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## Tomotectonics of Cordilleran North America since Jurassic times: double-sided subduction, archipelago collisions, and Baja-BC translation

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### Abstract

Tomotectonics hindcasts paleo-trenches, through the spatiotemporal superposition of subducted lithosphere (slabs imaged in the earth's mantle) with plate reconstructions (constrained by seafloor isochrons). The two geophysical datasets are linked through the tomotectonic null hypothesis, that oceanic lithosphere sinks vertically down after entering in the mantle. This linkage permits simple and testable predictions about the location and lifespan of volcanic arcs, and specifically, about arc-continent collisions, switches in subduction polarity, and switches from consuming to transform plate boundaries. Tomotectonics uses land geological observations for validation. We explain the tomotectonic method, with a conceptual separation of its (geophysical) hypothesis-generating stage from its (geological) hypothesis-testing stage.

We generate a full suite of tomotectonic inferences for the North American Cordillera from the slab assemblage now occupying the mantle to depths of 1800-2000 km. We reason why this assemblage originated as a completely intra-oceanic archipelago, at a time of worldwide tectonic reorganization around 200-170 Ma, when the Atlantic began to spread, and the Pacific plate was born. The Archipelago was bounded by two sets of trenches that pulled in seafloor from the east/northeast and from the southwest. While on the archipelago's western boundary, intra-oceanic Farallon arcs consumed purely oceanic plate, the eastern boundary arcs pulled in ocean lithosphere that was attached to western North America, until totally consumed. The resulting collision between the continental margin and the eastern bounding arc (which was built on Insular Superterrane) was diachronous, commencing ~155 Ma (Nevadan orogeny), and continuing through the Sevier orogeny times. Upon collision, subduction polarity was forced to flip at the affected latitudes, so the pre-existing Farallon trench grew southward to accommodate the new kinematic requirement for eastward subduction. The new southern Farallon subduction produced arcs on the continental-margin, including the Sierra Nevada Batholith ~120-80 Ma.

Slab-free areas hindcast that this Andean-type margin at U.S. latitudes did not persist beyond ~80 Ma, and that it must have been followed by a dextral transform regime, i.e., by boundary conditions conducive to large-scale terrane translations. This transform regime ended when the northern Farallon arc, still sitting offshore until ~75-50 Ma gradually collided with the margin to become the continental Cascades arc. In the northeastern boundary arcs of future Central Alaska collided with the continental margin 90-50 Ma, and then gradually collided with the northern Farallon arc. Oblique override of these two oceanic arcs produced a range of collision styles, including the Baja-BC northward sprint and the assembling of Alaska. From its combined accounting of arc override events over the past 170 Ma, tomotectonics indicates large-scale northward displacement of Insular Superterrane since its accretion, in direct and independent support for the “Baja-BC” hypothesis of paleomagnetism.

# Figure 1

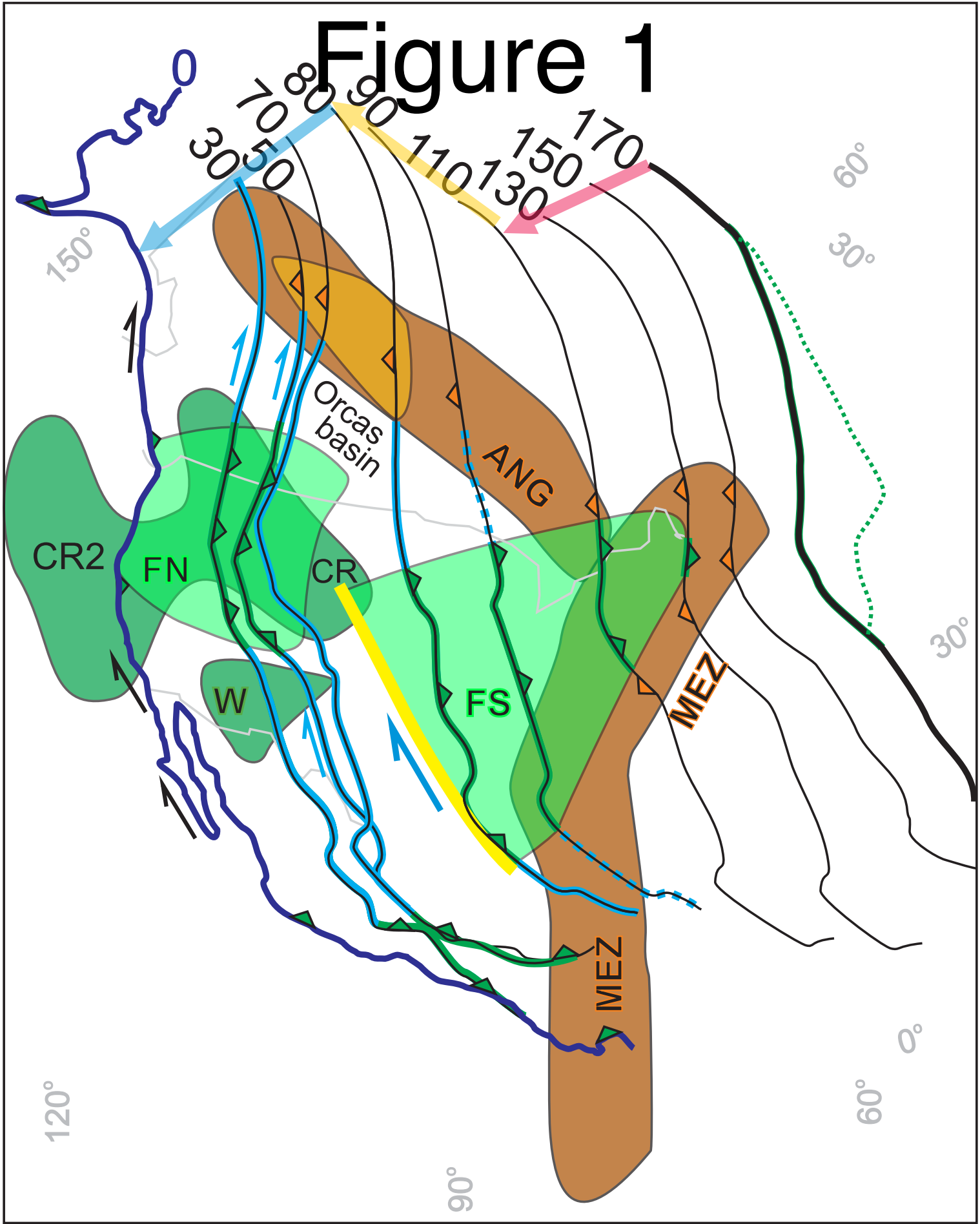


Figure 2

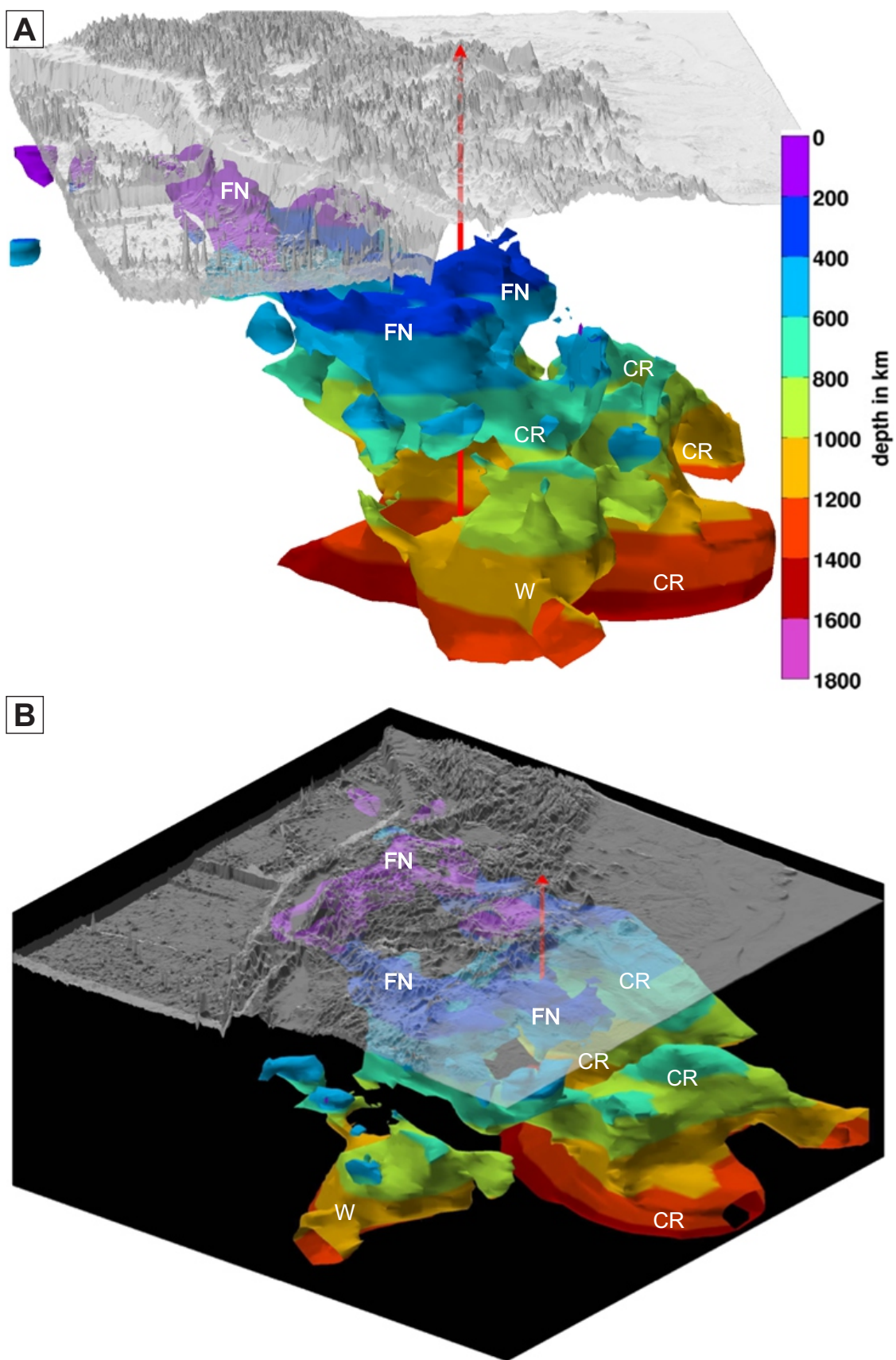
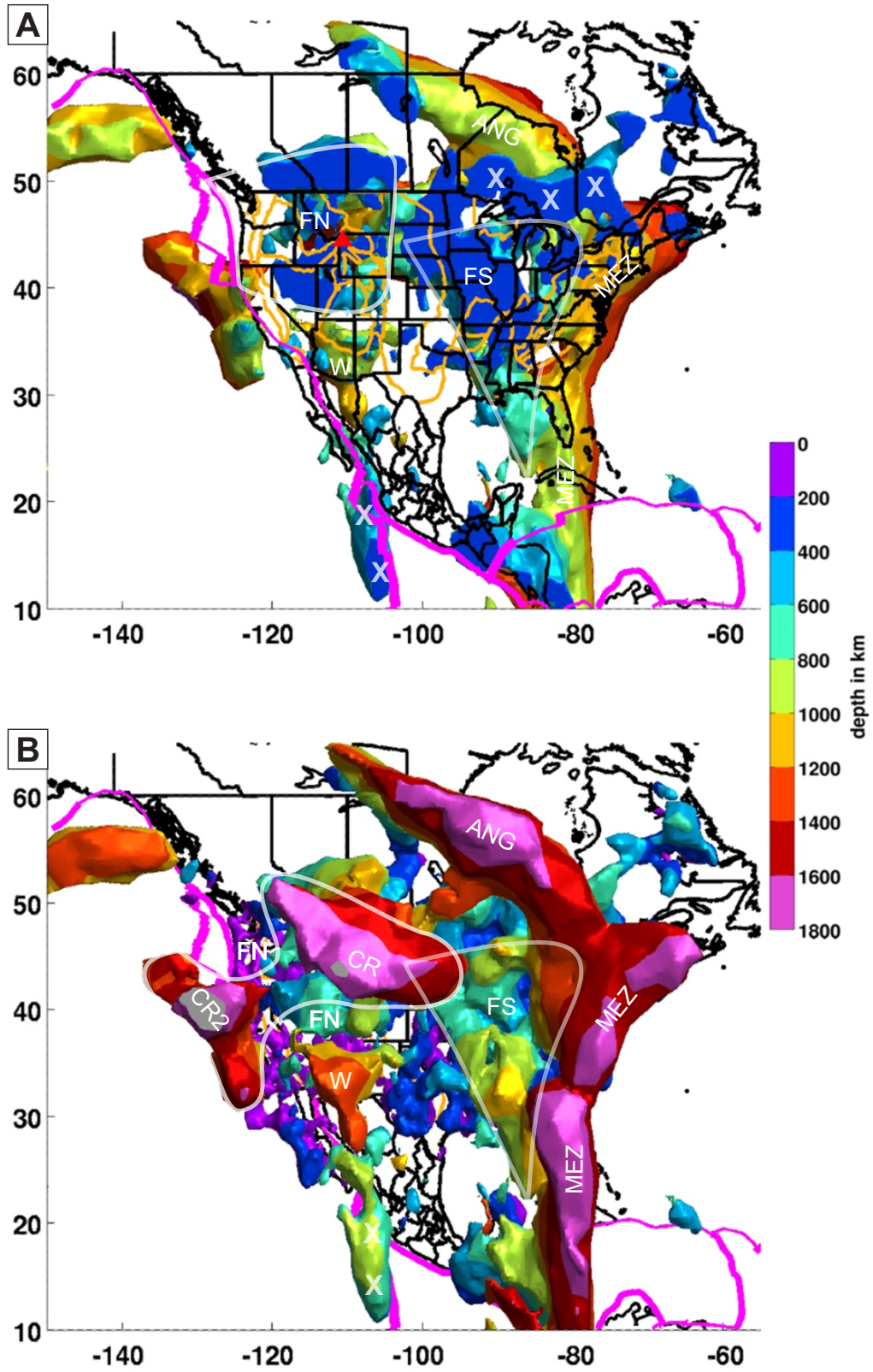


