# New Studies of the Lower Cretaceous Jackass Mountain Group on the Southern Margin of the Nechako Basin, South-Central British Columbia: Progress and Preliminary Observations

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## Introduction

The Nechako Basin (Figure 1) is part of the Interior Plateau physiographic region of British Columbia, and has been variously defined in terms of extent and age (Ferri and Riddell, 2006). Accurate assessment of the petroleum potential of the Nechako Basin requires a comprehensive understanding of the basin architecture developed within Cretaceous strata, which represent the most prospective targets in the subsurface. Modeling the subsurface distribution of these Cretaceous units requires a detailed stratigraphic analysis of coeval, laterally adjacent strata exposed along the basin margins (Mustard and Mahoney, 2007).

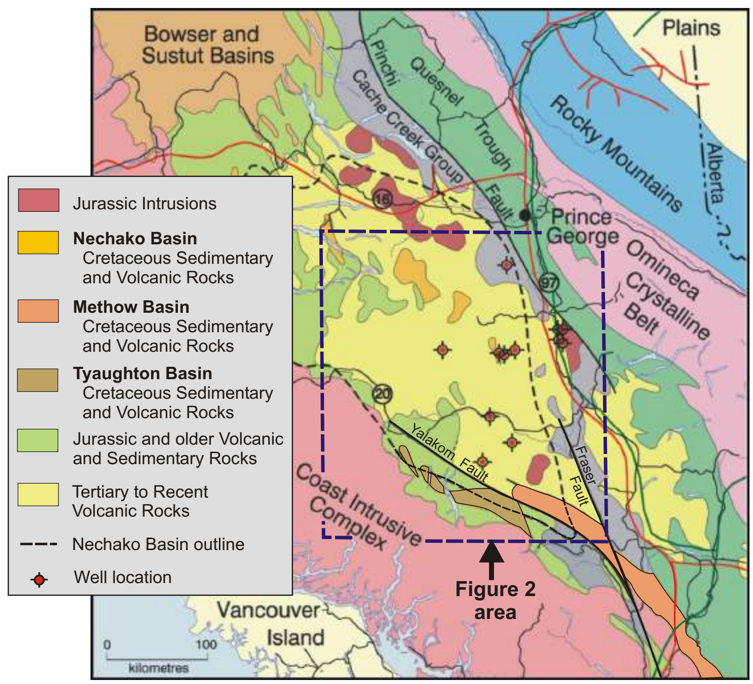


**Figure 1.** Regional geology, showing major Cretaceous units of the Nechako, Methow and Tyaughton basins and the outlined area of Figure 2 (*modified from* BC Ministry of Energy, Mines and Petroleum Resources, 2002; used with per-

The age and general lithological character of strata in the subsurface of the Nechako Basin are broadly known from industry drillholes (located on Figure 1) as well as through examination of isolated outcrops of Cretaceous intervals exposed beneath extensive Cenozoic volcanic and glacial cover (Ferri and Riddell, 2006; Mustard and MacEachern, 2007; Riddell et al., 2007). Regional facies patterns and basin architecture within the Nechako Basin are poorly understood, however, and even the stratigraphic affinities of subsurface units are unclear. For example, Hunt (1992) identified some subsurface strata as possible Jackass Mountain Group, a Lower Cretaceous succession that is exposed along the southern margins of the Nechako Basin, and that most previous studies have suggested is dominated by submarine fan deposits. In contrast, Hannigan et al. (1994) assigned these rocks to the Skeena 'assemblage' (more commonly termed the Skeena Group), a generally nonmarine Lower Cretaceous succession exposed along the northern margins of the Nechako Basin.

This confusion illustrates the poorly constrained nature of the subsurface strata in this region (for a more thorough discussion of the stratigraphic problems, *see* Ferri and Riddell, 2006) and the lack of understanding of the original extent of what is now termed the Nechako Basin. More recently, Rid-

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dell et al. (2007) have provided new palynological and radiometric age controls from subsurface drill cuttings of the existing hydrocarbon exploration wells. These change the suggested ages of some subsurface intervals considerably (e.g., expanding the amount of known Albian–Cenomanian subsurface strata). In addition, Mustard and MacEachern (2007) conducted a sedimentological and ichnological description and interpretation of the existing cored intervals from the archived wellcores. Most extant core from these wells represents either shallow marine or nonmarine environments of deposition, including those from Cretaceous strata. No deep marine facies were cored, although significant thicknesses of marine turbidites (presumably sub–wave-base depths) are interpreted to be present, based on geophysical well log profiles (Riddell et al., 2007).

At the southern end of the Nechako Basin, Lower Cretaceous Jackass Mountain Group (JMG) strata are unconformably overlain by Cenozoic volcanic rocks (Figure 2). The Cretaceous strata are generally classified as part of the Methow Basin, but are clearly the surface expressions of strata that continue northward into the subsurface beneath the Cenozoic rocks that form most of the exposed strata of the Nechako Basin (Hickson et al., 1994; Mahoney et al., pers. comm.). The JMG and associated strata include thick (>1000 m), laterally extensive (>10 km) sandstone successions that overlie and interfinger with mudstone. Previous studies have interpreted them as the deposits of large submarine fan deposystems (Kleinspehn, 1982, 1985), although Schiarizza et al. (1997) identified some areas of nonmarine strata, which they considered to be part of the JMG.

