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Logan Medallist 1. Seeking the Suture: The Coast-Cascade Conundrum

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Résumé de l'article

La limite entre les roches assignées au Superterrane d'intermont de l'intérieur des Cordillères canadiennes et celles du Superterrane insulaire dans la portion la plus à l'ouest de la Cordillère de Colombie-Britannique et du sud-est de l'Alaska se trouvent dans et au long de la Chaîne côtière, au sein de laquelle affleure le noyau d'un orogène qui est apparu comme entité tectonique distincte entre 105 et 45 millions d'années. Des indices de la Chaîne côtière et des régions environnantes montrent que des portions du Superterrane d'intermont (dans les terranes de Stikinia et de Yukon-Tanana) se trouvaient alors près de celles du Superterrane insulaire (terranes de Wrangellia et d'Alexander) au début du Jurassique (~180 Ma). Cette chronologie, ajoutée à certains facteurs paléobiogéographiques et paléomagnétiques semblent discréditer une hypothèse récente voulant qu'une subduction à pendage ouest sous un arc intra-océanique sur le Superterrane insulaire résultait d'une collision entre un arc et le continent, initiant ainsi l'orogénèse de la Cordillère à la fin du Jurassique (~146 Ma). Cette hypothèse relie aussi l'océan subduit qui séparait les superterranes à une anomalie de vitesse sismique plus rapide que la normale dans le manteau inférieur sous le littoral maritime oriental de l'Amérique du Nord. Pour créer une telle anomalie, la subduction du plancher d'un grand océan était nécessaire. La seule indication de surface de l'existence d'un tel océan à l'intérieur de la Cordillère canadienne est le terrane de Cache Creek qui, bien qu'il se trouve dans le Superterrane d'intermont, est plus ancien que le Jurassique moyen (~174 Ma). Ce terrane, avec son équivalent probable de Bridge River dans le sud-est de la Chaîne côtière, qui est aussi jeune que la fin du Jurassique (164 Ma) et peut-être aussi jeune que le début du Crétacé (⩾ 130 Ma), semblent être les seuls candidats au Canada offrant des vestiges en surface de cette anomalie sismique.

GAC MEDALLIST SERIES

Logan Medallist 1. Seeking the Suture: The Coast-Cascade Conundrum[1]

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SUMMARY

The boundary between rocks assigned to the Intermontane superterrane in the interior of the Canadian Cordillera and those of the Insular superterrane in the westernmost Cordillera of British Columbia and southeastern Alaska lies within/along the Coast Mountains, in which is exposed the core of an orogen that emerged as a discrete tectonic entity between 105 and 45 million years ago. Evidence from the Coast Mountains and flanking areas indicates that parts of the Intermontane superterrane (in Stikinia and Yukon-Tanana terranes) were near those of the Insular superterrane (Wrangellia and Alexander terranes) by the Early Jurassic (~180 Ma). This timing, as well as paleobiogeographic and paleomagnetic considerations, appears to discount a recent hypothesis that proposes westward-dipping subduction beneath an intra-oceanic arc on Insular superterrane resulted in arc-continent collision and inaugurated Cordilleran orogenesis in the Late Jurassic (~146 Ma). The hypothesis also relates the subducted ocean that had separated the superterranes to a massive, faster-than-average-velocity seismic anomaly in the lower mantle below the eastern seaboard of North America. To create such an anomaly, subduction of the floor of a large ocean was needed. The only surface record of such an ocean in the interior of the Canadian Cordillera is the Cache Creek terrane, which lies within the Intermontane superterrane but is no younger than Middle Jurassic (~174 Ma). This terrane, together with the probably related Bridge River terrane in the southeastern Coast Mountains, which is as young as latest Middle Jurassic (164 Ma) and possibly as young as earliest Cretaceous (≥ 130 Ma), appear to be the only candidates in Canada for the possible surface record of the seismic anomaly.

SOMMAIRE

La limite entre les roches assignées au Superterrane d'intermont de l'intérieur des Cordillères canadiennes et celles du Superterrane insulaire dans la portion la plus à l'ouest de la Cordillère de Colombie-Britannique et du sud-est de l'Alaska se trouvent dans et au long de la Chaîne côtière, au sein de laquelle affleure le noyau d'un orogène qui est apparu comme entité tectonique distincte entre 105 et 45 millions d'années. Des indices de la Chaîne côtière et des régions environnantes montrent que des portions du Superterrane d'intermont (dans les terranes de Stikinia et de Yukon-Tanana) se trouvaient alors près de celles du Superterrane insulaire (terranes de Wrangellia et d'Alexander) au début du Jurassique (~180 Ma). Cette chronologie, ajoutée à certains facteurs paléobiogéographiques et paléomagnétiques semblent discréditer une hypothèse récente voulant qu'une subduction à pendage ouest sous un arc intra-océanique sur le Superterrane insulaire résultait d'une collision entre un arc et le continent, initiant ainsi l'orogénèse de la Cordillère à la fin du Jurassique (~146 Ma). Cette hypothèse relie aussi l'océan subduit qui séparait les superterranes à une anomalie de vitesse sismique plus rapide que la normale dans le manteau inférieur sous le littoral maritime oriental de l'Amérique du Nord. Pour créer une telle anomalie, la subduction du plancher d'un grand océan était nécessaire. La seule indication de surface de l'existence d'un tel océan à l'intérieur de la Cordillère canadienne est le terrane de Cache Creek qui, bien qu'il se trouve dans le Superterrane d'intermont, est plus ancien que le Jurassique moyen (~174 Ma). Ce terrane, avec son équivalent probable de Bridge River dans le sud-est de la Chaîne côtière, qui est aussi jeune que la fin du Jurassique (164 Ma) et peut-être aussi jeune que le début du Crétacé (≥ 130

[1]*This article is the first in a series featuring research papers from recipients of GAC's prestigious Logan and Hutchison medals.*

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Ma), semblent être les seuls candidats au Canada offrant des vestiges en surface de cette anomalie sismique.

INTRODUCTION

The innovative and thought-provoking paper by Sigloch and Mihalynuk (2013) challenges the 'conventional wisdom' that suggests the Cordillera is largely the product of plate convergence between plates flooring the Pacific Ocean and its ancestors and the margin of the Laurentian craton, with arcs formed above subduction zones that mostly dipped towards the craton (e.g. Monger and Price 2002; Dickinson 2004; Nelson et al. 2013). Such scenarios vary in detail but basically suggest that in the late Paleozoic, convergence created magmatic arcs offshore of what was then northwestern Pangea in a setting probably analogous to the present southwestern Pacific Basin. Remnants of those arcs form most accreted terranes in the Cordillera. By the Middle Jurassic (174 Ma), all major offshore arc terranes had been accreted to the outer craton margin, although subsequently they were disrupted and displaced along that margin, and younger arcs were built across them. Arguably, in Cretaceous-earliest Cenozoic time the converging plates became strongly coupled, and Cordillera-wide deformation led to creation of an Andean-style orogen. Although it appears that subduction zones dipped toward the craton for most of the time, exceptions involved closure of a late Paleozoic marginal basin in Permian – Triassic time and possibly enclosure of remnants of an ocean basin by terranes now in northwestern British Columbia during Early-Middle Jurassic time and in the southern Coast Mountains in the Early Cretaceous.

In their hypothesis, Sigloch and Mihalynuk (2013) link faster-than-average-velocity seismic anomalies in the lower mantle, revealed by three-dimensional seismic tomography and interpreted as subducted oceanic lithosphere, to Cordilleran mountain-building initiated in the Late Jurassic. The hypothesis proposes that the ancestral Pacific Ocean west of Mesozoic North America contained long-lived magmatic arcs beneath which oceanic lithosphere sank steeply along stationary intra-oceanic trenches and accumulated in the lower mantle as massive, near-vertical 'slab walls' as much as 800–2000 km deep and 400–600 km thick. Today the slab walls mostly lie below the North American continent and its eastern seaboard. Sigloch and Mihalynuk (2013) contend the slab walls are geographically relatively immobile and serve as markers, called 'terrane stations,' that can be used (like mantle plumes) to track westward movement of the North American Plate across the lower mantle.

Comparison of x-y-z positions of slab walls with the surface record of Cordilleran orogenesis and with global plate reconstructions showing the sequentially westward-younging positions of the Pacific margin of North America (e.g. Shephard et al. 2012) led Sigloch and Mihalynuk (2013) to conclude that collision of the margin with the intra-oceanic arcs initiated mountain-building. Some younger slab walls, such as the northern and southern remnants of the Farallon Plate (respectively Juan de Fuca and Cocos plates) can be traced into active east-dipping subduction zones. Others, such as the Mezcalera slab wall (below) are completely detached from any surface record of the plate convergence that may have created them, which raises the challenge of linking those slab walls to the appropriate surface records of old ocean basins.

Only one aspect of Sigloch and Mihalynuk's (2013) hypothesis is addressed herein. The massive detached slab wall that resides in the lower mantle below the eastern seaboard of North America is interpreted by them to be subducted lithosphere that originated in the Mezcalera Ocean, which was named by Dickinson and Lawton (2001) from studies in Mexico. Sigloch and Mihalynuk (2013) suggest that prior to Late Jurassic – Early Cretaceous time this ocean separated an intra-oceanic magmatic arc on the Insular superterrane, now in the westernmost Canadian Cordillera, southeastern and southern Alaska, from the previously-accreted Intermontane superterrane in the interior of the Canadian Cordillera and east-central Alaska (Fig. 1). They propose that west-dipping subduction of the floor of the Mezcalera Ocean between ~200 Ma and 150 Ma beneath the Insular superterrane formed the Mezcalera slab wall, and brought the Intermontane superterrane (previously accreted to the leading edge of the North American Plate) into contact with the Insular superterrane, initially in the Late Jurassic (146 ± 24 Ma). Because the Coast Mountains of Canada and southeastern Alaska now separate the superterranes, any Late Jurassic – Cretaceous suture is within/along that range (Fig. 1).