Figure 3



# Figure 4

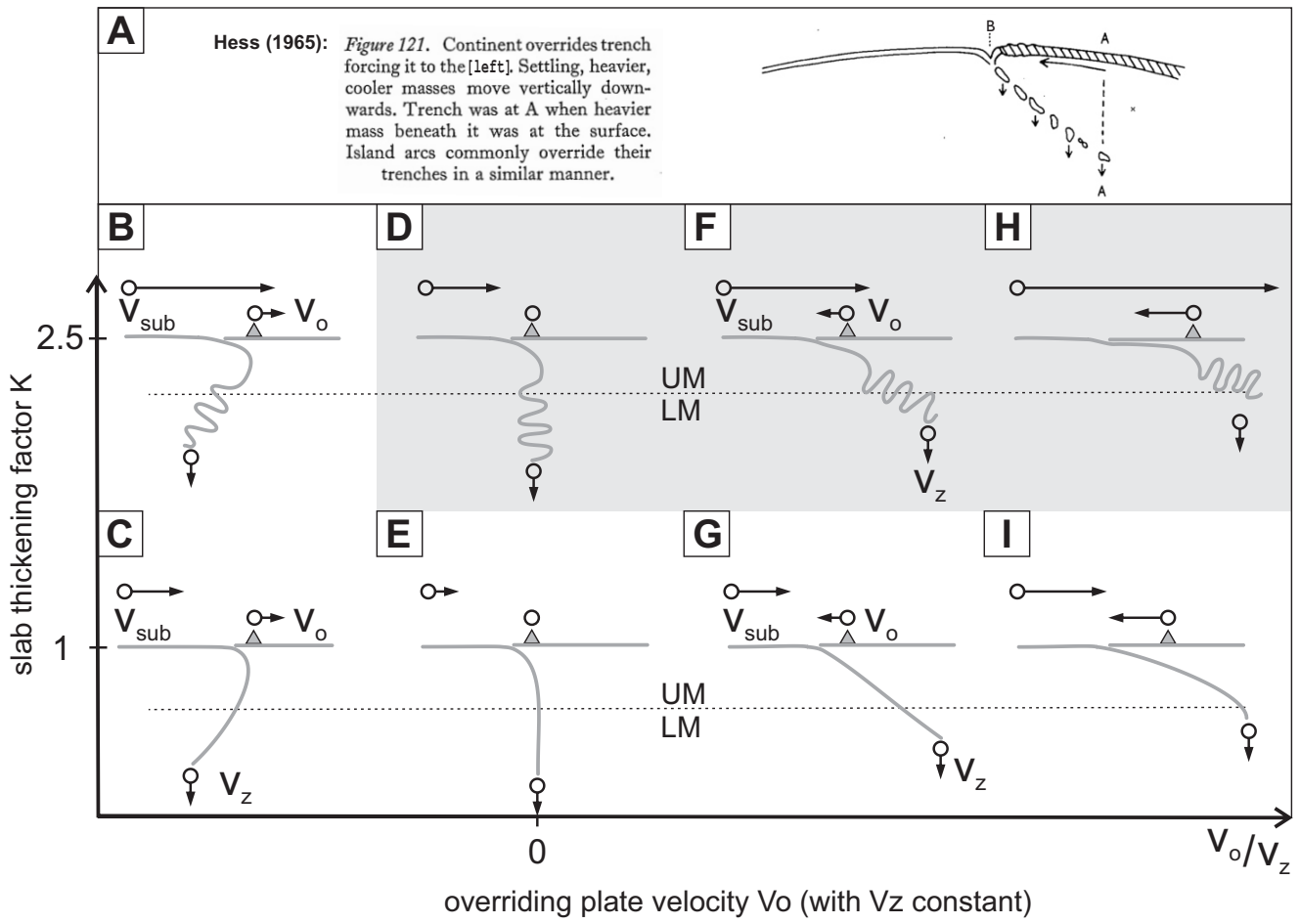


Figure 5

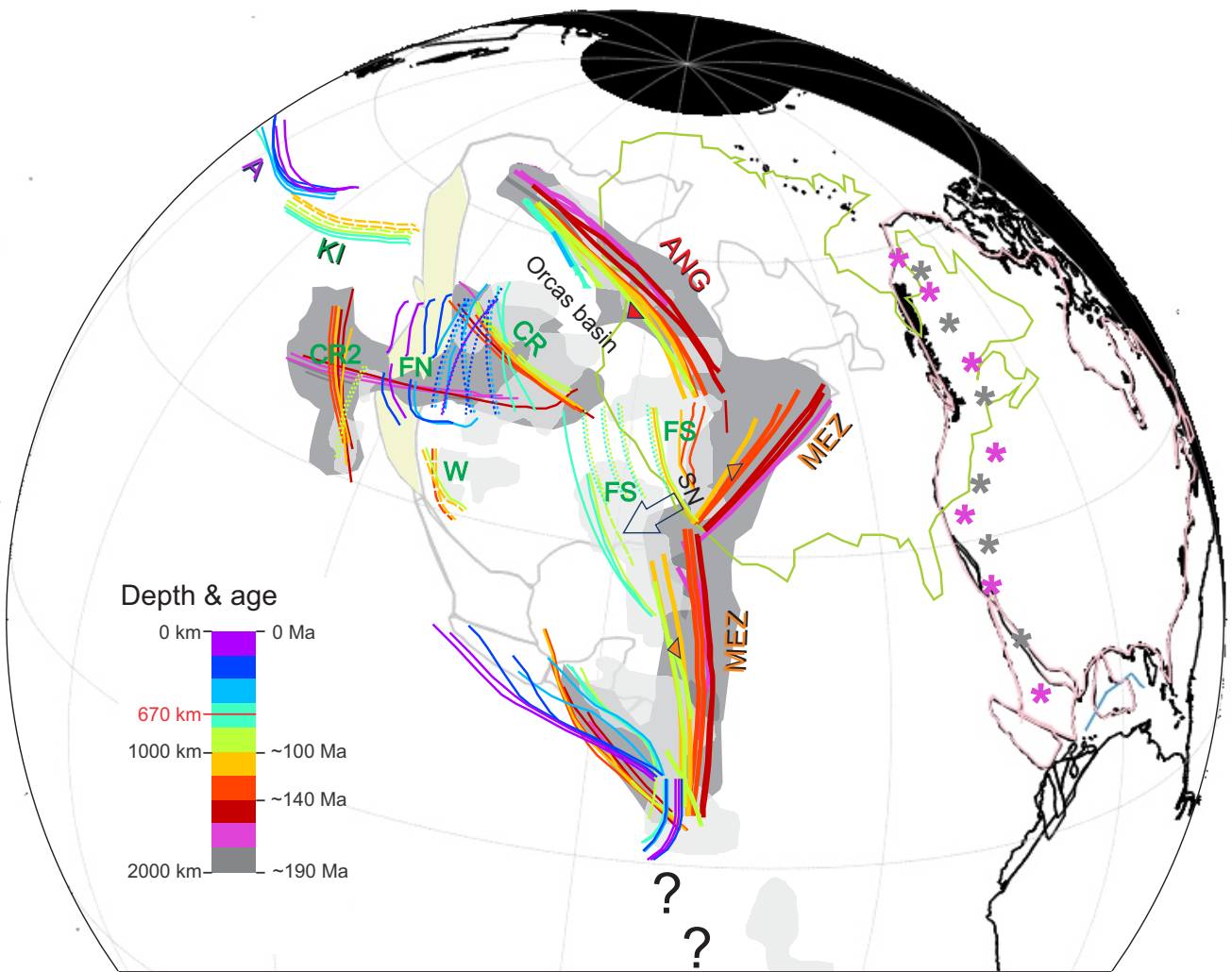
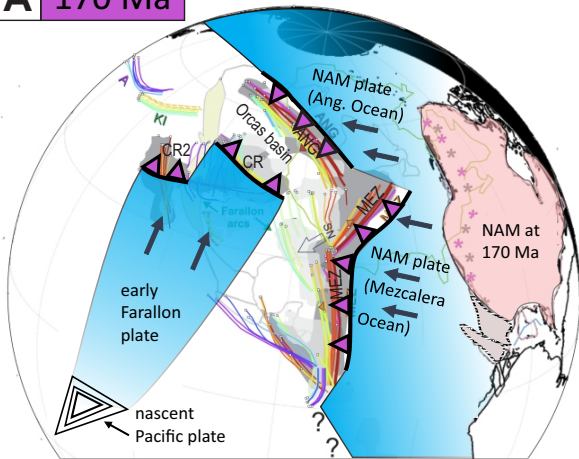
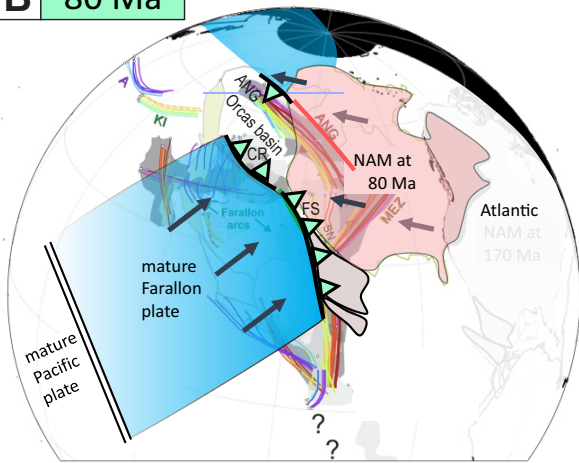


