The enigmatic Tintina–Rocky Mountain Trench fault: a hidden solution to the BajaBC controversy?

Robert S. Hildebrand [ORCID]

Saguaro-Miraflores Research Zone, 1401 N. Camino de Juan, Tucson, AZ 85745, USA

Corresponding author: **Robert S. Hildebrand** (email: bob@roberthildebrand.com)

Abstract

Paleomagnetic studies revealed that most Upper Cretaceous paleopoles in the North American Cordillera are anomalously shallow relative to those obtained from equivalent-age rocks of cratonic North America. This was interpreted to signify >1000 km of terrane migration along the north-trending paleomargin, yet geologists were unable to find the faults along which such migration might have taken place. This led to the BajaBC controversy, which has now bedeviled Cordilleran geologists for 50 years without a solution. The >3000 km long Tintina–Rocky Mountain Trench is one of the longest continental valleys in the world, and in the north, it contains the large-magnitude Tintina fault, yet in the south, it is widely believed to only contain normal faults. I use structural, stratigraphic, and temporal data to show that as it passes southward, the strike-slip fault, active from about 70–58 Ma, was progressively overrun by north northwest-trending northeast-vergent Eocene thrust faults, which buried the strike-slip fault. After thrusting, the area was exhumed 7–9 km, and eroded, shedding coarse debris eastward into the Western Interior basin, which left the older, dead trench variously filled. Farther south, the Rocky Mountain Trench vanishes near the Lewis and Clark lineament where it runs into the Basin and Range province, yet paleomagnetism and offset units suggest that it continues cryptically southward. Palinspastically restoring seven matching features, including two bands of Upper Cretaceous–Paleocene slab-failure magmatism, into a single zone, obviates the need for Laramide flat-slab subduction. Campanian shortening was generally east–west, orthogonal to the margin, but during the Maastrichtian–Paleocene, migration was dominantly transpressional, which led to emplacement of the allochthons, and distorted the Rocky Mountain foreland into a series of basement-cored uplifts.

Key words: Tintina–Rocky Mountain Trench fault, BajaBC, paleomagnetism, Eocene thrusts, strike-slip fault

Introduction

Paleomagnetic studies have repeatedly shown that magnetic inclinations measured in Cretaceous rocks of the North American Cordillera are anomalously shallow relative to those obtained from equivalent-age rocks of cratonic North America (Beck and Noson 1972; Packer and Stone 1974; Monger and Irving 1980). The paleomagnetic results have been interpreted to indicate a minimum of a thousand km of northerly meridional displacement of Cordilleran terranes relative to cratonic North America during the Cretaceous–Early Cenozoic (Beck 1976; Irving 1979; Granirer et al. 1986; Irving and Brandon 1990; Cowan et al. 1997). Whereas the majority of sample sites were located relatively close to the Pacific coast in British Columbia, most researchers inferred that it was the outer, westernmost rocks that had migrated northward from the latitude of Peninsular Mexico, so coined the name, "Baja British Columbia", or "BajaBC" (Irving 1985). The name caught on over the previously suggested "Baja Alaska" (Stone in Irving 1988), but the idea was highly controversial because Cordilleran geologists could not find the faults along which the rocks might have moved, and so they re-

jected the paleomagnetic results (Dickinson and Butler 1998; Mahoney et al. 1999a, 2021). Thus, despite decades of successful worldwide use (see, for example, van Hinsbergen et al. 2020), along with some of the most reliable and robust paleomagnetic data collected anywhere in the world (Enkin 2006), the concept that paleomagnetism might be used to document latitudinal migration of terranes along a long-lived, north-trending paleomargin was not accepted by most Cordilleran geologists.

Nevertheless, the Cordilleran earth-science community was sufficiently intrigued that they convened a sequestered meeting of more than 75 earth-science experts to resolve the issue, but after meeting for a week, they reported "*that outstanding problems or inadequate data sets prevent resolution of the problem*" (Mahoney et al. 1999b). In the decades since, not only were Cordilleran geologists unable to find (1) flaws in the paleomagnetic methodology, or (2) faults sufficiently large along which to accommodate the northward translation, but they also did not (3) convincingly link any geology between north and south, so had no matched features (piercing points) to resolve displacement if it had occurred. Attempts to

Fig. 1. Age (Ma) versus paleolatitude (°N) for selected Upper Cretaceous and Eocene bedded successions of western Canada and extreme northwest USA compared to the expected North American paleolatitude (modified from Enkin 2006). The size and shape of each "onion" reflect the errors inherent in the analytical method at 2 sigma. Note that rocks of the Carmacks Group, with their errors, overlap temporally with at least part of all of the other Cretaceous units, which, while allowing for a small amount of northerly displacement prior to 70 Ma, indicates that a solution for the Carmacks Group fundamentally solves the BajaBC problem. By 50 Ma, the Cordilleran block had cratonic paleolatitudes, such that the bulk of the northerly migration took place between about 70 and 50 Ma.
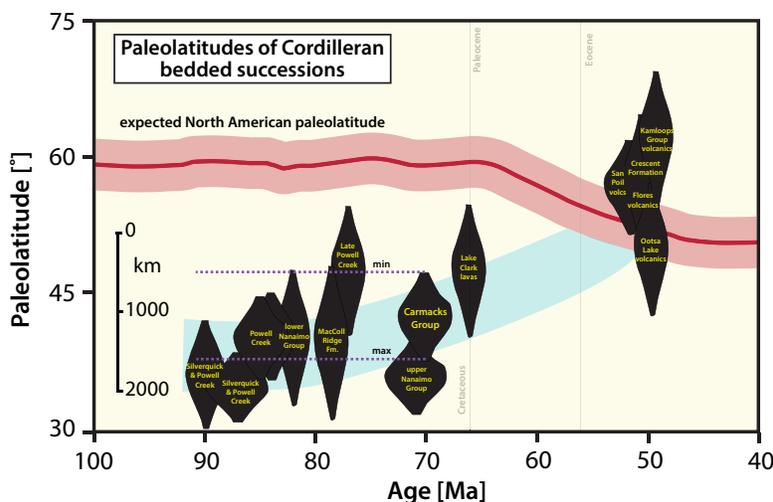
resolve the problem using detrital zircon analyses to match rocks of the Nanaimo basin on Vancouver Island (Mustard 1994) with rocks of the Belt-Purcell basin located much farther inboard led Mahoney et al. (2021, p. 2227) to conclude with that terranes of southwestern British Columbia had remained fixed at northern latitudes, and so suggested that the paleomagnetism was flawed, writing that " *the outstanding issue with the Baja B.C. hypothesis is how to explain the consistent paleomagnetic data that are interpreted to indicate large-scale latitudinal displacement*". Given that the controversy has raged unresolved for about 50 years, could it be, as suggested by Beck (1991), that the problems are not in the processes and methods used, but instead reflect a simple oversight in our understanding of the regional geology?

In this contribution, I gather, re-examine, and integrate geologic, geochronologic, and paleomagnetic constraints from the North American Cordillera into a simple, coherent, and comprehensive model that resolves the dilemma. This hypothesis is not without flaws or questions, but all other models with which I am familiar are even more limited and so fail to resolve the larger geodynamic problem(s). Also, to my knowledge, published solutions (Wynne et al. 1998; Keppie and Dostal 2001), other than my earlier contributions (Hildebrand 2013, 2014, 2015), have not produced robust piercing points, or matchable features, to document displacement. Here, I attempt to present the full gamut of data sets to generate a testable solution to the problem. Although there may be other viable solutions, the paleogeographical reconstruction introduced here is supported by *seven* palinspastically restorable geologic features, as well as kinematic plate reconstructions, that serve to constrain and support the veracity of the model.

Geological observations on the BajaBC problem and timing of northerly migration

Over the 50 years since Beck and Noson (1972) first discovered aberrantly shallow, far-sided paleopoles for Cretaceous rocks within the Cordillera, numerous other paleomagnetic studies were completed with more or less congruent results (Housen and Dorsey 2005; Enkin et al. 2006a, 2006b), but as stated above, geologists could not find the faults on which to move Cordilleran fragments northward, so blamed the paleomagnetic methodology. Recently, some researchers suggested that the missing faults were terrane boundaries and that most, if not all, of the northward migration occurred offshore (for example: Tikoff et al. 2023), but the problem with utilizing terrane boundaries within the Cordilleran tectonic collage is that the main period of northerly migration largely postdates terrane amalgamation (Hildebrand 2013), with rocks as young as the 70 Ma shoshonitic Carmacks Group of the Yukon Territory yielding 1950 ± 600 km of apparent northerly migration (Marquis and Globerman 1988; Johnston et al. 1996; Enkin et al. 2006a). This is mostly within error of the other Upper Cretaceous–Paleocene Cordilleran bedded units with large displacements (Fig. 1), such as the Nanaimo Group (Kim and Kodama 2004), Silverquick-Powell Creek successions (Enkin et al. 2006b), MacColl Ridge Formation (Stamatakos et al. 2001), Ghost Rocks (Housen et al. 2008), Ochoco basin (Housen and Dorsey 2005), Methow basin (Enkin et al. 2002), Blue Mountains terranes (Housen and Dorsey 2005; Housen 2018), and Lake Clark (Thrupp and Coe 1986). For bedded rocks in the range of 90–70 Ma, deviations from the mean are approximately an order of magnitude

lower than the overall mean translation of 2100 ± 700 km documented by Enkin (2006). Thus, the majority of the northward migration occurred after about 70 Ma, when all terranes except Siletzia, had already docked (Hildebrand 2013) and, as pointed out by others (Enkin et al. 2006a; Gladwin and Johnston 2006), must involve rocks as far east as the easternmost outcrops of the Carmacks Group, which collectively span the Intermontane belt from the Tintina fault westward to the Denali fault (Fig. 2). Therefore, it is unnecessary to invoke Mesozoic migrations older than about 70 Ma (Avé Lallemant and Oldow 1988; Irving and Wynne 1991; Monger et al. 1994; Kent and Irving 2010)—whether sinistral or dextral, onshore or offshore—to resolve the bulk of the BajaBC problem.

Northward migration ended by about 52 ± 2 Ma, as documented by several studies, which found coincident paleolatitudes (Fig. 1) from rocks of the Insular/Intermontane sector of the Cordilleran hinterland and those of cratonic North America: examples include the Clarno Formation of Oregon (Grommé et al. 1986), 30–40 Ma Lake Clark lavas of Peninsular Alaska (Thrupp and Coe 1986), rocks of the ~52 Ma Kamloops Group, southern British Columbia (Symons and Welling 1989), 45–52 Ma White Pass mafic dykes east of Skagway, Alaska (Symons et al. 2000), 50 Ma Flores volcanics on Vancouver Island (Irving and Brandon 1990; Kent and Irving 2010), 45–56 Ma Crescent Formation of the Olympic Peninsula (Warnock et al. 1993), and the 49.6 Ma Ootsa Lake Group of south-central BC (Vandall and Palmer 1990; Bordet et al. 2014). Thus, the bulk of the dextral, or northward, meridional migration within the Cordillera took place between 70 and 50 Ma, which, if correct, sets up a set of conflicting problems.

First, the easternmost paleomagnetic samples, those collected from volcanic and epiclastic strata of the Carmacks Group (Enkin et al. 2006a), occur just a few km west of the Tintina fault (Fig. 2), which lies along the northern extension of the Rocky Mountain trench, and is generally considered to have but 400–430 km of Eocene dextral displacement (Gabrielse et al. 2006). This interpretation conflicts with the 750 km to more than 900 km of displacement of Paleozoic sedimentary facies (Gabrielse 1985), and the ~2000 ± 700 km of dextral displacement indicated by paleomagnetic studies of the Carmacks Group (Marquis and Globerman 1988; Johnston et al. 1996; Enkin et al. 2006a). Although the truncations of many units, structures, and contacts on either side of the fault were utilized in attempts to constrain strike-slip displacement (Gabrielse 1985; Gabrielse et al. 2006), none provide convincing matches. These features include a variety of thrust faults, such as the Tombstone-Robert Service and Livengood thrusts (Fig. 2), along with sedimentary rocks, mafic lavas, and sills. For example, Chapman et al. (1980) attempted to correlate a dominantly chert unit in the Livengood area with a similar age shaley unit across the fault 300 km farther south, but the lithologies and overall stratigraphy are significantly different. Additionally, the Livengood thrust belt contains significant thrust slivers of Cambrian, or possibly Neoproterozoic, ultramafic rocks, along with Cretaceous sedimentary rocks (Weber et al. 1997), unknown across the fault in the Selwyn basin area 400 km to the south (Fig. 2).

Second, several erosional remnants of the Carmacks Group sit unconformably upon early Cambrian platformal rocks of the Cassiar platform (Fig. 2), which is truncated to the east by the Tintina fault where it is juxtaposed outboard, or west, of the outer clastic belt within the Selwyn basin (Fig. 2), located on the other side of the fault (Wheeler and McFeely 1991). The Cassiar platform comprises a west-facing complex of algal–archeocyathan mounds and intervening oolitic grainstone shoals, minor shale, and calc siltite, which was argued to have originated >1000 km farther south in Idaho, where there is a conspicuous gap in the Early Cambrian carbonate platform of western North America (Pope and Sears 1997; Pope et al. 2012).

Third, as pointed out by Enkin (2006), the Tintina fault cannot have significant Eocene slip as the paleolatitudes from Eocene units in the hinterland west of the fault have cratonic paleolatitudes (Fig. 1).

Fourth, the Omineca metamorphic–plutonic belt (Fig. 2), which largely lies west of both the Tintina fault and the Rocky Mountain trench, is the eastern of two metamorphic–plutonic crystalline belts in the Canadian Cordillera (Monger et al. 1982) and was deformed and metamorphosed between 124 and 105 Ma, yet there is no temporally comparable deformation in the fold-thrust belt to the east (Fig. 3) (Hildebrand 2013, 2014; Pană and van der Pluijm 2015; Hildebrand and Whalen 2017). This mismatch is supported by the presence of the Bourgeau thrust (Fig. 4), which has Santonian–Campanian marine shales in its footwall syncline, and in the southern Canadian Rockies, is the westernmost major thrust fault to affect the platform terrace (Price 2013). However, just to the west (Fig. 4), where Paleozoic sedimentary rocks sit atop metasedimentary rocks of the Mesoproterozoic Purcell Supergroup, thrusts were shown to be Aptian–Albian and predate 108 Ma, because they are cut by syn- to post-kinematic plutons of the Bayonne suite (Logan 2002; Larson et al. 2006). These observations led Hildebrand (2014) to argue that the Omineca belt was the metamorphic/plutonic hinterland of the 124 Ma Sevier orogeny of Utah and Wyoming.

Fifth, field mapping and U–Pb dating along the Salmon River suture (Fig. 2) of Idaho indicate that rocks of the Blue Mountains Superterrane and those of the Belt–Purcell–Windermere package were juxtaposed prior to 110 ± 5 Ma, as indicated by the age of the intrusive Little Goose complex, which cuts the contact (Manduca et al. 1992, 1993; Giorgis et al. 2008). Subsequent deformation, interpreted as transpressional deformation within the Idaho shear zone, overprints the suture, and is older than 90 Ma, on the basis of U–Pb ages of non-deformed granitic pegmatites that cut the fabric (Giorgis et al. 2008). Robust paleomagnetic data from the Blue Mountains terranes (Fig. 2) indicate 1760 ± 460 km of northerly movement after about 90 Ma (Housen and Dorsey 2005), which also must apply to rocks of the Belt–Purcell–Windermere block, as they were united as one block at that time. Thus, rocks along the western side of both the northern and southern sectors of the Rocky Mountain trench exhibit large paleomagnetic translations (~2000 ± 700 km; 1760 ± 460 km).

Sixth, most researchers who have mapped in the area of the southern Rocky Mountain trench argue that rocks

Fig. 2. Geological sketch map of the northern North American Cordillera, modified after Hildebrand and Whalen (2017), illustrating features discussed in text, tectonic terranes, plutonic belts, and approximate ages of fold-and-thrust belts, based on Wheeler and McFeely (1991); Reed et al. (2004); Pană and van der Pluijm (2015). The locations of Figs. 4, 9, 10, and 12 are shown. BC—British Columbia.
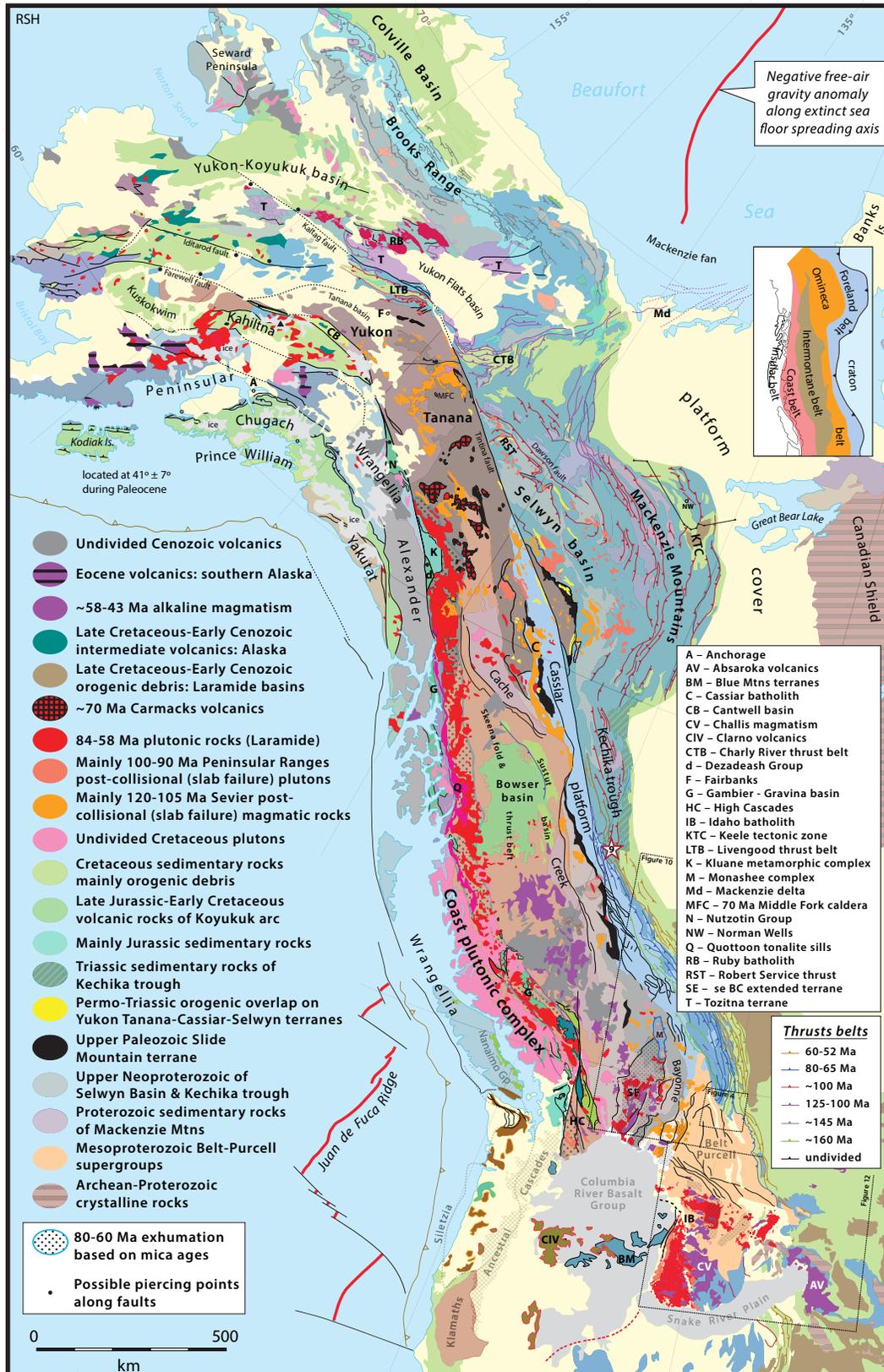
Fig. 3. Graphical illustration of mismatched deformational ages for the Great Basin and Canadian sectors of the Cordilleran orogen as discussed in the text. In the Great Basin area, rocks of the North American platform terrace were deformed and thrust eastward during the 125–105 Ma Sevier event, yet rocks to the west in the Great Basin show no evidence of this deformation. The opposite holds true for the Canadian sector where rocks of the North American platform terrace have a well-developed Santonian–Eocene Laramide fold-thrust belt, but rocks to the west have Sevier-age deformation. These and other data suggest that the arc and hinterland to the Sevier event are now resident in the Omineca belt of the Canadian Cordillera.
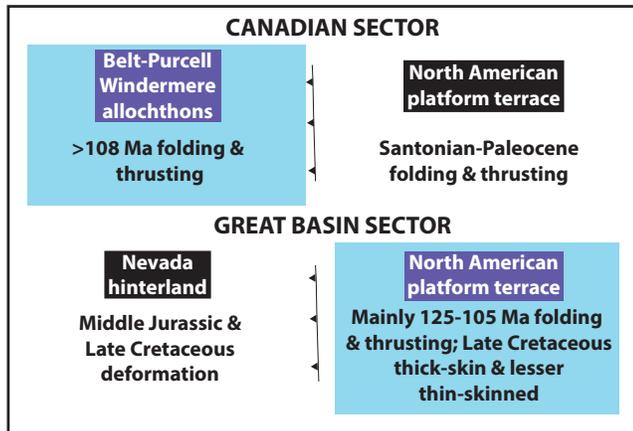
of the Belt–Purcell supergroups are not cut and translated by large-displacement strike-slip faults, only normal faults with at most a few km of strike-slip motion on faults in the trench (Murphy 1990*a*, 1990*b*; Price 2013). Thus, no matter whether you find 400–430 km or 1950 ± 600 km of strike-slip motion on the Tintina–northern Rocky Mountain trench fault credible, it is enigmatic because, on the basis of matching geology, most workers have concluded that the fault does not run through the southern Rocky Mountain trench, regardless of the continuity of the topographic trench itself (Leech 1966), which continues at least 1500 km farther south to Flathead Lake, Montana (Fig. 5).

Seventh, as the physiographic Rocky Mountain trench (Fig. 5) extends continuously for about 1600 km from Flathead Lake, Montana to the Liard Plain, and then continues north–northwestward an additional 1000 km into Alaska as the Tintina trench (Roddick 1967), it is hard to fathom how such a long, linear, and narrow valley could be anything but the locus of a significant strike-slip fault, despite evidence for local, late normal faulting, especially in the southern sector (Price 2013). Some researchers (van der Velden and Cook 1996) argued that the fault coincides with a deep, 10 km high cratonic ramp, imaged by near-basement reflections of mafic sills and Mesozoic thrust faults, and formed during the deposition of the mid-Proterozoic Belt–Purcell groups. Although the edge of the craton may have localized a fault, the great length and linearity of the narrow trench argue against an origin by normal faulting.

Eighth, detailed sedimentological studies (Fig. 6) documented that the Laramide foredeep broadened slightly during the Campanian but then migrated northward during the Maastrichtian and Paleocene (Roberts and Kirschbaum 1995; Catuneanu et al. 2000), the same time as proposed northward migration (Fig. 1) and the formation of the Laramide thick-skin thrusts in the Rocky Mountain region (Dickinson et al. 1988).

Finally, despite a decades-long, intense search by geologists, no other fault, collection of faults, splay, or branch of the Tintina fault itself, has been discovered along which more than 1000 km of dextral slip might have been transferred (Umhoefer and Miller 1996; Gabrielse et al. 2006).

It is difficult to understand how any of the preceding observations can be incorrect, yet no plausible solution has been presented, even though the conundrum has been widely recognized for decades. In the next section, I propose a testable solution for the problem and then explore some of its tectonic implications.

A solution to the problem

Although I examined the problem about a decade ago (Hildebrand 2015), I was unable to locate the fault along which the northerly migration might have taken place. However, during compilation of data for our paper on the collisional foredeep to the 100 Ma Peninsular Ranges orogeny (Hildebrand et al. 2023), I was once again drawn to the discontinuities and truncations of several geologic features, such as the cut-off of isopachs within the Shaftesbury Formation, part of the foredeep fill to the Peninsular Ranges orogen (Hildebrand et al. 2023), and located in northern Alberta and British Columbia (Fig. 7), as well as the abrupt southward truncation of the alluvial facies and shoreline of the overlying westerly derived, post-collisional molasse of the Dunvegan Formation (Fig. 8) along the Tintina–Rocky Mountain trench, which caused me to rethink the possibility that it was the locus of >1000 km of strike-slip movement. I found the truncations peculiar as the Peninsular Ranges orogen and its hinterland continue southward all the way to Mexico, so it seemed possible that the more westerly portions of the foredeep with their coarse clastic alluvial fans were simply missing to the south. These truncations, along with the paleomagnetic results for rocks of the Carmacks Group (Marquis and Globerman 1988; Johnston et al. 1996; Enkin et al. 2006*a*), and the continuous nature of the Rocky Mountain trench (Fig. 5), were compelling and collectively demanded a solution. The outstanding question is how does a fault with >1000 km of separation vanish along strike? While there could be many possible solutions, in this case, the likely answer turns out to be straightforward.

