Stratigraphy and sedimentology of the lower Black Bear Ridge section, British Columbia: candidate for the base-Norian GSSP

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ABSTRACT: The upper Ludington and lower Pardonet formations at Black Bear Ridge, northeastern British Columbia, Canada represent a continuously exposed succession through the upper Carnian and lower Norian (medial Upper Triassic). These strata were deposited in a deep marine setting (distally steepened carbonate ramp / medial to distal slope) on the northwestern margin of Pangaea. The Black Bear Ridge section is apparently continuous, with no evidence for either subaerial exposure or submarine erosion. The absence of erosional scours in the study interval confirms emplacement of these strata below both fair-weather and storm wave base.

Event beds, particularly those resulting from sediment gravity flows, dominate the Carnian-Norian boundary interval at Black Bear Ridge. Upper Carnian strata, primarily assigned to the Ludington Formation at Black Bear Ridge, record an upward transition from moderate-scale, olistolith-bearing debris flow deposits (debrites) to medium / thin-bedded turbidites remobilised as small-scale sediment slump /slides. The Carnian-Norian boundary interval and the lower Norian succession is dominated by medium- to thin-bedded calcareous turbidites and lesser hemipelagic suspension deposits.

Diverse and abundant fossil assemblages, particularly conodonts and bivalves, occur within the study interval. Despite evidence of post-depositional sediment remobilisation (i.e debrites and turbidites) conodont faunal successions indicate that the Black Bear Ridge section represents a complete and continuously exposed Carnian-Norian boundary succession. Rapid and relatively continuous sedimentation is attested to by the thickness of the section, the abundance of calcareous turbidites and the thin nature of intercalated hemipelagic beds.

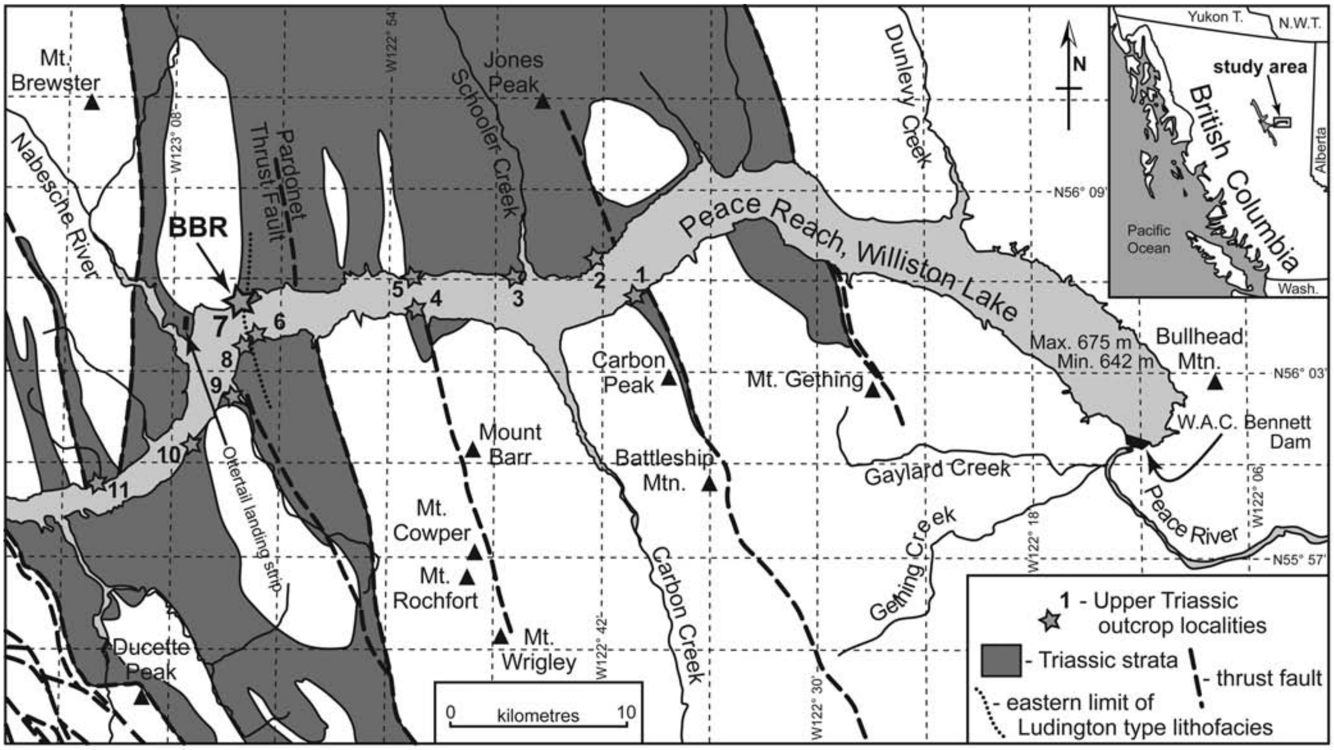
Abundant well-preserved fossils, evidence of continuous and rapid sedimentation and minimal alteration by tectonic disturbances, metamorphism or diagenesis make Black Bear Ridge an excellent candidate Global Stratotype Section and Point (GSSP) for the Carnian-Norian boundary.

INTRODUCTION

The Black Bear Ridge section (northeastern British Columbia, Canada) has been proposed as a candidate Global Stratotype Section and Point (GSSP) for the Carnian-Norian boundary (Orchard et al. 2001b; Orchard 2004; 2007a,b). The Carnian-Norian boundary occurs within the lower Pardonet Formation at Black Bear Ridge (NTS Map 94 B-/3; zone 10, UTM 497670E, 6215500N; Lat./Long. 123° 2' 22.6" W, 56° 5' 8.3" N). This site has proven highly fossiliferous, producing abundant ammonoids, bivalves, brachiopods, scattered elasmobranch (shark) dermal denticles, actinopterygian (bony fish) skeltetal debris (particularly teeth) and conodonts (Tozer 1982; 1994; Johns et al. 1997; Orchard et al. 2001a; 2001b; Orchard 2004; 2007a,b; McRoberts 2007). Conodonts are exceptionally abundant at Black Bear Ridge and are the focus of a new, detailed biostratigraphic zonation (Orchard 2004; 2007a,b). The abundance of biostratigraphically useful fossils in this section are the prime motivation for nominating Black Bear Ridge as the Carnian-Norian boundary GSSP (Orchard 2007a,b).

In accordance with the guidelines for establishment of GSSPs (Remane et al. 1996), nominate sections should be characterized by evidence of continuous deposition (i.e. absence of significant discontinuities). Black Bear Ridge occurs in the western part of the Triassic outcrop belt of the Canadian Rocky Mountains and thus has been inferred to record deposition in an offshore, deep water setting (i.e. Gibson and Edwards 1990; 1992; Zonneveld et al. 1997; 2003a, 2003b; Zonneveld and Gingras 2001; Carrelli 2002). Despite its importance, Black Bear Ridge has not previously been subjected to systematic, bed-scale lithologic analyses. Descriptions are limited to a series of field guides, most of which have not been published (i.e. Gibson and Edwards 1990; 1992; Zonneveld et al. 1997; Zonneveld and Gingras 2001; Zonneveld 2007).

Herein we present detailed data on the lithologic framework of the Black Bear Ridge succession, comment on the sedimentologic and stratigraphic continuity of the Ludington and Pardonet formations at this locality and assess its appropriateness as a Carnian-Norian boundary succession. This paper does



TEXT-FIGURE 1
Location of the Black Bear Ridge outcrop section (large star) on the Peace Reach (eastern arm) of Williston Lake, northeastern British Columbia. Also shown are other important Upper Triassic localities discussed in McLearn (1947; 1960), Gibson and Edwards (1990; 1992), Zonneveld and Gingras (2001) and Zonneveld and Orchard (2002). 1 = East Carbon Creek; 2 = McLay Spur; 3 = West Schooler Creek; 4 = Glacier Spur; 5 = Brown Hill; 6 = Pardonet Hill; 7 = Blackbear Ridge; 8 = Juvavites Cove; 9 = Pardonet Creek; 10 = Ne Parle Pas Point; 11 = Ursula Creek. The water level of Williston Lake from a seasonal low of ~642m in late winter / early spring to a seasonal high of ~675m in late summer / early fall.

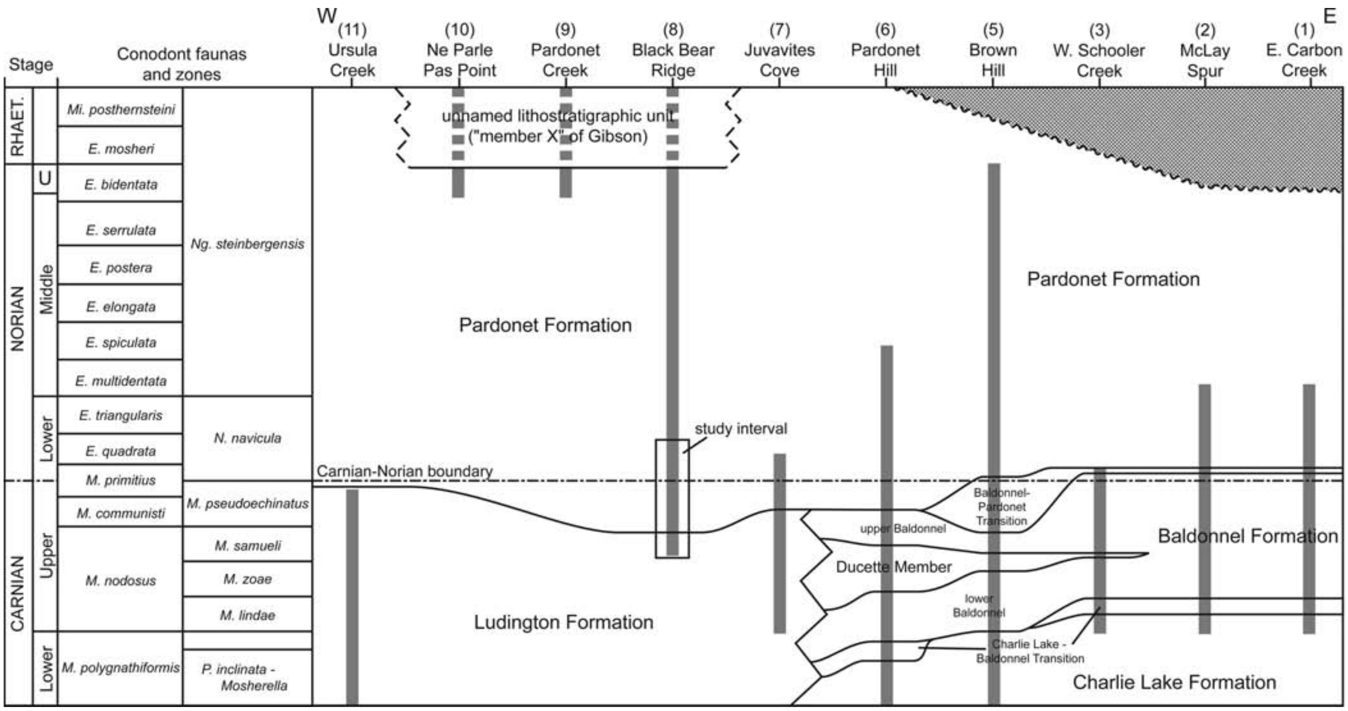
not discuss in detail biostratigraphic issues but rather relies upon the framework published by Orchard (2007b) and Orchard and others (2001b) and concentrates solely upon sedimentological issues and physical stratigraphic architecture.

STUDY AREA

The outcrop section discussed here occurs on the southeastern flank of Black Bear Ridge on the north shore of the Peace Reach of Williston Lake, 3.7 kilometres northeast of the mouth of the Nabesche River (text-fig. 1). Williston Lake was created in 1967 by the damming of the Peace River. Prior to this, Triassic strata in the Peace River valley were the focus of a number of paleontological investigations providing the first Triassic biostratigraphic zonations in western Canada (McLearn 1930; 1940; 1941a, b; 1960). Although these outcrop sections (including the type locality of the Pardonet Formation) are now submerged beneath Williston Lake, new, extensive and well-exposed Triassic outcrop sections now occur along the lake's perimeter (text-fig. 1). As no roads penetrate the Muskwa wilderness in the Williston Lake area, access to Black Bear Ridge is either via boat or bush plane to the Ottertail landing strip (~ 2 km west of the Black Bear Ridge section; text-fig. 1). The closest boat launch occurs beside the W.A.C. Bennett Dam at the eastern tip of the Peace Reach of Williston Lake (text-fig. 1).

The Triassic outcrop belt at Williston Lake occurs in the Rocky Mountain Foothills and the eastern margin of the Front Ranges. These strata in western Canada form a westward thickening wedge of primarily marine strata deposited on the western margin of the North American craton (Gibson 1993a). Triassic deposition in the study area predates the main accretionary events of allochthonous terranes that now comprise the Cordillera west of the Rocky Mountain Front Ranges. Thus, Triassic outcrop in the study area have been subsequently uplifted, tilted and folded. The outcrop section at Black Bear Ridge occurs on the Pardonet Hill Thrust sheet (text-fig. 1), on the eastern margin of the Nabesche Syncline. The Carnian-Norian boundary interval at Black Bear Ridge dips at ~75° to the west. Although minor bedding plane slippage occurred above the study interval during thrusting, fault repetition does not occur within the study interval.

