig Formation sand bodies in the Peace River area of Western Canada: Depositional and structural models, and the impact of diagenesis on reservoir properties. Unpublished M.Sc. Thesis, University of British Columbia, Vancouver, British Columbia, 205 pp.

Hedberg, H.D. (1976) International stratigraphic guide: A guide to stratigraphic classification, terminology and procedure. *International Union of Geological Sciences, Commission on Stratigraphy, International Subcommission on Stratigraphic Classification*. New York, Wiley, pp. 200.

Henderson, C.M. and Schoepfer, S. (2017) High-resolution biostratigraphic and XRF-geochemical correlation of the Montney Formation, NEBC. *GeoConvention 2017 Abstracts. Geological Association of Canada.*

Henderson, C.M., Richards, B.C. and Barclay, J.E. (1994) Permian strata of the Western Canada Sedimentary Basin: Geological atlas of the Western Canada Sedimentary Basin. Compiled by Mossop, G.D. and Shetsen, I. Canadian Society of Petroleum Geologists and Alberta Research Council, Special Report, 4, 251-258.

Henderson, C.M., Golding M.L. and Orchard, M.J. (2018) Conodont sequence biostratigraphy of the Lower Triassic Montney Formation. *Bulletin of Canadian Petroleum Geology*, 66, 7-22.

Heydari, E. and Hassanzadeh, J. (2003) Deev Jahi Model of the Permian-Triassic boundary mass extinction: A case for gas hydrates as the main cause of biological crisis on Earth. *Sedimentary Geology*, 163, 147-163.

Hinojosa, J.L., Brown, S.T., Chen, J., DePaolo, D.J., Paytan, A., Shen, S. and Payne, J.L. (2012) Evidence for end-Permian ocean acidification from calcium isotopes in biogenic apatite. *Geology*, 40, p. 743-746.

Howard, J.D. (1975) The sedimentological significance of trace fossils. In: The study of trace fossils (Ed R.W. Frey), pp. 131-146. Springer-Verlag, New York,

Hunt, A.D. and Ratcliffe, J.D. (1959) Triassic stratigraphy, Peace River area, Alberta and British Columbia, Canada. *American Association of Petroleum Geologists Bulletin*, 43, 563-589.

Hunt, D. and Tucker, M.E. (1992) Stranded parasequences and the forced regressive wedge systems tract: Deposition during base-level fall. *Sedimentary Geology*, 81, 1-9.
Kendall, D.R. (1999) Sedimentology and stratigraphy of the Lower Triassic Montney Formation, Peace River Basin, subsurface of northwestern Alberta. Unpublished M.Sc. Thesis, University of Calgary, Calgary, Alberta, 394 pp.

Lawyer, L.A., Grantz, A. and Gahagan, L.M. (2002) Plate kinematic evolution of the present Arctic region since the Ordovician. *Geological Society of America*, Special Paper 360, pp. 333-358.

Lawyer, L.A., Gahagan, L.M. and Norton, I. (2011) Palaeogeographic and tectonic evolution of the Arctic region during the Palaeozoic. *Geological Society, London*, Memoir 35, pp. 61-77.

MacEachern, J.A. and Bann, K.L. (2008) The role of ichnology in refining shallow marine facies models. In: *Recent Advances in Models of Siliciclastic Shallow-Marine Stratigraphy* (Ed G. Hampson, R. Steel, P. Burgess and R. Dalrymple (eds.), SEPM Special Publication, 90, 73-116.

Markhasin, B. (1997) Sedimentology and stratigraphy of the Lower Triassic Montney Formation, subsurface of northwestern Alberta. Unpublished M.Sc. Thesis, University of Calgary, Alberta, 289 pp.

Miall, A. D., and Blakey, R. C. (2008) The Phanerozoic tectonic and sedimentary evolution of North America. In: *Sedimentary Basins of United States and Canada* (Ed A.D. Miall), Elsevier, Amsterdam pp. 1-29.

Mitchell. N.C., Masselink, G., Huthnance, J.M. Fernandez-Salas, J.M. and Lobo, F.J. (2012) Depths of modern coastal sand clinoforms. *Journal of Sedimentary Geology*, 82, 469-481.

Mitchum, R.M. Jr. (1977) Seismic stratigraphy and global changes of sea level, part 11: glossary of terms used in seismic stratigraphy. In: *American Association of Petroleum Geologists Memoir 26* (Ed C.E. Payton), pp. 205-212.

Monger, J. W. H. and Price, R. A. (1979) Geodynamic evolution of the Canadian Cordillera — Progress and problems. *Canadian Journal of Earth Sciences*, 16, 770–791.