A cursory inspection of a tectonic map of the Canadian Cordillera, such as the classic map of Wheeler and McFeely (1991), coupled with a basic understanding of the ages of thrusting along strike in the Cordillera fold-thrust belt, reveals a geologically plausible solution to the paradox. First, there are two different-age thrust belts, which approach the Tintina–Rocky Mountain trench system from the east and broadly occur on opposite sides of the easterly flowing Peace

Fig. 4. Annotated geologic map of the Fernie area, southern Canadian Cordillera (Price 2013) showing locations and relations of units described in text. The Cambrian unconformity discussed in the text is flagged and colored green. Note particularly that the rocks of the Purcell supergroup lie across the Rocky Mountain trench. WH—Windermere High. Ages of plutons from Larson et al. (2006) and Pană (personal communication, 2025).
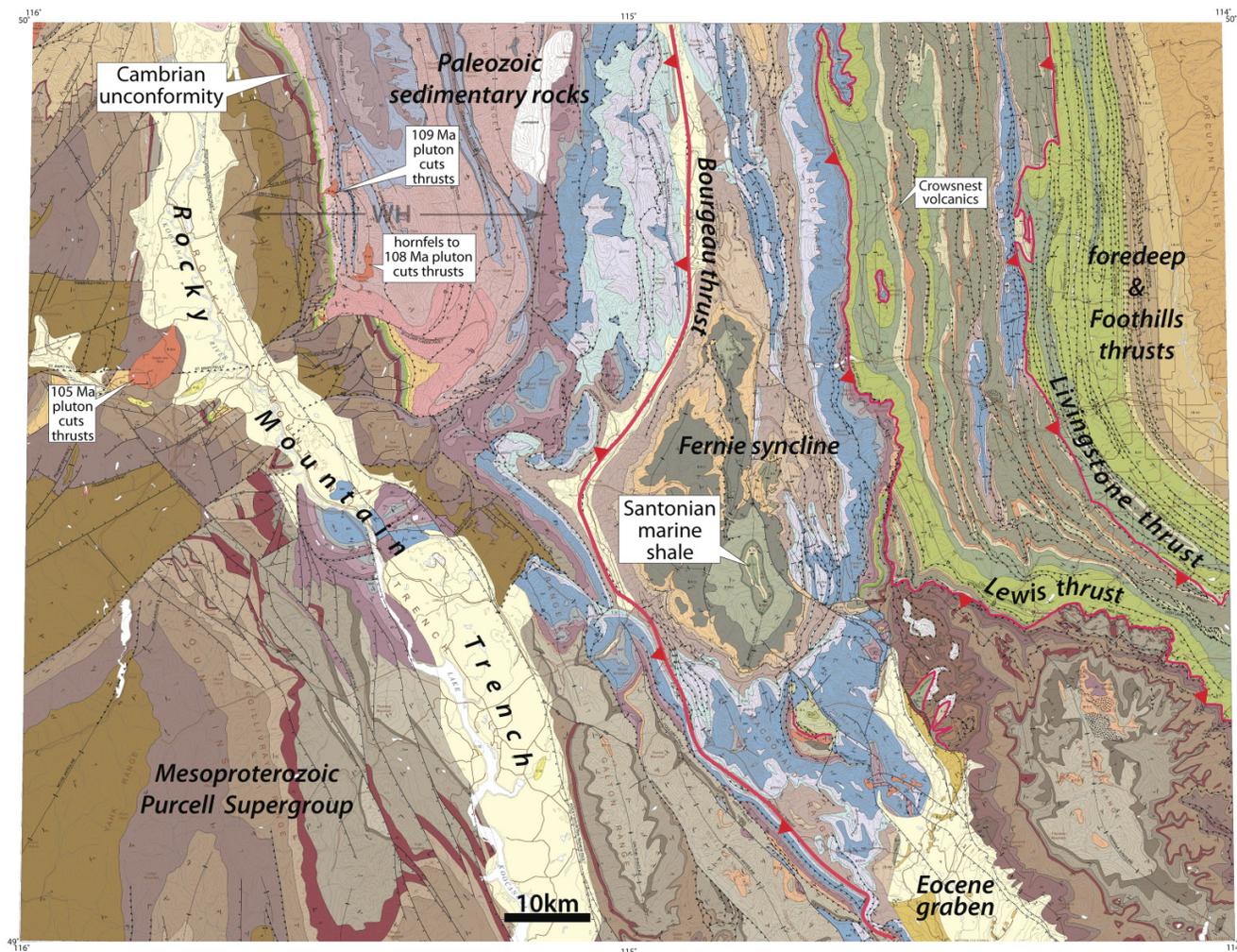
River, or nowadays what is known as the Peace Arm of Williston Lake (Fig. 9). In the Muskwa Ranges north of the river (Fig. 5), the east-vergent, fold-thrust belt of the Kechika trough, which is undated directly, but comprises thrust faults, rock units, and facies that widen and continue northward into the Selwyn basin, where rocks and thrusts were intruded by 99–92 Ma post-collisional plutons of the Tombstone-Mayo suites (Hart et al. 2004; Mair et al. 2006; Hildebrand and Whalen 2017; Hildebrand et al. 2023), whereas in the Hart Ranges, which lie south of the river (Fig. 5), the well-known Cordilleran fold-thrust belt of the southern Canadian Rockies, which is temporally complex, and had a major pulse of thrusting 54–50 Ma (van der Pluijm et al. 2006; Pană and van der Pluijm 2015), transects and overthrusts folds and thrust faults of the older northern belt extending southward from Selwyn basin (Stott et al. 1983; Thompson 1986; McMechan 1987; Wheeler and McFeely 1991).

Farther north and to the west of the Selwyn basin–Kechika trough (Fig. 2), thrusting appears to have been related to the

100 Ma Peninsular Ranges orogeny (Hildebrand and Whalen 2021a, 2021b; Hildebrand et al. 2023) and there the Tintina fault is readily recognized (Fig. 5), even topographically, and mapped as a major strike-slip fault (Gabrielse et al. 2006). However, south of the Peace River area, where many thrusts are younger than 54 Ma, an equivalent strike-slip fault is unrecognized; instead, the topographic southern Rocky Mountain trench is generally considered to be dominated by normal or small-displacement strike-slip faults (Murphy 1990a, 1990b; Price 2013; McMechan et al. 2020), although some researchers recognize evidence for more significant strike-slip motion (Pană 2021). These contrasting observations are reconcilable because the northern sector of the strike-slip system postdates 100 Ma folding and thrusting in the Selwyn–Kechika region (Mair et al. 2006; Hildebrand et al. 2023), whereas in the southern Cordillera, many thrusts postdate inferred northward migration as documented by 52–50 Ma cratonic paleopoles from the hinterland to the west (Enkin 2006). Thus, the most likely solution, first suggested in a

Fig. 5. Annotated three-dimensional shaded relief map of eastern Alaska, western Canada, and northern USA showing the Tintina–Rocky Mountain trench and outcrop areas of Carmacks Group. Note especially the small outcrops located as close as 7 km to the Tintina trench between the words Tintina and trench. The base map was produced using data from the Shuttle Radar Topography Mission (SRTM), processed by Ray Sterner at The Johns Hopkins University Applied Physics Laboratory.
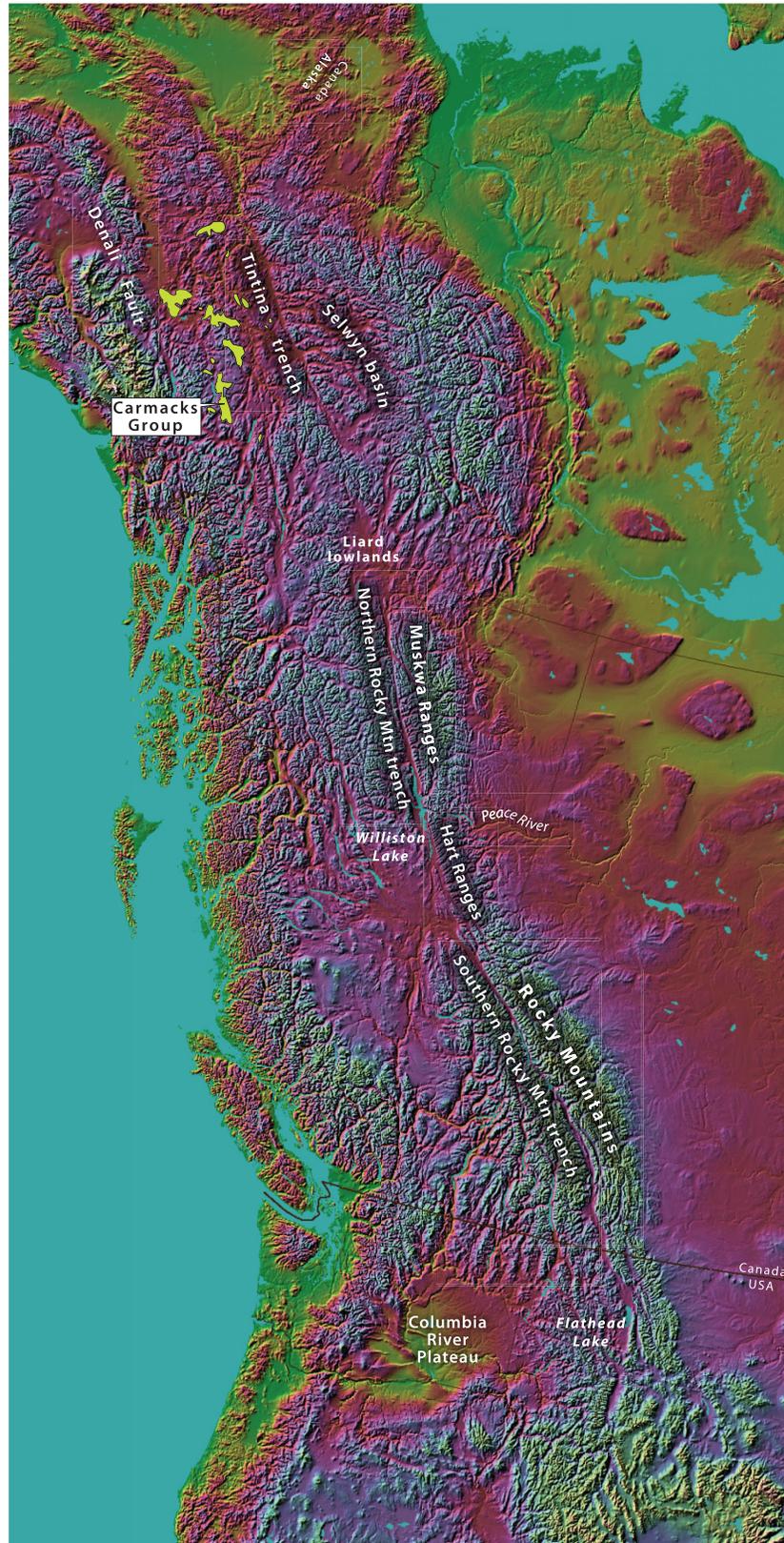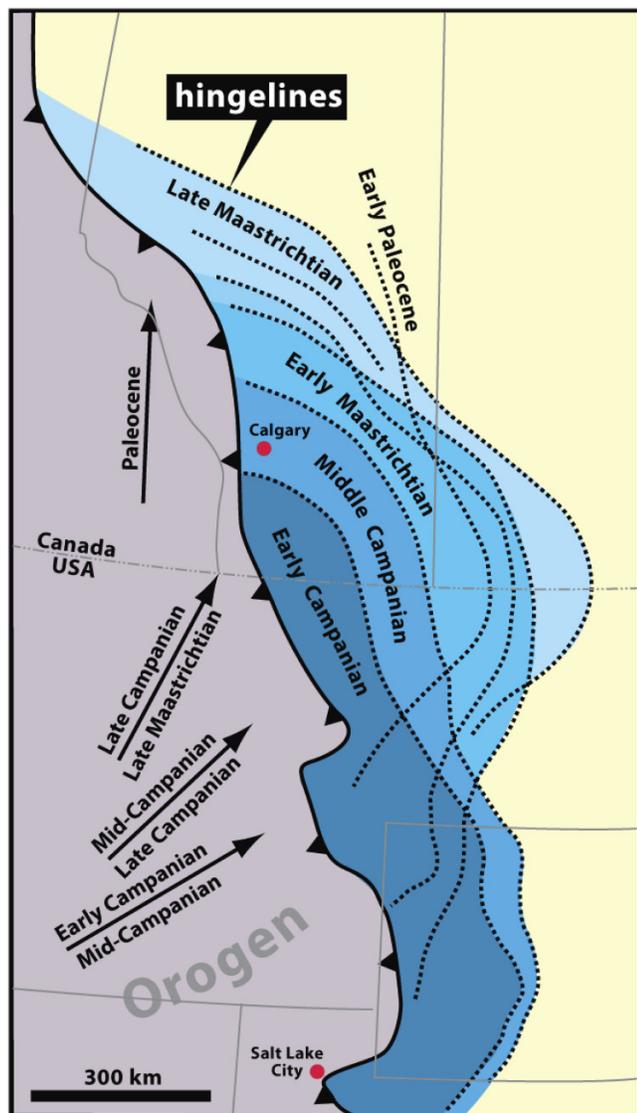
Fig. 6. Northward migration of the Laramide hingeline and foredeep during Maastrichtian–Paleocene transpressional deformation. Note that during the Campanian, the foredeep expanded but subsequently migrated northward. Modified from Catuneanu et al. (2000) and Hildebrand (2014).

model by Chamberlain and Lambert (1985), is that the southward continuation of the Tintina fault within the southern Rocky Mountain trench was overridden and buried by post-strike-slip thrust sheets derived from the southwest. The trench is now topographically obvious (Figs. 4 and 5) due to Eocene exhumation, extensional collapse, and erosion of ∼7–8 km of rock from the thrust stack, which included the Belt–Purcell allochthon, transported northeastward on the Lewis, and related, thrust faults (Constenius 1996).

The concept of a major tectonic break at the Rocky Mountain trench is also supported by seismic observations in both the crust and mantle. Seismic reflectors in the lower crust, inferred to represent Cambrian sedimentary rocks just above crystalline basement (Bally et al. 1966), were traced continuously westward from beneath the Lewis thrust to terminate

below the trench (Fermor 1999). Similarly, mantle tomography (Chen et al. 2019) suggests that the thick subcratonic mantle lithosphere of the North American craton is truncated beneath the region of the trench.

A potential problem with hypothesizing a major tectonic break at the Rocky Mountain trench comes from McMechan et al. (2020) who correlated stratigraphic units from drill core unconformably above cratonic basement beneath the Alberta Plains westward through the Cordillera, and on the basis of their correlations, claimed that stratigraphy from east to west was "nailed to the craton". If correct, this would preclude any significant break in the trench or elsewhere. There are, however, significant problems with such a hypothesis.

First, correlating thin, incomplete cratonic sections in drill core with sections of thick passive margin stratigraphy deposited on the continental slope can be challenging and is error-prone, as the stratigraphic units commonly represent different depositional environments, lack recognizable fauna, and are widely diachronous with complex cross-strike structure. Stratigraphic correlations are by nature, interpretations that could be flawed. Consider, for example, that in the Front Range sections, the Mount Whyte Formation is about 200 m thick and dominated by carbonate with minor siliciclastic rocks, whereas in drill core from beneath the Alberta Plains, the correlative formation comprises glauconitic sandstones and siltstones with only very subsidiary carbonate, if any, and is about 50 m thick (Aitken 1968).

Second, McMechan et al. (2020) indicated that a key carbonate unit, the middle Cambrian Ottertail Formation, lies across the renowned, lower Paleozoic shelf edge, of the Kicking Horse Rim (Cook 1970; Aitken 1971). They did not discuss how a single carbonate unit could sit atop both the carbonate platform edge and basinal mudstone facies, such as the Burgess Shale to the west, but given that the rim had steep to vertical escarpments hundreds of meters high, that periodically collapsed into the basin (Mullins and Hine 1989; Collom et al. 2009), it is difficult to understand how a shallow marine carbonate unit could have been continuous across the Kicking Horse Rim from platformal to basinal facies.

Third, still farther west, stratigraphic units thin markedly and have shallow marine facies on what is known as the Windermere High (Reesor 1973), a poorly understood, high-standing block west of the Kicking Horse Rim. There (Fig. 4), a Middle Cambrian unconformity cuts downward through the entire Lower Cambrian section such that rocks of the Middle to Upper Cambrian Jubilee Formation sit on Mesoproterozoic metasedimentary rocks of the Belt–Purcell supergroup (Larson and Price 2006; Price 2013). There is no recognized unconformity of this age or magnitude farther east on the west-facing Laurentian passive margin.

Fourth, on the Windermere High (Fig. 4), the Upper Cambrian McKay Group contains more than 500 m of mafic, bouldery volcaniclastic rocks (Larson and Price 2006), which, along with the existence of the Windermere High itself, are difficult to reconcile with a progressively cooling lithosphere beneath a westward thinning, passive-margin prism.

Fifth, rocks of the Belt and Purcell supergroups were tectonically transported over Cretaceous rocks of the North American margin on the Lewis and related thrust faults (Fig.

Fig. 7. Sketch map of western North America after Reed et al. (2004) showing distribution of Cretaceous sedimentary rocks of the Western Interior basin and geologic elements discussed in text. The dashed black circle marks the Peace River (PR)–Fort St. John (SJ) region of northern Alberta and British Columbia where sedimentary isopachs, related to foredeep sedimentation during the 100 Ma Peninsular Ranges orogeny, illustrate the extent to which sectors of the area to the south were removed (transported northward) during younger deformation. About 500 km of trans-strike isopachs from the base of the Fish Scales, a regional basin-wide isochronous horizon (Hildebrand et al. 2023), to the top of the Viking and Bow River formations (Leckie et al. 1994), show westward thickening sedimentary rocks (inset (*a*) truncated obliquely as they approach the fold-thrust belt and Rocky Mountain trench. Elsewhere in the Western Interior basin, equivalent age sedimentary rocks are thin and without evidence for westward thickening. These relations suggest that much of the western part of the original basin was removed. Supporting this conclusion are the truncations of the overlying Dunvegan coarse alluvial facies and shoreline as shown here and in Fig. 8. Single clinoforms of the Dunvegan formation were traced 900 km southeastward and document the former continuity of sedimentary basin fill (Plint et al. 2009). Modified from Hildebrand et al. (2023).
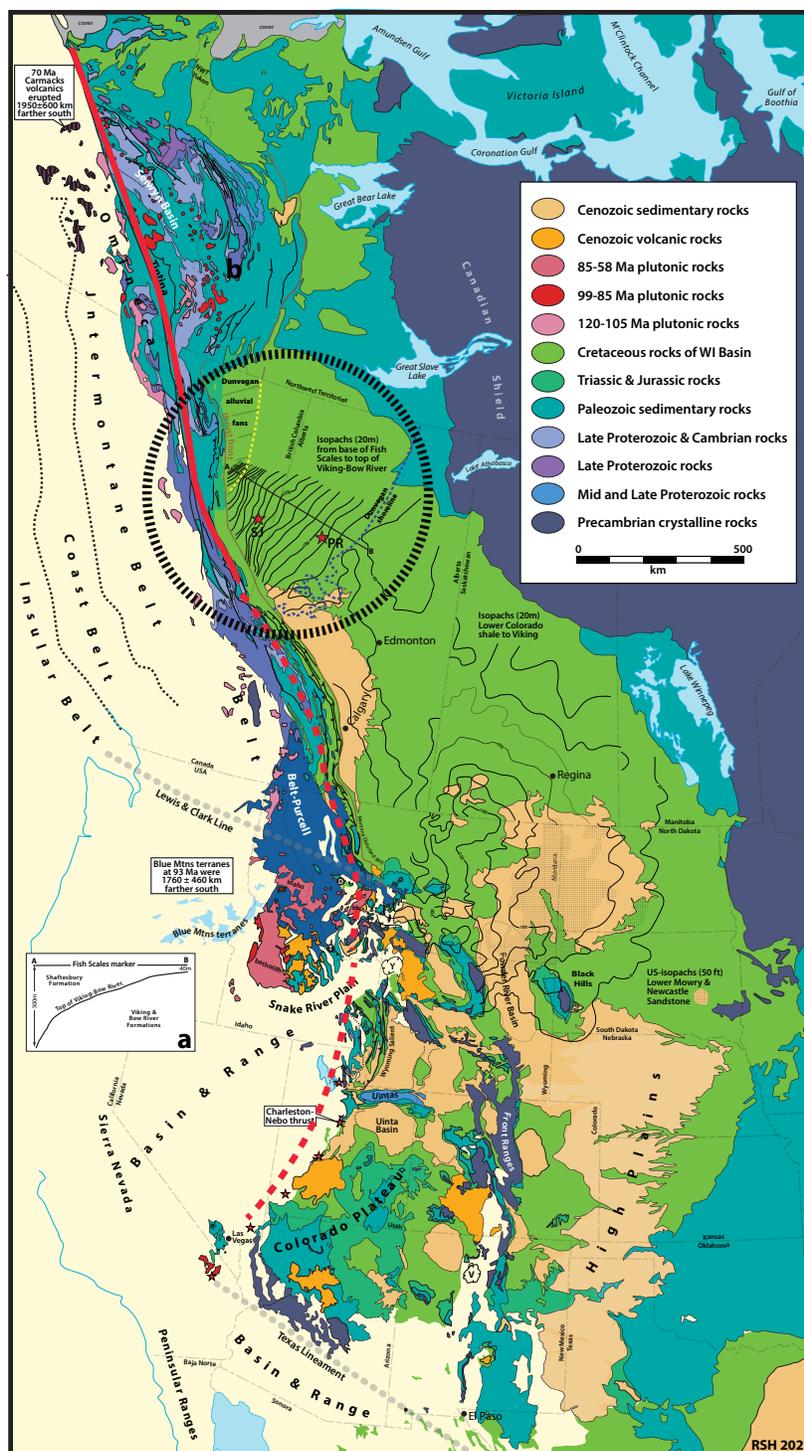
Fig. 8. Regional cross section of Dunvegan Alloformation illustrating its wedge-shaped form and that its various allomembers (labeled G to C) downlap onto the planar surface of the Fish Scales unit (modified from Bhattacharya 1994; Hildebrand et al. 2023), which is an isochronous, radioactive stratigraphic unit that formed under anoxic conditions in the foredeep at about the time of slab failure, as the regional slope changed from westerly during attempted subduction of North America, to easterly as the hinterland was exhumed and shed molasse into the evolving basin (see Hildebrand et al. 2023). Correlation lines are interpreted to be chronostratigraphically significant surfaces. Location of section A to B is shown in the inset. Note that in the north, facies trend more or less northerly, but to the south they are truncated by much younger Upper Cretaceous–Paleocene deformation in the Laramide fold-thrust belt and Rocky Mountain Trench.
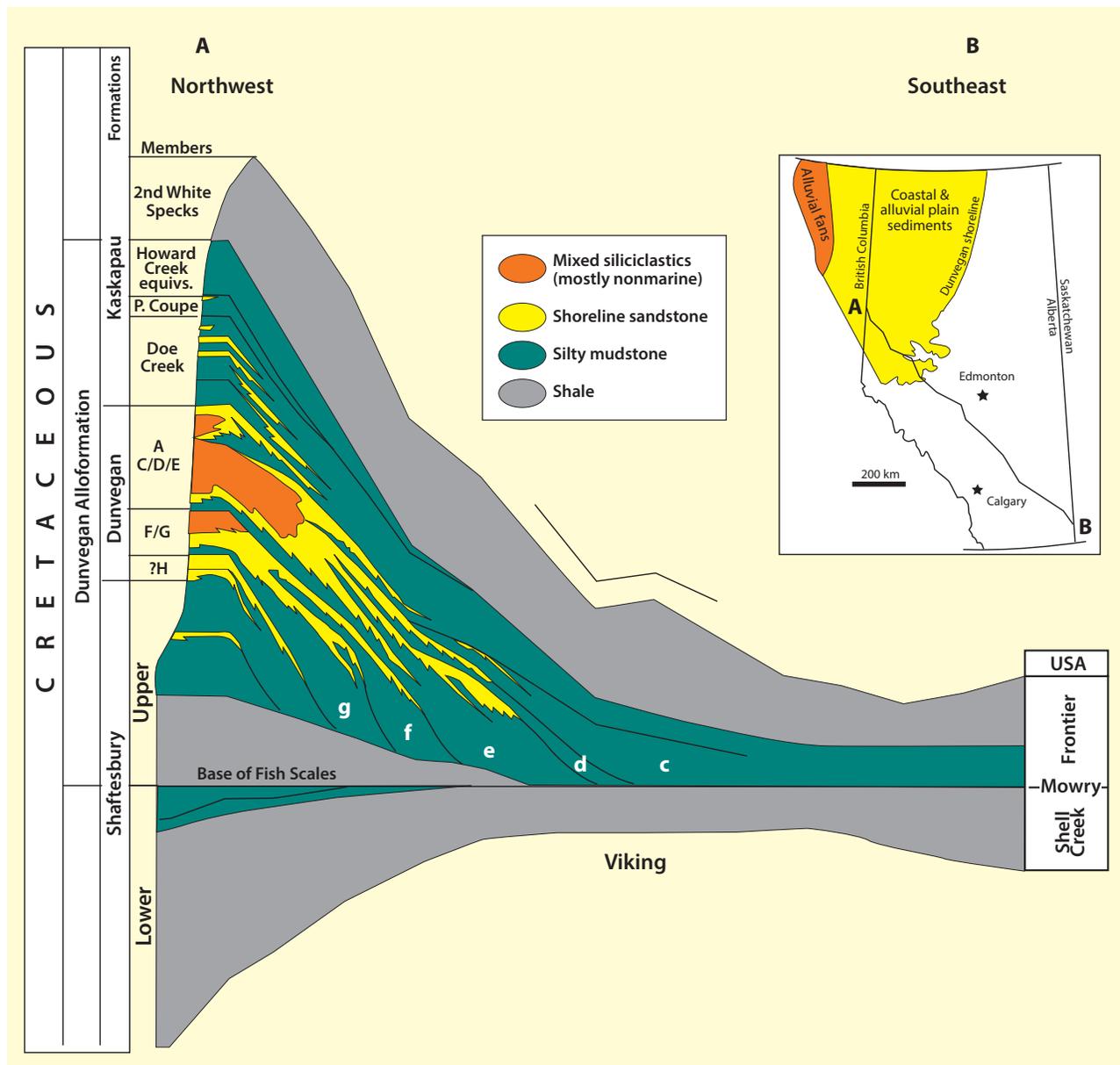

4), yet there are no known Belt–Purcell rocks in the footwall beneath the thrust belt of Alberta, despite numerous drill holes, which makes the amount of displacement on the Lewis and related thrust faults unknown and certainly not nailed to the craton at its current latitude.

