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The Cordilleran Ribbon Continent of North America

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Laramide orogeny, orocline, accretionary orogenesis, plate tectonics, paleomagnetism, Wilson cycle

Abstract

The North American Cordilleran Orogen is the result of a two-stage process: (*a*) Triassic-Jurassic accretion within Panthalassa forming SAYBIA, a composite ribbon continent, and (*b*) Late Cretaceous collision of SAYBIA with North America. This model requires that a large portion of the continental foreland of the orogen is exotic. The exotic continental component of SAYBIA, Cassiar Platform, is distinguished from the autochthon on the basis of its (*a*) Triassic Eurasian fauna; (*b*) involvement in a major Late Triassic-Early Jurassic orogenic event; and (*c*) young, in part Grenvillian basement and mantle. A mid-Cretaceous magmatic arc records west-dipping subduction beneath the east-margin of SAYBIA. The related accretionary prism consists of imbricated shale, chert, and deep-water limestones (the Medial Basin) and overlies an isotopically juvenile mantle domain. Carbonatite complexes delineate the cryptic suture separating SAYBIA and the autochthon. Paleomagnetic and paleobotanical data place SAYBIA 2000 km to the south relative to the autochthon at 80 Ma. Late Cretaceous thrust belt development records transpression between the north-moving ribbon continent and the autochthon. Pinning against the Okhotsk-Chukotka arc in Siberia buckled SAYBIA, giving rise to the Alaskan promontory.

INTRODUCTION

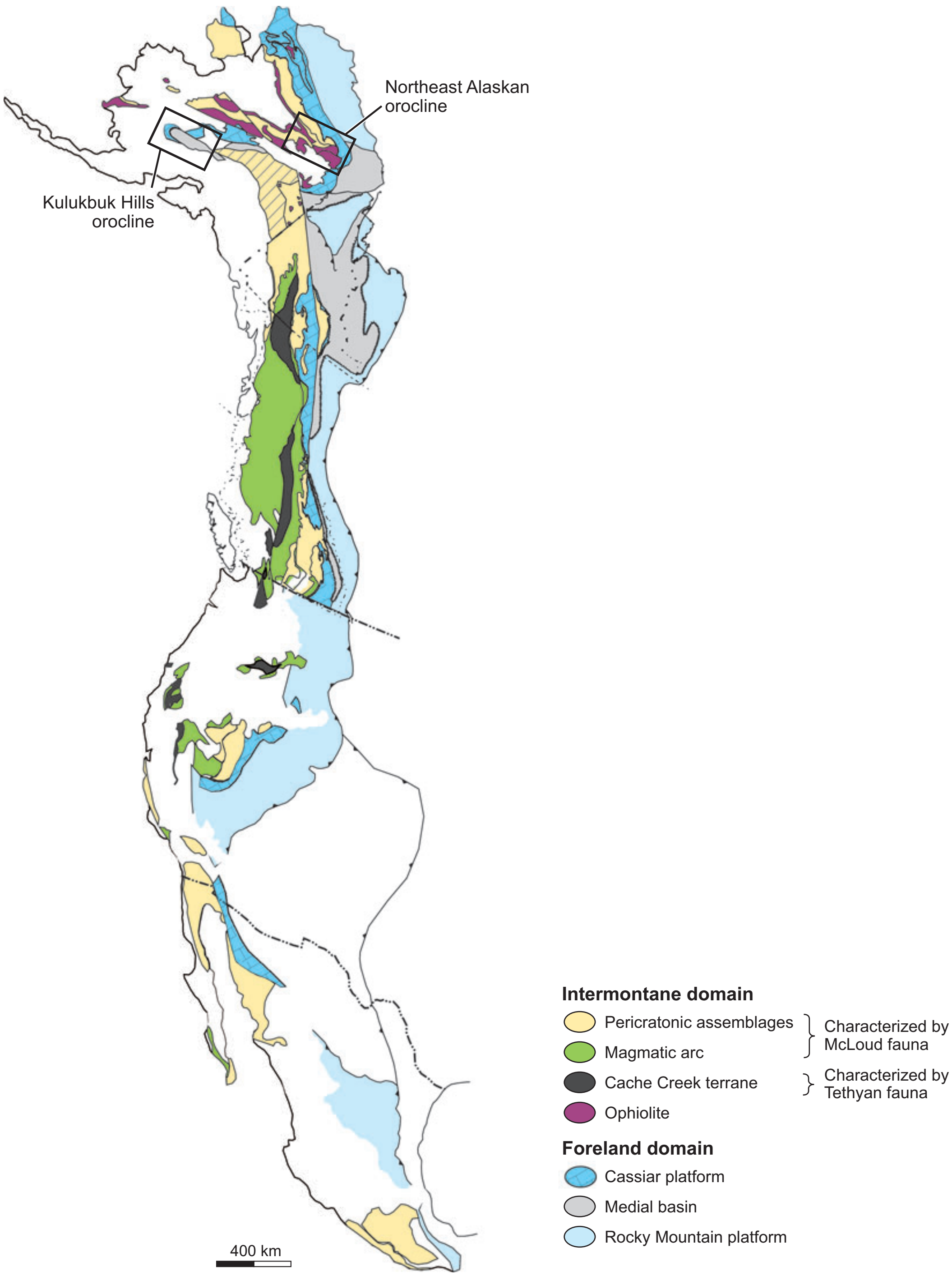
Between the autochthonous, undeformed strata of the plains to the east and the active convergent margin to the west lies the north-south trending Cordilleran Orogen of western North America (**Figure 1**). Within the confines of the orogen lies a boundary between deformed crust of North American affinity (para-autochthonous strata) and accreted, exotic crust. Determining the location, geometry, nature, and evolution of the boundary between exotic and para-autochthonous North American crust has been the subject of intense debate (Cook & Erdmer 2005, Johnston 2001), and is the focus of this paper.

Understanding the boundary between North American and accreted crust is fundamental to understanding the processes responsible for orogenesis and the growth of continents. For example, orogens recording a complete Wilson cycle, including a terminal continental collision, are commonly interpreted to result in significant continental growth (e.g. Bird & Dewey 1970, Hoffman 1980). The Cordilleran Orogen of western North American, however, is thought to represent an incomplete Wilson cycle in that it appears to have developed in the absence of a terminal continental collision. Instead, the Cordillera is interpreted as an accretionary orogen, and its evolution is explained as the result of the incremental, thin-skinned addition of terranes to the continental margin above a landward-dipping subduction zone (Monger 1997). Continental growth is not a requirement of accretionary orogenesis, and subduction erosion of the continent may even result in a net loss of continental mass.

If the Cordillera is, therefore, strictly attributable to accretionary processes, the bulk of the orogen may consist of little-disturbed North American crust underpinned by North American mantle (Cook et al. 2004, Snyder et al. 2002). I start by reviewing the basic character of the Canadian portion of the orogen, and assess a primary assumption in Cordilleran studies: that all continental assemblages are of North American affinity. I demonstrate that a large portion of the continental foreland of the orogen is exotic with respect to the autochthon and forms part of a composite ribbon continent, previously referred to as SAYBIA (Johnston 2001), which extends along strike to the northwest into Alaska and south into the conterminous United States of America. I finish by presenting a model of Cordilleran orogenesis as a product of a two stage process: (*a*) the accretionary construction of a composite ribbon continent, SAYBIA, followed by (*b*) collision of SAYBIA with North America. This model marks a return to a more Wilson cycle–style interpretation of the Cordillera, as it involves a continental collision and implies that North America has grown significantly westward during orogenesis. A key requirement of this model is the presence of a cryptic suture within the orogenic foreland, a region that has been extensively mapped

Figure 1

The Cordilleran Orogen of western North America. Yellow striped region in Alaska, shown here as a portion of the pericratonic belt (*yellow*), has recently been reinterpreted as being part of the Medial shale basin of the Foreland belt (Dusel-Bacon et al. 2006).


Northeast Alaskan orocline
Kulukbuk Hills orocline
400 km
Intermontane domain
Pericratonic assemblages
Magmatic arc
Characterized by McLoud fauna
Cache Creek terrane
Characterized by Tethyan fauna
Ophiolite
Foreland domain
Cassiar platform
Medial basin
Rocky Mountain platform

and studied. Determining the nature and location of the cryptic suture constitutes the primary test of this model.

GENERAL GEOLOGY

In the most general of terms, the Cordilleran Orogen is divisible into an eastern foreland domain characterized by sedimentary strata of continental affinity, a central intermontane domain consisting of oceanic assemblages, and a western insular domain of mixed oceanic and continental assemblages (**Figure 2**). The boundary region between the foreland and intermontane domains is referred to as the Omineca, the diagnostic component of which is the Omineca magmatic belt (OMB), and is commonly considered to consist largely of crust and mantle that extends west from and is a continuation of foreland domain crust and mantle.

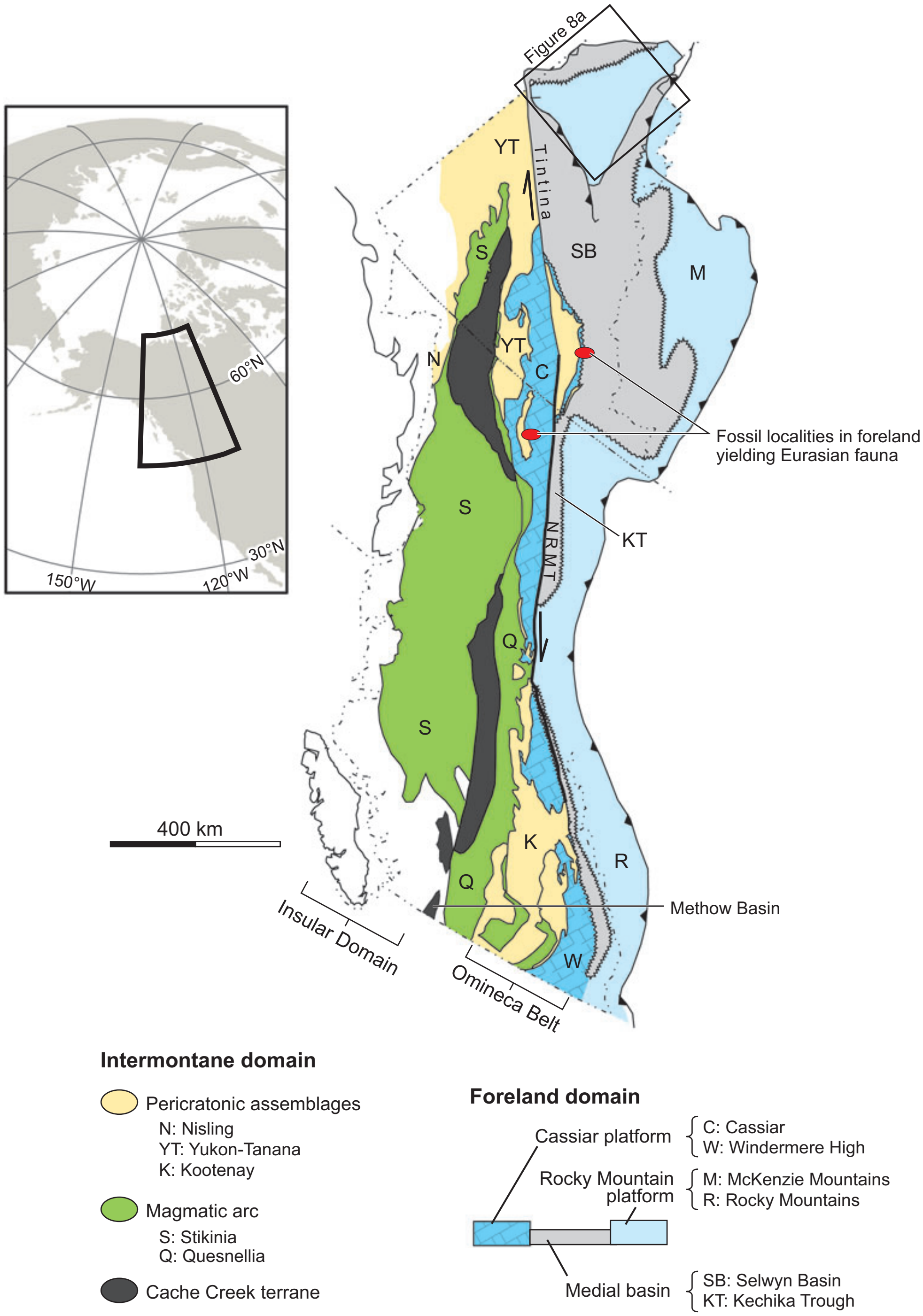
Crust of the insular domain, to the west of the intermontane domain, is exotic (Nokleberg et al. 2005) and was added to the North American margin sometime between Lower Jurassic and Lower Cretaceous time (McClelland & Mattinson 2000). I therefore focus on the eastern portion of the orogen, that region straddled by the foreland and intermontane domains, for it is within this region that the boundary between the ancient west margin of North America and accreted crust is located. Geological relationships limit accretion to having occurred between the Triassic and Upper Cretaceous. Hence, pre-Triassic tectonism and post-Cretaceous extension and magmatism in the southern Canadian Cordillera are little discussed.