The authors' emphasis on the Jackass Mountain Group reflects the hypothesis that this unit is probably the best candidate for major reservoir systems in the subsurface of the Nechako Basin. It is suggested that JMG strata represent the closest surface analogue and the most likely direct correlative to the 'Skeena assemblage' of the subsurface, which has been interpreted by Hannigan et al. (1994, p. 140) to contain "the most significant petroleum plays in this assessment". This confusion regarding stratigraphic nomenclature also highlights the confusion of 'basin' names traditionally assigned to different stratigraphic successions in the region. The authors suggest that the separation of stratigraphic successions of similar age and type into separate 'Nechako,' 'Methow,' and possibly 'Tyaughton' basins likely reflects the history of different researchers studying the same rocks in different areas, rather than discrete depositional basins. These studies will test the hypothesis that the Nechako, Methow and perhaps the Tyaughton 'basins' constituted one extensive and continuous regional area of deposition during at least Early Cretaceous time (a basin that may have been linked with Early Cretaceous deposition of the southern Skeena 'Basin' as well, although the current studies will not directly test this hypothesis). If these individual 'basins' were originally laterally continuous and thus represent a single Early Cretaceous depocentre, there would be major implications for the hydrocarbon potential of the Nechako 'Basin', greatly increasing both the volume of potential reservoir rocks and potential source rocks, such as the extensive black shale of the Ladner Group in the Methow Terrane (Ray, 1990).

A brief regional reconnaissance study in 2006 identified two major areas of well-exposed JMG suitable for detailed stratigraphic and sedimentological studies (Mustard and Mahoney, 2007). These detailed studies commenced in summer 2007, and form the basis for two M.Sc. research projects (Goodin and MacLaurin). Fieldwork will continue in 2008 on both of these studies and several regional studies on Cretaceous strata in the area, including the Nechako Basin.

## Summer 2007 Field Research

### Jackass Mountain Group in the Camelsfoot Range Area

During summer 2007, Goodin conducted a detailed examination of sections of the JMG in the Camelsfoot Range (Figure 2, locality A; Figure 3). The JMG is well exposed on several ridges in this area and is volumetrically the most significant geological unit in the central and eastern Camelsfoot Range (Hickson et al., 1994; Schiarizza et al., 1997; Mahoney et al., pers. comm.). The study area extends northwest along the Yalakom fault from the confluence of the Fraser and Bridge rivers, to the geographic junction between Nine Mile Ridge and the Yalakom River (Figure 3). The northern boundary is delineated by the northeast-trending Nine Mile Ridge. The study area is focused on the central part of an approximately 150 km long, southward-tapering wedge of mainly medium- to coarse-grained sandstone and polymictic conglomerate exposed between the Yalakom and Fraser fault systems. It 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 part exposed in moderately west-dipping beds in the eastern limb.

Within this study area, five detailed stratigraphic sections were measured (Figure 3). Forty-five lithological, 10 detrital zircon, 12 mudstone geochemistry, 11 microfossil and 3 macrofossil samples were collected, most from the stratigraphic sections. Section thicknesses include approximately 1500 m on Yalakom Mountain (A on Figure 3), 130 m on eastern Nine Mile Ridge (B on Figure 3), 130 m on western Nine Mile Ridge (C on Figure 3), 125 m on Madson Creek (D on Figure 3), and 70 m on a low-lying ridge in the central study area (E on Figure 3). Several additional traverses were conducted to collect general lithological, structural and fossil information.