Lastly, although outcrops of Lower Paleozoic rocks of the Main Ranges are typically correlated with similar-age, but quite different lithologies, in drill core from the subsurface to the east on the Interior Platform of Alberta (Aitken 1968,

1997; McMechan et al. 2020), there is no a priori reason that they could not be part of the passive margin deposited elsewhere, perhaps farther south, as they constitute an isolated allochthonous block that restores west of the trench in palinspastic reconstructions (Fermor 1999). Given that Lower and Middle Cambrian cyclic successions (Sauk I and II) of the western Laurentian margin formed in an east–west-trending belt close to the equator (Scotese and McKerrow 1990), they likely had similar facies, stratigraphy, and fauna along the

Fig. 9. Sketch map on the left, derived from Wheeler and McFeely (1991), showing the general geology surrounding the Williston Lake area with a focus on the geologic map and cross section of the Mt. Selwyn region on the right, as compiled by McMechan (1987). Both maps illustrate the truncation, or overthrusting, of ~100 Ma folds and thrust faults of the Peninsular Ranges orogeny trending southward from the Selwyn basin–Kechika trough region by younger north northwest-trending thrusts. Note as well that Neoproterozoic rocks of the Windermere Supergroup in brown, and carried by the younger transecting thrust faults, appear to cross the Rocky Mountain trench without significant separation, which indicates that the thrusts postdate strike-slip displacement on the Tintina–Rocky Mountain trench fault.
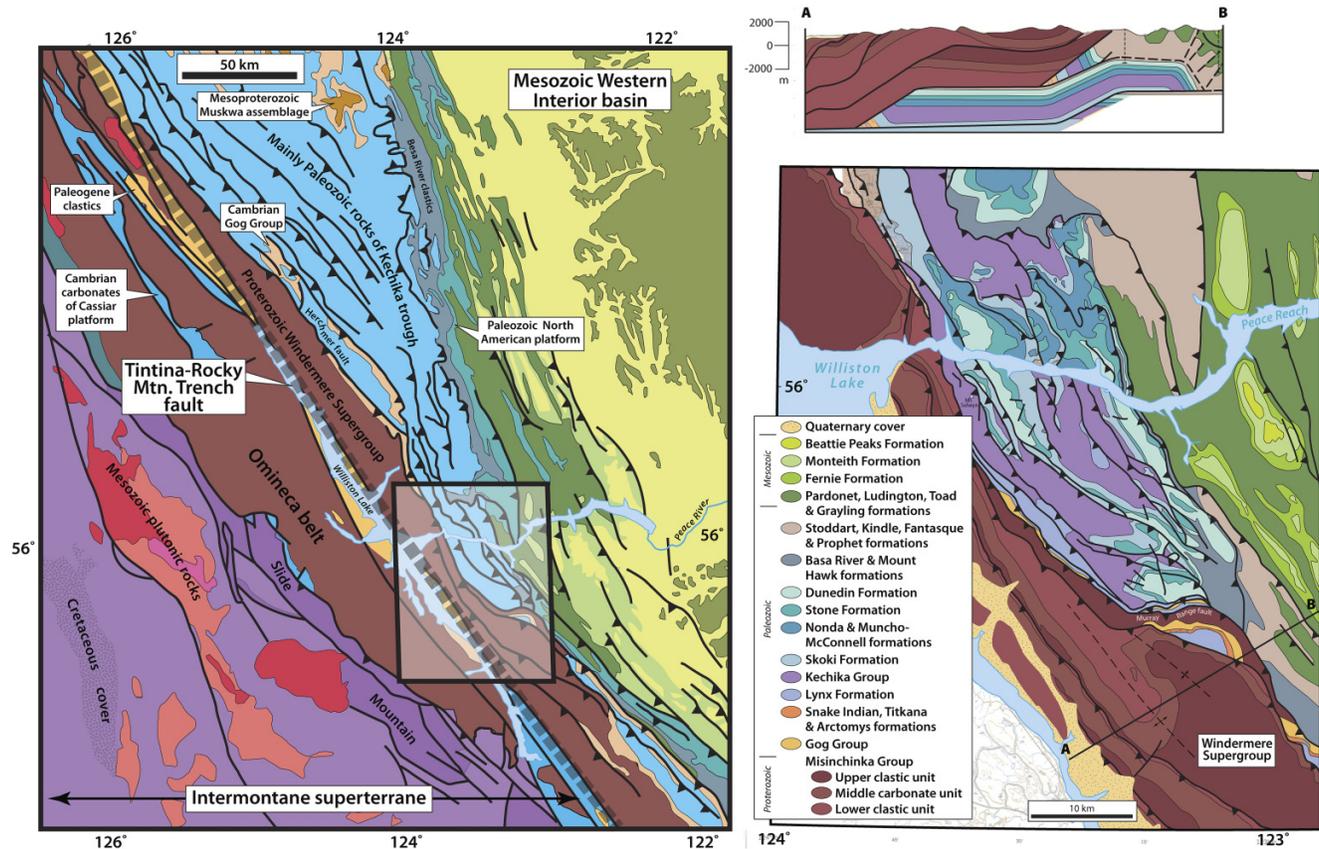
length of the margin. Although today they constitute a continuous belt that extends from northwestern Mexico to central Alaska (Palmer 1981; Bush et al. 2012; Pope et al. 2012), it is unclear where along the margin any particular fault-bounded sector of the platformal succession formed, especially since cycles in the Main Ranges of Canada and in the southern US Great Basin are "virtually identical" (Palmer and Halley 1979; Aitken 1981; Palmer 1981).

Thus, on the basis of lithology and stratigraphy, the sedimentary section in the Main Ranges was originally part of the North American passive margin, but, as it is an isolated block that seems problematic in its current location, nothing rules out it having been transported northward between about 70 and 50 Ma. Overall, the "nailed to the craton" hypothesis fails to (1) provide a sensible and robust evaluation of the stratigraphic possibilities and related unconformities, or (2) constrain the original location of the stratigraphic units of the Main Ranges.

Accordingly, there are no obvious impediments to significant dextral, strike-slip movement on the Tintina–Rocky Mountain Trench fault if the bulk of it occurred after about 70 Ma and prior to the Early Eocene (Enkin 2006), when cratonic paleopoles from the orogenic hinterland are indistinguishable from those of the North American craton (Fig. 1).

Age of thrusting

Building on the pioneering work of Pevear (1992, 1999), who developed a method of using K–Ar isotopic data in a process known as illite age analysis to better constrain the timing of basin heating relative to development of structural traps in oil fields, van der Pluijm et al. (2001) developed a procedure where authigenic and detrital grains in fault rocks can be separated, which allows the illite formed during movement of the fault to be reliably dated. Using this method, van der Pluijm et al. (2006) and Pană and van der Pluijm (2015) determined movement ages of a number of faults within the southern Canadian Cordillera and discovered several discrete pulses that form temporal belts of thrusting: Middle and Latest Jurassic, mid-Cretaceous, Cenomanian, and Eocene, from west to east (Fig. 10). The ages are reasonable matches for recognized orogenic events elsewhere in the Cordillera, with the

Fig. 10. Geological sketch map illustrating the general geologic relations, ages of various thrust faults, and displacement vectors of 56–50 Ma thrust faults within the Rocky Mountain thrust-fold belt of southern Canada modified from Hildebrand (2013). The Windermere–Belt–Purcell supergroups and the Paleozoic massifs of the Main and Western ranges are interpreted here to constitute exotic allochthons sitting atop rocks of the North American passive margin and the Rocky Mountain trench. Ages of various thrust faults from van der Pluijm et al. (2006) and Paná and van der Pluijm (2015). F—Fang stock; FB—Fernie basin; IR—Ice River complex; K—Kettle–Grand Forks dome; Kx—Kuskanax batholith; N—Nelson batholith; O—Okanagan dome; PR—Priest River complex; V—Valhalla dome. Geology from Wheeler and McFeely (1991) and Pell (1994).

Fig. 11. Geologic sketch map of Montana (Vuke et al. 2007) illustrating locations of coarse debris in the Wasatch Formation of the Western Interior basin, location of Lewis thrust system, and miscellaneous features discussed in text.
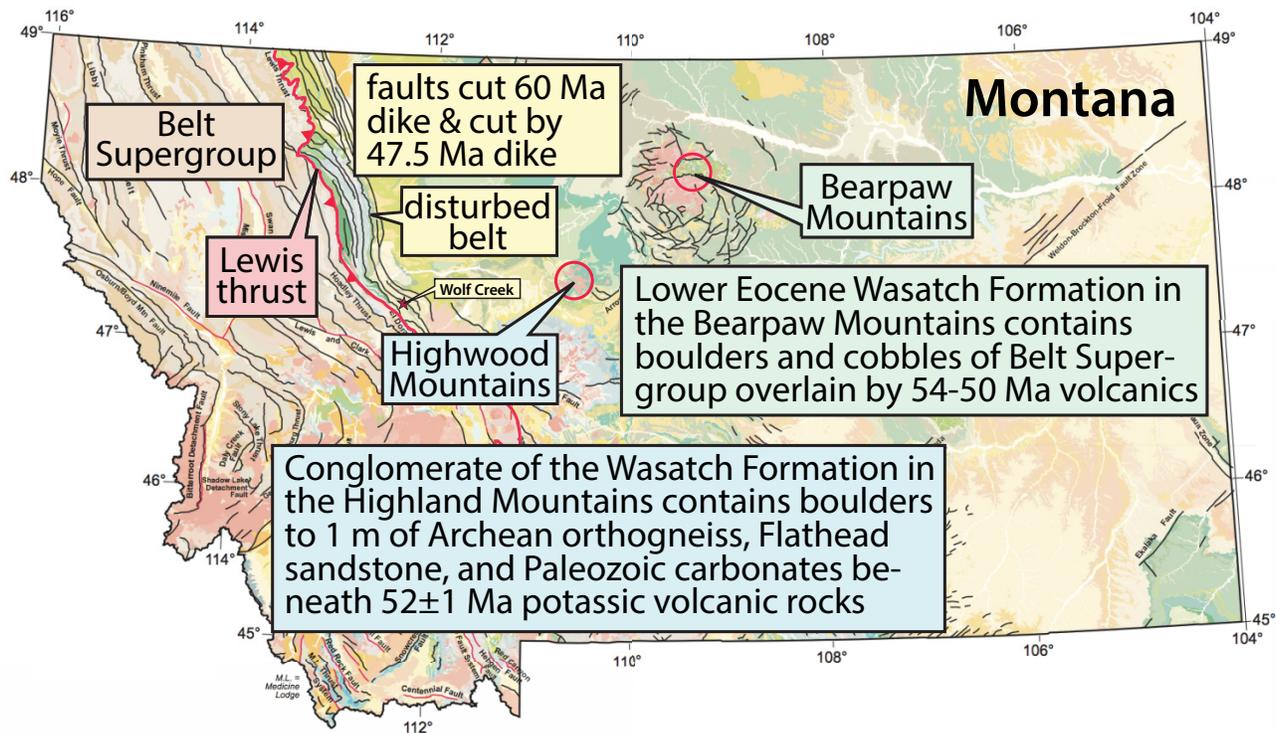
two Jurassic pulses matching a widespread 160 Ma event and the younger Nevadan orogeny, respectively, whereas the mid-Cretaceous thrusts are a good fit with the ∼100 Ma Peninsular Ranges orogeny (Hildebrand and Whalen 2021*a*, 2021*b*), and the Campanian and Eocene thrusts good matches for early and late Laramide deformation, which are largely coincident with the Maastrichtian to Eocene development of the thick-skin Rocky Mountain foreland massifs of the western Cordillera (Dickinson et al. 1988; DeCelles and Cavazza 1999; DeCelles 2004; Hildebrand 2013; Hildebrand and Whalen 2017).

Some workers had difficulty accepting the Early Eocene age for thrusting (Price 2007), but a large amount of independent data presented by Constenius (1996) suggest that an early Eocene age best fits movement on the Lewis and related thrusts and so support the illite ages. For example, in the Wolf Creek area of the Montana disturbed belt (Figs. 11 and 12), a K/Ar age of biotite collected from a quartz monzonite sill that was folded and cut by thrust faults, is 59.6 ± 1.6 Ma, whereas an undeformed monzonite dike produced a hornblende K/Ar date of 47.5 ± 1.3 Ma (Schmidt 1978; Whipple et al. 1987). Both combine to broadly bracket the age of thrusting as earliest Eocene.

Although the youngest stratigraphic unit cut by the Lewis thrust is the Campanian Belly River–Two Medicine Formation (Weimer 1955) and the youngest sedimentary unit transected by thrusts beneath the Lewis thrust in the Foothills belt is the Maastrichtian–early Paleocene Willow Creek Formation—composed of sandstone, shale, and minor limestone—there

are no coarse-grained rocks in the formation despite proximity to the Lewis thrust, which led McMannis (1965) to argue that thrusting was younger than deposition of the Willow Creek Formation. In fact, one of the great enigmas of the foredeep basin is the near absence of coarse debris linked to emplacement and erosion of the Belt–Purcell thrust sheets, from which at least 7–8 km of rock were exhumed and eroded during mid-Eocene extension (Constenius 1996). It appears that, except where overlain and protected by more resistant Eocene volcanic rocks, such as in the Bearpaw and Highwood mountains, any such deposits were eroded.

According to Constenius (1996), the oldest sedimentary rocks that might represent debris shed from the allochthons are Eocene sandstone and cobbly to bouldery conglomerate of the ∼54–50 Ma Wasatch Formation (Marvin et al. 1980) preserved beneath volcanic rocks within the Bearpaw Mountains (Fig. 11), nearly 200 km east of the frontal thrusts (Hearn 1976). There, Hearn et al. (1964) reported that clasts within the formation, which decrease in size from west to east, consist largely of quartzite and argillite derived from strata of the Belt Supergroup, with lesser amounts of Late Cretaceous–Paleocene volcanic rocks, possibly derived from the Elkhorn Mountains volcanic field.

Farther southwest, but about 100 km east and northeast of the thrust front, conglomerate with clasts of Archean orthogneiss, Flathead Sandstone, and Paleozoic limestone, up to 1 m across, crops out in the Highwood Mountains (Fig. 11), where it unconformably overlies incised Late Cretaceous foredeep fill and is interpreted to represent remnants of an

Fig. 12. Regional geological sketch map of the Helena salient, north-central U.S. Cordillera showing locations discussed in text. Modified from Hildebrand and Whalen (2017). H–Hazard Creek complex; W–Wolf Creek area; D–Drummond; chartreuse color represents areas of very thick Upper Cretaceous deposits within Belt–Purcell allochthon. Note location of a tectonic window, known as the Coolwater Culmination, where Upper Cretaceous metasedimentary rocks intruded by 87 Ma plutonic rocks are exposed beneath the Belt allochthon (Lund et al. 2008). Along the east side of the Boulder batholith on the Devil's Fence anticline, the Kimpton Ranch drillhole, a duplex structure comprising Cretaceous sedimentary rocks, was documented at depth beneath rocks of the Belt Supergroup (Burton et al. 1998).
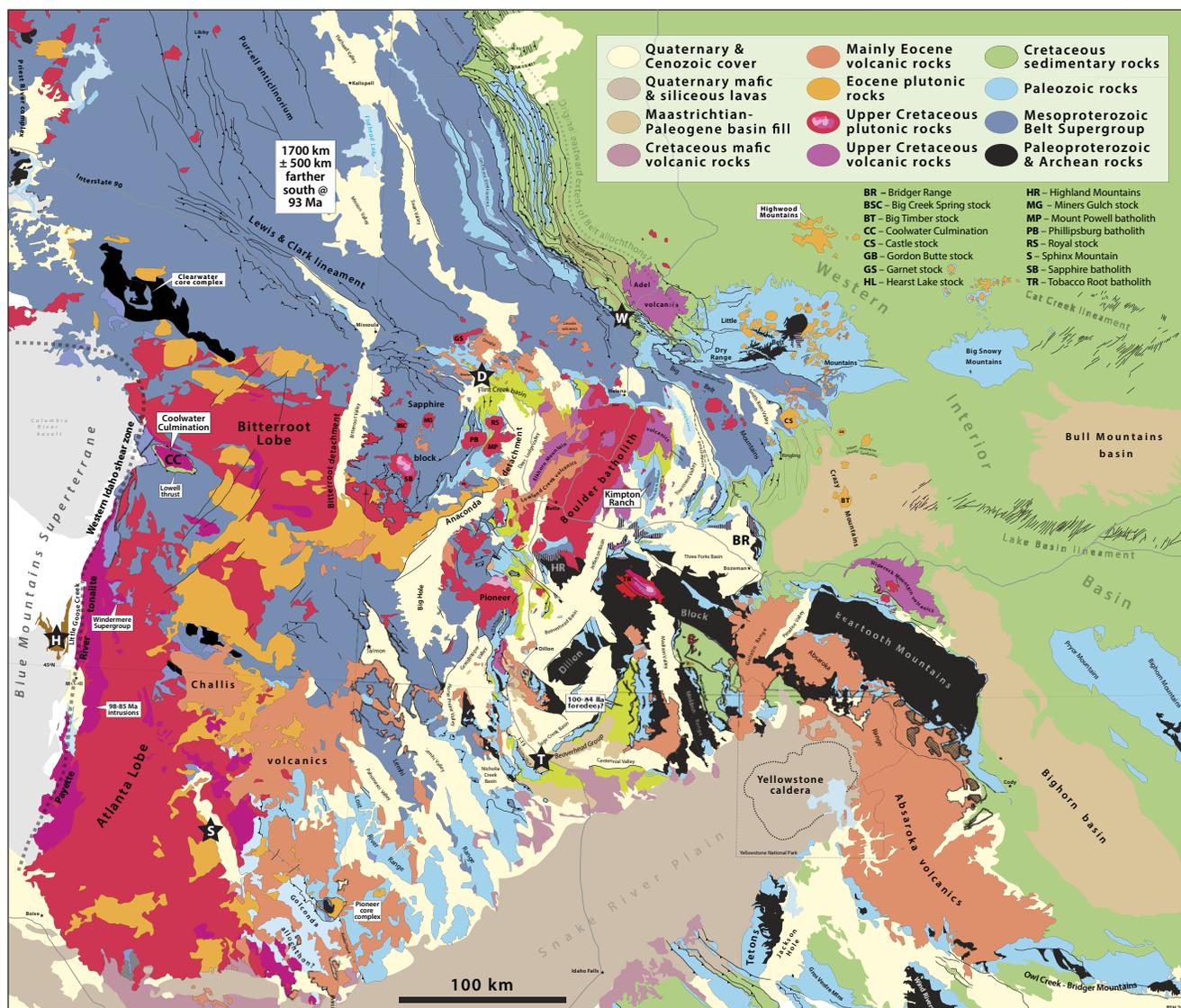
extensive early Eocene, alluvial-fan complex, which in turn, was overlain by 52 ± 1 Ma potassic volcanic rocks (O'Brien et al. 1991).

Constenius (1996) used those data to suggest that the Wasatch Formation and related conglomeratic units represent the youngest unit related to shortening in the fold-thrust belt, whereas the overlying early to middle Eocene potassic rocks represent magma erupted and intruded during widespread extension. Thus, the early Eocene illite ages reasonably reflect the emplacement of the Belt–Purcell allochthons, as well as thrusts structurally below them in the Foothills belt, which collectively serve to indicate that thrusts postdate the majority, if not all, the northward migration in-

dicated by paleomagnetic studies of the Carmacks volcanics. Additional support for 52 ± 2 Ma thrusting in the Foothills belt comes from paleomagnetism, which found that a chemically re-magnetized A component was of normal polarity in the Front Ranges but of reverse polarity in the Foothills and, because it matched the polarity of the younger B component, was younger there, preserved by rapid cooling due to exhumation and uplift (Enkin et al. 2000).

The age of thrusting is also critical to quantify the amount and direction of shortening in the fold-thrust belt to evaluate whether or not the Belt–Purcell allochthons (and others) might have been transported from west of the Rocky Mountain trench and so qualify as candidates for rocks that

traveled northward in the same block as rocks of the Car-macks Group and in the Blue Mountains. The McConnell thrust (Fig. 10) forms the boundary between the Front Ranges and Foothills geological and physiographic provinces (Bally et al. 1966; Wheeler and McFeely 1991; McMechan 1995). The fault system, which has a spectacular set of frontal duplexes (McMechan 1995, 2001), similar to those recognized in frontal thrust zones elsewhere (Hatcher et al. 2007; Searle et al. 2019), was linked to the Livingstone thrust farther south by Fermor (1999) who, along with McMechan (2001), estimated about 40 km of eastward displacement on the system, but total transport of the thrust sheet was *at least* 100 km when the shortening on thrusts and folds of the structurally lower Footbelt belt—as palinspastically restored by Bally et al. (1966), Price and Fermor (1985), and Fermor (1999)—is included. Fermor (1999) also found a *minimum* of 90 km of shortening on the Lewis thrust system, and these transport distances are summarily shown in Fig. 10, using the 235° transport direction he suggested. With these parameters, the Front Ranges restore approximately to, or just west, the Rocky Mountain trench and the Belt–Purcell block, the Main Ranges and Windermere allochthons—in part transported on the Lewis, Snake Indian, Murray Range, and Herchmer thrusts (Fig. 10)—all restore west of the trench as shown. It should be emphasized that because the rocks in the thrust sheets do not have corresponding cut-off units in their footwall, estimates of transport distance are minima.