This review examines evidence for the existence of such a suture between superterranes along the Coast Mountains where the original terrane relationships are obscured or obliterated by mid-Cretaceous – early Cenozoic (~105–45 Ma) granitic intrusions, deformation, and metamorphism. Sequentially below, Coast Mountains geology is reviewed; paleogeographic flags raised by paleomagnetic studies on Late Cretaceous rocks are noted; aspects of terranes flanking the Coast Mountains are summarized; evidence is examined from south to north along the Coast Mountains for times of terrane linkages; and the findings discussed and conclusions drawn.

COAST MOUNTAINS: CORE OF THE COAST-CASCADE OROGEN (CCO)

The Coast Mountains extend southward for about 1600 km from southwestern Yukon near latitude 60° and along the mainland coast of southeastern Alaska and British Columbia as far as Vancouver. Part of their bedrock continues south and east of the lower Fraser River (east of Vancouver) to as far south as latitude 48°30' in the Cascade Mountains of British Columbia and the North Cascade ranges of northwest Washington. North of ~latitude 55°, the Coast Mountains are about 50–100 km wide but south of this are up to twice the width. The rugged mountainous topography results from differential uplift of up to 4 km in the last 10 million years with increased rates of exhumation in the last 4 million years, together with glacial and fluvial sculpting of hard bedrock in a region of high precipitation (Parrish 1983; Farley et al. 2001).

The Coast Mountains are underlain mainly by plutonic rock that forms what has been called the "Coast Plutonic Complex" by Roddick (1983)

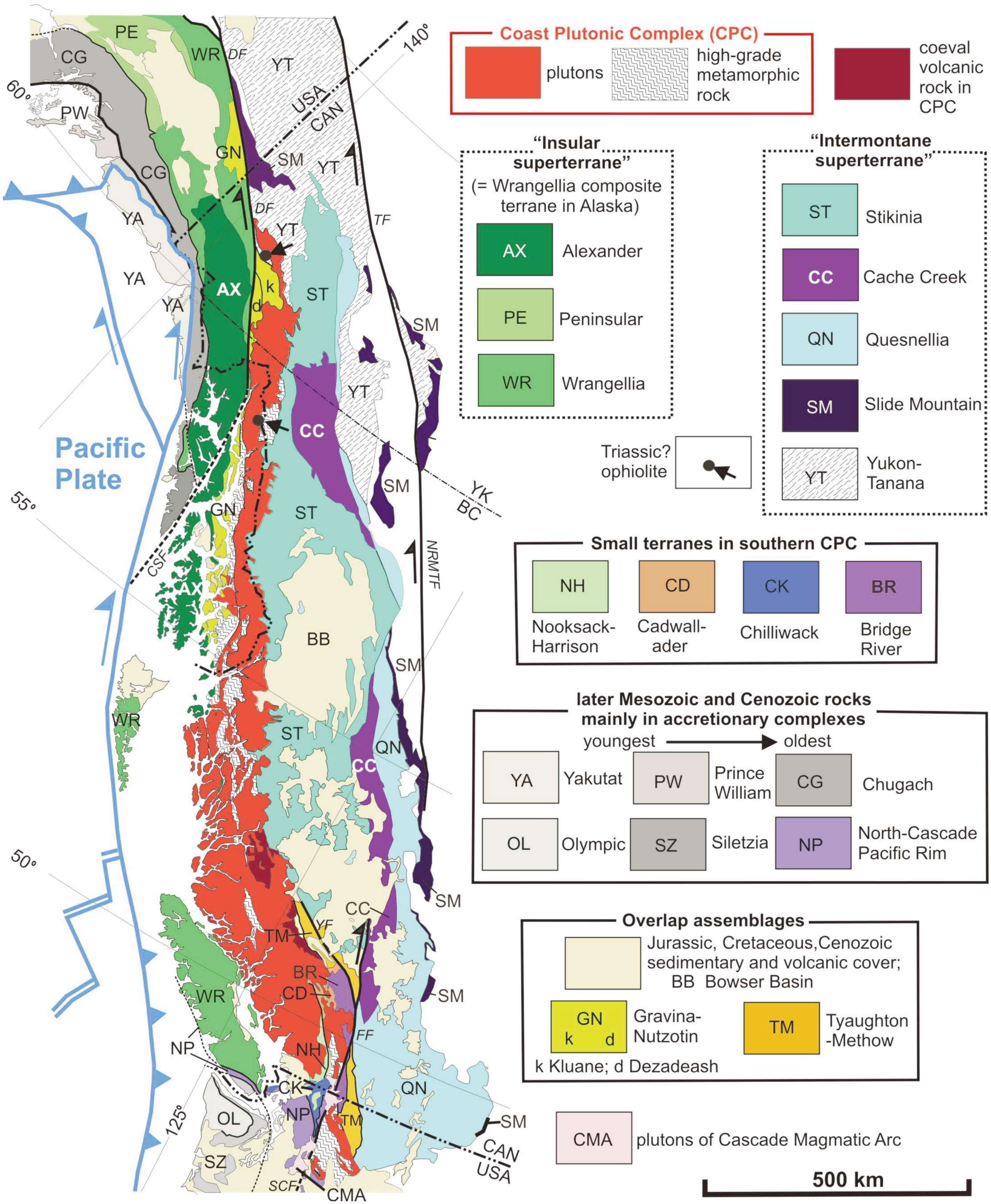

Figure 1. Terranes and overlapping basin deposits of the Canadian Cordillera and adjacent parts of the United States (modified from Silberling et al. 1992) shows the relationship of terranes grouped within Intermontane and Insular superterranes to the Coast Plutonic Complex.

and "Coast Mountains batholith" by Gehrels et al. (2009). The narrower northern part comprises mainly Late Cretaceous – early Cenozoic (~85–45 Ma) plutons, and plutons of this age range occur all along the Coast Mountains and North Cascade ranges. In the wider part south of latitude 55°, intrusions mostly range in age from Middle Jurassic (± 170 Ma) to Eocene (~45 Ma). Older 'terrane specific' plutons are present but rare, and south of ~latitude 50° late Eocene through Neogene (~34–0 Ma) plutonic and volcanic rocks form the northern end of the Cascade magmatic arc, which lies landward of the small, converging Juan de Fuca Plate (Fig. 2).

The Coast Mountains coincide with the core of an orogen that emerged as a discrete tectonic entity within the Cordillera between ~105 and 45 million years ago. That orogen was recognized in the North Cascades by Misch (1966), called the Pacific Orogen in Canada by Wheeler and Gabrielse (1972), and has been renamed the Coast-Cascade Orogen (CCO) by Monger and Brown (in press) and Monger (herein; Fig. 2). The CCO comprises a core of mid-Cretaceous to early Cenozoic (~105–45 Ma) syn-orogenic plutons and metamorphic rocks that is flanked on both sides by deformed sedimentary and volcanic strata (Fig. 2). The structural fabric of the CCO evidently formed mainly during transpression. In the past, emphasis has been placed on folds, thrust faults and reverse faults that diverge eastward and westward away from the core and result from orogen-normal compression (Misch 1966; Wheeler and Gabrielse 1972; Monger et al. 1982; Crawford et al. 1987; Rubin et al. 1990; Rusmore and Woodsworth 1991). A growing body of evidence shows these structures were in large part coeval with strike-slip faults, shear zones, fabrics in plutons and metamorphic rocks, and folds and thrust faults that formed in response to orogen-parallel movement (Lawrence 1978; Hurlow 1993; Monger et al. 1994; Hollister and Andronicos 1997; Schiarizza et al. 1997; Chardon et al. 1999; Evenchick 2001; Brown and Dragovich 2003; Evenchick et al. 2007; Nelson et al. 2012; Angen et al. 2014; Monger and Brown in press). Combined, the structures record transpression with a dominantly sinistral component into mid-Cretaceous time and a dextral one after then. The last stage of CCO evolution involved transtension, recorded by Eocene (~55–45 Ma) normal faults in the eastern Coast Mountains (and widespread to the east across southern British Columbia) that are in part coeval with movement on major dextral strike-slip faults (Coleman and Parrish 1991; Rusmore et al. 2005).

Latest Early Cretaceous through Paleocene transpression (~105–55 Ma) caused crustal thickening, deep burial, and differential uplift of rocks in the core of the CCO. Detritus eroded from the core was shed eastward into non-marine basins (Garver 1992; Evenchick et al. 2007) and also westward where it was deposited in foreland/forearc basins and also on the ocean floor. The detritus on the ocean floor was carried northward on the Kula and Pacific plates and some incorporated in the vast accretionary complexes of southern Alaska (Fig. 2; Mustard 1994; Trop and Ridgeway 2007).

South of ~latitude 55°, Middle Jurassic to Early Cretaceous (~175–105 Ma) plutons and locally coeval volcanic rocks occur not only within the Coast Mountains but are scattered east of them across the Intermontane superterrane as far east as Neoproterozoic and early Paleozoic strata thought by most to have been deposited along distal parts of the Laurentian continental margin (Figs. 1, 2; Wheeler and McFeely 1991; Massey et al. 2005). In contrast, north of latitude 55° Early Cretaceous and local Jurassic plutons and volcanic rocks are west of the northern Coast Mountains in/on the Insular superterrane. East of them, Bowser Basin contains easterly-sourced, Middle Jurassic through Early Cretaceous (~170–110 Ma) sedimentary detritus that was folded and thrust eastward in the Cretaceous to form the eastern structural component of the CCO (Fig. 2; Gehrels and Berg 1994; Evenchick et al. 2007).