Some earlier studies (i.e. Gibson 1993a; Gibson and Barclay 1989) have made reference to the "Triassic stable craton", downplaying the influence tectonic activity had on Triassic deposition. In contrast, recent studies have presented evidence that tectonism played an active, locally dominant, role in sediment accumulation in western Canada (i.e. Wittenberg 1992; 1993; Qi 1995; Davies 1997; Zonneveld et al. 2000). Subsidence associated with elements of the Peace River Arch and the Dawson Creek Graben Complex has been shown to have had a particularly significant effect on Triassic deposition in the northern Western Canada Sedimentary Basin (Cant 1988; Wittenberg 1992; 1993; Qi 1995; Davies 1997). It is also postulated that early docking of offshore allochthonous terranes (*sensu*



TEXT-FIGURE 2
Upper Triassic lithostratigraphic nomenclature and conodont biostratigraphy, Peace River outcrop belt, northeastern British Columbia (locations of outcrop sections shown on text-fig. 1). Gray bars show vertical extent of Upper Triassic strata at each locality. Although a number of internal unconformities occur within the Baldonnel and Charlie Lake Formations their temporal duration is uncertain and thus they are not shown here. The Pardonet Formation is progressively erosionally truncated towards the east. Close proximity of Late Jurassic strata of the Nikannasin Formation to the top of the Brown Hill section indicates that erosional truncation of Pardonet strata begins midway through the outcrop belt. Conodont biostratigraphy after Orchard and Tozer (1997). Data for Black Bear Ridge section from Orchard et al. (2001a; 2001b).

Beranek and Mortensen 2006; 2007; Ferri and Zonneveld 2008) is reflected in anomalous patterns of stratal thickness in proximal and distal settings as well as the dominance of debris flow and slump deposits in western outcrop of the Upper Triassic (Carnian) Ludington Formation.

STRATIGRAPHY

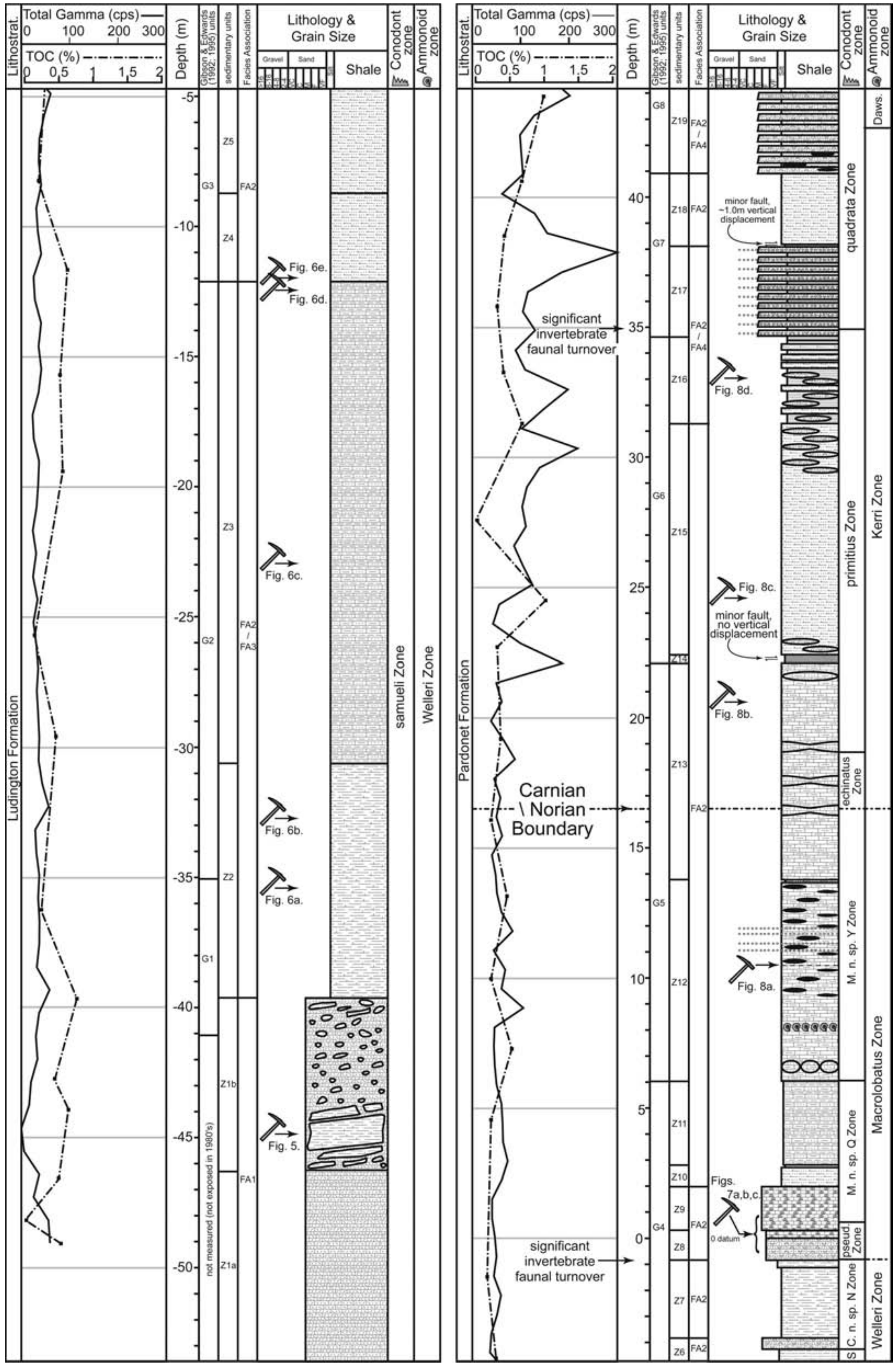
Triassic strata in the Peace River / Williston Lake region were first observed during the Selwyn expedition of 1875 (Selwyn 1877). Although a number of Upper Triassic fossils were collected on this expedition (Whiteaves 1877), Upper Triassic stratigraphy in this area was not described for 45 years. Initially, all Upper Triassic strata in the Peace River region were lumped into the Schooler Creek Formation (McLearn 1921). Subsequent studies elevated the Schooler Creek Formation to Group status and subdivided this unit into six distinct subunits: the Liard, Charlie Lake, Baldonnel, Ludington, Pardonet and Bocock formations (McLearn 1947; 1960; Gibson 1975). Upper Triassic strata at Black Bear Ridge consist of two of these formations: the Ludington and Pardonet formations (Gibson and Edwards 1990; 1992; Orchard et al. 2001a; 2001b; Zonneveld and Gingras 2001; Zonneveld 2008; text-fig. 2).

The Ludington Formation (text-fig. 2) consists of grey, brownish and buff weathering limestone, dolomitic siltstone, calcareous siltstone, bioclastic limestone and rare calcareous sandstone (Gibson 1975). The type section of the Ludington Formation occurs at Mount Ludington, approximately 25 kilometers north of Black Bear Ridge (Gibson 1975).

At Williston Lake the Ludington commonly contains thick bioclastic packstone / grainstone beds characterized by abundant brachiopods, crinoids, echinoids, gastropods, bivalves and rare scleractinian coral fragments (Zonneveld 2008). North of Williston Lake the Ludington is commonly bisected by bioclastic channel-fill complexes up to 170 metres thick (Gibson and Hedinger 1988). Fossils in these channel complexes are generally too altered / replaced for even generic identification (Gibson and Hedinger 1988; Gibson 1993b). The age of these channels is poorly constrained (identified as 'Carnian'; Gibson and Hedinger 1988; Gibson 1993b) and thus their relationship to specific events documented in the study interval (discussed below) is uncertain.

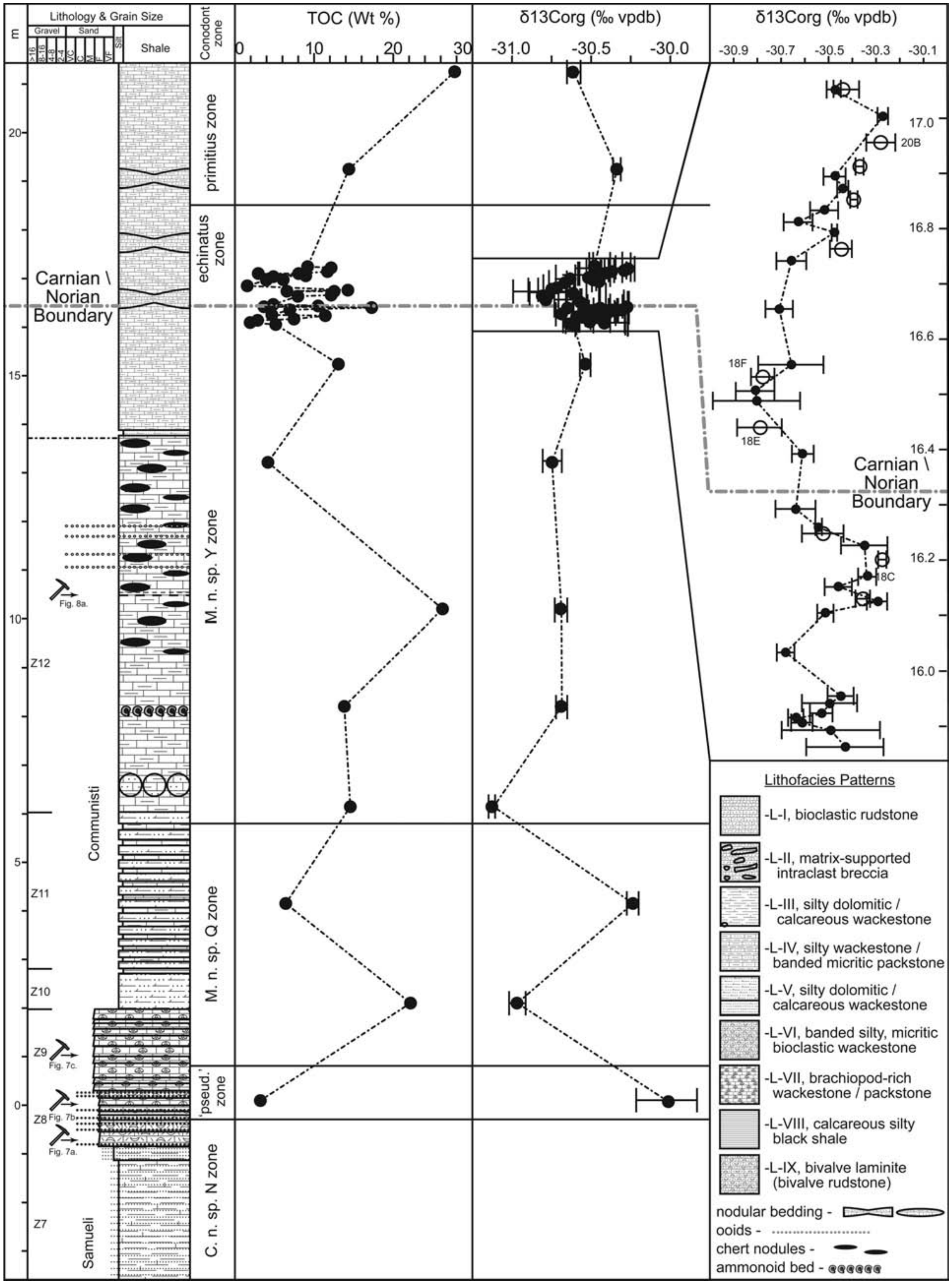
The Ludington Formation is laterally equivalent to the Charlie Lake, and Baldonnel formations (text-fig. 2). It ranges in thickness from 500 metres thick at Mount Ludington to approximately 960 metres at Laurier Pass (Gibson 1975). At Williston Lake it is thickest (~195m) at Juvavites Cove on Pardonet Hill (location 8, text-figs. 1, 2). At Black Bear Ridge exposure of the Ludington Formation is limited to the uppermost beds of the Ludington Formation in the basal ~460 meters of the exposed outcrop succession.