Interestingly, the ~100 Ma Crowsnest volcanics (Fig. 4), which are alkaline slab break-off volcanics (1) erupted during the Peninsular Ranges orogeny (Hildebrand et al. 2023); (2) transported eastward on the Livingstone thrust (Figs. 4 and 10); and (3) unknown in sections farther east, yielded a shallowly inclined paleopole discordant to the cratonic pole (Irving et al. 1986). Those authors indicated that if the samples span a sufficient time to average out paleosecular variations, then the paleopole suggests a paleolatitude 1900 ± 700 km farther south, which is of similar magnitude to other Cretaceous rocks from the Cordillera located farther west. Although the authors considered the idea that the rocks were transported northward, then thrust onto the North American craton, they stated that there was insufficient evidence to demonstrate that the paleosecular variation was averaged out, so could not reasonably conclude that the rocks had been transported northward; although they could not rule it out. Because the paleopoles from the Crowsnest volcanics match the paleopoles of more westerly units, I conclude that although additional paleomagnetic study of the Crowsnest volcanics is warranted, the available data are nevertheless consistent with the idea that rocks of the Front, Main, and Western Ranges (Fig. 10)—which all lie structurally above and west of the McConnell–Livingstone thrust—were transported northward, then emplaced northeastward over the Rocky Mountain trench.

At a higher structural level than the McConnell–Livingstone thrust system, the total amount of displacement on the Lewis and related thrust faults, which carry the rocks of the Belt–Purcell supergroups, is unknown, as there are no Mesoproterozoic rocks in the footwall comparable to those in the hanging wall. However, a minimum overthrust distance might be gleaned from the Coolwater culmination, an oval tectonic window (Fig. 12) where rocks beneath the basal thrust of the Belt–Purcell allochthon are exposed. Detailed studies by Lund et al. (2008), who named the fault there the Lowell thrust, showed that metasedimentary rocks beneath it were deposited after 98 Ma and prior to intrusion of an orthogneiss dated at 86 Ma. Given that the rocks of the Belt–Purcell allochthonous block are continuous for over 400 km to the east (Fig. 12), where they also sit structurally upon Cretaceous rocks, and they are known to be thrust over Cretaceous sedimentary rocks in the Kimpton Ranch drill core under the Devil's Fence anticline (Fig. 12) just east of the Boulder batholith (Burton et al. 1998), it seems that the entire allochthon, including local slivers of crystalline basement, was derived from west of the Coolwater culmination and transported a minimum of 400 km to the northeast after 86 Ma, similar in magnitude to overthrust distances of other megathrust sheets, such as the Blue Ridge–Piedmont sheet in the southern Appalachians (Cook et al. 1979; Hatcher et al. 2007).

Thus, data from stratigraphy and paleomagnetism—as well as age, direction, and minimum distance of thrusting—all allow and suggest that rocks of the Belt–Purcell supergroups, and their Neoproterozoic/Phanerozoic cover, were transported northward during the Maastrichtian–Paleocene and then emplaced northeastwardly as massive allochthons on the Lewis and McConnell–Livingstone thrust systems over the strike-slip fault(s) of the southern Rocky Mountain trench and Cretaceous rocks of the Western Interior basin during the early Eocene.

This is an important conclusion because Mahoney et al. (2021) made a case for deriving detrital zircons in the Nanaimo basin of the Insular terrane on Vancouver Island (Fig. 2) from rocks of the Belt Supergroup, which they then used as evidence for a minimum displacement model for western BajaBC terranes, as today the two areas differ little in latitude. However, their model is untenable if the rocks of the Belt Supergroup were transported northward along with the more westerly terranes, which is indicated by the paleomagnetic and geologic data.

Relationship of northward migration to thick-skin Laramide deformation

Another factor worthy of consideration is the temporal overlap—and hence possible interrelation—of (1) the 70–50 Ma northward migration, with (2) the thick-skin deformation of the US Rocky Mountain foreland, commonly referred to as Laramide deformation (Armstrong 1974). Laramide deformation (Fig. 13) appears to have been partitioned into an early east–west shortening phase represented by northerly trending Campanian folds and thrusts followed by a period of both thin and thick-skin deformation, depending on location (Hildebrand and Whalen 2017). The basement-involved, thick-skin deformation occurred mainly during the Maastrichtian–Eocene interval (Dickinson et al. 1988; Lawton 2008; Jepson et al. 2025) and is distinctly younger than the majority of thin-skin thrusts in the Cordilleran fold-and-

Fig. 13. Sketch map showing location of Laramide thin- and thick-skin thrust belts modified from Hildebrand and Whalen (2017). Thick-skin folds and faults of Rocky Mountain foreland are from Miller et al. (1992). The Lewis and Clark and Texas lineaments that Hildebrand (2015) used as piercing points are shown in their present positions. Note that if the lineaments are re-united, the two disparate belts of Late Cretaceous–early Cenozoic magmatism would form a continuous belt. TMVB—Trans-Mexican volcanic belt.
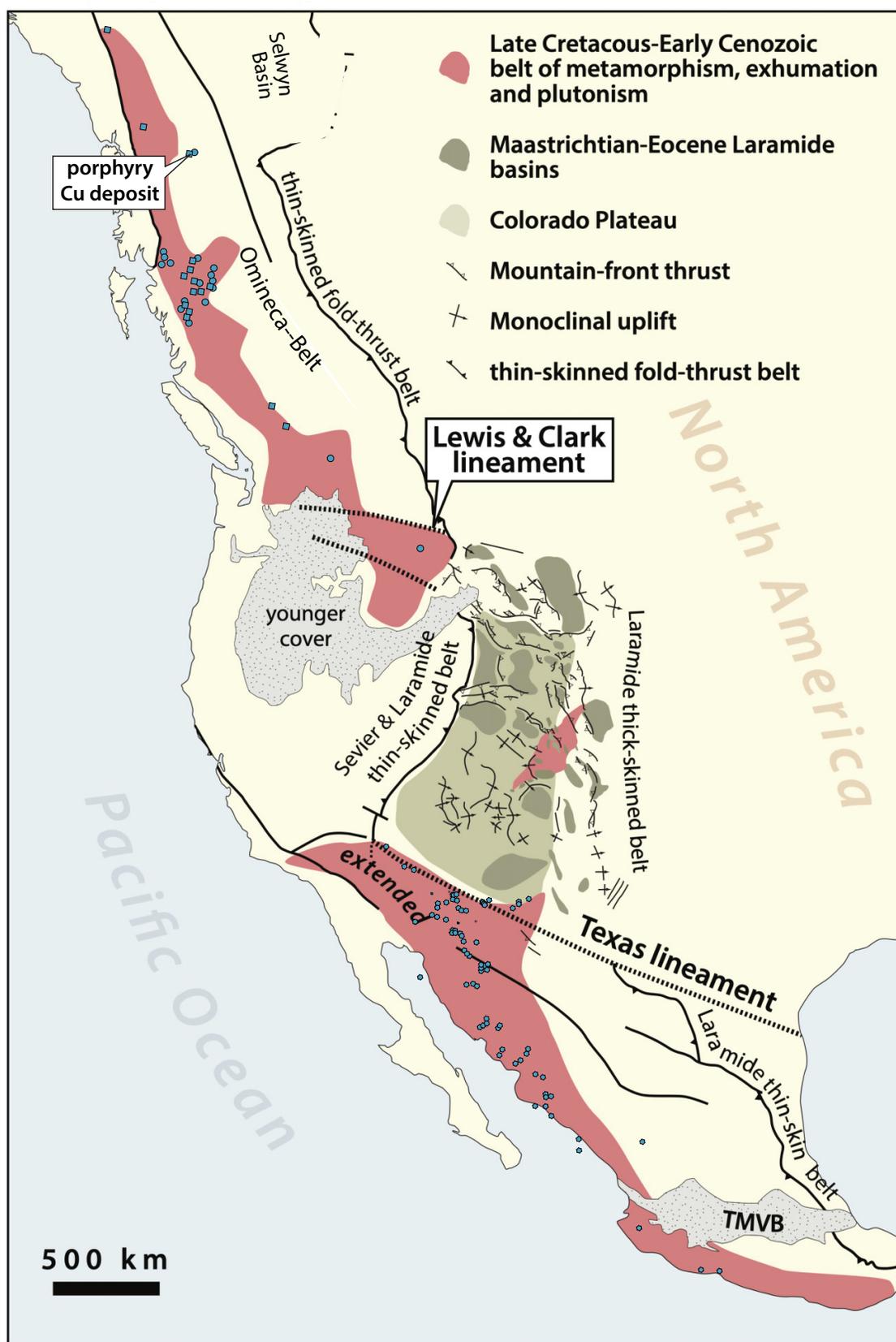
thrust belt directly to the west, where leading early Campanian thrusts were beveled and buried by huge west-derived alluvial fans no later than the mid-Campanian (DeCelles and Cavazza 1999). However, Laramide thick-skin deformation in the Rocky Mountain foreland occurred at the same time as some of the thin-skinned thrusting to the north in Canada, within Utah, and to the south in Mexico (Armstrong 1974), a feature recognized for over 100 years (Blackwelder 1914). In addition to the temporal overlap, one structural and two sedimentological studies within the Rocky Mountain foreland suggest a causal link between the northward migration of the Cordilleran block and the Laramide thick-skin deformation: (1) the direction of compression in the Laramide foreland changed progressively with time from nearly east—-west during the Campanian to north–south during the Eocene (Gries 1983); and (2) the Laramide foredeep migrated northward (Fig. 6) during the Maastrichtian and Paleocene (Roberts and Kirschbaum 1995; Catuneanu et al. 2000).

Hildebrand (2015) noted the apparent offset of the Lewis and Clark line and the future Basin and Range province to the south from the Texas Lineament and the future Basin and Range province of Mexico to its south (Henry and Aranda-Gomez 1992, 2000) and suggested that they were offset along faults (Fig. 14), possibly in the Sevier-Laramide fold-thrust belt. Although the extensional deformation of the Basin and Range province clearly postdates the northward migration, the characteristics of the two extended regions are so similar that, although largely unexposed, their relative basements behaved similarly during younger events. If correct, then any fault or group of faults along which northerly translation took place must lie between the Laramide thick-skin province and the more westerly Basin and Range province, a margin-parallel region of sparse outcrop and eastward-vergent thrust faults, developed during the Sevier, Peninsular Ranges, and Laramide orogenies. The 124 Ma Sevier and 100 Ma Peninsular Ranges orogenies occurred prior to the northward migration and are dismembered (Hildebrand and Whalen 2017; Hildebrand et al. 2023), whereas thrusts of the youngest phase of the Laramide, Maastrichtian to Paleocene, postdate northward transport and were followed by a pulse of Eocene extension (Constenius 1996; Constenius et al. 2003). Subsequently, Miocene Basin and Range extension created extensive valleys filled with debris, which makes restorations difficult, except at the broadest scale.

To explain the relations in the Rocky Mountain foreland, Lipman et al. (1971) used the age, composition, and distribution of Cenozoic volcanic rocks to suggest shallow subduction beneath the western United States. Lowell (1974) and Coney and Reynolds (1977), who summarized and interpreted radiometric data from volcanic rocks of southern California and Arizona, proposed that arc magmatism swept inboard 1000 km at 80 Ma and then back again at ca. 45 Ma due to progressive slab shallowing followed by steepening.

Although others (Glazner and Supplee 1982) presented contrary data sets that challenged the shallow subduction model, nearly all workers developed models in which the Laramide event was connected to shallowly dipping, eastward subduction of oceanic lithosphere beneath North America (Dickinson and Snyder 1978; Bird 1988; Hamilton 1988; Dumitru et al. 1991; Grove et al. 2003; Jacobson et al. 2011; Jones et al. 2011; Chapin 2012; Fan and Carrapa 2014). As pointed out by others (Maxson and Tikoff 1996; English et al. 2003), such upper-plate deformation requires the complete erosion of mantle lithosphere to transmit compressive stresses, yet isotopic studies of Cenozoic mantle xenoliths suggested its continued presence (Farmer et al. 1989; Livaccari and Perry 1993; Lee et al. 2000, 2001).Additionally, the trend of Laramide deformation and magmatism in southwestern North America is much closer to east–west than north–south (Hildebrand 2013, 2015), so that the Coney and Reynolds (1977) compilation, which used magmatic data collected from about Tucson, Arizona west to the Transverse Ranges of California, utilized data collected parallel to, or nearly along strike of, the belt rather than across it. Thus, it is not surprising that when plotted on age versus distance plots, they form near-horizontal arrays, which originally suggested to many researchers that subduction was gently inclined to flat.

In a variant of the flat-slab model, some scientists hypothesized that the Laramide deformation was caused by the collision of a topographically high-standing oceanic plateau with the North American continent (Livaccari et al. 1981; Henderson et al. 1984; English et al. 2003; Saleeby 2003). On the basis of ideas by Barth and Schneiderman (1996), a more recent variant (Liu et al. 2010) involved slightly different-aged collisions of hypothetical conjugates to the Hess and Shatsky Rises, both now located in the northwest Pacific region (Sager 2005).

While the complete subduction of the hypothesized collisional plateaux precludes any direct tests, Hildebrand (2013, p. 99) pointed out that (1) there are several such collisions taking place today and that, on the basis of studies by others (Miura et al. 2004; Phinney et al. 2004; von Huene and Ranero 2009), subduction of plateaux is unlikely to produce deformation akin to that observed in the Rocky Mountain foreland; and (2) studies of flat subduction and magmatism beneath Mexico and in southern Alaska indicate that flat slabs are able to transport volatiles well inboard of the normal arc–trench distance and still produce copious quantities of arc magmatism (Richter et al. 1995, 2006; Blatter et al. 2007; Trop et al. 2012), so that shallow subduction is unlikely to be a viable explanation for lack of magmatism in the region of Laramide thick-skinned deformation.

The intense focus by the geological community on the thick-skinned deformation, and its generation by flat-slab subduction, largely ignored several important regional observations: (1) thick-skinned deformation of the Rocky Mountain foreland was approximately coeval with the thin-skinned deformation north of the Lewis and Clark lineament within the Canadian Cordillera, and south of the Texas lineament within the Mexican sector of the orogen (Armstrong 1974); (2) the direction of shortening within the Laramide thick-skinned province changed progressively with time from nearly east–west to north–south (Gries 1983); (3) the large-scale arrangement of basins and uplifts along the east side of the Colorado Plateau in Colorado and New Mexico is en echelon, which Chapin and Cather (1983) suggested provides evidence for

Fig. 14. Schematic map showing many of the displaced Cordilleran elements discussed in the text. The two lineaments, Lewis and Clark and Texas, used as piercing points are shown in their present positions as are the two belts of Late Cretaceous–early Cenozoic magmatism and porphyry deposits, the Eocene extensional belts, and the two regions of Miocene Basin and Range faulting. Although the Basin and Range faulting occurred after the northward migration, Hildebrand (2015) proposed that the restored transverse zone formed as a sinistral transform fault during Jurassic opening of the central Atlantic Ocean, such that the crust south of the zone, whatever its nature and origin, was similar. Rotation of Colorado Plateau from Kent and Witte (1993).
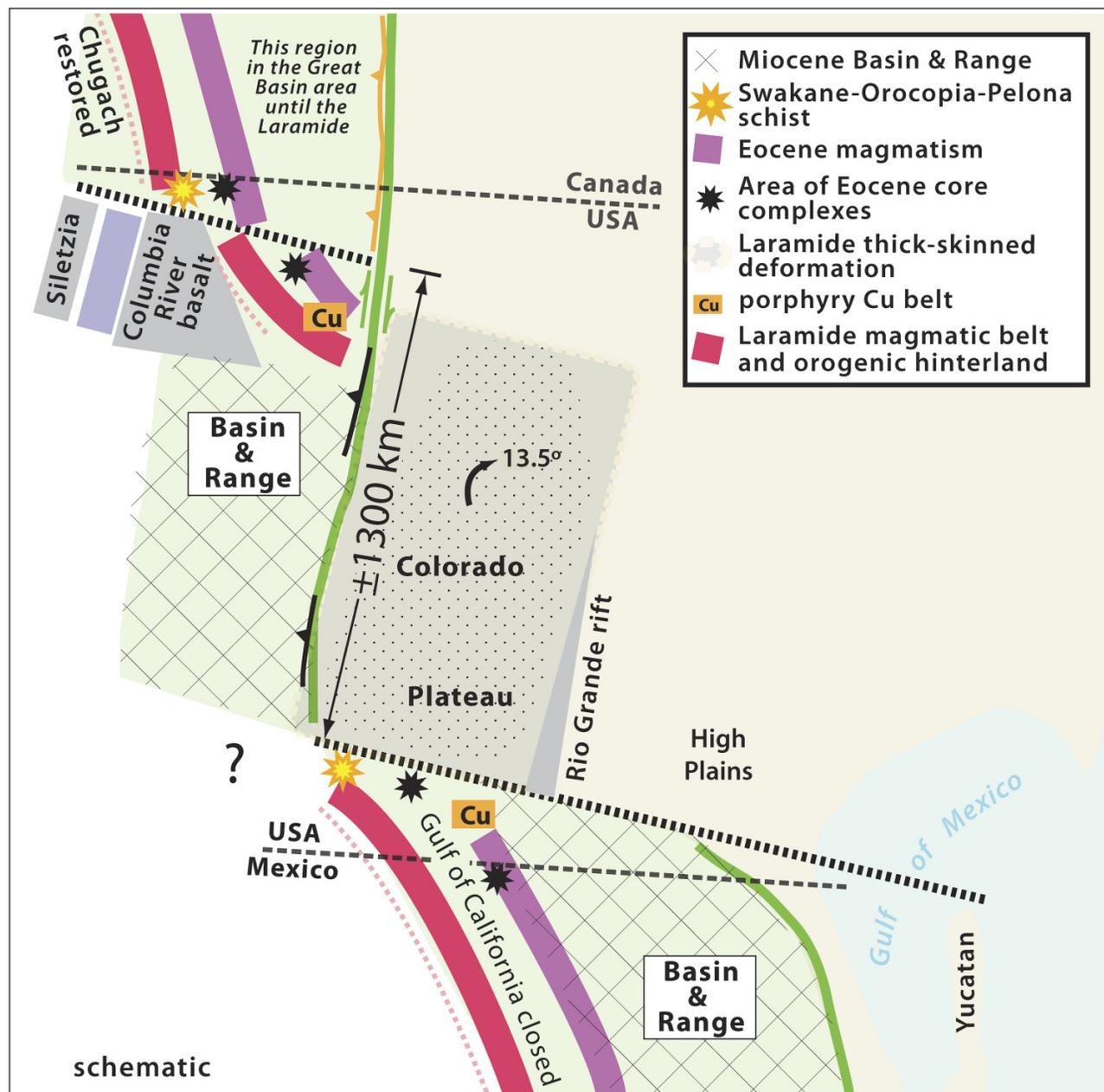
right-lateral slip, during which the plateau moved as many as 120 km to the north; (4) the Laramide foredeep migrated northward from the Maastrichtian to Paleocene (Roberts and Kirschbaum 1995; Catuneanu et al. 2000); (5) a linear band of intense Campanian deformation, exhumation, plutonism, and porphyry Cu mineralization occurs farther west, both south of the Lewis and Clark lineament and the Texas lineament to the south (Fig. 14), in what probably represents a dismembered orogenic hinterland (Hildebrand and Whalen 2017); and (6) an early to mid-Campanian (82–75 Ma) thin-skinned thrust belt is located east of the older Sevier fold-and-thrust belt. It is worth reiterating that thin-skin thrusting in this belt was more or less coeval with deformation, metamorphism, and plutonism within the proposed orogenic hinterland and stopped by the mid-Campanian, when the leading edge of the thrust belt was eroded and, along with rocks of

the adjacent foredeep, buried by conglomerate and gravels of fluvial megafans derived from the more interior portions of the thrust wedge (DeCelles and Cavazza 1999; DeCelles 2004; Liu et al. 2005).

By restoring the orogen to its pre–strike-slip configuration, Hildebrand (2015) showed, not only that most of the present-day Canadian Cordillera originated in the Great Basin sector, but also that once meridional migration is restored, the earlier mentioned metamorphic–plutonic hinterland of Campanian age, with its postcollisional exhumation and coeval magmatism, was also restored to a continuous belt from Mexico to Alaska (Figs. 13 and 14). Given that the Upper Cretaceous magmatic gap in the region of Laramide thick-skinned deformation was perhaps the principal reason to ascribe the thick-skinned deformation to flat-slab subduction (Dickinson and Snyder 1978; Humphreys 2009), the reconstruction of the Campanian Laramide hinterland, and its post-collisional magmatic belt, over thousands of kilometers along strike obviates the need for east-dipping flat-slab subduction. The temporal overlap of the thick-skinned deformation, which formed mainly during the Maastrichtian and Paleocene (Dickinson et al. 1988), and the major northerly, or dextral, migration of the adjacent Cordilleran block (Hildebrand 2015) suggests that the thick-skinned deformation was generated by transpression during meridional migration. Thus, the resolution of the long-standing BajaBC conundrum also provides an actualistic mechanism to generate the thick-skinned deformation of the Rocky Mountain foreland simultaneous with the northerly migration of the Cordillera as observed. It is, therefore, unnecessary to invoke models involving subduction of hypothetical plateaux or conjectural, shallow-dipping slabs, to cause the thick-skin deformation and the lack of arc magmatism in the Rocky Mountain foreland.

Southward continuation in the western US

The Rocky Mountain trench is unrecognized south of the Lewis and Clark line, yet the foregoing discussion implies that the proposed fault along which the bulk of the Cordillera was transported northward must continue to the south through the western United States, despite its obscurity. Perhaps the fault simply does not exist, but the apparent offset of four features that are readily restored to a single unit, Basin and Range province of the Great Basin and Mexican regions, Lewis and Clark/Texas lineaments, and the, linear belts—in Idaho and the Mojave-Sonora deserts—of both uppermost Cretaceous to Paleocene magmatism and related porphyry Cu mineralization, collectively suggest about 1300 km of offset (Figs. 13 and 14) after palinspastic restoration. Additionally, the current location of the Omineca belt of the Canadian Cordillera does not correspond temporally to rocks in the Canadian foreland fold-thrust belt to the east (Fig. 3), but it appears to match well if restored to a more southerly latitude, where the ages of Sevier thrusting in Wyoming and Utah match its metamorphism, magmatism, and deformation (Hildebrand 2015).

South of the Lewis and Clark lineament, younger events, such as Eocene thrusting, extensional collapse (Constenius 1996; Constenius et al. 2003; Vogl et al. 2012), and Basin and Range faulting (Allmendinger et al. 1983; Wernicke et al. 1988), have dismembered and stretched the region such that vast areas are covered by younger sedimentary basin fill. Although its location is poorly constrained due to lack of outcrop as well as burial by younger allochthons, there are abrupt geological truncations, which when coupled with seemingly out-of-place, and difficult-to-explain, geology, provide clues as to its existence. In fact, these truncations may *require* the existence of a major northerly trending fault, however cryptic its location might be today.

Just as in the area between Williston Lake and the Lewis and Clark lineament, Eocene thrust faults occur southward all along the western margin of North America (DeCelles 2004; Constenius et al. 2003; DeCelles and Coogan 2006), so it is possible that thrusts sit atop the hypothesized strike-slip fault and, unlike the region north of the Lewis and Clark lineament, the region south of it was severely disrupted and distorted by Eocene extension (Constenius et al. 2006), as well as subsequent Miocene Basin and Range extension, along with fault block rotation and burial under vast areas of basin fill. Thus, one can imagine the difficulty of identifying any remnant of a topographic trench, or older fault, because of subsequent thrusting and two episodes of extension. Further complicating its identification are common, abrupt platform-basin facies changes that define the hingeline, also all along the margin.

The complications start south of the Lewis and Clark line, where similar age mid-Cretaceous siliciclastic rocks occur both within the Belt–Purcell allochthon and beneath it in the footwall. In fact, some have argued that Cretaceous rocks of the Western Interior basin in Idaho–Montana preclude the Belt Supergroup and associated rocks from northward transport, as the Cretaceous units generally have been correlated across the region (Cobban et al. 1976; Zartman et al. 1995; Fuentes et al. 2010). However, Cretaceous rocks in the Belt allochthons are different in age, lithology, and thickness on both sides of the thrust as noted by Wallace et al. (1990). East of the Atlanta lobe of the Idaho batholith and west of the Boulder batholith in the Drummond, Montana area (Fig. 12), a succession of upper Albian to Santonian sedimentary units over 3500 m thick, likely deposited in a flexural foreland basin, were folded and thrust eastward prior to emplacement of 82 Ma intrusions (Wallace 1987; Wallace et al. 1990). They (p. 1034) also indicated that the >3000 m thick overlying "*sequence of rocks shares no similarities of lithologic succession with rocks of the upper Cretaceous*" in the thrust belt and that the dominantly coarse-grained succession was deposited in shallow, brackish water compared with the thin sequence of marine Cenomanian–Santonian black shales deposited farther east, which were apparently not disturbed during the Campanian event (see also Fuentes et al. 2010).