PALEOMAGNETISM OF CRETACEOUS ROCKS RAISES UNRESOLVED PALEOGEOGRAPHIC QUESTIONS

The following digression is included because paleomagnetic studies raise major questions about the latitude of the CCO relative to that of the craton during the Cretaceous. The Cordillera should be a paleomagnetic paradise: the paleolatitudes through time of the North American craton are well-known; its western margin has been oriented approximately north-south since the late Paleozoic; and the Cordillera contains abundant rocks with remnant magnetism. However, ever since Beck and Nosun (1972) found shallower-than-expected magnetic inclinations in the mid-Cretaceous (~95 Ma) Mount Stuart batholith in the North Cascade ranges and proposed that its magnetization was acquired over 3000 km south of the present latitude of the batholith relative to the craton, there has been vigorous debate about the paleogeography of the Cretaceous Cordillera (e.g. Cowan et al. 1997). Shallower-than-expected inclinations found in several other Cretaceous plutons in the CCO have been explained by other workers (e.g. Symons 1973; Butler et al. 2006) as the result of tilting and not translation ('attitude *vs.* latitude'). Other arguments against large latitudinal displacements employ Late Cretaceous faunas (Carter and Haggart 2006), floras (Trop et al. 1999; Pearson and Hebda 2006), and Archean detrital zircons in Late Cretaceous clastic strata on the west side of the southern Coast Mountains whose ages indicate derivation from northwest Laurentia (Mahoney et al. 1999).

To account for the apparent latitudinal translation, Hollister and Andronicos (1997) proposed that a sliver founded on the Insular superterrane moved northward for ~1500–2000 km along a boundary *within* the Coast Mountains. However, paleomagnetic results from stratified Cretaceous rocks, in which bedding and flow layering ideally record the paleohorizontal attitude acquired during deposition, suggest that rocks of the Coast Mountains and flanking regions moved northward together. Results from late Early Cretaceous (105 Ma) continental volcanic rocks of the Spences Bridge Group, which overlie the Intermontane superterrane just east of the southern Coast Mountains, position them ~850 to 1300 km south of their present lati-

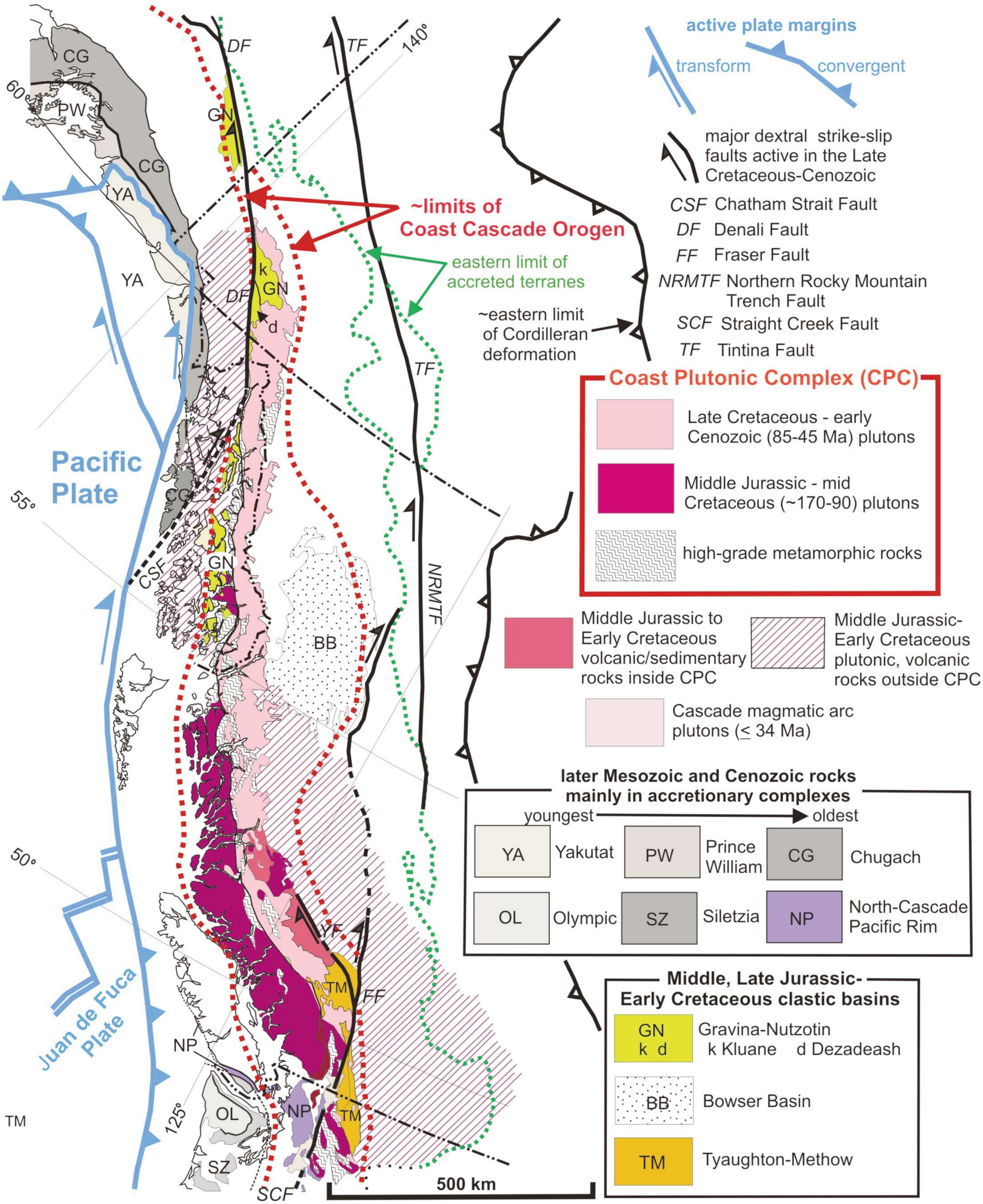

Figure 2. Middle Jurassic through early Cenozoic components of the Coast Plutonic Complex, core of the Coast-Cascade Orogen, and flanking coeval arc-related magmatic rocks, sedimentary basin deposits and accompanying accretionary complexes.

tude with respect to the craton (Irving et al. 1995; Haskin et al. 2003). This result is in accord with restoration of cumulative amounts of offset on Late Cretaceous and Cenozoic dextral strike-slip faults that locate rocks now in southwestern British Columbia to the latitude of mid-Cretaceous northern California (Wyld et al. 2006). However, paleomagnetism of the early Late Cretaceous (≥ 85 Ma) Powell Creek-Silverquick succession on the east side of the southern Coast Mountains, whose lower part is correlated with strata that overlie the Spences Bridge Group, indicate that the succession was laid down ~2300 km south of its present position relative to the craton (Enkin et al. (2006a), so that an additional ~1300 km of relative southward displacement apparently was acquired between 105 Ma and ~85 Ma (Enkin 2006; *his* fig. 4). Furthermore, Late Cretaceous (~80–67 Ma) sedimentary strata of the Nanaimo Group that overlie the Insular superterrane on Vancouver Island and the westernmost southern Coast Mountains appear to have been deposited as much as ~2700 km south of their present positions along the continental margin (Ward et al. 1997; Kent and Irving 2010). This amount has been questioned by Kodama and Ward (2001) who prefer ≤1500 km of northward displacement, based on compaction corrections and paleobiogeography. Results from the Late Cretaceous (~80 Ma) McColl Ridge Formation in southern Alaska, deposited in a tectonic setting similar to that of the Nanaimo strata, indicate northward translation of only ~1650 km (Stamatakos et al. 2001), an amount (~1700 km) similar to that determined from plutons in the central Coast Mountains that arguably were not tilted (Rusmore et al. 2013).

If paleomagnetic results from Late Cretaceous rocks on both flanks and within the southern Coast Mountains are combined they imply that the locus of major (> 1000 km) Late Cretaceous relative northward displacement is located somewhere east of the Coast Mountains and not within them, and that the Insular superterrane and at least part of the Intermontane superterrane moved northward together, as argued from geological evidence by Evenchick et al. (2007). This finding is supported by the relative northward displacement of ~1900 km obtained from the latest Cretaceous (70 Ma) Carmacks volcanics that overlie the Intermontane superterrane in Yukon (Enkin 2006b). Within limits of paleomagnetic resolution, all was more-or-less in place by the Eocene (~50 Ma; Irving and Brandon 1990).

The Late Cretaceous paleomagnetic record is a basic premise of the SAYBIA and the Rubia hypotheses of Johnston (2008) and Hildebrand (2009) in that it appears to support their suggestions that much of what now forms the Cordillera was removed from the northwestern Laurentian craton margin until the later Mesozoic. Both hypotheses postulate a ribbon continent that contained, in addition to the terranes, sedimentary successions in the eastern Cordillera regarded by most as parautochthonous (e.g. Nelson et al. 2013). The ribbon continent apparently was separated from North America by a wide basin, and west-dipping subduction of the basin floor beneath the ribbon continent resulted in its Cretaceous accretion. In the latter aspect, both hypotheses resemble that of Sigloch and Mihalynuk (2013), but differ considerably in that they locate the suture in the eastern Cordillera rather than the Coast Mountains. Unfortunately, no through-going structures on which there was ~1600 km of northward displacement (1900 km minus known Cenozoic *latitudinal* offset across the Tintina Fault; Figs. 1, 2) that were active between 70 and 50 million years ago have been recognized in the easternmost Cordillera.

