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EVOLUTION OF THE NORTH AMERICAN CORDILLERA

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■ **Abstract** The Cordilleran orogen of western North America is a segment of the Circum-Pacific orogenic belt where subduction of oceanic lithosphere has been underway along a great circle of the globe since breakup of the supercontinent Pangea began in Triassic time. Early stages of Cordilleran evolution involved Neoproterozoic rifting of the supercontinent Rodinia to trigger miogeoclinal sedimentation along a passive continental margin until Late Devonian time, and overthrusting of oceanic allochthons across the miogeoclinal belt from Late Devonian to Early Triassic time. Subsequent evolution of the Cordilleran arc-trench system was punctuated by tectonic accretion of intraoceanic island arcs that further expanded the Cordilleran continental margin during mid-Mesozoic time, and later produced a Cretaceous batholith belt along the Cordilleran trend. Cenozoic interaction with intra-Pacific seafloor spreading systems fostered transform faulting along the Cordilleran continental margin and promoted incipient rupture of continental crust within the adjacent continental block.

INTRODUCTION

Geologic analysis of the Cordilleran orogen, forming the western mountain system of North America, raises the following questions: 1. When was the Cordilleran system born, and from what antecedents; 2. which rock masses are integral to the Cordilleran continental margin, and how were they formed; 3. which rock masses were incorporated into the Cordilleran realm by tectonic accretion, and what were their origins; and 4. what geologic processes are promoting distension and disruption of the Cordilleran system today?

Figure 1 is a chronostratigraphic diagram of Cordilleran rock assemblages showing their relationships to major phases of Cordilleran evolution. The Cordilleran edge of the Precambrian basement, which forms the Laurentian craton, was first delineated by rifting to form a passive continental margin, along which a thick Neoproterozoic to Devonian miogeoclinal prism of sedimentary strata was deposited. From Late Devonian to Early Triassic time, oceanic allochthons were successively thrust across the miogeoclinal strata as internally deformed tectonic

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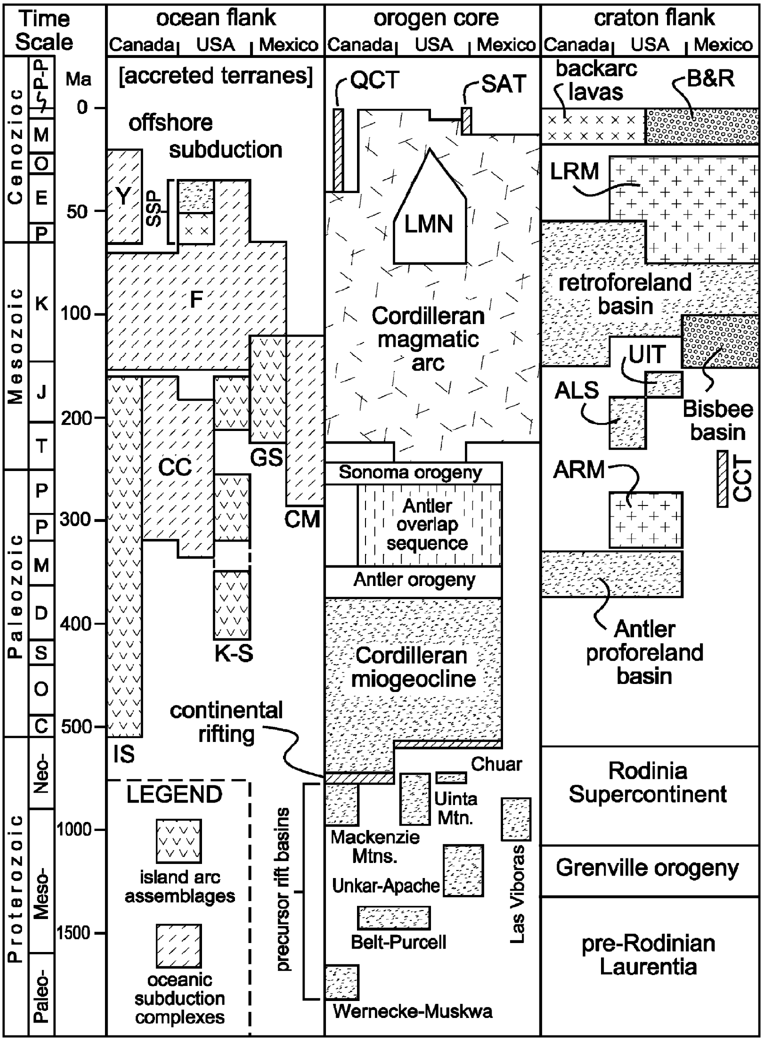

Figure 1 Schematic chronostratigraphic diagram of major Cordilleran rock assemblages (note changes in timescale at 100 Ma and 500 Ma). Canada includes the adjacent panhandle of southeastern Alaska, and Mexico includes the USA-Mexico border region south of the Colorado Plateau. Accreted island-arc assemblages: GS, Guerrero superterrane; IS, Insular superterrane; K-S, accreted arcs of Klamath Mountains and Sierra Nevada foothills. Subduction complexes: CC, Cache Creek; CM, central Mexico; F, Franciscan; Y, Yakutat. Transform faults (*diagonally ruled bars*): CCT, California-Coahuila; QCT, Queen Charlotte; SAT, San Andreas. Other features: ALS, Auld Lang Syne backarc basin; ARM, Ancestral Rocky Mountains province; B&R, Basin and Range taphrogen; LRM, Laramide Rocky Mountains province (LMN, Laramide magmatic null); SSP, accreted Siletzia and overlying forearc basin; UIT, Utah-Idaho trough.

assemblages accreted to the continent. An arc-trench system initiated along the modified continental margin in Triassic time was the tectonic regime that produced Mesozoic-Cenozoic subduction complexes and batholiths most characteristic of the Cordilleran orogen. During the subduction of oceanic lithosphere beneath the Cordilleran margin, Jurassic-Cretaceous accretion of intraoceanic island arcs contributed to the outward growth of the continental block. Beginning in mid-Cenozoic time, impingement of intra-Pacific seafloor spreading systems on the subduction zone at the continental margin gave birth to transform fault systems lying near the edge of the continental block and to associated inland deformation that distended continental crust previously overthickened by Cordilleran orogenesis.

On paleotectonic maps showing the distributions of Cordilleran rock assemblages adapted in part from Dickinson (2000, 2001, 2002) and Dickinson & Lawton (2001a,b; 2003), rock masses are plotted on present geography, with state and province boundaries for orientation, without palinspastic restoration to correct for distortion of rock masses by deformation. Offsets of rock masses across major Cenozoic strike-slip faults are shown, however, and curvatures of tectonic trends by oroclinal bending are indicated by annotations where appropriate.

To aid analysis of accretionary tectonics, the North American Cordillera has been subdivided into nearly 100 formally named tectonostratigraphic terranes (Coney et al. 1980) separated by faulted boundaries of varying tectonic significance and structural style (Silberling et al. 1992). For graphic display at feasible scale, various terranes are combined into generic groupings.

CORDILLERAN OROGEN

The Cordilleran mountain chain of western North America is an integral segment of the Circum-Pacific orogenic belt, which extends along a great circle path for 25,000+ km from the Antarctic Peninsula to beyond Taiwan (Figure 2). The length of the Cordilleran orogen from the Gulf of Alaska to the mouth of the Gulf of California is ∼5000 km, or ∼20% of the total length of the orogenic belt.

Characteristic geologic features of the Circum-Pacific orogenic belt derive from persistent subduction of oceanic lithosphere at trenches along the flanks of continental margins and offshore island arcs linked spatially to form a nearly continuous chain along the Pacific rim (Figure 2). The rock assemblages of subduction zones where oceanic plates are progressively consumed and of the parallel magmatic arcs built by related igneous activity are the prime signatures of Circum-Pacific orogenesis in the rock record. The oldest rock assemblages of the Cordilleran continental margin that reflect this style of tectonism mark initiation of the Cordilleran orogenic system in mid-Early Triassic time. Older rock assemblages exposed within the mountain chain record preceding tectonic regimes of different character.

Global Orogenic Patterns

In the Philippine-Indonesian region, the Circum-Pacific orogenic belt intersects the Alpine-Himalayan orogenic belt, which is aligned along a different great circle

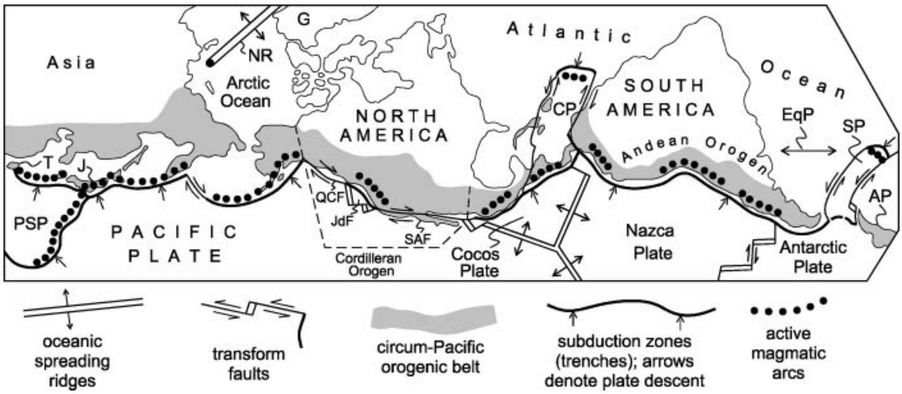

Figure 2 Position of the Cordilleran orogen of western North America along the Circum-Pacific orogenic belt (after Dickinson et al. 1986). Mercator projection with pole at 25° N Lat, 15° E Long (EqP is equatorial plane of projection). AP, Antarctic Peninsula; C, Cascades volcanic chain; CP, Caribbean plate; G, Greenland; J, Japan; JdF, Juan de Fuca plate; NR, Nansen Ridge (northern extremity of Atlantic spreading system); PSP, Philippine Sea plate; QCf, Queen Charlotte fault; SAf, San Andreas fault; SP, Scotia plate; T, Taiwan.

of the globe (Figure 3). Both orogenic belts relate to the breakup of the Permian-Triassic supercontinent of Pangea beginning early in Mesozoic time, but in different ways, as the Atlantic and Indian oceans opened to disrupt Pangea by seafloor spreading. Alpine-Himalayan evolution has involved the successive juxtaposition of disparate continental blocks (e.g., Africa, India, Australia against Eurasia) at suture belts marking the former positions of trenches where intervening ocean basins were closed by plate consumption (Figure 3), but no crustal blocks of comparable size have lodged against the Pacific margin of the Americas.