In southern Idaho, more than 3000 m of Pennsylvanian–Permian sediments were deposited in the Wood River basin, which was dominantly anoxic (Geslin 1998). There is no evidence for deformation on the Laurentian platform, or even the presence of a topographic highland to the east, al-

though paleocurrents and detrital zircons support a dominantly easterly provenance for the bulk of the basin (Geslin 1998; Thomas et al. in press).

Along the southern margin of the Belt–Purcell allochthon, north of the Snake River Plain (Fig. 12), rocks deposited in the Wood River basin outcrop in several thrust sheets, which are Upper Cretaceous in the west and Paleocene–Eocene in the east; locally also carry rocks of the Belt Supergroup; and are now broken and distended by Basin and Range normal faults (Skipp and Hait 1977; Skipp and Link 1992; Garber et al. 2020). Some of the easterly vergent thrust sheets contain rocks of the Belt Supergroup (Link et al. 2007) and like those to the north, the thrust faults have a collective eastward transport of hundreds of km (Skipp and Hait 1977; Skipp 1987; Rodgers and Janecke 1992), although distances are poorly constrained.

Within northwestern Utah and southwestern Idaho, up to 9 km of Upper Mississippian to Lower Permian sedimentary rocks of the Oquirrh basin, which has been interpreted as a continuation of the Wood River basin (Geslin 1998), are preserved in thrust plates such as the Absaroka and Charleston-Nebo (Erskine 1997). Rocks in the thrust plate are juxtaposed against a much thinner mixed siliciclastic–carbonate platformal succession on the Laurentian margin known as the Weber shelf. For more than 300 km along the contact there are (1) no transitional sections or facies containing features, such as slumped horizons, periplatformal talus, micritic mounds, hardgrounds, or mineralization, are known between the basin and platform; (2) no obvious adjacent elevated source regions; and (3) no evidence for Pennsylvanian–Permian deformation affecting the miogeoclinal platform, which makes the formation of the basin conceptually difficult (Erskine 1997). The lack of transitional facies is also difficult to understand from a sedimentological viewpoint (see for example: Hine and Mullins 1983; James and Mountjoy 1983) given sufficient subsidence for 9 km of sediment to accumulate. The complete lack of transitional facies between Laurentian shelf and Wood River–Oquirrh basin, and the absence of a recognized nearby topographic source, suggests a major break between the two. The hypothesized fault could be located beneath the Paleocene–Eocene thrust plates just west of the platform.

The Upper Devonian Pilot basin of Nevada, Utah, and southernmost Idaho is another feature seemingly disconnected from the Laurentian platform farther east. Giles et al. (1999) suggested that the basin formed as a foredeep during thrusting of the Roberts Mountain allochthon onto a west-facing platform margin in Nevada during the Upper Devonian, but Hildebrand (2009, 2013) argued that the platform shelf overrun by the Roberts Mountain allochthon was different from that of North America, located farther east, and he termed it the Antler platform. In addition, rocks of the foredeep, the Pilot shale, do not occur on the North American platform, and in both scenarios, the platform and basin share no transitional facies.

As pointed out by James and Mountjoy (1983), many fold-thrust belts worldwide contain remnants of a shelf-slope break, and thrusts of the platform units tend to be massive and contain recognizable stratigraphy, whereas slope rocks tend to be much more intricately folded and cleaved. Although the rocks from the US Paleozoic basins do occur in a fold-thrust belt, the platform and slope facies are completely detached with no transitional facies, which is peculiar given that most shelf-slope breaks in orogenic belts have transitional facies.

Detrital zircons in rocks of the Belt Supergroup and the Wood River–Oquirrh basin yielded abundant U–Pb ages in the 1.8–1.5 Ga Ma timespan (Link et al. 2014, 2016; Parker and Hendrix 2022; Hirtz et al. 2024; Thomas et al. in press), which is consistent with the model that they were transported from more southerly regions as similar ages occur in rocks of the Yavapai, Mazatzal, and Picurus orogens, all of which are well represented in the southwestern United States (Jones et al. 2015; Daniel et al. 2023). Rocks of the Wood River–Oquirrh basin also contain abundant grains in the age-range 1300–900 Ma, which are typically interpreted to represent material from the Grenville orogen, and smaller, but persistent Cryogenian–Ediacaran peaks in the range 660–500 Ma, which could represent zircons of similar provenance to those in the Permian of West Texas (Liu and Stockli 2020), transported from Gondwana along the Ouachita–Marathon sector of the Alleghanian orogeny. Thus, detrital zircons in both the upper Belt basin and the Wood River–Oquirrh basin are compatible with a southwestern US derivation.

Rocks of the Pilot basin contain detrital zircons with similar peaks at 1.5–1.4 Ga, and 1.2–1.0 Ga, with subordinate age groups of 2.8–2.5 Ga and 600–400 Ma, which, in addition to the Yavapai, Mazatzal, and Picurus orogens, have the additional complication of a source to the west with Paleoproterozoic zircons ultimately derived from Laurentia, but recycled from the Roberts Mountain allochthon (Cole et al. 2015).

The extensional deformation, thrusting, and poor outcrop do not refute the model presented here as any Maastrichtian–Paleocene strike-slip fault would have been overridden by the Eocene thrusts. The detrital zircon studies cited above also broadly support it. Careful palinspastic restorations of the thrust faults are needed to properly evaluate the facies along and around pre-thrusting shelf edges to ascertain whether the strike-slip fault passed between platform and basin as located during the Upper Cretaceous–Paleocene.

Farther south and west, in Southern California and on the Baja Peninsula, existing paleomagnetic data support the idea of large-scale northward migration of substantial Cordilleran tracts (Patterson 1984; Beck 1991, 1992; Lund et al. 1991), with many of those data subsequently compiled by Dickinson and Butler (1998). They attributed most of the discrepancies in paleopoles of sedimentary rocks discordant to cratonic poles as related to compaction flattening, or remagnetization; yet their own data set (Fig. 15) is remarkably consistent with paleopoles in sedimentary rocks located both farther north as shown in Fig. 1.

In fact, Beck (1991) had previously examined the various possibilities and concluded that the consistency of the data from north to south is remarkable and supports the far-traveled results. Also, Smith and Busby-Spera (1993) evaluated the effects of compaction, and analyzed slump blocks in an olistostromal unit to test the remagnetization hypothesis. They concluded that the rocks were not remagnetized

Fig. 15. Age in Ma versus apparent latitudinal migration in °N for sedimentary rocks of coastal and Baja California, created by flipping and rotating a figure from Dickinson and Butler (1998), to illustrate the similarity in age and migration distance with rocks in southern Canada (Fig. 1). Note that, just as with the southern BC data set, the farthest travel rocks were deposited at about 70 Ma, and by 50 Ma, the rocks generally have cratonic paleopoles. This, despite claims by Dickinson and Butler (1998) that the apparent northward migration in excess of migration on the San Andreas fault was instead generated by compaction flattening. The northerly displacement of 1300 km proposed here by reconstructing matching geological features is within error of nearly all pre-55 Ma paleomagnetic samples, similar to the northern data set (Fig. 1).
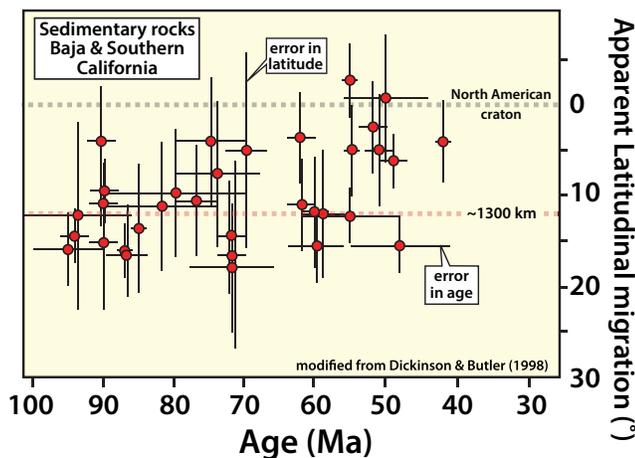
and that northward displacement of $18° \pm 7°$ best explained the data. More recently, Sedlock (2003) provided an excellent overview of the pros and cons of the paleomagnetic possibilities and concluded that northward migration of the westernmost terranes was most likely.

Broader effects of Laramide orogeny

One of the more puzzling, and largely unrecognized, observations in the US Cordillera is the demise of Franciscan subduction at ∼80 Ma, contemporaneous with, or just after, the Laramide event during the Campanian. Three lines of evidence indicate that subduction stopped at that time: (1) the youngest known blueschist formed at 84 Ma; (2) there is an abrupt gap in sedimentation from ∼80 to 53 Ma; and (3) the coherent blueschists were exhumed after 70 Ma, and at least locally at the surface by 67 Ma (see fig. 58 of Hildebrand 2013). Perhaps part of the problem is that we are uncertain where the Franciscan rocks originated, as there is the possibility that the Franciscan and the western Great Valley sequence were juxtaposed with the eastern <100 Ma Great Valley sequence along a major fault (Wright and Wyld 2007). Nevertheless, the temporal coincidence between the shutdown and exhumation of the Franciscan with the Campanian thrusts of the foreland suggests a causal relationship.

Farther north lies the Chugach flysch (Fig. 2), the most voluminous part of the Southern Margin composite terrane of

Alaska. The flysch was deposited after 85 Ma, but dominantly at around 68–67 Ma during the Maastrichtian–Paleocene (Sample and Reid 2003; Kochelek and Amato 2010; Kochelek et al. 2011; Garver and Davidson 2015). On the basis of paleomagnetic, isotopic, and provenance data, the flysch was probably derived from the Coast plutonic complex (Farmer et al. 1993; Sample and Reid 2003; Kochelek et al. 2011), when the collisional hinterland and its post-collisional plutons were subjected to at least 15 km of exhumation (Armstrong 1988) following slab break-off (Hildebrand 2009; Hildebrand and Whalen 2017), with a small percentage of zircons apparently derived from southwestern US sources such as the Yavapai–Mazatzal and Picuris orogens (Garver and Davidson 2015). The northward translation was supported by Roeske et al. (2003), who matched a distinctive 170 Ma intrusive suite in the Wrangell Mountains with the West Coast intrusive suite located on the western part of Vancouver Island, and documented that the northward transport may have begun as early as 85 Ma but was more or less continuous from 70 to 51 Ma.

Even farther seaward are Paleocene–Eocene flysch belts of the Prince William terrane (Fig. 2), which are interbedded with basaltic lavas—the Ghost Rocks Formation—on Kodiak Island located today at ∼55°N (Moore et al. 1983). The lavas yielded paleolatitudes from ∼48 to 41°N both in original work (Plumley et al. 1983) and in a recently completed study (Housen et al. 2008; Roeske et al. 2009).

Overall, the events of the Laramide orogeny were regionally widespread and need comprehensive examination over the length of the Americas (see Hildebrand and Whalen 2014). The composition and development of its exhumed post-collisional hinterland belt with its slab-failure plutons were discussed in Hildebrand (2013) and by Hildebrand and Whalen (2017). From the early Campanian thrusts, through the penultimate period of northerly migration along the Tintina–Rocky Mountain trench fault, and finally, the emplacement of huge allochthons over the fault itself, the tectonics appear to have been driven by, and after, collision of North America with the Kula plate, which apparently formed north of the spreading ridge between it and the Farallon plate at ∼85 Ma (Woods and Davies 1982; Lonsdale 1989). Although the location of the ridge at that time is highly speculative as it is now entirely destroyed, if the rapid northward migration of the Kula plate drove the Cordilleran block northward (Chamberlain and Lambert 1985; Umhoefer 1987; Irving et al. 1996; Hildebrand 2015), then the model constrains the long-uncertain position of the Kula-Farallon spreading ridge (Engebretson et al. 1985) to have been at least ±1300 km south of the current location of the Cordilleran block—about the latitude of La Paz, Mexico.

Restoration and matching features

Hildebrand (2015) proposed that two of the three different geologic regions of the Cordillera recognized by King (1969), on the basis of geological differences across two transverse zones: the Lewis and Clark transverse zone, which extends from Vancouver Island to the thrust belt in the Helena salient, and the Texas Lineament, which can be traced from

the Transverse Ranges of California through the Mojave and Sonoran deserts to the Gulf of Mexico, could be palinspastically restored to a continuous zone that constrains northward translation of the Cordillera to about 1300 km (Fig. 14). In addition to the two transverse zones, such a reconstruction restored several other features as follows.

1. Two widely separated sectors or belts, of Upper Cretaceous–Early Cenozoic post-collisional plutons (Figs. 13 and 14) with distinctive and comparable slab failure signature (Hildebrand and Whalen 2017) are re-united. The two belts approach the proposed fault at a high angle.
2. Porphyry copper deposits of the Butte porphyry Cu district of Montana align with porphyry Cu deposits of the US and Mexican Sonoran Desert (Figs. 13 and 14).
3. Two segments of the deformed and metamorphosed Laramide hinterland belt that was exhumed and collapsed during and after emplacement of the plutons (for example: Miller and Morton 1980; Armstrong 1988; Wells and Hoisch 2008; Miller et al. 2009) are combined into a continuous belt.
4. In restorations of southern California (Powell 1993; Nourse 2002), the eastern occurrences of the Pelona and Orocopia subduction-channel schists form an east–west band extending across much of southern California and western Arizona (Haxel and Dillon 1978; Ehlig 1981; Frost et al. 1982; Malin et al. 1995; Haxel et al. 2002, 2022; Jacobson et al. 2007) that constitute a close match with the high-grade Swakane gneiss (Valley et al. 2003; Matzel et al. 2004; Sauer et al. 2018), located in the High Cascades of Washington (Fig. 14) as originally suggested by Hildebrand (2013, 2014, 2015) and later heralded by Sauer et al. (2019).
5. Two segments of a likely continuous belt of Eocene magmatism and extension are reunited in the proposed reconstruction (Fig. 14).
6. The Mexican and US regions of Miocene Basin and Range faulting, which exist immediately south of their respective transverse zone (Fig. 14), are restored to a continuous region of extensional faults. This restoration suggests that the crust in both regions was similar and continuous prior to northerly translation.
7. The Omineca belt, which is a hinterland-like component with 125–105 Ma thrusts, metamorphism and plutonism—seemingly orphaned without an associated fold-thrust belt in Canada (Fig. 3)—matches well with the thrust faults and foredeep of the Wyoming-Utah Sevier orogeny east of the Cordilleran hingeline (Hildebrand 2014, 2015).
8. Several Permian–Pennsylvanian basins in the western US, such as the Oquirrh, are restored southward, where they may have been related to the assembly of Pangea as Gondwana slid zipper-like along the southern, or Ouachita–Marathon, sector of the US margin (Hatcher 2010).

Conclusions

The meridional migration (BajaBC) hypothesis for the bulk of the North American Cordillera presented here, which includes 1300 km of northerly migration along the Tintina–

Rocky Mountain Trench fault and its more cryptic continuation to the south, encompasses and explains a wide variety of seemingly disparate observations, including the generation of the thick-skin thrusts of the Rocky Mountain foreland, and brings them all into consilience. The model resolves and explains other long-lived problems, such as the general lack of 80–60 Ma magmatism in the region of the Rocky Mountain foreland. Also, it is compatible both temporally and kinematically with plate circuit reconstructions that found Pacific-to-North America relative motion in Late Cretaceous to middle Eocene time (73–46 Ma) to have been nearly northward as the result of dominantly northwest motion of the Pacific plate and steady southwest motion of North America (Doubrovine and Tarduno 2008).

Several seemingly offset, yet matchable, features, imply the existence of a fault with a displacement of about 1300 km. The model restoration presented here re-unites at least seven large-scale geologic features, which otherwise seem disjointed and enigmatic in their current configuration. In addition to the restoration, one of the strongest arguments for large-scale northward migration of Cordilleran terranes has always been the consistency of the paleomagnetic data, that is, Upper Cretaceous–Early Cenozoic rocks within the various terranes *all* have discordant poles, displaced from the North American cratonic poles in a *consistent manner* that indicates dextral shear or transpression along the margin after ~70 Ma and before 50 Ma (Beck 1991, 1992).

Following the Laramide collision, that part of North America west of the Tintina–Rocky Mountain Trench fault, which does not contain the thick subcratonic mantle lithosphere of the North American craton just east of the fault (Tesauro et al. 2015; Chen et al. 2019), was captured and joined with the Kula-Farallon plates as they migrated northward towards the Aleutian trench (Umhoefer 1987).

Three different sectors along the Tintina–Rocky Mountain Trench fault serve to illustrate how its character changes along strike to become progressively more concealed southward. In the northernmost sector from Alaska southward to Williston Lake, the Tintina fault is obvious as a major strike-slip fault because it juxtaposes pre-strike-slip thrusts and rocks of the Kechika Trough–Selwyn Basin with those of the Cassiar platform and the Yukon–Tanana terrane (Fig. 2). From Williston Lake south to the Lewis and Clark lineament, the strike-slip fault has not been recognized as such because it was overridden by Eocene thrust slabs, including the giant Belt–Purcell allochthon, but the trench is visible due to subsequent exhumation, collapse, and erosion of the thrust stack. South of the Lewis and Clark lineament, the proposed fault was overthrust by allochthons, exhumed and faulted, all in the Eocene, then during the Miocene, was strongly extended, broken, and tilted to create the Basin and Range with its vast debris-filled valleys concealing older structures. Mismatched units and paleomagnetism attest to its existence, but the fault can only be recognized there by detailed restorations of stratigraphic units in the overlying thrust belt. These relations serve to illustrate the difficulty of deciphering complex structural relations in orogenic belts after they have been progressively overprinted by subsequent deformational events.

Fig. 16. Much simplified schematic reconstruction of southwestern North America just prior to northward migration illustrating many of the geological features re-united by restoring 1300 km of dextral slip on the Tintina–Rocky Mountain Trench fault. The Transverse Ranges were restored eastward to about the California–Arizona state line to remove the effects of about 100% Miocene extension in the Colorado River corridor (Faulds et al. (2001). The Maria fold-thrust belt, with a trend approximately east–west, and more or less parallel to the southwest paleomargin, formed after 86 Ma, and was intruded by post-collisional plutons of the 75–70 Ma Coxcomb intrusive suite during metamorphism and subsequent extensional collapse, with deformation ending by about 55 Ma (Salem 2009). A summary of both northern and southern sectors of the dismembered Laramide orogenic hinterland with its metamorphism, post-collisional plutonism, porphyry copper deposits, exhumation, and extensional collapse is presented in Hildebrand and Whalen (2017, p. 48). Modified from Hildebrand (2015).
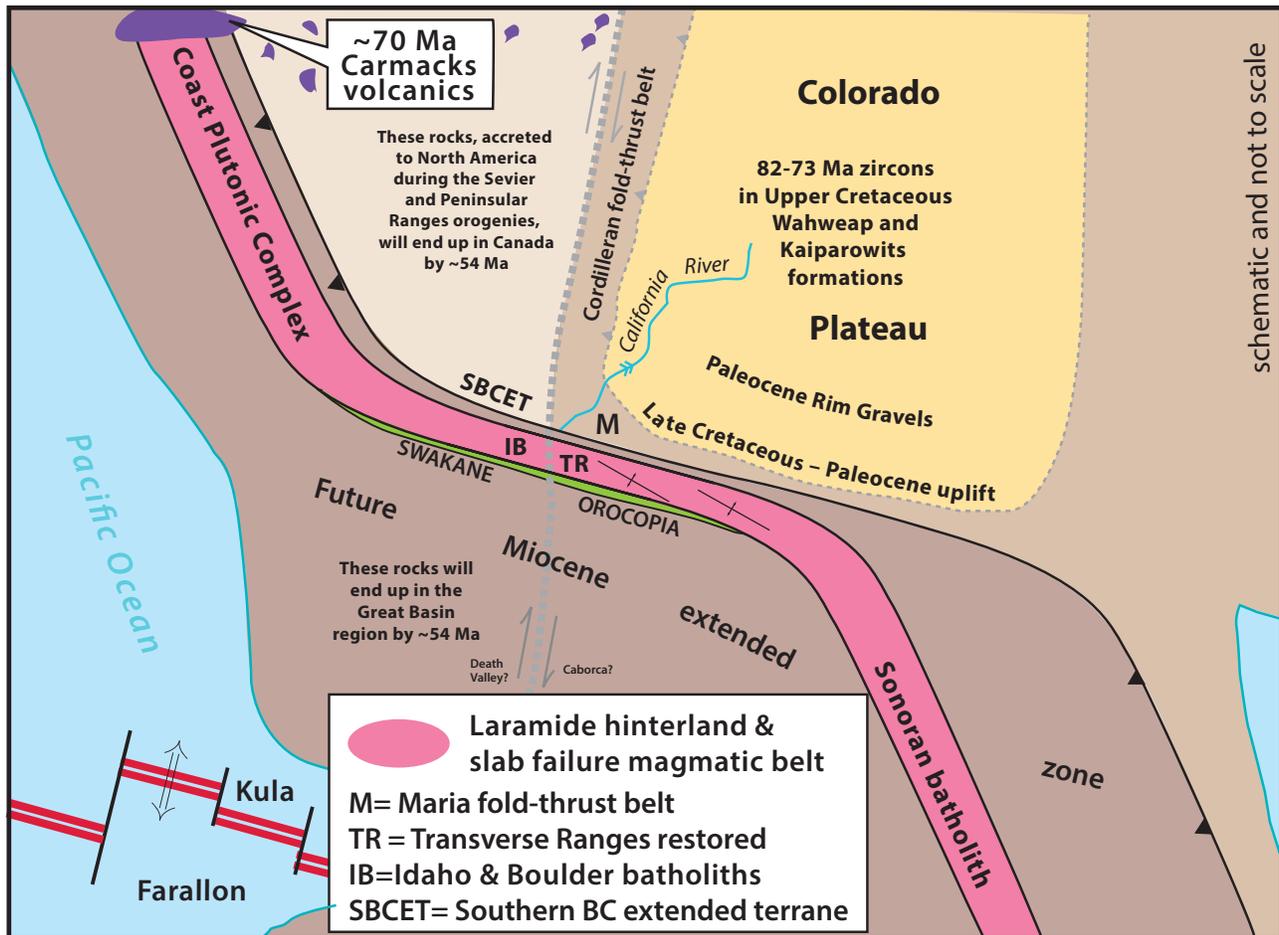
The model presented here might be correct, or not, but it resolves the 50-year problem of BajaBC by identifying the fault along which northerly migration took place and reconciles the data from both geology and paleomagnetism (Beck 1991; Gastil 1991). In the model presented here, seven geological features are restored by utilizing the Tintina–Rocky Mountain Trench fault and its cryptic continuation to the south. The restoration (Fig. 16) re-unites the two main sectors of the Laramide metamorphic and plutonic hinterland belt into a continuous strip striking northerly through Mexico, then bending counterclockwise to nearly east–west through the Sonoran and Mojave deserts and Montana–Idaho, before turning clockwise to a more northerly orientation and continuing through the Coastal batholith of British Columbia to Alaska. For the Rocky Mountain region, this removes the constraint that there was a gap in magmatism during the Laramide orogeny, for once restored,

there is no gap. And, as the vast bulk of magmatism in this belt is post-collisional, not arc, magmatism (Hildebrand and Whalen 2017), the model allows for new ideas and concepts for the nature, character, and polarity of the Laramide orogeny.

The development of the Laramide thick-skin belt synchronous with, and adjacent to, the northward migration during the Maastrichtian–Paleocene strongly suggests that the two are causally related and the change from dominantly east–west compression during the Campanian to transpressional during the Maastrichtian–Paleocene documents the progression from orthogonal to oblique slip along the margin and reflects the capture of the bulk of Cordilleran North America by the Pacific plates during the latter stages of the Laramide orogeny.

In addition to restoring the Laramide orogen, the model presented here also partly restores the older Sevier orogen as

it brings the Omineca hinterland belt of the Canadian Rocky Mountains back to the Great Basin region where it fits temporally and structurally with the 124 Ma thrust belt of the Sevier orogen in Utah and Wyoming, which lacks a metamorphic and magmatic hinterland belt in its current configuration.

