Regional Facies Patterns in the Northern Jackass Mountain Group, Northern Methow Basin, Southwestern British Columbia (NTS 092O)

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Introduction

The Jackass Mountain Group (JMG) is a thick accumulation (2–4 km) of clastic strata, which was deposited in the Methow Basin in late Early Cretaceous time. The Methow Basin is part of a complex Jurassic–Cretaceous depocentre that overlies a number of allochthonous terranes of the southern Canadian Cordillera (Figure 1a, b). The basin has been structurally imbricated and dismembered by Cretaceous contraction and Late Cretaceous to Tertiary transpression along the eastern edge of the Insular Belt and the western edge of the Intermontane Belt, and is currently exposed in a series of fault blocks strung out along the Yalakom, Fraser, Hozameen and Pasayten faults. Along the southern margin of the Nechako Plateau, two major exposures of the JMG of the Methow Basin on opposite sides of the Yalakom fault are spatially associated with the partly coeval Taylor Creek Group of the Tyaughton Basin. These strata extend northward under Neogene volcanic cover and potentially represent an important hydrocarbon reservoir within the Nechako Basin (Ferri and Riddell, 2006).

Accurate assessment of the petroleum potential of the Nechako Basin requires a comprehensive analysis of the basin architecture that developed within these Cretaceous strata, which represent the most prospective targets in the subsurface beneath the Nechako Plateau. However, regional facies patterns and basin architecture of the Cretaceous strata are poorly understood. The primary objective of this investigation is to undertake a comprehensive regional analysis of temporal and spatial lithofacies variations in Lower Cretaceous strata along the southern margin of the Nechako Basin; this will assist in constraining basin evolution and depositional history. This analysis will provide first-order constraints on the nature of Lower Cretaceous strata in the subsurface, which are considered the most significant petroleum targets in the Nechako Basin (Hannigan et al., 1994); such an analysis is also a prerequisite for an accurate assessment of reservoir quality.

Keywords: *sedimentology, stratigraphy, Jackass Mountain Group, Nechako, Methow, Tyaughton, Cretaceous*

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Regional Geological Setting

Regional mapping and stratigraphic studies demonstrate that Lower Cretaceous clastic strata of the Methow and Tyaughton basins represent an overlap assemblage linking several small allochthonous terranes (Methow, Bridge River, Cadwallader) with the eastern edge of the Insular Belt (Garver, 1992). The Hauterivian to Cenomanian–Turonian (?) JMG is a thick (2–4 km) succession of primarily feldspathic sandstone, siltstone and lesser conglomerate that unconformably overlies Middle to Upper Jurassic strata. The JMG has been interpreted by Kleinspehn (1982, 1985) as a coarsening-upward or progradational submarine-fan complex, although subsequent investigations suggest the system is a more complex assemblage of submarine-fan, deltaic and fluvial lithofacies (Schiarizza et al., 1997; Schiarizza and Riddell, 1997; Mustard et al., 2008). The Aptian to Cenomanian Taylor Creek Group is a thick succession of compositionally heterogeneous feldspathic to chert-lithic sandstone, chert-pebble conglomerate and siltstone that unconformably overlies Middle Jurassic and older strata of the Bridge River and Cadwallader terranes (Garver, 1992). The Taylor Creek Group is interpreted as having been deposited in a submarine-fan complex in a two-sided basin during major Albian–Cenomanian