Thorough reviews of the geology of the Canadian Cordillera are provided elsewhere and as a **Supplemental Appendix** (follow the **Supplemental Material** link from the Annual Reviews home page at **http://www.annualreviews.org**). The three salient points for this discussion are as follows:

1. Paleozoic to Middle Jurassic strata of the foreland domain are divisible into an easterly shallow water continental platform (the Rocky Mountain Platform); a medial basinal domain of shale, chert, and deep-water limestone (the Medial Basin); and a westerly shallow water platform (Cassiar Platform).
2. The intermontane domain is characterized by a mid-Paleozoic to mid-Mesozoic arc (Stikinia-Quesnellia) and a related accretionary complex (Cache Creek terrane) that includes offscraped seamounts that originated in the Tethyan domain.

Figure 2

Geological map of the Canadian Cordillera showing divisions of the foreland and intermontane domains, location shown in inset at upper left. The jagged line indicates a mapped facies boundary separating shallow water platformal sequences (M, McKenzie Mountains; R, Rocky Mountains; C, Cassiar; W, Windermere High) from basinal strata (SB, Selwyn Basin; K, Kechika Trough). The Tintina–Northern Rocky Mountain Trench (NRMT) fault is the locus of >400 km of Eocene dextral displacement (Gabrielse et al. 2006).



60°N
30°N
150°W
120°W
Figure 8a
YT
Tintina
SB
M
S
N
YT
C
Fossil localities in foreland yielding Eurasian fauna
S
KT
NRMT
Q
S
400 km
K
R
Q
Methow Basin
W
Insular Domain
Omineca Belt
Intermontane domain
Pericratonic assemblages
N: Nisling
YT: Yukon-Tanana
K: Kootenay
Magmatic arc
S: Stikinia
Q: Quesnellia
Cache Creek terrane
Foreland domain
Cassiar platform
C: Cassiar
W: Windermere High
Rocky Mountain platform
M: McKenzie Mountains
R: Rocky Mountains
Medial basin
SB: Selwyn Basin
KT: Kechika Trough

3. Pericratonic assemblages and structurally interleaved ophiolite separate the intermontane and foreland domains, and provide a record of Paleozoic Andean-type arc and related marginal basins.

CASSIAR PLATFORM: EXOTIC?

Despite the foreland position of the Cassiar Platform, a number of lines of evidence imply an exotic non–North America origin for the shallow-water continental platform. These include faunal and geological data inconsistent with autochthoneity, and paleomagnetic and paleobotanical data that require significant mobility of the platform relative to the autochthon into the Late Cretaceous.

FAUNAL PROVINCIALITY OF CASSIAR PLATFORM AND THE INTERMONTANE DOMAIN

In Yukon, Upper Triassic strata from near the Cassiar Platform–Medial Basin boundary includes *Epigondolella* and *Paragondolella*—conodont species that are Eurasian. In North America, these species are only known from the exotic Wrangellia terrane of the insular domain (Orchard 2006). Eurasian fauna similarly characterizes the intermontane domain. Permian strata of Stikinia-Quesnellia are characterized by schwagerinid fusulinids and additional fauna that are similar to those found in the McCloud Limestone of northern California and Nevada (Carter et al. 1992) (**Figures 1** and **2**). The fauna of the McCloud Belt terranes (Miller 1987) is distinct from the fauna of coeval North American strata. The degree of separation required to produce this faunal provincialism is assumed to be >1000 km and probably much greater (Stevens et al. 1990). A more distal origin for Stikinia-Quesnellia, consistent with the constraints provided by the Tethyan Cache Creek seamounts (Johnston & Borel 2007), is suggested by Devonian and Lower Carboniferous strata that are characterized by conodonts of exclusively Eurasian derivation (Orchard 2000), and by Permian and Triassic strata that, although characterized by a mixed faunal assemblage, includes corals, conodonts, and radiolarian that are otherwise unknown outside of Eurasia (Reid & Tempelman-Kluit 1987, Stanley & Senowbari-Daryan 1999). The slices of ophiolitic crust tectonically interleaved with the pericratonic assemblages are similarly characterized by Permian McCloud fauna, and Triassic mixed fauna, in part, of Tethyan affinity (Dusel-Bacon & Harris 2003, Nelson 1993). Hence, Eurasian fauna characterizes Devonian through Triassic strata of the intermontane domain, as well as the Cassiar Platform, distinguishing them from coeval North American strata of the Rocky Mountain Platform.

CONTRASTING TRIASSIC–JURASSIC GEOLOGICAL EVOLUTION

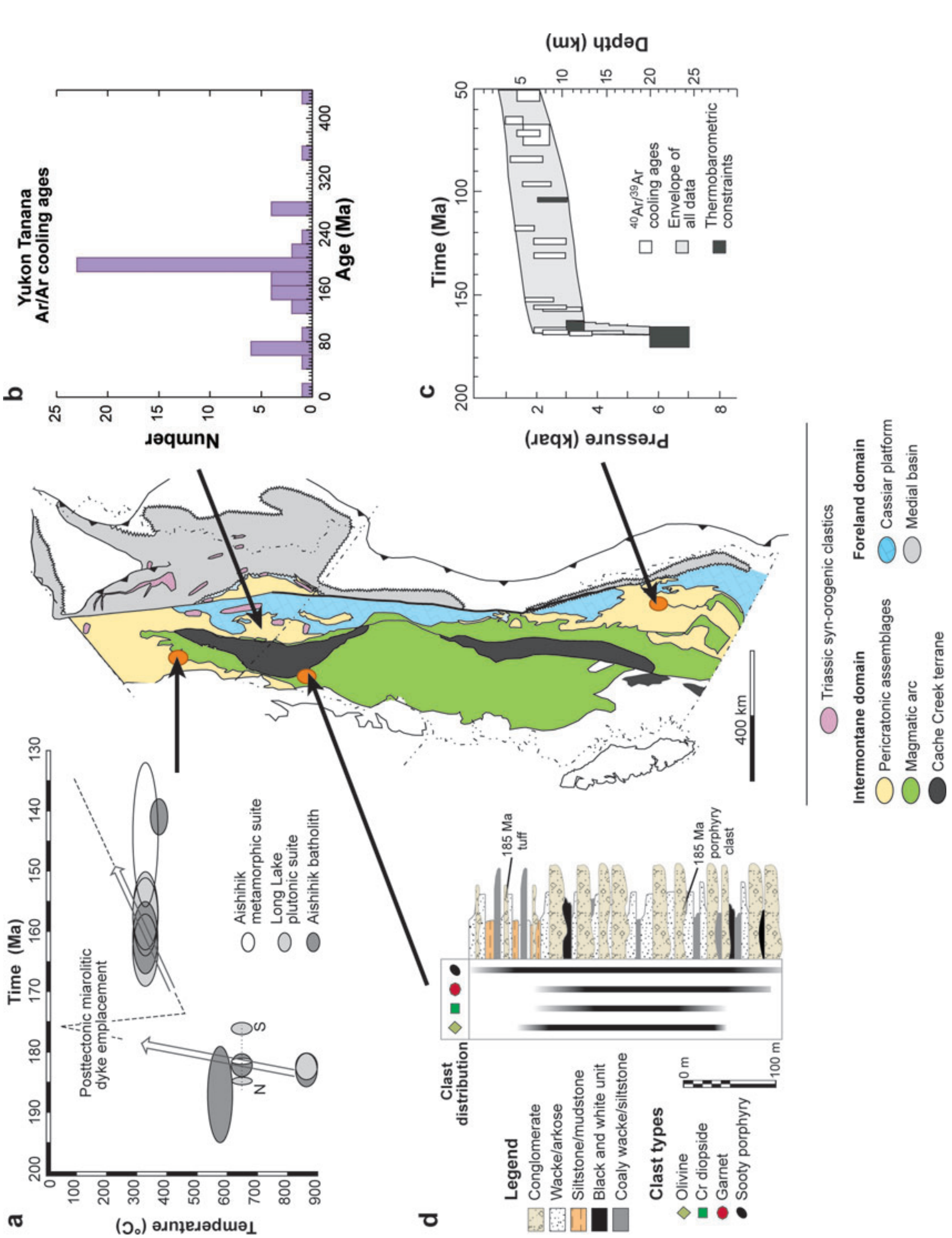
Stikinia-Quesnellia and the pericratonic assemblages were involved in a major Late Triassic collisional event that was not recorded on the autochthon. In the southern

Cordillera, rocks of Quesnellia overthrust the pericratonic assemblages along a major east-verging thrust fault that is plugged by Early Jurassic intrusions (Murphy et al. 1995). Rapid uplift and exhumation of deeply buried pericratonic strata is recorded by Early to Middle Jurassic cooling ages on continental margin assemblages that had been metamorphosed at pressures of greater than 7 kbar (Colpron et al. 1996) (**Figure 3**). In Yukon, Stikinia tectonically overlies the pericratonic assemblages (Johnston & Canil 2007). Early Jurassic posttectonic plutons and shallow-level miarolitic dyke swarms intrude and stitch together Stikinia and pericratonic assemblages (Johnston et al. 1996a) that had been previously metamorphosed at pressures of 8 to 12 kbars (Johnston & Erdmer 1995) (**Figure 3**). Collision is recorded in Stikinia-Quesnellia by the Late Triassic termination of arc magmatism and Early Jurassic molasse deposition.

Collisional orogenesis was thick-skinned, involving exhumation of lowermost mantle lithosphere. Pleinsbachian (~185 Ma) molasse shed off the collision zone includes clasts of ultrahigh-pressure garnet peridotite and eclogite unroofed from depths of 100 to 150 km (MacKenzie et al. 2005) (**Figure 3**). Micaceaous Triassic flysch was deposited across the pericratonic assemblages and their tectonically interleaved slices of ophiolite, the Cassiar Platform, and parts of the Medial Basin. These Triassic strata were derived from the west, are locally conglomeratic, and are interpreted as syn-orogenic sediments (Colpron et al. 2006; Colpron et al. 2007) (**Figure 3**). Detrital zircons of demonstrable pericratonic assemblage origin characterize Triassic strata overlying Medial Basin strata, consistent with interpretation as an overlap assemblage (Beranek & Mortensen 2006, Beranek & Mortensen 2007).