TERRANES INVOLVED IN COAST-CASCADE OROGENESIS

Details of northern Cordilleran terranes are given by Monger et al. (1991), Nokleberg et al. (2000), and Nelson et al. (2013), and the distribution of all Cordilleran terranes is shown by Silberling et al. (1992). East of the Coast Mountains, the Stikinia, Cache Creek, Quesnellia, Yukon-Tanana and Slide Mountain terranes are included in the Intermontane superterrane (Fig. 1). Metamorphic rocks derived from the Yukon-Tanana terrane and Stikinia can be traced right across the northern Coast Mountains, and into the eastern central Coast Mountains (Gehrels et al. 2009; Nelson et al. 2013). The Alexander and Wrangellia terranes form the Insular superterrane and occur west of the northern Coast Mountains, and these terranes are protoliths of metamorphic rocks in near-coastal parts of the central and southern Coast Mountains. In Alaska, where the Insular superterrane is called the Wrangellia composite terrane, it also includes the Peninsular terrane, which is composed of latest Triassic to Middle Jurassic arc-related rocks correlated with those within Wrangellia in Canada.

Proterozoic and early Paleozoic rocks in the Yukon-Tanana terrane evidently were detached from the Laurentian margin in the earliest Carboniferous and returned to it in Permian-Triassic time when the oceanic/back-arc Slide Mountain terrane which had separated Yukon-Tanana terrane from the craton margin was closed by west-dipping subduction (Nelson et al. 2013). West of the northern Coast Mountains, the Alexander terrane contains a record of latest Neoproterozoic – early Paleozoic arc magmatism and deformation and was juxtaposed with Wrangellia, with the boundary between them 'stitched' by Late Carboniferous plutons (301–307 Ma; Gardner et al. 1988; Beranek et al. 2014). In the Middle and Late Devonian (390–360 Ma) arc-related magmatic activity was initiated in the Quesnellia, Stikinia, Wrangellia and Yukon-Tanana terranes, as well as in strata in southeastern British Columbia considered by most to be outer parts of the Laurentian margin (Piercey et al. 2006; *their* fig. 7; Nelson et al. 2013). Quesnellia, Stikinia and Wrangellia all contain late Paleozoic–early Mesozoic arc rocks although an episode of rift- or plume-related Late Triassic mafic magmatism distinguishes Wrangellia from the other terranes (Jones et al. 1977). Triassic arc-related magmatic rocks and associated mineral deposits in Stikinia and Quesnellia are so similar in nature and age that the terranes hosting them are regarded as segments of the same arc (Mihalynuk et al. 1994; Nelson et al. 2013). Magmatic rocks in all of the arc terranes have juvenile chemistry except for the post-Triassic, arc-related magmatic rocks in Quesnellia (Samson and Patchett 1991). In the latter, the amount of crustal contamination increases with decreasing age and from west to east, changes that are interpreted to reflect incorporation of evolved crustal material as Quesnellia overrode the distal Laurentian margin in the Early Jurassic (187–185 Ma; Ghosh 1995; Murphy et al. 1995). The northern Cache Creek terrane became enclosed - somehow - between Quesnellia and Stikinia terranes by latest Early Jurassic time (~174 Ma; Mihalynuk et al. 1994, 2004).

Estimates of *large* amounts of terrane displacement relative to the Laurentian margin across lines of longitude presently rely largely on paleobiogeography, which is why the hypothesis of Sigloch and Mihalynuk (2013) is appealing because it potentially provides an additional, quantitative, tool. Early Paleozoic faunas in the Alexander terrane are exotic and support its origin somewhere in the present circum-Arctic region (Nelson et al. 2013). Permian and early Mesozoic faunas in Quesnellia, Stikinia and Wrangellia all have affinities with faunas found on northwestern Pangea (now the North American craton) and probably lived in northeastern Panthalassa (the ancestral Pacific; Monger and Ross 1971; Miller 1987; Cordey et al. 1992; Fedorowski et al. 1999; Belasky and Stephens 2006; Smith 2006). Notably, Early Permian coral faunas in Stikinia and Wrangellia are more similar to one another than to those in Quesnellia (Belasky and Stephens 2006). An Early Jurassic ammonite species in Wrangellia is known in northeastern Russia but unknown in other North American terranes (Smith et al. 2001).

The only clearly 'exotic' *faunas* (as opposed to individual species) of Permian through Middle Jurassic age occur in the accretionary complexes that form the Cache Creek and Bridge River terranes in Canada, and the innermost part of the Chugach terrane (McHugh Complex) in southern Alaska (Clark 1971, p. A54; Monger and Ross 1971; Cordey 1996; Orchard et al. 2001). These faunas are akin to those today in eastern, southeastern and central Asia and probably lived far out in Panthalassa, and in Paleotethys and Tethys oceans.

Paleomagnetic studies on Late Triassic and Early Jurassic volcanic rocks of Wrangellia on Vancouver Island and from volcanic rocks of similar age in Stikinia of north-central British Columbia indicate that both terranes moved southward relative to the craton between Late Triassic and Early Jurassic time (Kent and Irving 2010). The Triassic Karmutsen Formation on Wrangellia was 780 ± 660 km south of the latitude it presently occupies relative to the craton, whereas the Takla Group in eastern Stikinia (called Stuhini by Kent and Irving 2010) had no significant offset. For the Early Jurassic, the Bonanza rocks on Vancouver Island were 1650 ± 560 km south of their expected latitude and the Hazelton Group on Stikinia was 1200 ± 680 km to the south, results that agree well with Early Jurassic paleobiogeography (Smith 2006). Kent and Irving (2010) conclude that Wrangellia and Stikinia were not very far apart in the early Mesozoic.

Below, evidence is examined that bears on times when rocks included in the Insular and Intermontane superterranes were together in southern, central, and northern segments of the Coast Mountains.

(1) Southern Coast Mountains-North Cascade Ranges: Latitudes 47°30 to 51°30'

This is the only segment of the Coast Mountains that contains remnants of the floor of a long-lived ocean basin. Middle Jurassic to mid-Cretaceous (~164–90 Ma) arc-related magmatic rocks in the southwestern Coast Mountains, some in/on Wrangellia and others in/on the Nooksack-Harrison terrane, are separated in the southeastern Coast Mountains from coeval arc rocks to the east in/on the Intermontane superterrane by remnants of the floor of a Carboniferous to Middle Jurassic ocean basin. These form the Bridge River terrane that is overlapped by marine Jurassic and Early Cretaceous clastic deposits of the Tyaughton-Methow basin (Figs. 1, 3).

Plutons in the southeastern Coast Mountains are syn-orogenic, become younger eastward from mid-Cretaceous to Eocene (~95–45 Ma), and intrude the small Bridge River, Cadwallader and Methow terranes and the overlapping clastic rocks (Figs. 1, 2, 3; Friedman and Armstrong 1995; Bustin et al. 2013). Of these terranes, the Bridge River near latitude 51° comprises fragmented, faulted and folded Early Carboniferous through Middle Jurassic (~350–160 Ma) basalt, radiolarian chert, argillite, ultramafic rock, small carbonate olistoliths, and rare Late Triassic blueschist (Cordey and Schiarizza 1993; Schiarizza et al. 1997) and may in part grade into Late Jurassic and earliest Cretaceous clastic rocks in Tyaughton-Methow basin (Mahoney and Journeay 1993; Cordey 1996). The Cadwallader and Methow terranes also were founded on Permian oceanic lithosphere and overlain by Triassic and local Middle Jurassic arc-volcanic rocks and associated clastic strata. Marine clastic strata of the Tyaughton-Methow basin overlap all three terranes and according to Umhoefer et al. (2002) were deposited in three tectonic settings: Late Jurassic – earliest Cretaceous strata in a forearc and/or complex strike-slip setting; Early Cretaceous strata (≤ 130 Ma) in a basin between two arcs; and mid-Cretaceous strata that record uplift and erosion of the basin floor and herald emergence of the CCO. Deformation in the southeastern Coast Mountains is penetrative, and most structures reflect Cretaceous-earliest Cenozoic transpression and Eocene transtension (Schiarizza et al. 1997). Northward, the Bridge River terrane is pinched out between the dextral Yalakom and Tchaikazan faults near latitude 51°30'. Southward, the Bridge River and associated younger clastic rocks are in places metamorphosed up to high grades (Fig. 3), can be traced across the Fraser River into the core of the North Cascades, and there disappear near latitude 47°30' beneath Cenozoic volcanic rocks of the Cascade magmatic arc.

Both the Bridge River and Cache Creek terranes are considered to be remnants of the floor of Panthalassa (Cordey et al. 1992; Cordey and Schiarizza 1993; Cordey 1996; Orchard et al. 2001). In southern British Columbia they are separated from one another by rocks of the Tyaughton-Methow basin and Cenozoic volcanic rocks and by the Yalakom and Fraser-Straight Creek faults, but father north the Cache Creek lies entirely within the Intermontane superterrane, sandwiched between Stikinia and Quesnellia