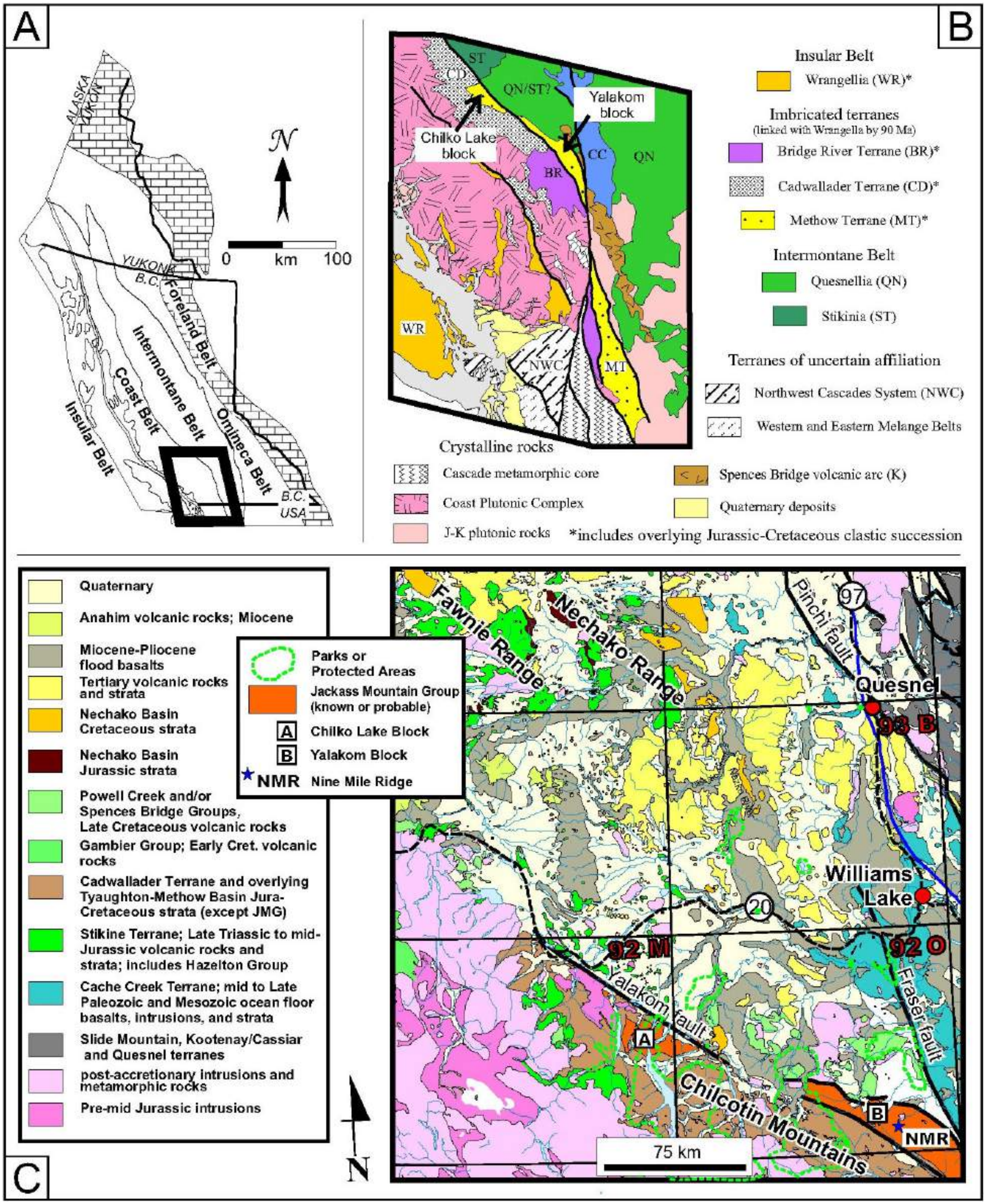


Figure 1. Regional geological framework and location of major areas of study discussed in this paper: **a)** morphogeological belts of the Canadian Cordillera; the boxed area indicates the location of (b); **b)** terrane map showing the regional geological framework of the Methow Terrane, including the Chilko Lake and the Yalakom blocks; **c)** smaller-scale terrane and geological map showing the location of the Chilko Lake and Yalakom blocks (JMG) in relation to physiogeographic and geographic landmarks (*modified with permission from* Ferri and Riddell, 2006, and Riddell, 2006).

contractional tectonism (Garver, 1992). Both the JMG and Taylor Creek Group are overlain by Albian–Santonian fluvial conglomeratic and volcaniclastic rocks of the Silverquick and Powell Creek formations, which were deposited in a complex series of northeast-vergent piggyback basins (Schiarizza et al., 1997; Riesterer et al., 2001).

Cretaceous strata of the Methow and Tyaughton basins are bordered on the southwest by intrusive rocks of the Coast Plutonic Complex (CPC), on the north by Neogene volcanic rocks of the Nechako Plateau, and on the east by Triassic to Cretaceous arc volcanic and associated strata of the Quesnellia Terrane. Tertiary dextral transpression led to the development of several major northwest-trending high-angle strike-slip faults along the eastern margin of the CPC that effectively dismembered the Cretaceous outcrop belt into several structural panels (Figure 1). Dextral translation along the Tchaikazan, Yalakom and Fraser faults and associated structures is primarily Late Cretaceous–Oligocene, and is limited in its extension to several tens to more than one hundred kilometres per fault.

