# A synthesis of the Jurassic–Cretaceous tectonic evolution of the central and southeastern Canadian Cordillera: Exploring links across the orogen

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## ABSTRACT

Restoration of tectonic elements in the central interior of the Canadian Cordillera southward to their paleogeographic position in the Mesozoic permits comparison of data across the active orogen, recognition of the interplay between coeval lithospheric thickening and basin evolution, and new constraints on models of tectonic evolution. The onset of Middle Jurassic clastic sedimentation in the Bowser basin, on the west side of the Jurassic orogen, occurred in response to accretionary events farther inboard. Shortening and thickening of the crust between the Alberta foreland basin on the east side of the Jurassic orogen and Bowser basin on the west side resulted in an Omineca highland between the two basins and lithospheric loading that influenced their Late Jurassic–Cretaceous sedimentation. The provenance of detritus in these basins, and in the Late Cretaceous Sustut basin on the east side of the Bowser basin, reveals migration of drainage divides in the intervening Omineca highland through time. Synchronous and compatible tectonic events within the basins and evolving accretionary orogen, and in rocks of the Stikine terrane and the western margin of North America, suggest that they were kinematically connected above a lower-crust detachment, beginning in the Middle Jurassic. The Coast belt was part of this wide, dynamically linked bivergent orogen from the mid-Cretaceous to earliest Cenozoic,

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**and the lower-crust detachment rooted near the active plate margin. Nested within the orogen, the east-vergent thin-skinned Skeena fold belt, equivalent in scale to the Rocky Mountain fold-and-thrust belt, was also linked to the detachment system.**

**Keywords:** Canadian Cordillera, tectonic evolution, Bowser basin, Alberta foreland basin, Sustut basin, Omineca belt.

## INTRODUCTION

The relationships among basin evolution, fold-and-thrust belt development, and thermotectonic evolution of core zones provide insight into progressive stages of orogenesis. The dynamic link between these realms also provides a basis for geodynamic modeling and feedback for understanding orogen-scale processes. The southeast Canadian Cordillera is an excellent example. The Late Jurassic through earliest Cenozoic inter-relationships among the northeasterly vergent thin-skinned fold-and-thrust belt of the Foreland belt (Fig. 1) on the east side of the Cordilleran orogen, the synorogenic Alberta foreland basin deposits within and east of the Foreland belt, and the internal core zone of the Omineca belt are relatively well understood (Bally et al., 1966; Price and Mountjoy, 1970; Price, 1973, 1981; Brown et al., 1986; McMechan and Thompson, 1989; Fermor and Moffat, 1992; Beaumont et al., 1993). Studies have associated part of their evolution to accretion of terranes in the western Omineca and eastern Intermontane belts during westward underthrusting of the North American plate (e.g., Cant and Stockmal, 1989; Brown et al., 1992a; Price, 1994; Brown and Gibson, 2006; Carr and Simony, 2006). However, analyses commonly extend only as far west as the easternmost of the accreted terranes on the west side of the Omineca belt, and relationships of orogenic processes in the Foreland and Omineca belts to those of the Intermontane and Coast belts farther west have not been explored, nor have their implications for tectonic evolution of the Cordillera as a whole.

New understanding of exhumed mid-crustal rocks exposed in core zones of the Canadian Cordillera (Coast and Omineca belts, Fig. 1) and of depositional and structural histories of the sedimentary basins that flank them, in particular the Bowser, Sustut, and Alberta foreland basins (Fig. 1), is used herein to illustrate links between the major tectonic elements of the orogen. One result is a tectonic reconstruction in which the entire width of the orogen is kinematically linked throughout the Mesozoic–early Cenozoic (Fig. 2). It evolved from a predominantly west-verging "small-cold" (Beaumont et al., 2006) accretionary orogen, ~300 km wide in the Middle Jurassic (Fig. 2A), into an ~1000-km-wide "large-hot" (Beaumont et al., 2006) bivergent orogen in the mid-Cretaceous (Fig. 2B). By the mid-Cretaceous, an unusual geometry developed with two major detachment systems (Figs. 2B and 2C). A lower-crust detachment system extending across the entire orogen rooted near the active plate margin and joined the western magmatic convergent belt (Coast belt) to the eastern front of deformation in the thin-skinned, east-vergent

foreland fold-and-thrust belt. A second detachment rooted in the Coast belt rose eastward to relatively high structural levels, forming the basal detachment of the east-vergent Skeena fold-and-thrust belt nested in the interior of the orogen—a fold belt that matches the classic Rocky Mountain fold-and-thrust belt (Foreland belt and eastern Omineca belt) in width and magnitude of horizontal shortening.

In this paper, we include a synthesis of the depositional and structural histories of the two major Mesozoic basins, the Bowser and Sustut basins (Fig. 1), that formed west of the site of initial accretionary orogenesis now preserved in the southern Omineca belt. The Bowser basin is a largely marine basin that formed the Middle Jurassic to Early Cretaceous western continental margin of North America during and following the accretion of its basement, Stikinia (Stikine terrane), to the North American plate (e.g., Evenchick and Thorkelson, 2005, and references therein). The Sustut basin was the site of Late Cretaceous nonmarine, synorogenic clastic sedimentation confined between, and sourced from, the evolving Skeena fold belt on the west and the Omineca highland on the east (Eisbacher, 1974a, 1985; Evenchick, 1991a). Previous work of Ricketts et al. (1992) has shown how early subsidence and sedimentation in the Bowser basin in the latest Early Jurassic or early Middle Jurassic in the central Intermontane belt was related to southwest thrusting of Cache Creek terrane (Fig. 1) over Stikinia, and that these events were contemporaneous with southwest-directed thrust faults in the southern Omineca belt. Eisbacher (1981, 1985) included the depositional and structural history of the basins west of the Omineca belt in a synthesis of depositional patterns across the Cordillera. We build on these works, using data and interpretations from more than 20 yr of research since Eisbacher's analysis, to examine the relationships between Mesozoic depositional and structural events across the orogen. The geological history of the Bowser basin is of fundamental importance to our understanding of the tectonic development of the Cordilleran orogen because it contains the earliest depositional record in response to mid-Mesozoic terrane accretion in the Canadian Cordillera, as well as the record of continued lithospheric response to Jurassic–Cretaceous development of the thickening orogen between the Bowser basin and the Alberta foreland basin; in this regard, the Bowser basin is the western counterpart to the Alberta foreland basin. Also critical to a regional tectonic analysis is the role of the Skeena fold belt, a thin-skinned fold-and-thrust belt that deformed Bowser and Sustut strata at the same time as horizontal shortening occurred at all structural levels in the Coast and Omineca belts and at
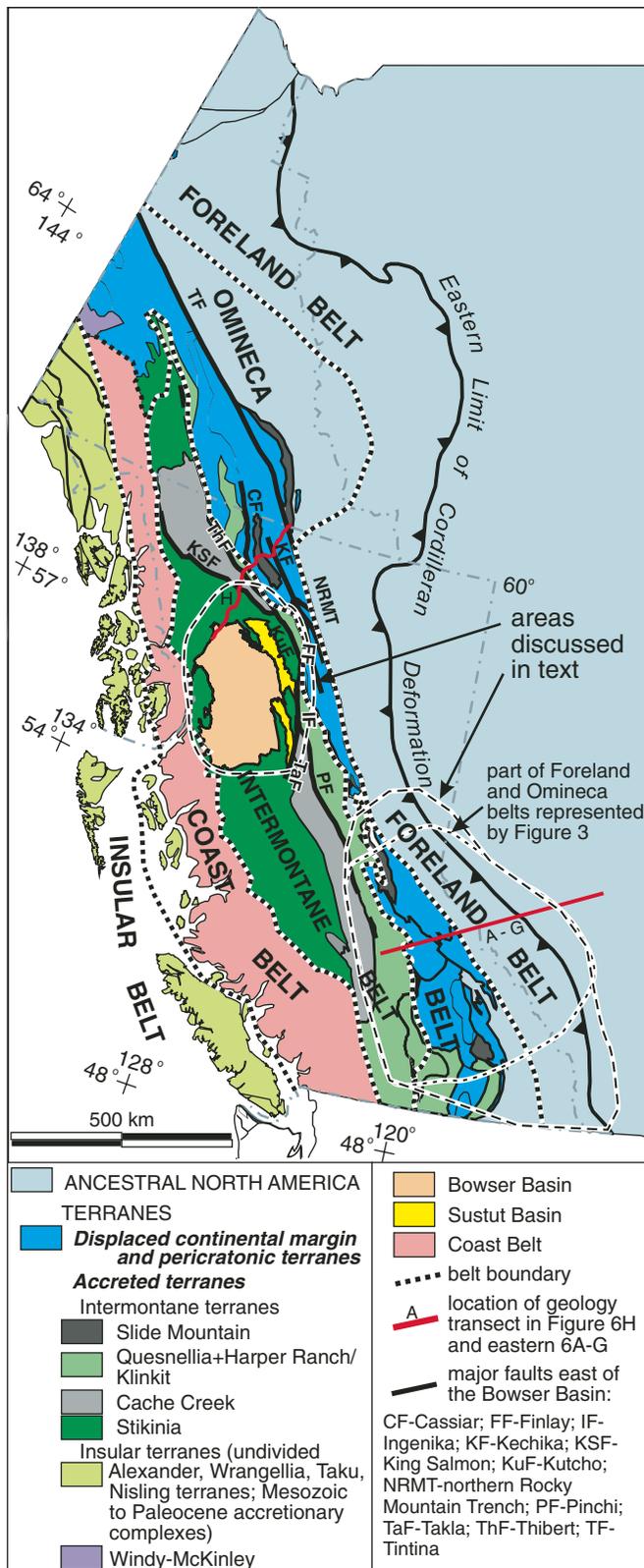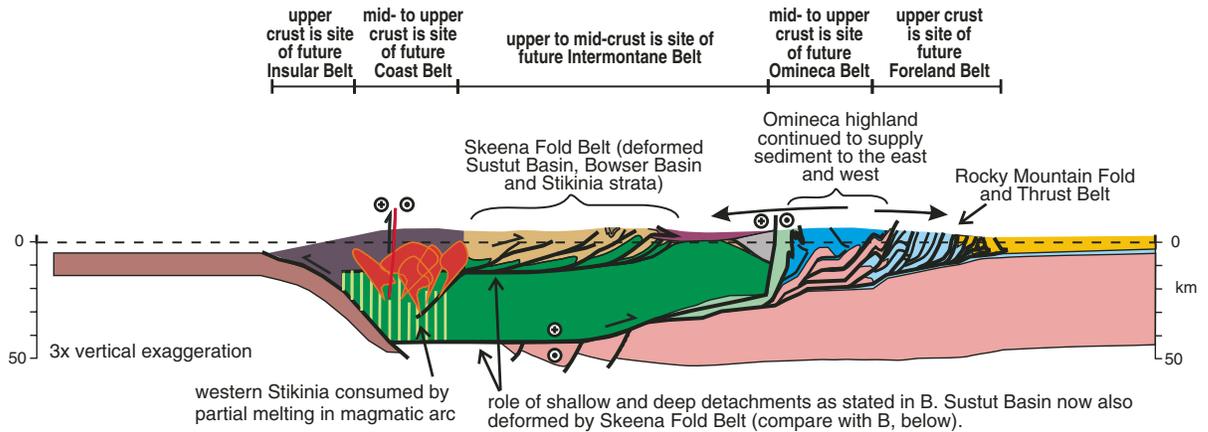
Figure 1. Morphogeological belts and major terranes of the Canadian Cordillera, locations of the Bowser and Sustut basins, major strike-slip faults east of these basins, and outlines of areas discussed in text (modified from Wheeler and McFeely, 1991; Colpron et al., 2006).

upper-crustal levels in the Foreland belt (Evenchick, 1991a). The site of the Bowser basin evolved from a region of marine deposition on the western margin of the continent in the Jurassic, to a region of significant horizontal shortening in the interior of the orogen during the Cretaceous, as well as localized Late Cretaceous sedimentation in the Sustut basin. The Bowser and Sustut basins are thus keystones bridging the eastern and western parts of the Cordilleran orogen.
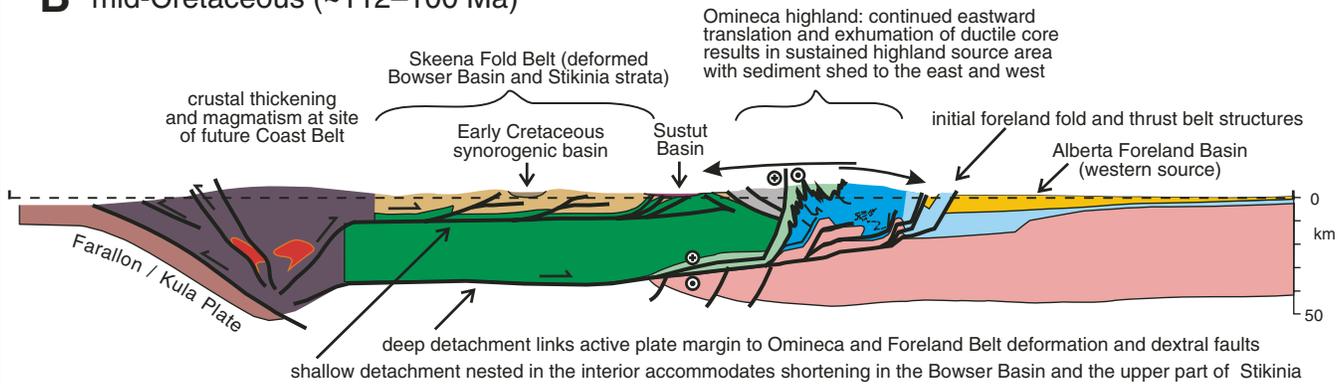
Data used as a basis for the synthesis presented here include: (1) integrated structural and geochronologic studies in the Omineca belt (O1–O10 in Table 1, and references therein), which reveal the diachronous nature of thermotectonic events at different structural levels, the evolution of structural geometry, and the role of metamorphism and plutonism in orogenic processes; (2) similar types of studies of the Coast belt, which have increased our knowledge of its Mesozoic tectonic evolution, and its association with the Intermontane belt (e.g., Crawford et al., 1987; Rubin et al., 1990; Rusmore et al., 2001); (3) a refined stratigraphic and structural framework for the Alberta foreland basin and Foreland belt (e.g., Mossop and Shetsen, 1994) and a new understanding of foreland basin provenance based on detrital zircon geochronology and isotope geochemistry (e.g., Ross et al., 2005); (4) mapping and interpretation of lithofacies assemblages across the Bowser basin, which illustrate the distribution of depositional environments (e.g., Evenchick et al., 2006); (5) integration of the depositional environments with fossil ages, resulting in the first paleontologically constrained depositional history for the Bowser basin (Evenchick et al., 2001; revised herein); (6) revision of the age of Cretaceous Sustut basin strata (A. Sweet, in Evenchick et al., 2001); (7) detrital zircon geochronology studies of the Bowser and Sustut basins, which refine our knowledge of the evolution of source areas (McNicoll et al., 2005); (8) recognition of at least 160 km of horizontal shortening in the Skeena fold belt (Evenchick, 1991a, 1991b, 2001); and (9) refined estimates of the timing and magnitude of Mesozoic–early Cenozoic dextral transcurrent faults east of the Bowser basin (Gabrielse, 1985; Gabrielse et al., 2006).