The ancestral Circum-Pacific orogenic system along the margin of Pangea was born along a great circle path (Le Pichon 1983), rimming an ocean (Panthalassa) that was effectively a paleo-Pacific realm with a Tethyan gulf that projected into the angle between Laurasian and Gondwanan segments of Pangea (Figure 4). The great circle configuration was maintained as expansion of the Atlantic and Indian Oceans led to a modern Pacific only 60% the size of the paleo-Pacific (Le Pichon et al. 1985) by insertion of Australia and its surrounding seas into the Pacific arena to step the Pacific rim eastward for ~5500 km along the Indonesian archipelago (Figure 3). During Circum-Pacific evolution, intra-Pacific seafloor spreading renewed oceanic lithosphere so rapidly that no vestiges of pre-Jurassic paleo-Pacific seafloor remain (Dickinson 1977).

Supercontinent History

The composite supercontinent of Pangea (Figure 4) formed during late Paleozoic time when Gondwana lodged against Laurasia along the Appalachian-Hercynian

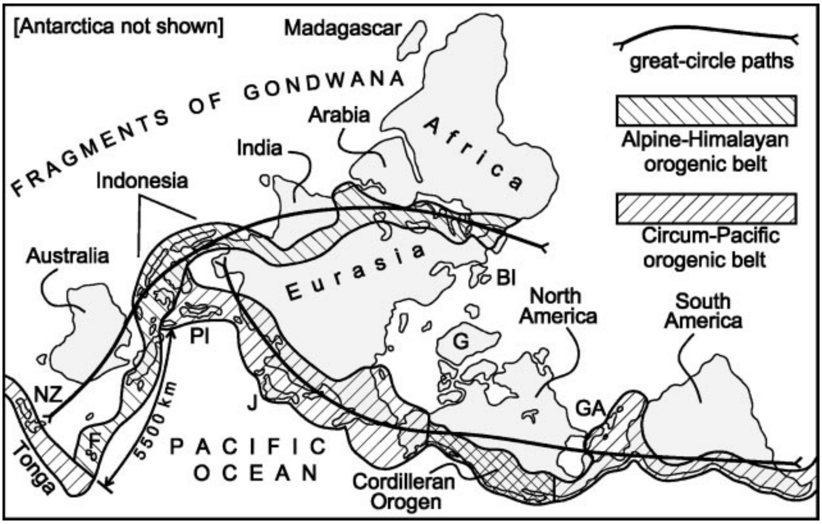

Figure 3 Distribution of continents in relation to the Alpine-Himalayan and Circum-Pacific orogenic belts (Cordilleran orogen: *cross-hatched*) in "circular" projection (after Challand & Rageau 1985). BI, British Isles; F, Fiji; G, Greenland; GA, Greater Antilles; J, Japan; NZ, New Zealand; PI, Philippine Islands.

orogen, a Paleozoic precursor of the modern Alpine-Himalayan system in that both achieved assembly of supercontinents (Pangea and Eurasia) through juxtaposition of previously separate continental blocks. Gondwana was a paleocontinent assembled in Neoproterozoic time (800–550 Ma) by juxtaposition of continental fragments across multiple internal suture belts (Meert & Van der Voo 1997). Laurasia included the ancient continental nuclei of Laurentia (North America) and Baltica (Europe), which had been conjoined in early Paleozoic time and linked in mid-Paleozoic time with Siberia. The Paleozoic precursor of the modern Circum-Pacific system was the Gondwanide orogenic belt, which lay along the Panthalassan (paleo-Pacific) margin of Gondwana, from South America past Antarctica to Australia (Figure 4), where consumption of oceanic lithosphere proceeded without interruption during the progressive assembly of Pangea (Ramos & Aleman 2000, Foster & Gray 2000).

The assembly of Pangea and its subsequent breakup during the assembly of Eurasia over the course of Phanerozoic time finds a Precambrian parallel in the geologic history of an earlier supercontinent, Rodinia, from which continental fragments were at first widely dispersed and then rearranged to form Gondwana and eventually Pangea. Rodinia was aggregated during Grenville orogenesis in Mesoproterozoic time (1325–1050 Ma), and the Cordilleran continental margin first took shape from Neoproterozoic breakup of Rodinia. As yet, however, there is no final consensus on the arrangement of continental cratons within the Rodinian

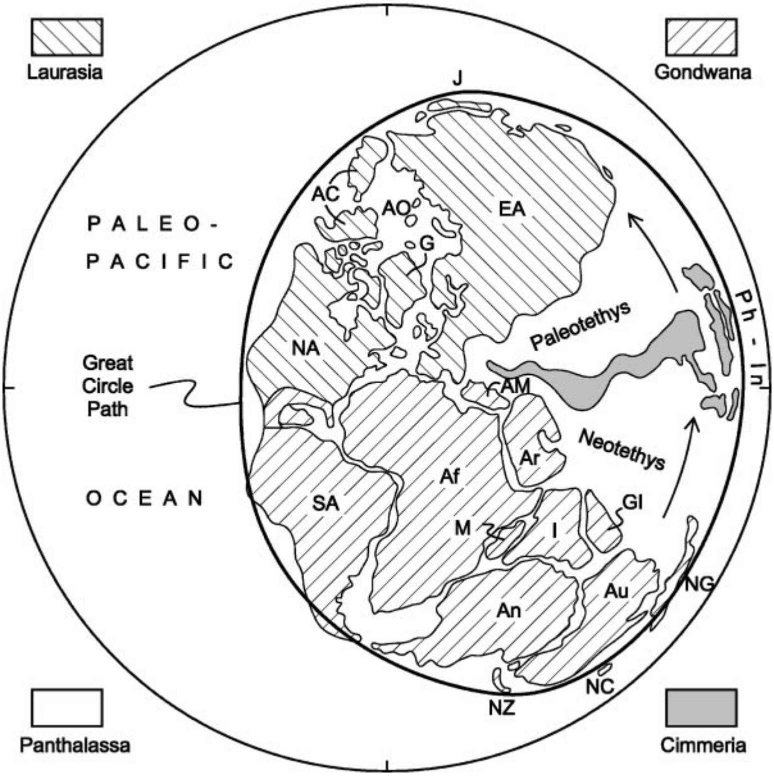

Figure 4 Permian-Triassic configuration of Pangea (Gondwana after Lawver & Scotese 1987) surrounded by Panthalassa (global sea including paleo-Pacific ocean and Tethys gulf) in Lambert equal-area projection (whole Earth). The Arctic Ocean closed by restoring transform slip of Alaska-Chukotka (Patrick & McClelland 1995). Arrows schematically denote the motion of Cimmerian landmasses in transit across the Tethys gulf, originating by rifting off the margin of Gondwana, toward Mesozoic accretion along the southern flank of Eurasia by closure of Paleothys as Neotethys opened. AC, Alaska-Chukotka; Af, Africa; AM, Asia Minor; An, Antarctica; AO, Arctic Ocean (closed); Ar, Arabia; Au, Australia; EA, Eurasia; G, Greenland; GI, Greater India; I, India; J; Japan; M, Madagascar; NA, North America; NC, New Caledonia; NG, New Guinea; NZ, New Zealand; Ph-In, Philippine-Indonesian archipelago; SA, South America.

supercontinent. Continental blocks suggested as conjugate to the Cordilleran rifted margin of Laurentia include Siberia (Sears & Price 2000), Antarctica-Australia (Dalziell 1992), Australia together with an unknown block farther north (Karlstrom et al. 1999), and China (Li et al. 2002). Of the various options, Siberia currently seems the most viable (Sears & Price 2003).

PRECAMBRIAN–PALEOZOIC MIOGEOCLINE

Along the Cordilleran margin of Laurentia, an elongate belt of thick sediment was deposited in Neoproterozoic and lower Paleozoic time as a miogeoclinal prism draped over a passive continental margin formed by rifting during the breakup of Rodinia (Figure 1). The narrow miogeoclinal belt truncates disrupted older Precambrian age provinces of interior Laurentia (Figure 5). The miogeoclinal prism thickened westward from a zero edge along a hinge line at the edge of the Laurentian craton. Miogeoclinal sedimentation continued, unbroken by tectonic disruption, until Late Devonian time, but the timing of its inception was apparently diachronous.

Cordilleran Rifting

North of the trans-Idaho discontinuity (Yates 1968), where the elongate trend of the miogeocline is offset by >250 km (Figure 5), basaltic rocks associated with glaciomarine diamictite in basal horizons of the miogeoclinal succession have been dated isotopically at 770–735 Ma (Armstrong et al. 1982, Devlin et al. 1988, Rainbird et al. 1996, Colpron et al. 2002). This time frame provides an age bracket for rifting that initiated deposition of the Windermere Supergroup along a newly formed passive continental margin open to the west in Canada (Ross 1991, MacNaughton et al. 2000). South of the trans-Idaho discontinuity, coeval rifting apparently formed only intracontinental basins in which redbed units such as the Chuar Group (775–735 Ma) of the Grand Canyon were deposited (Timmons et al. 2001), with continental separation delayed in the Death Valley region to the west until after 600 Ma (Prave 1999).

The subparallelism of the trans-Idaho discontinuity and a paleotransform delimiting the southwest margin of Laurentia (Figure 5) suggests that both originated as transform offsets of the nascent Cordilleran margin. Miogeoclinal strata present locally along the trans-Idaho discontinuity form a narrow band exposed only within roof pendants of the Idaho batholith (Lund et al. 2003) and contain intercalated bimodal volcanic rocks (685 Ma), which perhaps reflect prolonged deformation along a marginal offset at the edge of the continental block during the evolution of the rifted Cordilleran margin.