Facies Description and Distribution

The JMG is contained within two major outcrop belts, one on the northern side of the Yalakom fault, which is referred to as the Yalakom block, and one on the southwestern side of the Yalakom fault, referred to as the Chilko Lake block (Figure 1b, c). These two fault slices are offset by approximately 125 km of sinistral displacement on the Yalakom fault (Umhoefer and Miller, 1996). The most complete, structurally intact stratigraphic sections are exposed in a major northeast-trending synclinorium within the Chilko Lake block, where JMG strata unconformably overlie the Middle Jurassic Nemaia Formation and Middle to Upper Jurassic Relay Mountain Group (Figure 2). The upper Taylor Creek Group is exposed in a south-dipping monocline 10 km southeast of the JMG syncline, across the Konni Lake fault, where it unconformably overlies the Relay Mountain Group. In the Yalakom block, JMG strata are exposed in the central part of a ~150 km long, southward-tapering wedge of mainly medium- to coarse-grained sandstone, siltstone and polymictic conglomerate, which lies between the Yalakom and Fraser fault systems. The belt is cut by several high-angle faults (Schiarizza et al., 1997) and is part of a broad, asymmetric synclinorium with the base of the JMG exposed in steeply dipping beds on the western limb east of the Yalakom River, and the upper portion exposed in moderately west-dipping beds on the eastern limb (Mustard et al., 2008).

Jackass Mountain Group

One of the primary objectives of this investigation is to document the lateral and vertical variation in stratigraphic architecture and, from this data, reconstruct the history of basin evolution in the Cretaceous basin system. Stratigraphic analysis of the JMG along the southern margin of the Nechako Plateau has identified distinct lithofacies associations that grade laterally and vertically into one another, and provide a record of basin evolution from Hauterivian to at least Cenomanian time.

A. Proximal Delta Front

The stratigraphically lowest unit in the Chilko Lake area is a ~400 m thick succession of sandstone, sandstone with pebbly stringers and lesser lenticular conglomerate. The unit is thickest on the eastern side of the northern limb of the synclinorium, and thins to the south and to the west, characterizing the area as presenting signs of a wedge-shaped geometry (Figure 3, left two columns). The sandstone displays abundant planar-parallel strata with lesser low-angle planar to planar cross-stratification. Rare bivalve fossils and sparse bioturbation are present. Lenticular, matrix-supported to rare clast-supported pebble conglomerate encased in sandstone sequences are interpreted as channel deposits. This unit coarsens then fines upward and the uppermost 100 m of the section contains siltstone intervals which display current- to wave-generated laminations, features which all suggest that an upward decrease in energy occurred.

The wedge-shaped geometry, presence of shallow-marine fossils, current-generated cross-stratified sands and lenticular conglomerate channels suggest deposition in a wave-dominated shoreface, perhaps a proximal delta front.

B. Distal Delta Front/Prodelta

In the Chilko Lake area, this 400–650 m thick, southward-thickening unit is composed of a dark brown to black mudstone to silty mudstone intercalated with varying amounts of thinly bedded siltstone and very thin- to thick-bedded fine- to medium-grained sandstone (Figure 3, 400–900 m in left section and 0–700 m in central section). This is the most fossiliferous facies association, containing articulated bivalves, gastropods and ammonites, suggesting accumulation in a low-energy marine environment. Fossilized wood fragments are abundant. Bioturbation is intense locally, but not diverse, and is often limited to diminutive *Chondrites*. The most dominant sedimentary structures are planar-parallel and microhummocky laminations, but current-generated and combined-flow ripples and lenticular bedding are also present. The relative abundance of siltstone suggests a fining- (~200 m) then coarsening-upward (~300 m) succession.

The laterally continuous geometry, presence of both current and oscillatory bedforms, abundance of intact marine fauna, and intense nondiverse bioturbation suggest deposition in a relatively quiet water environment in which mud and silt accumulation was periodically disturbed by intermittent currents, all of which suggest a lower shoreface or distal delta front environment.