Finally, in the model presented here, paleomagnetism, regional geology, geochronology, and plate kinematics are brought into consilience. During the interval from about 70 to 50 Ma, convergence between Pacific oceanic plates and North America was strongly oblique (Doubrovine and Tarduno 2008), which resulted in a large segment of the Cordillera migrating about 1300 km northward along the Tintina–Rocky Mountain Trench fault and compressing the rocks of the Rocky Mountain foreland to create basement uplifts, folds, and sedimentary basins. The overall concordance of evidence presented allows for new and more testable models for the evolution of the Laramide orogeny, which is viewed herein as a continuously through-going belt of classic orogenic style and metallogeny, extending at least from Mexico to southern Alaska.

Acknowledgements

Article information

History dates

Copyright

Data availability
Data generated or analyzed during this study are provided in full within the published article.

Author information

Author ORCIDs
Robert S. Hildebrand https://orcid.org/0000-0001-5870-1342

Author contributions
Conceptualization: RSH
Data curation: RSH
Formal analysis: RSH
Funding acquisition: RSH
Investigation: RSH
Methodology: RSH
Project administration: RSH
Software: RSH
Supervision: RSH
Validation: RSH
Visualization: RSH
Writing – original draft: RSH

Competing interests

Funding information

References

Aitken, J.D. 1968. Cambrian sections in the easternmost southern Rocky Mountains and the adjacent subsurface, Alberta. Geological Survey of Canada Paper 66-23. 96p.

Aitken, J.D. 1971. Control of lower Paleozoic sedimentary facies by the Kicking Horse Rim, southern Rocky Mountains, Canada. Bulletin of Canadian Petroleum Geology, **19**: 557–569.

Aitken, J.D. 1981. Generalizations about grand cycles. *In* Short papers for the Second International Symposium on the Cambrian System. *Edited by* M. E. Taylor. U.S. Geological Survey, Open-File Report 81-743. pp. 8–14.

Aitken, J.D. 1997. Stratigraphy of the middle Cambrian platformal succession, southern Rocky Mountains. Geological Survey of Canada Bulletin 398. 322p.

Allmendinger, R.W., Sharp, J.W., Von Tish, D., Serpa, L., Brown, L., Kaufman, S., and Oliver, J. 1983. Cenozoic and Mesozoic structure of the eastern Basin and Range Province, Utah, from COCORP seismic-reflection data. Geology, **11**: 532–536. doi:10.1130/0091-7613(1983)11⟨532:CAMSOT⟩2.0.CO;2.

Armstrong, R.L. 1974. Magmatism, orogenic timing, and orogenic diachronism in the Cordillera from Mexico to Canada: Nature, **247**: 348–351. doi:10.1038/247348a0.

Armstrong, R.L. 1988. Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera. *In* Processes in continental lithosphere deformation. *Edited by* S.P. Clark, B.C. Burchfiel and J. Suppe. Geological Society of America Special Paper 218. pp. 55–91. doi:10.1130/SPE218-p55.

Avé Lallemant, H.G., and Oldow, J.S. 1988. Early Mesozoic southward migration of Cordilleran transpressional terranes. Tectonics, **7**: 1057–1075. doi:10.1029/TC007i005p01057.

Bally, A.W., Gordy, P.L., and Stewart, G.A. 1966. Structure, seismic data, and orogenic evolution of southern Canadian Rocky Mountains. Bulletin of Canadian Petroleum Geology, **14**: 337–381.

Barth, A.P., and Schneiderman, J.S. 1996. A comparison of structures in the Andean orogen of northern Chile and exhumed midcrustal structures in southern California, USA: an analogy in tectonic style? International Geology Review, **38**: 1075–1085. doi:10.1080/00206819709465383.

Beck, M.E. 1976. Discordant paleomagnetic pole positions as evidence of regional shear in the western Cordillera of North America. American Journal of Science, **276**: 694–712. doi:10.2475/ajs.276.6.694.

Beck, M.E., Jr. 1991. Case for northward transport of Baja and coastal southern California: paleomagnetic data, analysis, and alternatives. Geology, **19**: 506–509. doi:10.1130/0091-7613(1991)019⟨0506:CFNTOB⟩2.3.CO;2.

Beck, M.E., Jr. 1992. Tectonic significance of paleomagnetic results for the western conterminous United States. *In* The Cordilleran Orogen:

conterminous U.S. *Edited by* B.C. Burchfiel, P.W. Lipman and M.L. Zoback. Geological Society of America, Geology of North America, v. G-3. pp. 683–697. doi:10.1130/DNAG-GNA-G3.

Beck, M.E., Jr., and Noson, L. 1972. Anomalous palaeolatitudes in cretaceous granitic rocks. Nature Physical Science, **235**: 11–13. doi:10.1038/physci235011a0.

Bhattacharya, J.P. 1994. Chapter 22 – Cretaceous Dunvegan Formation of the western Canada sedimentary basin. *In* Geological atlas of the Western Canadian sedimentary basin. *Edited by* G.D. Mossop and I. Shetson. Canadian Society of Petroleum Geologists and Alberta Research Council, Calgary, AB. pp. 365–373.

Bird, P. 1988. Formation of the Rocky Mountains, western United States: a continuum computer model. Science, **239**: 1501–1507. doi:10.1126/science.239.4847.1501.

Blackwelder, E. 1914. A summary of the orogenic epochs in the geologic history of North America. The Journal of Geology, **22**: 633–654. doi:10.1086/622180.

Blatter, D.L., Farmer, G.L., and Carmichael, I.S.E. 2007. A north–south transect across the Central Mexican volcanic belt at ∼100°W: spatial distribution, petrological, geochemical, and isotopic characteristics of quaternary volcanism. Journal of Petrology, **48**: 901–950. doi:10.1093/petrology/egm006.

Bordet, E., Mihalynuk, M.G., Hart, C.J.R., Mortensen, J.K., Friedman, R.M., and Gabites, J. 2014. Chronostratigraphy of eocene volcanism, central British Columbia. Canadian Journal of Earth Sciences, **51**: 56–103. doi:10.1139/cjes-2013-0073.

Burton, B.R., Lageson, D.R., Schmidt, C.J., Ballard, D.W., and Warne, J.R. 1998. Large magnitude shortening of the Lombard thrust system, Helena salient, Montana fold and thrust belt: implications for reconstruction of the Belt Basin. *In* Belt Symposium III. *Edited by* R.B. Berg. Montana Bureau of Mines and Geology Special Publication 112. pp. 229–243.

Bush, J.H., Thomas, R.C., and Pope, M.C. 2012. Sauk megasequence deposition in northeastern Washington, northern Idaho, and western Montana. *In* The great American carbonate bank: the geology and economic resources of the Cambrian–Ordovician Sauk megasequence of Laurentia. *Edited by* J.R. Derby, R.D. Fritz, S.A. Longacre, W.A. Morgan and C.A. Sternbach. AAPG Memoir 98. pp. 751–768.

Catuneanu, O., Sweet, A.R., and Miall, A.D. 2000. Reciprocal stratigraphy of the Campanian–Paleocene western interior of North America. Sedimentary Geology, **134**: 235–255. doi:10.1016/S0037-0738(00)00045-2.

Chamberlain, V.E., and Lambert, R.St J. 1985. Cordilleria, a newly defined Canadian microcontinent. Nature, **314**: 707–713. doi:10.1038/314707a0.

Chapin, C.E. 2012. Origin of the Colorado mineral belt. Geosphere, **8**: 28–43. doi:10.1130/GES00694.1.

Chapin, C.E., and Cather, S.M. 1983. Eocene tectonics and sedimentation in the Colorado Plateau–Rocky Mountain area. *In* Rocky Mountain Foreland basins and uplifts. *Edited by* J.D. Lowell and R. Gries. Rocky Mountain Association of Geologists, Denver, Colorado. pp. 33–56.

Chapman, R.M., Weber, F.R., Churkin, M., Jr., and Carter, C. 1980. The Livengood Dome Chert redefined as Ordovician and its relation to displacement on the Tintina Fault. U.S. Geological Survey Professional Paper 1126-F. pp. Fl–F13.

Chen, Y., Gu, Y.J., Currie, C.A., Johnston, S.T., Hung, S.-H., Schaeffer, A.J., and Audet, P. 2019. Seismic evidence for a mantle suture and implications for the origin of the Canadian Cordillera. Nature, **10**: 2249.

Cobban, W.A., Erdmann, C.E., Lemke, R.W., and Maughan, E.K. 1976. Type sections and stratigraphy of the members of the Blackleaf and Marias River formations (Cretaceous) of the Sweetgrass Arch, Montana. U.S. Geological Survey Professional Paper 974. U.S. Geological Survey, Reston, VA. 71p. doi:10.3133/pp974.

Cole, D., Myrow, P.M., Fike, D.A., Hakim, A., and Gehrels, G.E. 2015. Uppermost Devonian (Famennian) to lower mississippian events of the western U.S. Stratigraphy, sedimentology, chemostratigraphy, and detrital zircon geochronology. Palaeogeography, Palaeoclimatology, Palaeoecology, **427**: 1–19. doi:10.1016/j.palaeo.2015.03.014.

Collom, C.J., Johnston, P.A., and Powell, W.G. 2009. Reinterpretation of 'middle' Cambrian stratigraphy of the rifted western laurentian margin: Burgess Shale Formation and contiguous units (Sauk II megasequence), Rocky Mountains, Canada. Palaeogeography, Palaeoclimatology, Palaeoecology, **277**: 63–85. doi:10.1016/j.palaeo.2009.02.012.

Coney, P.J., and Reynolds, S.J. 1977. Cordilleran Benioff zones. Nature, **270**: 403–406. doi:10.1038/270403a0.

Constenius, K.N. 1996. Late Paleogene extensional collapse of the Cordilleran foreland fold and thrust belt. Geological Society of America Bulletin, **108**: 20–39. doi:10.1130/0016-7606(1996)108%3c0020:LPECOT%3e2.3.CO;2.

Constenius, K.N., Esser, R.P., and Layer, P.W. 2003. Extensional collapse of the Charleston-Nebo salient and its relationship to space–time variations in Cordilleran orogenic belt tectonism and continental stratigraphy. *In* Cenozoic systems of the Rocky Mountain Region. *Edited by* R.G. Raynolds and R.M. Flores. SEPM (Society for Sedimentary Geology), Denver, Colorado, Rocky Mountain Section. pp. 303–353.

Cook, D.G. 1970. A Cambrian facies change and its effect on structure, Mount Stephens–Mount Dennis area, Alberta–British Columbia. *In* Structure of the Southern Canadian Cordillera. *Edited by* J.O. Wheeler. Geological Association of Canada Special Paper 6, Toronto. pp. 27–39.

Cook, F.A., Albaugh, D.S., Brown, L.D., Kaufman, S., Oliver, J.E., and Hatcher, R.D., Jr. 1979. Thin-skinned tectonics in the crystalline southern Appalachians; COCORP seismic-reflection profiling of the Blue Ridge and Piedmont. Geology, **7**: 563–567. doi:10.1130/0091-7613(1979)7%3c563:TTITCS%3e2.0.CO;2.

Cowan, D.S., Brandon, M.T., and Garver, J.I. 1997. Geologic tests of hypotheses for large coastwise displacement—a critique illustrated by the Baja British Columbia controversy. American Journal of Science, **297**: 117–173. doi:10.2475/ajs.297.2.117.

Daniel, C.G., Indares, A., Medaris, L.G., Jr., Aronoff, R., Malone, D., and Schwartz, J. 2023. Linking the Pinware, Baraboo, and Picuris orogens: recognition of a transLaurentian ca. 1520–1340 ma orogenic belt. *In* Laurentia: turning points in the evolution of a continent. *Edited by* S.J. Whitmeyer, M.L. Williams, D.A. Kellett and B. Tikoff. Geological Society of America Memoir 220. pp. 1–16. doi:10.1130/2022.1220(11).

DeCelles, P.G. 2004. Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western USA. American Journal of Science, **304**: 105–168. doi:10.2475/ajs.304.2.105.

DeCelles, P.G., and Cavazza, W. 1999. A comparison of fluvial megafans in the Cordilleran (Late Cretaceous) and modern Himalayan foreland basin systems. Geological Society of America Bulletin, **111**: 1315–1334. doi:10.1130/0016-7606(1999)111⟨1315:ACOFMI⟩2.3.CO;2.

DeCelles, P.G., and Coogan, J.C. 2006. Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah. Geological Society of America Bulletin, **118**: 841–864. doi:10.1130/B25759.1.

Dickinson, W., and Snyder, W.S. 1978. Plate tectonics of the Laramide orogeny. *In* Laramide folding associated with basement block faulting in the Western United States. *Edited by* V. Matthews, III. Geological Society of America Memoir 151. pp. 335–366.

Dickinson, W.R., and Butler, R.F. 1998. Coastal and Baja California paleomagnetism reconsidered. Geological Society of America Bulletin, **110**: 1268–1280. doi:10.1130/0016-7606(1998)110%3c1268:CABCPR%3e2.3.CO;2.

Dickinson, W.R., Klute, M.A., Hayes, M.J., Janecke, S.U., Lundin, E.R., McKittrick, M.A., and Olivares, M.D. 1988. Paleogeographic and paleotectonic setting of Laramide sedimentary basins in the central Rocky Mountain region. Geological Society of America Bulletin, **100**: 1023–1039. doi:10.1130/0016-7606(1988)100⟨1023:PAPSOL⟩2.3.CO;2.

Doubrovine, P.V., and Tarduno, J.A. 2008. A revised kinematic model for the relative motion between Pacific oceanic plates and North America since the Late Cretaceous. Journal of Geophysical Research: Solid Earth, **113**: B12101. doi:10.1029/2008JB005585.

Dumitru, T.A., Gans, P.B., Foster, D.A., and Miller, E.L. 1991. Refrigeration of the western Cordilleran lithosphere during Laramide shallow-angle subduction. Geology, **19**: 1145–1148. doi:10.1130/0091-7613(1991)019⟨1145:ROTWCL⟩2.3.CO;2.

Ehlig, P.L. 1981. Origin and tectonic history of the basement terrane of the San Gabriel Mountains, central Transverse Ranges. *In* The geotectonic development of California, Rubey. Vol. I. *Edited by* W.G. Ernst. Prentice-Hall, Englewood Cliffs, New Jersey. pp. 253–283.

Engebretson, D.C., Cox, A., and Gordon, R.G. 1985. Relative motions between oceanic and continental plates in the Pacific Basin. Geological Society of America Special Paper 206. 59p.

English, J., Johnston, S.T., and Wang, K. 2003. Thermal modelling of the Laramide orogeny: testing the flat-slab subduction hypothe-

sis. Earth and Planetary Science Letters, **214**: 619–632. doi:10.1016/S0012-821X(03)00399-6.

Enkin, R.J. 2006. Paleomagnetism and the case for Baja British Columbia. *In* Paleogeography of the North American Cordillera: evidence for and against large-scale displacements. *Edited by* J.W. Haggart, R.J. Enkin and J.W.H. Monger. Geological Association of Canada Special Paper 46, St. John's, Newfoundland. pp. 233–254.

Enkin, R.J., Johnston, S.T., Larson, K.P., and Baker, J. 2006a. Paleomagnetism of the 70 Ma Carmacks Group at Solitary Mountain, Yukon, confirms and extends controversial results: further evidence for the Baja British Columbia model. *In* Paleogeography of the North American Cordillera: evidence for and against large-scale displacements. *Edited by* J.W. Haggart, R.J. Enkin and J.W.H. Monger. Geological Association of Canada Special Paper 46, St. John's, Newfoundland. pp. 221–232.

Enkin, R.J., Mahoney, J.B., and Baker, J. 2006b. Paleomagnetic signature of the Silverquick/Powell Creek succession, south-central British Columbia: reaffirmation of late cretaceous large-scale terrane translation. *In* Paleogeography of the North American Cordillera: evidence for and against large-scale displacements. *Edited by* J.W. Haggart, R.J. Enkin and J.W.H. Monger. Geological Association of Canada Special Paper 46, St. John's, Newfoundland. pp. 201–220.

Enkin, R.J., Mahoney, J.B., Baker, J., Kiessling, M., and Haugerud, R.A. 2002. Syntectonic remagnetization in the southern Methow block: resolving large displacements in the southern Canadian Cordillera. Tectonics, **21**. doi:10.1029/2001TC001294.

Enkin, R.J., Osadetz, K.G., Baker, J., and Kisilevsky, D. 2000. Orogenic remagnetizations in the Front Ranges and inner foothills of the southern Canadian Cordillera: chemical harbinger and thermal handmaiden of Cordilleran deformation. Geological Society of America Bulletin, **112**: 929–942. doi:10.1130/0016-7606(2000)112⟨929:ORITFR⟩2.0.CO;2.

Erskine, M.C. 1997. The Oquirrh Basin revisited. Bulletin of the American Association of Petroleum Geologists, **81**: 624–636.

Fan, M., and Carrapa, B. 2014. Late Cretaceous–Early Eocene Laramide uplift, exhumation, and basin subsidence in Wyoming: crustal responses to flat slab subduction. Tectonics, 509–529, **33**:. doi:10.1002/2012TC003221.

Farmer, G.L., Ayuso, R., and Plafker, G. 1993. A Coast Mountains provenance for the Valdez and Orca groups, southern Alaska, based on Nd, Sr, and Pb isotopic evidence. Earth and Planetary Science Letters, **116**: 9–21. doi:10.1016/0012-821X(93)90042-8.

Faulds, J.E., Feuerbach, D.L., Miller, C.F., and Smith, E.I. 2001. Cenozoic evolution of the Northern Colorado River Extensional Corridor, southern Nevada and northwestern Arizona. *In* The geologic transition, high plateaus to great basin—a Symposium and Field Guide. The Mackin Volume. *Edited by* M.C. Erskine, J.E. Faulds, J.M. Bartley and P.D. Rowley. Utah Geological Association Publication 30—Pacific Section American Association of Petroleum Geologists Publication GB 78. pp. 239–271.

Fermor, P. 1999. Aspects of the three-dimensional structure of the Alberta Foothills and Front Ranges. Geological Society of America Bulletin, **111**: 317–346. doi:10.1130/0016-7606(1999)111⟨0317:AOTTDS⟩2.3.CO;2.

Frost, E.G., Martin, D.L., and Krummenacher, D. 1982. Mid-tertiary detachment faulting in southwestern Arizona and California and its overprint on the Vincent thrust system. Geological Society of America Abstracts with Programs, **14**(4): 164

Fuentes, F., DeCelles, P.G., Constenius, K.N., and Gehrels, G.E. 2010. Evolution of the Cordilleran foreland basin system in northwestern Montana, U.S.A. Geological Society of America Bulletin, **123**: 507–533. doi:10.1130/B30204.1.

Gabrielse, H. 1985. Major dextral transcurrent displacements along the Northern Rocky Mountain Trench ad related lineaments in north-central British Columbia. Geological Society of America Bulletin, **96**: 1–14. doi:10.1130/0016-7606(1985)96%3c1:MDTDAT%3e2.0.CO;2.

Gabrielse, H., Murphy, D.C., and Mortensen, J.K. 2006. Cretaceous and Cenozoic dextral orogen-parallel displacements, magmatism, and paleogeography, north-central Canadian Cordillera. *In* Paleogeography of the North American Cordillera: evidence for and against large-scale displacements. *Edited by* J.W. Haggart, R.J. Enkin and J.W.H. Monger. Geological Association of Canada Special Paper 46, St. John's, Newfoundland. pp. 255–276.

Garber, K.L., Finzel, E.S., and Pearson, D.M. 2020. Provenance of synorogenic foreland basin strata in southwestern Montana requires revision of existing models for Laramide tectonism: North American Cordillera. Tectonics, **39**: e2019TC005944. doi:10.1029/2019TC005944.

Garver, J.L., and Davidson, C.M. 2015. Southwestern Laurentian zircons in upper Cretaceous flysch of the Chugach–Prince William terrane in Alaska. American Journal of Science, **315**: 537–556. doi:10.2475/06.2015.02.

Gastil, G. 1991. Is there a Oaxaca–California megashear? Conflict between paleomagnetic data and other elements of geology. Geology, **19**: 502–505. doi:10.1130/0091-7613(1991)019%3c0502:ITAOCM%3e2.3.CO;2.

Geslin, J.K. 1998. Distal ancestral Rocky Mountain tectonism: evolution of the Pennsylvanian–Permian Oquirrh-Wood River basin, southern Idaho. Geological Society of America Bulletin, **110**: 644–663. doi:10.1130/0016-7606(1998)110%3C0644:DARMTE%3E2.3.CO;2.

Giles, K.A., Bocko, M., and Lawton, T.F. 1999. Stacked late Devonian lowstand shorelines and their relation to tectonic subsidence at the Cordilleran hingeline, western Utah. Journal of Sedimentary Research, **69**: 1181–1190. doi:10.2110/jsr.69.1181.

Giorgis, S., McClelland, W., Fayon, A., Singer, B.S., and Tikoff, B. 2008. Timing of deformation and exhumation in the western Idaho shear zone, McCall, Idaho. Geological Society of America Bulletin, **120**: 1119–1133. doi:10.1130/B26291.1.

Gladwin, K., and Johnston, S.T. 2006. Mid-Cretaceous pinning of accreted terranes to miogeoclinal assemblages in the northern Cordillera: irreconcilable with paleomagnetic data. *In* Paleogeography of the North American Cordillera: evidence for and against large-scale displacements. *Edited by* J.W. Haggart, R.J. Enkin and J.W.H. Monger. Geological Association of Canada Special Paper 46, St. John's, Newfoundland. 299–306.

Glazner, A.F., and Supplee, J.A. 1982. Migration of tertiary volcanism in the southwestern United States and subduction of the Mendocino fracture zone: Earth and Planetary Science Letters, **60**: 429–436. doi:10.1016/0012-821X(82)90078-4.

Granirer, J.L., Burmester, R.F., and Beck, M.E. 1986. Cretaceous paleomagnetism of the Methow-Pasayten belt, Geophysical Research Letters, **13**: 733–736. doi:10.1029/GL013i008p00733.

Gries, B. 1983. North–south compression of Rocky Mountain foreland structures. *In* Mountain Foreland basins and uplifts. *Edited by* J.D. Lowell and R. Gries. Rocky Mountain Association of Geologists, Denver, Colorado. pp. 9–32.

Grommé, C.S., Beck, M.E., Jr., and Engebretson, D.C. 1986. Paleomagnetism of the Tertiary Clarno Formation of central Oregon and its significance for the tectonic history of the Pacific Northwest. Journal of Geophysical Research: Solid Earth, **91**: 14089–14103. doi:10.1029/JB091iB14p14089.

Grove, M., Lovera, O., and Harrison, M. 2003. Late Cretaceous cooling of the east-central Peninsular Ranges batholith (33°N): relationship to La Posta pluton emplacement, Laramide shallow subduction, and forearc sedimentation, *In* Tectonic evolution of Northwestern Mexico and the Southwestern USA. *Edited by* S.E. Johnson, S.R. Patterson, J.M. Fletcher, G.H. Girty, D.L. Kimbrough and A. Martín-Barajas. Geological Society of America Special Paper 374. pp. 355–379. doi:10.1130/0-8137-2374-4.355.

Hamilton, W.B. 1988. Laramide crustal shortening. *In* Interaction of the Rocky Mountain Foreland and the Cordilleran Thrust Belt. *Edited by* C.J. Schmidt and W.J. Perry, Jr. Geological Society of America Memoir 171. pp. 27–39. doi:10.1130/MEM171-p27.

Hart, C.J.R., Goldfarb, R.J., Lewis, L.L., and Mair, J.L. 2004. The northern Cordillera mid-Cretaceous plutonic province: ilmenite/magnetite-series granitoids and intrusion-related mineralisation. Resource Geology, **54**: 253–280. doi:10.1111/j.1751-3928.2004.tb00206.x.

Hatcher, R.D., Jr. 2010. The Appalachian orogen: a brief summary. *In* From Rodinia to Pangea: the lithotectonic record of the Appalachian Region. *Edited by* R.P. Tollo, M.J. Bartholomew, J.P. Hibbard and P.M. Karabinos. Geological Society of America Memoir 206. pp. 1–19. doi:10.1130/2010.1206(01).

Hatcher, R.D., Jr., Lemiszki, P.J., and Whisner, J.B. 2007. Character of rigid boundaries and internal deformation of the southern Appalachian foreland fold-thrust belt. *In* Whence the mountains? Inquiries into the evolution of orogenic systems: a volume in honor of Raymond A.

Price. *Edited by* J.W. Sears, T.A. Harms and C.A. Evenchick. Geological Society of America Special Paper 433. pp. 243–276. doi:10.1130/2007.2433(12).