In contrast, passive margin sedimentation continued to characterize the Rocky Mountain Platform through at least the Middle Jurassic, in the south, and until the Cretaceous in the north (Gordey et al. 1992) (see **Supplemental Figure 1**). Phosphorite and, in deeper water strata, chert accumulation imply that the passive margin faced west toward an open ocean basin characterized by upwelling of large-scale deep water currents (Poulton 1984, Poulton & Aitken 1989). Westerly derived flysch and molasse did not inundate the southern Rocky Mountain Platform until the Upper Jurassic (155–152 Ma), and even then, most of the siliciclastic sediment appears to have been derived from autochthonous source terranes (Ross et al. 2005). Clastic sediments derived from erosion of isotopically juvenile source terranes, such as the oceanic arcs and ophiolite of the intermontane domain, do not appear in the foreland basin until 120 Ma (Ross et al. 2005).

The thick-skinned Late Triassic orogeny that involved the intermontane domain terranes, the Cassiar Platform, and the Medial Basin did not load and cause isostatic flexure of the lithosphere on which the Rocky Mountain Platform was located. Even in the southern Canadian Cordillera, where the orogenic welt is closest to the Rocky Mountain Platform (only 200 km to the west after palinspastic restoration of younger thrust faults), there is no evidence of any Triassic–Early Jurassic loading of the North American lithosphere and no orogenic sediments shed east off of the thickened crustal welt that characterized the orogen. Neither did the orogen impede or inhibit continued oceanic upwelling and related phosphatic sediment deposition along the North


a
Time (Ma)
Temperature (°C)
Posttectonic miarolitic dyke emplacement
Aishihik metamorphic suite
Long Lake plutonic suite
Aishihik batholith
b
Yukon Tanana Ar/Ar cooling ages
Number
Age (Ma)
c
Time (Ma)
Depth (km)
Pressure (kbar)
$^{40}Ar/^{39}Ar$ cooling ages
Envelope of all data
Thermobarometric constraints
d
Legend
Conglomerate
Wacke/arkose
Siltstone/mudstone
Black and white unit
Coaly wacke/siltstone
Clast types
Olivine
Cr diopside
Garnet
Sooty porphyry
Clast distribution
185 Ma tuff
185 Ma porphyry clast
0 m
100 m
400 km
Triassic syn-orogenic clastics
Intermontane domain
Pericratonic assemblages
Magmatic arc
Cache Creek terrane
Foreland domain
Cassiar platform
Medial basin

American passive margin. The implication is that the Triassic orogeny involving the intermontane domain terranes and the Cassiar Platform took place far removed from the Rocky Mountain Platform and involved plates separate from the North American plate.

CRUSTAL BASEMENT AND MANTLE PROVINCIALITY

The basement to the Rocky Mountain Platform consists of 1.84 Ga and older crust and mantle of the Canadian Shield (Ross 2000). This contrasts with the basement underpinning the Medial Basin, the Cassiar Platform, and the intermontane domains, which is younger. In the northern Cordillera, the Coates Lake Diatreme intrudes Proterozoic sedimentary rocks near the mapped eastern boundary of the Medial Basin (**Figure 4**). Lower crustal granitic xenoliths in the diatreme yield crystallization ages of 1.1 Ga (Jefferson & Parrish 1989, Mortensen & Colpron 1998). 1.0 to 1.1 Ga xenocrystic zircons characterize Paleozoic diatremes that intrude in or near the east margin of the Medial Basin in the southern Cordillera (Parrish & Reichenbach 1991) (**Figure 4**). Metabasite xenoliths in intrusive breccias in the Wernecke Mountains (Yukon) were recrystallized at 1.15 Ga (Milidragovic et al. 2007). 1.0 to 1.2 Ga crystalline rocks are unknown in the cratonic basement to the east and indicate that the depositional basement to Medial Basin and Cassiar Platform is a distinct, in part, Grenvillian-aged basement.

Precambrian crystalline rocks crop out within the pericratonic assemblages in British Columbia, including, from south to north, the Priest River Complex (Idaho), the Monahsee Complex, the Malton Complex, and the Sifton Range (**Figure 4**). The basement complexes are exposed within structural culminations and have been interpreted as para-autochtonous extensions of the cratonic North American basement to the east (Parrish 1992). However, the Priest River Complex, which lies west of the 3.3 Ga to 2.6 Ga Medicine Hat province of the craton, crystallized at 2.55 to 2.65 Ga, is intruded by 1.59 Ga felsic plutons and cannot be readily correlated with any cratonic basement to the east (Doughty et al. 1998) (**Figure 4**). Despite the abundance of Archean crust and mantle abutting the east margin of the Canadian Cordillera, no Archean crust has yet been documented within the orogen. Granite and felsic cobbles in a conglomerate in southern Quesnellia yield crystallization ages of 1.03 to 1.04 Ga, and were likely derived from erosion of exposed basement (Erdmer et al.

Figure 3

Map of the Cordillera showing region affected by Triassic orogeny. Only the Rocky Mountain Platform (not colored here) was unaffected. Examples of constraints on timing of crustal thickening and subsequent exhumation and cooling include (*a*) cooling curve from Nisling pericratonic assemblage showing Early Jurassic cooling and exhumation (Johnston et al. 1996a), (*b*) Ar-Ar cooling ages for Yukon-Tanana terrane that peak at 190 Ma (Breitsprecher & Mortensen 2004); (*c*) exhumation curve for Kootenay pericratonic assemblage showing unroofing by 180 Ma (Colpron et al. 1996); and (*d*) the stratigraphic record from Stikinia of unroofing of Ultra High Pressure rocks at 185 Ma (Canil et al. 2006). Also indicated is the distribution of westerly derived, Triassic, syn-orogenic clastic sequences (Murphy et al. 2006).

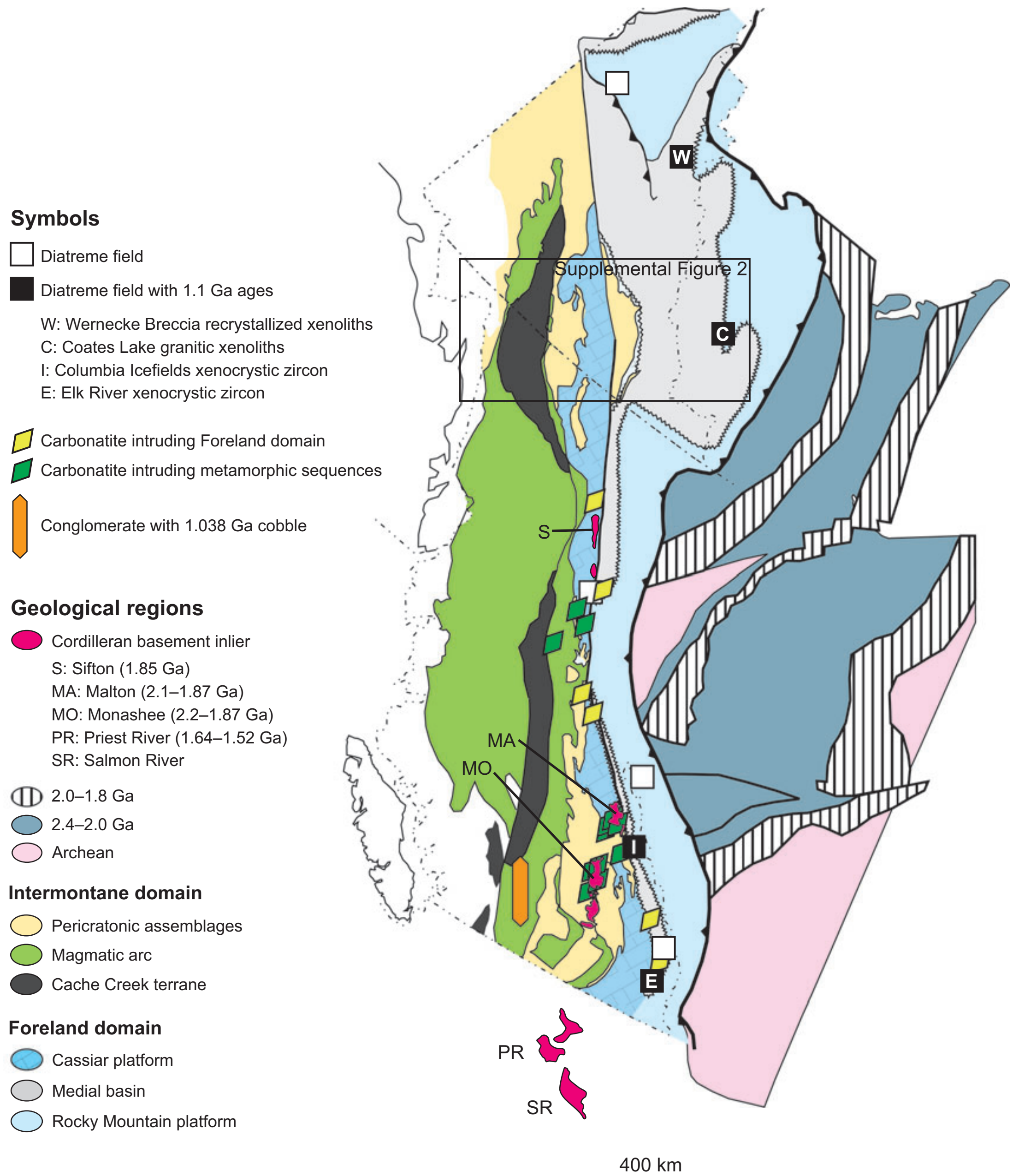


Figure 4

Diatremes (*squares*) and carbonatites (*diamonds*) of the Cordillera. Inliers of Precambrian basement within the Cordillera are indicated (*magenta*), as are the domains of the autochthonous Precambrian basement. Box shows location of **Supplemental Figure 2.**

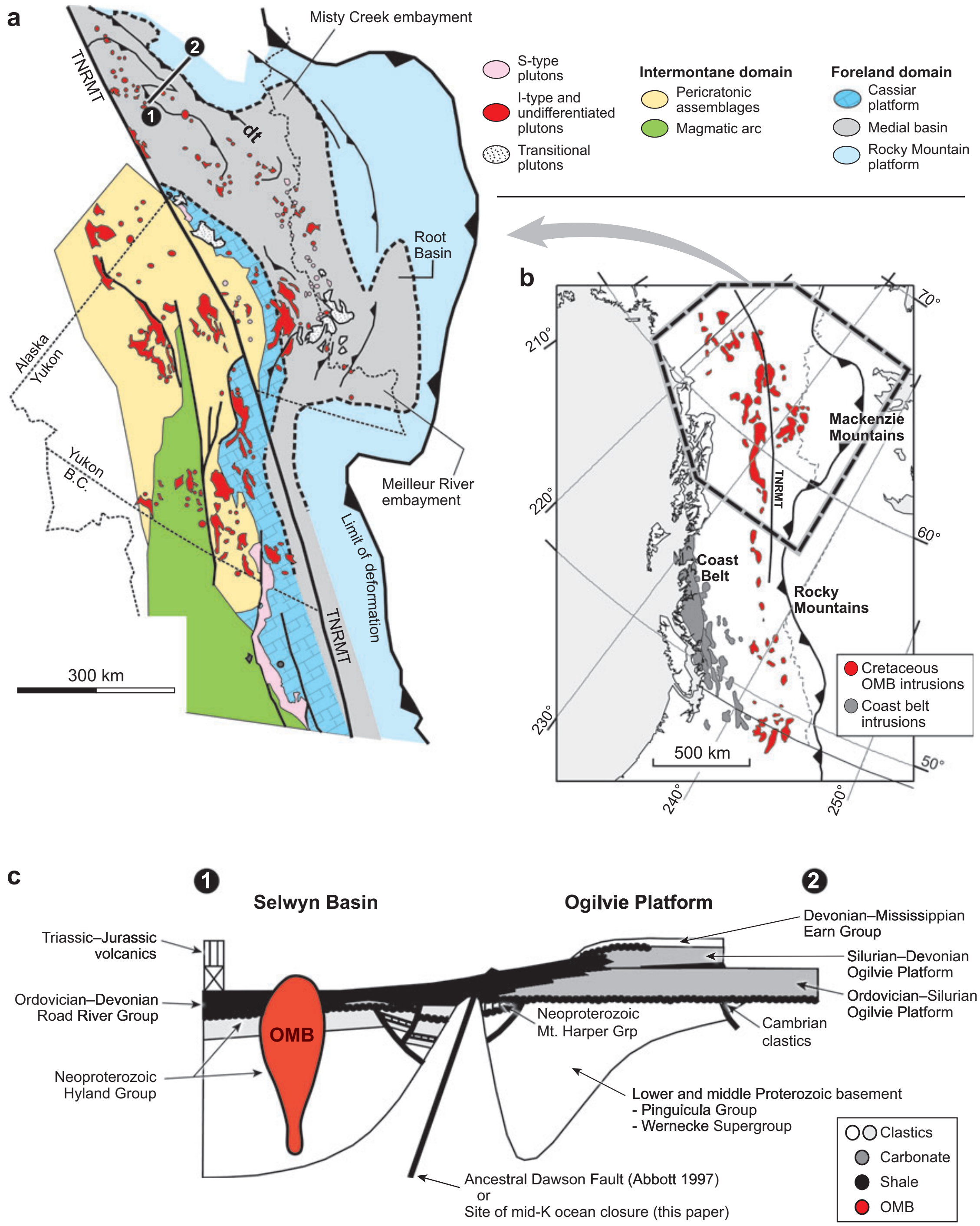
2002) (**Figure 4**) >700 Ma younger than any known basement within the adjacent autochthon.