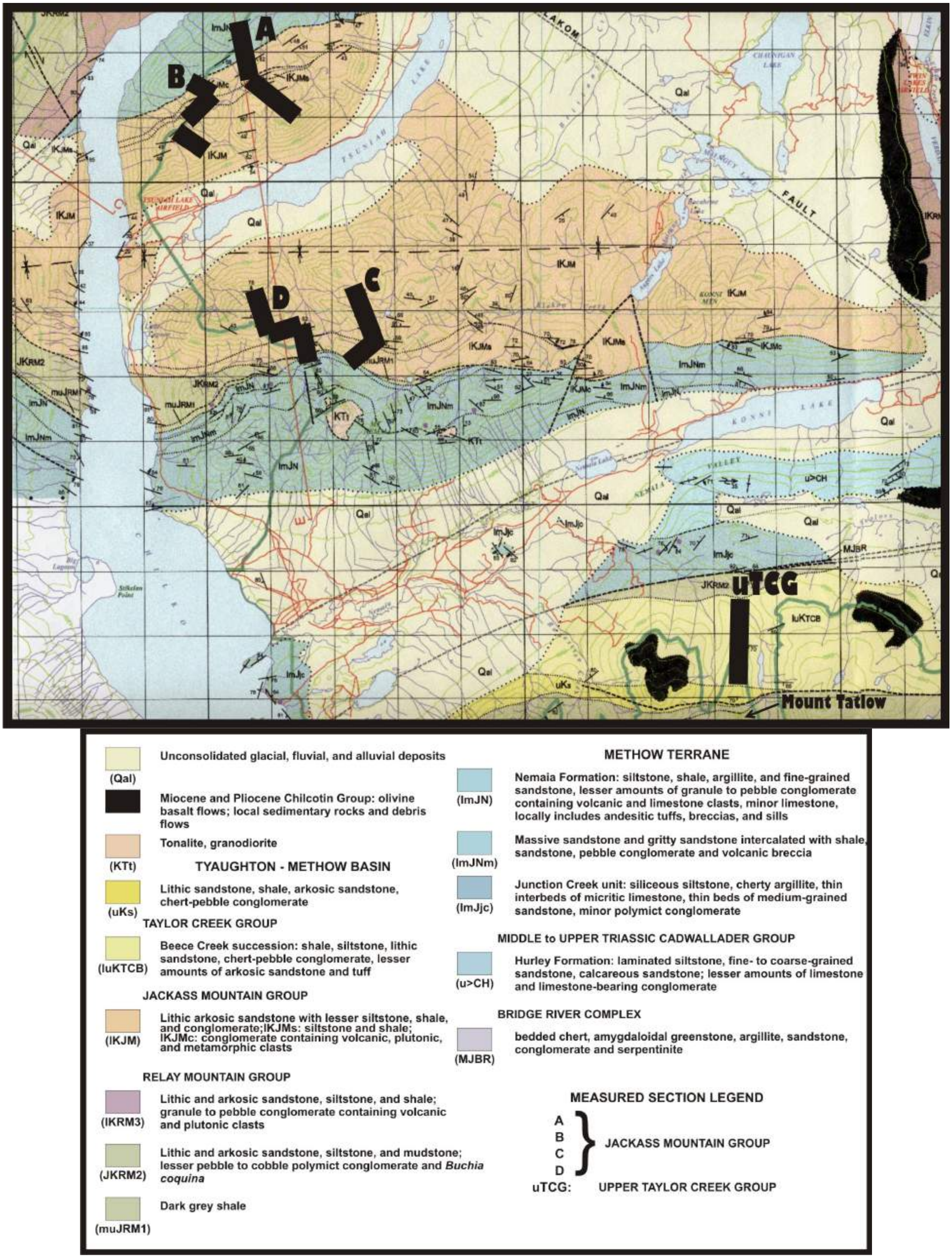


Figure 2. Geology of the area east of Chilko Lake, showing locations of measured sections (*modified from* Schiarizza et al., 1997).

C. Wave-Dominated Delta Front/Delta-Edge Turbidites

Approximately 50% of the sections in the Chilko Lake area are characterized by thick successions (700–1650 m on the middle section and 900–1700 m on the left section of Figure 3) of moderately well-sorted feldspathic arenite intercalated with lesser dark siltstone to mudstone intervals. The sandstone is well-stratified and represents both massive and nondescript, apparently structureless intervals, as well as successions containing abundant sedimentary structures; these include wavy lamination, swaley cross-stratification (SCS), loaded and erosional bases, and variably sized (<1–3 m long) rip-up clast horizons. Interbedded finer-grained intervals (on average 10 cm to a maximum of 15 m, 50 m in the south) display planar-parallel bedding, ripple cross-stratification, moderate bioturbation, water-escape structures, convolute bedding and soft-sediment deformation structures.

There is a distinct north to south transition in sedimentary structures within this lithofacies in the Chilko Lake area. Sedimentary structures in the northern limb vary from planar-parallel laminations to large-scale (<1.5 m) hummocky cross-stratification, progressively overlain by swaley cross-stratification followed by planar-parallel strata. Correlative strata on the southern limb are cyclic, grading from a thick (<1.5 m), massive, occasionally normally-graded to planar-parallel stratified sandstone; these strata are overlain by ~1 to 3 cm of planar-parallel–laminated sandy siltstone that grades into 1 to 3 cm of planar-laminated siltstone, which is in turn topped by mudstone of variable thickness. This siltstone often shows oscillatory to current-generated structures.