Published subsidence analyses for the Cordilleran miogeocline in both Canada and the USA imply that postrift thermotectonic subsidence of the passive continental margin did not begin until 560–555 Ma in Early Cambrian time (Bond et al. 1983, Armin & Mayer 1983, Bond & Kominz 1984, Levy & Christie-Blick 1991). Replotting the subsidence curves for revised estimates of the beginning of Cambrian time (545 Ma versus 570 Ma) puts onset of thermotectonic subsidence at 525–515 Ma, still within Early Cambrian time on the revised timescale. Projecting subsidence curves backward in time to allow for 1.1–1.2 km of synrift tectonic subsidence ($\sim$2 km of sediment accumulation) in the Great Basin area of the USA (Levy & Christie-Blick 1991) suggests that rifting that led directly to

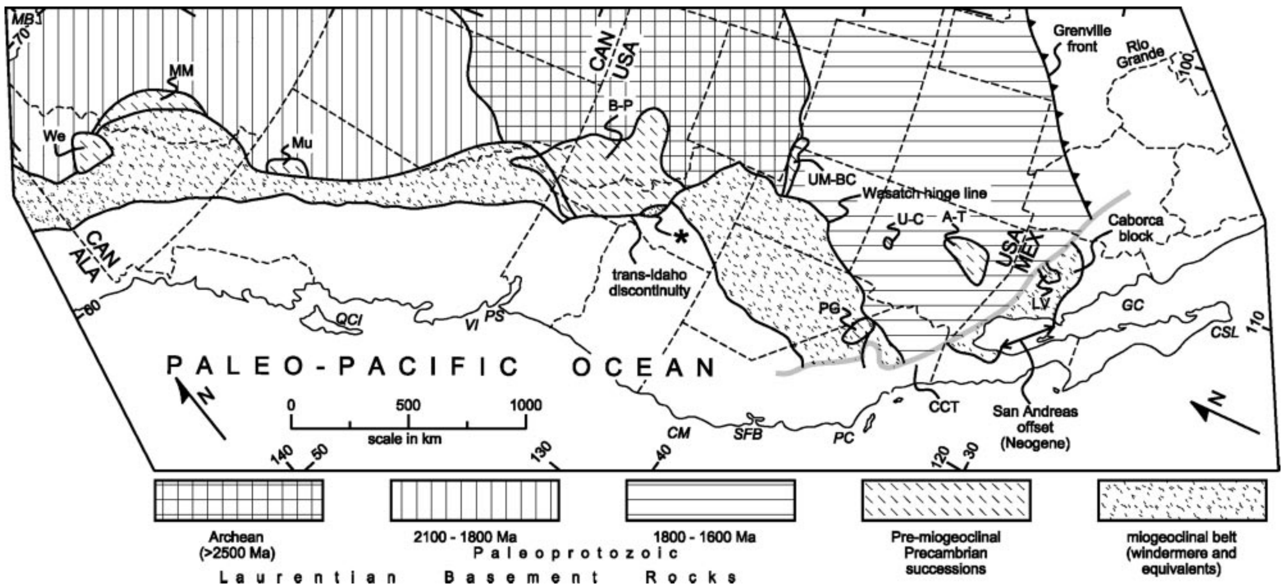

Figure 5 Neoproterozoic-Early Paleozoic Cordilleran miogeocline and premiogeoclinal sedimentary basins along the trend of the North American Cordillera (rock assemblages now present west of the miogeoclinal belt were added to the continental block after mid-Late Devonian time). Asterisk (*) denotes miogeoclinal strata along trans-Idaho discontinuity (Lund et al. 2003). Grenville front is margin of Mesoproterozoic Grenville orogen along which Rodinia was assembled. CCT is Permian-Triassic California-Coahuila transform (Dickinson 2000), which offset the Cordilleran miogeoclinal assemblage of the Caborca block by overprinting an older paleotransform system that delimited the early Paleozoic southwest margin of Laurentia (Dickinson & Lawton 2001a). See text for ages of premiogeoclinal successions. (A-T, Apache-Troy; B-P, Belt-Purcell; LV, Las Víboras; MM, Mackenzie Mountains; Mu, Muskwa; PG, Pahrump Group; U-C, Unkar-Chuar; UM-BC, Uinta Mountain—Big Cottonwood; We, Wernecke). Coastal locales (*italics*): CM, Cape Mendocino; CSL, Cabo San Lucas; GC, Gulf of California; MB, Mackenzie Bay of Arctic Ocean; PC, Point Conception; PS, Puget Sound; QCI, Queen Charlotte Islands; SFB, San Francisco Bay; VI, Vancouver Island.

continental separation south of the trans-Idaho discontinuity occurred during the interval 600–575 Ma (Armin & Mayer 1983). Isotopic dating of synrift volcanic rocks in southern British Columbia at 570 ± 5 Ma (Colpron et al. 2002) documents that active rifting persisted into latest Neoproterozoic time, north as well as south of the trans-Idaho discontinuity.

The indicated time span of 45–65 million years between initial rifting and onset of passive thermotectonic subsidence is comparable to the time span of 55 million years between initial development of Triassic rift basins and the first emplacement of Jurassic oceanic crust along the modern Atlantic continental margin (Manspeizer & Cousminer 1988). Cordilleran unconformities near the Precambrian-Cambrian time boundary (Devlin & Bond 1988, Lickorish & Simony 1995) may stem from reactivation of rift faults or from the influence of eustasy on a rift hinge undergoing flexure from sediment loading of oceanic crust offshore (Fedo & Cooper 2001).

The evidence for two rift events (Colpron et al. 2002), spaced 160–170 million years apart in pre-Windermere and latest Neoproterozoic time, suggests the possibility that two different continental blocks, one west of Canada and one west of USA-Mexico, were once conjugate with Laurentia, but no current Rodinian models are readily compatible with that interpretation. In any case, the onset of thermotectonic subsidence at the same time in both Canada and southward implies that the Windermere passive margin was reactivated at the time of the second rifting event, as suggested by stratal relationships near the USA-Canada border (Devlin 1989).

Precursor Rifts

A number of premiogeoclinal Precambrian sedimentary successions occur along the trend of the Cordillera but lack the longitudinal continuity of the overlying miogeocline (Figure 5). Each was deposited within an intracratonic basin formed by incipient rift extension within Rodinia or before its assembly (Figure 1). From the trans-Idaho discontinuity northward, isotopic dating of basin substratum, intercalated volcanics, and local intrusions establishes age brackets as follows for deep local rift troughs: Wernecke Supergroup, 1820–1710 Ma (Ross et al. 2001); Muskwa Assemblage, 1760–1660 Ma (Ross et al. 2001); Belt-Purcell Supergroup, 1470–1370 Ma (Evans et al. 2000, Luepke & Lyons 2001); Mackenzie Mountains Supergroup, 975–775 Ma (Rainbird et al. 1996); Uinta Mountain Group (and Big Cottonwood Formation), 975?–725? Ma. Farther south, thinner premiogeoclinal successions, deposited either in rift basins or on the craton, include the following: Unkar Group, Apache Group (including Troy Quartzite), and lower Pahrump Group, 1220–1070 Ma (Timmons et al. 2001), with the lowermost Apache Group as old as 1335 Ma (Stewart et al. 2001); Las Víboras Group, 1050?–850? Ma (Stewart et al. 2002); and the Chuar Group, 775–735 Ma (Timmons et al. 2001).

The precursor rift troughs may have acted as subregional guides helping to control the trend of eventual continental separation that initiated miogeoclinal sedimentation. In the Death Valley region, for example, diamictites of the Kingston Peak Formation in the upper Pahrump Group probably include correlatives of both syn-Windermere (∼750 Ma) rift fill and younger (∼600 Ma) synrift deposits at the base of the miogeoclinal succession (Prave 1999). Recent interpretations from deep seismic reflection profiles propose that pre-Windermere Canadian assemblages (Wernecke, Muskwa, Mackenzie Mountains) in the region north of the Belt-Purcell basin are all parts of a composite sediment prism built westward along an evolving passive continental margin that flanked the youngest basement components of the Laurentian craton and persisted over a time span that exceeded a billion years (Snyder et al. 2002). If so, no continental separation by Neoproterozoic rifting was required to form the Windermere continental margin, but the disparate age ranges and outcrop discontinuity of the pre-Windermere successions are difficult to reconcile with the postulate of a pre-Windermere passive continental margin continuous for the length of the Canadian Cordillera.

LATE PALEOZOIC–EARLY TRIASSIC ACCRETION

Between Late Devonian and Early Triassic time, internally deformed allochthons (Figure 6) of oceanic strata were thrust eastward as accretionary prisms across the seaward flank of the miogeoclinal belt when the margin of the Laurentian continental block was drawn into the subduction zones of intraoceanic island arcs that faced the Cordilleran margin and subducted offshore oceanic crust of marginal seas downward to the west (Dickinson 2000). Lithic constituents of the allochthons include pillow basalts, peridotite, and serpentinite of oceanic crust and subjacent mantle, as well as more voluminous argillite, ribbon chert, and turbidites of overlying seafloor sediment profiles. The turbidites of the allochthons include continental slope and rise deposits originally transported off the Laurentian margin and then thrust back toward the craton over the miogeoclinal shelf edge. Exposures where later tectonism and erosion has exhumed the thrust contact show that the allochthons traveled 100+ km across the structurally underlying miogeoclinal assemblage.

Antler-Sonoma Allochthons

Stratigraphic and structural analysis of the overthrust allochthons has documented their emplacement during two discrete episodes of incipient continental subduction termed the Antler and Sonoma orogenies in the USA. The two events were spaced ∼110 million years apart during comparatively brief intervals of time (∼25 million years each) spanning the Devonian-Mississippian and Permian-Triassic time boundaries (Figure 1). The two separate allochthons have been delineated with greatest confidence in the Great Basin of Nevada (USA), where allochthonous but unmetamorphosed oceanic facies of multiple Paleozoic horizons were thrust over autochthonous miogeoclinal facies of the same ages along the Roberts Mountains

(Antler) and Golconda (Sonoma) thrusts (Figure 6). Farther north, the lack of clearcut evidence for the presence of either allochthon along the trend of the trans-Idaho discontinuity (Figures 5 and 6) may stem from engulfment by batholiths, widespread erosion, and burial beneath volcanic cover, but may also reflect anomalous tectonic behavior along that atypical segment of the Cordilleran margin.

Within Canada, post-Triassic internal deformation and tectonic transport of Paleozoic Antler-Sonoma allochthons during Mesozoic arc-continent collision and subsequent retroarc thrusting complicate interpretations of their original character and positions (Hansen 1990, Ghosh 1995). Allochthons of both Antler (Smith & Gehrels 1991; 1992a,b) and Sonoma (Roback et al. 1994, Roback & Walker 1995) age have been identified in the Kootenay structural arc (Figure 6) spanning the USA-Canada border. Farther north, the Sylvester allochthon emplaced above the Cassiar platform (Figure 6) is composed exclusively of post-Devonian rocks (Nelson 1993) and apparently represents only the younger allochthon of Sonoma age. Nearby, however, the widespread and internally complex Yukon-Tanana terrane (Hansen 1988) probably includes both allochthons as well as underthrust miogeoclinal facies (Hansen & Dusel-Bacon 1998). Blueschists of both Devonian ($\sim$345 Ma) and Permian (270–260 Ma) ages are present in allochthonous Yukon-Tanana assemblages lying structurally above miogeoclinal strata along the west flank of the Cassiar platform and in the isolated Anvil allochthon (Figure 6) to the east (Erdmer et al. 1998). Juxtaposition of the Anvil allochthon against the Cassiar platform implies $\sim$485 km of post-thrust dextral displacement along the Tintina fault (Figure 6).