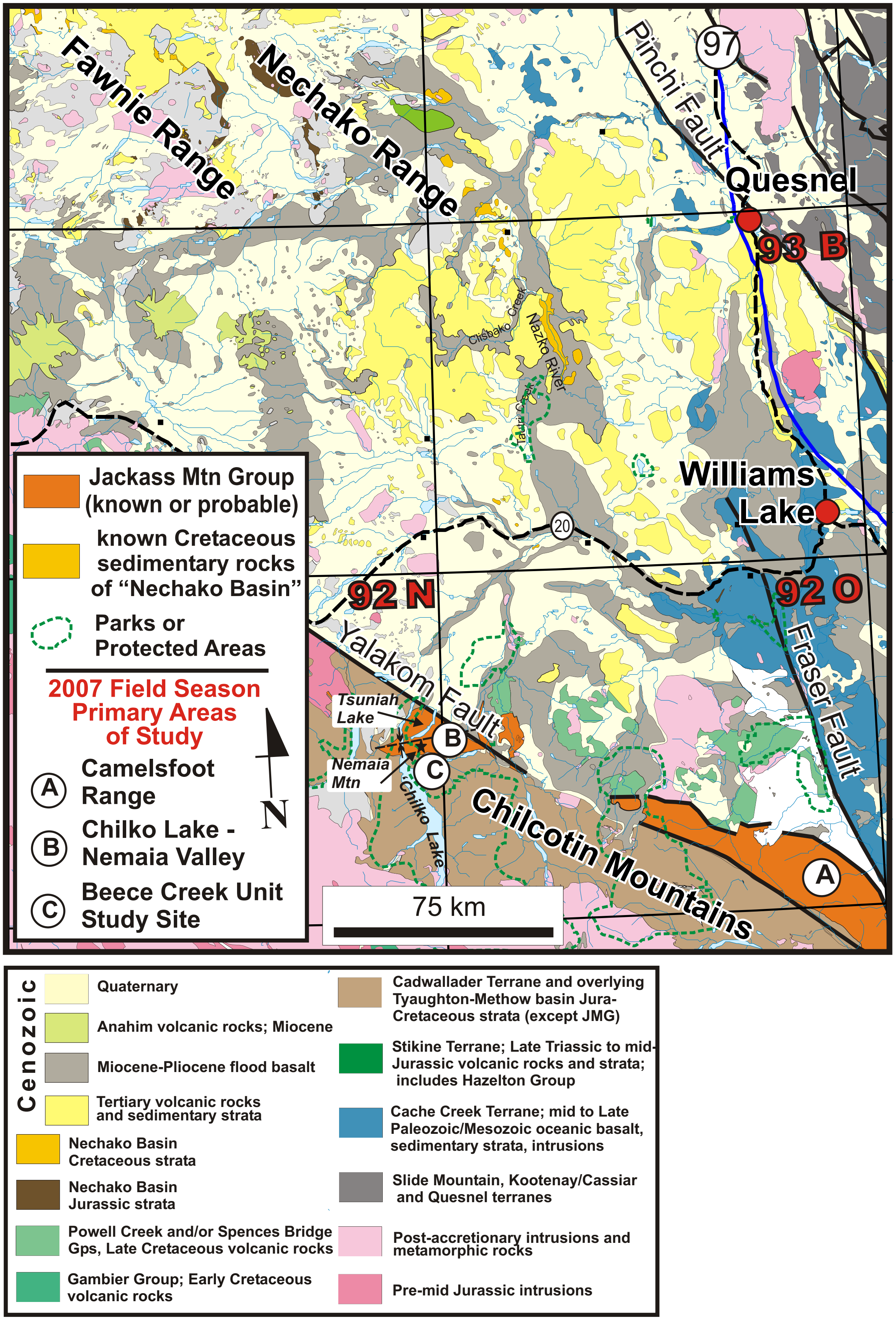


**Figure 2.** Regional geological framework and location of major areas of study discussed in this paper (*modified from* Ferri and Riddell, 2006 and Riddell, 2006; used with permission).

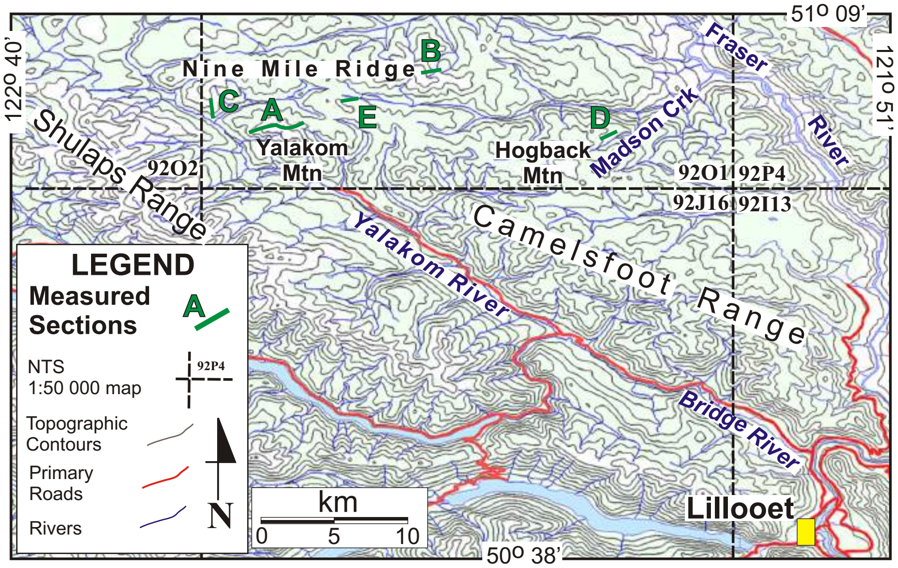


**Figure 3.** Location map for Camelsfoot Range study, showing main geographic features and the locations of sections measured during 2007.

At and near Yalakom Mountain (A on Figure 3), northwest-trending JMG strata dip steeply and are slightly overturned towards the north in some areas. Jackass Mountain Group units in this area overlie Middle Jurassic rocks of the Ladner Group (Mahoney, 1993; Schiarizza et al., 1997). These basal JMG rocks are dominated by massive, green, medium- to coarse-grained, lithic-rich feldspathic sandstone and interbedded siltstone. These form a >1500 m thick unit on Yalakom Mountain (Figure 3) that is correlative with the volcanic sandstone unit described by Schiarizza et al. (1997). Jackass Mountain Group strata containing fossils of probable Barremian age are present about 200 m below the base of this section, but above the basal unconformity with the underlying Lower to Middle Jurassic Dewdney Creek Formation (GSC Locality Number 74815; unpublished data provided by Poulton et al., 1994 *included in* Schiarizza et al., 1997). New fossil collections from the upper part of the stratigraphic section north of Yalakom Mountain are of Albian age (*Brewericeras hulenense* zone). Thus, the full stratigraphic section of the JMG in the Yalakom Mountain area appears to range in age from Barremian to Albian.