The Ludington is conformably / gradationally overlain by the Pardonet Formation (Zonneveld and Gingras 2001; Zonneveld



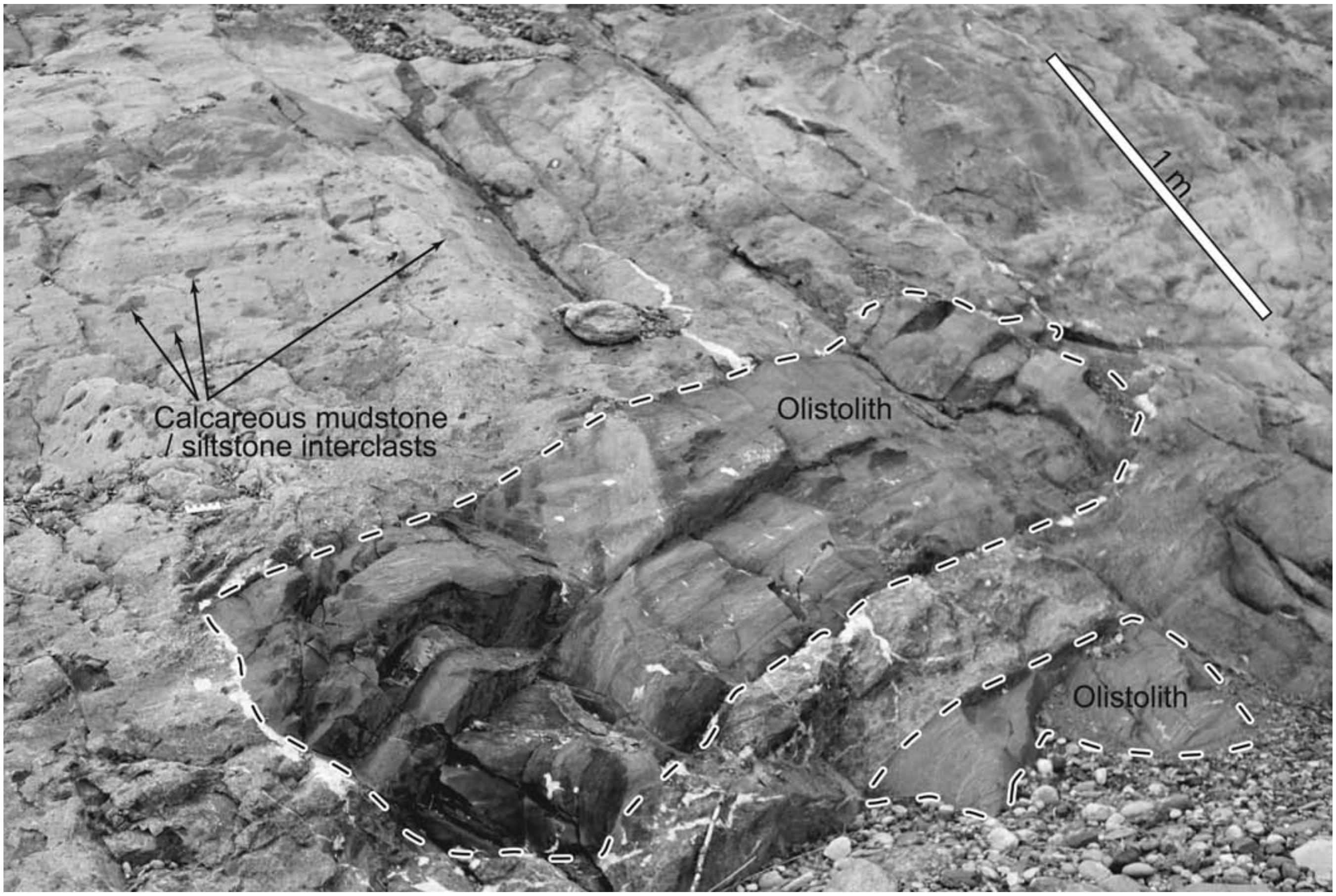
TEXT-FIGURE 3

Stratigraphic section showing the vertical arrangement of lithofacies and depositional environments in the Ludington and lower Pardonet Formations at Black Bear Ridge, northeastern British Columbia (see text-fig. 2 for location). Gamma ray data (counts per second) and biostratigraphic zonation obtained from Orchard and others (2001) and (Orchard, 2007). The letter 'S' in the conodont zone column (~-4.5 metres) denotes the upper part of the samueli conodont zone; 'pseud. Zone denotes the 'pseudoechinatus' Zone. Several conodont zones are characterized by new taxa including the 'C. n. sp. N zone' (*Carniepigondolella*) and the M. n. sp. Q and Y zones (*Metapolygnathus*). Total organic carbon (TOC) data obtained from Carrelli (2002). Rock hammer symbols denote the locations of illustrated outcrop and polished slab photographs. Lithology symbols shown on text-figure 4.



TEXT-FIGURE 4

Detail of the lowermost Pardonet Formation and the upper Ludington and lower Pardonet formations at Blackbear Ridge. Conodont zones from Orchard (2007). Rock hammer symbols denote the locations of illustrated outcrop and polished slab photographs. Isotope data following Williford and others (2007).



TEXT-FIGURE 5
Outcrop photograph of lower part of unit Z1 (-37 to -38m), upper Ludington Formation, showing large olistolith and carbonate mudstone/siltstone intraclasts in bioclastic rudstone.

and Orchard 2002; Zonneveld 2008). Gibson and Edwards (1990; 1992) placed the lithostratigraphic boundary at the contact between a brownish grey dolomitic siltstone unit and an overlying grey bioclastic wackestone / packstone unit (unit G3\G4; Z5\Z6 contact; text-fig. 3). As the two units contain many lithofacies in common, particularly at this locality, this choice of contact is somewhat arbitrary. Orchard and others (2001b) identified a transitional zone between the two formations, incorporating ~28 metres of section that contain lithofacies consistent with both formations (from base of unit G3 / Z6 to top of unit G5 / Z13; text-fig. 3). Although both usages are equally technically correct, the Gibson and Edwards (1990; 1992) solution is simpler and is followed here.

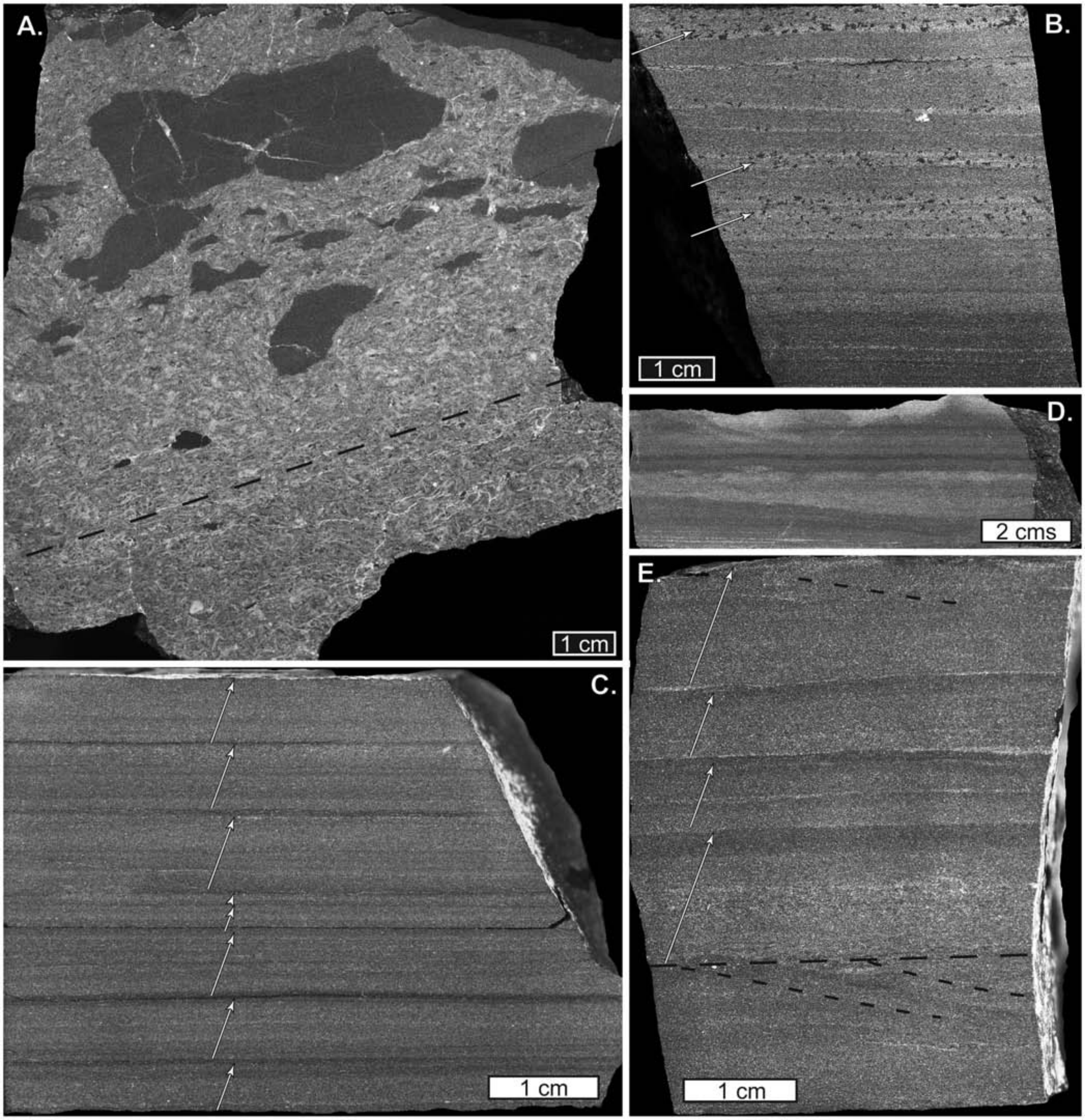
The Pardonet Formation (text-fig. 2) is primarily composed of grey carbonaceous limestone, calcareous and silty dolostone and shale. Carbonate and chert nodules are locally common (Zonneveld et al. 2004). Bioclastic limestone beds are common, particularly those composed of dense, monotypic accumulations of thin-shelled bivalves of the genera *Monotis* and *Halobia* (Zonneveld et al. 2004; McRoberts 2007). In addition to bivalves, ammonoids, belemnoids and marine vertebrates, particularly ichthyosaurs, are common in the Pardonet Formation (Nicholls and Manabe 2001).

The type locality for the Pardonet Formation occurs at Pardonet Hill on the south shore of Williston Lake, British Columbia (McLearn 1940; 1960; Zonneveld and Orchard 2002) however the type section contains several small scale thrust faults so reference sections have been established at Eleven Mile Creek south of Williston Lake and at Black Bear Ridge. The Pardonet is overlain by the Jurassic Fernie Formation in the subsurface and most of the outcrop belt and by the Upper Triassic Bocock Formation south of Williston Lake (Gibson 1975; Sephton et al. 2002; Zonneveld 2008).

BIOSTRATIGRAPHY

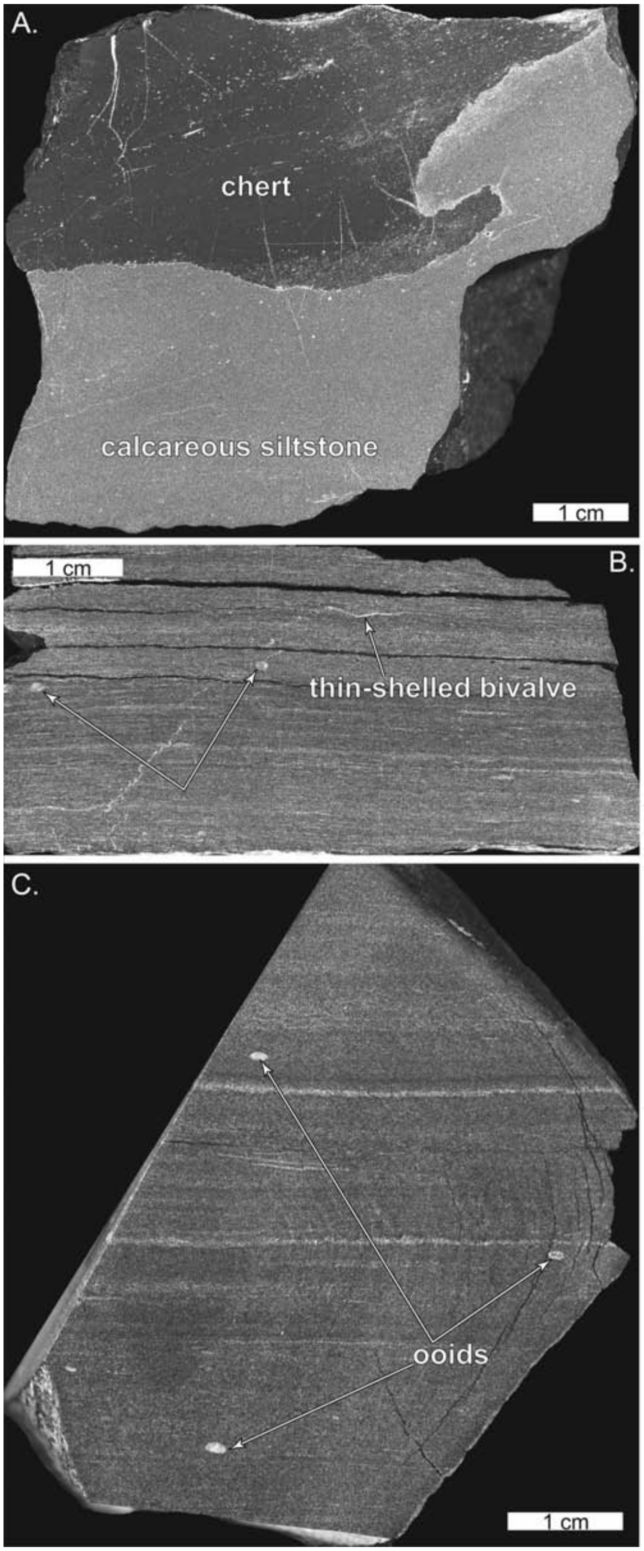
The biostratigraphy of the Black Bear Ridge section (Late Carnian-Early Jurassic) was summarized by Orchard and others (2001a; 2001b), McRoberts (2007) and Orchard 2007a, b. Conodonts, bivalves, ammonoids, brachiopods, and ichthyoliths have been documented in the lowest part of the section, with the first two being the most abundant. In particular, the conodont succession is remarkable and provides a detailed record of multiple lineages in the late Carnian and early Norian.