Antler-Sonoma Foreland

Tectonic loads of the overthrust Antler-Sonoma allochthons downflexed the Laurentian margin to form an elongate system of markedly asymmetric proforeland sedimentary basins extending across the miogeoclinal belt into the fringe of the interior craton (Lawton 1994, Savoy & Mountjoy 1995). The extent of the Antler foreland basin is defined by an apron of clastic sediment shed toward carbonate platforms of the interior craton, but the Sonoma foreland basin is defined only by the limit of Triassic marine strata (Figure 6). Widespread syndepositional normal faulting of Antler age along the foreland belt in Canada (Gordey et al. 1987) can be interpreted as a response to local extension induced by flexure of the foreland basin floor (Smith et al. 1993).

Proximal sandstone petrofacies along the western fringe of the Antler foreland belt are dominantly quartzolithic, a composition reflective of sediment recycling from the uplifted accretionary prisms of allochthons exposed farther west as sediment sources (Smith et al. 1993). Near the Canada-Alaska border, the ages of detrital zircons in Cambrian and Devonian sandstones suggest derivation of foreland sediment near the northern end of the Cordilleran orogen (Figure 6) from the Paleozoic Innuitian-Ellesmerian orogen of the Canadian Arctic to the northeast (Gehrels et al. 1999).

During the time interval between Antler and Sonoma thrusting along the Cordilleran margin, part of the continental block extending as far west as the Antler foreland basin and thrust front in the USA was disrupted by intracontinental reverse faulting to form yoked basins and uplifts of the Ancestral Rocky Mountains province (Figure 6). The intracontinental deformation, centered on Pennsylvanian time (Figure 1), was related to sequential intercontinental suturing along the Ouachita orogenic belt (Figure 6), where the southern flank of the Laurentian craton was drawn progressively, from east to west, into a subduction zone along the leading edge of Gondwana during the assembly of Pangea (Dickinson & Lawton 2003).

Accreted Island Arcs

Segments of accreted Devonian and Permian island arcs, composed of volcanic and volcaniclastic strata and paired geotectonically with Antler and Sonoma accretionary prisms to the east, are present in the Klamath-Sierran region (Figure 6) of the Cordilleran orogen to the south of volcanic cover in the Pacific Northwest (USA). The Paleozoic Klamath-Sierran arc system evolved as a system of frontal arcs and remnant arcs during slab rollback related to closure of marginal seas between the offshore arc complex and the Cordilleran continental margin (Dickinson 2000).

Farther north in Canada, remnants of comparable Devonian to Permian arc assemblages (Rubin et al. 1990, Brown et al. 1991), underlying the Mesozoic arc assemblages of Quesnellia and Stikinia (Figure 6), are interpreted here as northern analogues of the accreted Klamath-Sierran island arcs. Both east and west of the Cassiar platform (Figure 6), overthrust allochthonous assemblages include both Devonian (365–340 Ma) and Permian (∼260 Ma) granitic plutons of arc affinity (Mortensen 1992). Permian island-arc volcanics are closely associated with deformed seafloor volcanics within the internally complex Sylvester allochthon emplaced structurally above the Cassiar platform (Nelson 1993) and in correlative assemblages farther south (Ferri 1997). These occurrences of island-arc remnants within allochthonous Paleozoic assemblages suggest that severe structural telescoping in Canada during superposed mid-Mesozoic arc-continent suturing and later Mesozoic-Cenozoic retroarc thrusting closely juxtaposed island-arc and subduction-zone tectonic elements of Antler-Sonoma age that remain largely separate farther south.

MESOZOIC-CENOZOIC ARC-TRENCH SYSTEM

A Permian-Triassic (284–232 Ma) magmatic arc, built along the edge of Gondwanan crust in eastern Mexico (Dickinson & Lawton 2001a), was sustained by subduction of oceanic crust beneath present-day central Mexico (Figure 6). The northern margin of the subducting Mezcalera plate along the southwestern edge of

Laurentia was defined by the sinistral California-Coahuila transform, which offset the Caborca block of miogeoclinal strata, together with underlying basement and a structurally superposed allochthon of overthrust Paleozoic strata (Figure 6), from southern California into northwestern Mexico (Dickinson 2000, Dickinson & Lawton 2001a). Farther northwest, the transform fault obliquely truncated, along a northwest-southeast trend, island-arc complexes trending northeast-southwest that were accreted to the continental block in the Klamath-Sierran region by Antler-Sonoma orogenesis. Initiation of subduction beneath the truncated continental margin in mid-Early Triassic time (Dickinson 2000) closely preceded the breakup of Pangea, and was the earliest record of Cordilleran orogenesis as an integral facet of the circum-Pacific orogenic belt.

Subsequent evolution of the active Cordilleran continental margin was marked by incremental accretion of subduction complexes at a trench along the continental slope, and by arc magmatism involving both plutonism and volcanism along the edge of the continental block. Multiple imbricate thrust panels of accretionary mélange belts incorporate disrupted stratal successions of seafloor turbidites, argillite, and chert, together with pillow lavas of underlying oceanic crust and structural slices of peridotite and serpentinite derived from oceanic mantle, and with limestone enclaves representing carbonate platforms built on oceanic seamounts. Combined plutonic and volcanic contributions to arc magmatism were emplaced into and erupted through the composite Cordilleran crustal profile along a shifting belt of igneous activity that lay 100–250 km inland from the evolving subduction zone along the continental margin (Armstrong 1988, Armstrong & Ward 1991). The principal record of arc magmatism is a discontinuous alignment of deeply eroded Cretaceous granitic batholiths extending the full length of the Cordilleran orogen. Isotopic studies indicate that the granitic magmas were composed in part of juvenile mantle components and in part of recycled crustal materials (DePaolo 1981, Samson et al. 1991).

Mid-Triassic to Mid-Jurassic Cordilleran Arc

Volcanic assemblages and associated plutons of Upper Triassic to Middle Jurassic age developed within a continuous magmatic arc established along the margin of North America as modified by Antler-Sonoma tectonism. The central segment of the Triassic-Jurassic arc transected miogeoclinal and Laurentian cratonic crust along the truncated continental margin of the southwest USA (Busby-Spera 1988, Schweickert & Lahren 1993), but the arc trend extended southward across the Ouachita suture into Gondwanan crust of eastern Mexico (Dickinson & Lawton 2001a) and northward along the continental margin, as expanded by tectonic accretion, to merge with the Quesnellia or Nicola arc (Mortimer 1987) of the Canadian Cordillera (Figure 7).

The local preservation of forearc basins along the western flank of the nascent Cordilleran arc in both the Canadian Cordillera (Travers 1978) and the USA Pacific Northwest (Dickinson 1979) show that the arc-trench system faced west, subducting seafloor downward beneath North America, even where relations of the arc assemblage to Laurentian basement or miogeoclinal strata are unexposed. Past speculation that the Quesnellia arc was a freestanding intraoceanic structure only accreted to North America by later collapse of an intervening marginal sea or open ocean has been discounted by recent isotopic studies (Unterschutz et al. 2002, Erdmer et al. 2002). The backarc region was flooded in Canada by marine waters, but was occupied in the USA by desert ergs (Figure 7), with the accommodation space for both sedimentary assemblages probably provided by subsidence of the flank of the continental block under the geodynamic influence of a subducted slab in the mantle beneath (Lawton 1994).

West of the Triassic-Jurassic Cordilleran arc assemblage lies a paired subduction complex of mélange and variably deformed thrust panels of oceanic strata forming the Cache Creek terrane and its correlatives in the Canadian Cordillera, the central mélange belt (Baker terrane) of the Pacific Northwest, coeval assemblages in the central Klamath Mountains and the Sierra Nevada foothills of California, and remnants of the Arperos oceanic realm formed on the Mezcalera plate in central Mexico. This nearly continuous alignment of disrupted oceanic materials, conveniently termed the Cache Creek belt (Mortimer 1986), forms a suture zone trapped between the Triassic-Jurassic continental margin and various accreted arc assemblages lying farther west (Figure 7).

The suture belt is probably a compound subduction complex formed of combined tectonic elements added to the flank of North America at a trench lying just offshore from the Triassic-Jurassic Cordilleran arc but also accreted to the flank of intraoceanic arc structures as they approached the Cordilleran margin, with both components representing offscrapings from intervening paleo-Pacific seafloor. Cache Creek blueschists formed by subduction-zone metamorphism have yielded isotopic ages of 230–210 Ma (Late Triassic) in both Canada and the USA (Erdmer et al. 1998), where stratal components of the suture belt range in age from Carboniferous (locally Devonian) to Early or Middle Jurassic (Cordey et al. 1987, Blome and Nestell 1991, Cordey & Schiarizza 1993, Dickinson 2000, Struik et al. 2001, Orchard et al. 2001). In Mexico, where accretion of an intraoceanic arc to the continental margin occurred much later than farther north, only Permian to Early Cretaceous rocks are present within the suture belt of central Mexico (Dickinson & Lawton 2001a).

Mid-Jurassic to Mid-Cretaceous Arc Accretion

In Jurassic-Cretaceous time, tectonic accretion at the Cordilleran subduction zone was punctuated by the arrival of intraoceanic island arcs subducting seafloor downward to the west, rather than to the east, to produce arc-continent collisions (Godfrey & Dilek 2000, Ingersoll 2000, Dickinson 2001). For evaluating accretionary tectonism, a distinction must be drawn (Wright 1982) between incremental accretion within evolving subduction complexes (so-called disrupted terranes), even where far-traveled oceanic components are incorporated, and bulk accretion of tectonic elements transported intact, as integral exotic terranes, to the continental margin. Arc accretion expanded the continental edge by closing the Cache Creek suture and induced the subduction zone and the magmatic arc along the Cordilleran margin to step outward away from the continental interior. Subsequent Cordilleran arc magmatism was widely superimposed on the accreted arc and mélange terranes (van der Heyden 1992, Friedman & Armstrong 1995). The ages of the oldest superimposed plutons of the Cordilleran magmatic arc reflect north-south diachroneity of arc accretion from Middle Jurassic (~170 Ma) as far south as central California (Schweickert et al. 1999) to Early Cretaceous (~120 Ma) in Mexico (Dickinson & Lawton 2001a).