The presence of hummocky and swaley cross-stratification, basal erosive surfaces and abundant rip-up clast horizons suggests high rates of sedimentation prevailed in an environment characterized by periods of rapid, high-volume sediment influx and intermittent periods of wave reworking. Deposition was probably occurring in wave-dominated delta front to lower shoreface environments, with a transition to the south into a coarse-grained turbidite package, which accumulated at a depth above the storm wave base.

D. Mass Sediment Gravity Flows/Submarine Fan (?)

The Yalakom Mountain area contains a thick sequence (~1500 m) of northwest-trending, steeply dipping JMG strata dominated by massive, green, medium- to coarse-grained lithofeldspathic sandstone, minor pebble conglomerate and interbedded planar siltstone. The succession appears to gradationally overlie poorly exposed shallow marine JMG rocks, which themselves lie disconformably over Middle Jurassic strata adjacent to the Yalakom fault. The main JMG succession consists of thick sets of massive, medium- to thick-bedded, coarsening-upward sandstone intercalated with thin- to medium-bedded sandstone and thin-bedded siltstone and mudstone. Bed sets tend to thicken upward, with thin-bedded siltstone and mudstone coarsening- and thickening-upward into coarse-grained, thick-bedded (~50 cm), massive sandstone. These cyclic sequences are generally greater than 10 m thick, and can reach up to 100 m. Beds are tabular and laterally continuous for hundreds of metres. Sedimentary structures include parallel laminations, graded bedding, mudstone rip-up clasts, flame structures, dish-and-pillar structures and rare soft-sediment folds. Partial Bouma sequences (AB, ABC) are locally evident. The succession becomes finer grained in the upper 500 m, gradually incorporating a higher percentage of sandstone-mudstone couplets with a decreasing percentage of massive sandstone intervals.

The tabular, laterally continuous nature of the stratigraphy, the cyclic coarsening- and thickening-upward nature of the bed sets and the presence of graded bedding, abundant rip-up clast horizons, flame structures, and partial Bouma sequences suggest that the succession represents a sequence of high-density sediment gravity flows. These turbidite deposits are classically interpreted as being deposited on fan lobes in a submarine-fan environment (Kliensphen, 1982, 1985), but the presence of rare trough cross-stratification and shallow-water bivalves suggests that the succession may instead represent sediment gravity flows deposited on a distal delta front on the lower shoreface at a depth above the storm wave base.

E. Distal Delta Front/Lower Shoreface

Both east and northeast of Yalakom Mountain, in the Dash Creek–Churn Creek area, massive sandstone intervals are gradationally overlain by, and laterally interfinger with, a distinct succession of tabular, laterally continuous, thin- to medium-bedded rhythmically interbedded sandstone and siltstone couplets. These striped, dark grey and pale olive green sandstone-siltstone couplets display parallel laminations, crosslaminations, graded bedding, well-developed partial Bouma sequences (BC, BCD) and soft-sediment deformation, including asymmetric folds up to 1.5 m in amplitude. These beds form intervals 15–125 m thick encased by massive, green, medium- to coarse-grained lithofeldspathic sandstone and lesser pebble conglomerate. Wood fragments are locally abundant and rip-up clast horizons are common at the base of sandy intervals. The thin-bedded sandstone-siltstone couplets appear to coarsen and thicken upward into the massive sandstone intervals, which are similar to the thick-bedded sandstone documented in the Yalakom Mountain section as they also display sharp, erosive bases, graded bedding, parallel laminations and top cut-out Bouma (AB) sequences. The sandstone-siltstone couplet succession gradationally overlies the lower part of the mass sediment gravity-flow succession, but the thickness of the couplet intervals and the ratio of couplet to massive sandstone beds varies across the map area, which suggests that an interfingering relationship may have existed between the couplet intervals and the upper part of the Yalakom Mountain succession of thick lithofeldspathic sandstone beds.

In many localities, the upper portions of the couplets contain oscillation ripples, combined flow ripples, unusual cross-stratification patterns (possibly SCS) and erosive scour surfaces. Lenticular bedding is evident within finer grained intervals. The upper portion of the massive sandstone beds are locally trough cross-stratified or display oscillation ripples.

The classic bottom cut-out Bouma sequences (BCD, CDE, DE) that are noted in the sandstone-siltstone couplets indicate that the couplets represent thin-bedded turbidite deposits, whereas rip-up clast horizons, graded bedding and sharp erosive bases of the interbedded massive sandstone bodies suggest that these strata were deposited by coarse-grained mass sediment gravity flows. The presence of trough cross-stratification, lenticular bedding and oscillation ripples indicates wave reworking, which suggests reworking of the original turbidites due to wave activity; thus, deposition occurred at depths at least partially above the storm wave base. These strata are interpreted as having accumulated as the result of abundant sediment supply and rapid deposition on a distal delta front to lower shoreface area, where mass sediment gravity flows deposited in relatively shallow water were subjected to intermittent reworking by wave activity. This area is further interpreted as transitional in nature to the deeper (sub–storm-wave-base depth) areas of the Yalakom Mountain submarine-fan complexes, as well as the source of the sediment to those complexes.