The Madson Creek section (D on Figure 3) includes the best exposures of the most readily identifiable unit within the JMG of the Camelsfoot Range (Figure 3). These striped, dark grey and pale olive 'zebra beds', composed of rippled and synsedimentary folded, silt-sized and fine- to medium-grained sandstone units, respectively, form a 125 m thick succession bounded above and below by massive, medium- to coarse-grained, green lithic-rich feldspathic sandstone (Figure 4, with legend as Figure 5). Although the thickest observed outcrop of this lithofacies is in the Madson Creek area, the zebra beds are present throughout the central part of the study area, are considered to be laterally continuous for many kilometres, and form part of a sedimentary unit at least several hundreds of metres thick. These beds dominate the stratigraphic succession to the northeast of Hogback Mountain; however, further west, although still present, the beds seem to be in transition to, and become interbedded with, more massive and thicker sandstone beds. This suggests an interfingering relationship between the zebra beds and thick lithofeldspathic sandstone beds similar to those of the Yalakom Mountain area. While no fossils have yet been identified from the zebra beds, strata structurally underlying these beds in the Madson Creek area contain the belemnoid fossil *Acroteuthis*, suggesting a pre-Albian Cretaceous age.

Rocks on Nine Mile Ridge (B and C on Figure 3) comprise a unit several kilometres thick of repeated successions of <40 m thick bed sets consisting of abundant trough crossbeds of moderately- to well-sorted, medium-grained sandstone and rare pebbly sandstone at the base of some sets. These are separated by sections of poorly exposed siltstone, mudstone and lesser fine-grained sandstone units that are tens to hundreds of metres thick. In a few places, the finer packages include fine-grained, sandstone thin beds that are regular and rhythmically repeated, and dark grey mudstone interbeds that gradationally coarsen up to one of the crossbedded sandstone bed sets described above. The repeated more than 100 m thick successions of decimetre-thick trough cross-stratified sandstone separated by siltstone-rich intervals suggest accumulation in a fluvial environment, with river systems building across and into floodplains that may have included lacustrine areas (with rhythmically deposited fresh-water turbidites) and small, fresh-water deltaic successions.

The JMG strata in the Camelsfoot Range can be subdivided into three major facies associations, which roughly correspond to southern, central and northern geographic areas, as described above. In the south, directly northeast of the Yalakom fault, the thick succession includes massive sandstone units that were deposited as sediment gravity flows (mostly turbidites) in a sub–wave-base, marine environment. These correspond to the submarine fan deposits that Kleinspehn (1982, 1985) interpreted to be the dominant depositional environment for the entire JMG. In the central portion of the study area, the interbedded turbiditic sandstone and siltstone comprising the zebra beds of the Madson Creek area were most likely deposited near or within the migrating lobes of an active submarine fan system. Common wave reworking of the upper parts of many turbidites, however, indicates that depth was typically above the storm wave base, suggesting a relatively shallow shelf environment, possibly transitional to a marginal marine shoreline regime. It is considered likely that these shallow shelf turbidites comprise distal (e.g., prodeltaic units) deposits of river-dominated delta or fan delta systems, rather than as parts of deeper water submarine fan systems. The facies exposed on Nine Mile Ridge are indicative of nonmarine fluvial, floodplain and possible lacustrine environments. Unfortunately, poor exposure in the valleys near Nine Mile Ridge means that it is not possible to trace this nonmarine unit directly into the marine facies of the rest of the JMG in this region.

Assuming that the JMG study area in the Camelsfoot Range is all part of the same structural block (Mahoney et al., pers. comm.), these three major facies associations likely represent both lateral and vertical changes in basin depositional patterns over time. The southern submarine fan sandstone may represent the base of a relative marine regression, whereas the central facies of shallow marine turbidites may reflect either progressive shallowing of the basin over time or a time-equivalent, but more proximal, marine facies in the northern part of the study area. The Nine Mile Ridge nonmarine succession represents either a more proximal part of the basin or a progressive shallowing of JMG deposition over time. The current lack of age control on the nonmarine unit and possibility of structural separation from the other facies makes either interpretation feasible at this stage of the study.

## Jackass Mountain Group in the Nemaia Mountain Area

MacLaurin began a similar detailed stratigraphic study of JMG and related strata in the Chilko Lake–Nemaia Valley area (locality B on Figure 2), a study that will continue during the summer of 2008. The JMG and other Cretaceous and Jurassic sedimentary successions are well exposed in this area, especially on Nemaia Mountain and surrounding ridges (Figure 2; Schiarizza et al., 2002). These strata are exposed immediately southwest of the Yalakom fault and traditionally are considered part of the Tyaughton Basin, which Garver (1992) described as a discrete sub-basin from the Methow Basin, with different sedimentation patterns and source areas. Restoration of ~115 km of dextral offset on the Yalakom fault (as suggested *in* Schiarizza et al., 1997), however, restores the JMG of the Camelsfoot Range directly adjacent to the Chilko Lake–Nemaia exposures, suggesting original depositional continuity.