Figure 6

**A** 170 Ma

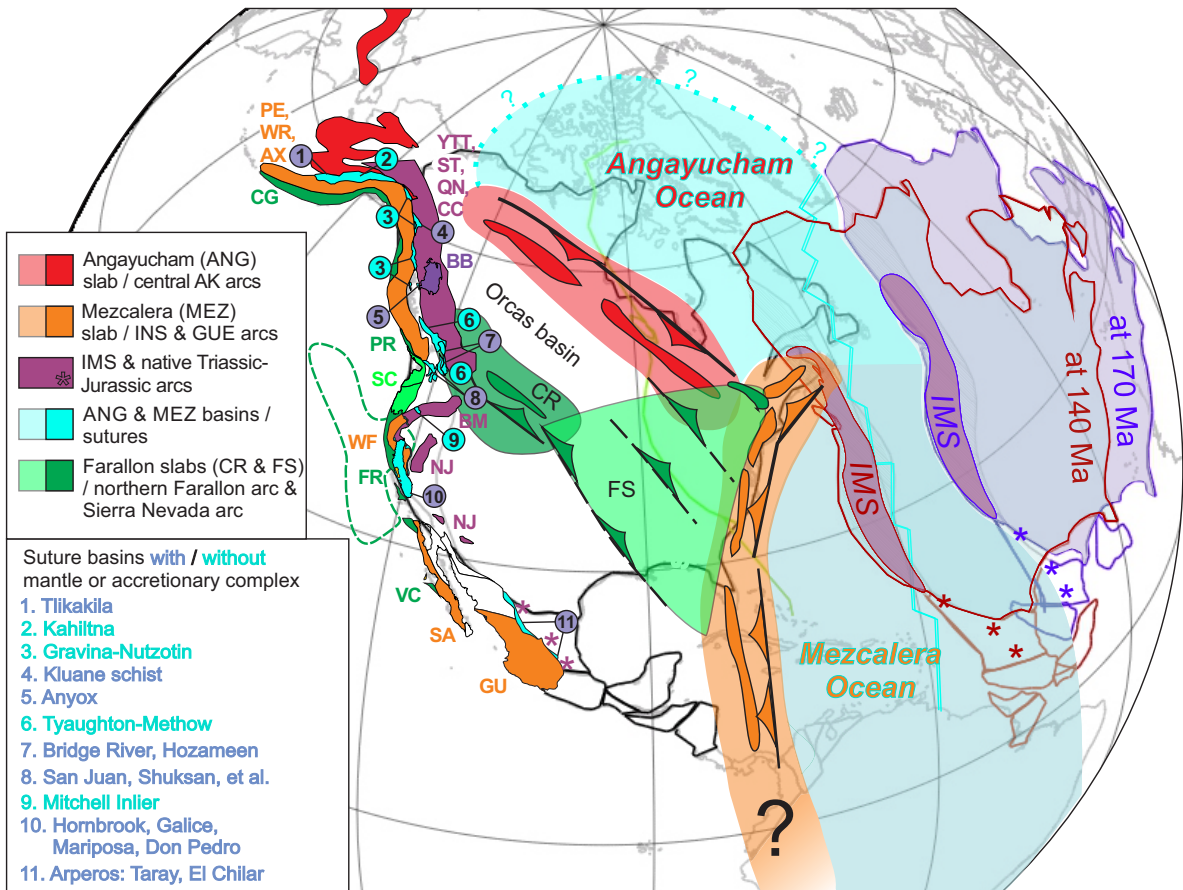


**B** 80 Ma





# Figure 7



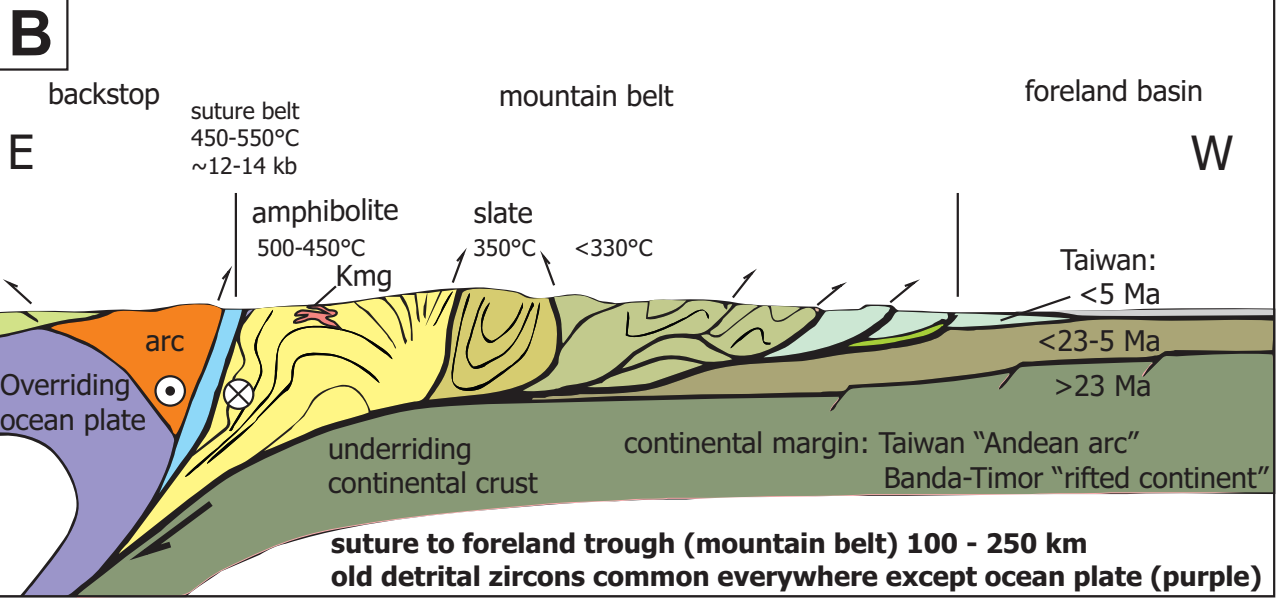
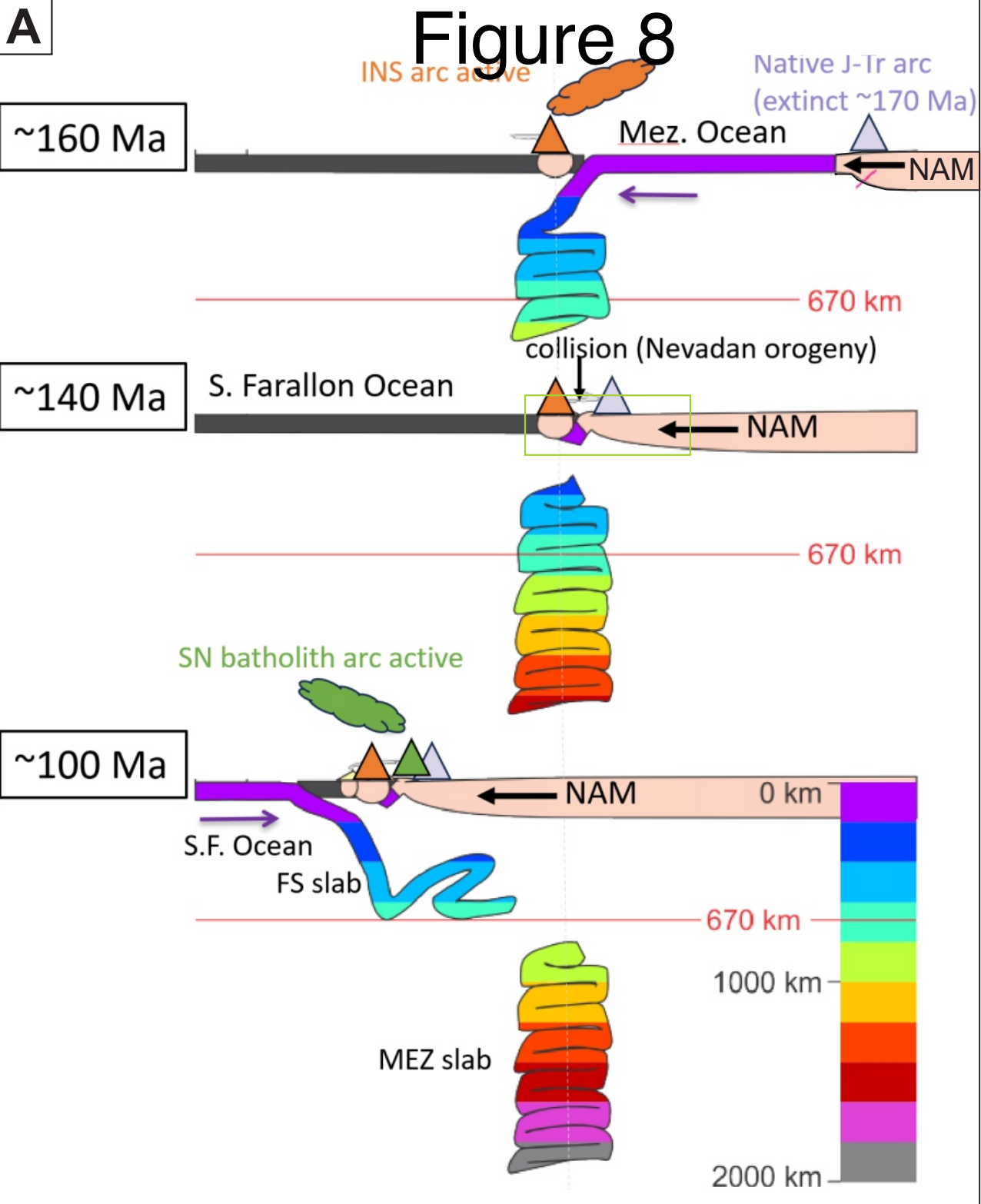
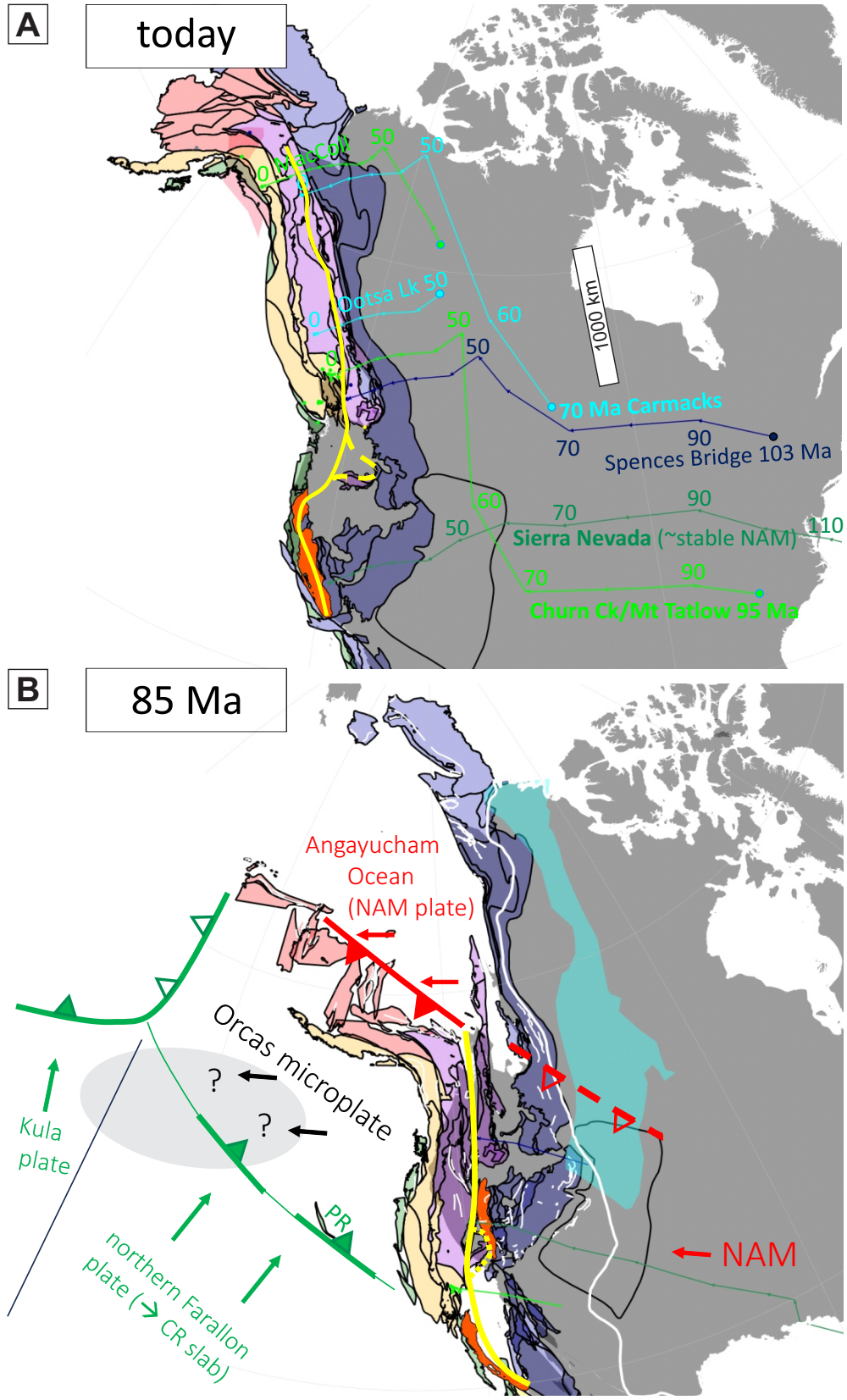