This paper begins with a review the geology of the morphogeological belts of the Canadian Cordillera (Fig. 1) with emphasis on Middle Jurassic to early Cenozoic evolution (Fig. 3; Table 1 provides sources of information). The focus is on a transect across the Cordillera that predates transcurrent faulting, wherein the Bowser and Sustut basins are restored to their probable site of formation adjacent to Omineca and Foreland belt rocks in the southeast Canadian Cordillera. We summarize the stratigraphy and depositional and structural histories of the Bowser and Sustut basins (Fig. 3), including new provenance data from detrital zircon studies (Fig. 4). The next section contains descriptions of the events occurring across the orogen in a series of successive "time slices," focusing on timing of basin initiation and sedimentation, deformation, magmatism, and metamorphism. These events are illustrated by paleogeographic maps (Fig. 5) and transorogen cross sections (Fig. 6).
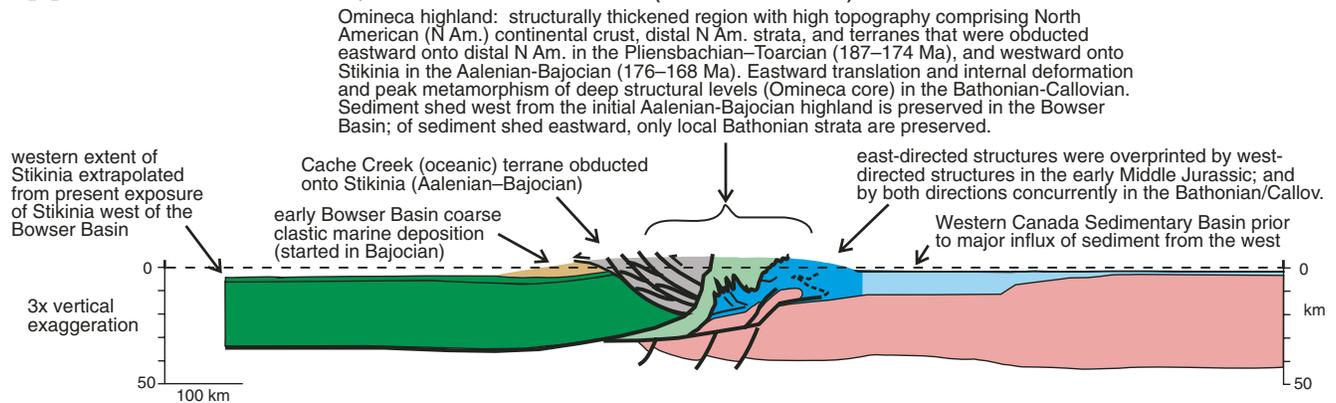
SW                                                                                                    NE

**C  latest Cretaceous–early Eocene (~70–50 Ma)**

upper crust is site of future Insular Belt

mid- to upper crust is site of future Coast Belt

upper to mid-crust is site of future Intermontane Belt

mid- to upper crust is site of future Omineca Belt

upper crust is site of future Foreland Belt

Skeena Fold Belt (deformed Sustut Basin, Bowser Basin and Stikinia strata)

Omineca highland continued to supply sediment to the east and west

Rocky Mountain Fold and Thrust Belt

0                                                                                                     0

km

50        3x vertical exaggeration                                                                    50

western Stikinia consumed by partial melting in magmatic arc

role of shallow and deep detachments as stated in B. Sustut Basin now also deformed by Skeena Fold Belt (compare with B, below).

**B  mid-Cretaceous (~112–100 Ma)**

Omineca highland: continued eastward translation and exhumation of ductile core results in sustained highland source area with sediment shed to the east and west

Skeena Fold Belt (deformed Bowser Basin and Stikinia strata)

crustal thickening and magmatism at site of future Coast Belt

Early Cretaceous synorogenic basin

Sustut Basin

initial foreland fold and thrust belt structures

Alberta Foreland Basin (western source)

Farallon / Kula Plate

0

km

50

deep detachment links active plate margin to Omineca and Foreland Belt deformation and dextral faults

shallow detachment nested in the interior accommodates shortening in the Bowser Basin and the upper part of Stikinia

**A  Late Middle Jurassic, Bathonian/Callovian (~168–161 Ma)**

Omineca highland: structurally thickened region with high topography comprising North American (N Am.) continental crust, distal N Am. strata, and terranes that were obducted eastward onto distal N Am. in the Pliensbachian–Toarcian (187–174 Ma), and westward onto Stikinia in the Aalenian-Bajocian (176–168 Ma). Eastward translation and internal deformation and peak metamorphism of deep structural levels (Omineca core) in the Bathonian-Callovian. Sediment shed west from the initial Aalenian-Bajocian highland is preserved in the Bowser Basin; of sediment shed eastward, only local Bathonian strata are preserved.

western extent of Stikinia extrapolated from present exposure of Stikinia west of the Bowser Basin

Cache Creek (oceanic) terrane obducted onto Stikinia (Aalenian–Bajocian)

early Bowser Basin coarse clastic marine deposition (started in Bajocian)

east-directed structures were overprinted by west-directed structures in the early Middle Jurassic; and by both directions concurrently in the Bathonian/Callov.

Western Canada Sedimentary Basin prior to major influx of sediment from the west

0

km

3x vertical exaggeration

50                                                                                                    50

100 km

**Pre-Middle Jurassic**

North American craton

strata deposited on cratonic North America

pericratonic terranes

Quesnellia and Slide Mountain terranes

Cache Creek Terrane

Stikinia; Stikinia incorporated into Coast Belt

Coast Belt; composed of intrusions (orange), Insular Belt terranes, and Stikinia and Bowser Basin strata west of present exposures

**Middle Jurassic and younger**

Sustut Basin

Alberta Foreland Basin

Bowser Basin

sedimentary transport direction; sources of clasts are indicated by regions directly under arrow

thrust fault

strike slip fault (dextral)

Figure 2. Generalized cross sections illustrate tectonic elements and key events during the Mesozoic to early Cenozoic evolution of the southern Canadian Cordillera, from a narrow accretionary orogen (A) to a wide orogen with two major detachment systems (B, C). The lower detachment system links structural elements across the entire Cordillera. The upper detachment is the sole fault of the Skeena fold belt nested within the interior of the orogen. The Skeena fold belt is similar in width, magnitude of shortening, and timing of formation to the Rocky Mountain fold-and-thrust belt. Note that zones of penetrative ductile strain are not depicted on the cross sections; please see text and Table 1 for documentation of structural style, particularly in the Omineca and Coast belts.

← 

Our purposes are to identify coeval and tectonically compatible events that illustrate linkages across the orogen and to use these as a basis for discussing its tectonic evolution.

## GEOLOGICAL SETTING

The Canadian Cordillera (Fig. 1) is an amalgam of: (1) predominantly sedimentary deposits formed on and adjacent to the continental margin of ancestral North America, referred to herein as the craton margin; (2) terranes made mostly of arc and oceanic rocks that evolved separately early in their histories and subsequently became part of the Cordilleran "collage" (Coney et al., 1980; Gabrielse and Yorath, 1991); and (3) supracrustal rocks deposited in basins during and after terrane accretion. The five morphogeological belts of the Canadian Cordillera reflect both geological history and physiography (Gabrielse et al., 1991; Fig. 1). The major zones of terrane amalgamation and accretion coincide with the metamorphic-plutonic Omineca and Coast belts (Monger et al., 1982). These are flanked by belts of little metamorphosed or relatively low-grade sedimentary, volcanic, and plutonic rocks that form the Foreland, Intermontane, and Insular belts. The Foreland belt contains strata deposited on the ancient cratonal margin of North America, whereas the Intermontane and Insular belts coincide largely with the accreted terranes. In addition, there are syn- and postaccretion successions that were deformed into fold-and-thrust belts of Cretaceous to early Cenozoic age. The principal period of accretion of terranes of the Intermontane belt to North America was in Early to Middle Jurassic (e.g., Gabrielse and Yorath, 1991). The timing of accretion of Insular belt terranes to those farther inboard was either in the Jurassic or earlier (e.g., van der Heyden, 1992; McClelland et al., 1992), or in the Cretaceous (Monger et al., 1982). During and following amalgamation, there was significant orogen-parallel displacement on transcurrent faults within or marginal to the metamorphic-plutonic belts. Faults were dextral in and bordering the Omineca and Coast belts from mid-Cretaceous to early Cenozoic (e.g., Gabrielse, 1991a; Gabrielse et al., 2006). Prior to that, sinistral displacement of uncertain magnitude is inferred for the Early Cretaceous rocks outboard of the Bowser basin (Evenchick, 2001, and references therein).

## Foreland Belt in British Columbia and Alberta

The Foreland belt is composed of Proterozoic to early Mesozoic continental-margin strata of the Western Canada sedimentary basin and of Mesozoic synorogenic strata of the Alberta foreland basin, the part of the Western Canada sedimentary basin that had the uplifting Cordillera as its main source (e.g., Stott and Aitken, 1993; Mossop and Shetsen, 1994). In the Foreland belt south of 58°N, west-derived sediments—a signal of emergence of a western source—first appear in the Oxfordian (F1 in Fig. 3; Table 1), except in the most southwestern part of the basin, where there is evidence for a western source in the Bajocian (Stronach, 1984). A major break in foreland basin sedimentation occurred in the Hauterivian to early Aptian, with a long period of pedimentation (Cadomin conglomerates; White and Leckie, 1999) and development of a low-angle unconformity with a stratigraphic separation that increases to the east (F3 in Fig. 3; Table 1). Clast composition and heavy mineral studies indicate that between 53°N and 57°N, western source areas for most of the coarse clastic units of the uppermost Jurassic to the Turonian include volcanic, plutonic, and medium-grade metamorphic rocks (McMechan and Thompson, 1993, and references therein). In contrast, south of 53°N, clast and heavy mineral studies, detrital zircon studies, and isotope geochemistry indicate that the western source areas were limited to low-grade metasedimentary rocks of the Omineca belt or the Foreland belt (McMechan and Thompson, 1993, and references therein; Ross et al., 2005). Exceptions are in Kimmeridgian strata, where detrital mica indicates a metasedimentary source, and in Albian strata, which have clasts of Intermontane belt volcanic and intrusive rocks (McMechan and Thompson, 1993, and references therein; Ross et al., 2005). Significant sediment accumulation and basin subsidence occurred in the western Alberta foreland basin during the Kimmeridgian to Valanginian (section up to 4 km thick; F2, Fig. 3), and over a broader area during the Campanian through Paleocene (section over 5 km thick; F5 in Fig. 3; Table 1).

Contractional thin-skinned structures of the Foreland belt are kinematically linked to structures in the polydeformed and metamorphosed Omineca belt and are essentially structurally continuous with them south of 53°N (McDonough and Simony, 1988; Kubli and Simony, 1994). Deformation of the foreland fold-and-thrust belt generally progressed from west to east and accommodated up to 200 km of horizontal shortening (Bally et al., 1966; Price and Mountjoy, 1970; Price, 1981; Fermor and Moffat, 1992). Structures near the western margin of the Foreland belt formed prior to ca. 108 Ma near 50°N (Larson et al., 2004) and ca. 100–112 Ma near 53°N (F4 in Fig. 3; McDonough and Simony, 1988). Faults in the east deform the youngest preserved strata (upper Paleocene near 53°N; Demchuk, 1990), and contractional deformation continued into the Eocene (Kalkreuth and McMechan, 1996). Most of the shortening of the southern Foreland belt occurred after the Turonian (younger than 89 Ma), concurrent with strike-slip faulting on the northern Rocky Mountain–Tintina fault system (Fig. 1; Price, 1994; Gabrielse et al., 2006).

**TABLE 1. SUMMARY OF TIMING OF EVENTS IN THE INTERMONTANE, OMINECA, AND FORELAND BELTS**

| Intermontane Belt | | | | Omineca Belt | | | | Foreland Belt | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fig. 3 code | Event | Timing | Reference | Fig. 3 code | Event | Timing | Reference | Fig. 3 code | Event | Timing | Reference |
| | | | | O10 | Penetrative high strain at the deepest structural levels (e.g., Thor-Odin dome; Frenchman Cap, in part); transition from transpressional to transtensional tectonics in Middle Eocene. | Eocene | Parrish et al. (1988); Gibson et al. (1999); Crowley et al. (2000); Hinchey (2005, and references therein) | F5 | Rapid, coarse clastic sedimentation (100 m/m.y.); dominant Foreland belt source; major period of deformation with deformation front migrating eastward across Front Ranges and Foothills. | Late Campanian–Early Eocene (ca. 77–53 Ma) | Price and Mountjoy (1970); Price (1981); Stott and Aitken (1993); McMechan and Thompson (1993, and references therein); Ross et al. (2005) |
| I6 | Initiation of coarse clastic deposition in Sustut basin (Campanian) and continued deformation in Skeena fold belt to affect youngest Sustut rocks (Maastrichtian). Sources same as in I5, but includes deposition of tuff. | Late Campanian to Early Maastrichtian, (ca. 74–68 Ma) | Eisbacher (1974a); Evenchick and Thorkelson (2005); MicNicoll (2005, personal commun.); McNicoll et al. (2005, 2006) | O9 | South of 52°N: Penetrative polydeformation and metamorphism (e.g., eastern Selkirk fan, Selkirk allochthon north of Monashee Complex; mid-crustal zone south of Thor-Odin), crystalline nappes carried on ductile shear zones (e.g., Gwillim Creek shear zone in Valhalla Complex); zones of high strain (e.g., Monashee décollement in Frenchman Cap dome). | Late Cretaceous–Paleocene | Carr (1992); Scammell (1993); Crowley and Parrish (1999); Gibson et al. (1999); Johnston et al. (2000, and references therein); Gibson (2003); Kuiper (2003); Williams and Jiang (2005); Carr and Simony (2006); Brown and Gibson (2006, and references therein) | | | | |
| I5 | First deposition of easterly derived metamorphic clasts, clasts of cratonic North American lithologies, and detrital zircons of Proterozoic age (Sustut basin). | late Early Cretaceous (Albian; ca. 112–110 Ma) | Eisbacher (1974a); Evenchick et al. (2001); Evenchick and Thorkelson (2005); V.J. MicNicholl (2005, personal commun.); McNicoll et al. (2005, 2006) | O8 | Purcell thrust system (post-Bearfoot and related thrusts and pre–Horsethief Creek batholith). | Mid-Cretaceous pre–ca. 93 Ma | Archibald et al. (1983); P.S. Simony (2005, personal commun.) | F4 | Northeast-directed thrust faulting in westernmost Foreland belt near 53°N; cooling of Yellowjacket gneiss ca. 110 Ma, and 100 Ma deformation thrust faults immediately to east. | 110–100 Ma (Albian) | McDonough and Simony (1988, and references therein) |
| | | | | O7 | Emplacement of Malton gneiss basement cored nappes via Bearfoot and related ductile thrusts (post–140–126 Ma as isograds [O6] deflected; pre– or syn–ca. 110 Ma cooling of Yellowjacket gneiss and 100 Ma deformation thrust faults in Foreland belt immediately to east). | late Early Cretaceous | McDonough and Simony (1988, and references therein); Digel et al. (1998); Crowley et al. (2000, and references therein) | | | | |

(continued)

**TABLE 1. SUMMARY OF TIMING OF EVENTS IN THE INTERMONTANE, OMINECA, AND FORELAND BELTS** *(continued)*

| Intermontane Belt | | | | Omineca Belt | | | | Foreland Belt | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fig. 3 code | Event | Timing | Reference | Fig. 3 code | Event | Timing | Reference | Fig. 3 code | Event | Timing | Reference |
| I4 | Development of piggyback basin within Skeena fold belt signals end of solely east-derived sedimentation and is probably a record of early Skeena fold belt deformation. | early Early to middle Early Cretaceous (ca. 145–135 Ma) | Evenchick et al. (2001); Evenchick and Thorkelson (2005); V.J. McNicoll (2006, personal commun.) | O6 | Penetrative polydeformation and metamorphism in the Cariboo, Monashee and Selkirk mountains (51.5–52.5°N latitude). Near line represented by Fig. 3: southeastward imbrication of basement slices at depth with SW-verging folds and faults at higher levels (e.g., Hobson Lake area); fold fans (e.g., Ozalenka fan). South of 52°N and at deep structural levels: generally NE-verging poly-deformation and high-strain zones (e.g., Scammell, 1993). | throughout the Late Jurassic, Early Cretaceous, and Late Cretaceous | Parrish (1995); Currie (1988); Scammell (1993); Digel et al. (1998); Crowley et al. (2000); Reid (2003, and references therein); Gibson (2003) | F3 | Major period of pedimentation; development of low-angle unconformity with stratigraphic separation increasing eastward except in westernmost Foreland basin. | Hauterivian to Early Aptian (ca. 136–110 Ma) | Stott and Aitken (1993); Stott (1998); White and Leckie (1999) |
| | | | | O5 | Penetrative polydeformation and metamorphism—Allan Creek area, Cariboo Mountains. | ca. 143–126 deformation; ca. 135 Ma metamorphism | Parrish (1995); Currie (1988) | | | | |
| I3 | Transition to nonmarine conditions across central and southern Bowser basin (no record in southwest). | Jurassic-Cretaceous boundary (ca. 145 Ma) | Evenchick et al. (2001); Evenchick and Thorkelson (2005); Smith and Mustard (2006); V.J. McNicoll (2005, personal commun.) | O4 | SW-verging penetrative deformation and metamorphism—eastern Hobson Lake area, Cariboo Mountains. | ca. 147 Ma syntectonic metamorphism | Reid (2003, and references therein) | F2 | Rapid, west (Omineca highland) derived sedimentation (to 100 m/m.y.); shallowing- and coarsening-up sequence in Upper Jurassic. | Kimmeridgian-Valanginian (ca. 156–136 Ma) | Poulton (1989); Poulton et al. (1993, 1994b); Stott and Aitken (1993); Stott et al. (1993); Stott (1998) |