CANADIAN TECTONIC ELEMENTS In Canada, two principal accreted tectonic elements, the Stikinia arc and the Insular superterrane, lie west of the Cache Creek suture belt (Figure 7). The Insular superterrane along the present continental fringe includes the Alexander terrane, a Paleozoic arc assemblage of largely pre-Devonian rocks overlain by less deformed Devonian to Permian strata including abundant limestone (Butler et al. 1997), and the Wrangellia terrane, a largely post-Carboniferous succession of Permian arc volcanics and overlying Triassic basalt capped by Upper Triassic limestone (Jones et al. 1977). The two components of the Insular superterrane were amalgamated by Carboniferous time, long before their joint incorporation into the Cordilleran continental margin, for they were both locally intruded by the same pluton (Gardner et al. 1988).

The Stikinia arc farther east is composed dominantly of Upper Triassic to Middle Jurassic volcanic and volcaniclastic rocks, intruded by cogenetic plutons (Marsden & Thorkelson 1992, Mihalynuk et al. 1994, Anderson 1993, Currie & Parrish 1997, MacIntyre et al. 2001). The arc assemblage is flanked on the northeast by a forearc basin (Dickie & Hein 1995, Johannson et al. 1997), lying adjacent to the Cache Creek suture in a position showing that the Stikinia arc faced the Cordilleran margin and subducted seafloor downward to the west. The ages of the youngest arc-forearc strata and the oldest strata in the postaccretion Jurassic-Cretaceous Bowser basin (MacLeod & Hills 1990), resting unconformably on Stikinia (Figure 7), indicate accretion of the northern part of Stikinia by early Middle Jurassic closure of the Cache Creek suture in either Aalenian (Ricketts et al. 1992) or early Bajocian (Thomson et al. 1986, Anderson 1993) time. The youngest strata known from the adjacent segment of the Cache Creek suture belt are Early Jurassic in age (Struik et al. 2001), but farther south in Canada deformed strata of the Cache Creek belt include strata as young as late Middle Jurassic (Callovian) in the Bridge River terrane (Cordey & Schiarizza 1993). The difference in stratal ages along tectonic strike suggest progressive southward closure of the Cache Creek suture from a tectonic hinge point on the north.

STIKINIA-QUESNELLIA OROCLINE Along tectonic strike to the north, the Stikinia arc merges, around the northern limit of the Cache Creek belt, with the northern end of the petrologically and lithologically similar Quesnellia arc along the edge of Triassic-Jurassic North America (Figure 7). This spatial relationship suggests that the Stikinia arc formed originally as a northern extension of the Quesnellia arc, but that oroclinal bending of the Quesnellia-Stikinia arc trend during continued subduction backfolded Stikinia against the Cordilleran margin to juxtapose Stikinia against Quesnellia across the Cache Creek suture, which was thereby enclosed within the tectonic orocline (Nelson & Mihalynuk 1993, Mihalynuk et al. 1994). Paleomagnetic data (May & Butler 1986, Vandall & Palmer 1990) showing no detectable latitudinal movement of Stikinia with respect to North America are compatible with the enclosure interpretation, and isotopic data indicating juvenile crustal origins are similar for Stikinia and Quesnellia arc assemblages (Samson et al. 1989, Smith et al. 1995). Pre-Mesozoic underpinnings of both Stikinia and Quesnellia include Devonian to Permian arc assemblages (Brown et al. 1991, Currie & Parrish 1997), inferred here to have been accreted to Laurentia during Antler-Sonoma events (Figure 6). Both Mesozoic arc assemblages also overlap depositionally upon deformed Paleozoic assemblages (Mortensen 1992, Roback & Walker 1995, Dostal et al. 2001, Acton et al. 2002), interpreted here as overthrust Antler-Sonoma allochthons.

Most of the contact zone between the Stikinia arc and the Insular superterrane is occupied by a sliver of strongly deformed pre-Mesozoic strata, forming a western arm of the Yukon-Tanana terrane (Gehrels et al. 1991, 1992) including the Taku terrane (Gehrels 2002), which underlie the Mesozoic arc assemblage of Stikinia and are regarded here as a product of Antler-Sonoma orogenesis oroclinally deformed along with Stikinia (Figures 6 and 7). The contact zone was overlapped by thick Upper Jurassic (Oxfordian) to Lower Cretaceous (Albian) strata of the intraarc Gravina basin (McClelland et al. 1992), but underlying metavolcanic rocks that also overlap the contact zone document initial accretion of the Insular superterrane to the western flank of Stikinia by Middle Jurassic (∼175 Ma) time (Gehrels 2001). Mid-Cretaceous thrusting later carried rocks east of the contact zone over the Gravina basin and the Insular superterrane (Gehrels et al. 1990, Rubin & Saleeby 1992).

INSULAR ARC ACCRETION As the Stikinia arc demonstrably faced east, subduction along its western flank could not have drawn the Insular superterrane toward the continental margin. Accordingly, Early to Middle Jurassic arc magmatism (190–165 Ma) within the Insular superterrane, as displayed in the Queen Charlotte Islands (Lewis et al. 1991) and on Vancouver Island (DeBari et al. 1999), is viewed here as evidence for activation of subduction along the eastern flank of the Insular superterrane, to draw the Insular superterrane closer to the back side of the Stikinia arc by subducting intervening seafloor downward to the west. The polarity of the Jurassic arc along the Insular superterrane is seemingly confirmed along tectonic strike to the northwest, beyond the head of the Gulf of Alaska, where Lower to Middle Jurassic plutons intruding the Wrangellia component of the Insular superterrane on the Alaska Peninsula display transverse compositional gradients indicative of a magmatic arc facing the continent (Reed et al. 1983).

Paleomagnetic data suggest that the Alexander terrane lay in the Arctic region near Baltica in mid-Paleozoic time, but that the associated Wrangellia terrane lay near the paleolatitude of the Pacific Northwest by Late Triassic time (Butler et al. 1997). Apparently, the Insular superterrane drifted as an intraoceanic arc structure within the paleo-Pacific Ocean, along paths that cannot be specified with present information, through late Paleozoic and early Mesozoic time before its accretion to the Cordilleran margin along the back side of Stikinia. If the sliver of the Yukon-Tanana terrane along the west flank of Stikinia includes miogeoclinal facies, as seems likely (Gehrels 2000), the oroclinal rotation of Stikinia was apparently initiated by calving of Stikinia off the edge of the Laurentian margin during backarc rifting. The complex plate motions required to achieve accretion of both the Stikinia arc and the Insular superterrane to the Cordilleran margin in the same general time frame (intra-Jurassic) are indeterminate with present information.

PACIFIC NORTHWEST RECONSTRUCTION The longitudinal correlation of premid-Cretaceous tectonic elements southward across the Pacific Northwest from Canada into the USA has long been a challenge (Monger et al. 1982) because of widespread Neogene volcanic cover (Figure 8*A*), the complex kinematics of an intersecting knot of strike-slip faults of latest Cretaceous to Eocene age spanning the USA-Canada border (Figures 7, 9), and structural complexity within the metamorphic cores of mountain ranges near the USA-Canada border where Cretaceous structural telescoping obscured earlier tectonic relationships between older rock masses.

An apparently satisfactory tectonic reconstruction is achieved here (Figure 8*B*) by reversing 105–110 km of Eocene (44–34 Ma) dextral slip on the Fraser River–Straight Creek fault zone and 110–115 km of previous dextral slip on the offset Yalakom–Ross Lake fault system of latest Cretaceous (<75 Ma) to Eocene age (Kleinspehn 1985, Umhoefer & Kleinspehn 1995, Umhoefer & Miller 1996, Umhoefer & Schiarizza 1996) and by backrotating the Oregon-Washington Coast Range and the Blue Mountains by 50° each (Figure 8) to recover clockwise tectonic rotations imposed during Eocene time (Heller et al. 1987, Dickinson 2002).

In Figure 8, the southern extension of the Stikinia arc assemblage includes the Cadwallader terrane of southern British Columbia (Rusmore 1987, Rusmore et al. 1988, Umhoefer 1990, Rusmore & Woodsworth 1991) and the Triassic-Jurassic Cascade River–Holden belt (Hopson & Mattinson 1994) in the Cascade Mountains east of the Straight Creek fault. Inland extensions of the Insular superterrane include the Chilliwack, Bowen Lake, and Harrison Lake terranes of southern British Columbia (Friedman et al. 1990, Mahoney et al. 1995), the Swakane Gneiss (Nason terrane) east of the Straight Creek fault in the Cascade Mountains (Mattinson 1972), and the Wallowa–Seven Devils segment of Wrangellia in the Blue Mountains. The Cache Creek suture belt flanking the Triassic-Jurassic continental margin is reconstructed as an alignment of similar lithologic units, including the Cache Creek and Bridge River terranes of southern British Columbia, the Hozameen terrane spanning the USA-Canada border, the Baker terrane of the Blue Mountains, and