Figure 9



## Figure captions

**Figure 1.** Roadmap figure for this study: the superposition of subducted lithosphere (slabs) in the mantle with continental drift, reconstructed with respect to the mantle. Coloured polygons show outlines of major slabs under North America from teleseismic P-wave tomography (Sigloch 2011). Slabs inferred to have been deposited by westward subduction are coloured in orange, those generated by eastward (Farallon) subduction in green. Darker colour shades are applied to lower-mantle slabs (MEZ, ANG and CR/CR2/W; light shades to shallower slabs: FS (400-1000 km deep), FN (0-700 km), and to the shallow western end of ANG. Superimposed are time snapshots tracking the westward migrating margin of North America, reconstructed in a mantle reference frame, which is constrained between 0-120 Ma by moving hotspots (Dubrovine et al., 2012) and 120-170 Ma by true polar wander-corrected paleomagnetic data (Torsvik et al., 2019). Colored arrows connecting the northern end points of the paleo-coastlines highlight three distinct episodes of absolute plate motion.

If the slabs sank vertically in place then a continental margin overlying a slab indicates a continent-arc interaction – because a slab constrains a paleo-subduction zone, which must have hosted a paleo-arc. Symbols on the paleo-margins indicate the nature of the tectonic regime along the margin, as inferable from the tomotectonic principles developed in the text. Orange barbs: NAM-beneath-arc collision (westward subducting slab located underneath). Green barbs: subduction beneath NAM (eastward subduction), with arc built on NAM. Light blue lines and arrows: transform boundary along the margin (no slab underneath). Black line: (quasi-)passive continental margin (no slab underneath, and no pre-existing plate boundary along the margin). Yellow line traces the sharp western edge of FS slab, associated with a sudden transition from eastward subduction to transform margin ~80 Ma. The starting point of our inference is ~170 Ma, the time when North America separated from Pangaea, and when absolute paleo-positioning in plate reconstructions becomes reasonably reliable.

Slab abbreviations: MEZ – Mezcalera, ANG – Angayucham, CR & CR2 – Cascadia Root, FN – Farallon North, FS – Farallon South. W is a non-interpretive slab name.

**Figure 2.** Mantle tomography: 3-D isosurface rendering of seismically fast anomalies imaged under the western U.S.A., from the surface to ~1800 km depth, in the teleseismic P-wave tomography model of Sigloch (2011). The isosurface rendering threshold is  $dV_p/V_p > 0.25\%$ . Color signals depth and changes in increments of 200 km. This structure represents subducted oceanic lithosphere (slab) of the former Farallon plate, dipping eastward down from beneath the Cascades (Juan de Fuca) trench. Surface topography of the North American Cordillera and the Pacific basin are overlain in translucent gray, with strong vertical exaggeration. Yellowstone (red triangle) and its vertical downward continuation are shown for visual reference. Seismically slow anomalies are not rendered (e.g., Yellowstone plume). Shallow fast anomalies representing the thick continental lithosphere of NAM are masked out as they would block the 3-D view on the slabscape. Panels A and B present alternative view angles on the same scene, comprising the FN and CR slabs of Figure 1 (subdivided at ~600 km depth, where structural breaks are visible especially in panel B). Slab W is also visible in the foreground. Deep CR2 slab under the Pacific is not rendered.

**Figure 3.** Three-dimensional isosurface rendering of all seismically fast P-wave anomalies (subducted slabs) in the upper and lower mantle beneath North America. Tomography model, rendering threshold and color scheme as in Figure 2. (A) Top-down view of fast structure below 400 km (in order to exclude the overlying lithosphere, which is fast but does not represent slab). Strictly speaking, the view is from ~390 km down due to slight interpolation smoothing of the contouring algorithm, explaining why the shallowest anomalies appear in dark blue, as part of the 200-400 km layer. (B) Inside-out view of all fast structure from the surface down, with the deepest structure (slab walls MEZ, ANG, CR/CR2) emerging

to the foreground. Imaging limitations include artifacts, especially near the margins of the regional dataset: resolution lost into the ocean basins and north of 55°. Two downward smearing artifacts are labeled with white x's and are not interpreted.

**Figure 4.** (A) The tomotectonic null hypothesis of vertical slab sinking, as envisioned by the very first cartoon of subduction to be published, by Harry Hess in 1965. Motions are drawn in a mantle reference frame, with the overriding plate moving laterally but not the subducting plate. (B)-(I) Range of possible slab geometries predicted for when oceanic lithosphere sinks vertically after entering the trench, as a function of the parameters  $v_o$ , the velocity of the overriding plate (or arc) on the x-axis, and of  $K$ , a measure for the vigor of subduction, on the y-axis. Dashed lines represent the viscosity discontinuity between upper mantle (UM) and lower mantle (LM), where the mantle becomes 1-2 orders of magnitude more viscous, resisting further slab sinking. Motions are drawn relative to the mantle, and velocity arrows are drawn to scale relative to each other.  $v_z$ , the slab sinking velocity in the lower mantle, is kept fixed in all panels (a typical value being 10 mm/year). Kinematic ratio  $K = v_{\text{sub}}/v_{\text{acc}}$  is the ratio of slab length subducted per unit time versus the length of accommodation space created for it, by means of the vertical sinking away of older slab and the migration  $v_o$  of the trench away from the site of older subduction (see Cerpa et al. 2022, eq. 1, for exact definition).  $K > 1$  indicates “traffic jam conditions”, where plate convergence is too rapid to be accommodated undeformed, so that slab is forced to thicken (probably by folding). The average value observed for present-day trenches is  $K \sim 2.5$  (Cerpa et al. 2022), with the associated slab types highlighted by grey shaded panels D, F, H.  $v_o < 0$  (trench advance, panels B & C) is practically not observed.

**Figure 5.** Paleo-trenches in absolute (mantle) coordinates, as predicted by the observed slab geometries of Figure 3 if the slabs sank vertically. Slab-to-trench transcriptions are drawn in depth increments of 100 km, using the same depth-to-colour mapping as Figure 3. Tracks of paleo-trench (or arc) locations are shown as thick lines if inferred to be produced by westward subduction, and thin lines if produced by eastward subduction or subduction of ambiguous polarity (mostly Farallon). For laterally extended slabs (FS, FN, CR, presumably produced as in figs 4F/H), the arc lines are shown as dashed when a locus of slab deposition is poorly constrained laterally, for a given depth. The colour bar also shows an indicative mapping of slab depth to time of subduction, using 10 mm/year as a typical, heuristic value for slab sinking rate. The coastlines of NAM reconstructed at times 170 Ma (black), ~80 Ma (green), and present day (grey). Grey polygons indicate slab footprints at 800 km depth (in light grey) and at 1400 km (dark grey). Label SN marks the approximate position of the Sierra Nevada batholith; the arrow denotes possible extents of the Hess-Shatsky Rise conjugate plateau. Arc abbreviations: A = Aleutian, KI = Kula-Izanagi. Purple-grey stars on western NAM mark the previous generation of arcs IMS & NJ, extinct and accreted by 170 Ma.

**Figure 6.** Tomotectonic constraints on the growth and consumption of ocean basins subducting into the Archipelago from opposite sides. (A) Time frame for 170 Ma (early Archipelago before NAM started moving west) and (B) for 80 Ma (override far advanced, westward subduction almost overridden). Trenches/arcs active at the respective reconstruction times are highlighted with barbs and the colours corresponding to their depths, and are plotted on the basemap of Figure 4, which shows all arc tracks over time. In (A), the lateral gap between the NAM and its nearest slabs (MEZ, ANG) constrains the extents of a paleo-ocean at 170 Ma (the Mezcalera-Angayucham Ocean), whose westward subduction into MEZ/ANG allows NAM to advance westward. The lateral gap between the reconstructed Farallon spreading ridge (isochrons preserved on today's Pacific plate) and its nearest slabs (CR, CR2) constrains the extents of another paleo-ocean, the Farallon Ocean. Orcas Basin is an oceanic microplate inferred to occupy the space between the double-sided, intra-oceanic CR and ANG trenches. (B) By 80 Ma, lateral overlap of NAM with arc tracks indicates accomplished arc collisions and accretions, except in the far

northwest of the ANG arc. Lateral overlap of NAM with the FS slab indicates that the (southern) Farallon trench is flush against the continental margin. The enduring gap between NAM and the CR slab further north indicates that the northern Farallon arc continues to sit offshore (but is in the process of being overridden and converted into a marginal arc, the future Cascades arc).

**Figure 7.** Arc terranes matched to slabs. Every substantive slab should be associated with a geologically known arc, and every known arc should be associated with a slab. Arc (super-)terranes are shown in their present positions in the Cordillera on the left part of the map. The same arc terranes are schematically reconstructed above their matched slabs and paleo-trenches, in absolute positions relative to the lower mantle. Colour legend gives the interpreted matches of slabs to geologically known arcs. Superterranes, slabs, arcs and trenches are coloured green if associated with Farallon Ocean subduction; orange if associated with Mezcalera Ocean subduction, and red if associated with Angayucham Ocean subduction. The reconstruction time for the arcs and slab walls corresponds to ~170 Ma (before Archipelago override began), except in the case of the SW-ward migrating southern Farallon (Sierra Nevada Batholith) arc, which is shown in several time snapshots migrating across the area occupied by its associated FS slab. North America is reconstructed at 170 Ma, 140 Ma and 0 Ma. Intermontane Superterrane (IMS) and its continental prolongation, the Native Jurassic arc (NJ) are coloured purple; by 170 Ma, their arc activity had ceased and IMS is shown docked against NAM. The interpreted suture of MEZ arcs (Insular & Guerrero Superterrane INS, orange) against IMS/NJ terranes, is represented by a dozen of collapsed oceanic basins coloured cyan and numbered/labeled in the legend.

Abbreviations: Guerrero-Insular arc terranes include WR (Wrangellia), AX (Alexander), PE (Peninsular), GU (Guerrero), WF (Western Jurassic, Western Hayfork, Foothills, and related terranes), SA (Santa Ana). Terranes are associated with Farallon subduction include CG—Chugach; FR—Franciscan; PR—Pacific Rim; SC—Siletz-Crescent; VC—Vizcaino.

IMS Superterrane (purple) includes terranes BM (Blue Mountains, CC (Cache Creek), QN (Quesnel), ST (Stikine) and YTT (Yukon Tanana). NJ (Native Jurassic arc) is the onshore continuation of IMS arcs, as is presumably its along-strike continuation of extensional magmatism in Mexico (“Nazas arc”), shown by purple asterisks.