The JMG and underlying Jurassic strata in this area are well exposed in a northeast-plunging syncline whose axis runs beneath and parallel to Tsuniah Lake (Figure 2; Schiarizza et al., 2002). Reconnaissance traverses of the area revealed dominantly undeformed JMG strata unconformably overlying the Jurassic Nemaia Formation in most areas. In other localities, JMG strata unconformably overlie the Jurassic Relay Mountain Group. Based on this reconnaissance work, five localities were identified as suitable for measuring detailed stratigraphic sections. These comprise two well-exposed ridges on the northern limb, two on the southern limb and one on the furthest southwest portion of the syncline.

During the summer of 2007, work on four of the stratigraphic sections was initiated, comprising the four sections on the northern and southern syncline limbs. One 2.2 km thick measured section on the northeastern side of the syncline documents a 1.9 km thick JMG succession of predominantly well-sorted sandstone with minor mudstone intervals (Figure 6, with legend as Figure 5). Above the JMG–Nemaia Formation contact in this section, a massive sandstone unit containing rare swaley cross-stratification and conglomeratic lenses fines upwards into a sandy siltstone. A 100 m thick mudstone succession, containing wave- and combined-flow ripple lamination, sandy interbeds and abundant fossil and organic material, overlies this sandy unit and coarsens upward into an interval of extensive, well-sorted sandstone bodies that display abundant very low angle cross-stratification and (in some localities) distinct trough- and hummocky cross-stratification. This unit is overlain by massive to planar stratified sand bodies and interbedded mudstone. The lower 800 m of a 1.2 km thick section on which measurement is in progress on the northwest side of the syncline exhibits similar stratigraphy with minor changes in unit thickness.

The upper 800 m of an 1.4 km thick stratigraphic section on which measurement is in progress on the southeast limb of the syncline is distinctly finer grained, with a higher percentage of mudstone in the middle sandstone unit, but is capped by an anomalous conglomeratic facies. Well-sorted sandstone dominates this unit, displaying abundant low-angle cross-stratification and soft-sediment deformation. The basal 200 m is composed dominantly of silty mudstone with minor fine-grained sandstone. The age of these basal JMG strata is poorly constrained, but the underlying Nemaia Formation strata contain ammonites of Bathonian age (*Iniskinites* sp.), whereas the upper part of this unit contains ammonites that appear to be referable to Hauterivian forms. The upper 200 m of the fourth section, located on the southwest limb of the syncline, is composed of well sorted, massively bedded sand intercalated with finer-grained intervals. This section is tentatively correlated to the upper portion of the measured section on the northeast limb of the