Morris N.J., Gardner, D. and Glemser C. (2014) Upper Montney geochemistry: Insights into sedimentary provenance. *GeoConvention 2014 Abstracts, Geological Association of Canada.*

Morris, N., Asgar-Deen, M., Gardner, D. and Glemser, C. (2018) A preliminary investigation of the igneous origins of the Montney and Doig formations: Integrating igneous geochemistry techniques for interpreting sedimentary provenance. *Bulletin of Canadian Petroleum Geology*, 66, 161-174.
Moslow, T.F. (2000) Reservoir architecture of a fine-grained turbidite system: Lower Triassic Montney Formation, Western Canada Sedimentary Basin. In: Deep-water Reservoirs of the World (Eds P. Weimer, R.M. Slatt, J. Coleman, N.C. Rosen, H. Nelson, A.H. Bouma, M.J. Styzen and D.T. Lawrence). Conference Proceedings, Gulf Coast SEPM, pp. 686–713.

Moslow, T.F. and Davies, G.R. (1997) Turbidite reservoir facies in the Lower Montney Formation, west-central Alberta. In: Triassic of the Western Canada Sedimentary Basin. (Eds T.F. Moslow and J. Wittenberg), Bulletin of Canadian Petroleum Geology, 45, 507-536.

Moslow, T.F., Haverslew, B. and Henderson, C.M. (2018) Sedimentary facies, petrology, reservoir characteristics, conodont biostratigraphy and sequence stratigraphic framework of a continuous (395,) full diameter core of the Lower Triassic Montney Fm, northeastern British Columbia. Bulletin of Canadian Petroleum Geology, 66, 259-287.

Mossop, G.D and Shetsen, I. (1994) Introduction to the Geological Atlas of the Western Canada Sedimentary Basin. In: Geological atlas of the Western Canada Sedimentary Basin (Ed G. Mossop and I. Shetsen), Canadian Society of Petroleum Geologists and Alberta Research Council, pp. 159-275.

Nelson, J.L., Colpron, M., Piercey, S.J., Dusel-Bacon, C., Murphy, D.C. and Roots, C.F. (2006) Palaeozoic tectonic and metallogentic evolution o the pericratonic terranes in Yukon, northern British Columbia and eastern Alaska. In: Palaeozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera (Eds M. Colpron and J.L. Nelson), Geological Association of Canada Special Paper, 45, 323-360.

O’Connell, S. C. (1994) Geological history of the Peace River arch. In: Geological Atlas of the Western Canada Sedimentary Basin (Eds G.D. Mossop and I. Shetsen), Canadian Society of Petroleum Geologists and Alberta Research Council, Special Report, 4, 431-438.

O’Connell, S.C., Dix, G.R. and Barclay, J.E. (1990) The origin, history and regional structural development of the Peace River Arch, Western Canada. Bulletin of Canadian Petroleum Geology, 34, 4-24.

Onoue, T., Zonneveld, J-P., Orchaard, M.J., Yamashita, M., Yamashita, K., Sato, H. and Kusaka, S. (2016) Palaeoenvironmental changes across the Carnian/Norian boundary in the Black...
Bear Ridge section, British Columbia, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 441, 721-733.

**Orchard, M.J. and Zonneveld, J-P.** (2009) The Lower Triassic Sulphur Mountain Formation in the Wapiti Lake area: Lithostratigraphy, conodont biostratigraphy and a new biozonation for the lower Olenekian (Smithian). *Canadian Journal of Earth Sciences*, 46, 757-790.

**Panek, R.** (2000) The sedimentology and stratigraphy of the Lower Triassic Montney Formation in the subsurface of the Peace River area, northwestern Alberta. Unpublished M.Sc. Thesis, University of Calgary, Calgary, Alberta, 275 pp.

**Payne, J.L. and Clapham, M.E.** (2012) End-Permian mass extinction in the oceans: An ancient analogue for the twenty-first century? *Annual Review of Earth and Planetary Sciences*, 40, 89-111.

**Playter, T., Corlett, H., Konhauser, K., Robbins, L., Rohais, S., Cormbex, V., MacCormack, K., Rokosh, D., Prenoslo, D., Furlong, C.M., Pawlowicz, J., Gingras, M.K., Lalonde, S., Lyster, S. and Zonneveld, J.P.** (2018) Clinoform identification and correlation in fine-grained sediments: A case study using the Triassic Montney Formation. *Sedimentology*, 65, 263–302.