**Figure 8.** Collisional deformation since ~155 Ma, when NAM first rode into the intra-oceanic MEZ arc, and welded it onto the continent’s westward-subducting margin. **(A)** Progression of deformation in three time slices before, during and after suturing. **At 160 Ma**, arc magmatism above the westward-subducting Mezcalera Ocean, at the leading edge of North America (NAM), adds crust to the Insular Superterrane (INS) arc and lithosphere to the MEZ slab wall. Circa 155 Ma, the last of Mezcalera lithosphere is consumed between NAM and easternmost INS: NAM collides with INS microcontinent, resulting in the Nevadan orogeny **At 140 Ma**, deformation at the California margin and upward truncation of the slab wall. As NAM is still being pulled westward (by intact trench segments in and out of the figure plane), subduction polarity at the collided segment is forced to flip. **At 100 Ma**, subduction has flipped, to eastward beneath the margin. Its slab, deposited by subduction of the Southern Farallon plate, creates an east-dipping blanket (100 Ma panel) as the trench is forced westward in front of advancing NAM. This subduction is building new, margin-hugging arcs that overprint the NAM-INS suture (including the Sierra Nevada batholith). Both north and south of the initial collision site, NAM continues to collide with microcontinental INS, resulting in widening Sevier deformation (Columbian orogeny in Canada). **(B)** Generalized cross-section through a continent-beneath-arc suture, such as between NAM and INS. This spatial zoom into the green box in the 140-Ma panel of A is based on a stylized cross section through central Taiwan, a modern example of continent-arc collision with subsequent subduction flip (after Beyssac et al., 2007; section oriented normal to the suture). Both the Taiwan and the INS-NAM

sutures show widespread distribution of units containing old detrital zircons, tectonically exhumed forearc (tectonically removed), and high grade, rapidly exhumed metamorphic rocks immediately inboard of the suture. Kmg is Cretaceous orthogneiss (Chipan gneiss) that has cooled through 240 °C in the past million years (Beysac et al., 2007).

**Figure 9.** Margin-parallel terrane translations based principally on paleomagnetic data from Late Cretaceous and Eocene strata. These data constrain the tomotectonic terrane reconstruction model of Clennett et al. (2020), which is modified in the figures. (A) Present-day terrane map shows the current locations of a half-dozen units that are very robustly constrained. The green/blue lines, with nodes every 10 Ma and date labels (in Ma) at key times, represent the spatio-temporal trajectories into the past of these units, back to when they were deposited. A 1000-km scale bar is shown for reference. Trajectories are in absolute coordinates relative to the lower mantle, according to our Clennett et al. 2020 reconstruction. This reconstruction honors the displacement constraints of the most solid paleomag sites, Carmacks & Mount Tatlow/Churn Creek, but Spences Bridge is not honored since it does not fully pass the fold test. The model is based on globally derived apparent polar wander paths (APWP), which reach the same conclusion as for APWP derived solely from North American rock units (Housen, 2021; Tikoff et al., 2022). The *main* BajaBC translations are implemented 70-50 Ma along the yellow line, which runs mainly through Intermontane terranes (and their left-behind correlatives in the Blue Mountains/U.S.). This Baja-BC fault line is necessarily speculative, but it must run inboard of all paleomag sites that show significant offsets (details in section 6.2). The trajectory of the Sierra Nevada, illustrative of a non-translated site on stable NAM, is shown in dark green. Accreted superterrane packages follow the colour scheme of Figure 7; additional pericratonic blocks are colored dark and light purple.

(B) Tomotectonic reconstruction of the assembly of Alaska from Baja-BC and Angayucham terrane translations. This 85-Ma snapshot of the Clennett et al. 2020 model reconstructs the configuration of Baja-BC (comprising at a minimum the terranes west of the yellow line) at the onset of its northward sprint. The locations of the Angayucham (red barbs) and northern Farallon trenches (green solid barbs) are constrained by the ANG and CR slabs, respectively. The terranes of the then-active ANG arc (Koyukuk, future Central Alaska, in red) were welded into the Orcas microplate, but gradually being dislodged and rotated by the obliquely colliding NAM – the “Great Alaskan Terrane Wreck” of Johnston (2001). The northern Farallon arc terranes (Pacific Rim, PR, and others now underplating INS) were also intruded into the Orcas plate and slowly accreted against INS. During its northward sprint, Baja-BC effectively became part of the Orcas plate, separated from NAM by the “Baja-BC fault” (yellow line) or collection of faults.

Baja-BC passes *inboard* of, and unimpeded by, the CR Farallon trench, which still sits offshore. As NAM advances westward, Orcas is squeezed out toward the west or north. It may have subducted into one of two small slabs observed under the grey areas (see text). Due to the small size and mobility of the plate, its disappearance can be rapid, and the Baja-BC and Central Alaskan terranes on it are transported along (the “sprint” phase). As the Orcas seafloor subducts, the northern Farallon trench persists and makes landfall on NAM, becoming the continental Cascades arc by ~50 Ma, which shut off this northwestern passage for shuffling terranes. Baja-BC and Central Alaska collapse against each other and against NAM, completing the assembly of Alaska. The angle between the yellow line (paralleling the NAM margin) and the ANG slab (red line) sets the angle of the Alaskan orocline.

# Tomotectonics of Cordilleran North America since Jurassic times: double-sided subduction, archipelago collisions, and Baja-BC translation

Karin Sigloch<sup>1</sup> and Mitchell G. Mihalynuk<sup>2</sup>

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## Abstract

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## 45 1. Introduction

46 The term “tomotectonics” refers to a set of quantitative reasoning tools for reconstructing the paleo-  
47 geographies of regions shaped by subduction. Tomotectonics aims to account for all observations that  
48 record the processes of (paleo-)subduction, above and below the surface, and to reconcile them in a  
49 hypothesis-driven framework. Two types of observations play a fundamental role in that they generate the  
50 predictions of the tomotectonic method, and they feature in its name: “tomo” (for seismic tomography of  
51 subducted lithosphere in the mantle) and “tectonic” (for plate tectonics). These are largely geophysical  
52 observations, which are linked by a null hypothesis about vertical slab sinking that generates a shared,  
53 absolute spatial reference frame for slabs and plate motions.

54  
55 Geological field observations play a different role: to test the tomotectonic predictions, and thus to reject  
56 or support the hypothesis. Pertinent geological observations are made in accretionary orogens, which are  
57 the surface products of the long-lived subduction processes recorded by the slabs. They contain the  
58 volcanic arc terranes that are directly and causally tied to the lithosphere that subducted. This paper  
59 applies the tomotectonic method to the North American Cordillera, inferring and evaluating its paleo-  
60 geographies since Jurassic times, which is the natural limit of scope in terms of confident geophysical  
61 observations, both for the mantle beneath North America and for the Farallon plate record surviving at  
62 the surface, on the Pacific plate.

63  
64 The strength of the tomotectonic approach is its particularly simple, strong working hypothesis, which  
65 describes the behavior of subducted oceanic plates once they have entered the mantle. With very few  
66 degrees of freedom, the vertical sinking hypothesis is highly predictive – and realistically falsifiable, the  
67 hallmark of a useful hypothesis. It does not follow that its falsification is easy in practice because the  
68 observational database of land geology is so complicated and incomplete. The essence of subduction is to  
69 remove its own traces from the surface into the subsurface. By contrast, the inventory of paleo-seafloor  
70 deposited in the mantle should be complete. That leaves the practical challenge of imaging it completely  
71 with seismic tomography, a domain where major progress has occurred over the past ~20 years (Earth  
72 Model Collaboration 2024, Hosseini et al. 2018, Pavlis et al. 2012).

73  
74 Part 1 of this study, the prediction-generating part, consists of Sections 2-4 (figures 1-6). Section 2  
75 presents the relevant observations from mantle tomography and quantitative, global-scale plate  
76 reconstructions. Section 3 explains the tomotectonic working hypothesis of vertical slab sinking, which  
77 links the two data sets and renders them predictive. Section 4 carries out this predictive program by  
78 hindcasting paleo-trenches and their override sequences for North America.

79  
80 Part 2 consists of Sections 5 and 6, which examine the predicted arc-building and accretion events in light  
81 of geological observations. Section 5 presents the validation principle: that every slab in the mantle  
82 predicts a (paleo-)arc at the surface, which should correspond with a geologically observed arc of suitable  
83 age, spatial extent and composition (e.g., continental versus oceanic). Equally important, every  
84 geologically known arc should be paired with a plausible slab in terms of location and depth. Section 5.3  
85 re-runs the tomotectonic override sequence of Section 4.4 in order to spell out its predictions for the  
86 paired, real-world arc terranes.

87  
88 We have been able to identify only one set of slab/arc matches that leaves no orphaned arcs or slabs, and  
89 invokes no more complicated behavior than admitted by the tomotectonic null hypothesis (Sigloch &  
90 Mihalyuk 2013, 2017). It has generated significant debate because it predicts more intra-oceanic  
91 subduction and later accretion events (Late Jurassic to Cenozoic) for Cordilleran superterrane than more  
92 established interpretations (Monger & Gibson, 2019). On the other hand, the established interpretations  
93 have all been challenged from within geology as well (Moores 1970, Moores 1998, Johnston 2008,  
94 Hildebrand 2009, Schweickert 2015, Tikoff et al. 2023). Here we focus more on inferring large-scale

95 transform motions from major structural breaks in the younger slab assemblage, and non-deposition –  
96 pertinent to “Baja-BC” displacements mostly between 80-50 Ma (Irving 1985, Enkin 2006, Kent & Irving  
97 2010, and extending to 100 Ma according to Tikoff et al. 2023). Such displacements obscure preceding  
98 terrane accretions and are seemingly at odds with concurrent continental arc construction (Cowan et al.,  
99 1997). However, the mantle is very informative and provides a geometric solution to the Baja-BC  
100 conundrum.

101  
102 The reasoning of Section 5 provides the skeptical reader with a template for proposing and evaluating  
103 alternative sets of slabs-arc pairings that satisfy the same observations and simple null hypothesis.  
104 Alternatively, the reader could envisage the level of mantle convection complexity required to link slabs to  
105 surface geology, and whether such complexity yields a predictive working hypothesis.

106  
107 Section 6 discusses how all collision types in the Cordillera were shaped by double-sided subduction in  
108 one form or another: from the early head-on collision in the U.S./Sierra Nevada segment, to oblique  
109 collisions during the Sevier orogeny (Columbian orogeny in Canada) and predominantly transform Baja-  
110 BC translation.

111  
112 In this Penrose Volume contribution, we continue to add tomographic tools for deriving past plate  
113 kinematics from tomographic images of subducted oceanic lithosphere. We specifically refine techniques  
114 for deciphering periods of transcurrent motion from the tomographic slabscape, applying these tools to  
115 the BajaBC debate. Section 7 provides a synopsis and considerations for guiding meaningful discussion  
116 and work in the future.

117

## 118 2. Observations for a tomotectonic reconstruction of Cordilleran 119 North America

120

121 Tomotectonics makes spatial and temporal superpositions of two types of structures that are observable  
122 essentially by geophysical means:

- 123 1) The 3-D geometries of subducted oceanic lithosphere in the mantle (“slabs”), obtained from  
124 seismic tomography.
- 125 2) Quantitative reconstructions of plate motions across the earth’s surface over time, mainly based  
126 on remnant magnetism of extant seafloor.

127

128 For North America (NAM) a superposition of slabs and plate motions for the past ~170 million years  
129 (Ma) is shown in Figure 1, which serves as a visual roadmap for this study. The translucent patches  
130 outline mantle regions (volumes) where subducted seafloor is observed at certain depths between the  
131 surface (0 km) and 1800 km. A first-order observation is that slab distribution is uneven, and that large  
132 regions of the mantle do not contain slab at any depth. Outlines of the NAM west coast trace the  
133 continent’s westward drift over the past 170 Ma, as reconstructed by the “Global R” absolute reference  
134 frame (Torsvik et al. 2019). If in a thought experiment, a resident of Washington state on the U.S. west  
135 coast could be transported 130 million years (m.y.) back in time with the continent, the reconstruction of  
136 figure 1 hindcasts that they would end up in a present-day latitude and longitude signaled by the “130  
137 Ma” coastline, an absolute position that is presently occupied by Maine on the U.S. *east* coast.