*(continued)*

TABLE 1. SUMMARY OF TIMING OF EVENTS IN THE INTERMONTANE, OMINECA, AND FORELAND BELTS  (continued)

| Intermontane Belt | | | | Omineca Belt | | | | Foreland Belt | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fig. 3 code | Event | Timing | Reference | Fig. 3 code | Event | Timing | Reference | Fig. 3 code | Event | Timing | Reference |
| I2 | Rapid westward migration of facies belts in the Bowser basin. | Late Jurassic (Oxfordian/ Kimmeridgian; ca. 157–151 Ma) | Evenchick et al. (2001); Evenchick and Thorkelson (2005) | O3 | Onset and/or formation of significant architecture of major structures such as SW-verging folds, fold fans, belts of NE-verging folds & faults. Peak of metamorphism ca. 165–160 Ma (biotite-grade Hobson Lake, Scrip Nappe). | (3a) 173–164 Ma in Kootenay arc & Purcell anticlinorium; >167 Ma Selkirk Fan (3b) 174–162 Ma in Cariboo Mountains | Archibald et al. (1983); Gerasimoff (1988); Struik (1988); Brown et al. (1992b); Parrish (1995); Warren (1997); Colpron et al. (1998); Gibson (2003); Reid (2003, and references therein); Brown and Gibson (2006, and references therein) | F1 | First regional subsidence and thick W-derived (Omineca highland) sediments; overlies thin, craton-derived, basal transgressive sandstone. | Oxfordian (post–Early Oxfordian (ca. 158–156 Ma) | Poulton (1984, 1989); Poulton et al. (1993, 1994b); Stott (1998) |
| I1 | At least 3 km deposition in Bowser basin focused in northeast trough. | Middle Jurassic (Bathonian to early Oxfordian; ca. 168–158 Ma) | Evenchick et al. (2001); Evenchick and Thorkelson (2005). | O2 | Southwest-verging thrusts and isoclinal recumbent folds south of 51°N. | onset by 175 Ma | Parrish and Wheeler (1983); Klepacki (1985); Smith et al. (1992); Warren (1997); Colpron et al. (1996, 1998); Gibson (2003); Reid (2003) | F0 | Time-transgressive erosive disconformity at base of Alberta foreland basin succession. | Callovian-Oxfordian (ca. 164–160 Ma) | Poulton (1984); Poulton et al. (1993, 1994b) |
| I0 | First east-derived sediment from the Cache Creek terrane deposited on Stikinia is the initial coarse clastic deposition in Bowser basin. Rapid exhumation of Cache Creek. | early Middle Jurassic (Aalenian/ Bajocian; ca. 176–168 Ma) | Gabrielse (1991b); Ricketts et al. (1992); Mihalynuk et al. (2004) | O1 | Obduction of Slide Mountain and Quesnellia terranes onto North America pericratonic terranes (e.g., Eureka, Pundata, Stubbs, Waneta faults and related structures). | ca. <187 Ma, 187–173 Ma | Tipper (1984); Parrish and Wheeler (1983); Murphy et al. (1995, and references therein); Beatty et al. (2006) | | | | |

## Southern Omineca Belt

The southern Omineca belt is composed of predominantly Proterozoic to Paleozoic supracrustal rocks formed on or near the cratonal margin of North America as well as late Paleozoic and early Mesozoic rocks of the most inboard accreted terranes. These rocks were polydeformed and metamorphosed during and following their Early to Middle Jurassic (ca. 187–174 Ma) accretion (O1 in Table 1), and some structural levels were reactivated and overprinted through the Jurassic, Cretaceous, Paleocene, and early Eocene (Table 1; Fig. 3). Protoliths are: (1) Paleoproterozoic basement exposed in structural culminations of the Monashee Complex and as imbricated thrust slices in the Malton Complex; (2) Mesoproterozoic to Paleozoic supracrustal rocks deposited on the western cratonal margin of North America; (3) lower Paleozoic sedimentary, volcanic, and igneous rocks of the pericratonic Kootenay terrane that formed on or adjacent to the North American margin; (4) Permian volcanic and ultramafic rocks of the oceanic Slide Mountain terrane; (5) Triassic to Lower Jurassic volcanic and sedimentary arc-related rocks of Quesnellia; (6) ca. 175–159 Ma calc-alkaline plutons of the Kuskanax and Nelson Suites; and (7) ca. 110–90 Ma granites of the Bayonne Suite. South of 51°N, Paleocene–Eocene peraluminous leucogranites occur in high-grade rocks exhumed from the mid-crust. The youngest rocks, middle Eocene intrusions of the syenitic Coryell Suite, coincide with the locus of significant Eocene east-west extension.

Although there is a record of Paleozoic interaction of offshore terranes with the western margin of North America (cf. Klepacki, 1985), and there is debate about the tectonic setting and paleogeography of the margin (cf. Thompson et al., 2006), our focus is tectonism related to the Late Triassic to Middle Jurassic obduction of terranes, and subsequent shortening and thickening of the orogen. Obduction of the Quesnellia and Slide Mountain terranes starting at ca. 187 Ma was accommodated by crustal shortening, as documented by folding and northeast-directed thrust faulting at low-grade metamorphic conditions, and this resulted in over 40 km of overlap of these terranes onto North American rocks (O1 in Table 1; Fig. 3). In the Middle Jurassic, shortening and thickening was accommodated by west-verging faults and fold systems, including regional-scale isoclinal folds with limbs tens of kilometers long (e.g., Scrip Nappe; Raeside and Simony, 1983; O2 in Table 1; Fig. 3). In the central Omineca belt, southwest-verging structures continued to form in the west (Schiarizza and Preto, 1987; Reid, 2003; Fig. 3). Elsewhere, upright folds, northeast-verging fold systems, regional fan structures, and northeast-directed thrust faults were superimposed on the southwest-verging nappes (O3 in Table 1; Fig. 3). Deformation was accompanied by regional greenschist-facies metamorphism, with some amphibolite-facies assemblages indicating that the crustal thickness was ~50–55 km (Table 1; Archibald et al., 1983; Colpron et al., 1996; Warren, 1997), or greater, and that this pulse of metamorphism reached its peak in the Middle Jurassic and was followed by rapid exhumation in the Middle Jurassic (O3 in Table 1). We follow the blind "tectonic wedge" model (Price, 1986; Struik, 1988; Murphy, 1989; Colpron et al., 1998) in which basement slices or ramps acted as wedges resulting in the formation of large-scale southwest-vergent structures in the detached and deforming overlying supracrustal rocks. Alternative models to explain the southwest-vergent Middle Jurassic structures, based on development of a retro-wedge geometry above a subduction zone (Brown et al., 1993; Brown and Gibson, 2006), are incompatible with timing and geometry of structures documented within the wedge, and the westward location of the magmatic arc and subduction zone relative to the position of deforming rocks (cf. Colpron et al., 1998). In the Late Jurassic and Early Cretaceous, progressive deformation and metamorphism continued in the Omineca belt (O4 and O5 in Table 1), and the foreland became progressively more involved, thus expanding the deforming highland and locus of thickening northeastward relative to the craton. In the Early Cretaceous, the lower structural levels of west-verging fold systems and related higher-level fold fans in the southern Omineca belt were reactivated and tightened during greenschist- and amphibolite-facies metamorphism, and sheets of basement and cover rocks of the Malton Complex were imbricated by northeast-vergent structures (O6 in Fig. 3). By the end of the Albian, the rocks at the latitude of discussion were being cooled and exhumed. However, more deeply exhumed rocks, now exposed south of 52°N, record zones of ductile moderate to extreme strain, folding, and transposition, indicating that mid-Cretaceous–Eocene strain partitioning at deep structural levels in the Omineca belt was concomitant with northeastward propagation of deformation and thin-skinned shortening in the Foreland belt (O9, O10 in Fig. 3).

## Central Intermontane Belt

Most of the central Intermontane belt is underlain by Stikinia (Fig. 1), a terrane composed of volcano-plutonic arc assemblages of Devonian to Permian, Late Triassic, and Early Jurassic to early Middle Jurassic age (e.g., Monger and Nokleberg, 1996, and references therein). These strata exhibit a range of styles of deformation, and metamorphism from subgreenschist to greenschist facies. The Cache Creek terrane, in the eastern Intermontane belt (Fig. 1), is an accretionary complex of rocks formed in oceanic environments, with lesser volcanic arc strata. Rocks of oceanic affinity are Mississippian to Early Jurassic (Toarcian) in age and contain Permian Tethyan fauna that indicate an origin far from the North American craton margin (e.g., Struik et al., 2001). The structural style of Cache Creek terrane is dominated by southwest-vergent fold-and-thrust fault systems, superimposed in places on chaotic disrupted structures, and locally overprinted by northeast-verging fold systems (e.g., Gabrielse, 1991b; Struik et al., 2001; Mihalynuk et al., 2004). In the northern segment (Fig. 1), the Cache Creek terrane structurally overlies Stikinia, and locally Bowser basin strata, along the southwest-directed King Salmon fault (KSF, Fig. 1; e.g., Gabrielse, 1991b). In the southern segment (Fig. 1), the western accretionary boundary of Cache Creek terrane with Stikinia is obscured. In both segments, the eastern boundaries of Cache Creek terrane with Quesnellia are Cretaceous and
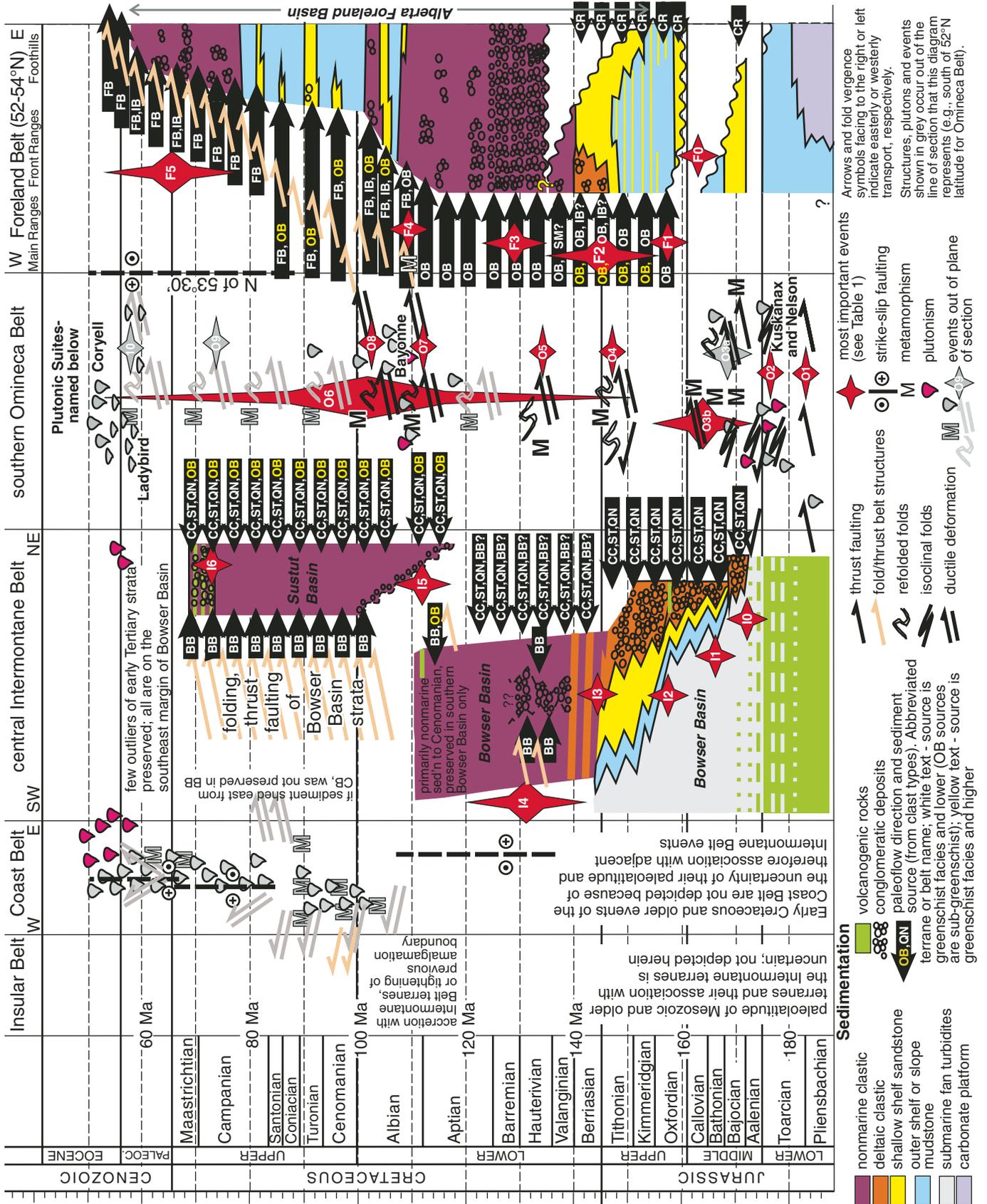
Figure 3. Chart illustrating late Early Jurassic to early Eocene tectonic events in the Canadian Cordillera, with emphasis on the central Intermontane, southern Omineca, and southern Foreland belts. Events labeled with red stars are discussed in the text; a summary of events and sources of information are provided in Table 1 and in the text. CC—Cache Creek; ST—Stikinia; QN—Quesnellia; BB—Bowser basin; OB—Omineca belt; FB—Foreland belt; SM—Slide Mountain; IB—Intermontane belt; CR—craton. Time scale here and elsewhere in text is after Gradstein et al. (2004).

◀

Cenozoic dextral strike-slip faults such as the Thibert and Pinchi faults, in the north and south, respectively (Fig. 1; Gabrielse, 1985; Struik et al., 2001). The latter is inferred to overprint the Triassic–Jurassic Pinchi suture (Struik et al., 2001). Quesnellia is an arc terrane similar to Stikinia in general age and lithology (e.g., Monger and Nokleberg, 1996; Beatty et al., 2006). Significant differences occur in their pre-Triassic stratigraphy (e.g., Monger and Nokleberg, 1996), and Quesnellia has stratigraphic and structural ties with pericratonic Kootenay terrane, Slide Mountain terrane and the North American continental margin, which demonstrate that it probably formed adjacent to the continent (Beatty et al., 2006, and references therein). In addition, although Quesnellia has considerable north-south extent (Fig. 1), its map area is small relative to Stikinia. On the seismic-reflection profile that crosses most of the terranes in northern British Columbia, Quesnellia and Cache Creek are interpreted to form thin sheets (~2.5 km thick and ~7.5 km thick, respectively), whereas Stikinia is interpreted to be relatively thick (~35 km), comprising the entire crust above the Moho (Cook et al., 2004).

### Bowser Basin

Much of northern Stikinia is overlain by strata of the Bowser Lake Group (Fig. 1), which were deposited in the Bowser basin and comprise a widespread upper Middle Jurassic to mid-Cretaceous marine and nonmarine clastic succession at least 6000 m thick (Tipper and Richards, 1976; Eisbacher, 1981; Evenchick and Thorkelson, 2005). Skeena Group, Cretaceous in age, contains rocks similar to coeval facies of the Bowser Lake Group, but includes volcanic successions, and many exposures occur south of its northern limit in the southern Bowser basin (Bassett and Kleinspehn, 1997; Smith and Mustard, 2006). Sand and pebble clasts in Bowser basin strata are dominated in many places by radiolarian chert derived from Cache Creek terrane; these clasts demonstrate the stratigraphic link between Cache Creek terrane and Stikinia and record the final stages of closure of the Cache Creek ocean (Gabrielse, 1991b; Evenchick and Thorkelson, 2005; I0 in Fig. 3).