North American mantle can similarly be distinguished from the mantle underpinning the Cassiar Platform and intermontane domain. Mantle xenoliths in Cretaceous and younger kimberlite pipes intruding the authochthon range in age from Archean to 1.8 Ga (LeCheminant et al. 1996). Alkalic magmatic rocks derived from melting of the cratonic mantle lithosphere are isotopically radiogenic. For example, phlogopite separated from the Lac de Gras kimberlites of the Slave craton yields initial Sr values ranging from 0.704 to 0.706 (Creaser et al. 2004). In contrast, Re-Os isotopic studies of mantle xenoliths sampled by young alkali basalts erupting through Stikinia-Quesnellia and the pericratonic assemblages all yield similar Os model ages of 1.1 Ga, interpreted as the age of melt extraction and lithospheric mantle formation (Peslier et al. 2000) (**Supplemental Figure 1**). Isotopic studies of the alkali basalts indicate that the mantle source region beneath the Medial Basin are less radiogenic (iSr = 0.7034) than either the cratonic mantle to the east or the mantle underpinning the Cassiar Platform to the west (Abraham et al. 2001) (**Supplemental Figure 1**).

MID-CRETACEOUS ARC MAGMATISM OF THE INTERMONTANE DOMAIN, CASSIAR PLATFORM, AND THE MEDIAL BASIN

A defining feature of the Canadian Cordillera is the mid-Cretaceous Omineca Magmatic Belt (OMB). Here I focus on the northern OMB (**Figure 5**) for which there is a significant geochemical and geochronological database. The northern OMB is a belt of I- and S-type plutons (**Figure 5**) that intrude the intermontane domain, Cassiar Platform and the Medial Basin. Resulting contact metamorphism is restricted to narrow aureoles (Gordey & Anderson 1993, Pigage & Anderson 1985, Smith & Erdmer 1990). The magmatic belt youngs to the northeast (**Figure 6**) (Breitsprecher & Mortensen 2004, Hart et al. 2004a, Mortensen et al. 2000). In the west, plutons intruded from 115 to 100 Ma, with small volume plutons as old as 124 Ma. Successively younger orogen-parallel intrusive bands to the northeast terminate in a set of 92 +/− 1 Ma plutons. The southwest to northeast age progression is accompanied by changes in lithology, chemistry, and structure (Hart et al. 2004a, Mortensen et al. 2000). The western plutons are midcrustal, concordant, foliated, metaluminous, calc-alkaline hornblende-biotite granodiorite sills with titanite and magnetite. Discordant, shallow-level plugs of granite are minor. The intrusions are spatially associated with and were syn-kinematic with steep, dextral-transpressive faults (Johnston 1999). Initial Sr is ∼0.707 (n = 12) and geochemical data indicate enrichment in large-ion lithophile elements (LILE) and negative Nb anomalies (Selby et al. 1999).

Younger plutons to the northeast are peraluminous and felsic, foliated to massive hornblende-biotite granodiorite and muscovite-biotite granite (**Figure 5**). Accessory ilmenite and monazite indicate reduced magmas (Hart et al. 2004a). Magmatism was syn- to postkinematic; different magmatic phases are juxtaposed along brittle-ductile high-strain zones (Gordey & Anderson 1993), with predominantly shallow-level plutons lying elongate parallel to and spatially associated with northeast-verging dextral


a
Misty Creek embayment
TNRMT
dt
Root Basin
Alaska
Yukon
Yukon
B.C.
Meilleur River embayment
Limit of deformation
300 km
S-type plutons
I-type and undifferentiated plutons
Transitional plutons
Intermontane domain
Pericratonic assemblages
Magmatic arc
Foreland domain
Cassiar platform
Medial basin
Rocky Mountain platform
b
Mackenzie Mountains
Coast Belt
Rocky Mountains
500 km
Cretaceous OMB intrusions
Coast belt intrusions
c
Selwyn Basin
Ogilvie Platform
Triassic–Jurassic volcanics
Ordovician–Devonian Road River Group
Neoproterozoic Hyland Group
OMB
Neoproterozoic Mt. Harper Grp
Devonian–Mississippian Earn Group
Silurian–Devonian Ogilvie Platform
Ordovician–Silurian Ogilvie Platform
Cambrian clastics
Lower and middle Proterozoic basement
- Pinguicula Group
- Wernecke Supergroup
Ancestral Dawson Fault (Abbott 1997)
or
Site of mid-K ocean closure (this paper)
Clastics
Carbonate
Shale
OMB

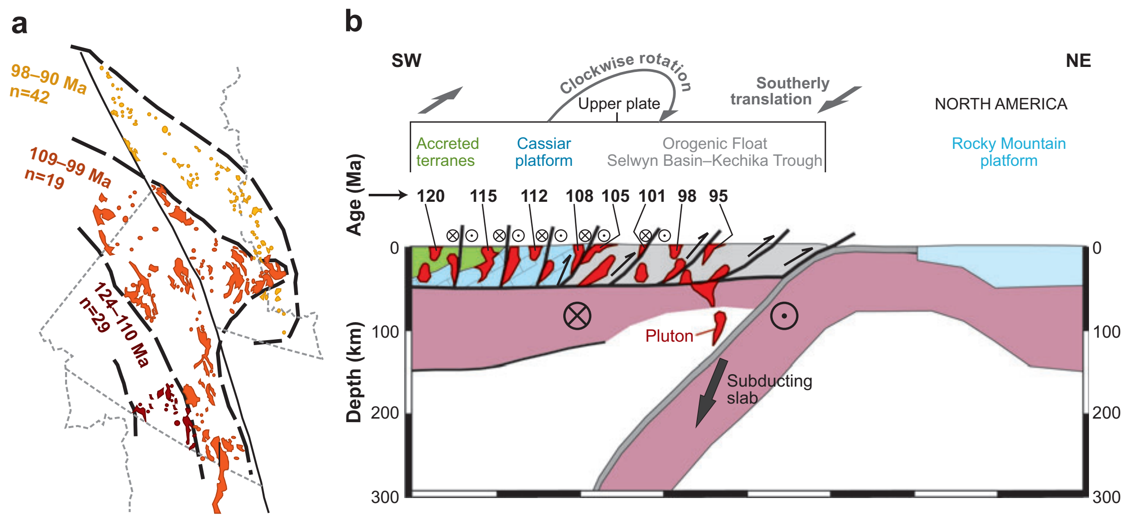


Figure 6

(*a*) Northern OMB plutons contoured (*long dash lines*) by age (Breitsprecher & Mortensen 2004). After Mortensen et al. (2000) and Hart et al. (2004b). n, number of age determinations. (*b*) Schematic cross section showing tectonic setting of OMB arc (plutons in *red*) at ∼95 Ma (Oldow et al. 1990). Oblique subduction is resolved into dextral strike-slip and NE-verging thrust faults that displace trenchward crust south (*toward reader*). The addition of orogenic float along thrusts results in younging of arc plutons to the NE (*large arrow* indicates motion of subducting slab). Arrows at top indicate southward displacements and clockwise rotations attributable to dextral strike-slip fault.

transpressive thrust faults (Murphy 1997) (**Figure 5**). The thrust faults root west beneath and are interpreted to share a common basal detachment with coeval dextral strike-slip faults. Hornblende and biotite-bearing intrusions have initial Sr of 0.706 to 0.710, LILE enrichment, and negative Nb anomalies; two mica granites have initial Sr of 0.709 to >0.730 (n = 15) (Driver et al. 2000). The most northeasterly plutons intruded from 94 to 90 Ma, have circular map-patterns and are bimodal metaluminous to alkaline, quartz monzonite to syenite, with rare gabbro and lamprophyre (Anderson 1987).

Figure 5

(*a*) The northern Omineca magmatic belt (OMB) showing distribution of S- (*pink*), I-type and undifferentiated (*red*), and (*stipple*) transitional plutons that are intermediate between I- and S-types (Gordey & Anderson 1993, Hart et al. 2004a, Mortensen et al. 2000). Four-hundred and twenty-five kilometers of Eocene displacement along the Tintina–Northern Rocky Mountain Trench (TNRMT) fault has been restored. Teeth on mid-Cretaceous thrust faults, including the Dawson Thrust (dt), point into the hangingwalls, opposite their sense of vergence; strike-slip faults are dextral. (*b*) Inset location map shows Cordilleran distribution of mid-Cretaceous OMB (*red*) and Coast belt (*gray*) intrusions. (*c*) Cross section at lower right (line a–b in *panel a*) shows palinspastically restored stratigraphic section across hangingwall (*left*, intruded by OMB) and footwall (*right*) sequences of Dawson Thrust (Abbott 1997).

Hornblende-biotite granodiorites characterized by LILE enrichment and negative Nb anomalies, like those of the OMB, are commonly explained as arc magmas (Hamilton 1995). An arc-interpretation has, however, been previously ruled out because of the broad width and lack of a nearby, temporally associated subduction complex. Previous explanations of OMB magmatism have included back-arc magmatism behind the coastal arc developed on the Insular Belt Wrangellia-Alexander terranes (Hart et al. 2004a, Kidwell et al. 2005, Mair et al. 2006) and melting of a thickened crustal welt (Armstrong 1988, Driver et al. 2000, Monger et al. 1982). These models have difficulty explaining the volume, lithology, and structural setting of the northern OMB. Continental back-arcs are typically characterized by small volumes of alkalic magmatism intruded during extension, modern flat slabs are amagmatic (Gutscher et al. 2000), and thermal modeling indicates that slab flattening yields no significant magmatism (English et al. 2003). Crustal welts yield irregularly developed, amphibolite-grade crystalline terranes with spatially associated plutons that postdate crustal thickening and lack a mantle component. Although Late Triassic orogeny thickened the crust in the OMB region, this crustal welt was unroofed by 180 Ma (Colpron et al. 1996, Johnston et al. 1996a). Neither back-arc magmatism nor melting of a crustal welt explains the systematic southwest- to northeast-younging and related geochemical changes of the OMB. I suggest a model involving the structural addition of orogenic float to the upper plate of a convergent margin (Oldow et al. 1990).

Orogenic float (Oldow et al. 1990), when added to the upper plate at a convergent margin, is bound by landward-dipping thrust faults that young oceanward and root into a basal decollement. Oblique subduction is resolved into margin-normal thrusts and coeval margin-parallel strike-slip faults. Assuming a fixed trench, the addition of orogenic float to the upper plate is accommodated by the displacement of upper plate crust, including previously intruded arc plutons, away from the trench (Oldow et al. 1990). Because arcs are produced at a relatively fixed distance from the trench (Hamilton 1995), the addition of orogenic float gives rise to a magmatic arc that youngs oceanward (**Figure 6**).