138

### 139 2.1 Tomographically imaged slabs

140

141 Figures 2 and 3 render all slabs (or rather, seismically fast P-wave anomalies) in the teleseismic P-wave  
142 tomography model of Sigloch (2011), down to ~1800 km depth in the mantle (where this regional model

143 loses resolution). Mantle imaging under North America made a quantum leap in the wake of the USArray  
144 Transportable Array deployment across the (western) U.S., when ~400 broadband seismometers rolled  
145 across the contiguous U.S. between 2004-2013 (Meltzer et al. 1999). In more recent tomographies,  
146 including global models that image deeper (Hosseini et al. 2018), the resolution under North America  
147 remains driven by the USArray data set. Other regional tomographies of North America can be inspected  
148 at the portal of (Earth Model Collaboration 2024). The massive slab complexes to be discussed are well  
149 delineated in practically all post-USArray tomographies. Imaging differences or uncertainties persist  
150 mainly in the shape of less massive, upper-mantle slabs. Examples concern the spatial continuity of  
151 recently subducted Cascadia (Farallon) slab (see review of Pavlis et al. 2012), or the vertical delineation of  
152 old, stable continental lithosphere against slab in the transition zone below it (both are seismically fast).

153

154 Figure 2 renders two 3-D oblique views of the slab complex into which the Farallon (Juan de Fuca) slab  
155 subducts today. Slow seismic anomalies, which are proxies mainly for hotter-than-average mantle (e.g.,  
156 Yellowstone), are not rendered but can be inspected in Sigloch (2011). We prefer these 3D iso-surface  
157 renderings to the more commonly seen 2-D depth slices (“red-blue” maps) because vertical continuity of  
158 structure is particularly important in tomotectonics. The disadvantage of oblique views is that their 3-D  
159 content cannot always be presented satisfactorily on 2-D paper. As a compromise, we show the same 3-D  
160 renderings in “map view”, with the virtual camera pointing vertically down – as in Figure 3a, or up as in  
161 Figure 3b. With color as a proxy for depth, such “3-D map views” convey the vertical connectivity of  
162 structures, and easily tie to surface map overlays. The “inside-out” map view of Figure 3b renders the  
163 deepest (red) slabs in the foreground, unobscured by the blanket of shallower slabs. The deepest slabs  
164 (1100-1800 km, red to yellow levels) are very steep and spatially concentrated in linear belts. We call them  
165 “slab walls”. By contrast, slabs above 1000 km show more lateral spread and are less clearly structured.  
166 To get oriented in the 3-D renderings, the reader may find it useful to match the slabs cartooned in  
167 Figure 1 with the 3-D slab observations in Figures 2 and 3. In section 4, we consider these slab  
168 geometries in detail, after discussing in section 3 how we propose to interpret their evolution over time  
169 and space.

170

171 That seismically fast anomalies (below lithospheric depths) represent subducted lithosphere has become a  
172 quasi-certainty as imaging resolution has improved over the decades. Lots of lithosphere is expected  
173 under North America from its subduction history, and at least recently subducted slab should remain  
174 tomographically visible. Indeed, fast anomalies are now unfailingly imaged in the upper mantle below  
175 subduction zones (e.g., the purple slab level beneath Cascadia in Fig. 2). These fast anomalies coincide  
176 with the band of seismicity produced within the slab in the upper mantle (<700 km depth), which  
177 ground-truths the tomographic detection of slab. The imaged anomalies usually continue below the  
178 deepest earthquake depths, and this satisfies *a priori* expectations from geologic or plate tectonic records  
179 of longer subduction histories (at least 180 m.y. in the case of the northern Farallon slab of Fig. 2).  
180 Finally, there is no plausible alternative for what the fast anomalies might represent other than cold,  
181 subducted lithosphere.

182

## 183 2.2 Quantitative plate reconstructions

184

185 The primary constraints on quantitative plate reconstructions come from paleo-seafloor spreading ridges.  
186 Their spreading histories are recorded as isochrons (“stripes”) of alternating seafloor magnetization,  
187 which in principle permit very detailed and accurate reconstructions of relative plate motion circuits as  
188 long as plates can be linked through paleo-spreading ridges. The activity of trenches destroys these  
189 records by subducting the magnetized seafloor. Hence isochron-based reconstructions do not reach back  
190 beyond 100-200 Ma, but for North American reconstruction, the situation is very favorable. We require

191 mainly the (completely preserved) Atlantic spreading record, which is completely preserved back to  
192 Pangean times (>170 Ma, Müller et al. 2008). For eastward subduction, constraints are provided by an  
193 exceptionally long (>180 Ma) record of Farallon-Pacific spreading in the Pacific basin (Engebretson et al.  
194 1985), although with the Farallon plate now subducted, we must rely on an assumption of symmetric  
195 spreading, which is well supported observationally (Müller et al. 1998).

196  
197 Seafloor isochrons only permit reconstructing the paleo-plates' motions *relative to each other*. It is crucial to  
198 appreciate that the reconstruction of Figure 1 is delivered in *absolute* coordinates relative to the lower  
199 mantle. The lower mantle is chosen as reference because it is the most slowly changing among the earth's  
200 layers, moving 1-2 orders or magnitude more slowly than tectonics plates, i.e., millimeters per year, versus  
201 several centimeters or more. The absolute tie of relative plate circuits to the lower mantle is achieved via  
202 intraplate hotspot tracks: the entire lithospheric shell of the earth must be translated relative to the deeper  
203 mantle over time, such that in the reconstruction for time 'T', all seamounts dated to time 'T' in the  
204 available hotspot tracks come to overlie the *present-day* positions of their generating hotspot volcano. The  
205 mantle plumes presumed to create the volcanic hotspot tracks are expected *a priori* to originate as  
206 upwellings from the lowermost mantle. Therefore, the reasoning becomes that hotspot tracks empirically  
207 yield the best available proxy for the quasi-stationary lower mantle. Indeed, the set of (Indo-Atlantic)  
208 hotspots is observed to have moved only very slowly relative to each other (<10 mm/yr) (Morgan 1983,  
209 O'Neill et al. 2005). The simplest explanation is that the hotspots do not move relative to the medium in  
210 which they are anchored, i.e., the lowermost mantle. The specification of "Indo-Atlantic" hotspots is  
211 important because North American paleo-positioning in Figure 1 is achieved relative to this well-behaved,  
212 near-stationary set of hotspots of the Pangean hemisphere. Pacific hotspots, whose stationarity is more  
213 questionable (Wessel & Kroenke 2008), are not needed and do not enter any of our reconstruction  
214 arguments. Pacific hotspots are not used to infer the sequence of North America drifting and override of  
215 the intra-oceanic archipelago that we infer from slab geometries.

### 216 3. The tomotectonic null hypothesis of slabs settling vertically

217

#### 218 3.1 Predictive power of the vertical sinking hypothesis

219

220 Tectonic plates at the surface move horizontally, at typical velocities of centimeters per year relative to the  
221 lower mantle (or rather, relative to hotspots, our best proxy of lower-mantle motion). A way of defining  
222 vertical slab sinking is that a sliver of tectonic plate loses all of its horizontal motion upon entering its  
223 trench, and subsequently moves only vertically down under the pull of gravity (Fig. 4a). An analogue  
224 would be a tablecloth draped too far over the edge of a table, and which starts sliding off the table under  
225 the pull of gravity. The part of the cloth still covering the table is moving horizontally, but at the table  
226 edge (the "trench"), its motion is abruptly converted into almost exclusively vertical motion, until all of  
227 the cloth has "subducted" off of the table. For this change of the motion vector to occur, the table cloth  
228 needs to be pliable; if instead it was stiff like a sheet of metal, motion vectors for portions above and  
229 astride the table would be identical. A defining characteristic of a tectonic plate is that it does behave like  
230 a stiff sheet at the surface, in principle not admitting internal deformation. Hence the vertical sinking  
231 hypothesis postulates that a plate entering the mantle in a subduction zone loses rigidity and deforms to  
232 follow only the pull of gravity, because stress transmission from its still-connected, surficial part has  
233 become ineffectual.

234

235 We first consider the utility of vertical slab-sinking behavior in paleo-geographic reconstruction that  
236 follow from the example of slabs beneath North America in figures 1 & 3. The vertical-sinking hypothesis  
237 predicts that every latitude and longitude where slab is observed (at any depth) must once have hosted a

238 paleo-trench and its arc at the surface. The slabs map out their own paleo-trench locations (vertically  
239 above them), although we need more information to determine when each trench was actively depositing  
240 slab. It is equally straightforward to hindcast the absolute locations where no trench was ever present,  
241 namely above the slab-free areas in figs. 1 & 3. No other method of inference provides such  
242 straightforward predictions of paleo-trench and -arc geometries. (In this paper, we variably refer to paleo-  
243 trenches or paleo-arcs in terms of predictions, sometimes interchangeably. Every subduction zone where  
244 plate is consumed must feature both a trench and an arc on the overriding plate – running in parallel,  
245 typically spaced by 80-200 km, which is a small distance compared to observational uncertainties in paleo-  
246 reconstruction. In the hypothesis-generating, geophysical sections 3 and 4, we typically refer to paleo-  
247 trenches being predicted (i.e., plate boundaries), whereas in the hypothesis-testing, geological sections 5  
248 and 6 we refer more to paleo-arcs, as the most survivable and localizable record of the paleo-plate  
249 boundary.

250

251 The joint consideration of slab geometries with the continent reconstruction of Figure 1 extends the  
252 predictions to the type of plate boundary. Recall that the west coast in Figure 1 is reconstructed relative to  
253 the lower mantle. Under the vertical-sinking hypothesis, the (lower-mantle) slabs of Figure 1 have not  
254 moved laterally since entering their trenches. Hence the slabs and the continent are shown in the same,  
255 lower-mantle reference frame, and their absolute coordinates are directly comparable.

256

257 Under this hypothesis, the passage of reconstructed North America across the slab-scape in Figure 1  
258 directly translates into a paleo-movie of the continental margin riding into a network of subduction zones.  
259 The trenches (slab-filled areas) can only have existed while the continent was not occupying their  
260 positions. By the end of the movie (0 Ma), all slabs must have been deposited in their observed positions,  
261 vertically below a network of paleo-trenches, the positioning of which must respect plate geometries and  
262 other plate tectonic rules. For example, if the orange, northern MEZ slab now located under the U.S.  
263 eastern seaboard sank vertically, it could not have been deposited after ~90 Ma because by that time, the  
264 continent was overlying all areas occupied by the slab. Hence no trench or arc younger than ~90 Ma can  
265 be assigned to those easterly absolute longitudes in a tomotectonic reconstruction. By the same argument,  
266 a paleo-trench must have been overlying, or migrating across, the absolute area now occupied by FS slab,  
267 and it must have been active before ~70 Ma, because by 70 Ma, the continent was overlying the entire  
268 area occupied by FS slab. Between ~170-150 Ma, the west coast traversed a slab-free zone, hence a  
269 trench along the west coast is not admissible for those times. For times more recent than ~150 Ma,  
270 increasingly large segments of the west coast overlap slab provinces (MEZ, ANG, FS), which means that  
271 a trench is required at those times and latitudes along the margin, Andean-style. If FS slab, for example,  
272 was laid down after ~130 Ma, then it must have been generated by eastward subduction; the sourcing of  
273 slab from west of FS would be inconsistent with NAM occupying this region by ~130 Ma. The vertical  
274 slab sinking hypothesis is testable in principle: if somehow, we could be sure that slab FS was deposited  
275 more recently than 70 Ma, we would have to conclude that the slab must have sunk significantly non-  
276 vertically, translated eastward in the mantle (unless the continental reconstruction was in error, placing  
277 NAM too far west).

278

### 279 3.2 The range of slab geometries generated by vertical sinking

280

281 There are two conditions for vertical slab sinking: (1) a plate must lose its rigidity upon entering the  
282 mantle, and (2) while sinking in the mantle, the slab does not get advected laterally by ambient mantle  
283 flow. These conditions may well be met, not perfectly but within the observational uncertainties. A crucial  
284 (tomographic) observation in this context is that slabs are much thicker than a single sheet of mature  
285 ocean lithosphere (i.e., much thicker than ~100 km) if they are located in or below the mantle transition

286 zone, i.e., below  $\sim 400$  km depth. Hence the question becomes whether the thickened slabs sink vertically  
287 within the observational uncertainties. We can limit the null hypothesis of vertical sinking to thickened  
288 slabs, since in tomography models, slabs appear ubiquitously thickened from the mantle transition zone  
289 down (figs 2 & 3).