Haxel, G.B., and Dillon, J.T. 1978. The Pelona-Orocopia Schist and Vincent–Chocolate Mountain thrust system, southern California. *In* Pacific Coast Paleogeography Symposium 2: Mesozoic Paleogeography of the Western United States. *Edited by* D.G. Howell and K.A. McDougall. Pacific Section, Society of Economic Paleontologists and Mineralogists, Los Angeles. pp. 453–469.

Haxel, G.B., Epstein, G.S., Jacobson, C.E., Wittke, J.H., Standlee, K.G., and Mulligan, S.R. 2022. Mantle peridotite and associated metasomatic rocks in the Orocopia Schist subduction channel (latest Cretaceous) at Cemetery Ridge, southwest Arizona: geologic map, petrology, and structural setting: Arizona Geological Survey contributed report CR-22-X, map scale 1:2000. 88p.

Haxel, G.B., Jacobson, C.E., Richard, S.M., Tosdal, R.M., and Grubensky, M.J. 2002. The Orocopia Schist in southwest Arizona: early tertiary oceanic rocks trapped or transported far inland. *In* Contributions to crustal evolution of the Southwestern United States. *Edited by* A. Barth. Geological Society of America Special Paper 365. pp. 99–128.

Hearn, B.C., Jr. 1976. Geologic and tectonic maps of the Bearpaw Mountains area, north-central Montana. U.S. Geological Survey Miscellaneous Investigations Map I-919.

Hearn, B.C., Jr., Pecora, W.T., and Swadley, W.C. 1964. Geology of the Rattlesnake quadrangle, Bearpaw Mountains, Blaine county, Montana. U.S. Geological Survey Bulletin 1181-B. p. 65p.

Henderson, L.J., Gordon, R.G., and Engebretson, D.C. 1984. Mesozoic aseismic ridges on the Farallon plate and southward migration of shallow subduction during the Laramide orogeny. Tectonics, **3**: 121–132. doi:10.1029/TC003i002p00121.

Henry, C.D., and Aranda-Gomez, J.J. 1992. The real southern Basin and Range: mid- to late Cenozoic extension in Mexico. Geology, **20**: 701–704. doi:10.1130/0091-7613(1992)020%3c0701:TRSBAR%3e2.3.CO;2.

Henry, C.D., and Aranda-Gomez, J.J. 2000. Plate interactions control middle–late Miocene, proto-Gulf and Basin and Range extension in the southern Basin and Range. Tectonophysics, **318**: 1–26. doi:10.1016/S0040-1951(99)00304-2.

Hildebrand, R.S. 2009. Did westward subduction cause Cretaceous–Tertiary orogeny in the North American Cordillera? Geological Society of America Special Paper **457**: 71. doi:10.1130/2009.2457.

Hildebrand, R.S. 2013. Mesozoic assembly of the North American Cordillera. Geological Society of America Special Paper 495. p. 169p. doi:10.1130/2013.2495.

Hildebrand, R.S. 2014. Geology, mantle tomography, and inclination corrected paleogeographic trajectories support westward subduction during cretaceous orogenesis in the North American Cordillera. Geoscience Canada, **41**: 207–224. doi:10.12789/geocanj.2014.41.032.

Hildebrand, R.S. 2015. Dismemberment and northward migration of the Cordilleran orogen: Baja-BC resolved. GSA Today, **25**(11): 4–11. doi:10.1130/GSATG255A.1.

Hildebrand, R.S., and Whalen, J.B. 2014. Arc and slab-failure magmatism in Cordilleran batholiths I—the Cretaceous Coastal batholith of Peru and its role in South American orogenesis and hemispheric subduction flip. Geoscience Canada, **41**: 255–282. doi:10.12789/geocanj.2014.41.047.

Hildebrand, R.S., and Whalen, J.B. 2017. The tectonic setting and origin of Cretaceous batholiths within the North American Cordillera: the case for slab failure magmatism and its significance for crustal growth. Geological Society of America Special Paper 532. Geological Society of America, Boulder, CO. 113p.

Hildebrand, R.S., and Whalen, J.B. 2021a. The mid-cretaceous Peninsular Ranges orogeny: a new slant on Cordilleran tectonics? I: Mexico to Nevada. Canadian Journal of Earth Sciences, **58**: 670–696. doi:10.1139/cjes-2020-0154.

Hildebrand, R.S., and Whalen, J.B. 2021b. The mid-Cretaceous Peninsular Ranges orogeny: a new slant on Cordilleran tectonics? II: northern United States and Canada. Canadian Journal of Earth Sciences, **58**: 697–719. doi:10.1139/cjes-2021-0006.

Hildebrand, R.S., Bhattacharya, J., and Whalen, J.B. 2023. The mid-Cretaceous Peninsular Ranges orogeny: a new slant on Cordilleran tectonics? III: the collisional foredeep. Canadian Journal of Earth Sciences, **60**: 214–262. doi:10.1139/cjes-2022-0089.

Hine, A.C., and Mullins, H.T. 1983. Modern carbonate shelf slope breaks. *In* The shelfbreak: critical interface on continental margins. *Edited by* D.J. Stanley and G.T. Moore. Society of Economic Paleontologists and Mineralogists Special Publication 33. pp. 169–188. doi:10.2110/pec.83.33.

Hirtz, J.A.M., Constenius, K.N., Horton, B.K., Valencia, V.A., and Pratt, B.R. 2024. Continental-scale drainage reorganization during Mesoproterozoic orogenesis: evidence from the Belt Basin of western North America. Geosphere, **20**: 1133–1161. doi:10.1130 /GES02732.1.

Housen, B.A. 2018. Paleomagnetism and rotation history of the Blue Mountains, Oregon, USA. *In* Tectonics, sedimentary basins, and provenance: a celebration of William R. Dickinson's career. *Edited by* R.V. Ingersoll, T.F. Lawton and S.A. Graham. Geological Society of America Special Paper 540. pp. 223–233. doi:10.1130/2018.2540(10).

Housen, B.A., and Dorsey, R.J. 2005. Paleomagnetism and tectonic significance of Albian and Cenomanian turbidites, Ochoco Basin, Mitchell Inlier, central Oregon. Journal of Geophysical Research: Solid Earth, **110**: B07102. doi:10.1029/2004JB003458.

Housen, B.A., Roeske, S.M., Gallen, S., and O'Donnell, K. 2008. Paleomagnetism of the Paleocene Ghost Rocks, Kodiak Islands, Alaska: implications for Paleocene Pacific-Basin/North America Plate configurations. Eos (Transactions, American Geophysical Union), **89**(53): Fall Meeting Supplement, abstract GP44A-02.

Humphreys, E. 2009. Relation of flat subduction to magmatism and deformation in the western United States. *In* Backbone of the Americas: shallow subduction, plateau uplift, and ridge and terrane collision. *Edited by* S.M. Kay, V.A. Ramos and W.R. Dickinson. W.R. Geological Society of America Memoir 204. pp. 85–98. doi:10.1130/2009.1204(04).

Irving, E. 1979. Paleopoles and paleolatitudes of North America and speculations about displaced terranes. Canadian Journal of Earth Sciences, **16**: 669–694. doi:10.1139/e79-065.

Irving, E. 1985. Whence British Columbia? Nature, **314**: 673–674. doi:10.1038/314673a0.

Irving, E., and Brandon, M.T. 1990. Paleomagnetism of the Flores volcanics, Vancouver Island, in place by eocene time. Canadian Journal of Earth Sciences, **27**: 811–817. doi:10.1139/e90-083.

Irving, E., and Wynne, P.J. 1991. Paleomagnetic evidence for motions of parts of the Canadian Cordillera. Tectonophysics, **187**: 259–275.

Irving, E., Wynne, P.J., Evans, M.E., and Gough, W. 1986. Anomalous paleomagnetism of the Crowsnest Formation of the Rocky Mountains. Canadian Journal of Earth Sciences, **23**: 591–598. doi:10.1139/e86-061.

Irving, E., Wynne, P.J., Thorkelson, D.J., and Schiarizza, P. 1996. Large (1000–4000 km) northward movements of tectonic domains in the northern Cordillera, 83 to 45 ma. Journal of Geophysical Research: Solid Earth, **101**: 17901–17916. doi:10.1029/96JB01181.

Irving, R. 1988. The paleomagnetic confirmation of continental drift. Eos, Transactions American Geophysical Union, **69**: 994–1014. doi:10.1029/88EO01169.

Jacobson, C.E., Grove, M., Pedrick, J.N., Barth, A.P., Marsaglia, K.M., Gehrels, G.E., and Nourse, J.A. 2011. Late Cretaceous–Early Cenozoic tectonic evolution of the southern California margin inferred from provenance of trench and forearc sediments. Geological Society of America Bulletin, **123**: 485–506. doi:10.1130/B30238.1., , (), .

Jacobson, C.E., Grove, M., Vuc´ic´, A., Pedrick, J.N., and Ebert, K.A. 2007. Exhumation of the Orocopia Schist and associated rocks of southeastern California: relative roles of erosion, synsubduction tectonic denudation, and middle Cenozoic extension. *In* Convergent margin terranes and associated regions: a tribute to W.G. Ernst. *Edited by* M. Cloos, W.D. Carlson, M.C. Gilbert, J.G. Liou and S.S. Sorensen. Geological Society of America Special Paper 419. pp. 1–37. doi:10.1130/2007.2419(01).

James, N.P., and Mountjoy, E.W. 1983. Shelf-slope break in fossil carbonate platforms: an overview. SEPM Special Publication 33. pp. 189–206.

Jepson, G., Carrapa, B., Reeher, L.J., DeCelles, P.G., Afonso, W.D., Howlett, C.J. et al. 2025. Regional exhumation of the Laramide Province. Geological Society of America Bulletin, doi: 10.1130/B37625.1.

Johnston, S.T., Wynne, P.J., Francis, D., Hart, C.J.R., Enkin, R.J., and Engebretson, D.C. 1996. Yellowstone in Yukon: the late Cretaceous Car-

macks group. Geology, **24**: 997–1000. doi:10.1130/0091-7613 (1996) 024⟨0997:YIYTLC⟩2.3.CO;2.

Jones, G.H., Farmer, L., Sageman, B., and Zhong, S. 2011. Hydrodynamic mechanism for the Laramide orogeny. Geosphere, **7**: 183–201. doi:10.1130/GES00575.1.

Jones, J.V., Daniel, C.G., and Doe, M.F. 2015. Tectonic and sedimentary linkages between the Belt-Purcell basin and southwestern Laurentia during the Mesoproterozoic, ca.1.60–1.40 Ga. Lithosphere, **7**: 465–472. doi:10.1130/L438.1.

Kent, D.V., and Irving, E. 2010. Influence of inclination error in sedimentary rocks on the Triassic and Jurassic apparent pole wander path for North America and implications for Cordilleran tectonics. Journal of Geophysical Research: Solid Earth, **115**: B10103. doi:10.1029/2009JB007205.

Kent, D.V., and Witte, W.K. 1993. Slow apparent polar wander for North America in the late Triassic and large Colorado Plateau rotation. Tectonics, **12**: 291–300. doi:10.1029/92TC01966.

Keppie, J.D., and Dostal, J. 2001. Evaluation of the Baja controversy using paleomagnetic and faunal data, plume magmatism, and piercing points. Tectonophysics, **339**: 427–442. doi:10.1016/S0040-1951(01)00126-3.

Kim, B., and Kodama, K.P. 2004. A compaction correction for the paleomagnetism of the Nanaimo Group sedimentary rocks: implications for the Baja British Columbia hypothesis. Journal of Geophysical Research: Solid Earth, **109**: B02102. doi:10.1029/2003JB002696.

King, P.B. 1969. The tectonics of North America—a discussion to accompany the tectonic Map of North America. U.S. Geological Survey Professional Paper 628, scale 1:5,000,000. 95p.

Kochelek, E.J., Amato, J.M., Pavlis, T.L., and Clift, P.D. 2011. Flysch deposition and preservation of coherent bedding in an accretionary complex: detrital zircon ages from the Upper cretaceous Valdez Group, Chugach terrane, Alaska. Lithosphere, **3**: 265–274. doi:10.1130/L131.1.

Kochelek, E.J., and Amato, J.M. 2010. Detrital zircon ages from the Valdez Group indicate rapid latest Cretaceous deposition in the Chugach accretionary complex, southern Alaska. Geological Society of America Abstracts with Programs, **42**(4): 46.

Larson, K.P., and Price, R.A. 2006. The southern termination of the Western Main Ranges of the Canadian Rockies, near Fort Steele, British Columbia: stratigraphy, structure, and tectonic implications. Bulletin of Canadian Petroleum Geology, **54**: 37–61. doi:10.2113/54.1.37.

Larson, K.P., Price, R.A., and Archibald, D.A. 2006. Tectonic implications of $^{40}Ar/^{39}Ar$ muscovite dates from the Mt. Haley stock and Lussier River stock, near Fort Steele, British Columbia. Canadian Journal of Earth Sciences, **43**: 1673–1684. doi:10.1139/e06-048.

Lawton, T.F. 2008. Laramide sedimentary basins. *In* The sedimentary basins of the United States and Canada. *Edited by* A.D. Miall. Elsevier, Amsterdam, Netherlands. pp. 429–450. doi:10.1016/S1874-5997(08)00012-9.

Leckie, D.A., Bhattacharya, J.P., Bloch, J., Gilboy, C.F., and Norris, B. 1994. Chapter 20—Cretaceous Colorado/Alberta Group of the western Canada sedimentary basin. *In* Geological atlas of the western Canadian sedimentary basin. *Edited by* G.D. Mossop and I. Shetson. Canadian Society of Petroleum Geologists and Alberta Research Council, Calgary, AB. pp. 335–352.

Lee, C.-T., Yin, Q., Rudnick, R.L., and Jacobsen, S.B. 2001. Preservation of ancient and fertile lithospheric mantle beneath the southwestern United States. Nature, **411**: 69–73. doi:10.1038/35075048.

Lee, C.-T., Yin, Q., Rudnick, R.L., Chesley, J.T., and Jacobsen, S.B. 2000. Osmium isotopic evidence for Mesozoic removal of lithospheric mantle beneath the Sierra Nevada, California. Science, **289**: 1912–1916. doi:10.1126/science.289.5486.1912.

Leech, G.B. 1966. Rocky Mountain Trench. Geological Survey of Canada Paper 66-14. pp. 307–329.

Link, P.K., Fanning, C.M., Lund, K.I., and Aleinikoff, J.N. 2007. Detrital zircon populations and provenance of Mesoproterozoic strata of east-central Idaho, USA: correlation with Belt Supergroup of southwest Montana. *In* Proterozoic geology of Western North America and Siberia. *Edited by* P.K. Link and R.S. Lewis. Society for Sedimentary Geology Special Publication 86. pp. 101–128. doi:10.2110/pec.07.86.0101.

Link, P.K., Mahon, R.C., Berenek, L.P., Campbell-Stone, E.A., and Lynds, R. 2014. Detrital zircon provenance of Pennsylvanian to Permian sandstones from the Wyoming craton and Wood River Basin, Idaho, U.S.A. Rocky Mountain Geology, **49**: 115–136. doi:10.2113/gsrocky.49.2.115.

Link, P.K., Stewart, E.D., Steel, T., Sherwin, J.-A., Hess, L.T., and McDonald, C. 2016. Detrital zircons in the Mesoproterozoic upper Belt Supergroup in the Pioneer, Beaverhead, and Lemhi Ranges, Montana and Idaho: the Big White arc. *In* Belt Basin: window to Mesoproterozoic Earth. *Edited by* J.S. MacLean and J.W. Sears. Geological Society of America Special Paper 522. pp. 1–22. doi:10.1130/2016.2522(07).

Lipman, P.W., Prostka, H.J., and Christiansen, R.L. 1971. Evolving subduction zones in the western United States, as interpreted from igneous rocks. Science, **174**: 821–825. doi:10.1126/science.174.4011.821.

Liu, L., and Stockli, D.F. 2020. U–Pb ages of detrital zircons in lower Permian sandstone and siltstone of the Permian Basin, west Texas, USA: evidence of dominant Gondwanan and peri-Gondwanan sediment input to Laurentia. GSA Bulletin, **132**: 245–262. doi:10.1130/B35119.1.

Liu, L., Gurnis, M., Seton, M., Saleeby, J., Müller, R.D., and Jackson, J. 2010. The role of oceanic plateau subduction in the Laramide orogeny. Nature Geoscience, **3**: 353–357. doi:10.1038/ngeo829.

Liu, S.F., Nummedal, D., Yin, P.G., and Luo, H.J. 2005. Linkage of Sevier thrust episodes and late Cretaceous megasequences across southern Wyoming (USA). Basin Research, **17**: 487–506. doi:10.1111/j.1365-2117.2005.00277.x.

Livaccari, R.F., and Perry, F.V. 1993. Isotopic evidence for preservation of Cordilleran lithospheric mantle during the Sevier-Laramide orogeny, western United States. Geology, **21**: 719–722. doi:10.1130/0091 -7613(1993)021⟨0719:IEFPOC⟩2.3.CO;2.

Livaccari, R.F., Burke, K., and Şengör, A.M.C. 1981. Was the Laramide orogeny related to subduction of an oceanic plateau? Nature, **289**: 276–278. doi:10.1038/289276a0.

Logan, J.M. 2002. Intrusion-related mineral occurrences of the Bayonne magmatic belt, southeast British Columbia. British Columbia Ministry of Energy and Mines Geoscience Map 2002-1, scale 1:500,000 map, with marginal tables.

Lonsdale, P.F. 1989. Geology and tectonic history of the Gulf of California. *In* The Eastern Pacific Ocean and Hawaii. *Edited by* E.L. Winterer, D.M. Hussong and R.W. Decker. Geological Society of America, Boulder, Colorado. pp. 499–521. doi:10.1130/DNAG-GNA-N.499.

Lowell, J.D. 1974. Plate tectonics and foreland basement deformation. Geology, **2**: 275–278. doi:10.1130/0091-7613(1974)2⟨275:PTAFBD⟩2.0.CO;2.

Lund, K., Aleinikoff, J.N., Yacob, E.Y., Unruh, D.M., and Fanning, C.M. 2008. Coolwater culmination: sensitive high-resolution ion microprobe (SHRIMP) U–Pb and isotopic evidence for continental delamination in the Syringa Embayment, Salmon River suture, Idaho. Tectonics, **27**: TC2009. doi:10.1029/2006TC002071.

Lund, S.P., Bottjer, D.J., Whidden, K.J., Powers, J.E., and Steele, M.C. 1991. Paleomagnetic evidence for terrane displacements and accretion in southern California. *In* Eocene geologic history, San Diego region. *Edited by* P.L. Abbott and J.A. May. Pacific Section, Society for Sedimentary Geology (SEPM) Book 68. pp. 99–10.

Mahoney, J.B., Haggart, J.W., Grove, M., Kimbrough, D.L., Isava, V., Link, P.K., et al. 2021. Evolution of the Late Cretaceous Nanaimo Basin, British Columbia, Canada: definitive provenance links to northern latitudes. Geosphere, **17**: 1–37. doi:10.1130 /GES02394.1.

Mahoney, J.B., Mustard, P.S., Haggart, J.W., Friedman, R.M., Fanning, C.M., and McNicoll, V.J. 1999a. Archean zircons in Cretaceous strata of the western Canadian Cordillera: the "Baja B.C." hypothesis fails a "crucial test. Geology, **27**: 195–198. doi:10.1130/0091-7613(1999)027%3c0195:AZICSO%3e2.3.CO;2.

Mahoney, J.B., Tikoff, B., Maxson, J., and Haugerud, R.A. 1999b. Terrane accretion along the western Cordilleran margin: constraints on timing and displacement. GSA Today, **10**(2): 11–13.

Mair, J.L., Hart, C.J.R., and Stephens, J.R. 2006. Deformation history of the northwestern Selwyn Basin, Yukon, Canada: implications for orogen evolution and mid-cretaceous magmatism. Geological Society of America Bulletin, **118**: 304–323. doi:10.1130/B25763.1.

Malin, P.E., Goodman, E.D., Henyey, T.L., Li, Y.G., Okaya, D.A., and Saleeby, J.B. 1995. Significance of seismic reflections beneath a tilted exposure of deep continental crust, Tehachapi Mountains, California. Journal of Geophysical Research: Solid Earth, **100**: 2069–2087. doi:10.1029/94JB02127.

Manduca, C.A., Kuntz, M.A., and Silver, L.T. 1993. Emplacement and deformation history of the western margin of the Idaho batholith near McCall, Idaho: influence of a major terrane boundary. Geological Society of America Bulletin, **105**: 749–765. doi:10.1130/0016-7606(1993)105⟨0749:EADHOT⟩2.3.CO;2.

Manduca, C.A., Silver, L.T., and Taylor, H. 1992. 87Sr/86Sr and 19O/16O isotopic systematics and geochemistry of granitoid plutons across a steeply-dipping boundary between contrasting lithospheric blocks in western Idaho. Contributions to Mineralogy and Petrology, **109**: 355–372. doi:10.1007/BF00283324.

Marquis, G., and Globerman, B.R. 1988. Northward motion of the Whitehorse Trough: paleomagnetic evidence from the upper cretaceous Carmacks Group. Canadian Journal of Earth Sciences, **25**: 2005–2016. doi:10.1139/e88-187.

Marvin, R.F., Hearn, B.C., Jr., Mehnert, H.H., Naeser, C.W., Zartman, R.E., and Lindsey, D.A. 1980. Late cretaceous–Paleocene–Eocene igneous activity in north-central Montana. Isochron-West, **29**: 5–25.

Matzel, J.E.P., Bowring, S.A., and Miller, R.B. 2004. Protolith age of the Swakane gneiss, North Cascades, Washington: evidence of rapid underthrusting of sediments beneath an arc. Tectonics, **23**: TC6009. doi:10.1029/2003TC001577.

Maxson, J., and Tikoff, B. 1996. Hit-and-run collision model for the Laramide orogeny, western United States. Geology, **24**: 968–972. doi:10.1130/0091-7613(1996)024⟨0968:HARCMF⟩2.3.CO;2.

McMannis, W.J. 1965. Resume of depositional and structural history of western Montana. American Association of Petroleum Geologists Bulletin, **49**: 1801–1823.

McMechan, M.E. 1987. Stratigraphy and structure of the Mount Selwyn area, Rocky Mountains, northeastern British Columbia. Geological Survey of Canada Paper 85-28. 34p.

McMechan, M.E. 1995. Rocky Mountain Foothills and Front Ranges in Kananaskis country, southwest of Calgary, Alberta. Geological Survey of Canada, Map 1865A, 1:100,000 scale.

McMechan, M.E. 2001. Large-scale duplex structures in the McConnell thrust sheet, Rocky Mountains, Southwest Alberta. Bulletin of Canadian Petroleum Geology, **49**: 408–425. doi:10.2113/49.3.408.

McMechan, M.E., Root, K.G., Simony, P.S., and Pattison, D.R.M. 2020. Nailed to the craton: stratigraphic continuity across the southeastern Canadian Cordillera with tectonic implications for ribbon continent models. Geology, **49**: 101–105. doi:10.1130/G48060.1.

Miller, D.M., Nilsen, T.H., and Bilodeau, W.L. 1992. Late cretaceous to early eocene geologic evolution of the U.S. Cordillera. *In* The Cordilleran Orogen: conterminous U.S. *Edited by* B.C. Burchfiel, P.W. Lipman and M.L. Zoback. Geological Society of North America, Boulder, Colorado. pp. 205–231. doi:10.1130/DNAG-GNA-G3.205.

Miller, F.K., and Morton, D.M. 1980. Potassium-argon geochronology of the eastern Transverse Ranges and southern Mojave Desert, Southern California. U.S. Geological Survey Professional Paper 1152. 30p.

Miller, R.B., Gordon, S.M., Bowring, S.A., Doran, B.A., McLean, N.M., Michels, Z.D., et al. 2009. Linking deep and shallow crustal processes in an exhumed continental arc, North Cascades, Washington. *In* Volcanoes to vineyards: geologic field trips through the dynamic landscape of the Pacific Northwest. *Edited by* J.E. O'Connor, R.J. Dorsey and I.P. Madin. Geological Society of America Field Guide 15. pp. 373–406. doi:10.1130/2009.fld015(19).

Miura, S., Suyehiro, K., Shinohara, M., Takahashi, N., Araki, E., and Taira, A. 2004. Seismological structure and implications of collision between the Ontong Java Plateau and Solomon Island Arc from ocean bottom seismometer–airgun data. Tectonophysics, **389**: 191–220. doi:10.1016/j.tecto.2003.09.029.