**Posamentier, H.W. and Vail, P.R.** (1988) Eustatic controls on clastic deposition II – sequence and systems tract models. In: *Sea level changes – An integrated approach*. (Eds E.K. Wilgus, B.S. Hastings, C.G. St., C. Kendall, H.W. Posmentier, C.A. Ross, and J.C. Van Wagoner), *SEPM Special Publication*, 42, 125-154.

**Posamentier, H.W. and James, D.P.** (1993) Sequence stratigraphy – uses and abuses. In: *Sequence stratigraphy and facies associations* (Eds H.W. Posmentier, C.P. Summerhayes, B.U. Haq, and G.P. Allen, G.P), *International Association of Sedimentologists Special Publication* 18, 3-18.

**Posamentier, H.W. and Allen, G.P.** (1999) Siliciclastic sequence stratigraphy: Concepts and applications. *SEPM Concepts in Sedimentology and Palaeontology*, No. 7, pp. 210.

**Posamentier, H.W., Jervey, M.T. and Vail, P.R.** (1988) Eustatic controls on clastic deposition I – conceptual framework. In: Sea level changes – An integrated approach (Eds C.K. Wilgus, B.S. Hastings, C.G. St., C. Kendall, H.W. Posmentier, C.A. Ross, and J.C. Van Wagoner), *SEPM Special Publicaion* n. 42, p. 109-124.
Prenoslo, D., Furlong, C.M., Gingras, M.K., Playter, T. and Zonneveld, J-P. (2018) The sedimentology, stratigraphy and reservoir characteristics of the Montney D1 and D2 horizons in the Greater Pouce Coupe area. *Bulletin of Canadian Petroleum Geology*, **66**, 336-358.

Price, R. A. (1994) Cordilleran tectonics and the evolution of the Western Canada Sedimentary Basin; Chapter 2. In: *Geological Atlas of the Western Canada Sedimentary Basin* (Eds G.D. Mossop and I. Shetsen), *Canadian Society of Petroleum Geologists*.

Proverbs, I.P., Bann, K.L., Fratton, C.M., Frostad, C.J. and Juska, A. (2018) Facies architecture and sequence stratigraphy of the Lower Triassic Montney Formation, NE British Columbia: Fundamental controls on the distribution of ‘sweet spots’ in a world-class unconventional reservoir. *Bulletin of Canadian Petroleum Geology*, **66**, 237-258.

Qi, F. (1995) Seismic stratigraphy and sedimentary facies of the Middle Triassic strata, Western Canada Sedimentary Basin, northeast British Columbia. Unpublished M.Sc. Thesis, University of Alberta, Edmonton, Alberta, 320 pp.

Reading, H.G. and Collinson, J.D. (1996) Clastic Coasts. In: *Sedimentary Environments: Process, Facies and Stratigraphy* (Ed H.G. Reading), Blackwells, Cornwall, p. 154-231.

Reineck, H.E. (1963) *Sedimentgefûge im Bereich der südlichen Nordsee: Abhandlungen der Senckenbergische Naturforschende Gesellschaft*, p. 505.

Reineck, H.E. (1967) Parameter von Schichtung und Bioturbation. *Geologische Rundschau*, **56**, 420-438.

Richards, B.C. (1989) Upper Kaskasia Sequence: uppermost Devonian and Lower Cretaceous. In: *Western Canada Sedimentary Basin – a case history* (Ed B.D. Ricketts), *Canadian Society of Petroleum Geologists, Special publication* No. 30, pp. 164-201.

Rohais, S., Crombez, V., Euzen, T. and Baudin, F. (2016) The Lower and Middle Triassic of Western Canada: Passive margin, Back-Arc or Fore-Arc geodynamic setting? *GeoConvention 2016 Abstracts. Geological Association of Canada*.

Rohais, S., Crombez, V., Euzen, T. and Zonneveld, J-P. (2018) Subssidence dynamics of the Montney Formation (Early Triassic, Western Canada Sedimentary Basin): insights for its geodynamic setting and wider implications. *Bulletin of Canadian Petroleum Geology*, **66**, 128-160.

This article is protected by copyright. All rights reserved
Schiarizza, P. (2013) The Wineglass assemblage, lower Chilcotin River, south-central British Columbia: Late Permian volcanic and plutonic rocks that correlate with the Kutcho assemblage of north British Columbia. In: Geological Fieldwork, 2012, British Columbia Ministry of Energy, Mines and Natural Gas, British Columbia Geological Survey Paper 2013-1, pp. 53-70.

Sloss, L.L. (1963) Sequences in the cratonic interior of North America. Geological Society of America Bulletin, 74, 239-254.