Ammonoids of both the Macrolobatus and Kerri ammonoid zones, between which the Carnian-Norian Boundary (CNB) has traditionally been placed (Tozer 1967; 1994; Orchard et al.



TEXT-FIGURE 6
Polished slabs from the upper Ludington Formation. **A.** Intraclast rich bioclastic rudstone, 30 metres below datum. The dashed line indicates bedding (up to top left side of page). Most intraclasts in this facies are oriented roughly parallel to bedding. **B.** Plane parallel laminated calcareous siltstone / very fine-grained sandstone with abundant phosphatic pellets (abundant black specks at laminae denoted by arrows), 27.5 metres below datum. **C.** Plane parallel laminated calcareous siltstone / very fine-grained sandstone with several normally graded lamina-sets (denoted by arrows), 17.6 metres below datum. **D.** Plane parallel laminated calcareous siltstone / very fine-grained sandstone with several normally graded lamina-sets, 12.4 metres below datum. **E**. Plane parallel laminated to current ripple laminated calcareous siltstone / very fine-grained sandstone, 12.0 metres below datum. Arrows denote normally graded laminasets; long-dashed lines denote bedding; short-dashed lines denote ripple foresets.

2001a,b; Krystyn et al. 2002), are present within the boundary interval at Black Bear Ridge. They are also common in nearby sections to the south (Pardonet Hill), where the intercalibration of the ammonoid and conodont chronologies provide a yardstick to which we can compare ammonoid zonal intervals in the Black Bear Ridge succession. Hence, the Macrolobatus - Kerri



TEXT-FIGURE 7
Polished slabs from the lowermost Pardonet Formation. **A.** Calcareous siltstone with partial chert replacement, 20.6 metres above datum. **B.** Laminated calcareous siltstone with abundant scattered bivalves, 24.5 metres above datum. **C.** Laminated calcareous siltstone with scatted ooids, 30.0 metres above datum.

ammonoid zone boundary is placed at ~ 16.3m above our zero datum (base of a prominent brachiopod-packstone marker bed) in the present study (text-figs. 3, 4). At this level, there is a dramatic faunal turnover in conodont fauna (Orchard 2007b, text-fig. 5) with the virtual replacement of smooth or weakly noded metapolygnathids by the more ornate elements formerly combined in *Metapolygnathus primitius* (Orchard 1983). The interval is further characterized by the common appearance of diminutive elements assigned to the *M. echinatus - parvus* group. Furthermore, the inferred ammonoid zonal boundary and associated conodont change are concurrent with the appearance of a new bivalve fauna (McRoberts 2007), strengthening the utility of this datum as the CNB.

Outstanding, well-preserved conodont lineages are one of the Black Bear Ridge Carnian-Norian boundary section's strongest attributes. Including the favoured CNB boundary level, seven biostratigraphic levels are identified on the basis of the evolving conodont fauna (text-fig. 3; Orchard 2007b). The succession begins with generally smooth metapolygnathids and diverse species of *Carniepigondolella* (Orchard 2007a, b) which facilitate recognition of 3 conodont intervals. Approximately concurrent with the near disappearance of *Carniepigondolella*, the first members of the *Metapolygnathus primitius* group appear (unit Z9) as do new, as yet unnamed taxa (Orchard 2007a, b). New elements appear a little higher (unit Z12) and higher still, at the proposed CNB within unit Z13, *M.* ex gr. *echinatus* appears coincident with the demise and rapid disappearance of most species other than *M. primitius* and its ornate relatives, including *Epigondolella orchardi*. Soon after, *Norigondolella navicula* becomes abundant and higher still *Epigondolella quadrata* replaces *Metapolygnathus* ex gr. *primitius* as the dominant element (Unit Z17; Orchard et al. 2001, 2001b; Orchard 2007a, b). By extrapolation, these conodont zones are interpreted to span and subdivide the Welleri (in part), Macrolobatus, and Kerri ammonoid zones, and extend into the lower Norian Dawsoni ammonoid Zone (Figs. 3 4). Preliminary discussion of the diagnostic conodont groups and their morphogenesis during the upper Carnian and lower Norian are available in Orchard (2007b).

The proposed CNB is also an appropriate choice with regard to halobiid bivalve distribution (Orchard et el. 2001b; McRoberts 2004; 2007): *Halobia* cf. *H. septentrionalis* is abundant in uppermost Carnian strata, disappearing at the proposed CNB datum (McRoberts 2007); *Halobia* cf. *H. radiata* extends from the upper Carnian to just above the CNB (McRoberts 2007); and *Halobia* new species aff. *H. beyrichi* occurs from just below the CNB to well above it, overlapping with *H.* cf. *H. austriaca,* which appears in the lowermost Norian (McRoberts 2007).

MAGNETOSTRATIGRAPHY / GEOCHRONOLOGY

Paleomagnetic reconnaissance was conducted during the late 1990s at three localities at Williston Lake (including two sites: Brown Hill and Black Bear Ridge; that span the Carnian-Norian boundary; Muttoni et al. 2001b). Characteristic magnetizations at all three localities differ significantly from Triassic North American cratonic reference sections (Muttoni et al. 2001b) leading to the hypothesis that the Williston Lake Triassic was subjected to post-depositional remagnetization. The exclusive occurrence of normal polarity in all samples obtained supports the theory that this remagnetization occurred during the Cretaceous long normal superchron (Muttoni et al. 2001b). Cretaceous remagnetization of older Mesozoic and Paleozoic rock has been reported from a number of sites in the Rocky Mountains of western North America, from Mexico, the western United States, British Columbia and the Yukon (i.e. Russell et al. 1982; Rees et al. 1985; Bohnel et al. 1990; Wynne et al. 1998; Muttoni et al. 2001b). Many remagnetization events were likely related to tectonically induced migration of mineralizing fluids during orogenic events in the Cretaceous Cordillera (i.e. Oliver 1986; Muttoni et al. 2001b).

Unambiguous volcanogenic sediments have, as yet, not been identified in the Triassic of the Western Canada Sedimentary Basin and thus radiometric age determination of these strata has not, as yet, been attempted. Recently, Re-Os isotopic analysis of organic-rich sedimentary rocks has been shown to be a viable chronometer in clastic sedimentary successions (i.e. Ravizza and Turekian 1989; Creaser et al. 2002). It is intended that reconnaissance samples be obtained from several localities at Williston Lake, including from the Black Bear Ridge section, to assess the viability of this chronometer in Triassic sedimentary strata of western Canada.

Sedimentary Facies & Facies Associations

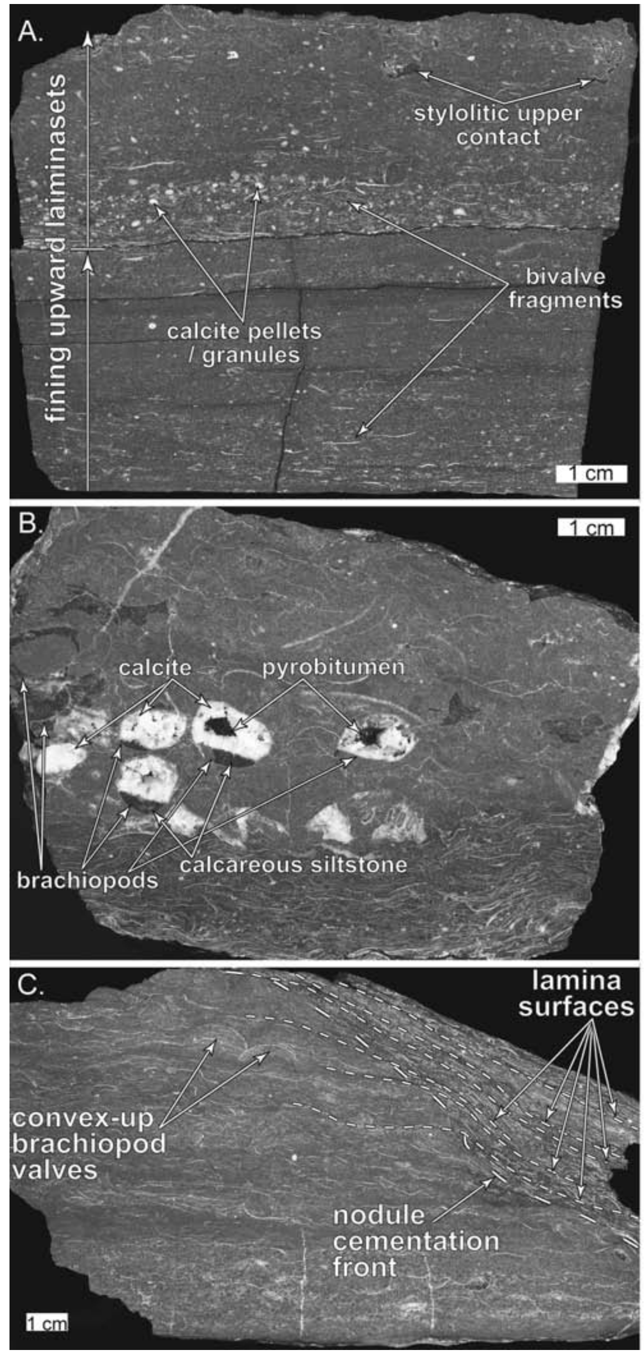
Sedimentary facies in the upper Ludington and lower Pardonet Formation were studied by both outcrop and laboratory scale analyses including description of polished hand-samples, thin-sections and acetate peels. A total of nine sedimentary facies are recognized in the study interval (Table 1). Lithofacies were identified on the basis of lithology, bounding surfaces, primary physical sedimentary structures, and bioclastic or fossil composition. With the exception of micro borings in fish teeth and some invertebrate fossil fragments, trace fossils were not observed in the study interval and thus were not utilized in lithofacies segregation. We use the Dunham (1962) carbonate classification system modified by Embry and Klovan (1971). Biostratinomic terminology follows that established by Kidwell and others (1986).

General depositional affinities for each facies are indicated on Table 1 however, specific interpretations for the depositional environments require consideration of facies associations which are discussed below. All facies associations in the study area are interpreted to reflect deposition in a deep marine setting (i.e. well below storm wave base). Facies associations are discussed in order of their occurrence from the base of the section upwards.

Facies Association 1 - Debris flow

Description: This facies association comprises bioclastic rudstone (L-I) and matrix-supported intraclast breccia (L-II; Figs. 5, 6A). These deposits vary from massive or structureless to convolute bedded. Rare decimeter-scale flame and water escape structures and rare current ripples were observed in this association. Other physical sedimentary structures were not observed. The bioclastic detritus that comprises the bulk of these lithofacies consists of disarticulated, fragmentary and abraded bivalves, brachiopods and pelmatazoans (primarily echinoid and crinoid skeletal elements) (text-fig. 6A). Bioturbation was not observed in these lithofacies.