F. Delta Plain/Fluvial

Northwest of Yalakom Mountain, strata on Nine Mile Ridge and on the western flank of Red Mountain consist of thick successions (10–100+ m) of olive green to black thin-bedded, parallel-laminated, organic-rich, sandy to silty shale and siltstone intercalated with thin-bedded, parallel-laminated to cross-stratified, fine- to coarse-grained lithic arenite to lithic wacke. These fine-grained intervals are dominantly recessive, concretionary in part, and contain organic-rich stringers, coal seams and *in situ* tree moulds. On Nine Mile Ridge, the fine-grained successions are separated by repeated intervals of 10–40 m thick medium- to coarse-grained trough cross-stratified sandstone and rare pebbly sandstone. To the north, the fine-grained successions are interbedded with a 10–30 m thick interval of clast- to matrix-supported, pebble to boulder, disorganized, volcanic plutonic conglomerate and associated coarse-grained sandstone. The conglomerate successions are lenticular, display channellized, erosive bases and tend to fine upward into lenticular beds of medium- to coarse-grained sandstone, pebbly sandstone and conglomeratic stringers.

The presence of fining-upward trough cross-stratified sandstone, lenticular conglomerate with erosive channellized bases, abundant organic material, and the dominance of recessive thin-bedded siltstone and shale indicates that deposition occurred in a fluvial environment, possibly on an emergent or near-emergent delta plain. The sandstone and conglomerate intervals represent fluvial channels, and the fine-grained intervals represent fluvial