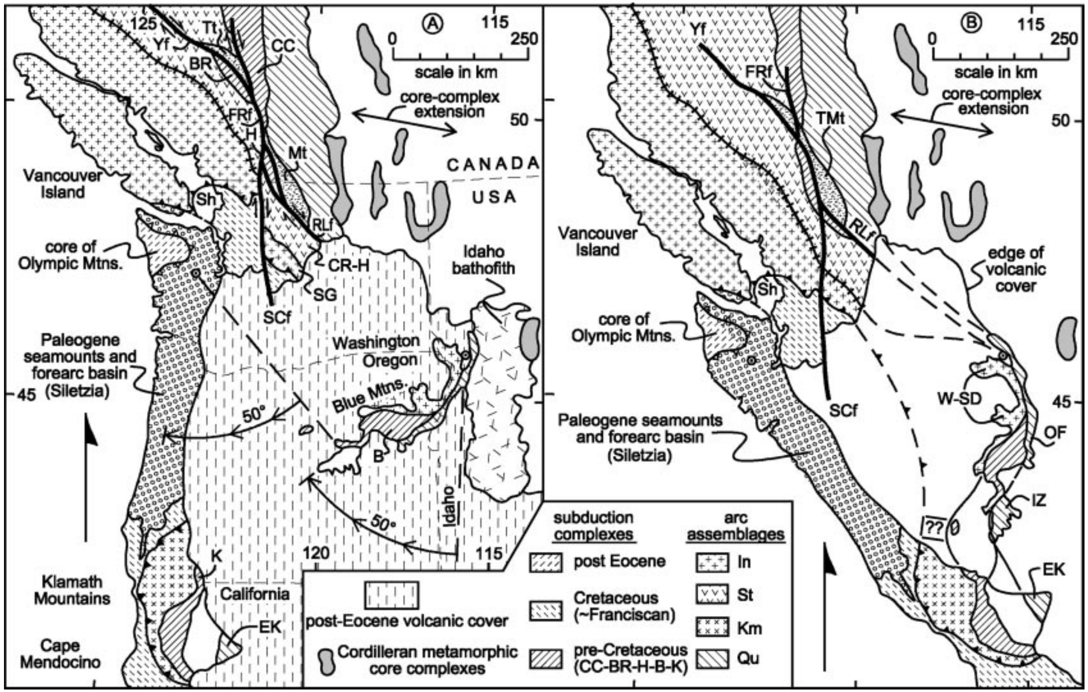

Figure 8 Pre-Oligocene geotectonic features in the Pacific Northwest (USA) and adjacent Canada at present (*A*) and as reconstructed (*B*) before clockwise rotations of the Oregon-Washington Coast Range and Blue Mountains provinces, and before dextral slip on branching faults near the USA-Canada border. Arc assemblages: In, Insular (SG, Swakane Gneiss; W-SD, Wallowa–Seven Devils); Km, accreted western Klamath Mountains arcs; Qu, Quesnellia and related terranes (IZ, Izee forearc basin; EK, eastern Klamath Mountains Mesozoic arc, OF, Olds Ferry terrane or Huntington arc); St, Stikinia (CR-H, Cascade River–Holden belt). Pre-Late Jurassic subduction-complex terranes: B, Baker; BR, Bridge River; CC, Cache Creek; H, Hozameen, K, central Klamath Mountains mélange belt. Other geologic features: Sh, Shuksan thrust system (schematic); TMt, Tyaughton–Methow trough (offset segments: Mt, Methow trough; Tt, Tyaughton trough).

the central mélange belt of the Klamath Mountains (Figure 8*B*). Closer proximity of restored tectonic elements near the USA-Canada border to counterparts in the Blue Mountains could be achieved by additional recovery of the significant Eocene intracontinental extension recorded by Cordilleran core complexes (Figure 8) in southeastern British Columbia (Dickinson 2002).

The Tyaughton-Methow trough (Figure 8) was initiated in Early Jurassic time as a forearc basin flanking the Quesnellia arc (Anderson 1976), but evolved during Late Jurassic and Early Cretaceous time to overlap the accreted Stikinia arc (Garver 1992, Umhoefer et al. 2002). West and south of the Shuksan thrust system (Figure 8), an internally deformed underthrust assemblage, including Upper Jurassic to Lower Cretaceous blueschists and clastic strata (Brown 1987, Brandon et al. 1988, Monger 1991), is presumed to be a northern counterpart of the late Mesozoic Franciscan subduction complex and associated forearc basins of coastal California to the south (Brown & Blake 1987).

USA-MEXICO ARC ACCRETION The Insular superterrane extends as far south as the Blue Mountains (Figure 8) of the Pacific Northwest, where intense mid-Cretaceous crustal telescoping near the Snake River has thrust strata of Wrangellia beneath the Mesozoic continental margin (Lund & Snee 1988). Stratigraphic analysis of Blue Mountains terranes indicates, however, that initial accretion of the Wrangellia component of the Insular superterrane was completed in Middle Jurassic (Bajocian) time (Follo 1992, White et al. 1992, Avé Lallemant 1995), coordinate with accretion farther north in Canada. The oroclinally deformed Stikinia arc apparently does not extend farther south than the Cascades Mountains along the USA-Canada border (Figure 8), and there is no indication that active magmatism was still underway at the southern end of the Insular superterrane when the Wallowa–Seven Devils segment (Figure 8) of Wrangellia was drawn passively into a subduction zone along the continental margin (Dickinson 1979).

Accreted intraoceanic arc assemblages of Jurassic age in the Klamath Mountains and Sierra Nevada foothills of California rest on ophiolitic basement formed near the Triassic-Jurassic time boundary (Dilek 1989, Edelman 1990, Hacker & Ernst 1993, Wright & Wyld 1994, Hacker et al. 1995), as does the Guerrero superterrane (Figure 7) of western Mexico (Dickinson & Lawton 2001a). The accreted Mesozoic arc complexes in the USA and Mexico can perhaps be regarded as southern extensions and descendants of the Jurassic arc along the Insular superterrane where subduction continued southward across paleo-Pacific oceanic crust lying beyond the southern limits of the older Alexander and Wrangellia terranes. In California, severely deformed mélange belts separate accreted arc assemblages on the west from the pre-Jurassic continental margin (Wright 1982, Edelman & Sharp 1989, Edelman et al. 1989b, Dilek et al. 1990, Hacker et al. 1993), but a superimposed magmatic arc built along the Cordilleran continental margin across the accreted tectonic elements by late Middle Jurassic (Callovian) time (Wright & Fahan 1988, Edelman 1990, Edelman et al. 1989a, Harper et al. 1994, Girty et al. 1995) implies arc accretion during early Middle Jurassic (Bajocian) time (170–165 Ma).

In the southwestern USA and Mexico, final closure of the oceanic realm between accreted Mesozoic arcs and the Cordilleran continental margin in Early Cretaceous time promoted slab rollback of the Mezcalera plate to induce crustal extension within the overriding continental block (Dickinson & Lawton 2001a). The resulting border rift belt, including the Bisbee basin and Chihuahua trough, supplanted arc magmatism along the USA-Mexico border region (Figure 7), with Late Jurassic rifting accompanied by bimodal magmatism and followed by Early Cretaceous thermotectonic subsidence (Dickinson & Lawton 2001b). Farther north, the extensional Utah-Idaho trough (Figure 7) of Middle to Late Jurassic age and development of a wide zone of Late Jurassic to Early Cretaceous backarc magmatism (Figure 7) closely followed arc accretion along the California continental margin to the west (Dickinson 2001). Earlier Middle Jurassic thrusting along the Luning-Fencemaker thrust (Wyld 2002), which carried the fill of the Auld Lang Syne backarc basin eastward (Figure 7), coincided closely in timing with arc accretion farther west.

Mid-Cretaceous to Mid-Tertiary Cordilleran Arc

Following Jurassic-Cretaceous arc accretion at the evolving subduction zone along the continental margin, the Cordilleran magmatic arc stepped oceanward to a trend that was largely superimposed upon accreted terranes (Figure 9). Massive Late Cretaceous plutonism, continuing until mid-Eocene time in Canada, formed the major Cordilleran batholith belt along the arc axis. To the west, a parallel belt of Jurassic-Cretaceous forearc basins is prominent along the coastal fringes of the USA and Mexico, and lies immediately inland from exposures of the Jurassic-Cretaceous subduction complex forming the Franciscan superterrane (Figure 9). Farther north in Canada, however, Cenozoic modification of the continental margin by strike slip along the Cenozoic Queen Charlotte transform and its splays has largely disrupted or submerged tectonic elements of the late Mesozoic forearc region.

Past speculation (Cowan et al. 1997), based on paleomagnetic data, that the western part of the Canadian Cordillera, including a large segment of the Cretaceous batholith belt, was transported northward in Cretaceous-Paleocene time from an origin along the continental margin of California or Mexico encounters the insuperable difficulty that no segment of the Cretaceous arc-trench system is missing from California or Mexico (Figure 9). The anomalously shallow paleomagnetic vectors that gave rise to the hypothesis of large lateral displacements can be interpreted instead as the result of widespread pluton tilt coupled with compaction in sedimentary strata (Butler et al. 2001).

Crustal shortening across the Cordilleran orogen gave rise by Late Jurassic time in Canada (Cant & Stockmal 1989) and mid-Early Cretaceous time in the USA (Dickinson 2001) to initiation of a backarc thrust belt that was continuous from the interior flank of the Canadian Cordillera into the Sevier thrust belt (Figure 9). The tectonic load of the thrust sheets downflexed an extensive retroforeland basin with a distal fringe that extended well into the continental interior. Deformation within the Canadian Cordillera produced intraorogen thrusting associated with development of the Skeena foldbelt (Evenchick 1991) accompanied by downflexure of the Sustut basin, and analogous intraorogen deformation formed the Eureka thrust belt in the USA (Figure 9).

Scattered plutons of Late Cretaceous age present in the interior hinterland of the backarc thrust belt, but most prominent in the Omineca region of the Canadian Cordillera (Figure 9), were not an integral facet of the arc magmatism active farther west, but instead were derived largely from sources within underthrust continental crust. Backarc thrusting and the associated retroforeland basin did not extend as far south as the region occupied until mid-Cretaceous time by the Bisbee basin and related rift troughs along the USA-Mexico border. Although somewhat diachronous in timing, backarc rifting (Figure 7) and backarc thrusting (Figure 9) occupied different realms marked by distinct contrasts in geodynamics along the Cordilleran orogen.

In Canada, arc magmatism along the eastern flank of the Coast batholith continued until mid-Eocene time (∼45 Ma), as did deformation along the backarc thrust belt. Farther south, however, in both the USA and Mexico, subhorizontal subduction of the Farallon plate during latest Cretaceous through Eocene time altered the progress of both magmatism and tectonism (Dickinson & Snyder 1978). Inland migration and diminution of igneous activity led to a magmatic null through much of the USA Cordillera (Figure 1), and basement-involved crustal shortening produced yoked uplifts and basins of the Laramide Rocky Mountains well inland from the continental margin (Figure 9).

Deformation began ∼70 Ma throughout the Laramide Rocky Mountains while thrusting was still underway along the Sevier thrust belt to the west, but its termination was diachronous (Dickinson et al. 1988). The development of Laramide basins and uplifts was complete in the northern part of the Laramide province by mid-Eocene time (∼50 Ma), coincident with the terminal phase of deformation along the Sevier thrust belt to the west (DeCelles 1994). Farther south, however, Laramide deformation continued until the end of Eocene time. In Mexico, south of the magmatic null, Laramide basin evolution (Figure 9) during Late Cretaceous and Paleocene time (Dickinson & Lawton 2001b) was accompanied by arc magmatism that migrated inland from the Cretaceous batholith belt near the coast. The time-space pattern of Laramide magmatism and deformation suggests that the shallow angle of plate descent that gave rise to both resulted from subduction of a buoyant oceanic plateau beneath the continental margin (Dickinson et al. 1988).