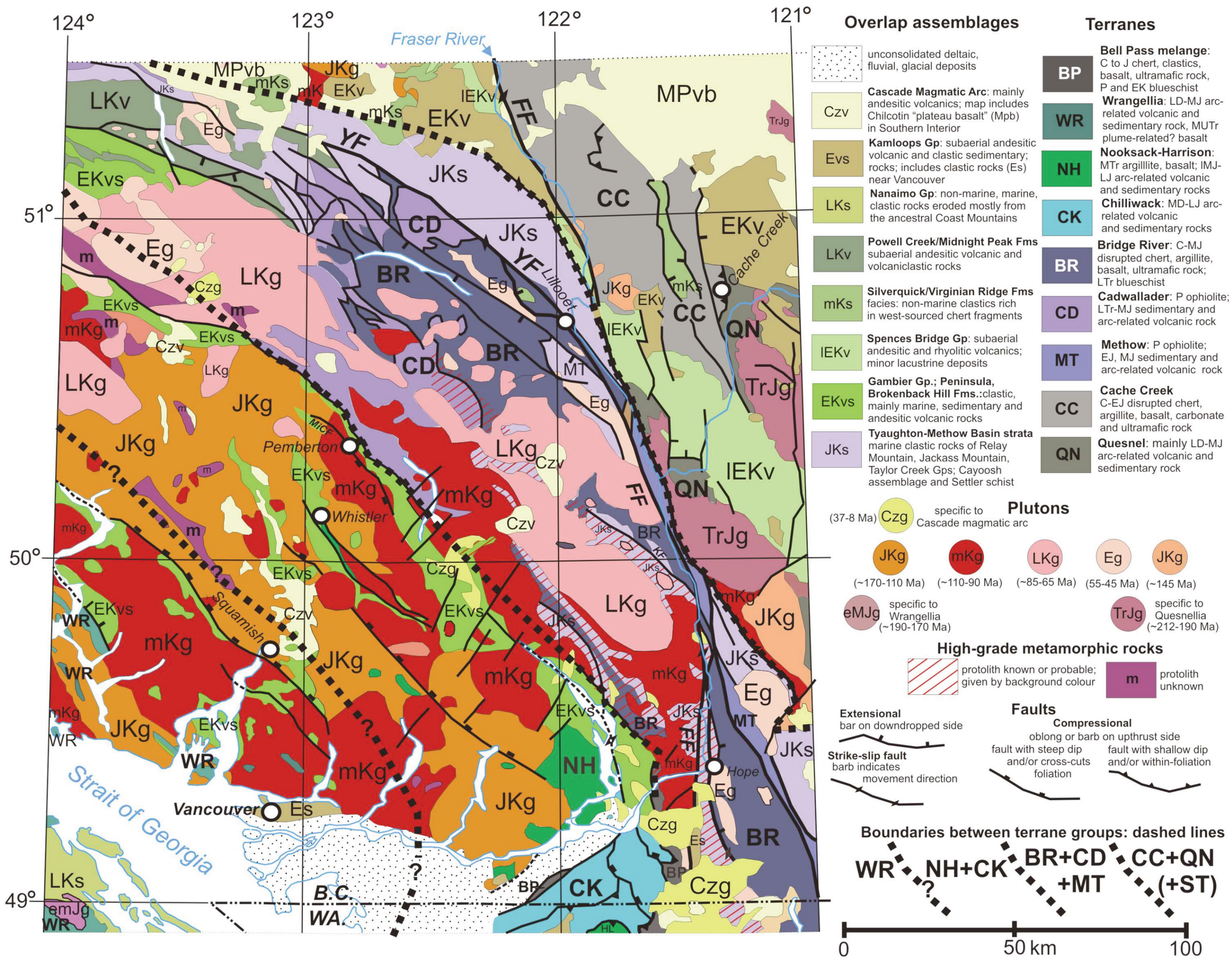

Figure 3. Geology of the southern Coast Mountains and parts of flanking regions, showing the distribution of plutonic rocks, terranes, and overlap assemblages (modified from Bustin et al. 2013). *FF* Fraser Fault; *YF* Yalakom Fault.

(Figs. 1, 3). Restoration of dextral displacements of ~115 km on the latest Cretaceous-Paleocene Yalakom Fault (Umhoefer and Schiarizza 1996) and of ~140 km of Eocene movement on the Fraser-Straight Fault (Monger and Brown, in press) aligns the Bridge River terrane south along strike with the Cache Creek terrane. Both terranes contain Late Triassic blueschist, but differ in that the Bridge River terrane is generally 'more pelagic' with abundant radiolarian chert and rare, small, carbonate olistoliths whereas Cache Creek terrane is characterized by enormous masses of Late Carboniferous to Late Triassic shallow water carbonate, as well as widely distributed remnants of a Permian–Triassic (~250 Ma) intraoceanic arc (Schiarizza et al. 1997; Schiarizza 2012). Furthermore, the Bridge River terrane is at least as young as Callovian (~164 Ma) in chert-rich facies and may grade into clastic facies as young as earliest Cretaceous (≥ 130 Ma; Mahoney and Journeay 1993; Cordey 1996), whereas no strata younger than latest Early Jurassic (~180 Ma) are known from the Cache Creek terrane. Although both the Bridge River and Cache Creek terranes probably originated in Panthalassa, the former evidently faced open ocean until trapped in the Early Cretaceous (≤130 Ma) behind the arc rocks in the southwestern Coast Mountains, whereas in northern British Columbia the Cache Creek terrane was thrust southwestward over Stikinia in the earliest Middle Jurassic (~174 Ma) (Mihalynuk et al. 2004), and in southern British Columbia was thrust eastward over Quesnellia probably in the Late Jurassic (≤ 160 Ma) (Travers 1978).

The southwestern Coast Mountains contain abundant plutonic rocks that range in age from 167–91 Ma (Fig. 3; Monger and McNicholl 1993; Friedman and Armstrong 1995; Bustin et al. 2013, *their* fig. 2). Deformation is mainly along widely spaced, north northwest-trending early Late Cretaceous reverse faults and shear zones (one active between 94–91 Ma) between which most rocks are little deformed, and metamorphism is mainly low-pressure greenschist and amphibolite facies. It appears that during mid-Cretaceous–early Cenozoic orogenesis, rocks of the southwestern Coast

Mountains together with Wrangellia on Vancouver Island formed a broad, semi-rigid block that acted as both foreland *and* forearc to magmatism, deformation and metamorphism then focused in the southeastern Coast Mountains.

In the southwestern Coast Mountains, three arc-related terranes are present whose relationships are obscured by the abundant plutons (Fig. 3). In the western flank of the southern Coast Mountains, late Middle Jurassic through mid-Cretaceous (≤ 164 Ma) plutons intrude Wrangellian strata that had been penetratively deformed between 185 Ma and 156 Ma (Friedman et al. 1990). Farther east near Harrison Lake, which is about 100 km east of Vancouver, Middle and Late Jurassic (≤ 167 Ma) plutons intrude a Middle Triassic through Jurassic volcanic and sedimentary succession called the Nooksack-Harrison terrane. Present only locally in the southernmost Coast Mountains, but exposed widely south of the Fraser River in the northwest Cascades, is the Devonian through Jurassic Chilliwack terrane. Detritus eroded from the Chilliwack terrane is found in latest Early Jurassic (~180 Ma) conglomerate in the Nooksack-Harrison terrane (Fig. 3; Crickmay 1930; Arthur et al. 1993). Furthermore, Mahoney and DeBari (1995) suggest that younger parts of the Jurassic (Bonanza) arc-succession in Wrangellia correlate with late Early Jurassic volcanic rocks of the Nooksack-Harrison succession, so it appears that the Wrangellia – Nooksack-Harrison and Chilliwack terranes were together by ~180 Ma.

Monger and Struik (2006) proposed that the Chilliwack and (?)Nooksack-Harrison terranes are southward-displaced fragments of Stikinia, a conclusion supported by the presence in the eastern Coast Mountains as far south as ~latitude 51° of metamorphic rocks with affinities to the Yukon-Tanana terrane and Stikinia (Gehrels et al. 2009; Nelson et al. 2012). Thus, in the southwestern Coast Mountains it appears that rocks assigned to both the Insular and Intermontane superterranes, represented respectively by Wrangellia and by the Chilliwack and Nooksack-Harrison terranes, were together by the late Early Jurassic (~180 Ma).

East of the Coast and North Cascade mountains between latitudes 47°30’ and 55°, the Cache Creek terrane, Quesnellia, and Stikinia and some rocks assigned to the distal Laurentian margin are intruded by Middle Jurassic (~175–166 Ma), Late Jurassic (~157–148 Ma) and Early Cretaceous (~105 Ma) plutons. Volcanic rocks of these ages are rare, probably because for much of this period the region was elevated and being eroded, with detritus shed westward in the Jurassic across Quesnellia (Petersen et al. 2004) and by the late Early Cretaceous into the Tyaughton-Methow basin (DeGraaff-Surpless et al. 2003). As noted earlier, the southernmost Cache Creek rocks were thrust eastward over Quesnellia in the Late Jurassic (Fig. 3; Travers 1978), and in a probably related but structurally deeper event, westernmost Quesnellia was deformed and intruded by Late Jurassic (157–148 Ma) tonalite gneiss (Greig et al. 1992; Price and Monger 2003).

Late Early Cretaceous arc-related volcanic rocks interlayered with marine clastic strata in the southwestern Coast Mountains (Gambier Group; Fig. 3) are coeval with continental arc-rocks just east of the southern Coast Mountains (Spences Bridge Group) and separated from them by youngest parts of the marine Tyaughton-Methow basin in the southeastern Coast Mountains. Thorkelson and Smith (1989) suggested that both arcs faced oceanward, whereas Lynch (1995) thought the arcs faced one another in a configuration akin to that of the modern Molucca Sea collision zone.

(2) Central Coast Mountains: Latitudes 51°30’ to 55°

Rocks in this segment assigned to the Intermontane and Insular superterranes were juxtaposed and intruded by Middle Jurassic and younger plutons (Figs. 1, 2; Crawford et al. 1987; Rusmore and Woodsworth 1991; van der Heyden 1992; Haggart et al. 2006; Gehrels et al. 2009; Mahoney et al. 2009; Nelson et al. 2012). Stikinian strata and Early and Middle Jurassic (~190–160 Ma) and younger plutons can be traced westward into the Coast Mountains, which also contain Middle Jurassic to Early Cretaceous volcanic rocks (Fig. 2). The western central Coast Mountains are bounded by tidewater, and contain plutons that range in age from 177–100 Ma. North of ~ latitude 54° they intrude the Alexander terrane and in the south, east of northern Vancouver Island, intrude Wrangellian strata (Fig. 1; Gehrels et al. 2009; Mahoney et al. 2009). Protolith compositions, dated detrital zircons, and ages of orthogneiss bodies distinguish two discontinuous belts of metamorphic rock in this segment of the Coast Mountains (Gehrels and Boghossian 2000; Gehrels et al. 2009; Nelson et al. 2012). The eastern belt has affinity with the Stikinia and Yukon-Tanana terranes and extends at least as far south as ~latitude 51°. The western belt has been traced southward from the Alexander terrane, near latitude 54°, as far as ~latitude 52°. Deformed latest Early Jurassic (~177 Ma) volcanic rocks (Moffatt volcanics) overlie rocks assigned to the Insular superterrane near latitude 54° and also to rocks of the Intermontane superterrane near latitude 54°45’ (Gehrels 2001).