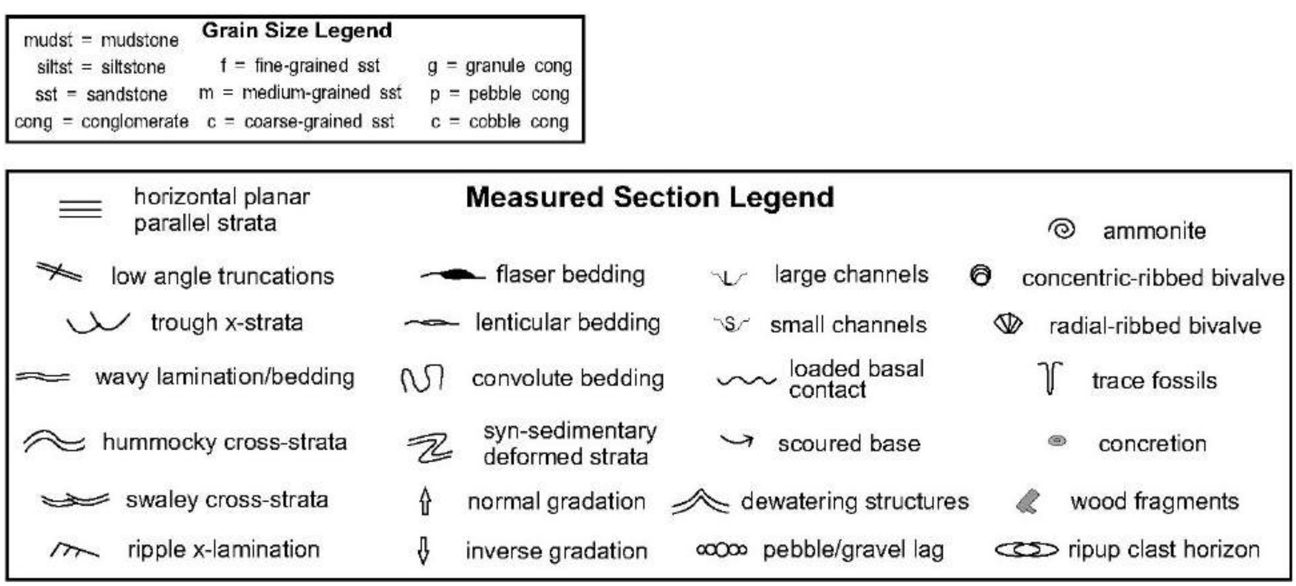
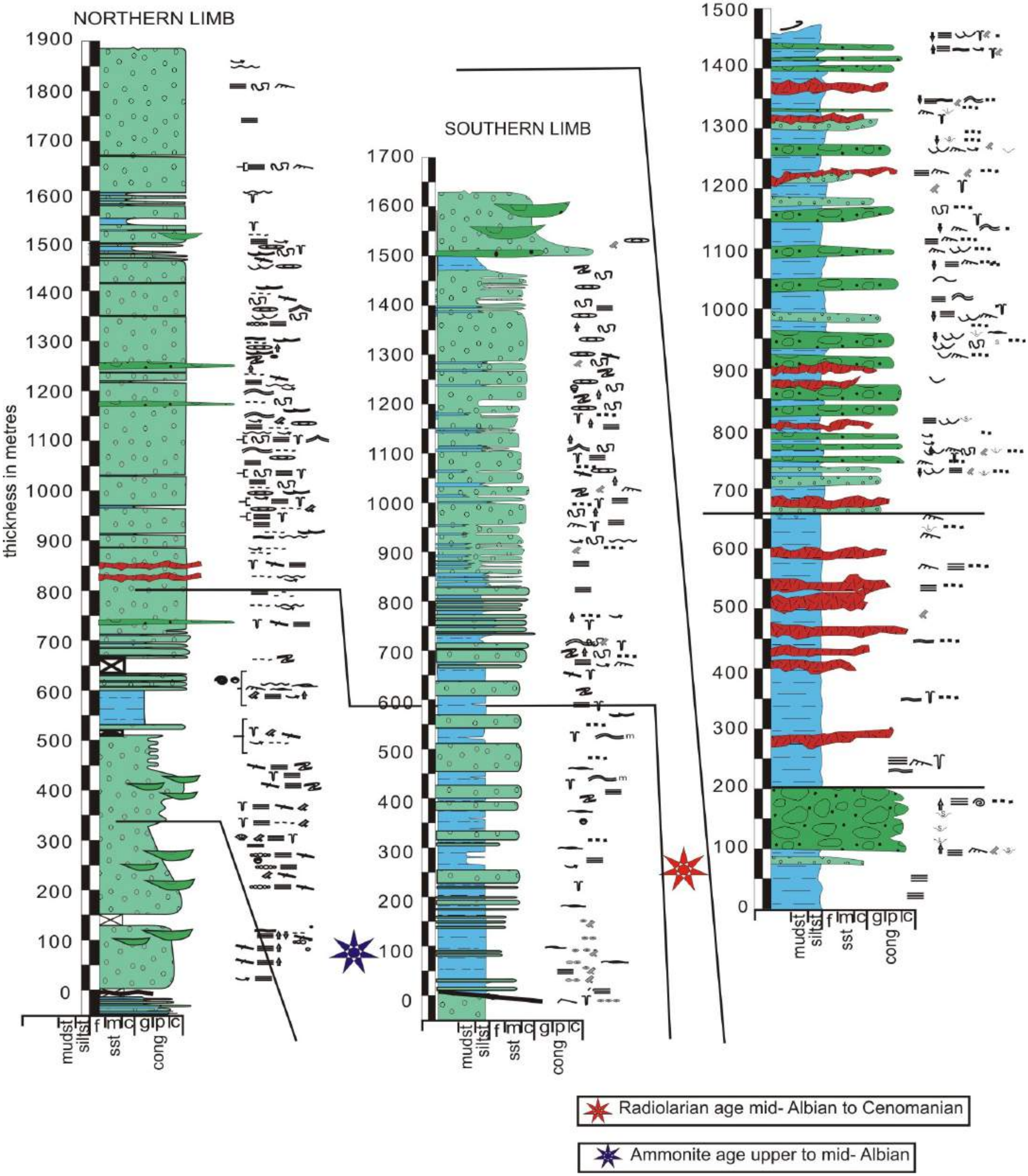


Figure 3. Stratigraphic sections of the JMG in the Chilko Lake area and of the upper Taylor Creek Group, north of Mt. Tatlow.

Jackass Mountain Group
Chilko Lake area

U.Taylor Creek Group
Mt. Tatlow



overbank or possibly interdistributary deposits on the delta plain.

Taylor Creek Group

The Taylor Creek Group strata along the southern margin of the Nechako Plateau have been analyzed to constrain potential stratigraphic correlations between the Taylor Creek Group and coeval JMG strata. Stratigraphic analysis in the northern portion of the outcrop belt near Mt. Tatlow (Figure 2) documented the lithofacies shown on Figure 3 and discussed below.

A. Submarine Fan

The stratigraphically lowest unit (0–200 m on Figure 3, right column) in the Mt. Tatlow area consists of dark grey, thin-bedded, parallel-laminated siltstone and sandy shale intercalated with thinly-bedded, cross- to parallel-laminated, chert-lithic micaceous arenite. These strata are overlain by a thick sequence (~100 m) of organized, massively bedded, pebble to cobble, chert-rich conglomerate characterized by distinct nests of overlapping lenticular, crudely stratified channels. The conglomerate unit is interpreted as a channel fill in a submarine fan.