In an orogenic float model, the northern OMB is an arc that was constructed across an upper plate consisting of the intermontane domain and the Cassiar Platform; abyssal strata of the Medial Basin are inferred to be orogenic float derived from a subducting lower plate. The transfer of the orogenic float from a subducting slab displaced upper plate crust away from the trench. The younging direction of the arc plutons and coeval thrust faults implies that upper plate crust was displaced to the southwest, indicating that the trench lay northeast of the Cassiar Platform. Because the abyssal strata of the Medial Basin are allochthonous orogenic float, eastward salients of the basin (**Figure 5**) are probably structural artifacts of the accretionary process (discussed below). Entry of continental crust of North American into the trench at 92 Ma terminated subduction.

The eastward transition from I-type, oxidized magnetite-bearing plutons to reduced ilmenite-bearing, I- and S-type plutons reflects arc migration onto the accreting orogenic float (**Figure 6**). Underplating of argillaceous float by gabbro would melt the float, explaining the radiogenic S-type plutons. The radiogenic character of some I-type plutons has been used to argue that all of the intrusions are the result of crustal melting. Subduction of transitional lithosphere and fluxing of the mantle wedge by continental components derived from the heavily sediment-laden downgoing plate may, however, explain the evolved, radiogenic mantle-derived magmatism.

Interpretation of the northern OMB as an east-facing arc implies that the Medial Basin is host to a cryptic suture. The imbricated, cleaved, disrupted and deformed chert, argillite, and deep-water limestones of the Medial Basin are an "accretionary prism," limiting the cryptic suture to being beneath or along its east margin. It remains unclear if any of the voluminous suite of ophiolitic rocks mapped in Alaska (Patton et al. 1994) originated within the forearc of the OMB arc. Along strike to the south, the OMB in northern Idaho is characterized by the Salmon River suture in which ophiolitic rocks were obducted, sheared, and overprinted by OMB intrusions, all between 130 and 80 Ma (McClelland et al. 2000). These relationships are consistent with the Salmon River ophiolite being a preserved remnant of the suture separating the OMB arc from North America.

PALEOMAGNETIC AND PALEOBOTANICAL DATA

Cretaceous bedded sedimentary and volcanic rocks that unconformably overlie the intermontane domain consistently yield anomalously shallow paleomagnetic inclinations relative to cratonic North America (Enkin et al. 2003, 2006; Irving et al. 1996, Wynne et al. 1998) (**Figure 7**). These paleomagnetic data imply that the intermontane domain crust lay >2000 km to the south relative to the autochthon between 90 Ma and 70 Ma (Enkin 2006). Paleomagnetic studies of plutons provide less consistent results, probably owing to the difficulty in constraining paleohorizontal and the age of magnetic remanance. Although some studies of plutons have been interpreted as showing little evidence for a southerly origin (McCausland et al. 2006, Symons et al. 2005), the bulk of pluton studies yield results consistent with results obtained from layered supracrustal rocks (Enkin 2006, Irving & Wynne 1992).

In Yukon, 70 Ma volcanic flows and interlayered sedimentary rocks of the Carmacks Group unconformably overlie the pericratonic assemblages and Stikinia-Quesnellia (**Figure 7**). Paleomagnetic studies of the Carmacks Group indicate deposition 1950 ± 600 km to the south relative to cratonic North America (Enkin et al. 2006, Johnston et al. 1996b, Marquis & Globerman 1988, Wynne et al. 1998) (**Figure 7**). The most easterly exposure of the Carmacks Group, at Solitary Mountain, lies just 5 km west of the fault zone along which the pericratonic assemblages and the Cassiar Platform are juxtaposed (Colpron et al. 2005). A 105 Ma batholith, one of the mid-Cretaceous OMB plutons, plugs the fault zone. The contact aureole for the batholith extends unbroken across the fault zone into the pericratonic assemblages, limiting fault juxtaposition of the intermontane domain and the adjacent Cassiar Platform to having occurred prior to 105 Ma, long before deposition of the Carmacks Group.

Intrusions of the mid-Cretaceous OMB are, as indicated above, widespread in Yukon, pinning together Stikinia-Quesnellia, the pericratonic assemblages, Cassiar

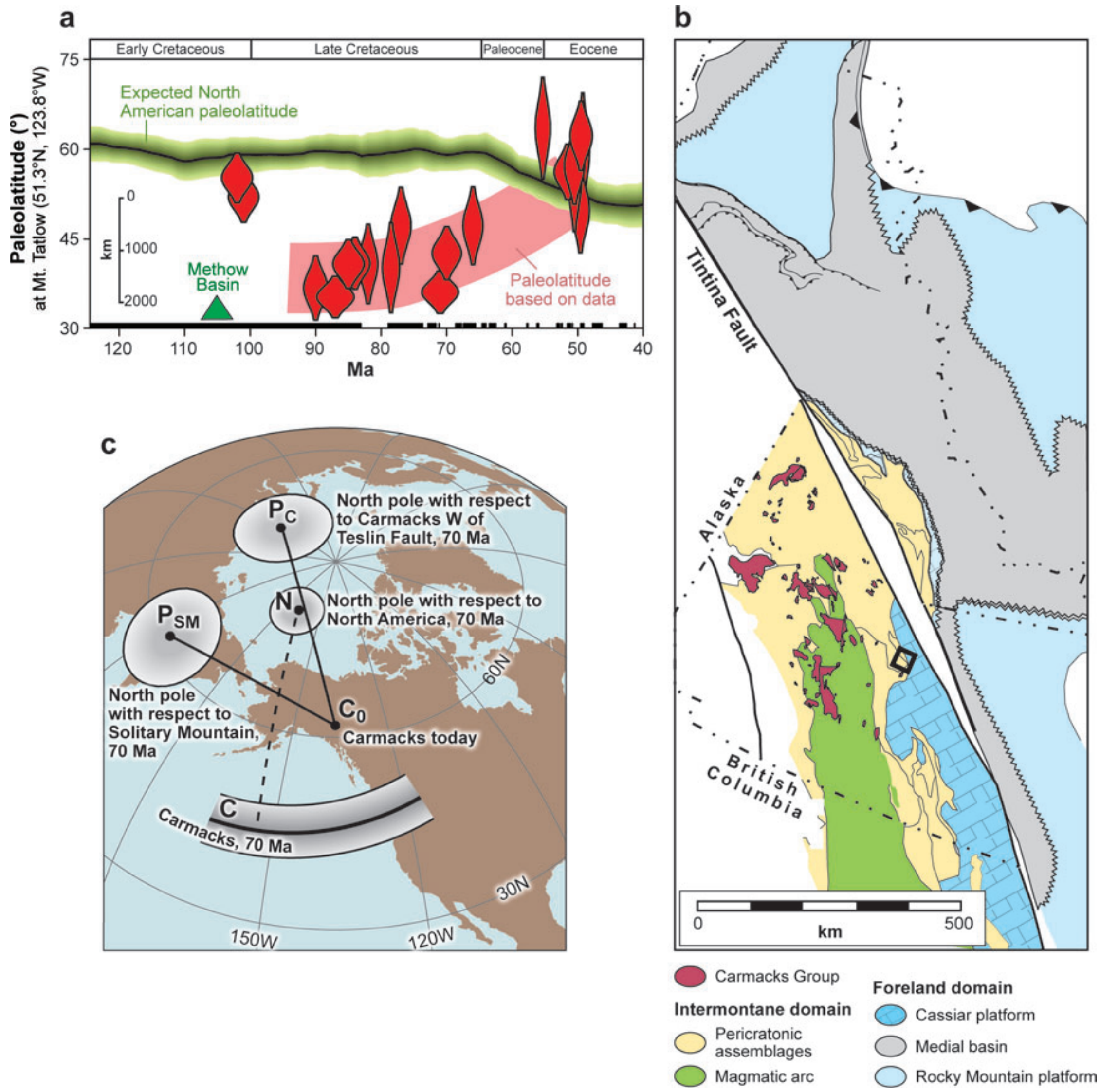


Figure 7

(*a*) Paleolatitudes relative to the expected North American paleolatitude (*green line*) for Cretaceous and Paleogene bedded rocks based on paleomagnetic data (*red diamonds*; see Enkin 2006 for primary data and locations) and on paleobotanical data (Miller et al. 2006) from Winthrop Basin (*green triangle*, the Methow Basin). Global polarity record (black: normal; white: reversed) shown at bottom. (*b*) Geology map, with 425 km dextral motion along Tintina fault restored, showing distribution of Carmacks Group (*maroon*) at left (Gladwin & Johnston 2006, Wynne et al. 1998). Black box indicates location of Solitary Mountain. (*c*) Paleomagnetic results for the Carmacks Group at right, showing far-sided poles relative to the cratonic North American pole location. Carmacks Group at Solitary Mountain yields a different azimuth indicating rotation relative to Carmacks Group to the west (Enkin et al. 2006).

Platform, and much of the Medial Basin (**Figure 5**) (Woodsworth et al. 1992). The plutons extend east almost to the eastern margin of the Medial Basin (Gordey & Anderson 1993). Hence, the paleomagnetic results for the Carmacks Group apply to the Cassiar Platform and much of the Medial Basin (Gladwin & Johnston 2006). The implications of these findings are that (*a*) the Cassiar Platform did not become fixed to autochthonous North America until the Eocene; (*b*) that it, together with Medial Basin strata to the east and intermontane domain strata to the west, resided ∼2000 km to the south relative to cratonic North America at 70 Ma; and (*c*) that the structures along which Late Cretaceous northward motion were accommodated lie in the easternmost Medial Basin, along the eastern boundary of the Medial Basin, or in the Rocky Mountain Platform to the east.

Layered sedimentary rocks overlying the intermontane domain locally contain fossil leaves that can be used to estimate mean annual temperature (MAT). Because the MAT is primarily a function of latitude (Miller et al. 2006), paleobiographic MAT analyses can be used to constrain paleolatitude. The mid-Cretaceous (110 to 100 Ma) Winthrop Formation, part of the Methow Basin of the southwestern intermontane domain (**Figure 2**), contains fossil angiosperm leaves. Leaf-margin analysis of the angiosperm fossils indicates a subtropical to tropical growth environment, consistent with a latitude of 38.4° and implying deposition 2200 km to the south (Miller et al. 2006) (**Figure 7**), consistent with the paleomagnetic data. Because the intermontane domain can be tightly tied to the pericratonic assemblages and the Cassiar Platform by the Early Jurassic, the southerly latitude indicated by the paleobiographic analysis provides further confirmation of the mobility of the Cassiar Platform and western Medial Basin into the Late Cretaceous.

Paleomagnetic studies of older rocks in the Cordillera similarly imply significant mobility of the intermontane domain relative to cratonic North America. Ophiolitic sequences interleaved with the pericratonic assemblages include Permian abyssal seafloor sedimentary rocks. A primary paleomagnetic remanance in the sedimentary rocks yields anomalously shallow inclinations relative to cratonic North America, implying deposition >2000 km to the south (Richards et al. 1993). Triassic and Jurassic paleomagnetic results from Stikinia-Quesnellia yield paleolatitudes that are broadly similar to cratonic values but that require large and variable rotations, and for which the hemisphere of origin is ambiguous (Irving & Wynne 1992).

BENDS OF FAULTS AND FACIES BOUNDARIES

The east margin of the Medial Basin is characterized by numerous eastward salients, including the Meilleur River and Misty Creek embayments (**Figure 2**). The distribution of shallow- and deep-water facies is commonly interpreted as primary features reflecting the geometry of the original rifted west margin of the continent (Cecile et al. 1997). However, two structural observations are inconsistent with the distribution of shallow- and deep-water facies being a primary feature: Cretaceous faults commonly parallel and mimic the older facies boundary and interpreted Paleozoic rift structures are continuous around bends of 180°. I provide two examples, the Ogilvie deflection and the Misty Creek embayment.