The central segment of the Coast Mountains contains widespread evidence of the deformation related to CCO orogenesis. In the east side of the Coast Mountains near latitudes 54° and 52°, east-vergent thrust faults that involve Stikinian rocks were active in the Late Cretaceous (~85 Ma; Rusmore and Woodsworth 1991; Mahoney et al. 2009). Near latitude 51º30’, sinistral faulting as young as ~89 Ma was succeeded by dextral strike-slip faulting in the latest Cretaceous (Israel et al. 2006). Within the western Coast Mountains between latitudes 54° and 52°30’ there are numerous sub-vertical faults and shear zones, some of which formed during Early Cretaceous (123–105 Ma) sinistral transpression (Chardon et al. 1999; Haggart et al. 2006; Nelson et al. 2012; Angen 2014). On the west side of the Coast Mountains near latitudes 54° and 52°, west-vergent thrust faults were active in the mid-Cretaceous (~100–90 Ma) and on some faults, rocks assigned to the Intermontane superterrane override those of the Insular superterrane (Rubin et al. 1990; Crawford et al. 2000; Mahoney et al. 2009).

Records of deformation that pre-date formation of the CCO are sparse but found locally within and flanking the core, although they are different ages on eastern and western sides of the Coast Mountains. On the east side, near Terrace (latitude 54°30'), strongly folded Permian and Triassic Stikinian strata are unconformably overlain by volcanic rocks of the Hazelton Group, the latter recently dated to be as old as latest Triassic (203 Ma; Joanne Nelson, personal communication 2013). The western side of the central Coast Mountains is bounded by Queen Charlotte Sound and Hecate Strait, west of which on Haida Gwaii (the former Queen Charlotte Islands) the Wrangellian succession features southwest-directed folding and thrust faulting of latest Aalenian-early Bajocian age (~170 Ma; Thompson et al. 1991).

(3) Northern Coast Mountains: Latitudes 55° to 62°

The northern segment of the Coast Mountains lies within the Intermontane superterrane, whose western boundary is exposed near tidewater along the western flank of the Coast Mountains and on easternmost islands of the Alexander Archipelago in southeastern Alaska. Although the rocks involved are intruded by plutons, complexly deformed and metamorphosed, the original boundary is not completely obliterated and has been closely studied over the past few decades with U/Pb dating playing an important role (Figs. 1, 2; e.g. Gehrels et al. 1991; Saleeby 2000; Gehrels 2001). The Late Cretaceous–early Cenozoic plutons of the northern Coast Mountains intrude metamorphic rocks whose protoliths are late Neoproterozoic–early Paleozoic, quartz-rich sedimentary rocks correlated with rocks of the Yukon-Tanana terrane and volcanogenic rocks correlated with those of Stikinia (Currie and Parrish 1997; Gehrels and Kapp 1998; Gehrels 2001; Gehrels et al. 2009). Also within the Coast Mountains near latitude 59° is an ophiolite complex associated with slightly metamorphosed strata of Early and Middle Triassic age that is faulted against high grade metamorphic rocks derived from the Yukon-Tanana terrane (Brew et al. 2009).

East of the northern Coast Mountains, Middle Jurassic to Early Cretaceous clastic rocks of Bowser Basin were eroded mainly from the Cache Creek terrane, deposited on Stikinia, and folded and thrust eastward in the Cretaceous (Figs.1, 2; Evenchick et al. 2007); absent are the Middle Jurassic to Early Cretaceous arc-related rocks widespread south of latitude 55°. In places on the western flank of the northern Coast Mountains west-vergent thrusts and folds of mid-Cretaceous age carry rocks correlated with the Yukon-Tanana and Stikinia over Late Jurassic – Early Cretaceous marine clastic and volcanogenic strata of the Gravina-Nutzotin belt (Figs. 1, 2; e.g. Crawford et al. 1987). Because the Gravina-Nutzotin belt in part overlies the Alexander terrane, the Cretaceous structures in places delineate the boundary between the Intermontane and Insular superterranes.

However, other evidence from the region shows that the superterranes were in proximity with one another in the Jurassic. Along the western flank of the northern Coast Mountains and on nearby islands of the Alexander Archipelago, highly deformed and metamorphosed rocks form a long narrow belt bounded by faults or shear zones, some of which record strike-slip movement (Figs. 1, 2; Wheeler and McFeely 1991; Gehrels and Berg 1994). These rocks are correlated with those of the Yukon-Tanana terrane and Stikinia on the bases of lithologies and content of dated detrital zircons, and were overlapped by Gravina-Nutzotin strata (Rubin and Saleeby 1991; Currie and Parrish 1997; Gehrels and Kapp 1998; Saleeby 2000; Gehrels 2001). On more westerly islands of the Alexander Archipelago and in the St. Elias Mountains farther north, the Alexander terrane was intruded by Early Cretaceous and locally Late Jurassic plutons coeval with volcanogenic Gravina-Nutzotin strata that overlie its eastern side (Figs. 1, 2; Berg et al. 1972; Gehrels and Berg 1994; Kapp and Gehrels 1998). In addition, west of the Coast Mountains near latitude 55° rocks of the Alexander terrane were thrust beneath rocks correlated with those of Stikinia and locally emerge on their eastern side. The thrust fault is cross-cut by dykes dated between 162 and 139 Ma and overlapped by Late Jurassic–Early Cretaceous Gravina-Nutzotin strata (Saleeby 2000). As noted earlier, near the boundary between southeastern Alaska and coastal British Columbia, ~latitude 54°45', the Middle Jurassic (~177 Ma) Moffat volcanics were laid down on both the Alexander terrane and on rocks correlated with Stikinia and overlain by Gravina-Nutzotin strata (Gehrels 2001). Additional evidence that the Intermontane and Insular superterranes were not separated by a wide Late Jurassic ocean basin is given by the ages of detrital zircons in Gravina-Nutzotin strata. As expected, the dominant detrital zircon populations (165–145 Ma; 120–105 Ma) were derived from the coeval arc on the Alexander terrane, but older populations have ages (400–450 Ma; 520–560 Ma) found in the Alexander terrane, and ages (310–380 Ma; 920–1310 Ma; 1755–1955 Ma) more typical of the Yukon-Tanana terrane (Kapp and Gehrels 1998).

Arguably, the Intermontane and Insular superterranes were parts of the same convergent margin before the Jurassic. Initiation of the mainly Jurassic arc successions of Wrangellia and Stikinia was in the latest Triassic: the oldest U/Pbdate from the Bonanza volcanics in Wrangellia on Vancouver Island is ~204 Ma, although fossil ages from the succession indicate the lowest part is slightly older (Graham Nixon, personal communication 2014); the oldest date from the Hazelton volcanics in Stikinia is ~203 Ma (Joanne Nelson, personal communication 2013); and that from the Talkeetna volcanics in Wrangellia composite terrane of southern Alaska is 207 Ma (Pálfy et al. 1999; Amato et al. 2007). Furthermore, in and near the eastern Coast Mountains between latitudes 54°30' and 57°, folds and thrust faults of latest Triassic age (> 203 Ma) involve Permian and Triassic Stikinian strata (Brown and Greig 1990; Greig and Gehrels 1995). Early Jurassic (~185 Ma) uplift and deep erosion of the Stikinian arc near latitude 60° was speculatively related by Johannson et al. (1997) to processes accompanying strike-slip faulting. The cause of the early Mesozoic deformation in western Stikinia is not known, but possibly records Triassic amalgamation of rocks of the Insular superterrane with those of Stikinia and subsequent displacement along the boundary between them.

The continuation of the Gravina-Nutzotin belt along strike in southwestern Yukon (latitudes 60°–61°) is represented by Late Jurassic–Early Cretaceous (~160–137 Ma) clastic rocks of the Dezadeash Formation that were deposited on a northeast-dipping paleoslope by turbidity flows fed from a western source (Figs. 1, 2; Eisbacher 1976). Separated from the Dezadeash Formation by ~300 km of dextral offset on the Cenozoic Denali Fault (Figs. 1, 2) the partly correlative sequence in the Nutzotin Mountains of Alaska was more proximal to the arc and overlies the Wrangellia composite terrane (Nokleberg et al. 1994).

The northernmost pluton in the CCO is early Cenozoic (64–57 Ma), and its northwestern end is truncated and offset dextrally by the Denali Fault near latitude 62° (Figs. 1, 2). The pluton intrudes the Yukon-Tanana terrane and together both form the upper part of a stack of northeast-dipping structures that override the Kluane schist. The latter is mainly quartz-mica schist, some actinolite schist and rare bodies of carbonate and ultramafic rock, and contains detrital zircons whose ages suggest their sources were the Yukon-Tanana terrane and Mesozoic plutons that intrude it. Some zircons as young as 95 Ma show that the basin was receiving detritus in the early Late Cretaceous and overgrowths on other zircons show that the rocks were metamorphosed at ~85 Ma (Israel et al. 2011). The schist is juxtaposed with the Dezadeash Formation on a possible northeast-dipping reverse fault (Eisbacher 1976). Both Eisbacher (1976) and Mezger et al. (2001) concluded that the Kluane schist protolith and the Dezadeash strata probably were deposited in the same basin but derived from different source areas, although Israel et al. (2011) found no detrital zircons characteristic of the Insular superterrane in the Kluane schist.