The Bowser Lake Group is a monotonous assemblage of sandstone, siltstone, and conglomerate lacking laterally continuous stratigraphic markers. Lithofacies assemblages interfinger laterally and repeat vertically on a range of scales (I0 to I3 in Fig. 3). Strata were deposited in submarine fan and interfan, slope, shallow-marine, deltaic, fluvial, and lacustrine environ-
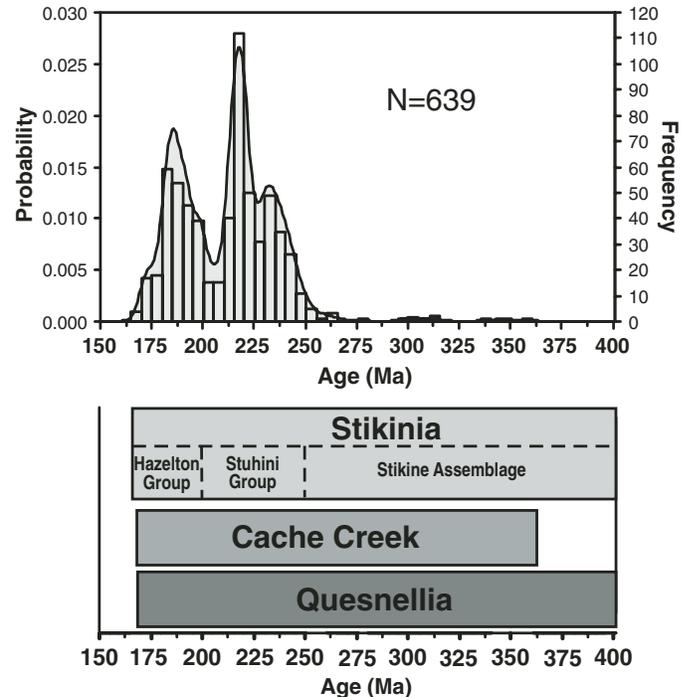


Figure 4. Cumulative probability plot of Bowser basin detrital zircon data for grains older than basin strata (Mississippian to early Middle Jurassic, ca. 360–169 Ma), from all Bowser basin samples (*n* = 21). Ages of rocks in Stikinia, Cache Creek, and Quesnellia are shown below. Of over 1435 single-grain analyses, 639 have ages older than the depositional age of strata in the basin. This diagram shows only the older Bowser basin data to highlight the ages of pre–Bowser basin sources. Potential source rock ages in Stikinia, Cache Creek and Quesnellia are from: Monger et al. (1991) and references therein; Monger and Nokleberg (1996) and references therein; Mihalynuk et al. (2004) and references therein; and Evenchick and Thorkelson (2005) and references therein.

ments from southeast, east, and northeasterly sources in an overall regressive basin history (Tipper and Richards, 1976; Evenchick and Thorkelson 2005, and references therein).

Integration of timing constraints from index fossils with the distribution of major lithofacies assemblages demonstrates the migration of facies boundaries through time (Evenchick et al., 2001; Fig. 3). From Bathonian through early Oxfordian time, the major depocenter was restricted to the north-northeastern part of the basin (I1 in Table 1; Fig. 3) and only a condensed marine section formed at the western side. Sections in the south are also relatively thin and fine grained compared to those in the northeast (Tipper and Richards, 1976). Between mid-Oxfordian and early Kimmeridgian time, there was rapid south and southwest migration of facies proximal to the source over more distal facies (I2 in Fig. 3). New mapping in the central Bowser basin (Evenchick et al., 2006) indicates that the shelf–slope break migrated ~200 km southwestward during this time. The result was a wide, shallow, marine shelf bounded on the southwest by a region of submarine fan deposition at least 80 km wide that, based on its marine fauna, was probably
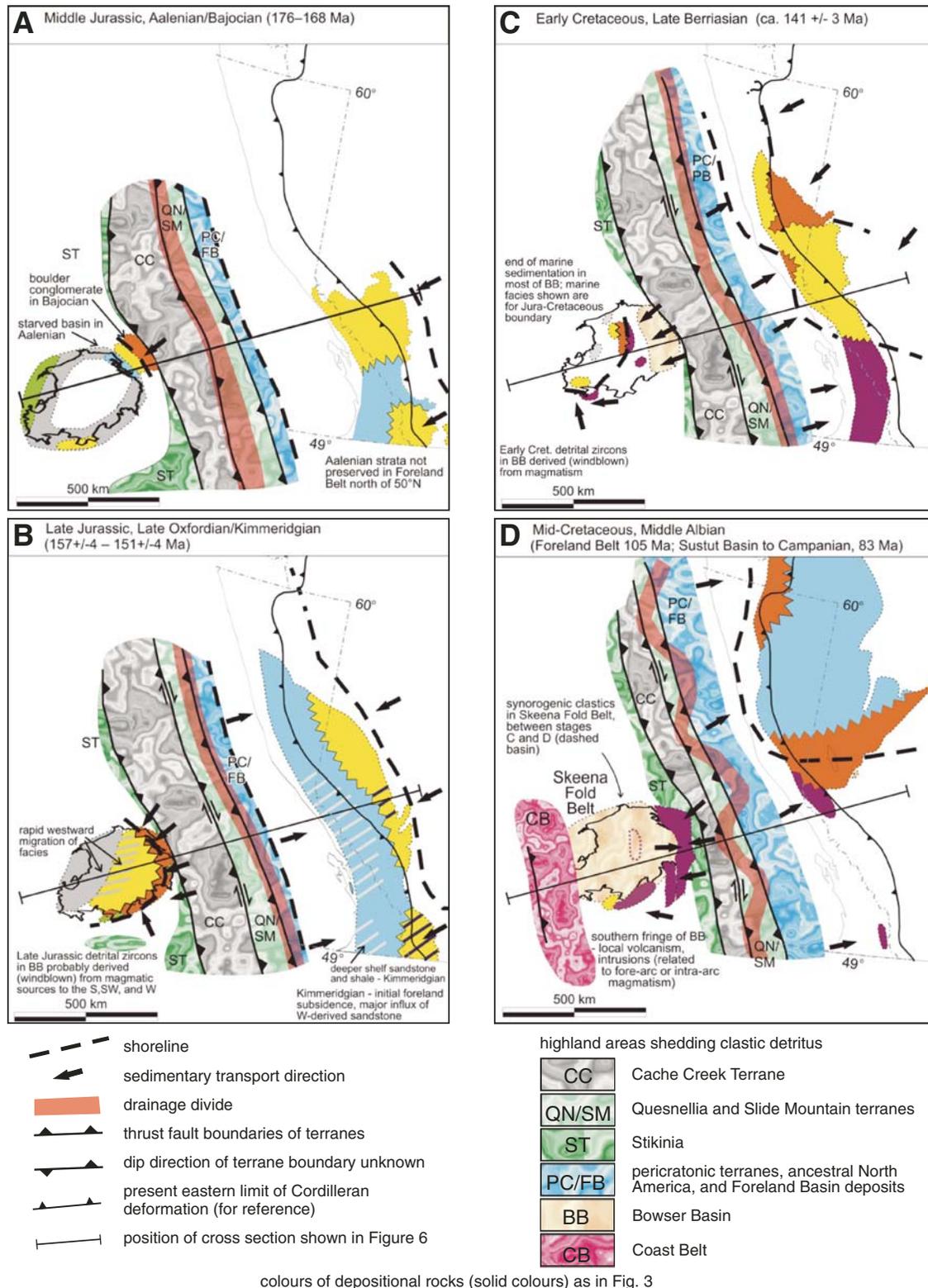
Figure 5 (*on this and following page*). Paleogeographic maps for the early Middle Jurassic through Late Cretaceous showing the inferred position of Bowser basin relative to cratonic North America (as discussed in text; North America is shown in present geographic coordinates), areas and types of sedimentation in the Bowser basin and Foreland belt, inferred source areas and drainage divide, and location of cross sections in Figure 6. The outline of the Bowser basin, with 50% shortening of the Skeena fold belt (SFB) restored, is shown for reference. Sources of information for deposition in the Bowser and Sustut basins are Eisbacher (1974a), Tipper and Richards (1976), Bassett and Kleinspehn (1997), Evenchick et al. (2001; and revisions based on new mapping in Evenchick et al., 2006), and Evenchick and Thorkelson (2005). Sources of information for facies belts in the Alberta foreland basin are Stott (1982, 1998), Hall (1984), Smith (1994), Poulton et al. (1994b), Stott et al. (1993), Leckie and Burden (2001), and McMechan et al. (2006).
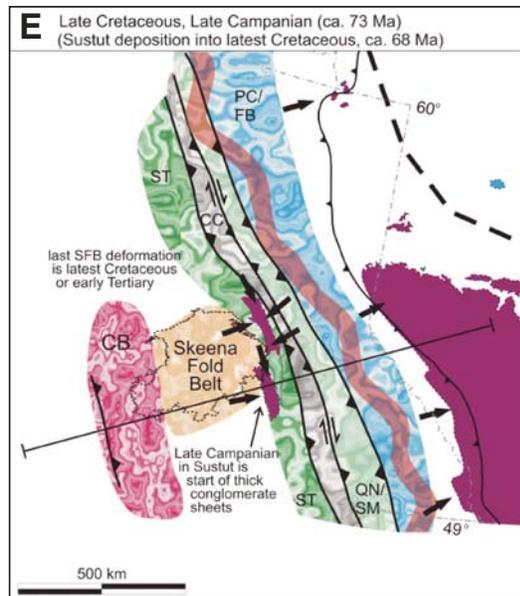
Figure 5 (*continued*).

open to the Pacific Ocean (Poulton et al., 1994a). Facies boundaries in the southern basin also migrated more rapidly than previously (Tipper and Richards, 1976). The shelf–slope break in the central and northern basin remained in about the same position into the latest Jurassic or earliest Cretaceous (I3 in Fig. 3); younger strata are absent in the western basin. In earliest Cretaceous time, deltaic and nonmarine strata were deposited in large parts of the northern basin, and nonmarine strata were deposited in the southern basin (Bassett and Kleinspehn, 1997; Smith and Mustard, 2006; V.J. McNicoll, 2006, personal commun.). By middle Early Cretaceous, these strata included thick conglomeratic braided river and alluvial fan deposits in the north-central Bowser basin (Eisbacher, 1974b; I4 in Fig. 3). Preserved strata of mid-Cretaceous age are restricted to the southern basin and are largely nonmarine clastic, but they include local volcanic centers and minor marine strata (Bassett and Kleinspehn, 1997). The youngest fluvial systems were probably continuous with the oldest Sustut fluvial systems deposited farther northeast. Ages of most Early Cretaceous strata are not narrowly constrained (Bassett and Kleinspehn, 1997; Evenchick and Thorkelson, 2005, and references therein; V.J. McNicoll, 2004, 2006, personal commun.). Deposition of detrital muscovite in the southern basin, likely starting in Aptian or Albian time, signals initiation of metamorphic Omineca belt detritus shed to the west (Bassett and Kleinspehn, 1997), and its initiation was roughly coeval with deposition of muscovite in the Sustut basin farther northeast (Eisbacher, 1974a; Evenchick and Thorkelson, 2005).

New provenance data that refine our understanding of the depositional history of the Bowser basin are provided by detrital zircons analyzed from sandstone samples that have paleontologically well-constrained depositional ages and from diverse ages, map units, and areas of the basin. The results, based on U-Pb

sensitive high-resolution ion microprobe (SHRIMP) analyses of over 1435 detrital zircons from 21 samples of Bowser Lake Group, ranging from Bathonian to earliest Cretaceous age, show that the Bowser basin was receiving detritus mainly from sources of Early Triassic age to as young as the depositional age of the rock sampled (Fig. 4; McNicoll et al., 2005). The source regions indicated by paleocurrents, clast types, and facies distribution of Bowser basin strata are Cache Creek terrane, Quesnellia, and Stikinia (e.g., Evenchick and Thorkelson, 2005, and references therein). These are potential sources for the detrital zircons that are older than Bowser basin strata (Fig. 4). However, the age of the youngest zircon population in each rock is indistinguishable from the paleontologically determined depositional age of the rock, and it is interpreted to have originated from wind-blown ash from sources south, southwest, and/or possibly west of the Bowser basin (McNicoll et al., 2005).

Regional relationships indicate that basin subsidence for the Jurassic and earliest Cretaceous Bowser basin was controlled, in part, by flexural subsidence resulting from sediment load and obduction of Cache Creek terrane, and by thermal subsidence resulting from cessation of arc-related magmatism within northern Stikinia (e.g., Eisbacher, 1981; Ricketts et al., 1992; Evenchick and Thorkelson, 2005); the role of dynamic subsidence in Bowser basin evolution is unknown. An outlier of Early Cretaceous braided river and alluvial fan deposits in the northern Bowser basin (I4 in Fig. 3) is interpreted to represent synorogenic deposition within the Skeena fold belt (Evenchick and Thorkelson, 2005).

### Sustut Basin

The Sustut Group is composed of more than 2000 m of Late Cretaceous nonmarine clastic strata (Eisbacher, 1974a). Since Eisbacher's (1974a) description and interpretation of the group, new constraints on the ages of units (A. Sweet, in Evenchick and Thorkelson, 2005), and additional stratigraphic and structural relationships, have clarified its tectonic significance (Evenchick and Thorkelson, 2005).

The lower of two formations, the Tango Creek Formation, is up to 1400 m thick and overlies Triassic to Late Jurassic units, including Bowser Lake Group, with angular unconformity (Eisbacher, 1974a). It is dominated by sandstone, siltstone, and mudstone, and in the upper part, by mudstone, calcareous siltstone, and calcareous sandstone. Paleocurrents, which in the lowest part are to the south and southwest, and high quartz clast content of sandstone are both consistent with the interpretation of derivation from a northeastern, Omineca belt source (Eisbacher, 1974a). Quartzite characteristic of Lower Cambrian miogeoclinal strata occurs as pebbles; these were also likely derived from the Omineca belt. In the middle and upper part of the formation, paleoflow to the northeast was accompanied by an increase in chert content in sandstone, interpreted as Cache Creek clasts recycled from Bowser Lake Group strata. The base of the formation is diachronous, ranging from Barremian–early Albian, to Coniacian–Campanian, and the upper age limit is late Campanian (I5 in Fig. 3).

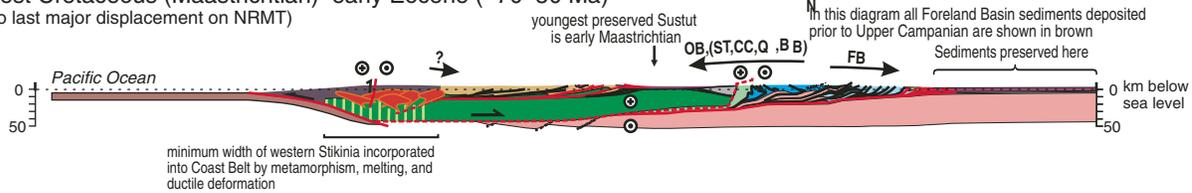Southwest                                                                                                    Northeast

**H** interpretation of present crustal structure of northern Canadian Cordillera based on seismic reflection
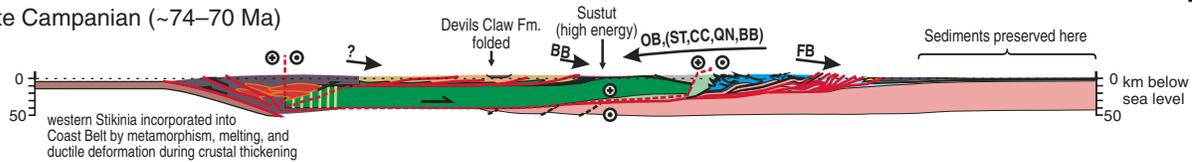
This interpretation of a seismic reflection profile of the northern Cordillera crossing the western Bowser Basin and Stikinia (modified from Evenchick et al., 2005) has similar structures and relationships between Stikinia, Cache Creek Terrane, and North American basement as the upper 35 km of the crust shown in section G below. The extent of North American basement for sections A through G is based on relationships in the southern Canadian Cordillera. In the interpretation depicted below, by the end of the Eocene Stikinia and overlying strata were displaced far northward relative to the North American basement that Stikinia overrode in the Jurassic. Section H is at same scale as sections A to G, and is aligned so that the eastern limit of Cache Creek Terrane is the same as in section G.
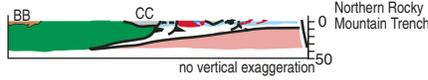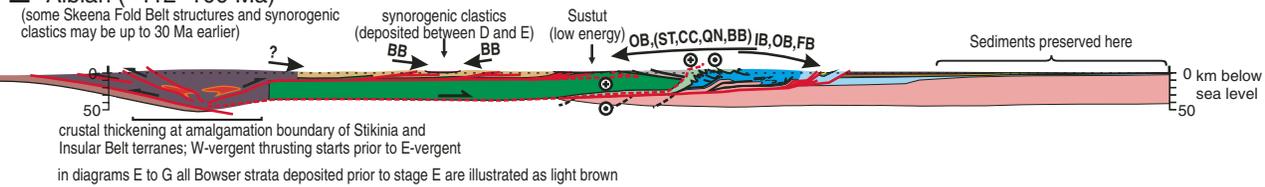
**G** latest Cretaceous (Maastrichtian)–early Eocene (~70–50 Ma)
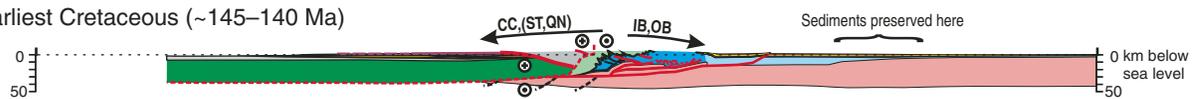(prior to last major displacement on NRMT)
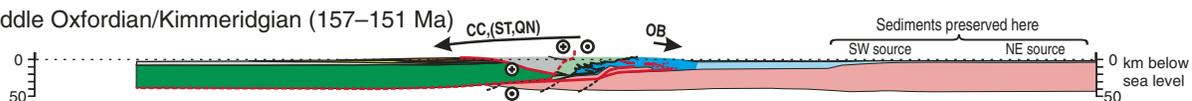
**F** Late Campanian (~74–70 Ma)