Monger, J.W.H., and Irving, E. 1980. Northward displacement of north-central British Columbia. Nature, **285**: 289–294. doi:10.1038/285289a0.

Monger, J.W.H., Price, R.A., and Templeman-Kluitt, D. 1982. Tectonic accretion and the origin of two metamorphic and plutonic welts in the Canadian Cordillera. Geology, **10**: 70–75. doi:10.1130/0091-7613(1982)10⟨70:TAATOO⟩2.0.CO;2.

Monger, J.W.H., van der Heyden, P., Journeay, J.M., Evenchick, C.A., and Mahoney, J.B. 1994. Jurassic–Cretaceous basins along the Canadian Coast Belt: their bearing on pre-mid-cretaceous sinistral displacements. Geology, **22**: 175–178. doi:10.1130/0091-7613(1994)022⟨0175:JCBATC⟩2.3.CO;2.

Moore, J.C., Byrne, T., Plumley, P.W., Reid, M., Gibbons, H., and Coe, R.S. 1983. Paleogene evolution of the Kodiak Islands, Alaska: consequences of ridge-trench interaction in a more southerly latitude. Tectonics, **2**: 265–293. doi:10.1029/TC002i003p00265.

Mullins, H.T., and Hine, A.C. 1989. Scalloped bank margins: beginning of the end for carbonate platforms? Geology, **17**: 30–33. doi:10.1130/0091-7613(1989)017%3c0030:SBMBOT%3e2.3.CO;2.

Murphy, D.C. 1990a. Stratigraphy and structure, southern Rocky Mountain Trench to the headwaters of the North Thompson River, Cariboo Mountains, British Columbia. *In* Current Research, Part E, Geological Survey of Canada, Paper 90-IE. pp. 71–80.

Murphy, D.C. 1990b. Direct evidence for dextral strike-slip displacement from mylonites in the southern Rocky Mountain Trench near Valemount, British Columbia. *In* Current Research, Part E, Geological Survey of Canada, Paper 90-IE. pp. 91–95.

Mustard, P.S. 1994. The upper Cretaceous Nanaimo Group, Georgia Basin. *In* Geology and geological hazards of the Vancouver Region, Southwestern British Columbia. *Edited by* J.W.H. Monger. Geological Survey of Canada, Bulletin 481. pp. 27–95.

Nourse, J.A. 2002. Middle Miocene reconstruction of the central and eastern San Gabriel Mountains, southern California, with implications for the evolution of the San Gabriel fault and Los Angeles basin. *In* Contributions to crustal evolution of the Southwestern United States. *Edited by* A. Barth. Geological Society of America Special Paper 365. pp. 161–185.

O'Brien, H.E., Irving, A.J., and McCallum, I.S. 1991. Eocene potassic magmatism in the Highwood Mountains, Montana: petrology, geochemistry, and tectonic implications. Journal of Geophysical Research: Solid Earth, **96**: 13237–13260. doi:10.1029/91JB00599.

Packer, D.R., and Stone, D.B. 1974. Paleomagnetism of Jurassic rocks from southern Alaska, and the tectonic implications. Canadian Journal of Earth Sciences, **11**: 976–997. doi:10.1139/e74-095.

Palmer, A.R. 1981. On the correlatability of grand cycles tops. *In* Short papers for the Second International Symposium on the Cambrian System. *Edited by* M. E. Taylor. U.S. Geological Survey, Open-File Report 81–743. pp. 156–159.

Palmer, A.R., and Halley, R.B. 1979. Physical stratigraphy and trilobite biostratigraphy of the Carrara Formation (Lower and Middle Cambrian) in the southern Great Basin. U.S. Geological Survey Professional Paper 1047. 131p.

Panã, D.I. 2021. ^{40}Ar/^{39}Ar dating of phyllonite in the southern Rocky Mountain Trench and adjacent Rocky Mountains unravels kinematic links between the Omineca and Foreland belts of the southern Canadian Cordillera. The Journal of Geology, **129**: 255–281. doi:10.1086/715243.

Panã, D.I., and van der Pluijm, B.A. 2015. Orogenic pulses in the Alberta Rocky Mountains: radiometric dating of fault gouge from major thrusts and comparison with the regional tectono-stratigraphic record. Geological Society of America Bulletin, **127**: 480–502. doi:10.1130/B31069.1.

Parker, S.D., and Hendrix, M.S. 2022. Detrital zircon record of the Mesoproterozoic Belt basin and implications for horizontal and vertical tectonic models. *In* In the footsteps of Warren B. Hamilton: new ideas in Earth science. *Edited by* G.R. Foulger, L.C. Hamilton, D.M. Jurdy, C.A. Stein, K.A. Howard and S. Stein. Geological Society of America Special Paper 553. pp. 159–176. doi:10.1130/2021.2553(14).

Patterson, D.L. 1984. Paleomagnetism of the Valle Formation and the Late Cretaceous paleogeography of the Vizcaino basin, Baja California, Mexico. *In* Geology of the Baja California peninsula. *Edited by* V.A. Frizzell, Jr. Pacific Section, Society of Economic Paleontologists and Mineralogists, Los Angeles. pp. 173–182.

Pell, J. 1994. Carbonatites, nepheline syenites, kimberlites and related rocks in British Columbia. British Columbia Geological Survey Memoir 88. 132p.

Pevear, D.R. 1992. Illite age analysis, a new tool for basin thermal history analysis. *In* Water-rock interaction. *Edited by* Y.K. Kharaka and A.S. Maest. Balkema, Rotterdam, The Netherlands. pp. 1251–1254.

Pevear, D.R. 1999. Illite and hydrocarbon exploration. Proceedings of the National Academy of Sciences, **96**: 3440–3446. doi:10.1073/pnas.96.7.3440 10.1073/pnas.96.7.3440.

Phinney, E.J., Mann, P., Coffin, M.F., and Shipley, T.H. 2004. Sequence stratigraphy, structural style, and age of deformation of the Malaita

accretionary prism (Solomon arc–Ontong Java Plateau convergent zone). Tectonophysics, **389**: 221–246. doi:10.1016/j.tecto.2003.10.025.

Plint, A.G., Tyagi, A., Hay, M.J., Varban, B.L., Zhang, H., and Roca, X. 2009. Clinoforms, paleobathymetry, and mud dispersal across the Western Canada Cretaceous foreland basin: evidence from the Cenomanian Dunvegan Formation and contiguous strata. Journal of Sedimentary Research, **79**: 144–161. doi:10.2110/jsr.2009.020.

Plumley, P.W., Coe, R.S., and Byrne, T. 1983. Paleomagnetism of the Paleocene Ghost Rocks formation, Prince William terrane, Alaska. Tectonics, **2**: 295–314. doi:10.1029/TC002i003p00295.

Pope, M.C., and Sears, J.W. 1997. Cassiar platform, north-central British Columbia: a miogeoclinal fragment from Idaho. Geology, **25**: 515–518. doi:10.1130/0091-7613(1997)025⟨0515:CPNCBC⟩2.3.CO;2.

Pope, M.C., Hollingsworth, J.S., and Dilliard, K. 2012. Overview of Lower Cambrian mixed carbonate–siliciclastic deposition along the western Laurentian passive margin. In The great American carbonate bank: the geology and economic resources of the Cambrian–Ordovician Sauk megasequence of Laurentia. Edited by J.R. Derby, R.D. Fritz, S.A. Longacre, W.A. Morgan and C.A. Sternbach. AAPG Memoir 98. pp. 735–750.

Powell, R.E. 1993. Balanced palinspastic reconstruction of pre–late Cenozoic paleogeography, southern California: geologic and kinematic constraints on evolution of the San Andreas fault system. In The San Andreas Fault System: displacement, palinspastic reconstruction, and geologic evolution. Edited by R.E. Powell, R.J.H. Weldon and J.C. Matti. Geological Society of America Memoir 178. pp. 1–106. doi:10.1130/MEM178-p1.

Price, R.A. 2007. Fault dating in the Canadian Rocky Mountains: evidence for Late Cretaceous and Early Eocene orogenic pulses: comment. Geology, e134–e134, **35**. doi:10.1130/G23592C.1.

Price, R.A. 2013. Geology, Fernie, British Columbia–Alberta: Geological Survey of Canada Map 2200A, scale 1:125,000.

Price, R.A., and Fermor, P.R. 1985. Structure section of the Cordilleran foreland thrust and fold belt west of Calgary, Alberta. Geological Survey of Canada Paper 84-14, 1 sheet.

Reed, J.C., Wheeler, J.O., and Tucholke, B.E., 2004. Geologic Map of North America. Geological Society of America, Boulder, Colorado. Decade of North American Geology Continental Scale Map 001, scale 1:5,000,000.

Reesor, J.E. 1973. Geology of the Lardeau map-area, east-half, British Columbia. Geological Survey of Canada, Memoir 369. 122p.

Richter, D.H., Preller, C.C., Labay, K.A., and Shew, N.B. 2006. Geologic Map of the Wrangell–Saint Elias National Park and Preserve, Alaska. U.S. Geological Survey Scientific Investigations Map 2877, scale 1:350,000.

Richter, D.H., Rosenkrans, D.S., and Steigerwald, M.J. 1995. Guide to the volcanoes of the Western Wrangell Mountains, Alaska–Wrangell–St. Elias National Park and Preserve: U.S. Geological Survey Bulletin 2072. 31p.

Roberts, L.N.R., and Kirschbaum, M.A. 1995. Paleogeography of the Late Cretaceous of the western interior of Middle North America—coal distribution and sediment accumulation. U.S. Geological Survey Professional Paper 1561. 155p.

Roddick, J.A. 1967. Tintina Trench. The Journal of Geology, **75**: 23–33. doi:10.1086/627228.

Rodgers, D.W., and Janecke, S.U. 1992. Tertiary paleogeologic maps of the western Idaho–Wyoming–Montana thrust belt. In Regional geology of Eastern Idaho and Western Wyoming. Edited by P.K. Link, M.A. Kuntz and L.B. Platt. Geological Society of America Memoir 179. pp. 83–94.

Roeske, S., Housen, B.A., O'Connell, K., and Gallen, S. 2009. Paleocene–Early Eocene displacement of terranes along the northern Cordillera margin. Geological Society of America Abstracts with Programs, **41**(7): 518.

Roeske, S.M., Snee, L.W., and Pavlis, T.L. 2003. Dextral-slip reactivation of an arc-forearc boundary during Late Cretaceous–Early Eocene oblique convergence in the northern Cordillera. In Geology of a transpressional orogen developed during ridge-trench interaction along the North Pacific Margin. Edited by V.B. Sisson, S.M. Roeske and T.L. Pavlis. Geological Society of America Special Paper 371. pp. 141–169.

Sager, W.W. 2005. What built Shatsky Rise, a mantle plume or ridge tectonics? In Plates, plumes, and paradigms. Edited by G.R. Foulger, J.H. Natland, D.C. Presnall and D.L. Anderson. Geological Society of America Special Paper 388. pp. 721–733. doi:10.1130/2005.2388(41).

Saleeby, J.B. 2003. Segmentation of the Laramide slab—evidence from the southern Sierra Nevada region. Geological Society of America Bulletin, **115**: 655–668. doi:10.1130/0016-7606(2003)115⟨0655:SOTLSF⟩2.0.CO;2.

Salem, A.C. 2009. Mesozoic tectonics of the Maria fold and thrust belt and McCoy basin: an examination of polyphase deformation and synorogenic response. Doctoral dissertation, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque. 260p.

Sample, J.C., and Reid, M.R. 2003. Large-scale, latest Cretaceous uplift along the northeast Pacific Rim: evidence from sediment volume, sandstone petrography, and Nd isotope signatures of the Kodiak Formation, Kodiak Islands, Alaska. In Geology of a transpressional orogen developed during ridge-trench interaction along the North Pacific Margin. Edited by V.B. Sisson, S.M. Roeske and T.L. Pavlis. Geological Society of America Special Paper 371. pp. 51–70.

Sauer, K.B., Gordon, S.M., Miller, R.B., Jacobson, C.E., Grove, M., Vervoort, J.D., and Fisher, C.M. 2019. Deep-crustal metasedimentary rocks support late cretaceous "Mojave-BC" translation. Geology, **47**: 99–102. doi:10.1130/G45554.1.

Sauer, K.B., Gordon, S.M., Miller, R.B., Vervoort, J.D., and Fisher, C.M. 2018. Provenance and metamorphism of the Swakane Gneiss: implications for incorporation of sediment into the deep levels of the North Cascades continental magmatic arc, Washington. Lithosphere, **10**: 460–477. doi:10.1130/L712.1.

Schmidt, R.G. 1978. Rocks and mineral resources of the Wolf Creek Area, Lewis and Clark and Cascade Counties, Montana. U.S. Geological Survey Bulletin 1441. 91p.

Scotese, C.R., and McKerrow, W.S. 1990. Revised world maps and introduction. Geological Society, London, Memoirs, **12**: 1–21. doi:10.1144/GSL.MEM.1990.012.01.01.

Searle, M.P., Cornish, S.B., Heard, A., Charles, J.-H., and Branch, J. 2019. Structure of the northern Moine thrust zone, Loch Eriboll, Scottish Caledonides. Tectonophysics, **752**: 35–51. doi:10.1016/j.tecto.2018.12.016.

Sedlock, R.L. 2003. Geology and tectonics of the Baja California peninsula and adjacent areas. In Tectonic evolution of Northwestern Mexico and the Southwestern USA. Edited by S.S. Johnson, S.R. Paterson, J.M. Fletcher, G.H. Girty, D.L. Kimbrough and A. Martin-Barajas. Geological Society of America Special Paper 374. pp. 1–42.

Skipp, B. 1987. Basement thrust sheets in the Clearwater orogenic zone, central Idaho and western Montana. Geology, **15**: 220–224. doi:10.1130/0091-7613(1987)15⟨220:BTSITC⟩2.0.CO;2.

Skipp, B., and Hait, M.H., Jr. 1977. Allochthons along the northeast margin of the Snake River plain, Idaho. In Rocky Mountain Thrust Belt geology and resources. Edited by E.L. Heisey and D.E. Lawson. Wyoming Geological Association, Annual Field Conference, 29. pp. 499–516.

Skipp, B., and Link, P.K. 1992. Middle and Late Proterozoic rocks and Late Proterozoic tectonics in the southern Beaverhead Mountains, Idaho and Montana: a preliminary report. In Regional geology of Eastern Idaho and Western Wyoming. Edited by P.K. Link, M.A. Kuntz and L.B. Platt. Geological Society of America Memoir 179. pp. 141–154.

Smith, D.P., and Busby-Spera, C.J. 1993. Shallow magnetic inclinations in the Cretaceous Valle Group: remagnetization, compaction, or terrane translation? Tectonics, **12**: 1258–1266. doi:10.1029/93TC01378.

Stamatakos, J.A., Trop, J.M., and Ridgeway, K.D. 2001. Late Cretaceous paleogeography of Wrangellia: paleomagnetism of the MacColl Ridge Formation, southern Alaska, revisited. Geology, **29**: 947–950. doi:10.1130/0091-7613(2001)029⟨0947:LCPOWP⟩2.0.CO;2.

Stott, D.F., McMechan, M.E., Taylor, C.C., and Muller, J. 1983. Geology of Pine Pass (Mackenzie) map area, NTS 93-0, British Columbia. Geological Survey of Canada, Open File Report 925.

Symons, D.T.A., and Wellings, M.R. 1989. Paleomagnetism of the eocene Kamloops Group and the cratonization of Terrane I of the Canadian Cordillera. Canadian Journal of Earth Sciences, **26**: 821–828. doi:10.1139/e89-066.

Symons, D.T.A., Harris, M.J., Gabites, J.E., and Hart, C.J.R. 2000. Eocene (51 Ma) end to northward translation of the Coast Plutonic Complex: paleomagnetism and K–Ar dating of the White Pass Dikes. Tectonophysics, **326**: 93–109. doi:10.1016/S0040-1951(00)00148-7.

Tesauro, M., Kaban, M.K., and Mooney, W.D. 2015. Variations of the lithospheric strength and elastic thickness in North America. Geochemistry, Geophysics, Geosystems, **16**: 2197–2220. doi:10.1002/2015GC005937.

Thomas, W.A., Lawton, T.F., Gehrels, G.E., Sundell, K.E., George, S.W.M., Guenthner, W.R., et al. Detrital zircon chronofacies and sediment dispersal, Upper Mississippian–Middle Permian strata of the Ancestral Rocky Mountains intracratonic orogen, western U.S.A.: implications for orogenic evolution and climatic influence on depositional process: Geological Society of America Special Paper. In press.

Thompson, R.I. 1986. Geology, Halfway River. Geological Survey of Canada, Map 1634A, 2 sheets. doi:10.4095/122796.

Thrupp, G.A., and Coe, R.S. 1986. Early tertiary paleomagnetic evidence and the displacement of southern Alaska. Geology, **14**: 213–217. doi:10.1130/0091-7613(1986)14%3c213:ETPEAT%3e2.0.CO;2.

Tikoff, B., Housen, B.A., Maxson, J.A., Nelson, E.M., Trevino, S., and Shipley, T.F. 2023. Hit-and-run model for Cretaceous–Paleogene tectonism along the western margin of Laurentia. *In* Laurentia: turning points in the evolution of a continent. *Edited by* S.J. Whitmeyer, M.L. Williams, D.A Kellett and B. Tikoff. Geological Society of America Memoir 220.

Trop, J.M., Hart, W.K., Snyder, D., and Idleman, B. 2012. Miocene basin development and volcanism along a strike-slip to flat-slab subduction transition: stratigraphy, geochemistry, and geochronology of the central Wrangell volcanic belt, Yakutat–North America collision zone. Geosphere, **8**: 805–834. doi:10.1130/GES00762.1.

Umhoefer, P.J. 1987. Northward translation of "Baja British Columbia" along the Late Cretaceous to paleocene margin of western North America. Tectonics, **6**: 377–394. doi:10.1029/TC006i004p00377.

Umhoefer, P.J., and Miller, R.B. 1996. Mid-Cretaceous thrusting in the southern Coast Belt, British Columbia and Washington, after strike-slip reconstruction. Tectonics, **15**: 545–565. doi:10.1029/95TC03498.

Valley, P.M., Whitney, D.L., Paterson, S.R., Miller, R.B., and Alsleben, H. 2003. Metamorphism of the deepest exposed arc rocks in the Cretaceous to Paleogene Cascades belt, Washington. Evidence for large-scale vertical motion in a continental arc. Journal of Metamorphic Geology, **21**: 203–220. doi:10.1046/j.1525-1314.2003.00437.x.

van der Pluijm, B.A., Hall, C.M., Vrolijk, P.J., Pevear, D.R., and Covey, M.C. 2001. The dating of shallow faults in the Earth's crust. Nature, **412**: 172–175. doi:10.1038/35084053.

van der Pluijm, B.A., Vrolijk, P.J., Pevear, D.R., Hall, C.M., and Solum, J. 2006. Fault dating in the Canadian Rocky Mountains: evidence for Late Cretaceous and early Eocene orogenic pulses. Geology, **34**: 837–840. doi:10.1130/G22610.1.

van der Velden, A.J., and Cook, F.A. 1996. Structure and tectonic development of the southern Rocky Mountain Trench. Tectonics, **15**: 517–544. doi:10.1029/95TC03288.

van Hinsbergen, D.J.J., Torsvik, Schmid, S.M., Matenco, L.C., Maffione, M., Vissers, R.L.M., et al. 2020. Orogenic architecture of the Mediterranean region and kinematic reconstruction of its tectonic evolution since the Triassic. Gondwana Research, **81**: 79. doi:10.1016/j.gr.2019.07.009.

Vandall, T.A., and Palmer, H.C. 1990. Upper limit of docking time for Stikinia and Terrane I: paleomagnetic evidence from the eocene Ootsa Lake Group, British Columbia. Canadian Journal of Earth Sciences, **27**: 212–218. doi:10.1139/e90-021.

Vogl, J.J., Foster, D.A., Fanning, C.M., Kent, K.A, Rodgers, D.W., and Diedesch, T. 2012. Timing of extension in the Pioneer metamorphic core complex with implications for the spatial–temporal pattern of Cenozoic extension and exhumation in the northern U.S. Cordillera. Tectonics, **31**: TC1008. doi:10.1029/2011TC002981.

von Huene, R., and Ranero, C.R. 2009. Neogene collision and deformation of convergent margins along the backbone of the Americas, *In* Backbone of the Americas: shallow subduction, plateau uplift, and ridge and terrane collision. *Edited by* S.M. Kay, V.A. Ramos and W.R. Dickinson. Geological Society of America Memoir 204. pp. 67–83. doi:10.1130/2009.1204(03).

Vuke, S.M., Porter, K.W., Lonn, J.D., and Lopez, D.A. 2007. Geologic Map of Montana: Montana Bureau of Mines and Geology, Geologic Map 62, Scale 1:500,000.

Wallace, C.A. 1987. Generalized geologic map of the Butte 1° x 2° quadrangle, Montana. United States Geological Survey, Miscellaneous Field Studies Map MF-1925, scale 1:250,000.

Wallace, C.A., Lidke, D.J., and Schmidt, R.G. 1990. Faults of the central part of the Lewis and Clark line and fragmentation of the late cretaceous foreland basin in west-central Montana. Geological Society of America Bulletin, **102**: 1021–1037. doi:10.1130/0016-7606(1990)102⟨1021:FOTCPO⟩2.3.CO;2.

Warnock, A.C., Burmester, R.F., and Engebretson, D.C. 1993. Paleomagnetism and tectonics of the Crescent Formation, northern Olympic Mountains, Washington. Journal of Geophysical Research: Solid Earth, 11729–11741, **98**:. doi:10.1029/93JB00709.

Weber, F.R., Wheeler, K.L., Rinehart, C.D., and Light, T.D. 1997. Generalized geologic map of the Livengood Quadrangle, Alaska. U.S. Geological Survey, Open-File Report 97-484-A.

Weimer, R.J. 1955. Geology of the two Medicine-Badger Creek area, Glacier and Pondera counties, Montana. Billings Geological Society: Guidebook: Sixth Annual Field Conference, September 7–9. pp. 143–149.

Wells, M.L., and Hoisch, T.D. 2008. The role of mantle delamination in widespread late Cretaceous extension and magmatism in the Cordilleran orogen, western United States: Geological Society of America Bulletin, **120**: 515–530. doi:10.1130/B26006.1.

Wernicke, B., Axen, G.J., and Snow, J.K. 1988. Basin and Range extensional tectonics at the latitude of Las Vegas, Nevada. Geological Society of America Bulletin, **100**: 1738–1757. doi:10.1130/0016-7606(1988)100%3c1738:BARETA%3e2.3.CO;2.

Wheeler, J.O., and McFeely, P. 1991. Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America. Geological Survey of Canada Map 1712A, scale 1:2 000 000.

Whipple, J.W., Mudge, M.R., and Earhart, R.L. 1987. Geologic map of the Rogers Pass area, Lewis and Clark county, Montana. U.S. Geological Survey Miscellaneous Investigations Series Map I-1642, scale 1:48 000.

Woods, M.T., and Davies, G.F. 1982. Late Cretaceous genesis of the Kula plate. Earth and Planetary Science Letters, **58**: 161–166. doi:10.1016/0012-821X(82)90191-1.

Wright, J.E., and Wyld, S.J. 2007. Alternative tectonic model for Late Jurassic through Early Cretaceous evolution of the Great Valley Group, California. *In* Convergent margin terranes and associated regions: a tribute to W.G. Ernst. *Edited by* M. Cloos, W.D. Carlson, J.G. Gilbert, Liou and S.S. Sorensen. Geological Society of America Special Paper 419. pp. 81–95. doi:10.1130/2007.2419(04).

Wynne, P.J., Enkin, R.J., Baker, J., Johnston, S.J., and Hart, C.J.R. 1998. The big flush: paleomagnetic signature of a 70 ma regional hydrothermal event in displaced rocks of the northern Canadian Cordillera. Canadian Journal of Earth Sciences, **35**: 657–671. doi:10.1139/e98-014.

Zartman, R.E., Dyman, T.S., Tysdal, R.G., and Pearson, R.C. 1995. U–Pb ages of volcanogenic zircon from porcellanite beds in the Vaughn Member of the mid-Cretaceous Blackleaf Formation, southwestern Montana. United States Geological Survey Bulletin 2113-B. United States Geological Survey, Denver, CO. pp. 1–16.