(4) Mainland Alaska: West of Longitude 141°

Before mid-Cretaceous time, few if any, of the rocks that underlie Alaska today were in the positions they presently occupy relative to the North American craton (Plafker and Berg 1994; Nokleberg et al. 2000). Restoration of Late Cretaceous and Cenozoic offsets across the Tintina, Denali and other big dextral strike-slip faults amounts to ~1000 km (Wyld et al. 2006; Gabrielse et al. 2006), and as noted earlier paleomagnetic studies on Late Cretaceous stratified rocks indicate relative displacements of ± 2000 km relative to the craton (Stamatakos et al. 2001; Enkin 2006; Enkin et al. 2006b). Regardless of these differences, rocks in southern and central Alaska evidently were located much farther south relative to the craton before the Cenozoic. The 'backstop' of the Arctic Alaska-Chukotka terrane of northern Alaska - northeastern Russia was not in place relative to other Alaskan rocks until 130–80 million years ago when it may have undergone anticlockwise rotation out of a position near the western Arctic islands of Canada (Plafker and Berg 1994).

Late Jurassic and Cretaceous clastic basin deposits in south-central and southwestern Alaska are located mainly south of the western extension of the Denali Fault and lie between the Yukon-Tanana terrane and small continentally-derived terranes to the north and the Wrangellia composite terrane to the south. For the most part, the deposits occur along a wide zone of latest Jurassic through early Cenozoic (~155–60 Ma) folding, thrust faulting and local metamorphism and regional uplift that in the Cenozoic was disrupted by dextral strike-slip faulting on the Denali and associated faults (Ridgway et al. 2002). The zone appears to be the structural continuation of the CCO in Canada but was offset from it along those faults. Trop and Ridgway (2007) propose from sedimentological analysis that initial closure of the basin was in the Late Jurassic when the inboard margin of Wrangellia started to impinge on the Yukon-Tanana terrane and separated the Kahiltna sub-basin to the west from the Nutzotin-Dezdeash-Gravina sub-basin to the southeast. The end of Kahiltna and Dezadeash sedimentation in mid-Cretaceous time (~110–90 Ma) coincided approximately with onset of the deformation that initiated formation of the CCO. However, Hults et al. (2013) suggest that no stratigraphic link can be made until the Late Cretaceous between a southern group of basins in mainland Alaska that overlie, and contain detritus eroded from, the Wrangellia composite terrane and its Jurassic–Cretaceous arc, and a northern group of Cretaceous basins derived from the Yukon-Tanana terrane and small terranes in central Alaska.

Scraps of ophiolite lie near the boundary between the Intermontane superterrane (mainly (the Yukon-Tanana terrane and Stikinia) and the Insular superterrane (or Wrangellia composite terrane). As noted earlier, in the core of the CCO near ~latitude 59° ophiolite associated with metamorphosed Early and Middle Triassic sedimentary and volcanic rocks is faulted against metamorphosed Yukon-Tanana rocks (Fig. 2; Brew et al. 2009). An ophiolite with primitive arc signature of Triassic age occurs near the thrust fault that separates the Kluane schist from the overriding Yukon-Tanana terrane (Metzger 2000; Donald Murphy, personal communication 2014). In south-central Alaska, the Chulitna terrane along the Denali Fault (near latitude 64°, longitude 150°W) contains Devonian–Carboniferous(?) ophiolite (Nokleberg et al. 1994). Along strike in south-western Alaska (~latitude 60° 30', longitude 154° W), the Tlikakila complex includes a probable suprasubduction zone ophiolite of Late Triassic age (~210 Ma) that was deformed and metamorphosed at the end of the Early Jurassic (177 Ma; Amato et al. 2007).

These isolated ophiolite bodies hint at what may have separated the Insular superterrane from the Stikinia and Yukon-Tanana terranes in the Triassic.

DISCUSSION AND CONCLUSIONS

It has been recognized for many years that the Coast Mountains are far more than the roots of a vast Middle Jurassic–Cenozoic arc system located on the western margin of the North American Plate. Dawson (1881) reported 'Appalachian-style folding' in their southeastern part, Crickmay (1930) recognized that 'Laramide' structures in the southeastern Coast Mountains were deflected around the buttress of the southwestern Coast Mountains and continued southward into the North Cascade ranges where Misch (1966) described a two-sided orogen with a metamorphic and granitic core flanked by less metamorphosed rocks and so defined the south end of the much later-named Coast-Cascade Orogen.

The plate-tectonic paradigm gave rise to two main models for the origin of the CCO. Consideration of the geology of the southern Coast Mountains and North Cascade ranges led Davis et al. (1978) and Monger et al. (1982) to propose that the CCO resulted from Cretaceous collision of Wrangellia with the then-western margin of North America, a proposal that readily accommodates the hypothesis of Sigloch and Mihalynuk (2013). Subsequently, Rusmore et al. (1988) noted evidence for Middle Jurassic accretion along the southwestern edge of the Intermontane superterrane, and Armstrong (1988) used then-newly-acquired isotopic data to suggest that most terranes in the Canadian Cordillera had been accreted by the Early Cretaceous (~130 Ma) with an Andean-style arc built across them above an east-dipping subduction zone. Van der Heyden (1992) worked in the central Coast Mountains, latitudes 53°30'–54°, where Middle Jurassic–Early Cretaceous plutons intrude rocks assigned to both the Intermontane and Insular superterranes, and extended the age of his 'Andean-Sierran' arc back through Middle Jurassic time (~175 Ma). Late Jurassic and Early Cretaceous Gravina-Nutzotin deposits along the west flank of the Coast Mountains north of latitude 55° and in the Tyaughton-Methow basin in their east side south of latitude 52° were thought to have accumulated in post-accretionary, back-arc and/or dextral pull-apart basins (Figs. 1, 2, 3; Gehrels and Saleeby 1987; McClelland et al. 1992; van der Heyden 1992). However, these models did not take into account the fact that the Jurassic–Cretaceous Tyaughton-Methow basin in the southeastern Coast Mountains is floored by remnants of oceanic lithosphere, some of which, in the Bridge River terrane, are as young as latest Middle Jurassic (164 Ma) and possibly even younger.

In an attempt to reconcile van der Heyden's (1992) model with the oceanic foundations of the Tyaughton-Methow basin, Monger et al. (1994) speculated that a Middle Jurassic–Early Cretaceous arc located in/on both the Insular and southern Intermontane superterranes had been acutely transected by a sinistral strike-slip fault and the segment west of the fault displaced southward by ~800 km. By the Early Cretaceous (~130 Ma), the southward-moving arc segment lay west of the Tyaughton-Methow basin in the southeastern Coast Mountains and had duplicated the arc segment in the southern British Columbia interior. Gehrels et al. (2009) considered this to be the 'most likely explanation' for the distribution of dated plutons in the central Coast Mountains. It is not possible to reconcile such a 'single-arc' model with Sigloch and Mihalynuk's (2013) hypothesis.

In spite of the difficulty of seeing through the veil of mid-Cretaceous–early Cenozoic plutonism, metamorphism and deformation that created the Coast Cascade Orogen and obscures and obliterates the original terrane relationships, evidence cited above from the southern, central, and northern Coast Mountains shows that rocks assigned to the Insular and Intermontane superterranes were not far apart by the late Early Jurassic (~180 Ma) and probably even earlier. The similar times of initiation (latest Triassic; 203 Ma, 204 Ma, 207–198 Ma) of the mainly Jurassic arc-related volcanic rocks in respectively Stikinia, Wrangellia on Vancouver Island and southern Alaska, and the similar paleomagnetic results from Late Triassic and Early Jurassic rocks of Wrangellia on Vancouver Island and from Stikinia in central British Columbia, indicate these terranes were associated by latest Triassic time, perhaps as different segments of the same convergent margin. Only in mainland Alaska can a case be made that the Wrangellia composite terrane and Yukon-Tanana terrane were not together before their initial juxtaposition in Late Jurassic or even Late Cretaceous time.

Furthermore, it seems that the 'superterranes' were never independent entities but rather reflect Early Jurassic to early Cenozoic orogenesis. The superterrane names derive from the traditional division of the Canadian Cordillera into Foreland, Omineca, Intermontane, Coast, and Insular morphogeological belts. The bedrock bases for these divisions is clearly seen on a metamorphic map (Fig. 4) in which high-grade metamorphic and plutonic rocks exposed in the Omineca and Coast belts record deep burial, differential uplift, and erosional and tectonic exhumation. The two belts of metamorphic and plutonic rocks lie between respectively, rocks of the Laurentian craton margin in the Foreland Belt and terranes in the Intermontane Belt, and terranes in the Intermontane Belt and those in the Insular Belt. Monger et al. (1982) suggested that the two metamorphic and plutonic belts reflect sequential Jurassic and Cretaceous accretions of amalgamated terranes in, respectively, the Intermontane and Insular belts, a suggestion that would accommodate Sigloch and Mihalynuk's hypothesis (2013). However the many isotopic and paleontological dates acquired since 1982 now make this scenario untenable: Quesnellia was thrust eastward over rocks correlated with the outer Laurentian margin deposits by 185 Ma; Stikinia was near the Alexander terrane and Wrangellia by ~180 Ma and possibly by ~200 Ma; and the northern Cache Creek terrane was thrust over Stikinia at 174 Ma. An integral part of Sigloch and Mihalynuk's (2013) hypothesis is that the 'superterranes' were separated by the Mezcalera Ocean until at least the Late Jurassic, which implies that they were discrete entities before then. This evidently is not the case.