In the Pacific Northwest, the elongate oceanic seamount chain of Siletzia (Figure 9), which formed during Paleocene-Eocene time (Figure 1) at some unknown distance offshore, was accreted in bulk to the Cordilleran margin early in Eocene time, and was subsequently buried beneath the Eocene forearc basin (Figure 8) of the Oregon-Washington Coast Range (Heller et al. 1987). A subduction complex (Brandon & Vance 1992), composed of premid-Miocene Cenozoic strata underthrust beneath the accreted mass of Siletzia, forms the core of the Olympic Mountains near the USA-Canada border (Figure 9). Incrementally accreted Paleocene-Eocene components of the Franciscan subduction complex are exposed along the coastal fringe of California farther south, but elsewhere most Cenozoic subduction along the Cordilleran margin occurred along an offshore zone still unexposed underwater.

CENOZOIC TAPHROGENY

The Cordilleran arc orogen as a typical segment of the Circum-Pacific orogenic belt reached peak development in Late Cretaceous time. During Tertiary time, arrival at the Cordilleran margin of successive segments of spreading systems bounding the Pacific plate progressively converted segments of the continental margin into transform fault systems along the Pacific plate boundary. As the transform continental margin evolved, subsidiary strike slip and associated crustal extension disrupted the adjacent continental block and gave rise to the rift trough of the Gulf of California, an incipient ocean basin that is expanding obliquely within the transform regime (Figure 10).

North of the Tofino triple junction (Figure 10), subduction associated with waning phases of batholith generation along the coastal fringe of the Canadian Cordillera was supplanted in mid-Eocene time (Hyndman & Hamilton 1993) by dextral slip along the Queen Charlotte transform fault. The change in coastal geodynamics, from convergence to strike slip, was triggered by amalgamation of the offshore Kula and Pacific plates at ~42.5 Ma (Lonsdale 1988). Subsequent Oligocene-Miocene magmatism within the Queen Charlotte Islands was associated with evolution of a slab window (Hamilton & Dostal 2001), and the Neogene Queen Charlotte basin farther east (Figure 10) developed as a pull-apart basin within the transform system (Lewis et al. 1991). The Chatham Strait–Denali fault system, initiated in mid-Eocene time as a branch of the Queen Charlotte transform (Cole et al. 1999), has displaced segments of the Insular superterrane laterally along the continental margin (Figure 10). A discrepancy between 370 km of slip along the Denali fault and 150 km of slip along the linked Chatham Strait fault suggests that 220 km of slip parallel to the continental margin, southward from the elbow where those two fault segments meet, was accommodated by the Coast shear zone along the eastern flank of the Insular superterrane (Gehrels 2000).

Farther south, subduction along the Cordilleran margin continues at the foot of the continental slope along an offshore trend parallel to and coextensive with the active Cascades volcanic arc of the Pacific Northwest (Figure 10). Arc volcanism, which extended southward through the USA in Miocene time (Figure 10), was progressively extinguished south of the Cascades arc by evolution of the San Andreas transform system along the continental margin as the Mendocino triple junction (Figure 10) migrated northward to shorten the Cascades subduction zone. Beginning near the Oligocene-Miocene time boundary, slab-window volcanism evolved in coastal California along a belt parallel to the evolving San Andreas transform (Dickinson 1997). Neogene arc volcanism was extinguished in similar fashion within Baja California when the Rivera triple junction (Figure 10) migrated southward in mid-Miocene time to a position near the mouth of the modern Gulf of California.

Following Laramide events, establishment of mid-Cenozoic arc magmatism along a trend near the USA-Mexico continental margin had been accomplished by the migration of successive volcanic fronts toward the coast (Figure 10) as the slab of oceanic lithosphere subducting beneath the Cordilleran orogen steepened or foundered (Dickinson 2002). Subsequent initiation of the San Andreas transform along the continental margin in Early Miocene time triggered crustal extension within the Basin and Range taphrogen (Figure 10), where multiple fault blocks distended the Cordilleran orogen once the continental block was partly coupled to the Pacific plate. A largely intact remnant of the mid-Cenozoic arc assemblage lies along the Sierra Madre Occidental (Figure 10), where flat-lying volcanic strata form an enclave of largely undistended crust enclosed within the Basin and Range taphrogen. Baja California was calved from mainland Mexico when the San Andreas transform plate boundary south of the USA jumped inland in Late Miocene time to open the Gulf of California by oblique extension.

In the Pacific Northwest (USA), extensive volcanic fields of flood basalt that have erupted behind the Cascades volcanic arc since Early Miocene time mask older rock assemblages over wide areas (Figure 10). The volcanism may have been related to mantle advection induced by deformation of the continental lithosphere after shear was imposed on the continental block by interaction of the Pacific and American plates along the San Andreas transform system at the continental margin (Dickinson 1997). Less voluminous but comparably extensive Middle Miocene and younger volcanic fields of basaltic character in the Canadian Cordillera (Edwards & Russell 2000) may reflect analogous shear coupling of the Pacific and American plates along the nearby Queen Charlotte transform.

SUMMARY PERSPECTIVES

The questions posed in the introduction can be answered as follows:

1. The Cordilleran system, as an integral segment of the circum-Pacific orogenic belt, was established when subduction was initiated between Early and Late Triassic time along a continental margin that had been delineated by Neoproterozoic rifting during the breakup of Rodinia, and later modified in late Paleozoic and earliest Mesozoic time by the emplacement of oceanic allochthons upon the edge of the continental block during the final assembly of Pangea.
2. Rock masses native to the Cordilleran margin include the miogeoclinal prism deposited between Neoproterozoic and Late Devonian time along a passive continental margin, volcanic and plutonic rocks of the Cordilleran magmatic

arc built along an active continental margin from mid-Triassic time to the present, and the sedimentary and volcanic assemblages of basins and lava fields superimposed upon the miogeoclinal succession and the arc assemblage.

3. Accreted tectonic elements include subduction complexes thrust bodily over the miogeoclinal prism in Devonian-Mississsippian and Permian-Triassic time; intraoceanic island arcs sutured to the continental block at those times and also later, between Middle Jurassic and Early Cretaceous time; and subduction complexes accreted incrementally to the continental block at the Cordilleran subduction zone between Late Triassic and mid-Cenozoic time.
4. Postmid-Cenozoic internal distension and incipient dislocation of Cordilleran crust has occurred in response to transform tectonism imposed on the continental margin when intra-Pacific seafloor spreading systems impinged on the Cordilleran trench.

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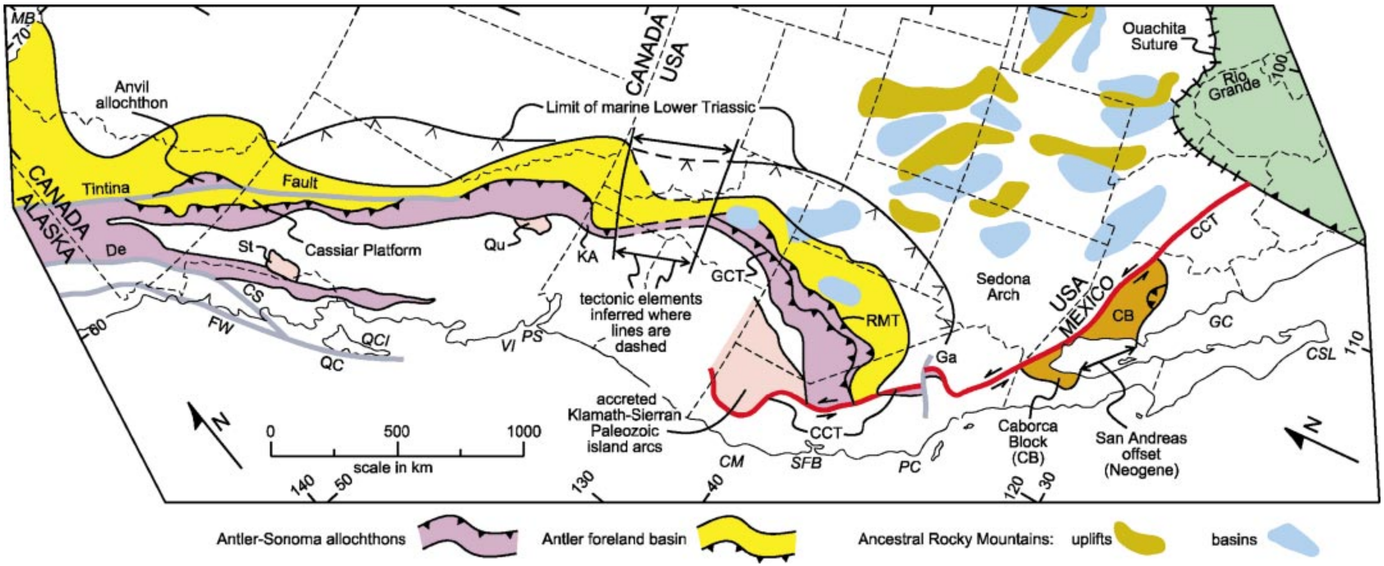

Figure 6 Geotectonic features of the Antler orogen (Late Devonian–Early Mississippian), the Ancestral Rocky Mountains province (Pennsylvanian–Early Permian), and the Sonoma orogen (Late Permian–Early Triassic) of the North American Cordillera (allochthons of Antler and Sonoma age are combined, but note the uncertain continuity of tectonic trends along the trans-Idaho discontinuity of Figure 5). See text for discussion of Kootenay structural arc (KA) and remnants of Paleozoic arc assemblages in Quesnellia (Qu) and Stikinia (St). Key active faults: RMT, Devonian-Mississippian Roberts Mountains thrust; GCT, Permian-Triassic Golconda thrust; CCT, Permian-Triassic California-Coahuila transform. Gondwanan Mexico restored (after Dickinson & Lawton 2001a) to position before mid-Mesozoic opening of the Gulf of Mexico. Tintina and De-CS-FW-QC fault systems are Cenozoic structures. See Figure 5 for geographic legend.