B. Prodelta

The middle portion of the section (200 to ~900 m on Figure 3, right column) consists of a thick package of dark grey, bioturbated shale to siltstone interbedded with minor calcareous lithic feldspathic arenite that locally displays parallel laminations to crosslaminations and thin-bedded, parallel-laminated, orange weathering micrite beds. Plant material is abundant, locally, on bedding planes. Rare ammonites and radiolarians indicate accumulation occurred in a marine setting.

The lateral continuity, monotonous fine-grained nature of the unit, rare cross-stratification and presence of marine fauna suggest deposition in a quiet-water marine environment that was periodically disturbed by wave or current activity, such as a distal prodelta setting.

C. Delta Plain

The upper portion of the Mt. Tatlow section (900+ m) consists of a coarsening-upward succession of chert-pebble conglomerate and chert-lithic micaceous feldspathic arenite intercalated with siltstone and shale. Coarse-grained intervals are lens-shaped, channellized and display trough cross-stratification, abundant rip-up clast horizons, and erosive bases. Within the conglomeratic intervals, bedding becomes distinctly thinner and grain size decreases upsection, while the relative abundance of conglomeratic intervals increases. The encasing intervals contain thinly-bedded, parallel- to cross-stratified sandy siltstone and silty shale with locally abundant plant debris, which, along with bioturbation, increases in abundance upsection. Hummocky stratification is noted in the upper third of the succession.

The presence of multiple fining- and thinning-upward channellized sandstone and conglomerate packages encased in organic-rich, fine-grained siltstone and shale suggests that deposition took place in a channellized delta plain system. The presence of hummocky cross-stratification indicates that deposition occurred in a subaqueous environment characterized by intermittent storm wave activity. The overall coarsening-upward sequence suggests that deposition took place in a prograding upper to lower delta plain distributary system.

Facies Architecture

Regional stratigraphic analysis suggests that the lithofacies assemblages within the JMG grade laterally and vertically into one another. However, stratigraphic position, structural reconstructions, preliminary detrital zircon analysis and limited fossil control suggest the overall stratigraphic architecture presented in Table 1.

This generalized stratigraphic architecture is not strictly valid for each location within the outcrop belt, due to lateral stratigraphic variations. For example, the massive sandstone succession interpreted as mass sediment gravity flows is found primarily in the southeastern portion of the outcrop belt, whereas the wave-dominated delta front deposits are primarily restricted to the Chilko Lake block. On a regional basis, however, it is clear that the stratigraphic succession recorded in the JMG represents an overall shallowing-upward basinal succession.

The stratigraphic relationship between the JMG and the Taylor Creek Group is the subject of ongoing investigation. However, results of preliminary stratigraphic analysis, geochemistry and detrital zircon analyses suggest the Taylor Creek Group may interfinger with, and in part overlie, the JMG.

Summary and Regional Implications

Regional stratigraphic analysis of Cretaceous strata along the southern margin of the Nechako Plateau constrains the stratigraphic architecture and basin evolution represented

Table 1. Generalized stratigraphic architecture of the Jackass Mountain Group.

~~ Top of section (modern erosive surface) ~~~~~~
Delta front/Fluvial
Distal delta front/Lower shoreface
Wave-dominated delta front/Delta-edge turbidites
Mass sediment gravity flows/Submarine fan
Shallow marine/Proximal delta front
~~ Unconformity ~~~~~~~~~~~~~~~~
Jurassic strata

by the JMG, which contains extensive and, locally, extremely thick facies interpreted to represent shallow-marine, primarily deltaic, and nonmarine depositional environments. In the Yalakom block, sub–wave-base submarine-fan facies form a thick stratigraphic succession northeast of the Yalakom fault. These rocks interfinger laterally with, and are in part overlain by, a thick succession of shallow-marine deltaic and fluvial successions. Thick sequences of clastic strata in the Chilko Lake region, originally interpreted as submarine-fan facies (Kleinsphen, 1982, 1985), are documented herein as shallow-marine deltaic and shoreface facies. Taylor Creek Group rocks in the region also contain deltaic sequences that may stratigraphically overlie, and interfinger with, the JMG strata. Regionally, Cretaceous strata along the southern margin of the Nechako Plateau represent a shallow-marine to nonmarine transition between Barremian to Cenomanian time. Furthermore, the lithofacies assemblages are much more varied than originally thought, which has significant implications for hydrocarbon reservoir potential in the region.

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