Somme, T.O., Howell, J.A., Hampson, G.J. and Storms, J.E.A. (2008) Genesis, architecture and numerical modelling of intra-parasequence discontinuity surfaces in Sunnyside Member, Blackhawk Formation, Book Cliffs, Utah, USA. In: Recent Advances in Models of Siliciclastic Shallow-Marine Stratigraphy (Eds G. Hampson, R. Steel, P. Burgess and R. Dalrymple), SEPM Special Publication, 90, 421-441.

Stephenson, R.A., Zelt, C.A., Ellis, R.M., Hajnal, Z., Morel-a-l’Huiissier, P., Mereu, R.F., Northey, D.J., West, G.F. and Kanasewich, E.R. (1989) Crust and upper mantle structure and the origin of the Peace River Arch. Bulletin of Canadian Petroleum Geology, 37, 224-235.

Storms, J.E.A. and Hampson, G.J. (2005) Mechanisms for forming discontinuity surfaces within shoreface-shelf parasequences: sea level, sediment supply or wave regime? Journal of Sedimentary Research, 75, 67-81.

Taylor, A.M. and Goldring, R. (1993) Description and analysis of bioturbation and ichnofabric. Journal of the Geological Society, London, 150, 141-148.

Utting, J. (2001) Permian and Early Triassic palymorph assemblages from the Canadian Arctic Archipelago, Alaska, Greenland and Arctic Europe. Natura Bresciana. Annunario del Mucso civico de scienze natura, Brescia Manografia, no. 25, pp. 327-340.

Utting, J., Zonneveld, J-P., MacNaughton, R.B. B Falls, K.M. (2005) Palynostratigraphy, lithostratigraphy and thermal maturity of the Lower Triassic Toad and Greyling, and Montney formations of western Canada and comparisons with coeval rocks of the Sverdrup Basin, Nunavut. Bulletin of Canadian Petroleum Geology, 53, 5-24.

Van Wagoner, J.C. Posamentier, H.W., Mitchum, R.M. Jr., Vail, P.R., Sarg, J.F., Loutit, T.S. and Hardenbol, J. (1988) An overview of sequence stratigraphy and key definitions. In: Sea level
changes – An integrated approach (Eds C.K. Wilgus, B.S. Hastings, C.G. St. C. Kendall, H.W. Posmentier, C.A Ross and J.C. Van Wagoner), SEPM Special Publication n. 42, p. 39-45.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M. and Rahmanian, V.D. (1990) Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: concepts for high resolution correlation of time and facies. American Association of Petroleum Geologists Methods in exploration series, n. 7, 1-55.

Willis, A. and Wittenberg, J. (2000) Exploration significance of healing-phase deposits in the Triassic Doig Formation, Hythe, Alberta. Bulletin of Canadian Petroleum Geology, 48, 179-192.

Wilson, K.M., Hay, W.W. and Wold, C.N. (1991) Mesozoic evolution of exotic terranes and marginal seas, western North-America. Marine Geology, 102, 311-361.

Wilson, N., Zonneveld, J-P. and Orchard, M. (2014) Biostratigraphy of the Montney Formation: From the Alberta and British Columbia subsurface, to the outcrop. GeoConvention 2012 Abstracts. Geological Association of Canada.

Wittenberg, J. (1992) Origin and stratigraphic significance of anomalously thick sandstone trends in the Middle Triassic Doig Formation of west-central Alberta. Unpublished M.Sc. thesis, University of Alberta, Edmonton, Alberta, 600 pp.

Wittenberg, J. (1993) The significance and recognition of mass wasting events in cored sequences, impact on the genesis of several anomalously thick sandstone bodies in the Middle Triassic Doig Formation of west-central Alberta. In: Carboniferous to Jurassic Pangea Core Workshop (R. Kavonen, J. den Haan, K. Jang, D. Robinson, G Smith, T. Webb and J. Wittenberg), Canadian Society of Petroleum Geologists, 131-161.

Ziegler, P.A. (1988) Evolution of the Arctic-North Atlantic and the western Tethys – a visual presentation of a series of palaeogeographic-palaeotectonic maps. AAPG Memoir 34, pp. 164-196.

Zonneveld, J-P. (2001) Triassic biostromes from the Liard Formation, British Columbia, Canada: oldest examples from the Mesozoic of NW Panges. Sedimentary Geology, 145, 317-341.

Zonneveld, J-P. (2011) Suspending the rules: Unraveling the ichnological signature of the Lower Triassic post-extinction recovery interval. Palaios, 26, 677-681.

This article is protected by copyright. All rights reserved
Zonneveld, J-P. and Moslow, T.F. (2014) Perennial River Deltas of the Montney Formation: Alberta and British Columbia subcrop edge. GeoConvention 2014 Abstract. Geological Association of Canada.