290

291 This section considers the first condition of slab softening near the trench, leaving the second question of  
292 lateral entrainment to section 3.3. Historically, vertical slab sinking has served as the physically plausible  
293 starting position from first principles; deviations from it were considered as and when required by  
294 observations. The first-ever cartoon of subduction, published by Harry Hess (1965) and reproduced in  
295 Figure 4A, spells out vertical sinking beneath a moving trench. Hess conveys the concept of softening  
296 with clarity by envisaging a slab as a chain of viscous droplets, each of which should sink vertically if they  
297 are relatively dense and not entrained by pre-existing, lateral motion of the low-viscosity mantle through  
298 which they sink. The trench in Figure 4A has moved from points A to B, *relative to the mantle*, and Hess  
299 spells out how the ratio between trench velocity and slab sinking rate determines the slab dip angle: “If  
300 the overriding continent or island arc moved forward at the same rate that the current [i.e., droplet]  
301 descends then a plane dipping at  $45^\circ$  will represent the zone along which the motion is taking place.” An  
302 unrealistic aspect of Hess’ cartoon, published a few years before the plate tectonics breakthrough of his  
303 postdoc (Morgan 1968), is that the subducting plate does not actively converge onto the trench (zero  
304 motion relative to the mantle). Hence it has no horizontal velocity to lose upon entering the mantle,  
305 whereas actual subducting plates are typically observed to move trenchward several times faster than their  
306 overriding plates (Forsyth & Uyeda 1975, Cerpa et al. 2022). Figure 4, panels B-I explores the slab  
307 geometries predicted to result from vertical sinking as a function of the velocities  $v_{\text{sub}}$  and  $v_o$  of the  
308 subducting plate and overriding plates, respectively (keeping the slab sinking rate  $v_z$  constant in all  
309 scenarios). This regime diagram includes the most frequently observed regimes where  $v_{\text{sub}}$  is significantly  
310 faster than  $v_o$  or  $v_z$  (panels B, D, F and H).

311

312 The geometrically simplest case (Fig. 4E) is vertical sinking under a stationary upper plate and arc ( $v_o=0$ ),  
313 with a relatively slow subducting plate. This results in a vertically dipping slab, which remains undeformed  
314 because the rate at which it enters the mantle is fully accommodated by the vertical removal of older slab  
315 through sinking:  $v_{\text{sub}} = v_z$ , with  $v_o=0$ . By contrast, the mantle entry rate in Figure 4D much exceeds the  
316 sinking rate ( $v_{\text{sub}} = 2.5v_z$ , a typical value for present-day subduction zones, Cerpa et al. 2022), and this  
317 excess of subducted lithosphere is accommodated by slab thickening (“shortening”) – most likely through  
318 a folding process, as cartooned (Ribe et al. 2007, Stegman et al. 2010). The result is a thickened slab that  
319 dips vertically, since the trench is stationary.

320

321 Vertical sinking under migrating trenches ( $v_o \neq 0$ ) results in dipping slabs (Fig. 4B/C, F/G, H/I), the dip  
322 angle determined by the ratio between trench motion  $v_o$  and sinking rate  $v_z$ , as already noted by Hess  
323 (1965). Whether or not a dipping slab is thickened again depends on whether the slab entry rate exceeds  
324 the rate at which accommodation space is generated in the mantle. Not only slab sinking out of the way  
325 ( $v_z$ ), but also lateral trench migration  $v_o \neq 0$  contribute to accommodating the slab in this generalized  
326 scenario. The “traffic jam” conditions that result in slab thickening prevail in most present-day  
327 subduction zones (Cerpa et al. 2022): plate convergence is typically 50-100 mm/yr, of which only one half  
328 to one quarter can be accommodated by vertical slab sinking and lateral trench motion. Thus, thickened  
329 slabs are expected *a priori*, and are indeed observed: the slabs contoured in figs. 2 & 3 are several times  
330 thicker than a sheet of lithosphere, except immediately below the Cascadia trench (purple in Fig. 2).

331

332 We interpret the massive slab walls MEZ, ANG and CR/CR2 in Figure 3B to have formed similar to  
333 Figure 4D, and slabs FS and FN to have formed as in Figure 4F. Very rapid convergence in Figure 4H

334 produces a flatly subducting slab, a regime which may apply to part of FS slab (Laramide flat subduction  
335 episode). While most slabs are predicted and/or observed to thicken, tomography cannot (yet) resolve  
336 their internal structure, e.g., the individual folds. For the slabs' continued sinking behavior, it makes no  
337 difference how exactly they thickened, but this likely happens by folding (as cartooned), a process shown  
338 to be viable and probable by numerical and physical experiments (e.g., Ribe et al. 2007, Stegman et al.  
339 2010, Cerpa et al. 2022). The physics are those of a viscous thin sheet (lithosphere) encountering a semi-  
340 rigid backstop (the lower mantle) – sometimes observed when pouring honey or cake batter.

341  
342 Slab thickening is a viscous deformation process; at the depth where it is observed the lithosphere has lost  
343 its “platiness”. For the currently subducting Farallon (FN) plate, thickening is observed ~400 km under  
344 the well-illuminated Cascadia trench (Fig. 2, or more clearly in Sigloch et al. 2008, their Fig. 1). While  
345 softening at 400 km depth is not the same as immediately after trench entry, the difference is small for  
346 paleo-reconstruction (even less when reconstructing arcs, which form above lithosphere that has already  
347 subducted 80-200 km). A massive slab wall should consist of many lithospheric folds, and the sheet from  
348 the trench down to the slab merely corresponds to the next limb to be laid down on the slab wall (Fig.  
349 4D). The laying down of the limb implies non-vertical motion, on the scale of the lateral width of the slab  
350 wall (400-700 km). Hence the width of a slab wall represents a quantification of the deviation from strictly  
351 vertical sinking (in the upper mantle), and the resulting spatial fuzziness needs to be evaluated together  
352 with other spatial uncertainties concerning, e.g., the hotspot frame, plate reconstruction, or the shape of  
353 the continental paleo-margin before it encountered the arc, and changes thereof during collision or  
354 extension (quantified by Sigloch & Mihalyuk 2013, Supplementary Information). Reconstructing the  
355 paleo-arc centered above the slab wall probably entails 100-200 km of uncertainty (the arc might have  
356 been shifted towards the downgoing or the overriding plate). But this uncertainty is small compared to  
357 other interpretable geometries of interest, such as slab length along strike, or the slab-free gaps between  
358 two slabs. Despite the widened slab geometries, the overall slab-scape in Figure 3 remains highly  
359 structured, with individual slabs well separated.

360

### 361 3.3 The vertical sinking hypothesis for thickened slabs

362

363 The width of a slab wall signals and quantifies a moderate amount of non-vertical sinking in the  
364 uppermost mantle, associated with the thickening/folding process. Once a slab is thickened, it is not  
365 expected to undergo much additional lateral displacement during its continued sinking towards the core.  
366 The wider a slab (wall), the more massive it is and the more nearly vertically it is expected to sink because  
367 gravity, vertically down, is the only primary force driving mantle convection. Lateral mantle flow (“mantle  
368 wind”) is a secondary effect that translates material between regions of (active) downwelling or upwelling.  
369 Even if lateral flows were pronounced, they are not likely to effectively entrain thickened slabs because  
370 those are the most massive sinkers in the mantle, and because the ambient mantle is less viscous and will  
371 therefore tend to flow around a slab in toroidal motion rather than carrying it along.

372

373 Lateral entrainment can be quantified by numerical modelling, although a fully realistic setup –  
374 3-D spherical geometry; self-consistent, spontaneous plate formation and subduction rather than forced  
375 plate motions; sufficient rheology contrasts in the upper mantle to produce slab folding –  
376 remain beyond today's computational possibilities. Van der Wiel et al. (2024) found 2 mm/year average  
377 lateral displacement for 10-15 mm/year vertical sinking in the lower mantle, which translates to 266-400  
378 km of lateral displacement while sinking through the lower mantle. As a caveat, their slabs did not fold  
379 nor thicken significantly until the lowermost mantle, biasing upward the lower-mantle value (of 2  
380 mm/year) for lateral displacement. If folding had happened in the upper mantle as observed by  
381 tomography (and achieved in a 2-D model by Cerpa et al. 2022, through the implementation of an

382 asthenosphere), then the resulting, more massive slabs would probably have incurred even less lateral  
383 motion in the lower mantle. In a physically much more approximate setup, Steinberger et al. 2012 also  
384 obtained several hundred kilometers of lateral slab displacement during sinking from surface to core. In  
385 summary, models are not fully realistic but point towards several hundred kilometers of lateral slab  
386 displacement while sinking through the lower mantle, which may still be an overestimate.

387

388 A strong observational indicator for vertical sinking, in both upper and lower mantle, is that the slab walls  
389 of Figure 3B have remained so vertical and structurally intact, despite their great “height” of >1000 km in  
390 places (MEZ, ANG) and their great age (proportional to the amount of lithosphere they contain). By far  
391 the simplest explanation for the formation of these slab walls is vertical sinking beneath a stationary arc-  
392 trench system (Fig. 4D). The alternative of non-vertical sinking (plus a non-stationary trench exactly  
393 compensating for this non-vertical sinking) seems contrived, especially considering the massive slab  
394 volumes that would need to have moved around laterally. To remain vertical into the lower mantle,  
395 entrainment into lateral flow could not have been significant without destroying the observed vertical wall  
396 geometries of Figure 3A/B.

397

398 We conclude that first-order considerations, observations and simulations all point to vertical sinking of  
399 slabs through the upper and lower mantle, with lateral deviations not exceeding a few hundred kilometers,  
400 a small amount relative to slab dimensions of  $10^3$ - $10^4$  km. Most non-vertical sinking is probably due to  
401 the thickening (folding) process in the upper mantle, with the subsequent descent of thickened slab even  
402 more nearly vertical. While remaining a hypothesis, this proposition is likely to accrue more support from  
403 simulations and from tomotectonic analyses in other regions. Vertical sinking of lower-mantle slabs  
404 makes very strong predictions about paleo-geography at the surface. Even where predictions contradict  
405 widely held *interpretations* of Cordilleran geology, they are worth pursuing because the vertical sinking  
406 hypothesis is so plausible and because the resulting inferences arising from it are straightforward, detailed  
407 and geologically testable.

408

### 409 3.4 Vertical slab sinking not tenable for North America?

410 We have repeatedly encountered a perception that for the slab assemblage under North America, vertical  
411 slab sinking has been rejected conclusively. This would be correct only if framed by the current consensus  
412 interpretation of paleo-geography: “Vertical slab sinking beneath *an always margin-hugging Farallon trench* is  
413 untenable” – whereas for intra-oceanic subduction of the early Farallon and other plates, the question had  
414 not been asked. Tomographic interpretations that guided geodynamic models prior to Sigloch &  
415 Mihalyuk (2013) had not considered anything but margin-hugging Farallon subduction, and have indeed  
416 shown that vertical sinking under a margin-hugging, migrating trench would have generated slab  
417 assemblages significantly different from the observed (Lithgow-Bertelloni & Richards 1998) – more  
418 evenly spread beneath the continent, rather than concentrated in slab walls with strikes not resembling the  
419 contour of the ancestral western continental margin. Bunge & Grand (1997) attributed this mismatch to  
420 one specific episode of non-vertical sinking, namely flat subduction during Laramide times (they used  
421 ~70-40 Ma), although their numerical forward modelling did not actually produce the postulated, non-  
422 vertical sinking. Liu et al. (2008) did achieve highly non-vertical sinking for the same Laramide scenario,  
423 but only by replacing forward modelling of Farallon subduction with adjoint (inverse) modelling, and by  
424 additionally adopting an unusual mantle rheology *a priori*. Whereas forward modelling predicts present-day  
425 slab geometries by numerically subducting plates over a past time period, adjoint modelling solves for  
426 paleo-mantle structure at the simulation’s starting time (tens of m.y. ago), by minimizing the misfit  
427 between observed and simulated mantle structure at present day. Specifically, Liu et al. (2008) investigated  
428 whether a paleo-mantle state could be found that was capable of driving sufficiently effective lateral flow  
429 to translate the Laramide Farallon slab eastward in the upper mantle (into the MEZ slab), given that the



430 (margin-hugging) trench was too westerly to deposit MEZ slabs in forward models (Bunge & Grand  
431 1997). Hence the adjoint model was basically asking for lateral slab displacement. It could in principle  
432 conclude that non-vertical sinking was physically possible *if all input boundary conditions (including paleo-trench*  
433 *locations) were correct*. It could not diagnose *whether* the simulated paleo-trench locations were correct, even  
434 less whether non-vertical sinking was actually required. For the same reasons, the adjoint modelling  
435 recently deployed by Fuston (2022) cannot diagnose that non-vertical sinking is required in the real  
436 mantle – unless it was certain that their *a priori* placement of paleo-trenches (for explaining Insular  
437 superterrane evolution) was correct. Note that “flat slab” subduction, which we consider very likely for  
438 Laramide times (in agreement with Liu et al. 2008, Humphreys, 2009; Humphreys et al., 2024) can  
439 alternatively be produced by *vertical* sinking combined with very rapid lateral trench motion, Figure 4H/I.