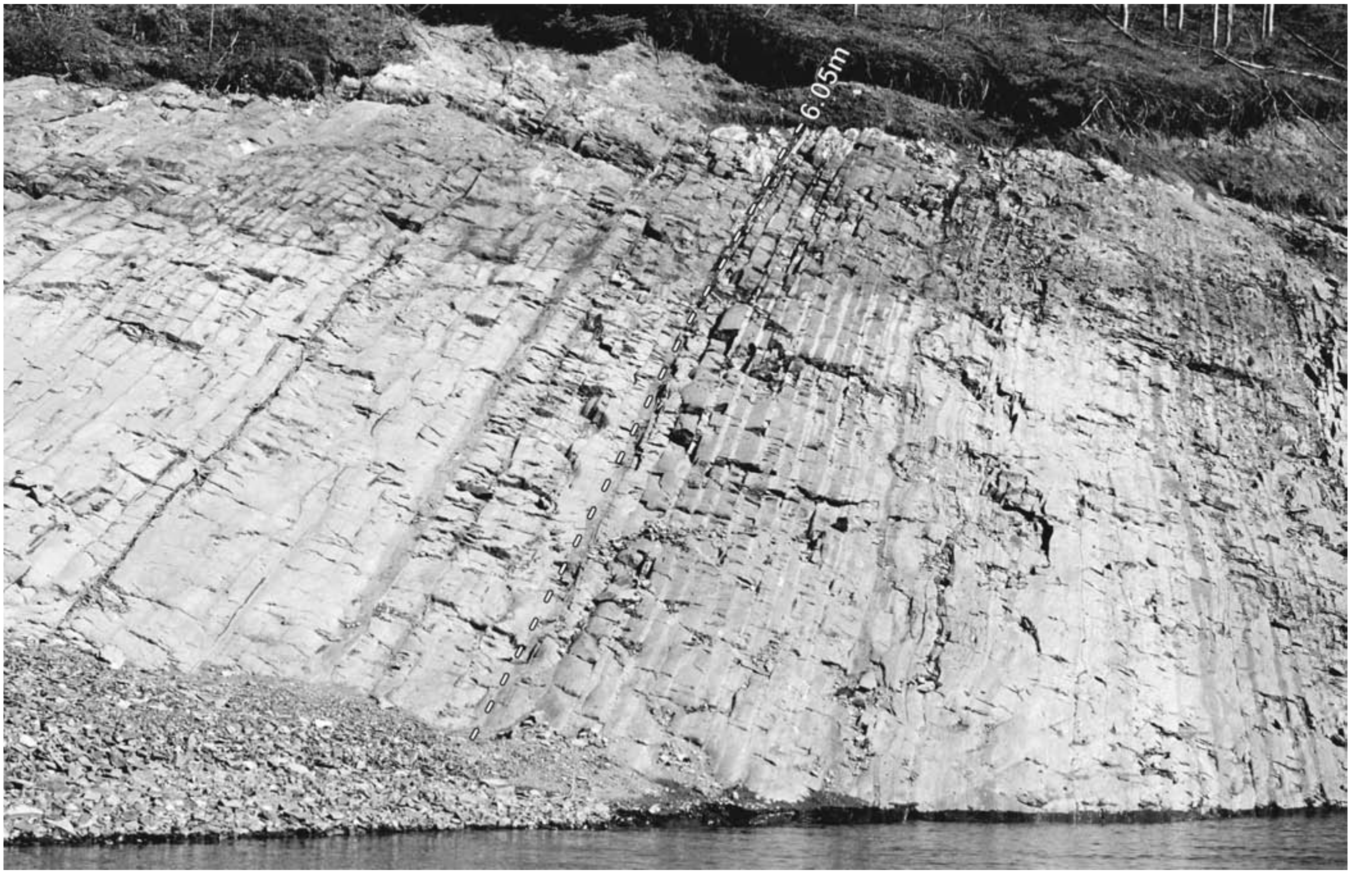
Intraclasts in L-II consist primarily of planar bedded, silty calcareous wackestone identical to lithofacies L-III. Most clasts are oriented roughly concordant to bedding (Figs. 5; 6A) however rare examples oriented oblique or perpendicular to bedding were also observed. Intraclasts consist primarily of silty, dolomitic and calcareous wackestone, identical in composition



TEXT-FIGURE 8
Polished slabs from the lowermost Pardonet Formation. **A.** Normally graded bioclastic wackestone, with concordantly emplaced bivalves and abundant calcareous pellets/granules, 1 metre below datum. **B.** Brachiopod-rich bioclastic wackestone/packstone, zero datum (see text-fig. 3). **C.** Nodular bioclastic packstone, 0.85 metres above datum.

to L-III. Biostratigraphic analyses of these clasts have produced a similar conodont assemblage to that in the bioclastic rudstone matrix surrounding them.

Facies association 1 occurs solely at the base of the study interval (~-50 to -39.6m). Instability of Pleistocene and Holocene deposits above this part of the Black Bear Ridge outcrop expo-



TEXT-FIGURE 9
Outcrop photograph of the lower Pardonet Formation showing the position of the traditional Carnian – Norian boundary at ~6.05 metres above the datum (see figs. 3 and 4). All beds included within Facies Association 2 (FA2).

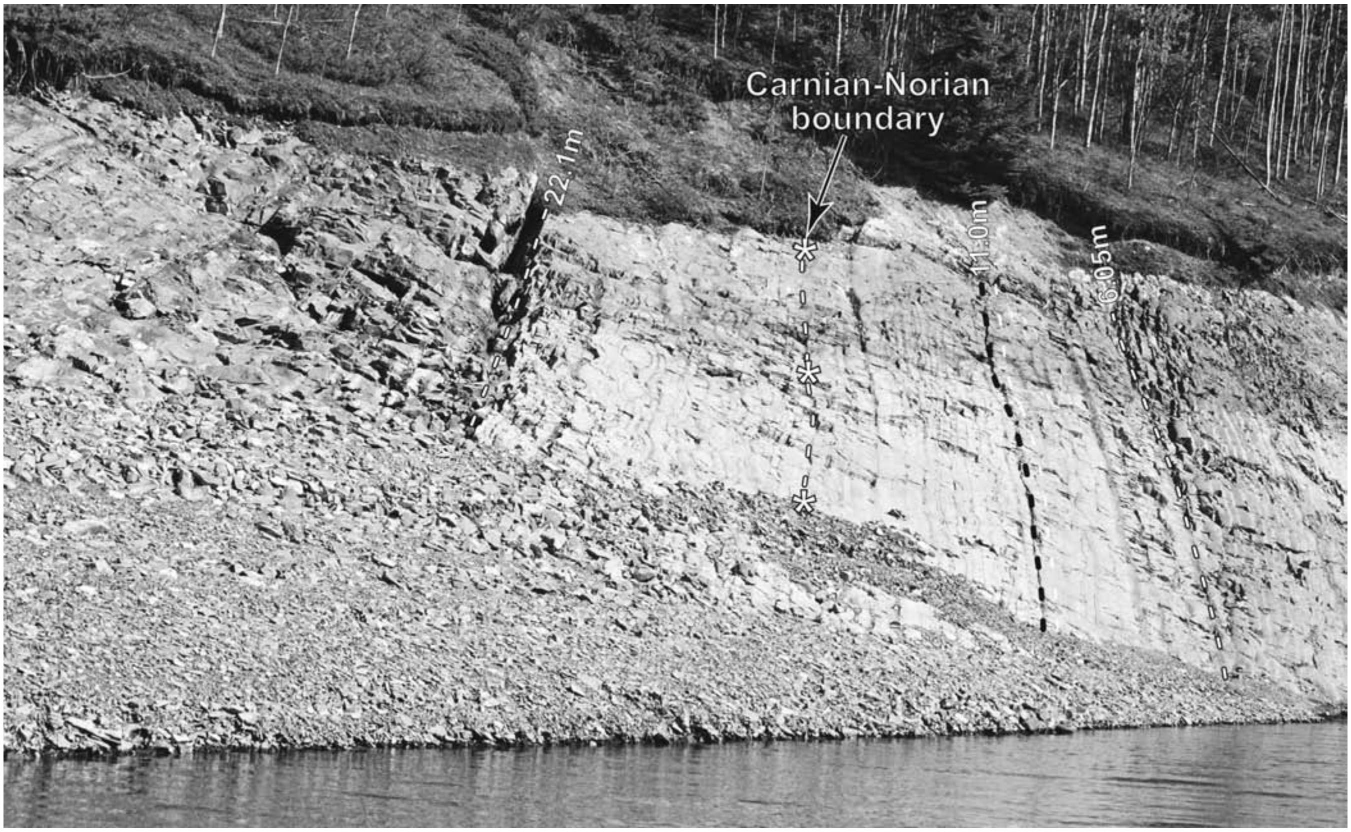
sure occasionally results in partial burial of this facies association at times obscuring important depositional features.

Interpretation: Carbonate breccias, such as those in facies association 1, occur in a broad range of depositional settings, most commonly seaward of the shelf-slope break (i.e. James and Mountjoy 1983; Eberli 1991a,b; Coniglio and Dix 1992) but also in shallower settings, both below and above storm wave base (i.e. Seguret et al. 2001; Bouchette et al., 2001). Evidence of reworking (fair-weather or storm) is absent in the Black Bear Ridge section and thus they are interpreted to be deposited below the zone of storm reworking.

The massive to convolute bedded bioclastic rudstone and matrix-supported intraclast breccia are interpreted to reflect deposition by debris flows in a distally steepened carbonate ramp setting (*sensu* Read 1985). These debris flow deposits (i.e. debrites *sensu* Stow 1984; 1986) are the product of slope failure of both coherent (firm / cemented) and incoherent (loose) carbonate deposits in more proximal settings and subsequent basinward transport via sediment gravity flows (Playton and Kerans 2002). Evidence that the sediment was supported by fluid turbulence (i.e. graded beds) is lacking and thus these deposits are not interpreted as turbidites. Absence of a clay mineral matrix may suggest that these deposits may result from a combination of grain flow and debris flow processes (Middleton and Hampton 1976) however beds in this facies association more strongly resemble debrites than grain flow deposits.

Large and small intraclasts in L-I occur as abundant isolated, blocks ‘floating’ in a bioclastic rudstone matrix (text-fig. 5, 6A). Biostratigraphic analyses of clasts and matrix confirm that both are derived from deposits of similar age (Zoae subzone of the Nodosus conodont zone) providing evidence of early submarine cementation. The presence of out-sized ‘floating’ blocks and rare medium-scale water escape structures provides evidence for sudden, *in situ* freezing of a sediment mass rather than particle-by particle sedimentation that characterizes traction deposits (Hampton 1972; Middleton and Hampton 1976; Enos 1977). Individual sediment gravity flows freeze when the driving stress decreases to a point less than that necessary to propel the flow (Middleton and Hampton 1976).

Large, out-sized clasts may be transported within turbidity flows at the interface between a pseudolaminar inertia-flow layer and an overlying, faster moving turbulent layer (Postma et al. 1988). These deposits are usually characterized by either normal grading or a combination of inverse and normal grading, as well as flute casts on bed soles and physical sedimentary structures consistent with deposition by turbidity currents (Postma et al. 1988). These features are lacking in facies association 1 at Black Bear Ridge and thus the breccia beds are interpreted as debrites rather than turbidites.



TEXT-FIGURE 10
Outcrop photograph of lower Pardonet Formation showing reference horizons, traditional boundary (at 6.05 metres), minor bedding plane fault (22 metres) and the location of the proposed Carnian-Norian boundary (16.5 metres; dashed line with asterisks).

Many debrites form from progressive, incremental accretion rather than abrupt, *en masse* deposition (Major 1997; 1998). These beds are commonly characterized by vertical changes in particle sorting, strong particle alignment and numerous, internal graded sub-beds (Major 2003), features that are missing in the Black Bear Ridge debrites. Debrites in the study interval occur as a stacked succession of decimeter to metre scale beds characterized by primarily massive internal structure and crude clast grading and are thus interpreted to occur from several discrete debris flow events rather than progressive, incremental accretion.

FA2 - Thin- / medium-bedded turbidites

Description: This facies association consists of four lithofacies: silty, dolomitic, and calcareous, wackestone (L-III); intercalated banded micritic packstone/silty wackestone (L-IV); sandy dolomitic/calcareous wackestone (L-V); brachiopod-rich bioclastic wackestone/packstone and banded silty micritic bioclastic wackestone (L-VII). Physical sedimentary structures in silty and sandy, dolomitic and calcareous wackestone beds (L-III, L-IV, & L-V) consist primarily of plane parallel laminae (Fig. 6B-E; 7A-C) although rare current ripples also occur (Fig. 6E). Physical sedimentary structures in bioclastic wackestone and bioclastic packstone beds (L-IV, L-VII) consist solely of plane parallel laminae (text-fig. 8A). Concretionary intervals and black chert nodules occur in bioclastic wackestone and bioclastic packstone beds (L-IV, L-V, L-VII; Fig. 7A, C). Chert nodules are particularly abundant in L-VII.

Beds consist primarily of tabular sheets with thicknesses vary from 0.5 to 25cm (text-fig. 9, 10). Analysis of polished slabs has revealed that many 10 to 25cm thick 'beds' are actually bedsets consisting of numerous internal, normally graded beds varying from 0.5 to 5.0cm in thickness (text-fig. 6 B-E). Stylolitic bed contacts are present in dolomitized occurrences of L-V. In all other cases bed contacts are sharp but non-erosive.

Phosphatic pellets, interpreted as faecal pellets, occur in all lithofacies in FA2. Ooids and other carbonate granules (possibly peloids) are also common in some lithofacies (i.e. L-III, L-IV; L-VII; text-fig. 7B,C; 8A,B). Bioclastic detritus is rare in L-III and L-V, consisting primarily of articulated and disarticulated bivalves and bivalve fragments and rare crinoid skeletal elements (text-fig. 7B). Bioclastic material is abundant in other lithofacies in this facies association (text-fig. 8A-C). This material consists of abundant, primarily concordantly emplaced, articulated and disarticulated bivalves (most commonly *Halobia*) and bivalve fragments, disarticulated crinoid and echinoid skeletal elements and scattered ammonoids, straight nautaloids and chordate material (conodonts, fish and reptile skeletal debris, etc...). Brachiopods of the genus *Piarorhynchia* are exceptionally common in L-VI (text-fig. 8B). Biogenic structures were not observed in any lithofacies in this facies association.

Interpretation: The sharp-based, primarily normally graded wackestone and packstone beds that comprise FA2 are interpreted to have been deposited by turbidite currents in a medial to distal slope setting. Turbidity currents are gravity-driven sediment flows wherein fluid turbulence maintains grain dispersion in the flow and suspended sediment results in a gravity differential between the current and the ambient water (i.e. Middleton and Hampton 1976; Middleton 1993; Mulder and Cochonat 1996).