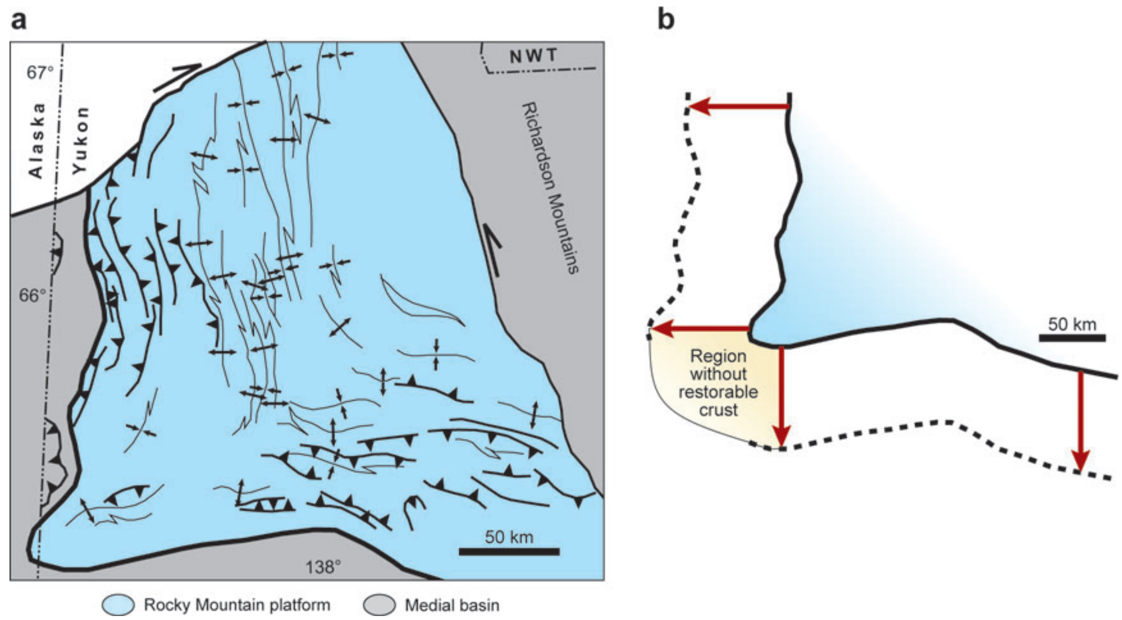


Figure 8

(*a*) Structural map of the Ogilvie Mountains (location on **Figure 2**) showing distribution of shallow and deep water facies and of Cretaceous thrust faults (McMechan et al. 1992, Norris 1985). (*b*) Simplified palinspastic restoration of facies boundary, assuming 75 km shortening along the south and west limbs of the mountain belt.

The Ogilvie Mountains are a foreland-verging fold and thrust belt of mid-Cretaceous age that is spatially coincident with the boundary between basinal shales to the south and the more northerly Ogilvie or Yukon Platform (**Figures 3** and **8**). To the west, the south margin of the platform describes a 90° deflection from an east-west trending feature to a north-south orientation. The change in the orientation of the facies boundary is paralleled by a change in the orientation of the fold and thrust belt, a feature referred to as the Ogilvie deflection (Norris 1972). The east-west trending fold and thrust belt verges north, and is continuous through the Ogilvie deflection into east-verging faults of the north-south trending portion of the belt.

Palinspastic restoration of the thrust sheets results in a significant room problem; the restored east-west trending southern and north-south trending western portions thrust belts are restored a considerable distance away from one another around the hinge region, implying that what is now the hinge region lacked crust prior to the development of the fold and thrust belt (**Figure 8**). This room problem is significant—the "hole" in the palinspastic restoration covers an area of almost 10,000 km^2. The problem can also be thought of as a line-length problem: Propagation of thrust sheets continuous around a preexisting bend toward the foreland should have resulted in enormous strike-parallel contraction within the hinge region, for which there is no evidence (**Figure 8**). Bending of an originally linear fold and thrust belt removes the

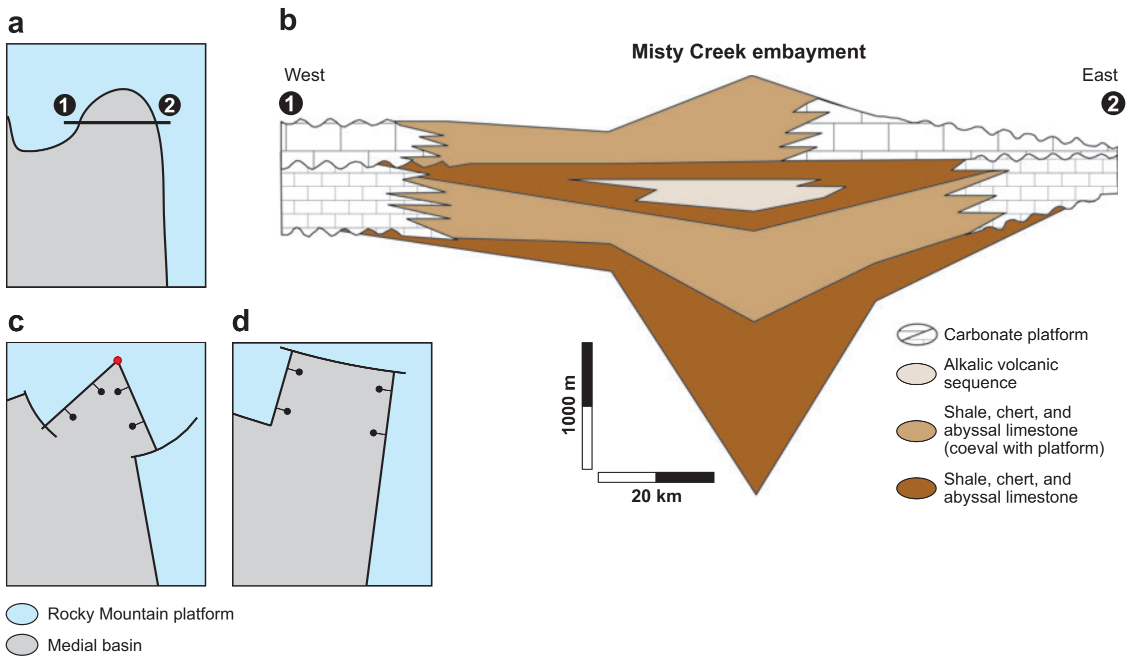


Figure 9

(*a*) Simplified geology map of Misty Creek embayment (location indicated on **Figure 5**). (*b*) Cross section 1–2 showing symmetric "steer's head" geometry of lithofacies across basin (Cecile et al. 1997). (*c*, *d*) Simplified models showing how steer's head rift (*black dots with stems on down-dropped blocks*) has to end either in a pole of rotation (*red dot*) or a transform fault, respectively.

room/line length problem and implies that the facies boundary geometry is the result of strain and is not primary.

Cross sections drawn perpendicular to the long axis of the north-northwest-trending Misty Creek embayment show that it is symmetric, with a "steer's head" profile (White & McKenzie 1988) consisting of a central "head" of shale and deep-water limestone with fringing "horns" of shallow-water carbonates (Cecile 1982) (**Figure 9**). Based on the observed steer's head symmetry, a model of symmetrical rifting was employed to explain the origin and geometry of the embayment (Cecile et al. 1997). A prediction of a model of parallel, symmetrical opposing rifts is that they must terminate along strike in either an Euler pole of rotation, or (given a distant Euler pole) a transform fault (**Figure 9**). Instead, the sedimentary facies and bounding structures are continuous through 180° around the entire embayment; sections drawn perpendicular to the facies boundary are everywhere identical, a geometry that cannot be produced through any simple rift model. Bending of an originally linear rift margin best explains the geometry of the Misty Creek embayment.

Parallelism of Cretaceous thrust faults around major bends in facies boundaries, and continuity rift margins around bends of 180°, indicate that the geometry of the platform to basin facies boundary is not a primary feature of the orogen, but is the result of Cretaceous bending, about vertical axes of rotation, of originally more linear rift margins and fold and thrust belts.

Rift-Related Carbonatites and Alkaline Igneous Complexes

The margins of the Medial Basin are characterized by Lower to Middle Paleozoic alkaline igneous and carbonatite complexes along the length of the orogen (Pell 1994) (**Figure 4**). The intrusive complexes are locally spatially associated with coeval alkaline and potassic basalts (Goodfellow et al. 1995). Deformation of the complexes is indicated by the presence of a weak to moderately well-developed foliation, local mylonitization, folding, boudinage, and truncation by thrust faults (Johnston & Pyle 2005, Pell 1994). The presence of syn-magmatic extensional structures (Johnston & Pyle 2005) and proximity to the margins of the Medial Basin imply that the complexes lie along and mark ancient rift zones.

Global study of deformed alkaline igneous and carbonatite complexes indicate that they commonly lie along and characterize suture zones; >90% of deformed African nepheline syenite and carbonatite complexes lie along and mark known and inferred sutures (Burke et al. 2003). Because alkaline igneous complexes and carbonatite intrusions characterize intracontinental rifts (Bailey 1977), their location within collisional orogens can be explained in terms of a Wilson cycle model, with magmatism occurring along and marking the rifted margin of a continent, and deformation occurring during ocean closure and subsequent collision (Burke et al. 2003). The distribution of Cordilleran carbonatites, alkaline igneous complexes, and coeval alkaline basalts within the Medial Basin is, therefore, consistent with the Medial Basin being a cryptic suture separating a west-facing autochthonous continental margin (the Rocky Mountain Platform) from a more westerly, east-facing exotic continental margin represented by the Cassiar Platform.

Late Cretaceous Fold and Thrust Belt Formation

The Canadian Cordillera is characterized along its entire length by a Late Cretaceous, foreland-verging fold and thrust belt (**Figures 1** and **2**), of which the Rocky Mountains of southwest Alberta are the most spectacular and well-known manifestation. Shortening accommodated by the thrust belt decreases northward from a maximum of >250 km in southern Alberta (Price & Sears 2000) to less than 50 km in the north (McMechan et al. 1992). Cooling ages, paleomagnetic studies, direct dating of fault rocks, and the age of deformed and overlapping undeformed strata limit deformation to having occurred between the Campanian (~80 Ma) and the Early Eocene (~50 Ma) (Enkin et al. 2000, McMechan et al. 1992, Price 1981, van der Pluijm et al. 2006).

Explaining the origin of the fold and thrust belt is problematic. Most workers assume fold and thrust belt formation postdates previous accretion of the intermontane and insular domains (Monger et al. 1982). Hence the fold and thrust belt is assumed to have formed 1000 to 1500 km inboard from the active Late Cretaceous west margin of the continent and in the absence of any collisional event (English & Johnston 2004). Noncollisional explanations of the fold and thrust belt appeal to interaction with the slab subducting beneath the west margin of the continent. A compressive stress regime is inferred to have resulted from rapid relative convergence between the North American and the oceanic plate to the west (Hyndman 1972), possibly coupled with the presence of a thermally weakened back-arc region (Hyndman et al. 2005). Alternative explanations of compression involve flat slab subduction of the oceanic plate (Dickinson 2004), possibly due to the presence of an oceanic plateau on the subducting plate (Murphy et al. 2003) or because of subduction of a spreading ridge (Bird 1988). A model of transcurrent deformation links fold and thrust belt formation to 430 km of dextral strike-slip motion along the Northern Rocky Mountain–Tintina trench fault (**Figure 2**) via an inboard transfer of displacement (Price & Carmichael 1986).