Zonneveld, J-P. and Moslow, T.F. (2015) The Montney-Doig boundary and the ‘Anisian Wedge’ in northeastern British Columbia. British Columbia Unconventional Gas Technical Forum Abstracts, BC Oil and Gas Commission.

Zonneveld, J-P. and Moslow, T.F. (2018) Palaeogeographic setting, Lithostratigraphy, and sedimentary framework of the Lower Triassic Montney Formation of western Alberta and northeastern British Columbia. Bulletin of Canadian Petroleum Geology, 66, 93-127.

Zonneveld, J-P., Moslow, T.F. and Henderson, C.M. (1997) Lithofacies associations and depositional environments in a mixed siliciclastic-carbonate depositional system, upper Liard Formation, Triassic, northeastern British Columbia. Bulletin of Canadian Petroleum Geology, 45, 553-575.

Zonneveld, J-P., Beatty, T.W. and Gingras, M.K. (2010a) Diverse ichnofossil assemblages following the P-T mass extinction, Lower Triassic, Alberta and British Columbia, Canada: evidence for shallow marine refugia on the northwestern coast of Pangaea. Palaios, 25, 368-392.

Zonneveld, J-P., MacNaughton, R.B., Utting, J., Beatty, T.W., Pemberton, S.G. and Henderson, C.M. (2010b) Sedimentology and ichnology of the Lower Triassic Montney Formation in the Pedigree-Ring/Border Kahntah River area, northwestern Alberta and northeastern British Columbia. Bulletin of Canadian Petroleum Geology, 58, 115-140.

Zonneveld, J-P., Golding, M., Moslow, T.F., Orchard, M.J., Playter, T and Wilson, N. (2011) Depositional framework of the Lower Triassic Montney Formation, West-central Alberta and Northeastern British Columbia. 2011 CSPG CSEO CWLS Convention: Recovery, Abstract p. 1-4.

Zonneveld, J-P., Furlong, C.M., Gegolick, A., Gingras, M.K., Golding, M., Moslow, T., Orchard, M., Playter, T., Prenoslo, D. and Sanders, S.C. (2015) Stratigraphic Architecture of the Montney Formation, Peace District, Alberta and British Columbia. William C. Gussow Geoscience Conference Abstracts. Canadian Society of Petroleum Geologists.

Zonneveld, J-P., Furlong, C.M., Gegolick, A., Gingras, M.K., Golding, M., Moslow, T., Orchard, M., Playter, T., Prenoslo, D. and Sanders, S.C. (2016) The Montney-Doig Boundary
and the “Anisian Wedge”. *International Core Conference Abstracts. Canadian Society of Petroleum Geologists.*

Figure Captions

Figure 1 – Lithostratigraphic formations of Triassic strata within the Western Canada Sedimentary Basin. Modified from (Dixon, 2011).

Figure 2 – Location map of the study area. (A) North American map with Western Canada outlined in red. (B) Regional map of Western Canada with the location of the Western Canada Sedimentary Basin. Triassic strata within the sub-basins, Alberta Basin and Williston Basin, are outlined. The Sweetgrass Arch separates the two sub-basins. (C) Regional map of Triassic strata in the Alberta Basin (modified from Zonneveld *et al.*, 2011). Major structural features influencing Lower and Middle Triassic strata are identified and were compiled from previously published maps (Barclay *et al.*, 1990; Davies, 1997a, b; Davies *et al.*, 1997; Berger, 2005; Berger *et al.*, 2009).

Figure 3 – Summary of lithological, sedimentological, ichnological and palaeontological characteristics of the lithofacies in the Sunset Prairie Formation. Sedimentary structure abbreviations include: AS = Asymmetrical ripples; C = Calcisphere; HACL = High Angle Cross Laminae; HCS = Hummocky Cross Stratification; LACL = Low Angle Cross Laminae; PDS = Penecontemporaneous Deformation Structures; PG = Pyrite Grains; Phos = Phosphate Material; PL = Planar Laminae; PSL = Pinstripe Laminae; PWL = Planar-wavy Laminae; Rup = Rip Up Clasts; WL = Wavy Laminae. Body fossil abbreviations include: G = Gastropod; BI = Bivalve; E = Echinoid; BR = Brachiopods; CR = Crinoid. Trace fossil abbreviations include: As = Asterosoma; Ch = Chondrites; Cy = Cylindrichnus; Di = Diplocraterion; He = Helminthopsis; Pa = Palaeophycus; Ph = Phycosiphon; Pl = Planolites; Rh = Rhizocorallium; Ro = Rosselia; Sc = Scolicia; Sk = Skolithos; Te = Teichichnus; Th = Thalassinoides; Z = Zoophycos.
Figure 4 – Schematic of a Sunset Prairie Formation parasequence. Generalized distribution of lithology, physical sedimentary structures, trace fossils, bioturbation intensity (BI) and body fossils are denoted. Associated depositional environments are interpreted.