Turbidity currents are important transport vectors in the relocation of coarse clastic and carbonate material from shallow to deep marine settings (Eberli 1991a,b; Haak and Schlager 1989). The turbidites (deposits of turbidity currents) that comprise FA2 record the transport of invertebrate taxa that normally inhabited shallow water (i.e. pelmatazoans, brachiopods, moderate- to thick-shelled bivalves) to medial / distal slope settings. Geopetal structures in recrystallized brachiopods (*Piarorhynchia winnemae*) indicate that transport occurred prior to sediment infill or shell recrystallization implying that the organism died during, or shortly before, transport (text-fig. 8B). The presence of sharp-based tabular beds, normally graded laminasets / beds (text-fig. 6B-F; text-fig. 7B-C), plane parallel laminae, bimodal grain-size distribution and partial Bouma sequences in FA2 are diagnostic characteristics of calcareous turbidites (Eberli 1987; 1991a,b; Haak and Schlager 1989). Current ripples, although observed, were rare in these beds. Evidence of scour or erosion is absent. Coarse-grained, poorly sorted, variably graded beds (i.e. L-VI; text-fig. 8B) may indicate a transport mechanism intermediate between a true turbidity current (grains supported by fluid turbulence) and a debris flow (grains supported by grain-grain interaction; i.e. Crevallo and Schlager 1980). Chert nodules (text-fig. 7A) are common in calcareous turbidites, due to secondary silicification during lithification, likely sourced from siliceous skeletal debris transported in the turbidity current (Eberli 1991a,b).

As evidenced by examples from FA2, calcareous turbidites are typically poorly sorted compared to siliciclastic ones (Eberli 1991a, 1991b). This is due both to poor sorting in the source area as well as to variable bulk densities and hydraulic qualities for similar sized grains (Rusnak and Nesteroff 1964; Eberli 1991a, 1991b Siliciclastic turbidites are most commonly associated with turbidite fan complexes however calcareous turbidites are much more widespread in their distribution as their source material is more or less evenly distributed along many carbonate shelves / platforms margins (Eberli 1991a,b).

FA3 - Slide facies association

Description: This facies association comprises silty, dolomitic and calcareous, wackestone (L-III) and intercalated banded micritic packstone / silty wackestone (L-IV). Physical structures and bioclastic composition in this facies association are identical to those in FA2. This facies association differs from FA2 primarily in bed and bedset orientation and the apparent truncation of some bed contacts below other bedding surfaces (text-fig. 11A, B).

Interpretation: Deposition of individual beds and bedsets occurred under similar conditions to those in FA2 however those included in FA3 exhibit clear evidence of post-depositional sediment remobilization. Despite mass movement physical sedimentary structures are well-preserved and thus this facies association is interpreted as a succession of submarine slide blocks. Slides result from downslope sediment movement of a coherent mass above a basal shear surface (Martinsen 1994; 2003). The deposits of slides differ from those of related phenomena such as slumps and debris flows in retaining well-preserved internal bedding (see text-fig. 11). Excellent preservation of internal bedding provides evidence that individual slide blocks did not likely travel far, presumably on the order of several metres to possibly as much as several hundred metres. Paleontological evidence supports this interpretation, as fossil faunas within included facies are identical to those in adjacent facies that show no evidence of slide movement.

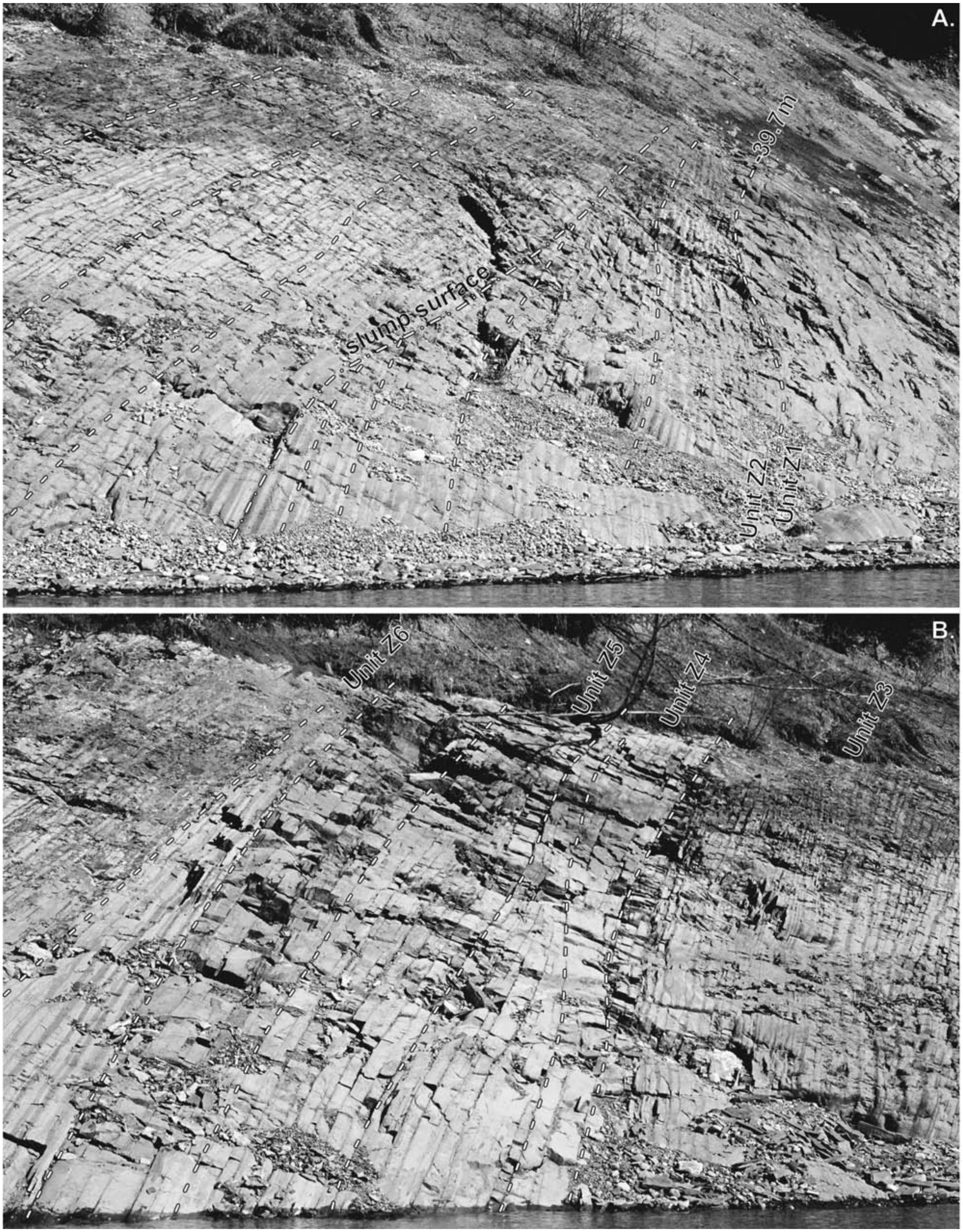
This facies association is limited in occurrence at Black Bear Ridge to Upper Carnian strata assigned to the samueli conodont zone. Submarine slides invariably result in minor repeated section in some areas and minor missing section in others. In the Black Bear Ridge it is apparent that the section is overthickened by ~1-2 metres (text-fig. 11A). This phenomenon occurs only in Carnian-aged strata, well below the Carnian-Norian boundary interval.

FA4 - Hemipelagic suspension deposits

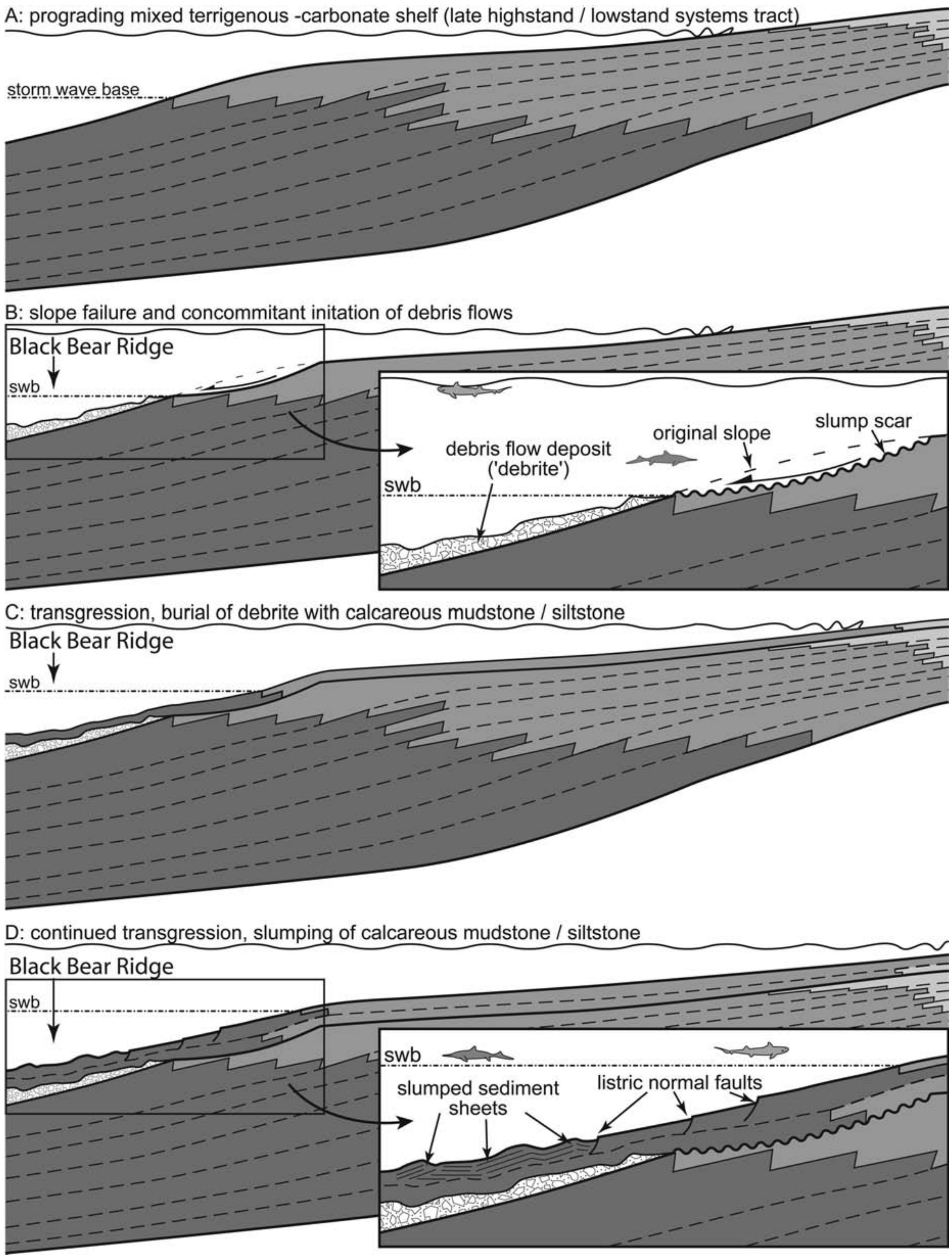
Description: This facies association consists of two lithofacies: silty, calcareous shale (L-VIII) and bivalve-dominated rudstone (bivalve laminite; L-IX). Increased abundance of shale laminae and beds is reflected in the slightly more recessive nature of these strata then underlying beds (text-fig. 11).

Physical sedimentary structures in this facies association are limited to plane parallel laminae. In some bivalve-dominated rudstone beds, articulated and disarticulated thin-shelled bivalves (commonly *Halobia*) are tightly packed together imparting a crinkly, laminated appearance in vertical section. In the study interval these bivalve rudstones are dominated by *Halobia* however other bivalves as well as ammonoids, nautaloids and vertebrate (fish and marine reptile) skeletal elements also occur. This lithofacies (L-IX) is the quintessential Pardonet lithofacies occurring at most outcrop sections in the Rocky Mountain Foothills and Front Ranges (i.e. Westermann,1962; 1966; Tozer 1979; Zonneveld et al. 2004). FA4 occurs solely at the top of the present study interval (text-fig. 3) and is characterized by higher total organic carbon (TOC) levels than lower in the section (Riediger et al. 2004).