Flat slab models, no matter what the cause, do not explain shortening along the entire length of the orogen. The Late Cretaceous fold and thrust belt runs the length of the continent (**Figure 1**); hence, appeals to subducted oceanic plateau and spreading ridges, although possibly explaining some local variation in structural style, do not provide a framework for explaining the entire thrust belt. Linking fold and thrust belt formation to the dextral strike-slip Northern Rocky Mountain–Tintina trench fault suffers the same dilemma in that it provides a local explanation for a continent-scale problem. In addition, displacement on the strike-slip fault occurred in the Eocene (Gabrielse et al. 2006) and would, therefore, have been coeval with only the final increments of thrust belt shortening recorded along the McConnell and related thrust faults (van der Pluijm et al. 2006). Appeals to high relative convergence are inconsistent with there having been at least two and possible three different oceanic plates west of North America, each moving in different directions. Neither does it explain why fold and thrust belt formation occurred within the continent, well removed from the margin.

As discussed above, paleomagnetic and paleobiographic data from Cretaceous layered sedimentary and volcanic rocks imply >2000 km of northward motion of the intermontane domain, Cassiar Platform, and much of the Medial Basin. The Late Cretaceous fold and thrust belt is, therefore, coeval with the timing of northward motion, and is located along the eastern boundary of the region that moved north. The simplest explanation of the fold and thrust belt is, therefore, that it lies along and marks the boundary between the crust that moved north and the autochthon, and that it is a product of transpression during northward motion (Johnston 2001). In this model, the Northern Rocky Mountain–Tintina trench fault records the last component of northward motion and the McConnell thrust system the last component of convergence between the Cassiar Platform–Medial Basin and the autochthon.

THE CORDILLERAN COMPOSITE RIBBON CONTINENT

The Cassiar Platform is exotic with respect to autochthonous North America and has the following characteristics: (*a*) It has Triassic Eurasian fauna; (*b*) it was involved in a major Late Triassic orogenic event, whereas the coeval ancient west margin of North

America remained a passive margin facing west toward a broad open ocean; (*c*) it is underlain by a basement and lithospheric mantle that, having formed at least in part at 1.1 Ga, is 700 Ma younger than the youngest portions of the basement and lithospheric mantle underpinning the autochthon; (*d*) it is separated from autochthonous mantle by isotopically juvenile and oceanic-like mantle beneath the Medial Basin; (*e*) it is bound to the east by a belt of carbonatites, which likely delineate a cryptic suture; (*f*) it is characterized by an east-facing mid-Cretaceous magmatic arc that records west-dipping subduction beneath its eastern margin; and (*g*) it lay 2000 km to the south relative to the autochthon as recently as 80 Ma as indicated by paleomagnetic and paleobotanical data. The geometry of the boundaries separating platformal and basinal facies within the foreland domain is the product of Cretaceous tectonism and is not a reflection of the shape of the ancient rifted margin of the continent.

If the Cassiar Platform is not North American, from where does it hail? As discussed by Johnston & Borel (Johnston & Borel 2007; see **Supplemental Appendix**), the Cache Creek terrane places tight constraints on the location of the Cassiar Platform from the Permian through the Jurassic. Tethyan fauna and DUPAL-anomaly basalts characterize off-scraped Cache Creek seamounts, constraining the seamounts to having originated in the Tethyan Sea sensu stricto. The seamounts, Stikinia-Quesnellia, the pericratonic terranes, and the Cassiar Platform are pinned together by the end of the Triassic. Hence, the Cache Creek seamounts constrain the paleogeographic location of the Cassiar Platform, placing it in central Panthalassa, >4000 km west of the autochthon at 180 Ma (the most easterly possible point that could have been reached by the seamounts assuming that they migrated eastward out of the Tethys Sea at 11 cm year^{-1}) (**Figure 10**). Continental crust within the Cordilleran Orogen is, therefore, divisible into an eastern autochthonous platform and a western allochthonous platform, separated by a cryptic suture located within or along the margins of the Medial Basin (**Figures 1** and **2**).

The Cassiar Platform and intermontane domain terranes constitute a composite ribbon continent that can be followed northwest into Alaska (Johnston 2001), where it is continuous through two major oroclines, the Kulkbuk Hills orocline in the southwest (Bradley et al. 2003) and the Northeast Alaskan orocline in the northeast (Patton & Tailleur 1977) (**Figure 1**). The Farewell terrane is continuous around the hinge of the Kulukbuk Hills orocline, consists of an east-facing carbonate platform and a more easterly basinal facies of shale and chert, which are correlative with the Cassiar Platform and Medial Basin, respectively. Precambrian basement to the Farewell terrane carbonate platform consists of metasedimentary rocks and metabasite intruded by rhyolites that yield zircon crystallization ages as old as 979 Ma (Bradley et al. 2003), consistent with the evidence for a Grenvillian basement beneath the ribbon continent in the Canadian Cordillera. Lower Paleozoic Farewell terrane strata are characterized by distinct Siberian fauna, including trilobites, conodonts, and brachiopds (Blodgett et al. 2002, Dumoulin et al. 2002). Silurian aphrosalpingid sponges are only known elsewhere from the Alexander terrane of the insular domain and the Urals (Soja & Antoshkina 1997). Based on the faunal provinciality, Bradley et al. (2003) concluded that the Farewell terrane lay far removed from autochthonous North America, probably throughout the Paleozoic, consistent with an exotic origin for the

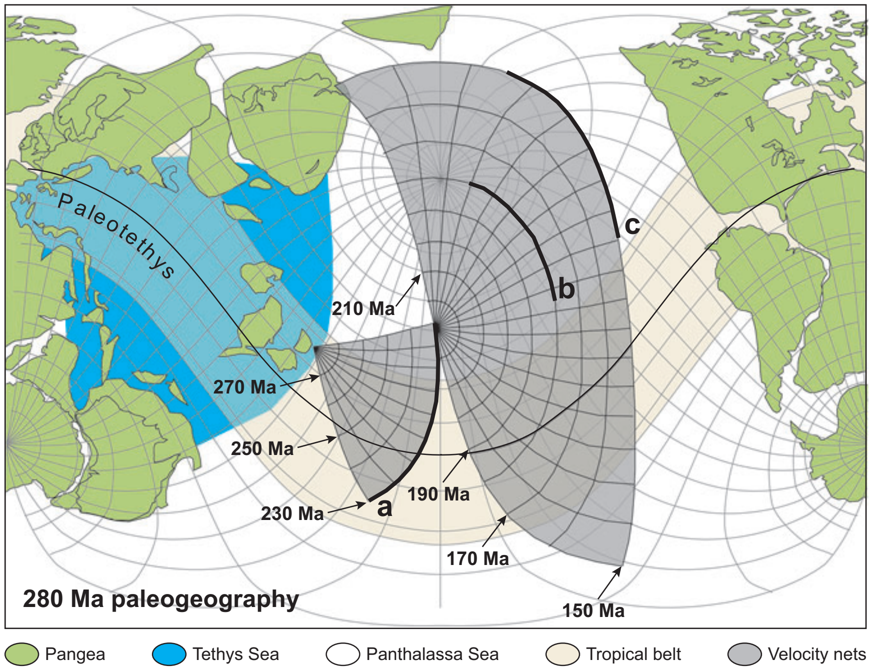


Figure 10

Paleogeographic map of Earth at 280 Ma (Stampfli & Borel 2002). The Tethys Sea (*blue*) separates the Laurasian (*north*) and Gondwanan (*south*) components of the supercontinent Pangea (*green*). The tropical belt is indicated through the uncolored superocean, Panthalassa, and the Tethyan Sea. Two velocity nets, one constructed for the period 280 Ma to 230 Ma and a second for the period 230 Ma to 150 Ma are shown. The velocity nets define the potential translation paths for the Cache Creek seamounts (assumptions outlined in text). Bold lines indicate the limits for the location of (*a*) seamount accretion to Quesnellia-Stikinia at 230 Ma (a point on this curve in the northernmost tropics is then used as the point of origin for the 230–150 Ma velocity net); (*b*) the intermontane domain terranes and Cassiar Platform at 180 Ma upon cessation of exhumation subsequent to orogenesis at 180 Ma; and (*c*) these same terranes at 150 Ma, the time of drowning of the passive margin of western North America, and the first influx of westerly derived orogenic sediments onto the autochthon (Johnston & Borel 2007).

Cassiar Platform. Correlative strata in the western Brooks Range yield a paleomagnetic remanance acquired during mineralization at 330 Ma that places the Cassiar Platform >3000 km to the south and having since rotated 50° to 70° counterclockwise (Lewchuk et al. 2004).

In northernmost Alaska, the autochthon is largely buried beneath a thick Cretaceous foreland basin siliciclastic sequence, but is recognizable from aeromagnetic images (**Figure 11**). The boundary between autochthonous and exotic platform margins lies within the Brooks Range, but does not appear to be separated by a basinal facies equivalent to the Medial Basin (**Figures 1** and **12**). It may be that the excess of basinal facies rocks forming the Selwyn Basin were derived from this portion of