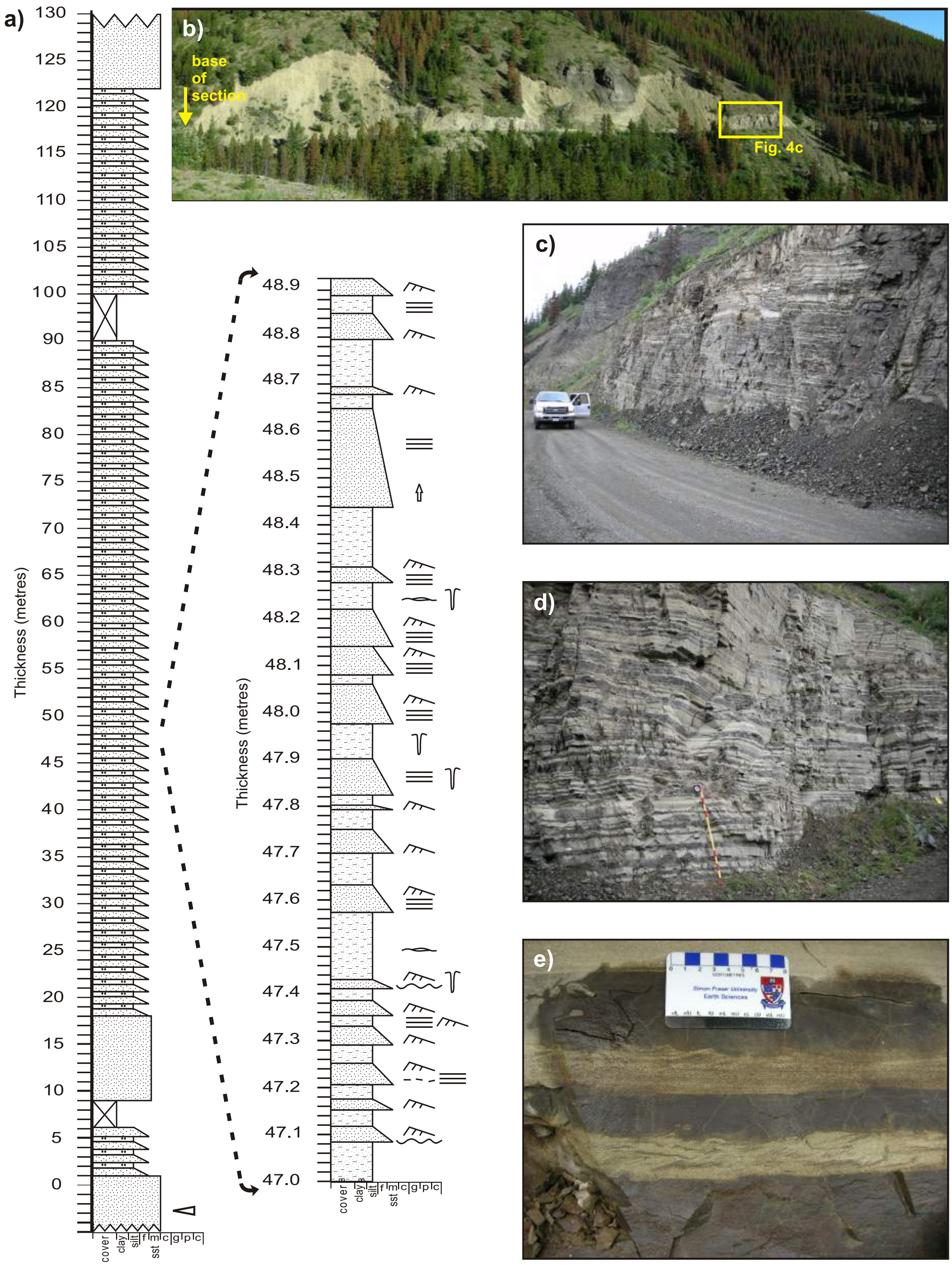


**Figure 4**. a) Measured stratigraphic section located on Madson Creek (D on Figure 3), Figure 5 provides a common legend for Figures 4 and 6; **b)** roadcut of the lower part of the section on the west side of Madson Creek; **c)** middle portion of the section, showing typical sheet-like sandstone-mudstone couplets; **d)** closer view of sandstone-mudstone couplets where a detailed section from 47 to 48.9 m was measured; **e)** close-up view of two sandstone beds displaying aggradational current ripple forms, some possible reworking of upper ripples and trace fossils at the sand-mud interface and above.

syncline and contains probable Albian-aged fossils in its uppermost part.

Extensive sampling of rock types keyed to stratigraphic position will facilitate detailed petrological, organic maturation and porosity and permeability analyses. Approximately 70 rock samples, distributed between the four measured sections, were collected for petrological analyses. Ten detrital zircon sandstone samples and 17 mudstone geochemical samples were collected for isotopic provenance studies. One thermal maturation sample of a carbonized wood fragment found in the southeastern section and one total organic carbon mudstone sample were also taken.

Several new fossil locations were identified in this area. A distinctive 100 m thick, dark grey mudstone unit present in both measured sections on the northern limb yielded common fossil specimens, including ammonites, gastropods and bivalves of probable Hauterivian age. The conglomeratic unit beneath the mudstone unit also yielded bivalves and a few ammonite and gastropod fossils, presently under study.

Primary observations indicate that correlations between these four sections can be undertaken, and preliminary interpretations suggest an overall deepening of the basin over time from a shallow marine environment to an outer shelf or slope environment. The northern limb of the syncline is interpreted to be a storm-dominated lower to upper shoreface environment with intermittent, but moderate, deltaic influence. The southern limb shows significant dissimilarities to the northern limb, including a distinctly finer-grained basal unit. A very preliminary study of the section suggests it represents a shallow marine depositional environment that underwent transgression from lower shoreface to outer shelf conditions. The conglomeratic facies may be associated with a deltaic influence.

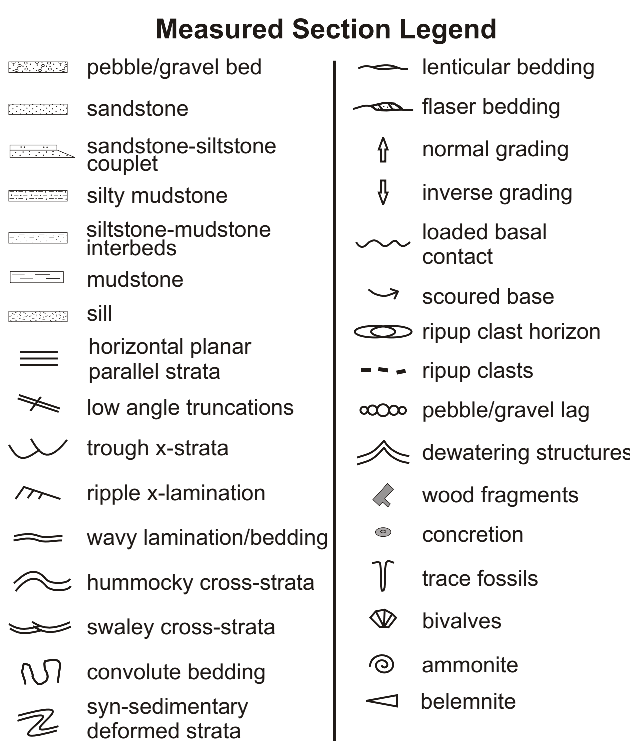


**Figure 5.** Common legend for measured sections of Figures 4 and 6.

## Regional Studies

In addition to the focused graduate student studies summarized above, several regional sampling programs were initiated. Sampling of Lower Cretaceous strata in the areas between the Camelsfoot Range and Chilko Lake region was initiated to compare the detrital zircon and other geochemical characteristics of these strata to those of the main study areas, and to test suggestions made in previous studies that Methow and Tyaughton basins were distinct sub-basins during Early Cretaceous time (e.g., Garver, 1992).