**E** Albian (~112–100 Ma)
(some Skeena Fold Belt structures and synorogenic clastics may be up to 30 Ma earlier)

crustal thickening at amalgamation boundary of Stikinia and Insular Belt terranes; W-vergent thrusting starts prior to E-vergent

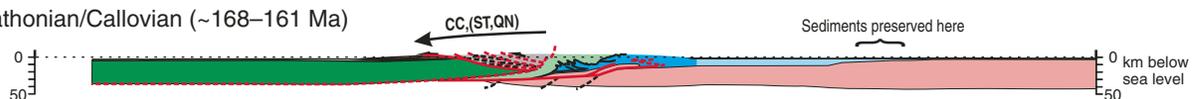in diagrams E to G all Bowser strata deposited prior to stage E are illustrated as light brown
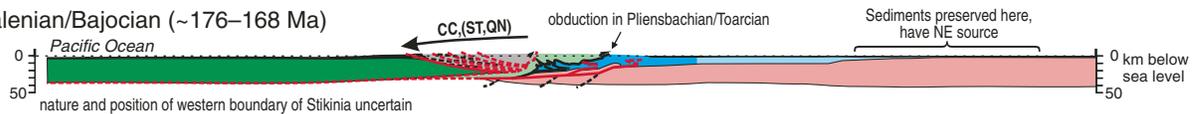
**D** Earliest Cretaceous (~145–140 Ma)

**C** Middle Oxfordian/Kimmeridgian (157–151 Ma)

**B** Bathonian/Callovian (~168–161 Ma)

**A** Aalenian/Bajocian (~176–168 Ma)

nature and position of western boundary of Stikinia uncertain



see Figure 3 for legend for Bowser, Sustut, and Alberta Foreland basins

50 km
no vertical exaggeration
100 km
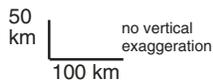
**Pre-Middle Jurassic strata**
North American craton
strata deposited on cratonic North America
pericratonic terranes
Quesnellia and Slide Mountain terranes
Cache Creek Terrane
Stikinia; Stikinia incorporated into Coast Belt
Coast Belt, composed of intrusions (orange), Insular Belt terranes, and Stikinia and Bowser Basin strata west of present exposures

sedimentary transport direction and sources of clasts; short forms as in Figure 3. Potential sources, but not required by data are in parentheses.
thrust fault
strike slip fault
structure active in time slice
structure inactive in time slice
inferred structures

Figure 6 (*on this and following page*). Cross sections illustrating major depositional, structural, metamorphic, and plutonic events in the region discussed in the text. Abbreviations are as in Figure 3. Note that zones of penetrative ductile strain are not depicted on the cross sections; please see text and Table 1 for documentation of structural style, particularly in the Omineca and Coast belts. The set with no vertical exaggeration shows structural relationships. The set with 3× vertical exaggeration is included to show the depositional units. The location of cross sections A, C, D, and E are given in Figure 5.
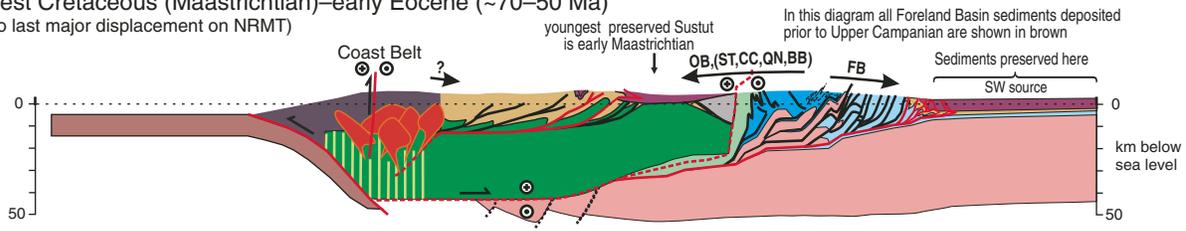
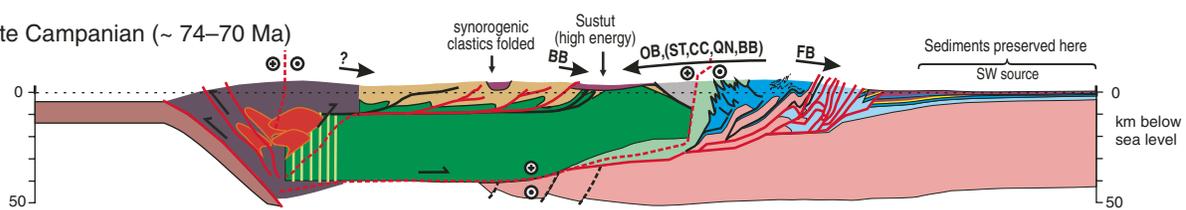Southwest                                                                                        Northeast

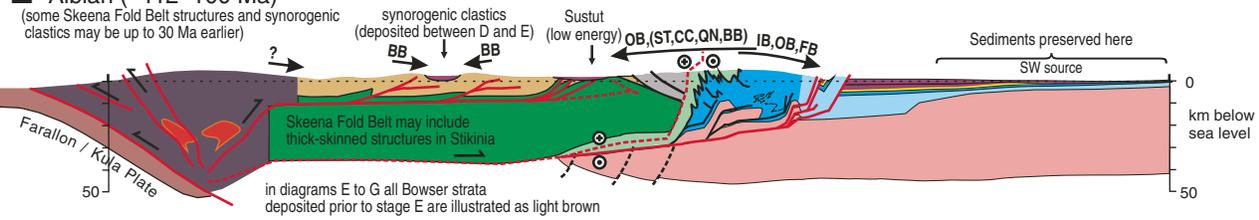**H** interpretation of present crustal structure
see page 1 of Figure 6 for explanation
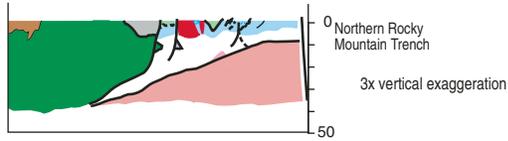
0  Northern Rocky
   Mountain Trench

3x vertical exaggeration

50

**G** latest Cretaceous (Maastrichtian)–early Eocene (~70–50 Ma)
(prior to last major displacement on NRMT)

youngest preserved Sustut
is early Maastrichtian

In this diagram all Foreland Basin sediments deposited
prior to Upper Campanian are shown in brown

Coast Belt                                     OB$_3$(ST,CC,QN,BB)        FB        Sediments preserved here
                                                                                   SW source

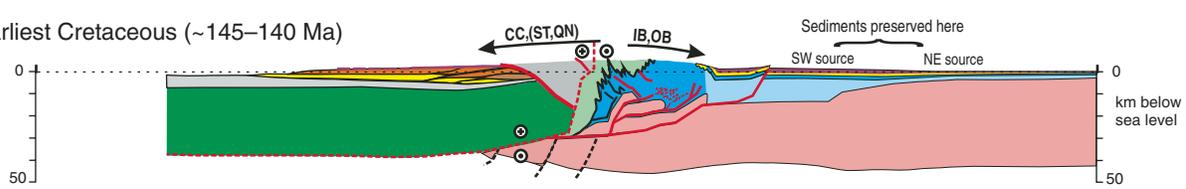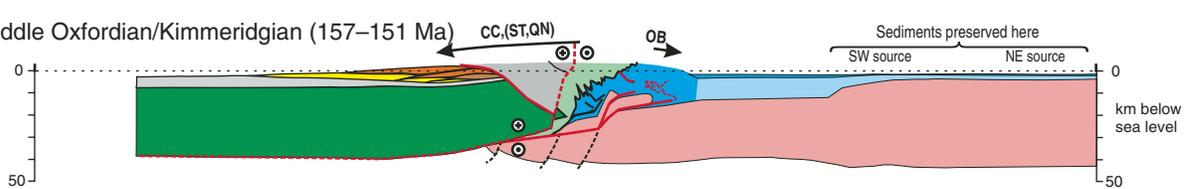0                                                                                                    0

                                                                                   km below
                                                                                   sea level

50                                                                                                   50
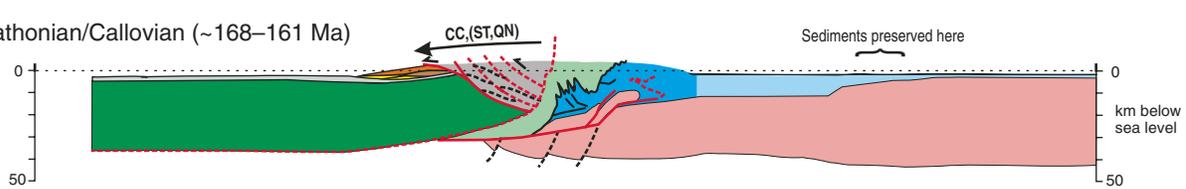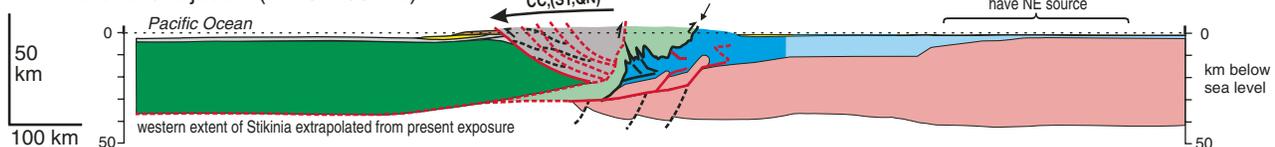
approximately 430 km northward translation of Stikinia, Bowser and Sustut basins

**F** Late Campanian (~ 74–70 Ma)

synorogenic
clastics folded      Sustut
                     (high energy)
              BB     OB$_2$(ST,CC,QN,BB)    FB          Sediments preserved here
                                                        SW source

0                                                                                                    0

                                                                                   km below
                                                                                   sea level

50                                                                                                   50

**E** Albian (~112–100 Ma)
(some Skeena Fold Belt structures and synorogenic
clastics may be up to 30 Ma earlier)

synorogenic clastics
(deposited between D and E)        Sustut
       BB        BB                (low energy)   OB$_1$(ST,CC,QN,BB)  IB,OB,FB   Sediments preserved here
                                                                                 SW source

0                                                                                                    0

Farallon / Kula Plate

Skeena Fold Belt may include
thick-skinned structures in Stikinia                                              km below
                                                                                  sea level

in diagrams E to G all Bowser strata
deposited prior to stage E are illustrated as light brown

50                                                                                                   50

**D** Earliest Cretaceous (~145–140 Ma)

CC$_1$(ST,QN)    IB,OB           Sediments preserved here

                                 SW source    NE source

0                                                                                                    0

                                                                                   km below
                                                                                   sea level

50                                                                                                   50

approximately 360 km northward translation of Stikinia and Bowser Basin

**C** Middle Oxfordian/Kimmeridgian (157–151 Ma)

CC$_1$(ST,QN)    OB          Sediments preserved here

                             SW source    NE source

0                                                                                                    0

                                                                                   km below
                                                                                   sea level

50                                                                                                   50

**B** Bathonian/Callovian (~168–161 Ma)

CC$_1$(ST,QN)                Sediments preserved here

0                                                                                                    0

                                                                                   km below
                                                                                   sea level

50                                                                                                   50

**A** Aalenian/Bajocian (~176–168 Ma)

Pacific Ocean          CC$_1$(ST,QN)    obduction in Pliensbachian/Toarcian   Sediments preserved here,
                                                                              have NE source

0                                                                                                    0

50                                                                                 km below
km                                                                                 sea level

100 km      western extent of Stikinia extrapolated from present exposure           50

Figure 6 (*continued*).

The Tango Creek Formation is abruptly and conformably overlain by the Brothers Peak Formation, which is characterized by polymict conglomerate, sandstone, and felsic tuff (Eisbacher, 1974a). A basal conglomeratic succession is commonly more than 50 m thick. Paleocurrents were primarily southeast, longitudinally down the basin, with input from the north, east, and west (Eisbacher, 1974a). Strata are late Campanian to late early Maastrichtian (A. Sweet, in Evenchick et al., 2001). Two felsic tuff layers in the formation have been dated at ca. 75 and ca. 71 Ma (V.J. McNicoll, 2004, personal commun.). The dramatic change upward from the mudstone and siltstone of the upper Tango Creek Formation to the conglomerate-rich base of the Brothers Peak Formation (I6 in Fig. 3) indicates a marked increase in energy of Sustut fluvial systems.

Paleocurrent and clast types show that initial Sustut basin deposits had an eastern Omineca belt source that continued throughout the depositional history; however, early in this history, development of the Skeena fold belt provided an additional, southwest, source of sediment (Eisbacher, 1974a). Detrital zircon data show that the Sustut basin shared similar Triassic to Early Cretaceous sources with the Bowser basin, and/or zircons were recycled from the Bowser basin (McNicoll et al., 2005). In contrast, the Sustut basin also received Archean, Paleoproterozoic, Mesoproterozoic, Paleozoic, and Late Cretaceous zircons that are clearly distinct from Bowser basin sources (McNicoll et al., 2005) and are consistent with provenance studies of the Sustut Group that illustrate an Omineca belt source in the late Early Cretaceous (Eisbacher, 1974a).

### Skeena Fold Belt

The Skeena fold belt is a regional fold-and-thrust belt that is best expressed in the thinly bedded clastic rocks of the Bowser and Sustut basins, but also involves Stikinia, as shown by folded contacts, structural culminations of Stikinian rocks within the fold belt, and klippen of early Mesozoic Stikinian rocks on Cretaceous Sustut basin strata. Details of the geometry, magnitude of shortening, and timing of the fold belt have been documented by Evenchick (1991a, 1991b, 2001) and Evenchick and Thorkelson (2005). The fold belt has accommodated a minimum of 44% (160 km) northeasterly shortening, it locally terminates to the northeast in a triangle zone within the Sustut basin, and is inferred to root to the west in the Coast belt.

Folds of a range of scales, from several hundred meters to a kilometer or more in wavelength, are the most obvious structures, and northwest-trending fold trains occupy most of the fold belt. Most verge northeast, and they vary from upright to overturned. Thrust faults in Bowser strata are apparent where they juxtapose the Bowser Lake Group against other map units, but they are difficult to recognize in most of the basin unless hanging-wall or footwall cutoffs are exposed. Thrust faults and/or detachment zones are required by the style of folding and are inferred to be largely bedding-parallel, blind thrusts (Evenchick, 1991b).

The age of the fold belt is constrained by regional stratigraphic relationships. The youngest folded marine Bowser basin strata, deposited at the Jurassic–Cretaceous boundary, lack a western source or other indications that the fold belt had evolved significantly. Sustut basin strata unconformably overlie contractional structures that involve Bowser basin and Stikinia strata, illustrating contractional deformation and erosion of Stikinian and Bowser strata in the northeast prior to the Albian (I5 in Fig. 3). Uppermost Sustut Group strata are the youngest deformed rocks. Western Skeena fold belt structures are overlain by flat-lying Pliocene volcanic rocks (Evenchick and Thorkelson, 2005). These relationships demonstrate that the fold belt was initiated in the Early Cretaceous with at least some deformation prior to the Albian, and that it ended in latest Cretaceous or early Cenozoic time.

Direct constraints on the magnitude of shortening for specific structures and/or time periods are sparse. A ca. 84 Ma post-tectonic pluton near the central Bowser basin intruded Late Jurassic strata and constrains deformation there to between Late Jurassic and Campanian (Evenchick and McNicoll, 1993). Synorogenic clastic rocks include an Early Cretaceous piggyback basin in the north-central part of the fold belt, which records Early Cretaceous (I4 in Fig. 3) subaerial erosion of topographic highs in the central and eastern fold belt. The Sustut Group itself is synorogenic and records a western source (Skeena fold belt) from Albian through early Maastrichtian time. Angular unconformities within the lowest Sustut strata are indications of Albian or Cenomanian tectonism in the northeastern fold belt. The dramatic change within the Sustut Group from low- to high-energy fluvial systems at the base of the Brothers Peak Formation (I6 in Fig. 3) indicates increased relief in the late Campanian.