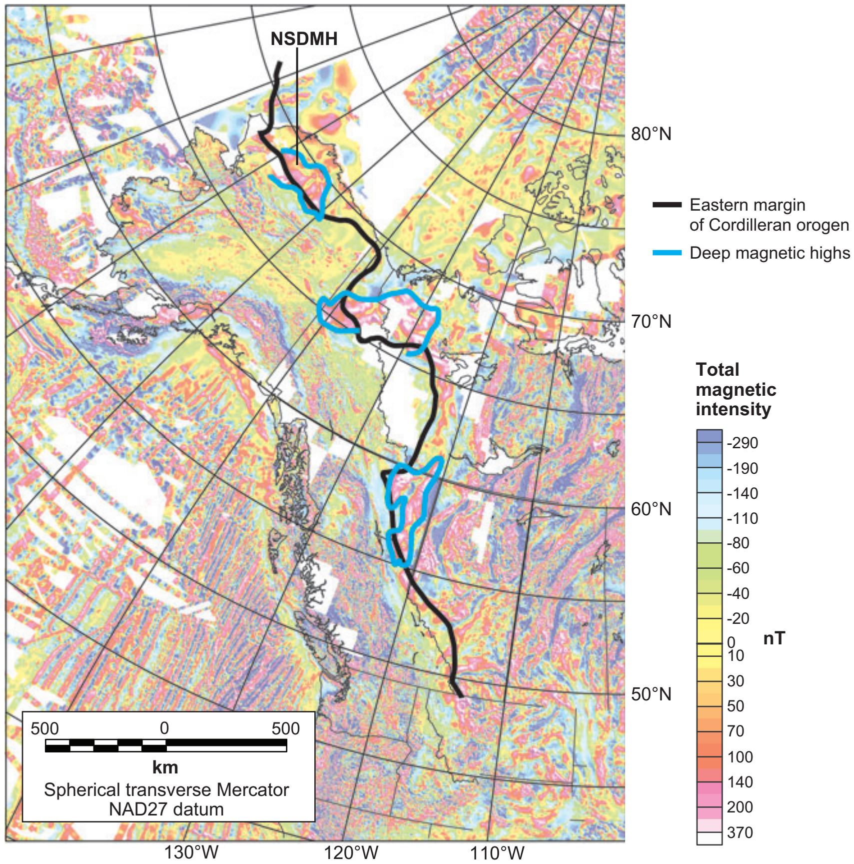


Figure 11

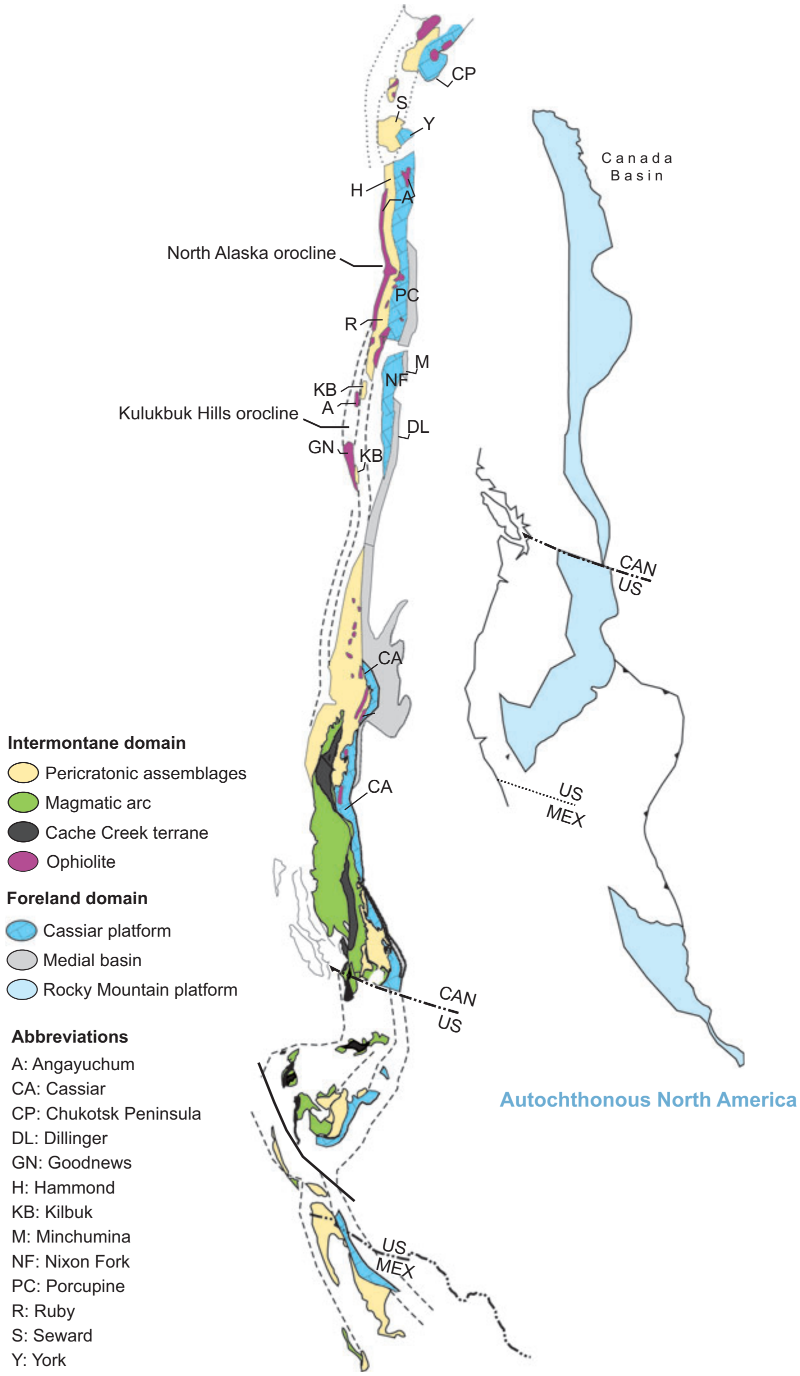
Magnetic anomaly map of northwestern North America (Saltus & Hudson 2007). The black line shows the eastern margin of the Cordilleran Orogen. Blue lines outline major deep magnetic highs that characterize the autochthon and include the NSDMH (north slope deep magnetic high).

the margin during mid-Cretaceous margin parallel motion in response to oblique subduction beneath the east-margin of the ribbon continent.

The ribbon continent is continuous to the south into the coterminous United States (**Figures 1** and **12**). Accretionary assemblages characterized by Tethyan

Figure 12

Palinspastic restoration of the Cordilleran composite ribbon continent to its geometry prior to buckling giving rise to the Kulukbuk Hills and Northeast Alaskan oroclines. There has been no attempt to restore bending and faulting of the southern coterminous U.S.A. portion of the ribbon continent. The ribbon continent is shown as being separated from the autochthon, but it may have been in close proximity to at least parts of the autochthon.



Restored Cordilleran ribbon continent

fauna are correlative with the Cache Creek terrane and can be followed south into California (**Figure 1**). Volcanic and sedimentary sequences that bound the accretionary assemblages to the east are characterized by McCloud fauna and are correlative with Stikinia-Quesnellia. East of the McCloud fauna terranes are ophiolite (e.g., the Golcanda allochthon) and pericratonic assemblages (e.g., the Roberts Mountains allochthon), that together are correlative with the pericratonic assemblages of the eastern intermontane domain. Identifying strata correlative with the Cassiar Platform and Medial Basin remains, however, controversial. Nonetheless, the Tethyan and McCloud faunal belts provide a template for identifying the southern continuation of the Ribbon continent as far south as Mexico.

The geometry of the ribbon continent in Alaska is the result of oroclinal bending of the originally more linear ribbon continent (Johnston 2001). Bending postdates mid-Cretaceous magmatism, as parallel belts of 120 to 100 Ma magnetite- and ilmenite-bearing plutons are continuous around the Alaskan oroclines (Hart et al. 2004a). Post-Eocene strata unconformably overlie the oroclines, providing a minimum age constraint for oroclinal buckling. Northward subduction of the largely oceanic plate that bore the ribbon continent into a subduction zone marginal to and dipping beneath the Okhotsk-Chukotka arc of eastern Siberia resulted in northward motion of the continental ribbon (**Figure 13**). Buckling resulted from pinning of the leading edge of the ribbon continent into the Siberian upper plate, while the trailing portions of the ribbon remained within and moving north as part of the subducting lower plate. As the buckling ribbon continent was transferred from the lower to upper plate it became progressively overprinted by upper plate arc magmatism of the Okhotsk-Chukotka arc in Siberia and the Late Cretaceous to Eocene Kluane arc in Alaska. Buckling of the smaller Bowers-Shirshov-Kamchatka ribbon was coeval with buckling of the Cordillera ribbon continent and indicates that the two ribbons lay within and were translated north within the same plate (**Figure 13**). It seems likely that the combined buoyancy of the buckling Cordilleran and Bowers-Shirshov-Kamchatka ribbons eventually resulted in the failure of the Okhotsk-Chukotka subduction zone, at which point the oceanic plate bearing the ribbon continents broke behind the two "terrane wrecks" initiating the Aleutian subduction zone (**Figure 13**), and giving rise to the major change in motion of the oceanic plates of the Pacific basin at 45 Ma. Palinspastic restoration of the Alaskan oroclines restores the southern U.S. portion of the ribbon continent well to the south (**Figure 12**).

The nature of the boundary between the ribbon continent and the autochthon in the Late Cretaceous immediately prior to northward displacement and orocline formation remains poorly constrained. The ribbon continent has previously been depicted as being separated from the autochthon by a basin (Johnston 2001) (**Figure 12**). There is, however, little evidence to support the presence of a broad open oceanic basin separating the ribbon continent from the autochthon in the Late Cretaceous. A more likely scenario is that the ribbon continent adjoined the autochthon along a major transcurrent fault boundary (**Figure 13**). Minor transpression, together with the buckling of the ribbon continent in the north, would have

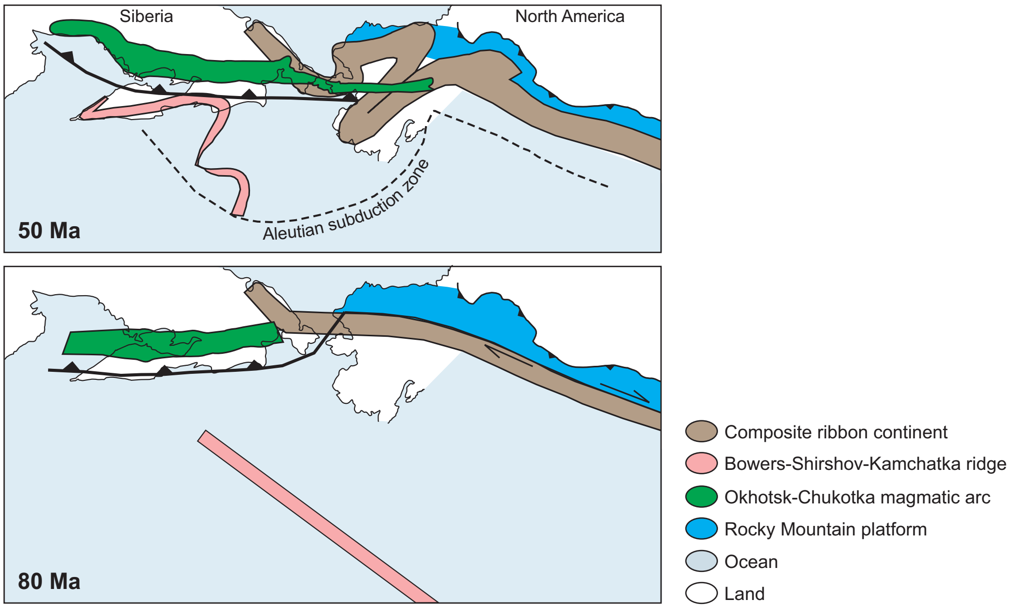


Figure 13

Schematic maps at 80 and 50 Ma showing buckling of the composite ribbon continent (*brown*) and the Bowers-Shirshov-Kamchatka ridge (*pink*) in response to subduction of oceanic lithosphere to the north giving rise to the Okhotsk-Chukotka magmatic arc (*green*). Northward motion is accommodated by a dextral transform fault that is gradually overprinted by foreland-verging thrust belts owing to a component of transpression. As the composite ribbon continent buckles and is transferred from the lower to upper plate, it becomes progressively overprinted by arc magmatism (Kluane arc in Alaska). Eventual failure of the Okhotsk-Chukotka subduction zone leads to the initiation of the Aleutian subduction zone (*dashed line*) oceanward of the buckled ribbon continent.

resulted in the original transcurrent boundary faults being carried inboard onto the autochthon where they were reactivated as thrust faults (Johnston 2001).

Two distinct phases of Cordilleran orogenesis can be distinguished (Johnston & Borel 2007). A Triassic to Early Jurassic accretionary phase involved the amalgamation of seamounts (Cache Creek), oceanic arcs (Stikinia-Quesnellia), pericratonic assemblages, and continental lithosphere (Cassiar Platform) (**Figure 10**). Accretionary orogenesis spanned at least 50 Ma (230 to 180 Ma) and produced a composite ribbon continent previously referred to as SAYBIA (Johnston 2001). The Upper Jurassic (150–155 Ma) drowning of the North American passive margin and the coeval deposition of the first orogenic clastic sediments on the autochthon records the initiation of the collisional second phase of Cordilleran orogenesis. The Late Cretaceous–Eocene Rocky Mountain fold and thrust belt records the terminal phase of collision, and involved transpression between the northward-translating composite ribbon continent and the autochthon (**Figure 13**). Cordilleran orogenesis was, therefore, far more akin to a complete Wilson cycle than has been previously recognized. Proterozoic and younger rifting of the west margin of Laurentia established a passive margin and led to the formation of an adjacent ocean basin. Closure of that basin in the Upper Jurassic led to collision and tectonic burial of the passive margin beneath a colliding continent. What distinguishes the Cordillera Wilson cycle from the classic Wilson cycle is that (*a*) the colliding continent was a composite ribbon continent constructed through an earlier accretionary orogenic phase, (*b*) collision was prolonged (150 to 50 Ma) and involved a final stage (80 to 50 Ma) in which the major motion was margin parallel (>2000 km of margin parallel displacement versus only hundreds of kilometers of margin normal convergence), (*c*) final collision involved oroclinal buckling of the accreting ribbon continent, and (*d*) the high aspect ratio of the colliding ribbon continent (long and narrow) prevented collision from being terminal—subduction continued beneath the new west margin of the continent.

DISCLOSURE STATEMENT

The authors are not aware of any biases that might be perceived as affecting the objectivity of this review.

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