South of the synclinorium in the Nemaia Mountain area, across a series of high-angle faults, strata of probable Albian age are exposed on the northern flanks of Mt. Tatlow (C on Figure 2). This unit consists of black silty mudstone, lithic sandstone and chert-pebble conglomerate, which unconformably overlies the Upper Jurassic Relay Mountain Group. These rocks have been assigned to the Beece Creek succession of the mid-Cretaceous Taylor Creek Group in several previous studies and published geological maps (e.g., Schiarizza and Riddell, 1997; Schiarizza et al., 2002). Preliminary stratigraphic analysis indicates these strata conformably overlie both the middle to late Albian Dash and Lizard formations of the Taylor Creek Group, and that these strata may be directly correlative to part of the Jackass Mountain Group on Nemaia Mountain. If this interpretation is correct, this correlation would provide the earliest definitive tie between the Methow and Tyaughton basins, and would substantially increase the extent of the regional Early Cretaceous depocentre. The well-exposed stratigraphic section on the northern flanks of Mt. Tatlow will be examined in detail as part of a fourth year B.Sc. project (M. Forgette of University of Wisconsin–Eau Claire, one of the student assistants of the 2007 season). The section has been measured in detail and extensively sampled for thin section petrography, shale geochemistry, detrital zircon analysis, palynological and microfaunal studies and total organic carbon.

## Summary and Regional Implications

The 2007 field season focused on detailed field investigations, measurement of stratigraphic sections and sample collection as part of two studies of well-exposed Jackass Mountain Group strata. In addition, some initial sampling was conducted for more regional studies of Early Cretaceous units in adjacent areas. Much of the final interpretation from these studies will follow further fieldwork in