## Coast and Insular Belts

The Coast belt is composed mainly of Middle Jurassic to early Cenozoic plutonic rock and lesser amounts of greenschist- to amphibolite-, and locally granulite-facies metamorphic rock (e.g., Gabrielse et al., 1991). In the northern Coast belt (Fig. 1), Cretaceous continental arc magmatism, interpreted to be associated with accretion of terranes and subduction of Farallon, Kula, and possibly Resurrection plates, migrated eastward, resulting in a western 105–90 Ma arc and an eastern 80–50 Ma arc, separated by the Coast shear zone (e.g., Crawford et al., 2005, and references therein). Contractional deformation of these arcs resulted in significant crustal thickening in the mid-Cretaceous, continuing to ca. 60 Ma; arc igneous activity ended at ca. 50 Ma with the beginning of a period of extension, and the eastern side of the arc was exhumed on bounding shear zones (e.g., Andronicos et al., 2003; Crawford et al., 2005). Farther west, the Insular belt consists of little metamorphosed Late Proterozoic to early Mesozoic volcanic arc terranes (mainly Wrangellia and Alexander) that are stratigraphically distinct from the more inboard terranes (e.g., Monger and Nokleberg, 1996, and references therein). Additional components of the Insular belt are minor late Mesozoic and Cenozoic accretionary complexes (e.g., Gabrielse et al., 1991) and Proterozoic to Paleozoic metamorphosed continental-margin

sequences (e.g., Gehrels and Boghossian, 2000, and references therein). The western boundaries of Stikinia and the Bowser basin are within the Coast belt, but their relationships with Insular belt terranes are obscured by the large volume of intrusive rocks, medium- to high-grade metamorphism, and high-strain zones; thus, the timing of amalgamation of terranes of the Intermontane and Insular belts is controversial. It was either in the Jurassic or earlier (e.g., van der Heyden, 1992; McClelland et al., 1992) or the mid-Cretaceous (e.g., Monger et al., 1982). Uncertainty in the accretion history and in magnitude of postaccretion orogen-parallel translation leads to uncertainties about the Middle Jurassic to early Cenozoic paleogeography of these terranes. For these reasons we discuss only Cretaceous and early Cenozoic features of significant strike length, and only in general terms. Examples are: Cretaceous northeast-vergent contractional structures on the east side of the Coast belt that merge with contractional structures in the Intermontane belt (e.g., Evenchick, 1991a, 1991b; Journeay and Friedman, 1993; Rusmore and Woodsworth, 1994); mid-Cretaceous crustal thickening and magmatism (e.g., Crawford et al., 1987, 2005); and west-vergent contractional structures on the west side of the Coast belt (e.g., Rubin et al., 1990; Journeay and Friedman, 1993).

## MESOZOIC TECTONIC EVOLUTION

### Paleogeographic Reconstructions—Restoration of Jurassic to Eocene Orogen-Parallel Faults

Discussion of the Mesozoic evolution of the Bowser basin and Skeena fold belt in the context of tectonism in the Omineca and Foreland belts requires restoration of displacement on orogen-parallel strike-slip faults within and bordering the Omineca belt (Fig. 1). The discrepancies between geological and paleomagnetic estimates of dextral motion in the Late Cretaceous and Eocene have been reviewed and discussed by Gabrielse et al. (2006). The amount of Late Cretaceous to Eocene dextral displacement on the array of faults including the Tintina, Northern Rocky Mountain Trench fault, and related splays (Fig. 1) is estimated to be 490 km, with 430 km primarily in the Eocene, and ~60 km on the Northern Rocky Mountain Trench fault in early Late Cretaceous (Gabrielse et al., 2006). Additional strike-slip faults of this age are the Kechika-Spinel (80 km; a splay of the Northern Rocky Mountain Trench fault), and the Pinchi fault. The magnitudes and specific ages of older displacement on these faults, and of older faults, are less well constrained. Offset of lower Paleozoic facies boundaries suggest a total of ~700 km displacement (Gabrielse et al., 2006) on the Northern Rocky Mountain Trench fault; if 490 km of this was in the Late Cretaceous to Eocene, earlier displacement must have been ~210 km. Other Late Cretaceous or older fault systems to consider are (see Fig. 1): (1) the pre-Eocene part of the Kechika-Sifton fault, a splay of Northern Rocky Mountain Trench (~90 km); (2) the Kechika-Thudaka-Finlay-Ingenika-Takla system (~110 km); and (3) the Cassiar-Kutcho-Thibert system, which must be younger than the

early Middle Jurassic (or younger) contractional structures and Early Jurassic intrusions that they displace. Faults of the latter two fault systems that cut the Cassiar batholith are considered to be synchronous with intrusion of the batholith at ca. 95–110 Ma (Gabrielse et al., 2006).

Figure 5A reconstructs the paleogeography of the early Middle Jurassic to account for the faults listed previously. Their continuation to the south as discrete structures is problematic (see Gabrielse et al., 2006), which makes an accurate paleogeographic reconstruction challenging. Accordingly, we restore Stikinia and the Bowser basin southward to approximately the latitude indicated by strike-slip faults in the north (~800 km), yet outboard enough to allow for shortening in the Foreland and Omineca belts (~300 km), stacking of terranes in the Omineca belt, and Eocene extension. Following Gabrielse (1985), we depict the Cache Creek terrane and Quesnellia in Figure 5A as continuous belts, with Cache Creek in thrust fault contact with Stikinia. In doing so, we assume that most of the later dextral fault displacement occurred within and/or between Cache Creek terrane and Quesnellia and is now obscured by Paleogene and younger strata of the southern Intermontane belt. Stikinia and the Bowser basin are restored with clockwise rotation from the present orientation, which in part reflects the restoration of known faults and allows for rotation about the Euler pole during northward translation (Price and Carmichael, 1986). To depict the minimum original width of Stikinia and the Bowser and Sustut basins, horizontal shortening of the Skeena fold belt, estimated at ~50%, is restored from across the Bowser basin, from more than half of the Sustut basin and most of Stikinia.

This reconstruction puts the Bowser basin adjacent to the site of the southern Canadian Cordillera at the time of final closure of the Cache Creek ocean in the Aalenian-Bajocian, just prior to the onset of major clastic deposition. In the absence of constraints on net displacements on strike-slip faults for specific periods, we assume, from Gabrielse et al. (2006), that dextral displacements were (1) ~300 km between Middle Jurassic and mid-Cretaceous time, with ~100 km on the fault systems west of the Northern Rocky Mountain Trench fault and 200 km on the Northern Rocky Mountain Trench fault, and (2) ~500 km on the Northern Rocky Mountain Trench–Tintina faults and related splays in the Late Cretaceous to late Eocene.

### Relationship of Structures in Neighboring Intermontane, Omineca, and Foreland Belts, and Development of Basins and Fold-and-Thrust Belts Flanking the Omineca Belt

In the following sections, the major deformation, metamorphic, magmatic, and depositional events in the north-central and southeastern Canadian Cordillera are summarized for a series of time periods from the Middle Jurassic to Early Cretaceous, with emphasis on the regions that became the Intermontane, Omineca, and Foreland belts. The morphogeologic belt terminology applies to the Cordillera today; however, we use the terms as a convenient way to refer to regions that eventually

became the belts. Cross sections (Fig. 6) for each time period show the tectonic evolution and relationships between events in neighboring belts, such as links between highland sources and basins of deposition. Although the cross sections are drawn with the east side fixed relative to eastward translation of terranes and structures, events described are the result of the North American plate moving westward relative to the hot-spot reference frame, with its western convergent plate boundary interacting with, and accumulating, parts of microcontinents, volcanic arcs, and intervening ocean basins of the Pacific Ocean—the future terranes of the Cordillera (e.g., Engebretson et al., 1985; Coney and Evenchick, 1994). Deposition in the Bowser and Alberta Foreland basins, shown in Figure 5, and development of mid-crustal structures in the Omineca belt and those in the upper crust in the Foreland belt, shown in Figure 6, are relatively well constrained because they are now exposed, are confidently inferred by plunge projection of structures, or have been drilled by hydrocarbon exploration wells. The geometry of the boundary between the Cache Creek terrane and Quesnellia in Figure 6, however, is highly uncertain because the only contacts known are the dextral faults that may obscure possible earlier low-angle faults. Other geometries that satisfy the constraint of the Cache Creek terrane forming a major part of the source region for clasts deposited in the Bowser basin are possible. The thickness of Stikinia in Figure 6 is interpreted from seismic sections (Cook et al., 2004), but its thickness through time is poorly constrained. It could have been significantly thinner in the Jurassic and later thickened by a combination of thin- and thick-skinned contractional structures during formation of the Skeena fold belt, with inversion of early Mesozoic extensional structures. The nature and position of the original western boundary of Stikinia are poorly constrained, and thus only the palinspastically restored width of exposed Stikinia strata is represented Figure 6.

### Early Jurassic–Pliensbachian/Toarcian (ca. 190–176 Ma)

Prior to the Middle Jurassic, Stikinia was separated from cratonic North America by a region of marginal or pericratonic terranes, Quesnellia, and the last vestiges of the Cache Creek ocean, which was closing probably as a result of southwest subduction beneath Stikinia and northeast subduction beneath Quesnellia (e.g., Mortimer, 1987; Marsden and Thorkelson, 1992). Upper parts of Cache Creek terrane were delaminated to form the accretionary complex that now sits in thrust contact above Stikinia. Deposition in the Cache Creek ocean ended in the latest Early Jurassic (Toarcian; e.g., Struik et al., 2001), and northern Stikinia evolved from a region of widespread subduction-related volcanism in the Pliensbachian and earlier, to a largely marine clastic environment with minor volcanism by the Aalenian-Bajocian (Fig. 3; e.g., Marsden and Thorkelson, 1992; Anderson, 1993). The structural overlap of Quesnellia over North American basement at this time is documented by changes in the geochemistry of volcanic-arc rocks (Ghosh and Lambert, 1995) and the geochemistry and composition of detritus in volcaniclastic sediments of the arc (Petersen et al., 2004). Early Jurassic I-type

intrusions of the Kuskanax and Nelson Suites indicate the presence of a subduction zone, and their isotope geochemistry indicates primitive signatures contaminated with that of continental North America (Armstrong, 1988; Ghosh and Lambert, 1995). In northern Quesnellia, there was increasing cratonal influence on granitic rocks of Triassic to mid-Cretaceous age (Gabrielse, 1998). Quesnellia and Slide Mountain terranes were obducted onto the North American pericratonic terranes and imbricated and thrust eastward along the Eureka, Pundata, Stubbs, and related faults between ca. 187 and 173 Ma (O1 in Fig. 3; Murphy et al., 1995, and references therein). Obduction was closely followed by the onset of southwest-directed thrusts and isoclinal recumbent folding, which continued in the Middle Jurassic (O2 in Fig. 3). Dating of east-vergent structures in eastern Quesnellia in the east-central Intermontane belt indicates that the initial stages of obduction there occurred at ca. 186 Ma (Nixon et al., 1993). In the Foreland belt, a Sinemurian to middle Toarcian cherty carbonate platform south of 54°N changed westward and northward into a narrow belt of shale and carbonate sandstone and then into a westward thinning unit of phosphatic mudstone and limestone (Asgar-Deen et al., 2004). All facies in the Foreland belt were overlain by a thin, euxinic, black shale deposited during the worldwide Toarcian (anoxic black shale) "transgressive" event (Poulton et al., 1994b).

### Early Middle Jurassic–Aalenian/Bajocian (ca. 176–168 Ma)

An early phase of Bowser basin deposition began with subsidence in the northeast, marked by a starved phase in the Aalenian, and followed in the Bajocian by deposition of subaerially eroded Cache Creek strata in the northeasternmost part of the basin (I0 in Fig. 3; Fig. 6A). These events are interpreted to be a result of southwest thrusting of Cache Creek strata onto Stikinia (Gabrielse, 1991b; Ricketts et al., 1992). Stacking of Quesnellia and pericratonic terranes onto or against Cache Creek probably facilitated crustal thickening in the source area (Fig. 6A). Some of the first Cache Creek chert clasts deposited in the Bowser basin are close in age to the youngest blueschist ($173.7 \pm 0.8$ Ma) resulting from Cache Creek subduction, a relationship interpreted by Mihalynuk et al. (2004) to indicate rapid exhumation of northern Cache Creek strata at ca. 174–171 Ma. In the northern part of the south segment of Cache Creek terrane, westward obduction of Cache Creek onto Stikinia occurred between 190 and 165 Ma, and west-vergent structures were overprinted by east-vergent ones (Struik et al., 2001).

In the Omineca belt, the formation of large southwest-verging, recumbent isoclinal folds and polyphase deformation record progressive crustal thickening and low- to medium-grade regional metamorphism (O1–O3 in Table 1; Fig. 3). By ca. 173–168 Ma, northeast-verging fold and fault systems were superimposed on southwest-verging fold systems, south of 52°N, as indicated by the relationships of syn- and post-tectonic ca. 173–168 Ma plutons of the Kuskanax and Nelson plutonic suites in the Selkirk and Purcell Mountains (Armstrong, 1988; Parrish and Wheeler, 1983; Colpron et al., 1998; Gibson, 2003; O2 in Table 1; Fig. 3).

North of 52°N, polyphase southwest-verging fold systems in the Cariboo Mountains and thrust faults at higher structural levels were coeval with northeastward thrusting on shear zones and penetrative deformation at depth (O3b in Table 1; Fig. 3; Struik, 1988). Following Price (1986), Struik (1988), and Murphy (1989), we use a tectonic wedge model with southwest-directed back thrusting and folding of the cover above northeast-directed detachments and thrusting of the craton to explain the geometry and structural evolution of the internally deforming and thickening crust (Fig. 6A). In the Foreland belt, 30–90 m of shelf mudstone and northeasterly derived sandstone were deposited in the Bajocian and possibly Aalenian (Fig. 3; Hall, 1984).

The western Omineca belt and eastern Intermontane belt collectively defined a growing region of structurally thickened Cache Creek, Quesnellia, and pericratonic terranes, the growth of which was concomitant with the onset of westward deposition of Cache Creek detritus into the Bowser basin. Changes in structural vergence are present in both Intermontane (Cache Creek) and Omineca belt rocks and may indicate the onset of decoupling of supracrustal rocks from the westward underthrusting of North America. Coincident timing of southwest-verging structures in the Omineca belt with southwest thrusting of Cache Creek on Stikinia has been used to suggest a link between the southern Omineca belt and Stikinia at this time (Ricketts et al., 1992). The size and types of clasts that were deposited in the Bowser basin record deposition from the west side of the Omineca highland, in high-energy conditions, during rapid exhumation of Cache Creek strata, and they provide further evidence for linkage between these realms. The structurally thickened crust and emerging highland had little effect on the sedimentary record preserved in the Foreland belt over 350 km to the east (Figs. 3, 5A, 6A), suggesting that the loading occurred on weak lithosphere too far to the west to have elastically depressed the thick craton to the east.

### Late Middle Jurassic–Bathonian/Callovian (ca. 168–161 Ma)

A major increase in deposition of chert-rich detritus in the northeastern Bowser basin began in the Bathonian, with up to 3000 m of strata deposited in base-of-slope to deltaic environments, and expansion of the extent of Cache Creek chert clasts ~130 km farther southwest than in the Bajocian (I1 in Table 1; Figs. 3 and 6B). Rapid denudation of northern Stikinia or the Cache Creek terrane is indicated by deposition of ca. 161 Ma dacite boulders in the early Callovian slope assemblage of the Bowser basin (Ricketts and Parrish, 1992). The development of fan deltas in the northern part of the basin demonstrates high sedimentation rates (Ricketts and Evenchick, 1991, 2007). Sections of this age elsewhere in the basin are considerably finer grained and thinner and lack the spectacular submarine channel deposits present in the north. This scenario continued into the early Oxfordian, with ~30 km of south and southwest migration of facies boundaries. Southern Bowser basin facies migrated northerly away from a westerly trending arch of Stikinia that defined the south margin of the basin (Tipper and Richards, 1976).

In the Omineca belt, the crust was 50–55 km thick or greater (O3 in Table 1), and it likely formed a broad highland that was internally deforming as it was being translated toward the craton (Table 1; Fig. 6B). Southwest-verging polyphase folding was ongoing in the Cariboo and Monashee Mountains (Reid, 2003; O3b in Fig. 3), but elsewhere, upright folds and northeastward-verging fold systems and faults dominated after ca. 168–167 Ma (Warren, 1997; Colpron et al., 1998; Gibson, 2003; O3a in Fig. 3). The peak of regional metamorphism occurred at ca. 165–160 Ma, although at higher structural levels, it had started to wane (Gerasimoff, 1988; Warren, 1997; Parrish, 1995). Plutons of ca. 167–159 Ma age, within the Nelson Suite, crosscut large-scale belts of folds (e.g., Scrip nappe, early Selkirk fan, Dogtooth structure, and Kootenay arc), indicating that the architecture of these belts had largely formed by the end of the Middle Jurassic (Warren, 1997, and references therein). In the southwest Foreland belt, an 80-m-thick Bathonian section appears to provide the first record of increased subsidence due to tectonic loading (Poulton et al., 1993), and the local presence of cherty quartz-arenites provides the first evidence of a western source area (Stronach, 1984). Elsewhere in the Foreland belt, the first preserved record of west-derived sediments occurs in the Upper Jurassic (Bally et al., 1966; Poulton, 1984; Poulton et al., 1993; Fig. 3). A period of pre-Oxfordian uplift removed much of the Middle Jurassic record in the eastern Foreland belt.