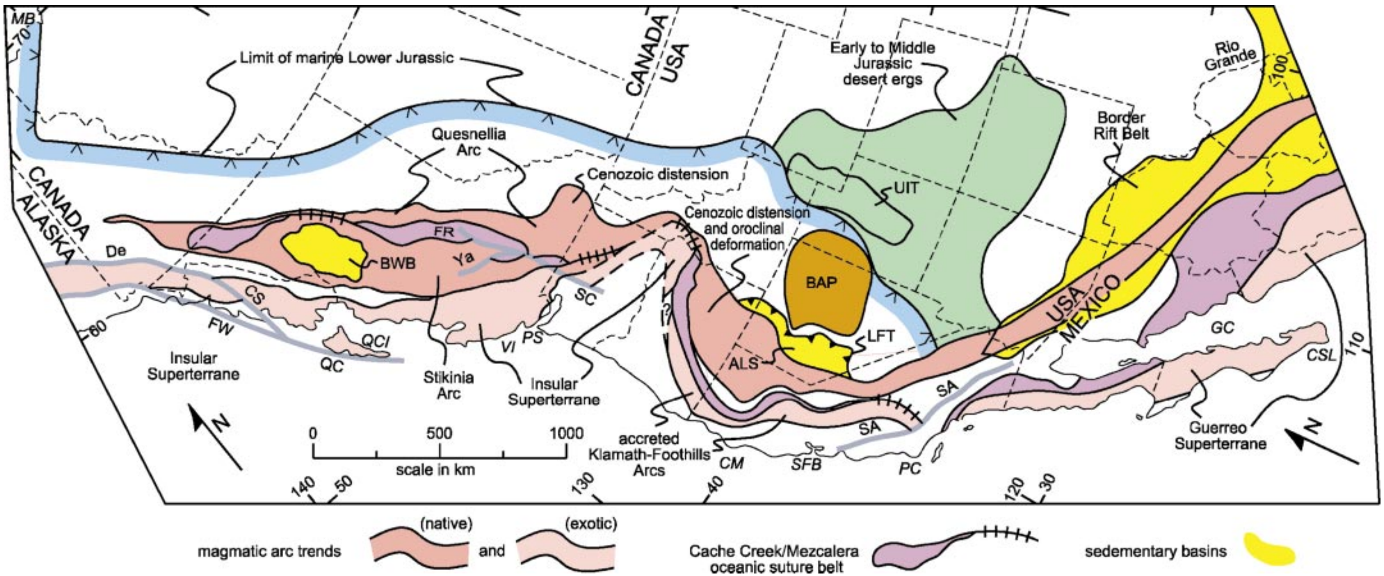

Figure 7 Mid-Early Triassic (~247.5 Ma) to mid-Early Cretaceous (~120 Ma) geotectonic features of the Cordilleran arc-trench system, including intraoceanic arc structures accreted to the Cordilleran continental margin between Middle Jurassic and Early Cretaceous time. Selected geologic features: ALS, Late Triassic to Early Jurassic Auld Lang Syne backarc basin; LFT, Middle Jurassic Luning-Fencemaker backarc thrust system; BAP, zone of diffuse Middle to Late Jurassic backarc plutonism (Nevada-Utah); UIT, Middle to Late Jurassic Utah-Idaho backarc trough; BWB, Late Jurassic to Early Cretaceous Bowser successor basin (superimposed on accreted Stikinia arc). Border rift belt (Late Jurassic to Early Cretaceous) includes Bisbee basin and Chihuahua trough. Cenozoic faults (*gray*): De-CS, Denali-Chatham Strait; FR, Fraser River; FW, Fairweather; QC, Queen Charlotte; RL, Ross Lake; SA, San Andreas; SC, Straight Creek; Ya, Yalakom. See Figure 5 for geographic legend.

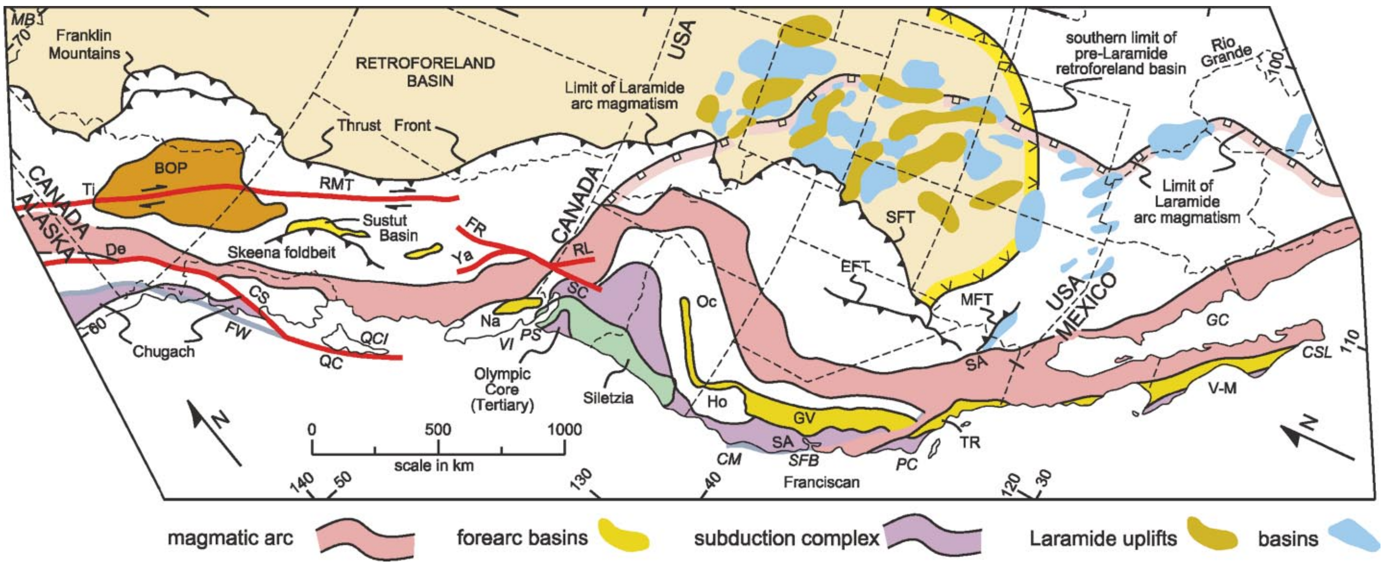

Figure 9 Mid-Early Cretaceous (~120 Ma) to mid-Cenozoic (Eocene/Oligocene boundary) geotectonic features of the Cordilleran arc-trench system, including the Laramide province of intracontinental deformation. The main batholith belt is delineated as the magmatic arc, but subsidiary arc magmatism spread inland for varying distances (BOP, Omineca zone of backarc mid-Cretaceous plutonism). Active Paleogene strike-slip faults (*red lines*): De-CS, Denali-Chatham Strait; FR, Fraser River; QC, Queen Charlotte; RL, Ross Lake; SC, Straight Creek; Ti-RMT, Tintina–Rocky Mountain Trench; Ya, Yalakom. Younger Neogene strike-slip faults (*gray lines*): FW, Fairweather; SA, San Andreas. Key active fold-thrust belts: EFT, Eureka; MFT, Maria; SFT, Sevier. Key forearc basin segments: GV, Great Valley (California); Ho, Hornbrook; Oc, Ochoco; Na, Nanaimo; TR, Transverse Ranges; V-M, Vizcaino-Magdalena. See Figure 5 for geographic legend.

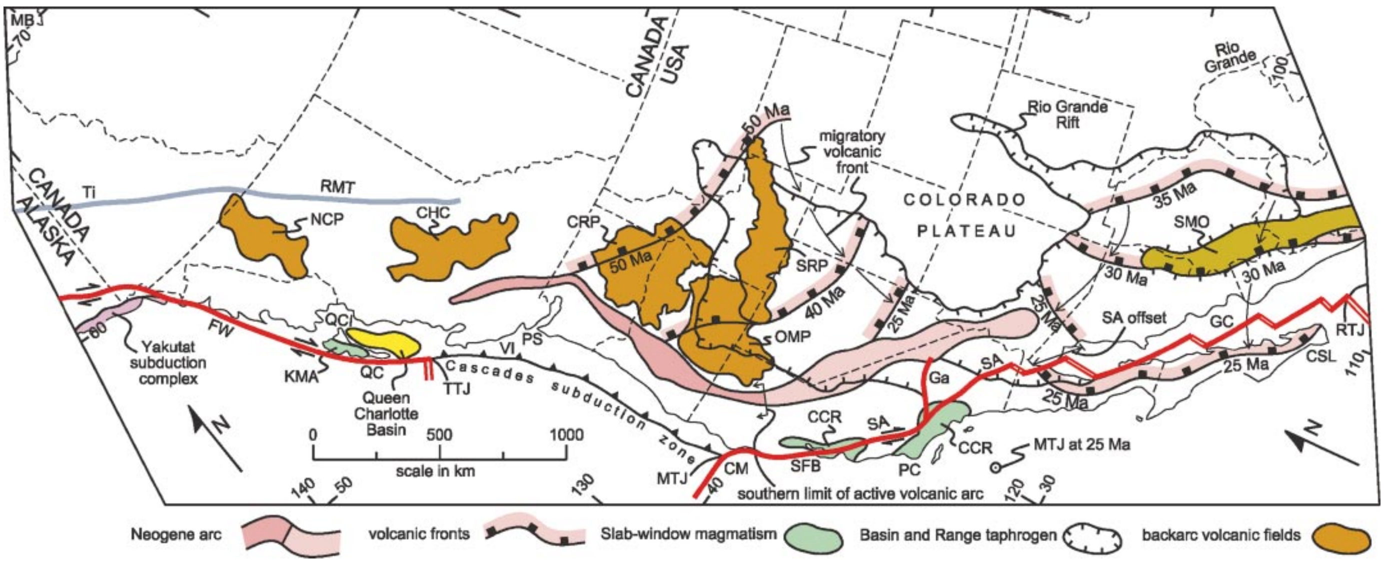

Figure 10 Post-Eocene geotectonic features of the North American Cordillera, including the Basin and Range taphrogen (SMO, Paleogene magmatic arc remnant in the Sierra Madre Occidental). Active Neogene strike-slip faults (*red lines*): FW, Fairweather; Ga, Garlock; QC, Queen Charlotte; SA, San Andreas. Offshore triple plate junctions: MTJ, Mendocino (FFT); RTJ, Rivera (RTF); TTJ, Tofino (RTF). Slab-window magmatism (near the coastal transform systems): CCR, California Coast Ranges (28–0 Ma); KMA, Queen Charlotte Islands (46–17 Ma). Backarc lava fields (erupted inland from main Cordilleran arc trend): CHC, Chilcotin (14–6 Ma); CRP, Columbia River Plateau (17–8 Ma); NCP, Northern Cordilleran Province (8–0 Ma); OMP, Oregon-Modoc Plateau (17–7 Ma); SRP, Snake River Plain (16–0 Ma). See Figure 5 for geographic legend.

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