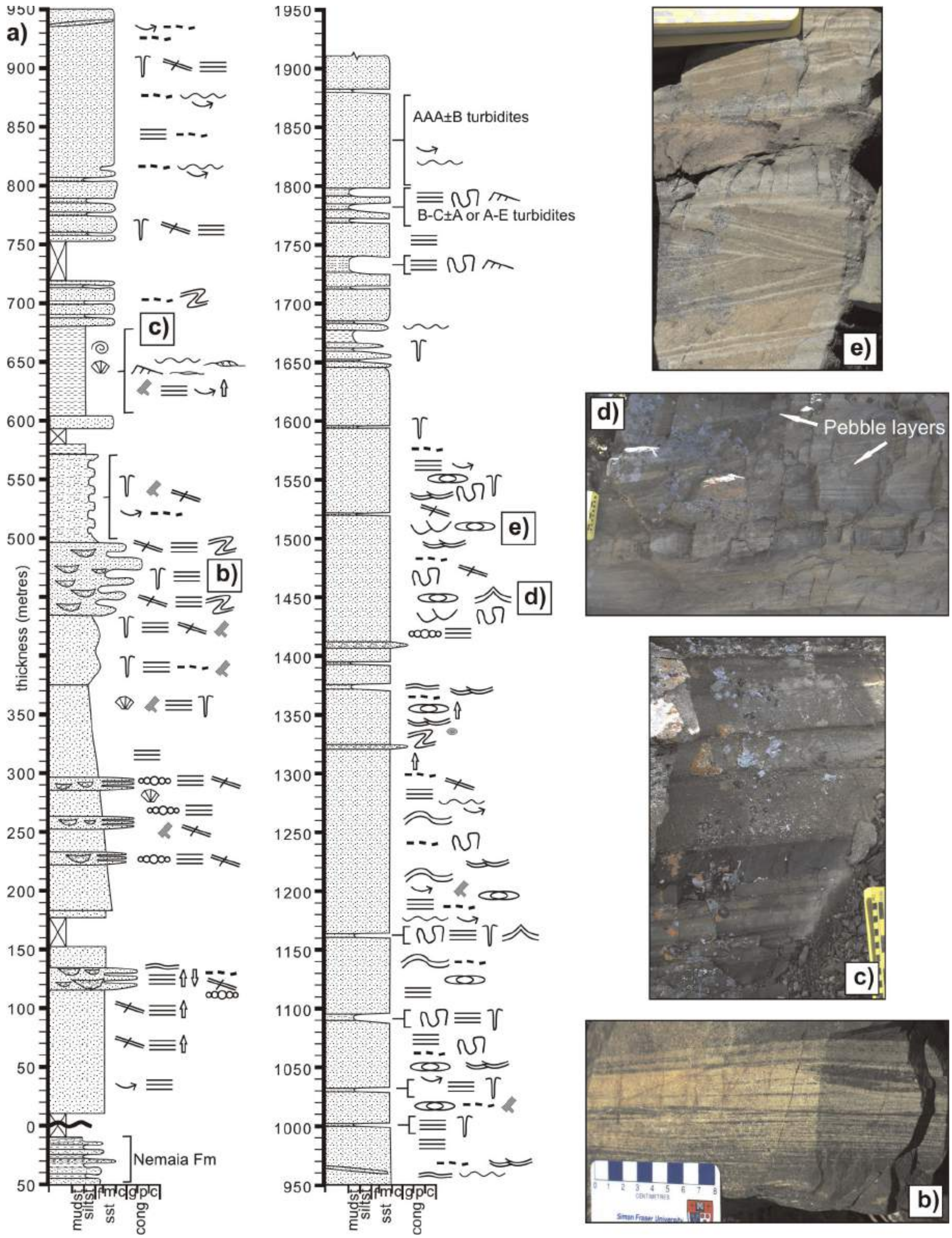


**Figure 6. a)** Simplified stratigraphic section through JMG from ridge north of Tsuniah Lake (common legend in Figure 5); **b)** fine-grained laminated sandstone displaying irregular wispy lamination and cross-laminated ripple forms, typical of the lower sand-rich unit; **c)** fine- to medium-grained sandstone beds (most are normally graded) with mudstone capping or between beds, probably constituting turbidites, although this unit also contains some shallow-water features; **d)** light and dark sandstone (mostly fine to medium grained) with rare pebbly layers in erosive-based troughs (central) and top bed, high-angle discontinuities are probably channel bases; **e)** medium-grained sandstone displaying high-angle cross-stratification typical of this upper sandstone unit (both swaley and trough cross-stratification occur in this unit).

2008 and extensive processing of geochemical samples, examination of thin sections from rock samples and analysis of new macrofossil collections. As well, extensive collections of mudstone samples processed for microfossils (palynology and foraminifers) will hopefully provide additional age constraints. Some preliminary implications are, however, apparent.

The presence in the Jackass Mountain Group of extensive and extremely thick facies intervals interpreted to represent shallow marine and nonmarine environments was surprising, given that the main previous study of the JMG interpreted it to be dominated by submarine fan deposition in relatively deep (sub–wave-base) environments (Kleinspehn, 1982, 1985; although Schiarizza et al., 1997 did recognize some nonmarine components within the JMG in their regional synthesis). In the Camelsfoot Range, sub–wave-base submarine fan facies are present as a thick succession immediately northeast of the Yalakom fault. The JMG in large areas of the northern Camelsfoot Range, however, comprises nonmarine fluvial and possibly lacustrine successions. In addition, the central Camelsfoot Range contains extensive exposures of sandstone-mudstone turbidites, but with common reworking of the tops of these turbidites by wave processes, indicating a relatively shallow marine environment of deposition. The precise age of the nonmarine facies is presently unknown, but detrital zircon samples from fluvial sandstone in this facies will at least provide a maximum age, and palynology samples will hopefully provide more specific age constraints and other biostratigraphic information. The implication is that a continuous, nonmarine to marine succession is preserved in this area, which possibly spans Barremian to Albian–Cenomanian time. The presence of thick and moderately well-sorted, cross-stratified fluvial sandstone packages in the northern Camelsfoot Range provides a new potential hydrocarbon reservoir system, which may have had better original porosity and permeability characteristics than the less well-sorted massive sandstone turbidites common to the southern Camelsfoot Range.

Detailed work in the Nemaia Mountain study area also suggests that much, if not most, of the JMG in this area lacks submarine fan turbidites. Thick successions of marine sandstone with swaley and, locally, hummocky and trough cross-stratification indicate shallow and relatively high-energy nearshore environments of deposition, as do associated heterolithic sandstone-mudstone packages containing wave and combined-flow ripple types. These shallow marine intervals appear to be more common in the northern and lower parts of the JMG succession in this area and change upward and southward to massive sandstone beds and interbedded mudstone successions that are more typical of deeper marine submarine fan systems, although the extent and thickness of these facies do not appear to be great. The presence of very thick successions of shallow marine (shoreface or delta front) facies, which include extensive decimetre thick intervals of well-sorted sandstone, is an important new discovery. If these strata continue in the subsurface to the north, they may represent high priority targets to test as a hydrocarbon reservoir system.

The presence of significant thicknesses of shallow marine and terrestrial units within the JMG also increases support for correlation of this unit with similar subsurface Lower Cretaceous strata of the Nechako Basin. Shallow marine sandstone, in particular, is likely to serve as well-sorted and laterally extensive units with sufficient porosity and permeability to act as high-volume reservoir units for significant hydrocarbon accumulation. As well, this correlation greatly expands the extent of potential source rocks for the subsurface strata. Mud-rich source rocks of the Tyaughton and Methow basins include the extensive Ladner Group and Relay Mountain Group units. Both of these extensive units are current objects of study for source-rock potential, both as part of this project and the ongoing projects described in Ferri and Riddell (2006).

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