Figure 5 – Facies distribution of the Sunset Prairie Formation in cored wells within the Fort St. John Graben system. Abbreviations include: mfs = marine flooding surface; FS/SB = flooding surface/sequence boundary.

Figure 6 – Cross sections showing the petrophysical wire line characteristics, spatial distribution and sequence stratigraphic architecture of the Sunset Prairie Formation. Locations of cross sections are identified in Figure 7.

Figure 7 – Location and thickness maps of the Sunset Prairie Formation in west-central Alberta and northeast British Columbia. Isopachs depict total thickness of the formation and thickness of each parasequence present in the Sunset Prairie Formation. The isopachs were constructed using vertical wells with geophysical well logs, which were ground-truthed using full-diameter core penetrating the Sunset Prairie Formation. Well control is shown through the location of wells in the dataset and includes wire line (n=248) and cored wells (n = 25). Total thickness ranges from 0-80 m.

Figure 8 – Fence diagram of the Sunset Prairie Formation within the Fort St. John Graben system. Parasequences are identified and separated by flooding surfaces. Parasequences are coloured blue based on their transgressive nature.

Figure 9 – Sequence stratigraphic schematic of the Montney Formation, Sunset Prairie Formation and Doig phosphate zone. Litholog from the Shell Groundbirch 16-29-079-20W6 drill core showing the distribution of lithological characteristics and facies distribution of the Sunset Prairie Formation. Sequence stratigraphic schematic corresponding to the deposition of different parasequence sets and stratigraphic surfaces associated with the Upper Montney Formation, Sunset Prairie Formation and Doig phosphate zone.
Figure 10 – Alternative sequence stratigraphic framework schematic of the Montney Formation, Sunset Prairie Formation and Doig phosphate zone. Litholog from the Shell Groundbirch 16-29-079-20W6 drill core showing the distribution of lithological characteristics and facies distribution of the Sunset Prairie Formation. Sequence stratigraphic schematic corresponding to the deposition of different parasequence sets and stratigraphic surfaces associated with the Upper Montney Formation, Sunset Prairie Formation and Doig phosphate zone.

Figure 11 – Summary table of the sequence stratigraphic frameworks of the Lower to Middle Triassic. The studies summarized are limited to publications that provide detailed cross sections, reference well or wells with geophysical well log data, or schematic drawings, which have sequence stratigraphic surfaces and/or systems tracts identified. Very localized studies and high-resolution sequence stratigraphy frameworks for stratigraphically limited intervals were not considered in the table. Abbreviations for systems tract include: AGG = aggradation (no systems tract specified); FSST = falling stage systems tract; HST = highstand systems tract; LST = lowstand system tract; R = regressive; RST = regressive systems tract; SMST = shelf margin system tract; T = transgressive; TST = transgressive systems tract. Stratigraphic member abbreviations include: CS = Calais Sandstone Member; Pk = Pocketknife Member; LS = La Glace Sandstone Member; AC = Anten Coquina Member; AM = Altares Member.

Figure 12 – Dip-oriented cross section of the Upper Montney Formation, Sunset Prairie Formation and Doig phosphate zone located within the Fort St. John Graben system. Interpreted sequence stratigraphic surfaces are identified in core, tied to geophysical well logs and extrapolated between cored wells.
| Facies | Minimally Bioturbated | Pervasively Bioturbated | Associated with Regional/Local Surfaces |
|--------|----------------------|------------------------|-----------------------------------------|
| Core Expression | Light | Dark to medium grey, laminated, bituminous siltstone with minimal bioturbation | Dark to light grey bioturbated siltstone | Pervasively bioturbated sandy siltstone | Burrowed firmground | Amalgamated sandstone and conglomerate bed |
| Lithological Description | Dark to light grey siltstone with minimal bioturbation | Dark to light grey bioturbated siltstone | Pervasively bioturbated medium to light grey siltstone | Pervasively bioturbated sandstone | N/A | Phos |
| Sedimentary Structures | PL, PWL, WL, LACL, HACL, AS, PG, Phos | PSL, PL, PWL, WL, AS, Phos | N/A | N/A | N/A | N/A |
| Body Fossils | N/A | N/A | N/A | N/A | N/A | Shell and bone fragments |
| Grain Size | Fine to coarse silt | Fine to coarse silt | Fine silt to very fine sand | Fine silt to very fine sand | Fine silt to very fine sand | N/A | Sand to gravel |
| Ichnology | Ph, He, Pa, Pl, Ch | Ph, He, Pa, Pl, Ch | Ph, He, Te, Pa, Pl, Ch, Z | Ph, He, Pa, Pl, Ch | Ph, Ro, Cy, As, Te, Pa, Pl, Sk, Sc, Rh, Di | Pl, Sk, Th, Rh | N/A |
| BI | 0-2 | 0-2 | 5-6 | 4-6 | 5-6 | 2 | N/A |
| Depo. Enviro. | Offshore to Lower Offshore Transition | Lower Offshore Transition | Lower to Upper Offshore Transition | Upper Offshore Transition to Lower Shoreface | Glossifungites discontinuity surfaces | Lag deposit |
| Lithology | Sedimentary Structures | Trace Fossils | Body Fossils | Depositional Environment | Legend |
|-----------|------------------------|---------------|--------------|--------------------------|--------|
| F7        |                        |               |              | Lower Shoreface          |        |
| F6        |                        |               |              |                          |        |
| F5        |                        |               |              |                          |        |
| F4        |                        |               |              |                          |        |
| F3        |                        |               |              |                          |        |
| F2        |                        |               |              |                          |        |
| F1        |                        |               |              |                          |        |