Interpretation: Finely laminated mudstone beds, absence of discernible scour / erosional surfaces or any other higher energy physical sedimentary structures, and a lack of evidence for storm reworking is consistent with deposition well below storm wave base. Laminated black shale intervals with variably abundant bivalves emplaced concordant to bedding in both convex-up and concave-up orientations suggests quiescent, likely suspension dominated deposition. Some bioclastic beds in this facies association exhibit normal grading and are thus likely calcareous turbidites, similar to those described in FA2. Densely packed bivalve-dominated bioclastic rudstones are the hallmark of the Pardonet Formation (McLearn 1960; Zonneveld et al. 2004; McRoberts 2007). Dominance of whole, unabraded, articulated and disarticulated bivalves (primarily Halobiids; McRoberts 2007) in both convex-up and concave-up orientations is indicative of minimal transport and likely emplacement of the bivalves at or near where they lived (i.e. life location but not likely life position). Similar deposits north of the study area were interpreted to have been deposited in an open marine, outer ramp setting (*sensu* Burchette and Wright 1992) below

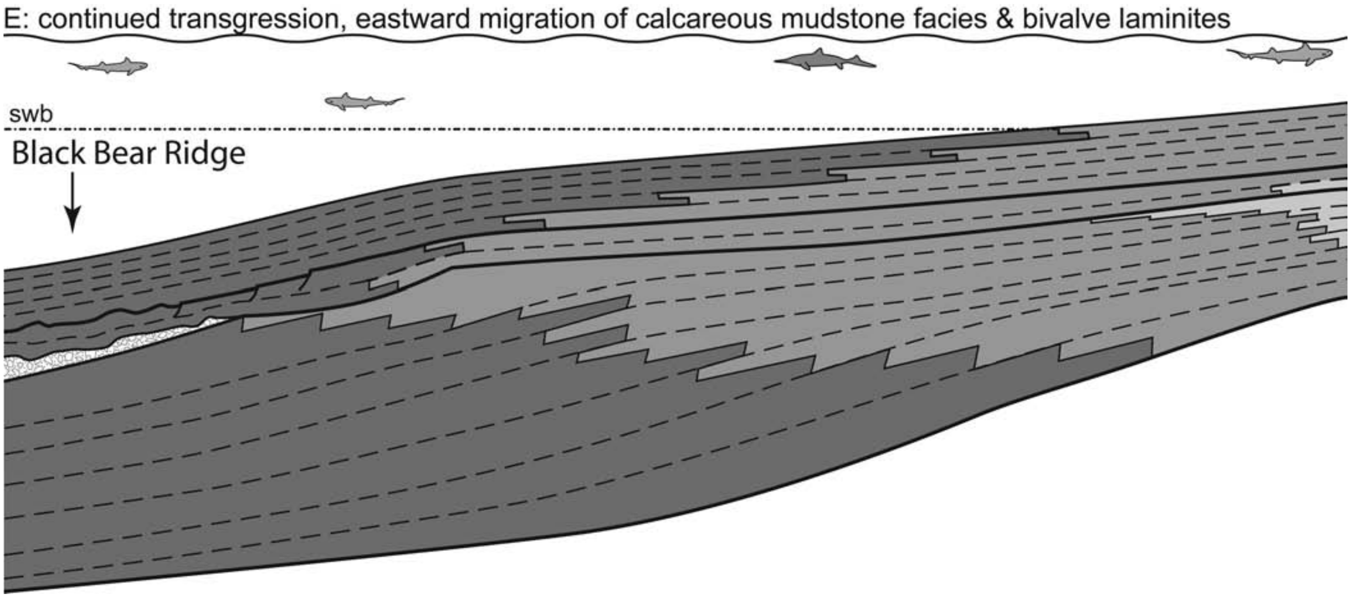


TEXT-FIGURE 11
Outcrop photographs of the upper Ludington Formation showing sediment slides reflected by non-parallel bedding surfaces and truncation of some beds / bedsets. **A.** Contact between units Z1 and Z2 (-39.7 m) and slump / slide surface within unit Z2. B. Concordant contacts between units Z3, Z4. Z5 and Z6 (~-18.0 to-1.0m).



TEXT-FIGURE 12a-d

Depositional model for the Upper Triassic Ludington - lower Pardonet succession, Peace Reach of Williston Lake. Arrows denote the location of Black Bear Ridge. **A.** Late Carnian deposition (units below -46.3m on text-fig. 3) took place on an overall prograding mixed siliciclastic-carbonate shelf during late highstand to lowstand conditions. **B.** Slope failure resulted in sediment remobilization and movement at a location landward (east) of Black Bear Ridge resulting in deposition of thick debrites. This interval includes the interval between -46.3 and -39.5 metres on Figure 3. The cause of this slope failure remains uncertain but may have been related to regional tectonic influences. **C.** During a marine transgression that started in the latest Carnian the debrites were buried in a thick calcareous mudstone and siltstone succession (units between -39.5 and ~-25 m, text-fig. 3). **D.** Renewed slope failure landward of Black Bear Ridge resulted in deposition of slumped sediment sheets at Black Bear Ridge (units from ~-30 to ~-12 m, text-fig. 3).



TEXT-FIGURE 12e
E. Deposition of the upper part of the study interval (latest Carnian and earliest Norian) occurred coeval with continuing marine transgression resulting in deposition of a thick succession of medium-bedded and thin-bedded turbidites (units above ~-12m, text-fig. 3). Tectonic quiescence in this interval is reflected in a thick succession of concordant strata spanning the Carnian-Norian boundary interval.

storm wave-base (Zonneveld et al. 2004). The occurrence of this facies association, relative thinness and lesser abundance of intercalated turbidite beds (FA2), as well as higher TOC levels and gamma ray counts in this facies association (text-fig. 3), are consistent with the interpretation that this facies reflects deposition basinward of other facies associations.

Total Organic Carbon (TOC) and Stable Carbon Isotopes

The Carnian-Norian boundary section at Black Bear Ridge was sampled for stable organic carbon isotope analyses and total organic carbon (TOC) in order to assess the presence or absence of a significant isotope excursion in the boundary interval and to gauge the degree to which faunal turnover in this interval was accompanied by major changes in biogeochemical cycling (Williford et al. 2007). The ratio of stable carbon isotopes in bulk sedimentary organic matter ($\delta^{13}C_{org}$) was measured via elemental analyzer continuous flow isotope ratio mass spectrometry in the ISOLAB at the University of Washington. Isotope samples were taken at approximately two-meter intervals. The interval between beds 18 and 20, thought to contain the conodont turnover event, was sampled at approximately 10 cm intervals. Conodont samples were subsampled for carbon isotope analysis as well. The data reported here reflect a combination of all three sample sets.

Details on sample preparation and analysis are available in Williford and others (2007). Isotope analyses were made with a Costech ECS 4010 Elemental Analyzer coupled to a ThermoFinnegan MAT253 mass spectrometer via a ThermoFinnegan CONFLO III gas interface. Isotope ratios are reported in standard delta (?) notation relative to Vienna Pee Dee Belemnite (vpbd) where $\delta^{13}C = [[(^{13}C/^{12}C)sample/(^{13}C/^{12}C)vpdb]-1]*1000$. Data reported are the mean of three replicate analyses. Average standard deviation of sample replicates was 0.06‰ for $\delta^{13}C_{org}$ (n = 55). Average analytical precision based on routine analysis of the internal acetanilide reference material was 0.07‰ for $\delta^{13}C_{org}$ (1?; n = 39).

The records of $\delta 13C_{org}$ and total organic carbon (TOC) from the Carnian-Norian boundary section at Black Bear Ridge are shown in text-fig. 4. $\delta^{13}C_{org}$ varies between -30.01‰ and -31.12‰, with a mean of -30.53 and a standard deviation of 0.20‰. Overall, this is a very small amount of isotopic variability. Within this context, however, the following patterns can be recognized given the high precision and replicability of the isotope analyses. The first 8m of section is the most variable, with 4 swings of 0.5‰ (> 2σ), and then isotope ratios trend positively from 8 to 26.5 m, negatively from 26.5 to 37 m, and positively again to the highest sampled bed at 40m. An expanded view of carbon isotope data for the critical boundary interval between beds 18B and 20C is also shown in text-fig. 4. A negative excursion of approximately 0.5‰ occurs between beds 18C and 20B, or between 16.2 and 17m in the section, reaching the lowest isotope value in this study of -30.81‰ at 16.5 m, between beds 18E and 18F. TOC varies between 1.51 and 27.70% by weight, with a mean of 8.97%.

Discussion

Depositional Framework: Facies associations that comprise the Ludington and Pardonet formations at Black Bear Ridge all reflect deposition in marine offshore settings. Sharp lateral demarcation between the Baldonnel Formation in the eastern and the Ludington Formation in the western portion of the Williston Lake region indicates an abrupt transition between shallow water (proximal ramp) and deep water (distal ramp) settings (i.e. Zonneveld et al. 2003a,b) consistent with interpretation as a distally steepened carbonate ramp (Zonneveld 2008). Erosional scours are absent in all facies in the study interval confirming emplacement of these strata below both fair-weather and storm wave base in a setting apparently devoid of significant submarine current activity.

All facies associations in the study interval are dominated by, or contain appreciable quantities of event beds, particularly those resulting from sediment gravity flows. Event beds in the study interval include debrites and grain flow deposits (FA1), medium- and thin-bedded turbidites (FA2, FA4) and slumps / slides (FA3). This is true of the Ludington Formation throughout the Williston Lake area (Zonneveld 2008). Thus, many fossil assemblages in the study area represent thanatocoenoses in which taxa were transported from shallower settings and admixed with taxa from more distal settings. Although event deposits dominate the study interval, all were deposited well below storm wave base and evidence (either physical or biostratigraphic) of erosional discontinuities is lacking.

Debris flows, slumps and slides in carbonate successions commonly result from slope instability related to sediment overloading (i.e. Crevello and Schlager 1980; Betzler et al. 1994). Other possible causes include wave and surge loading and tectonic shock (Eberli 1991a,b; Mulder and Cochonat 1996). The causal mechanism for these events in the study area remains unknown however tectonic shock and / or wave loading are strongly suspected. Anomalous thickness changes and evidence of rapid bathymetric flux (sudden subaerial exposure or submarine inundation) in Middle and Upper Triassic strata have been used as evidence for tectonic mediation in Triassic sediment accumulation in western Canada (i.e. Wittenberg 1992; 1993; Qi 1995; Davies 1997; Zonneveld et al. 2000).

Subsidence associated with elements of the Peace River Arch and the Dawson Creek Graben Complex have been shown to have had a particularly significant effect on Triassic deposition in the northern part of the Western Canada Sedimentary Basin (Cant 1988; Wittenberg 1992; 1993; Qi 1995; Davies 1997). These tectonic elements may have been reactivated during the Late Permian and Early Triassic as subduction along the western margin of Pangaea resulted in the first collisions of island arcs (allochthonous terranes) with the western cratonic margin (Davies 1997). This tectonic activity may have generated tectono-eustatic sea-level changes and provided the shock that resulted in release of debris flow and slide / slump successions.

Event deposits at Black Bear Ridge were emplaced during an interval of overall sea-level rise (Zonneveld and Orchard 2002; Zonneveld et al. 2004) (text-fig. 12A). Early-medial Carnian deposition in western Canada coincided with maximum progradation of the paleoshoreline to the west (text-fig. 12A) which is reflected by deposition of marginal and nonmarine deposits of the Charlie Lake Formation in western localities in the Williston Lake area (Arnold 1994; Zonneveld et al. 2001; Zonneveld and Orchard 2002). Regional Stratigraphic correlation of the basal part of the Black Bear Ridge section with other localities, both adjacent (i.e. Pardonet Hill, Juvavites Cove, Brown Hill; text-fig. 1) and more distant (i.e. McLay Spur, West Schooler Creek, East Carbon Creek; text-fig. 1), indicates that the base of the section closely approximates lowstand / early transgressive deposits in the Baldonnel Formation to the east (Zonneveld and Gingras 2001; Zonneveld and Orchard 2002; Zonneveld 2008).

The base of the study interval records a series of poorly sorted, coarse-grained debrites deposited during an interval of regional sea level lowstand (text-fig. 12B), possibly initiated by tectonic shock, or alternatively by wave loading during severe storms. During transgression debrite deposition in the study area ceased, possibly due to shifting of the debrite depocentre to the east. Deposition in the study area became dominated by fine-grained turbidites at this time (text-fig. 12C). As the transgression progressed slope failure resulted in slides / slumps of sediment sheets, possibly as a result of tectonic shock (text-fig. 12D). Continued transgression resulted in landward shift of lithofacies and intercalation of calcareous siltstone / wackestone turbidites with thin calcareous shale beds and *in situ* bivalve laminites (text-fig. 12E).

Occurrence of carbonate turbidites, debris flows and slides / slumps in an overall transgressive succession is similar to the situation in siliciclastic systems where sediment transport and deposition via turbidite currents is commonly associated with falling, or lowstand in, sea-level (Posamentier and Vail 1998; Walker 1992). This is the inverse of the situation in carbonate platform settings, wherein the carbonate 'factory' is shut off during intervals of subaerial exposure and produces significant volumes of carbonates only during intervals wherein the platform is flooded (Read 1985; Droxler and Schlager 1985; Coniglio and Dix 1992). In these settings calcareous turbidites occur most commonly during intervals of elevated sea-level during which times the platforms sheds abundant carbonate skeletal debris (Eberli 1991a,b).

Occurrence of carbonate sediment gravity flows at Black Bear Ridge within intervals associated with lowstand / early transgressive conditions rather than intervals of elevated sea-level supports the interpretation of the Upper Triassic at Williston Lake as a distally steepened carbonate ramp succession.