Subduction of the floor of a large ocean would have been needed to create the enormous Mezcalera slab wall in the way suggested by Sigloch and Mihalynuk (2013). The probably related Cache Creek and Bridge River terranes contain rocks that span about 180 million years and, together with the 'exotic' fossils they contain, are the only remnants of a large Mesozoic ocean basin preserved in the Canadian Cordillera. The youngest fossils known from the Cache Creek terrane are latest Early Jurassic (~180 Ma) and the terrane was thrust over Stikinia in the Middle Jurassic (174 Ma) in northern British Columbia. The youngest fossils in *bona-fide* Bridge River rocks are latest

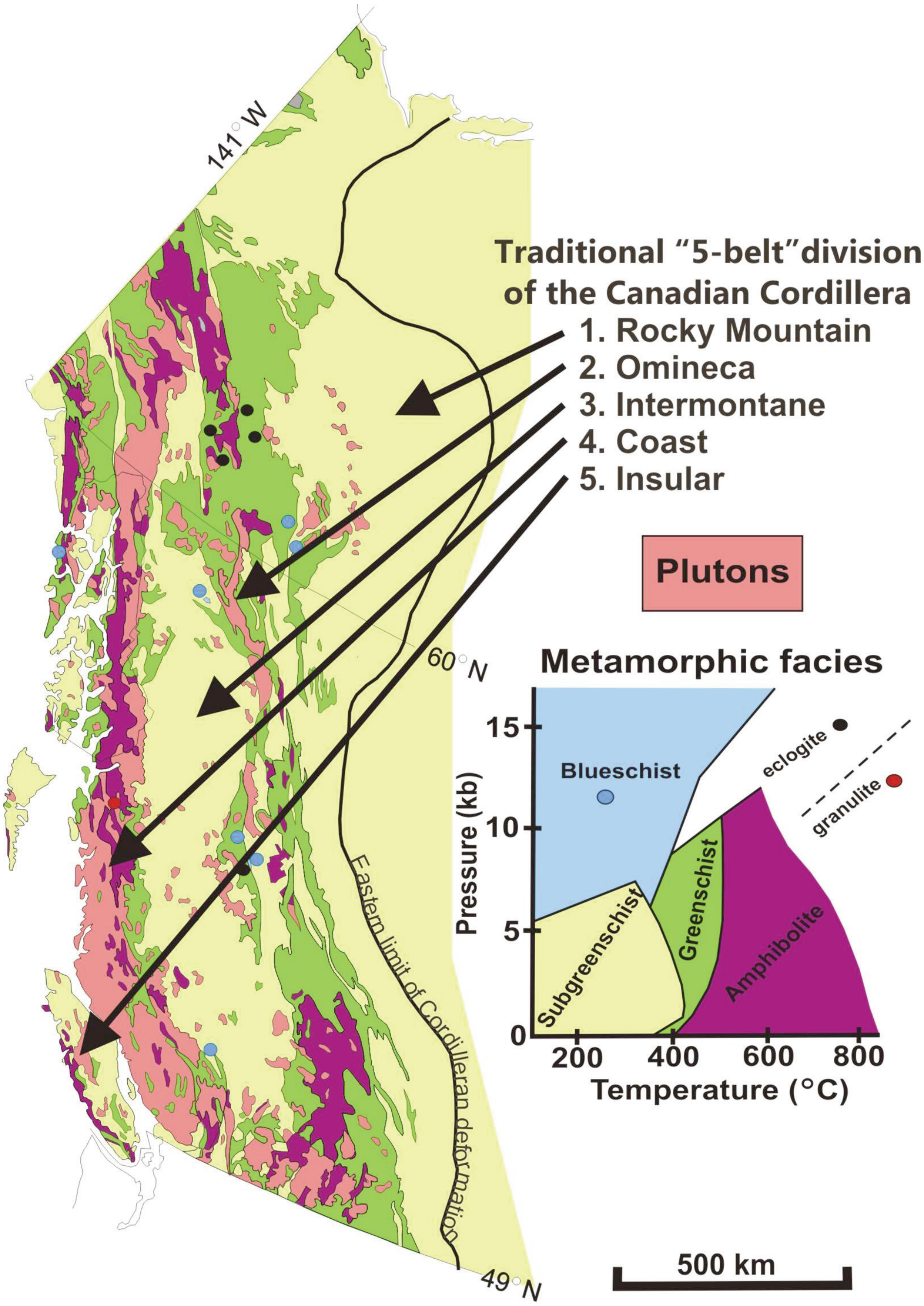

Figure 4. The distribution of metamorphic and plutonic rocks shows the bedrock basis for the traditional division of the Canadian Cordillera into the five 'morpho-geological' belts that result from late Early Jurassic through Cenozoic Cordilleran orogenesis and not from pre-accretionary terrane combinations denoted by the names Intermontane and Insular superterranes.

Middle Jurassic (~164 Ma) although the terrane may continue in clastic facies into earliest Cretaceous time. If the slab sinking rates and plate reconstructions of sequential positions of the western margin of the North American plate used by Sigloch and Mihalynuk (2013) are accepted, then it seems that the Bridge River terrane is the best candidate to be the surface record of the Mezcalera slab wall.

In Canada, the Cache Creek and Bridge River terranes lie between at least partly coeval Mesozoic arcs, and a similar relationship exists in the western Cordillera from southern Yukon to Mexico. This raises the question of whether two facing arcs were brought together by subduction of the intervening ocean floor, as in the Molucca Sea region of Indonesia, or whether the western arc was positioned oceanward of the accretionary complex terranes by transform and/or strike-slip faulting, much as the San Andreas transform in California moves the Salinian block northward to lie oceanward of the Franciscan Complex. The only direct evidence available for the facing direction of an early Mesozoic arc in the Canadian Cordillera comes from the west-facing arc on Quesnellia in southern British Columbia (Mortimer 1987), although the case is made that the early Mesozoic Talkeetna arc in southern Alaska faced towards Panthalassa with the accompanying accretionary complex preserved in the innermost Chugach terrane (Plafker and Berg 1994). 'Molucca Sea models' have been invoked by Mihalynuk et al. (1994) for Early – Middle Jurassic enclosure of the Cache Creek terrane between arcs on Stikinia and Quesnellia, by Lynch (1995) for Early Cretaceous enclosure of the Tyaughton-Methow basin between arcs in the southwestern Coast Mountains and the southern interior of British Columbia, by Schwartz et al. (2010) for Late Jurassic enclosure of the Baker terrane between the Wallowa and Olds Ferry arcs in eastern Oregon, and by Dickinson and Lawton (2001) in Mexico for Jurassic – Cretaceous enclosure of the Mezcalera Ocean between the Guerrero terrane and a continental margin arc.

A strike-slip model was used by Monger and Ross (1971) to explain how the Permian 'McCloud' fauna in Stikinia, found also in Quesnellia and the Slide Mountain terrane, came to lie outboard of coeval, but exotic, Panthalassa-Paleotethys fauna in the Cache Creek terrane. Models that emplace arcs now west of the Cache Creek terrane by migration across a large ocean basin ignore or downplay this paleobiogeographic relationship. Mihalynuk et al. (1994; *their* fig. 14) accommodated the 'McCloud' fauna in Stikinia and Quesnellia by showing the pre-Triassic arc terranes in the northern Cordillera as segments of the same convergent margin, with Quesnellia near northwestern Pangea, Stikinia intermediate, and Wrangellia-Alexander farthest away. A combination of oroclinal rotation of Stikinia about an axis in Yukon and sinistral strike-slip faulting was proposed by Mihalynuk et al. (1994) to enclose the Cache Creek terrane between Stikinia and Quesnellia by the Middle Jurassic (~174 Ma).

Finally, what created the Coast-Cascade Orogen, if not Cretaceous collision of the Insular superterrane with the leading edge of the North American Plate? Emergence of the CCO between late Early Cretaceous and early Cenozoic time (~105–45 Ma) was largely contemporaneous with deformation across the entire Canadian Cordillera, including the east-directed folding and thrust faulting in the Rocky Mountains that by early Cenozoic time (~60 Ma) had carried rocks up and on to the edge of the continental platform (e.g. Evenchick et al. 2007; *their* fig. 6). Cordilleran mountain-building has long been linked to spreading of the Atlantic Ocean by the early 'continental drifters' and later, when details of North Atlantic ocean-floor spreading had started to emerge, by Wheeler (1970) and Coney (1972). Initial slow spreading of the central Atlantic starting at ~190 Ma (Seton et al. 2012) was nearly coeval with the time of emplacement of Quesnellia over distal parts of the Laurentian margin. Initiation of Cordilleran-wide deformation in the late Early Cretaceous correlates with onset of ocean floor spreading in the Atlantic after ~125 Ma. Arguably, westward advance of the North American Plate caused strong coupling between the North American Plate and plates on the ancestral Pacific Ocean floor with strain becoming focused in weak Late Cretaceous–early Cenozoic arc lithosphere along the future Coast Mountains.

In conclusion, evidence cited from the Canadian segment of the Cordillera shows that the Yukon-Tanana terrane and Stikinia (assigned to the 'Intermontane superterrane') were not far from Wrangellia and the Alexander terrane ('Insular superterrane') by the early Mesozoic, and, from their faunal contents, by the Permian. This makes it improbable that the 'superterranes' were ever separated by a large ocean that closed initially in the Late Jurassic, as required by Sigloch and Mihalynuk (2013). Furthermore, the only evidence for a large Mesozoic ocean basin within the Canadian Cordillera resides in accretionary complexes called the Cache Creek and Bridge River terranes that separate Stikinia from Quesnellia, and of these the Bridge River terrane may be the only surface remnant of the Mezcalera slab wall in Canada.

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