**Legend**

- **Sedimentary Structure**
  - Planar laminae
  - Planar-wavy laminae
  - Wavy laminae
  - Ripple laminae
  - HCS

- **Depositional Environment**
  - Parasequence
  - 4.22 m

- **Trace Fossils**
  - Asterosoma (As)
  - Chondrites (Ch)
  - Cylindrichnus (Cy)
  - Diplocraterion (Di)
  - Helminthopsis (He)
  - Phycosiphon (Ph)
  - Paleeophyctus (Pa)
  - Planolites (Pl)
  - Rhizocorallium (Rh)
  - Roselia (Ro)
  - Teichichnus (Te)
  - Thalassinoides (Th)
  - Scolicia (Sc)
  - Skolithos (Sk)
  - Zoophycos (Z)
  - Glossifungites

- **Bioturbation Index**
  - 6 (100% bioturbated)
  - 0 (no bioturbation)

- **Body Fossils**
  - Spiriferid Brachiopod
  - Terebratulid Brachiopod
  - Crinoid
  - Shell Debris
  - Bone Fragment
  - Ammonoid

- **mfs** = Marine flooding surface
**Lithostratigraphy**

Core Depth (m)

**Depositional Environment**

- **Bioturbation**
  - SF / OT
  - OT / OT
  - SF / OT

**Sequence Stratigraphic Framework**

- **Facies**
  - Facies 1
  - Facies 2
  - Facies 3
  - Facies 4
  - Facies 5
  - Facies 6
  - Facies 7

**Legend**

- Sunset Prairie Fm Facies
  - Facies 1
  - Facies 2
  - Facies 3
  - Facies 4
  - Facies 5
  - Facies 6
  - Facies 7

- Bioturbation Index (BI)
  - 6 (100% bioturbated)
  - 0 (no bioturbation)

- Depositional Enviro.
  - SF: Lower Shoreface
  - OT: Upper Offshore Transition
  - OT: Lower Offshore Transition
  - O: Offshore

- Formations in Schematic
  - Montney Fm
  - Sunset Prairie Fm
  - Doig Phosphate Zone

- Sequence Stratigraphic Framework
  - Sequence Boundary
  - Correlative Conformity
  - Maximum Flooding Surface
  - Flooding Surface
  - TST = Transgressive Systems Tract
  - HST = Highstand Systems Tract
| Age        | Formation | Seq. Strat. | Formation | Seq. Strat. | Formation | Seq. Strat. | Formation | Seq. Strat. | Formation | Seq. Strat. | Formation | Seq. Strat. | Formation | Seq. Strat. |
|------------|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|
| Anisian    | Halfway   | HST         | Halfway   | HST         | Halfway   | RST         | Halfway   | HST         | Halfway   | HST         | Halfway   | HST         | Halfway   | HST         |
|            | Doig      | TST         | Doig      | TST         | Doig      | RST         | Doig      | TST         | Doig      | TST         | Doig      | TST         | Doig      | TST         |
|            | Doig Sand | LST         | Doig Sand | LST         | Doig Sand | RST         | Doig Sand | LST         | Doig Sand | LST         | Doig Sand | LST         | Doig Sand | LST         |
|            | Phosphate Zone | HST | Phosphate Zone | HST | HST         | Phosphate Zone | HST | HST         | Phosphate Zone | HST | HST         | Phosphate Zone | HST | HST         |
|            | TST       | Phos. Zone  | TST       | Phos. Zone  | TST       | Phos. Zone  | TST       | Phos. Zone  | TST       | Phos. Zone  | TST       | Phos. Zone  | TST       | Phos. Zone  |
| Montney    | Montney   | Montney     | Montney   | Montney     | Montney   | Montney     | Montney   | Montney     | Montney   | Montney     | Montney   | Montney     | Montney   | Montney     |
|            | Montney   | LST         | Montney   | LST         | Montney   | LST         | Montney   | LST         | Montney   | LST         | Montney   | LST         | Montney   | LST         |
|            | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         |
| Dozierian  | Doig      | Doig        | Doig      | Doig        | Doig      | Doig        | Doig      | Doig        | Doig      | Doig        | Doig      | Doig        | Doig      | Doig        |
|            | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         |
| Griesbachian | Doig | Doig | Doig | Doig | Doig | Doig | Doig | Doig | Doig | Doig | Doig | Doig | Doig | Doig |
|            | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         |