Geochemistry: TOC in the Black Bear Ridge sediments varies considerably, but is generally quite high, and in some cases extraordinarily so (>20%). High TOC in marine sediments suggests low oxygen conditions conducive to efficient burial of organic matter, and indeed, model results suggest that the Late Triassic was a time of anomalously low atmospheric oxygen concentration (Berner 2006; Algeo and Ingall 2007 and references therein). The boundary interval between beds 18C and 20B has lower average TOC (7.11%) than the section taken as a whole (8.97%), and the sample with the lowest TOC value for the entire section (1.51%) was taken from 15cm above the peak faunal turnover.

An earlier study reported a positive excursion of approximately 2‰ coincident with the disappearance of *Monotis* across the Norian-Rhaetian boundary higher in the section at Black Bear Ridge (Sephton et al. 2002). Mean $\delta^{13}C_{org}$ in that study was 30.37‰, comparable to the mean value observed in this study, lower in the same section: -30.53‰. There is much less variability overall in $\delta^{13}C_{org}$ across the Carnian-Norian boundary than across the Norian-Rhaetian boundary, however, implying relative stability in carbon cycling during Carnian-Norian time. The lack of variability is also consistent with the interpretation of continuous deposition and minor facies change in this part of the section at Black Bear Ridge.

Although we do not find evidence for large-scale perturbations in carbon cycling associated with the significant turnover in ammonoids, bivalves, radiolaria and conodonts (Carter and Orchard 1999; Orchard et al. 2000) recognized at this boundary, high resolution sampling revealed a subtle negative carbon iso-

TABLE 1
Summary of sedimentary facies characteristics in the Ludington and lower Pardonet Formations, Black Bear Ridge, northeastern British Columbia.

FACIES	LITHOLOGY	DESCRIPTION	BIOTA	PROCESS OF DEPOSITION
L-I	bioclastic / rudstone	moderately sorted, primarily massive appearing rudstone dominated by bioclastic detritus; ~10% subangular quartz sand; scattered silt-sized well-rounded phosphatic grains common; sorting moderate to poor; rare current ripples; rare flame structures; beds several dm to m thick	primarily disarticulated, fragmentary bivalves brachiopods & disarticulated pelmatozoan elements	high-concentration turbidity current / debris flow
L-II	matrix-supported intraclast breccia	intraclasts of planar bedded silty dolomitic / calcareous wackestone in packstone / rudstone matrix; clasts vary in size from mm to m scale; large clasts oriented ~ concordant to bedding; small clasts randomly oriented ~10% subangular quartz sand; scattered silt-sized, well-rounded, phosphatic grains; sorting poor; beds 4-5 m thick; possibly inversely graded	no fossils observed in breccia clasts; matrix bioclast consists primarily of disarticulated, fragmentary bivalves brachiopods & disarticulated pelmatozoan elements (i.e. identical to facies L-I)	debris flow
L-III	silty dolomitic / calcareous wackestone	plane parallel laminated silty micrite / dolomicrite; ~2-10% quartz silt; stylolitic contacts locally common; scattered ooids; laterally restricted bands of carbonate concretions; beds 1 to 30 cm thick; scattered silt- to sand-sized, well-rounded, phosphatic grains; rare mudstone interbeds; mm-scale v.f. sandstone laminae	rare, concordantly emplaced, thin-shelled bivalve beds in some occurrences; rare disarticulated pelmatozoan elements	hemipelagic & low-concentration turbidity current
L-IV	banded micritic packstone / silty wackestone	packstone beds sharp-based & massive to normally graded, 3 to 25 cm thick; silty wackestone beds plane parallel & wavy laminated, 2 to 20 cm thick; concretionary intervals common; ooid-rich laminae; carbonate pellets / granules in some beds	articulated & disarticulated bivalves, scattered ammonoids & ammonoid layers	hemipelagic & low-concentration turbidity current
L-V	sandy dolomitic / calcareous - wackestone	plane parallel laminated sandy micrite / dolomicrite; rare current ripple laminated beds; ~2-8% quartz silt / sand; sharp-based normally-graded packages common, beds 3 to 15 cm thick, mm-scale f. / m. sandstone laminae	fossils very rare, primarily isolated bivalve fragments	low-concentration turbidity current
L-VI	banded silty, micritic bioclastic wackestone	decimetre-scale bioclastic wackestone beds with centimetre-scale calcareous siltstone interbeds; wackestone beds 5 to 25 cm thick, siltstone interbeds 1 to 2 cm thick; concretionary horizons present; chert nodule horizons present; ooid lags at some horizons; rare centimetre-scale mudstone interbeds	abundant concordantly emplaced bivalve fragments, scattered ammonoids & rare ammonoid beds, straight nautaloids & rare ichthyosaur bone present, scattered, ichthyosaur bone debris, disarticulated pelmatozoans	low- & high- concentration turbidity currents
L-VII	brachiopod-rich bioclastic wackestone / packstone	sharp-based, normally and (rarely) inversely graded bioclastic wackestone / packstone; ~ 1% quarts silt; scattered medium sand-sized well-rounded phosphatic grains; scattered carbonate pellets / granules (peloids?); beds plane parallel laminated to massive; rare current ripples; beds 1 to 20 cm thick	abundant concordantly emplaced bivalve fragments, abundant whole, articulated rhynchonellid brachiopods (*Piarorhynchia winnemae*) & disarticulated pelmatozoan elements	low- & high- concentration turbidity currents
L-VIII	calcareous silty black shale	planar laminated, black, calcareous, silty shale, 0.5 to 15 cm thick laminasets.	scattered bivalves concordant to bedding	hemipelagic
L-IX	bivalve laminite (bivalve rudstone)	bioclastic rudstone composed of densely compacted thin-shelled bivalves; compaction of bivalves on many laminae results in crinkly or wavy aspect to this lithology; concretionary intervals common; ooids in many beds, beds from 5 to 35 cm thick	dominated by whole, articulated & disarticulated bivalves (commonly *Halobia* sp. valves) deposited concordant to bedding, ammonoids & straight nautaloids, common, ichthyosaur bones	hemipelagic & low-concentration turbidity currents

tope perturbation in the critical boundary interval between 16.2 and 17.0 metres (text-fig. 4). This perturbation reaches its most negative values at the exact horizon across which the predominant conodont and bivalve turnover is recognized. If they are demonstrably global in scale, negative excursions in $\delta^{13}C_{org}$ can be attributed to the indirect effects of rising atmospheric CO_2 concentration (e.g. Kump and Arthur 1999; Korte et al. 2009). While the coincidence of the most negative $\delta^{13}C_{org}$ values with peak faunal turnover is intriguing, the small magnitude of the isotope excursion observed in this study and the lack of corroborating data from other localities makes it difficult to completely rule out confounding factors at this time. For example, shifts in $\delta^{13}C_{org}$ can be caused by variability in organic matter source, as terrestrial and marine organic matter have different characteristic isotopic compositions (Meyers 1994). However, we support the argument of Sephton et al. (2002) that source variability is unlikely to have had a strong impact on the isotopic composition of bulk organic matter in the Black Bear Ridge sediments because of their distal environment of deposition.

Appropriateness of Black Bear Ridge as a Carnian-Norian GSSP: Geological requirements of GSSPs include adequate thickness of exposure, evidence of continuous and sufficiently rapid sedimentation and absence of vertical facies changes at, or near, the boundary (Cowie 1986; Remane et al. 1996). Also important is the absence of significant alteration from tectonic or synsedimentary disturbances, metamorphism or pronounced diagenesis (Remane et al. 1996).

The Black Bear Ridge section meets all of these criteria. The Carnian-Norian boundary interval at Black Bear Ridge is thick (~80 m) and occurs in fully marine strata with evidence of neither subaerial exposure nor submarine erosion. Rapid and relatively continuous sedimentation is attested to by the thickness of the section, the abundance of calcareous turbidites and the thin nature of intercalated hemipelagic beds.

Evidence of tectonic disturbance at Back bear Ridge is minimal. The entire section has been uplifted and tilted so that the beds dip westward at ~75°. This has rendered the Black Bear Ridge section easily accessible without disturbing beds and bedsets in the section. Synsedimentary remobilisation in the form of small-scale sediment slides characterize facies association 2 however these beds occur well below, and do not effect, any of the three candidate horizons (text-fig. 3). Similarly, evidence of metamorphism is absent and diagenesis moderate in the Black Bear Ridge section.

The proposed Carnian-Norian boundary at Black Bear Ridge occurs intermediate through both an individual facies (LVII; Figs. 3,4) and facies association (i.e. there is no evidence of a change in depositional setting, and thus a potential unconformity, within the boundary interval). It is characterized by an excellent biostratigraphic record, recording several ammonoid horizons, abundant bivalves and exceptionally abundant and diverse conodonts (i.e. Orchard et al. 2001a, b; Orchard 2004; McRoberts 2004). The only other current candidate site, the Pizzo Mondello section, Sicily (Muttoni et al. 2001a, 2001b, 2004) is characterized by excellent magnetostratigraphy. Similar to Black Bear Ridge, Pizzo Mondello is characterized by multi-taxonomic biostratigraphy. Conodonts, ammonoids, bivalves and radiolarians have been reported from Pizzo Mondello (Guaiumi et al. 2007; Nicora et al. 2007; Balini et al. 2008). Published descriptions of the faunas of both localities have historically been sparse however recent publications and ongoing work are erasing these short-comings (Orchard et al. 2001a, 2001b, Orchard 2004, 2007; McRoberts 2004, 2007; Guaiumi et al. 2007; Nicora et al. 2007; Balini et al. 2008).

Carbonate strata are commonly characterized by poor retention of paleomagnetic characteristics and thus few Carnian-Norian boundary sections are characterized by similar high quality paleomagnetic data to Pizzo Mondello. Excellent magnetostratigraphy makes Pizzo Mondello an excellent Carnian-Norian reference section. However Pizzo Mondello remains an isolated locality in a structurally complex portion of western Sicily. Although other potential Carnian-Norian boundary sections do occur in western Sicily, most are poorly exposed and have not been studied in detail. The Williston Lake area and Rocky Mountain Foothills surrounding the Black Bear Ridge section has numerous other well-exposed localities nearby, including Juvavites Cove (~3km south), Pardonet Hill (~2 kms south-southeast), Brown Hill, West Schooler Creek, East Carbon Creek, and McLay Spur (Zonneveld and Orchard 2002; Zonneveld 2007, 2008). This allows characterization of the faunal succession in deep-water intervals, such as Black Bear Ridge, as well as closely-associated shallow-water successions to the east. Thus we favour Black Bear Ridge as the Carnian-Norian GSSP section. Ultimately, in light of the fact that both sections possess strong attributes and occur on opposite sides of the Triassic world we believe that the geological community is likely best served by establishing one of these sections as the GSSP and the other as an Auxiliary Reference Section.

SUMMARY

The Black Bear Ridge section at Williston Lake, northeastern British Columbia has been proposed as a candidate Global Stratotype Section and Point (GSSP) for the Carnian-Norian boundary. Previous work has established that this section is characterized by a detailed, multi-taxonomic biostratigraphic framework.

The Black Bear Ridge section records deposition in a deep marine setting (distally steepened carbonate ramp / medial to distal slope) on the northwestern margin of the Pangaea supercontinent. Detailed sedimentologic analyses considered in association with biostratigraphic data indicate strongly that the Black Bear Ridge section is continuous, exhibiting evidence of neither subaerial exposure nor submarine erosion. Absence of erosional scours and physical sedimentary structures dominated by plane parallel laminae confirms that sedimentary deposits in the study interval were emplaced below both fair-weather and storm wave base in an area unaffected by strong submarine currents.

Lithofacies in the study interval are subdivided into four facies associations: FA1 (debris flow); FA2 (thin- / medium-bedded turbidites); FA3 (slide); and FA4 (thin-bedded turbidites / hemipelagic suspension). The Carnian-Norian (i.e. base-Norian) boundary proposed herein occurs within FA2. All facies associations were deposited in an overall deepening-upwards succession (late lowstand and transgressive systems tracts) which is reflected by increasingly fine-grained strata up section (Zonneveld 2008). Event beds (debrites, slides and turbidites) were likely initiated by either tectonic shock or wave loading in association with severe storms.

Diverse and abundant fossil assemblages (dominated by conodonts and bivalves) occur in these strata. These fossils primarily represent thanatocoenoses in which shallow water taxa were transported basinward and admixed with taxa from more distal settings. Despite transport of many taxa from their original dwelling sites, detailed biostratigraphy confirms that these fossil assemblages occur sequentially with no evidence for mixing of successive faunas. Rapid and relatively continuous sedimentation in the study interval is attested to by the thickness of the section, the abundance of calcareous turbidites, the sequential nature of faunas in these turbidites, and the thin nature of intercalated hemipelagic beds.

Abundant fossils, evidence of continuous and rapid sedimentation and minimal alteration from by tectonic disturbances, metamorphism or diagenesis make Black Bear Ridge an excellent candidate Global Stratotype Section and Point (GSSP) for the Carnian-Norian boundary.

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