In summary, links across the orogen may be inferred from evidence for continued growth of the Omineca highland, which loaded the lithosphere and affected the sedimentation patterns of adjacent basins as it was translated inboard from distal transitional crust that was significantly thinned during Proterozoic and early Paleozoic rifting, onto thicker, more rigid transitional crust. This is expressed in the northeastern Bowser basin by substantially thicker and more widespread deposits sourced from the Cache Creek terrane, and in the Foreland belt by the first, but limited, westerly derived foreland basin sediments. A time-transgressive Callovian–Oxfordian erosive disconformity developed across the Foreland belt (F0 in Fig. 3) and adjacent craton, marking the northeastward migration of the forebulge (Poulton, 1984). Detrital zircon analyses from Bowser basin strata indicate that in addition to wind-blown ash, the source areas were Triassic to Middle Jurassic in age (McNicoll et al., 2005). These data, combined with paleocurrents, facies distribution, and clast types in the Bowser basin indicate that the Cache Creek, and Stikine, and/or Quesnel terranes (Fig. 4) formed the upper structural levels of at least the western Omineca highland, and that no cratonic North American detritus was being shed to the west (Fig. 6B).

### Late Jurassic–Middle Oxfordian/Kimmeridgian (ca. 158–151 Ma)

Starting in the middle Oxfordian, the Bowser basin changed from a relatively narrow northeastern depocenter of base-of-slope to deltaic deposits, to widespread deposition when the shelf–slope break migrated ~200 km west (I2 in Table 1; Figs. 3, 5B, and 6C). The result was accumulation of up to 2 km of shelf

deposits in the central basin, and over 4 km of submarine fan deposits in the western basin. Deltas migrated westward to occupy much of the northeastern basin. Facies boundaries in the southern basin also migrated rapidly, and pebbly deposits became widespread there for the first time, accompanied by local volcanic flows in the Oxfordian (Tipper and Richards, 1976). Regionally, the dominant pebble and sand type remained Cache Creek radiolarian chert (e.g., Evenchick and Thorkelson, 2005, and references therein), but at the basin's southern margin, clasts reflect a local source of Stikinia strata from the arch to the south.

In the Omineca belt between 52°N and 53°N, a zone of medium-grade metamorphism that trends approximately northnorthwest across the Cariboo, Monashee, and Selkirk Mountains represents the deepest exposed levels of rocks at this latitude. These rocks preserve evidence of penetrative shortening throughout the Late Jurassic and Early Cretaceous accompanied by metamorphism, folding, shearing, and reactivation of structures (Ferguson, 1994; Currie, 1988; Digel et al., 1998; Crowley et al., 2000; Reid, 2003; Ghent and Simony, 2005, and references therein). Deformation progressed northeastward and carried the accreted terranes farther onto the craton (Fig. 6C). South of 52°N, post-tectonic plutonism and cooling indicate rapid exhumation and quenching at higher structural levels in the Late Jurassic (Warren, 1997, and references therein), providing a source for sediments deposited in the Alberta foreland basin. Pronounced flexural subsidence and development of a two-sided foredeep trough in the Alberta foreland basin began in the Oxfordian. Immense quantities of west-derived silty mud were transported into the trough along its western side at the same time as thin, craton-derived, basal, transgressive sandstone was deposited along its eastern side (Poulton, 1984; Stott, 1998; F1 in Fig. 3). Pronounced subsidence continued through the Kimmeridgian, and sands containing detrital chert, stretched quartz, and mica derived from sedimentary or metasedimentary rocks were deposited into the trough from the west (Hamblin and Walker, 1979). These are the first indications of an Omineca belt source for the Alberta foreland basin; however, isotope geochemistry studies of these strata have not detected juvenile material from the accreted terranes (Ross et al., 2005; F2 in Fig. 3; Fig. 6C).

We conclude that links across the orogen in the Oxfordian can be inferred from events within the Omineca belt and significant changes in regions bordering it. The Omineca highland was likely maintained by continued internal structural thickening during northeastward translation of the Omineca belt core relative to the North American craton. To the west, the Bowser basin experienced a dramatic westward migration of facies boundaries, indicating sustained topography in the source areas, and to the east, the Foreland belt experienced its first significant flexural subsidence and deposition. The latter resulted from the elastic response of the first widespread loading of the North American craton by thickened North American supracrustal rocks and the western thickened lithosphere of pericratonic terranes, Quesnellia, Cache Creek, and possibly Stikinia. Detrital zircons in Bowser basin strata indicate that the sources were still

within the accreted terranes (Cache Creek, and Stikinia and/or Quesnellia) that were incorporated into the western Omineca highland, whereas sources for Alberta foreland basin deposition included mica and quartz from exhumed metamorphic rocks of continental origin then exposed at the surface of the eastern Omineca highland. Accordingly, the drainage divide in the Omineca highland is shown on Figures 5B and 6C as lying in the eastern part of the carapace of accreted terranes such that sediments were transported from the exhumed terranes west to the Bowser basin, and Alberta foreland basin drainages had access only to the eastern Omineca highland.

### Early Early Cretaceous (ca. 145–135 Ma)

In the early Early Cretaceous, deposition in the Bowser basin changed from widespread marine and marginal marine, to nonmarine, including floodplain deposition marginal to deltas, and low-energy fluvial systems (I4 in Table 1; Figs. 3 and 6D). The only widespread strata preserved of this age are in the northcentral part of the basin. Other strata deposited in this stage, or prior to the Albian, include the synorogenic coarse clastic deposits in the north-central Bowser basin and nonmarine strata in the southern basin (Evenchick and Thorkelson, 2005; Bassett and Kleinspehn, 1997; V.J. McNicoll, 2006, personal commun.; Smith and Mustard, 2006).

In the Omineca belt, Early Cretaceous zones of penetrative deformation and metamorphism occurred at mid-crustal levels within the existing edifice (Currie, 1988; Digel et al., 1998; Crowley et al., 2000; Reid, 2003; O4–O6 in Fig. 3), while imbrication of the basement and northeastward translation of the belt occurred on shear zones at depth, near the base of the edifice (Fig. 6D). Middle Jurassic plutons, such as the Hobson Lake and Fang plutons, which crosscut early southwest-verging structures, record Early Cretaceous quenching to low temperatures as they were progressively exhumed to higher structural levels. The interplay between exhumation of older structures and renewed metamorphism and penetrative deformation at depth is consistent with a model of progressive shortening of the Omineca belt during northeastward translation.

In the Foreland belt, west-derived sands and conglomerates flooded into the Alberta foreland basin, locally filling the western foreland trough with over 1.5 km of lower Lower Cretaceous sediments (Stott, 1998; Fig. 3). Sedimentation changed from marine to nonmarine in the late Tithonian south of 52°N, and during the late Berriasian to early Valanginian further north (52°N–55°N). In the Berriasian, a west-sourced delta system with rivers carrying volcanic and metamorphic clasts and abundant radiolarian chert entered the basin near 54°N, indicating that the depositional system had sources in the Slide Mountain terrane and metamorphic parts of the Omineca belt (McMechan et al., 2006). Relatively rapid Late Jurassic to Early Cretaceous sedimentation (Valanginian; up to 100 m/m.y.) was followed by pedimentation and conglomeratic sedimentation in the Hauterivian and Barremian (F3 in Fig. 3). There was substantial erosion of lower Lower Cretaceous and Upper Jurassic sediments in the eastern

part of the Alberta foreland basin, and the conglomerates were derived solely from sedimentary sources (Gibson, 1985, and references therein; Ross et al., 2005). The westernmost Alberta foreland basin sediments were being deformed and eroded by the end of the Valanginian (Fig. 6D). Near the line of section in Figure 6D, northeast-directed thrusting likely reached the western Foreland belt in the early Early Cretaceous with the initiation of the Malton Gneiss basement slice (O7 in Table 1).

From the material presented here, we conclude that the early Early Cretaceous was a time of significant change across the Cordillera and that events in adjacent regions were kinematically linked within the developing orogen. The basins flanking the Omineca highland became regions of exclusively nonmarine deposition, with >1.5 km of sediment deposited in the western Alberta foreland basin, and probably >2 km of sediment deposited in the Bowser basin. A major middle Early Cretaceous unconformity in the Alberta foreland basin developed within all but the westernmost areas. This period also records the first significant deformation of western Alberta foreland basin deposits, and possibly the initial deformation in the Skeena fold belt. The age of the latter is not narrowly constrained, but the presence of locally derived early to middle Early Cretaceous coarse synorogenic clastic rocks in the north-central Bowser basin suggests that deformation started in this period, or shortly thereafter. Detrital zircons in Early Cretaceous Bowser basin strata have similar source ages as the older strata, indicating that the drainage divide remained in the western Omineca–eastern Intermontane components of the Omineca highland, and detritus of only Cache Creek, Quesnellia, and Stikinia was carried westward (Fig. 5C and 6D).

### Albian (ca. 112–100 Ma)

By the mid-Cretaceous, the Insular belt terranes were accreted to western Stikinia, and a major phase of ductile deformation, metamorphism, and magmatism began in the Coast belt (e.g., Monger et al., 1982; Crawford et al., 1987, 2005; Fig. 6E). In the west-central Coast belt, greenschist metamorphism prior to ca. 98 Ma was followed by burial locally to 8 kbar (800 MPa; 30 km), and regional west-directed thrusting started at ca. 100 Ma (e.g., Crawford et al., 1987; Rubin et al., 1990). Farther east in the central Coast belt, crustal thickening by thrust faulting and emplacement of tabular syntectonic plutons resulted in 6 kbar (600 MPa) metamorphism by ca. 90 Ma (Crawford et al., 1987). Rocks in the central Coast Belt, west of the southern Bowser basin, presently overlie 30 km of crust (Morozov et al., 1998; Hammer et al., 2000), suggesting that in the mid-Cretaceous, part of the central Coast belt crust was up to 60 km thick (e.g., Crawford et al., 1987). Ductile east-directed thrusting involving Stikinia on the east side of the central and southern Coast belt began at ca. 90 Ma, about the same time as the major crustal thickening described previously (e.g., Rusmore and Woodsworth, 1994; Rusmore et al., 2000; Crawford et al., 2005).

Shortening of Bowser basin strata in the Skeena fold belt started before the Albian, and there is no record of Albian or younger Bowser basin deposition except at the southern mar-

gin of the basin (Evenchick, 1991a; Evenchick and Thorkelson, 2005; Bassett and Kleinspehn, 1997; I5 in Table 1; Fig. 3). Widespread fluvial deposition in the Sustut basin began in the Albian with an eastern (Omineca belt) source of detrital micas and clasts distinctive of the early Paleozoic Cordilleran margin (Eisbacher, 1981), including recycled detrital zircons of Archean, Paleoproterozoic, Mesoproterozoic, and Paleozoic ages initially derived from the North America craton (McNicoll et al., 2005; I5 in Fig. 3; Fig. 6E). Omineca belt sources may be represented in the southern Bowser basin earlier than Albian (Bassett and Kleinspehn, 1997). The depositional overlap of Skeena fold belt structures by basal Sustut Group strata illustrates the extent of contractional deformation, which reached far to the northeast part of the Bowser basin prior to Albian time (Eisbacher, 1981; Evenchick, 1991a). Clasts of chert recycled from the Bowser Lake Group into the Sustut basin in this period suggest that the Skeena fold belt formed highlands southwest of the Sustut basin (5e in Fig. 3; Fig. 5D; Eisbacher, 1981).

In the Omineca belt, the general structural style established in the Early Cretaceous prevailed, whereby zones of penetrative deformation in the mid-crust and movement on deep-seated shear zones accommodated deformation and translation across the belt (O7 in Table 1; Fig. 6E) and transferred shortening across the orogen from the plate margin to the active foreland. Emplacement and stacking of imbricated basement-cored nappes of the Malton Complex occurred in the Albian, as bracketed by the ca. 140–120 Ma isograds south of the complex, which were deflected during emplacement of the complex, and the ca. 110–100 Ma cooling dates for the complex (O7 in Table 1). The ca. 105–90 Ma Cassiar batholith, now located in the northern Omineca belt, was probably emplaced in the southern Omineca belt and translated northward. Geochemistry indicates derivation mainly from melting of continental crust (Driver et al., 2000), which was associated with, and facilitated by, movement on mid-Cretaceous transcurrent faults within a transpressive environment (Gabrielse et al., 2006).

In the Foreland belt, renewed subsidence of the Alberta foreland basin occurred during the Albian. The greatest subsidence was associated with extensional faulting near 56°N above the ancestral Peace River Arch, following a pattern established in the Aptian (Stott, 1993). Several regional transgressive-regressive cycles in the north caused an alternation of marine, coastal, and nonmarine environments, whereas nonmarine deposition and disconformities developed in the south (Fig. 5D; Stott, 1993; Smith, 1994). Rock fragments and heavy minerals in Albian strata indicate a mixed sedimentary, metamorphic, and volcanic/intrusive source between 53°N and 56°N, and a dominant volcanic and intrusive Quesnellian source south of 53°N (McMechan and Thompson, 1993; Ross et al., 2005). Exhumation and cooling of metasedimentary rocks and basement slices above northeast-directed thrust faults occurred in the Albian near 53°N (F4 in Fig. 3; McDonough and Simony, 1988).

We conclude that the Albian was a milestone in tectonic development across the southern Canadian Cordillera, includ-

ing the Coast belt. A fundamental change in detrital sources for regions west of the Omineca highlands was marked by a flood of clasts derived from deeper levels of the Omineca belt, including the first clasts of exhumed metamorphic rocks that had originally been deposited on the Paleozoic margin of cratonic North America (Fig. 6E). Either exhumation and erosion of the Omineca belt reduced the carapace of accreted terranes on the west side of the highland, or increased surface uplift of the Omineca belt shifted the drainage divide eastward. After an initial flood of clastics into the Sustut basin from the east (Omineca belt), deposition in the basin was focused in a northwest-trending trough, confined between the Omineca highland and highlands of the Skeena fold belt (Fig. 6E). Widespread sedimentation in the Alberta foreland basin driven by flexural and dynamic processes (Beaumont et al., 1993) produced a westward-thickening wedge, locally up to 1.7 km thick, that extended 1000 km eastward onto the craton. In most of the southern Alberta foreland basin, sediments were derived from the Omineca and Foreland highlands. In contrast, south of 51°N, the Albian was the only time when rivers flowed unimpeded from a region underlain by Quesnellia strata in the western Omineca belt into the foreland basin with little input from central Omineca or Foreland belt strata (Leckie and Krystinik, 1995). The structural architecture formed in the Jurassic to Early Cretaceous within the Omineca and eastern Intermontane belts was carried northeastward by deep-seated zones of deformation, and in the Foreland belt deformation occurred mainly on northeast-directed thrust faults (Fig. 6E). The net result of mid-Cretaceous tectonism in the Coast belt was significant crustal thickening by stacking of thick crustal slabs. Involvement of Stikinia in the east-directed ductile thrust system on the east side of the Coast belt is the basis for the interpretation that the high-level structures of the Skeena fold belt, also involving Stikinia, root in the Coast belt (Fig. 6E; Evenchick, 1991a). We speculate that the crustal thickening in the Coast belt may have provided a western source of sediment deposited over deformed Bowser basin strata of the western Skeena fold belt. Strata of this age are not preserved, but apatite fission-track and vitrinite reflectance data suggest that since the latest Cretaceous–early Cenozoic, 4.4–7 km of section has been eroded from the northwest Bowser basin–Skeena fold belt (O'Sullivan et al., 2005).

### Late Campanian/Maastrichtian–Early Eocene (ca. 74–50 Ma)

The contractional ductile deformation of the Coast belt that began in the mid-Cretaceous continued into the earliest Cenozoic with emplacement of large volumes of magma and an eastward migration of magmatism; deformation included the development of large recumbent nappes in the core of the Coast belt (younger than ca. 85 Ma), with the result that thick crust was created by latest Cretaceous time (e.g., Crawford et al., 1987, 2005; Fig. 6G). These events occurred in an environment of dextral transpression that lasted into earliest Cenozoic time (Rusmore et al., 2001; Andronicos et al., 2003). Exhumation began during the Cretaceous during contraction (e.g., Crawford et al., 1987). Extension, pluton emplacement, and rapid (2 mm/yr) exhuma-

tion followed in the Paleocene and early Eocene (Hollister, 1982; Andronicos et al., 2003, and references therein).