- **SB** = Sequence boundary
- **FS/SS =** Flooding surface sequence boundary
- **CC/FS =** Correlative conformity flooding surface
- **TSE =** Transgressive surface of erosion
- **MFS =** Maximum flooding surface
- **RSME =** Regressive surface of marine erosion
- **SMR =** Basal surface of marine regression
- **LSE =** Lowstand surface of erosion
- **Erosionally removed**
- **Interval not included in the study**

**Legend:**
- **SB** = Sequence boundary
- **FS/SS =** Flooding surface sequence boundary
- **CC/FS =** Correlative conformity flooding surface
- **TSE =** Transgressive surface of erosion
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- **MFS =** Marine flooding surface
- **BSMR =** Basal surface of marine regression
- **RSME =** Regressive surface of marine erosion
- **LSE =** Lowstand surface of erosion

**Formations:**
- Montney
- Doig
- Phosphate Zone

**Age:**
- Anisian
- Ladinian
- *Erosionally removed***

**Intervals:**
- Halfway
- Upper
- Lower
- Middle
- Lower
- Upper

**Notations:**
- **N/A** = Not applicable
- **TST** = Transgressive surface
- **HST** = Highstand surface
- **TSE** = Transgressive surface of erosion
- **MFS** = Maximum flooding surface
- **LSE** = Lowstand surface of erosion

**Studies:**
- Evoy and Moslow, 1995
- Evoy, 1997
- Davies et al., 1997
- Emby, 1997
- Moslow & Davies, 1997; Moslow, 2000
- Markhasin, 1997
- Kendall, 1999

**Locations:**
- Belloy
- Halfway
- Montney
- Doig
- Doig Sand
- Phosphate Zone

**Other Terms:**
- *Anisian Wedge*
| Age       | Formation | Seq. Strat. | Formation | Seq. Strat. | Formation | Seq. Strat. | Formation | Seq. Strat. | Formation | Seq. Strat. | Formation | Seq. Strat. | This Study |
|-----------|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|------------|
| Anisian   | Doig      | HST         | Halfway   | TST         | 'Anisian Wedge' | SMW | Sunset Prairie | N/A | Sunset Prairie | LST/FSST | Sunset Prairie | N/A | Sunset Prairie | TST |
|          |           |             |           |             |           |             |           |             |           |             |           |             |            |
| Spithian  | Upper     | TST         | Upper     | HST         | Upper     | HST         | Upper     | RST         | Upper     | HST         | Upper     | RST         | HST       |
|          | LST       | FST         | LST       | LST         | TST       | LST         | TST       | TST         | TST       | LST         | TST       | TST         |            |
|          |           |             |           |             |           |             |           |             |           |             |           |             |            |
| Smithian  | Middle    | TST         | Middle    | HST         | Middle    | HST         | Middle    | AM          | Middle    | HST         | Middle    | AM          | LST       |
|          | LST       | FST         | LST       | FST         | LST       | FST         | LST       | FST         | LST       | FST         | LST       | FST         |            |
|          |           |             |           |             |           |             |           |             |           |             |           |             |            |
| Devonian  | Lower     | TST         | Lower     | HST         | Lower     | HST         | Lower     | N/A         | Lower     | HST         | Lower     | N/A         | HST/ RST  |
|          |           |             |           |             |           |             |           |             |           |             |           |             |            |
| Griesbachian | TST   | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         | TST       | TST         |            |

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- **FS/FSB** = Flooding surface sequence boundary
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- **LSE** = Lowstand surface of erosion
- **Erosionally removed**
- **Interval not included in the study**