The last major depositional change in the Sustut basin was in the late Campanian, when the relatively low-energy fluvial systems of the Tango Creek Formation were succeeded by high-energy systems that deposited sheets of conglomerate of the Brothers Peak Formation (Eisbacher, 1981; I6 in Table 1; Figs. 3 and 6F). Deformation of uppermost Sustut strata constrains the youngest Skeena fold belt deformation to post-Maastrichtian. Preliminary apatite fission-track thermochronology results (O'Sullivan et al., 2005) and thermal maturity data (Stasiuk et al., 2005) suggest that a few kilometers of strata have been eroded from above present exposures of Sustut and northeastern Bowser strata, and 4.4–7 km has been eroded from northwestern Bowser strata (O'Sullivan et al., in 2005) since the latest Cretaceous–early Cenozoic; some of this "missing" section may have been mid-Cretaceous age, as described earlier, but some, or all, may have been late Maastrichtian to early Eocene age, in part supplied from the west during the rapid exhumation of the Coast belt.

Continued internal deformation and northeastward translation of the Omineca belt (O9 in Table 1; Fig. 6F) is manifested by out-of-sequence structures, such as the pre–ca. 93 Ma Purcell thrust (Archibald et al., 1983; P.S. Simony, 2005, personal commun.), by crystalline thrust nappes, such as the Gwillim Creek shear zone in Valhalla complex, which carried metamorphic rocks inboard and ramped them onto cold basement (Carr and Simony, 2006), and by belts of penetrative deformation within mid-crustal rocks, such as those exposed in the eastern Selkirk Mountains and in the Monashee Mountains north, west, and south of the Monashee Complex (Johnston et al., 2000; Gibson, 2003; Hinchey, 2005; Williams and Jiang, 2005; Brown and Gibson, 2006). Dextral displacement primarily in the Eocene, on faults within and transecting the western Omineca highlands, amounted to ~430 km (Gabrielse et al., 2006) and resulted in the final northward movement of the Bowser-Sustut region and western Omineca highlands (including Cassiar batholith) relative to cratonic North America.

A major change from dominantly marine shale with pulses of westerly derived deltaic sand to dominantly nonmarine coarse clastics occurred during the Santonian in the western Alberta foreland basin south of 51°N (Stott, 1963; Leahy and Lerbekmo, 1995; Payenberg et al., 2002); a similar change occurred at the base of the late Campanian elsewhere in the western foreland basin (Dawson et al., 1994; 4e in Fig. 3). At the eastern margin of the Foreland belt, rapid, nonmarine sedimentation probably continued into the early Eocene, with up to 4 km of late Campanian to Paleocene strata preserved (Stott and Aitken, 1993; F5 in Fig. 3). An additional 2–2.5 km accumulation of Paleocene and Eocene strata, no longer preserved, is inferred for the eastern edge of the Foreland belt, south of 54°N, from coal reflectance data (Nurkowski, 1984; Kalkreuth and McMechan, 1996). Most Santonian to Paleocene sediments were derived from the Foreland highlands and from volcanic airfall (Ross et al., 2005). Two exceptions occur near 53°N (Fig. 3), where local conglom-

erates, one late Maastrichtian and the other middle Paleocene, contain a few andesitic pebbles (Jerzykiewicz, 1985), which indicate that the drainage divide locally extended into the Intermontane belt. The leading edge of the thrust system progressed eastward from the central Foreland belt to its eastern edge during the late Campanian to early Eocene (Fig. 6G), doubling its width and resulting in exhumation, erosion, and cannibalization of the Alberta foreland basin wedge (Price and Mountjoy, 1970). Motion on major thrust faults in the Eastern Front Ranges (e.g., Lewis, McConnell) deformed late Campanian strata, and major thrust faults in the Foothills (e.g., Bighorn, Brazeau) deformed Paleocene strata (Price, 1981; McMechan and Thompson, 1993). Alberta foreland basin subsidence ended with the cessation of contractional deformation in the early Eocene (Fig. 6G).

The late Campanian to earliest Eocene was the last period of trans-Cordilleran horizontal shortening and sedimentation that may be attributed to kinematic links across the orogen. It was characterized by northeastward translation of the Omineca belt on mid-crustal structures at the same time as significant nonmarine deposition in basins on the east and west sides of the Omineca highland, thickening and horizontal shortening at high crustal levels in the Skeena fold belt and Foreland belt, and crustal thickening and eastward migration of magmatism in the Coast belt. The start of this period marks one of the fundamental changes in sedimentation in the basins flanking the Omineca highlands. In the Sustut basin, the change was from low- to high-energy fluvial deposition, and in the Alberta foreland basin, it changed from deltaic marine pulses to entirely nonmarine deposition. Confinement of Sustut Group deposition to a linear northwest-trending trough with southeast paleocurrents suggests that the Skeena fold belt and Omineca highland continued to form topographic barriers bounding the Sustut basin. During the late Campanian to early Maastrichtian, ~1.5 km of strata accumulated in the Sustut basin, while up to 2 km accumulated in the Alberta foreland basin. Deposition in the Alberta foreland basin continued into the early Eocene, forming a late Campanian to Eocene westward-thickening wedge over 6 km thick at the eastern margin of the Foreland belt. Deposition of strata, no longer preserved, across the Sustut basin and/or a broader and younger basin and originating in part from exhumation of the Coast belt, may have continued into the latest Cretaceous or earliest Cenozoic.

## LINKS ACROSS THE OROGEN AND THEIR SIGNIFICANCE

The previous section demonstrated the kinematic and dynamic links across the orogen through time, illustrated by Figure 3 and tectonic interpretations in Figure 6. To summarize:

(1) Middle Jurassic obduction of Quesnellia and Slide Mountain terranes onto pericratonic terranes and distal North America was followed closely by southwest obduction of Cache Creek onto Stikinia, which resulted in initiation of flexural subsidence in the Bowser basin and deposition of coarse Cache Creek detritus in the Bowser basin (I0, I1, O1, O2 in Table 1);

(2) Ongoing deformation, crustal thickening, and/or exhumation in the Omineca belt from the Late Jurassic to Paleocene occurred while sediment was shed from the Omineca highland eastward into the Alberta foreland basin, and westward into the Bowser and Sustut basins (I2–I6, O3–O9, F1–F5 in Table 1; expanded on herein);

(3) Mid-Cretaceous initiation of thin-skinned shortening in the Foreland belt, major crustal thickening in the Coast belt, thin-skinned shortening in the Skeena fold belt, initiation of the Sustut basin, and continued eastward translation of the exhuming core of the Omineca belt above a basal detachment system (I5, O6, O7, O8, F4 in Table 1; Crawford et al., 1987)—in summary, shortening across the width of the Cordillera—was accommodated at different structural levels;

(4) Approximately synchronous pulses of synorogenic coarse clastics were deposited in the Sustut basin and Alberta foreland basin in the late Campanian–early Maastrichtian, during a period of major structural thickening and denudation (I6, O9, F5 in Table 1); and

(5) Horizontal shortening across all belts lasted into the latest Cretaceous to early Cenozoic (I6, O9, O10, F5 in Table 1; e.g., Crawford et al., 1987).

Such links are permissible, despite uncertainties in timing and magnitude of superimposed transcurrent faults, because fundamental aspects of each belt have considerable strike length. Although the ~300-km-long Bowser basin is the most restricted tectonic element discussed, it was the major center of sedimentation west of the evolving orogen in the Middle and Late Jurassic, and it was probably localized adjacent to the region of maximum crustal thickening in the Omineca belt.

From these examples of synchronous and compatible tectonic events in adjacent belts, we suggest that the Intermontane, Omineca, and Foreland belts were kinematically connected from the Middle Jurassic to early Cenozoic, and that the Insular and Coast belts were included in this kinematic connection from mid-Cretaceous to early Cenozoic. Both the Bowser and Alberta Foreland basins received sediment from a persistent source in the Omineca highland, which was composed of the eastern accreted terranes, pericratonic terranes, and supracrustal rocks of western North American. This source lasted for ~120 m.y., from earliest Bowser basin deposition to the final Alberta foreland basin deposition. Throughout the evolution of the orogen, changes in source rocks for each basin reflect changes in the level of exhumation in the intervening highland, which progressively exposed deeper rocks, and migration of the drainage divide. The relationship between basin evolution and lithospheric loading for the Foreland and Omineca belts has been well established (e.g., Beaumont et al., 1993). This relationship is less direct for the Bowser basin because much of northern Stikinia was already the site of marine deposition, although limited in thickness, prior to the Bajocian/Bathonian. Subsidence was caused, at least in part, by cooling of Stikinia, which probably continued through at least the early phases of coarse Bowser basin deposition. Facies relationships indicate that the northeastern part of the basin was the primary

site of deposition during the late Middle and early Late Jurassic, presumably in response to lithospheric loading by the growing accretionary orogen to the east and by accumulating sediment. The large scale of both the Foreland and Bowser basins and widespread contractional structures are incompatible with the alternative explanation of basin formation in a transtensional regime. Therefore, the basins are most likely related, in differing degrees, to subsidence due to flexure and progressive loading of the lithosphere by the thickened crust between them and by deposition of sediments from the same persistent source, the elevation of which was maintained by the processes that resulted in continued exhumation of the Omineca belt.

Shortening of the orogen and inferred linkages across the orogen were likely accommodated by a lower-crustal detachment as illustrated in Figure 6. Support for this interpretation is provided by interpretation of SNORCLE line 2a, which displays a low-angle boundary between Stikinia and North American rocks that rises eastward from the lower crust to middle crust (Fig. 6H; Cook et al., 2004; Evenchick et al., 2005). This boundary may be part of the lower-crustal detachment illustrated in Figure 6. The deformation and structural architecture of mid- and upper-crustal rocks in the western Foreland and eastern Omineca belts were established in the Middle Jurassic to Early Cretaceous (Carr and Simony, 2006, and references therein); therefore, linkage of mid-Cretaceous to Eocene structures in the Foreland and Omineca belts must have occurred via a detachment that passed beneath the western Foreland belt. This interpretation is consistent with geophysical data that are, in part, controlled by outcrop and drill-hole information (Cook et al., 1988, 1992; Cook and van der Velden, 1995).

We suggest that the southern Canadian Cordillera evolved from a relatively narrow, doubly vergent, "small-cold" orogen in the Jurassic with the core centered in the Omineca belt (Figs. 6A–6D) to a much broader doubly vergent, "large-hot" orogen in the mid-Cretaceous (terminology of Koons, 1990; Beaumont et al., 2006). The mid- and Late Cretaceous orogen (Figs. 6E–6G) may be viewed as a wide doubly vergent orogen with the predominantly east-directed structures in the Omineca and Foreland belts on the eastern, retro-wedge side (terminology of Willett et al., 1993), and west-directed structures of the accretionary orogen of the Coast belt on the pro-wedge side, at the active oblique subduction margin, all linked by a basal detachment. At this time, the Jurassic core of the orogen was mainly translated eastward and exhumed as part of the retro-wedge, which included the active thrust front in the eastern Foreland belt. However, within this first-order, large-scale geometry, there was a detachment beneath the east-directed upper-crustal Skeena fold belt, which soled westward into mid- and lower-crustal ductile structures in the eastern Coast belt. Thus, there were two coeval cratonward-verging upper-crust fold-and-thrust belts, equally large in cross section, at the same latitude in the Cordilleran orogen: the Rocky Mountain fold-and-thrust belt and the Skeena fold belt.

The Mesozoic history of Stikinia as an arc and (or) back arc may have facilitated development of the lower-crust detachment.

Hyndman et al. (2005) argued that back arcs or recent back arcs are hot as a result of transfer of convective heat below thin lithosphere, and that the high temperature results in weak lower crust, facilitating development of lower-crust detachments, which separate crustal elements above from underlying lithosphere in the manner of "orogenic float" (Oldow et al., 1990). The decay in temperature after the source is removed is slow enough that former back-arc regions may remain weak long after cessation of arc activity (Hyndman et al., 2005). From Hyndman et al.'s (2005) calculations of temperature decay, and Monger and Nokleberg's (1996) review of the evolution of arc development in the Cordillera, Stikinia probably remained relatively hot for the period discussed herein. To illustrate their model, Hyndman et al. (2005) explained the relationship between the modern collision of the Yakutat block in the Gulf of Alaska and shortening in the Mackenzie Mountains at the front of the thrust belt as being facilitated by a detachment in a weak lower crust. We suggest that the connectivity of tectonic elements across the Cordillera in the Cretaceous is an ancient example of this phenomenon.

Recognition of a deep detachment across the orogen may provide a broader context for understanding structural relationships. For example, Rusmore et al. (2001) posed the problem of accommodation in the Coast belt of the large horizontal displacement inferred from plate motions. They concluded that reverse motion on the Paleocene Coast shear zone represents the orthogonal component of oblique convergence, but we question the magnitude of shortening that may be accommodated by this structure, and instead suggest that a lower-crust detachment transferred a component of shortening eastward. This is also an effective way to accommodate the regional transpression inferred by Rusmore et al. (2001) who associated dextral faults in the Coast belt with dextral faults in the western Omineca belt–Northern Rocky Mountain Trench.

A question that arises from consideration of the Cordillera as one kinematically connected orogen is the perplexing thickness of Stikinia, which is interpreted from seismic-reflection data as being ~35 km thick (e.g., Cook et al., 2004). Was this Paleozoic–early Mesozoic arc terrane, possibly built partly on rifted fragments of continental margin, always thick, or was it substantially thinner prior to its accretion to North America and then thickened during Cretaceous Cordilleran-wide contraction?

In this interpretation, the mid-orogen Skeena fold belt was carried piggyback above a lower-crust detachment connected to the Rocky Mountain fold-and-thrust belt. This scenario is unusual in modern or ancient orogens. A factor that may have contributed to the geometry is the mechanical effect of the stratigraphy within the Intermontane belt. The Bowser succession, formed just prior to deformation, is a thinly bedded succession with substantial mechanical heterogeneity, and therefore it was relatively weak. In contrast, Stikinia is composed of units of limited lateral continuity, such as volcanic edifices and surrounding sedimentary units with rapid facies changes, and associated plutons. Pre-Triassic strata underwent at least two phases of deformation and local low-grade metamorphism, and Early Jurassic intrusions pierce

all sub-Bowser stratigraphy. Compared to the Bowser succession, Stikinia contains few laterally continuous horizontal weak layers. An exception is the thinly layered early Middle Jurassic clastic succession, immediately below the Bowser Lake Group, which, along with underlying layered Early Jurassic volcanic successions, was intimately involved in thin-skinned deformation. We infer that the relative strength of Stikinia, combined with a relatively weak lower crust, as discussed previously, localized a deep detachment, whereas the mechanical heterogeneity of the Bowser succession and immediately underlying strata of Stikinia facilitated an upper-crustal detachment leading to the Skeena fold belt in uppermost Stikinia, Bowser, and Sustut strata.

## CONCLUSIONS

Synthesis of the Jurassic and Cretaceous depositional and tectonic histories of the central Intermontane belt, and the southern Omineca and Foreland belts, when considered in paleogeographic context, reveals sedimentation and structural linkages across the orogen and highlights the tectonic interplay among crustal thickening, basin formation, and topographic evolution. We conclude that coeval and tectonically compatible events in regions considered to have been in close proximity require kinematic linkage across the entire orogen. In our model for the mid- and Late Cretaceous, a detachment in the lower crust extended from the active plate boundary and Coast belt eastward below the Intermontane belt and then rose into the middle crust in the Omineca belt and, ultimately, to the upper crust at the front of the orogen in the Rocky Mountain fold-and-thrust belt. It was also connected to dextral strike-slip faults, facilitating regional transpression partitioned across the orogen in response to oblique plate convergence. In the Intermontane belt, this lower-crust detachment carried Stikinia as well as the Skeena fold belt, an upper-crust and craton-verging fold-and-thrust belt nested in the interior of the orogen. The basal detachment of the Skeena fold belt rooted in ductile structures on the east side of the Coast belt. Development of this nested fold belt was in part a consequence of the mechanical stratigraphy of Stikinia and overlying basins. Consideration of the orogen as a whole, in paleogeographic context, should lead to improved tectonic models of Cordilleran evolution.

## ACKNOWLEDGMENTS

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## A synthesis of the Jurassic−Cretaceous tectonic evolution of the central and southeastern Canadian Cordillera: Exploring links across the orogen

Carol A. Evenchick, Margaret E. McMechan, Vicki J. McNicoll, et al.

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