440

441 Bunge & Grand (1997) or Liu et al. (2008) could not have envisaged anything but a margin-hugging  
442 Farallon trench, which justified their escalation from forward to adjoint modelling in order to obtain  
443 sufficiently non-vertical sinking. The Cascadia slab of Figure 2 had not yet been imaged, and thus the slab  
444 walls under the U.S. eastern seaboard and across Canada (“MEZ” and “ANG”) appeared to be the only  
445 possible resting places for 180 m.y. of demonstrated Farallon subduction. For lack of additional slabs,  
446 MEZ-ANG slabs needed to be matched with the Farallon plate, and the trench must have been margin-  
447 hugging from plate kinematics. This situation fundamentally changed with the imaging of the Cascadia  
448 (FN/CR) slab into the lower mantle (Sigloch et al. 2008) – a slab that currently receives Farallon  
449 lithosphere and arguably always has (c.f. section 4). This discovery made it possible and necessary to  
450 question the margin-hugging nature of the (northern) Farallon trench, and to envisage additional intra-  
451 oceanic trenches (Sigloch & Mihalynuk, 2013). Hence it is natural to revisit the physically appealing and  
452 predictive hypothesis of vertical slab sinking under North America.

453

### 454 3.5 Uniformity of slab sinking

455

456 There is no need to hypothesize further specifics about slab sinking, and in particular, no stipulation of  
457 any sinking rates *a priori*. If deeper slabs are found spatially adjacent to shallower slabs, there is an intuitive  
458 expectation that the deeper slabs subducted earlier, because all slabs sank through essentially the same  
459 medium. We will occasionally use this expectation to arbitrate between two explanatory alternatives (e.g.,  
460 for slab W), but there is no need to elevate this expectation to a part of the hypothesis. The slabs will turn  
461 out to embody this principle automatically, e.g., deeper slabs where trenches are known to have been in  
462 the deeper past.

463

464 There are many opportunities to *estimate* sinking rate from the slab geometries –we present some, and  
465 proper quantifications can be found in Sigloch & Mihalynuk (2013) and Mohammadzaheri et al. (2021).  
466 These estimates indicate that the slabs sank at  $\sim 10$  mm/yr ( $\pm 2$  mm/yr), more or less everywhere across  
467 the Americas, which is a remarkably uniform result. It has led to misconceptions that tomotectonics  
468 *assumes* or imposes a sinking rate arbitrarily. To counter this impression, the present study limits mention  
469 of sinking rate, leaving it largely implicit in the tomotectonic observables. An explicit sinking rate is only  
470 needed when making an actual tomotectonic movie, where slabs grow at a rate commensurate with plate  
471 advances (e.g., Sigloch & Mihalynuk 2017) – in which case  $\sim 10$  mm/year is the only value that “works”  
472 with vertical sinking.

473

474 We finish with a single striking observation that suggests a basically uniform sinking rate: the deep ends of  
475 the slab walls of figure 3b all reach to 1800-2000 km depth, across the entire study domain. (The regional  
476 tomography of figs. 2 & 3 loses resolution around these depths, but global-scale tomographies confirm  
477 1800-2000 km as the deep ends of these slab walls (Hosseini et al, 2018). Below 1800-2000 km, copious

478 volumes of slab are present into the lowermost mantle, but in geometrically different arrangements. This  
479 suggests a comprehensive and relatively sudden reconfiguration of paleo-trenches across the area, *plus a*  
480 *constant sinking rate across the domain*, otherwise the slabs that were deposited after the reconfiguration event  
481 (and which are the subject of our study) would not all have reached the same depth of ~1800-2000 km.  
482 What was this event? Section 4 will yield the answer without reference to a sinking rate, but at 10  
483 mm/year, a slab depth of 1800 km translates to a mantle entry time of 180 Ma. This is the time when  
484 Central Atlantic opening started appreciably, setting North America on its westward drift, and also when  
485 the Pacific plate (and possibly the Farallon plate) were born – indeed a major reconfiguration that may  
486 have fundamentally reset paleo-Pacific subduction zones. These observations are all mutually consistent –  
487 supporting uniform slab sinking, as well as clear correspondences between deep mantle structure and  
488 known, major surface events. The slab breaks at 1800-2000 km depth thus provide a natural limit for the  
489 scope for our reconstruction. An older archipelago, below ~2000 km, is not as sharply resolved by  
490 tomography, and the uncertainties on absolute paleo-positioning at the surface (in absence of hotspot  
491 tracks) become unworkable beyond Jurassic times.  
492

## 493 4. Tomotectonic reconstruction of North America

494

### 495 4.1 A western and an eastern slab complex under North America

496

497 We are ready to execute the predictive stage of tomotectonics. One by-product is Figure 5, which makes  
498 paleo-trench predictions by “transcribing” the slab-scape of Figure 3 using the tomotectonic null  
499 hypothesis. The tomography model is sliced into horizontal maps in depth increments of 100 km. At each  
500 depth, a paleo-trench line is drawn above every slab present, and colored according to the depth-to-color  
501 scheme of Figure 3. For slab walls, it is easy to draw the inferred trench lines (centered inside the narrow  
502 slab). For the almost vertical slabs, the lines change little with depth, resulting in tightly clustered lines in  
503 Figure 5. For dipping slabs, the transcription is subject to larger uncertainties, and paleo-coastlines or  
504 interpolations may also be used, as will be explained.  
505

506 The assemblage of slabs under North America clearly separates into two groups (Figs. 1 and 3): a Western  
507 Slab Group comprising slabs CR, W and FN; and an Eastern Slab Group, comprising slabs MEZ, ANG,  
508 and FS. Slabs within each group are spatially connected and separated from the other group by slab-free  
509 mantle.  
510

511 Figures 1 and 3a show a small overlap between the two slab groups (easternmost CR and westernmost  
512 FS), but only laterally, not in depth. This does not violate the vertical sinking hypothesis: the area hosted  
513 two different trenches, at different times. The older trench deposited the deeper CR, and the more recent  
514 trench deposited FS. The deepest slabs in both groups are slab walls (MEZ, ANG, deep CR), and they all  
515 reach to the same depth of 1800-2000 km (magenta color level in Fig. 3b).  
516

### 517 4.2 Tomotectonic reconstruction of the Western Slab Group (northern Farallon slabs)

518

519 The three slabs of the Western Group (FN, CR, and W) are jointly rendered in Figure 2. The view angle  
520 of Figure 2a emphasizes spatial continuity, making clear that the three slabs form a single system that  
521 slopes down to the east. By contrast, the view angle of Figure 2b highlights intra-slab breaks and  
522 structural divisions. Slab W is seen to be a separate fragment in Figure 2b, but clearly in a spatial  
523 correspondence with CR in Figure 2a. The subdivision of the main slab into FN and CR in Figure 1 may  
524 seem arbitrary from Figure 3a (FN is the upper-mantle part, corresponding to the purple, light and dark

525 blue levels), but Figure 3b shows that this upper-mantle slab is almost “floating” freely, due to gaps  
526 towards the slab components surrounding it.

527

528 For visual clarity, Figure 2 masks out certain slab parts by comparison with Figure 3, which renders *all*  
529 seismically fast structure (below 400 km depth). Figure 2 omits the deep slab fragment CR2, west of  
530 today’s west coast. It also masks out an upper-mantle slab that strikes east-west under southern  
531 Saskatchewan, Alberta and B.C. (dark blue in Fig. 3a), and which does not participate in the sloping  
532 continuity of the Western Group but rather seems to rest on top of it. (We later return to this slab as the  
533 speculated Orcas slab.)

534

#### 535 4.2.1 FN slab – northern Farallon slab in the upper mantle, margin-hugging trench

536

537 “FN” stands for Farallon North. Near the trench, the slab must represent Farallon lithosphere because  
538 the Farallon (Juan de Fuca) plate is subducting into it today. Below the present-day coastline of the Pacific  
539 Northwest in Figures 2 and 3, shallow slab is imaged beneath the active Farallon (Juan de Fuca)  
540 subduction, but neither north nor south of it. This provides a first reassurance that the tomography  
541 “works”: a slab is imaged below a confirmed (present-day) subduction zone, no slab is imaged below  
542 adjacent non-subduction zones.

543

544 For depositing the upper-mantle slab FN to the east of the trench, a margin-hugging trench is the only  
545 plausible scenario i.e., a continuation of the present-day situation into the past. The continental margin  
546 gradually traversed FN slab over the past ~70 m.y. (Fig. 1), and FN slab shallows to the west (Fig. 2a).  
547 Westward shallowing is consistent with deposition of FN under a westward migrating (marginal) trench,  
548 so that easterly FN is deeper because it had more time to sink, as in fig 4F.

549

550 Magnetic isochrons on the Pacific plate trace the growth of the (northern) Farallon plate from ~180 Ma  
551 to 0 Ma (Atwater, 1989; Engebretson et al., 1985), spreading towards the Western Slab Group. Since  
552 these slabs represent the paleo-trenches closest to the reconstructed Pacific-Farallon spreading ridge over  
553 time (e.g., Engebretson et al., 1985, Seton et al., 2012), and since Farallon plate is still subducting into this  
554 slab today, the Farallon plate must have subducted into FN in the past as well.

555

556 In summary, FN holds Farallon lithosphere, and today’s Farallon trench is built on the continental  
557 margin. The margin’s eastward progression back into the past in Figure 1 matches the FN slab’s eastward  
558 down dip: everything points to a margin-hugging trench in the past as well.

559

#### 560 4.2.2 CR slab – northern Farallon slab in the lower mantle, intra-oceanic subduction

561

562 At first glance, lower-mantle CR slab (turquoise levels and below in Figures 2 and 3) seems to smoothly  
563 continue the downward dip of FN slab (with a margin-hugging Farallon trench as the explanation), but  
564 there are serious problems with this proposal. With increasing depth, CR slab appears increasingly spread  
565 out laterally in Figure 2a because at those depths CR is no longer dipping east. Rather it has steepened  
566 into a slab wall and rotated counterclockwise relative to FN and the coastline, with its long axis striking  
567 NW-SE (especially clear in Fig. 3b). If the deep CR dips at all, it is to the west, in the “wrong” direction  
568 for subduction beneath a west-migrating continental margin. Deposition of the voluminous slab wall  
569 portion of the CR required a stationary trench striking highly oblique to the coastline (Fig. 1). At  
570 yellow/green depth levels in Figures 2 and 3, the CR slab looks segmented and complex, including the  
571 detached fragment W – again, not a good match to the paleo-coastline.

572

573 CR is much more voluminous than FN, requiring a trench that dwelled in the area, but the coastline did  
574 not dwell: by >80 Ma, it shows no overlap with CR slab in Figure 1. The northern Farallon plate was  
575 spreading since >180 Ma, meaning the continental margin outlined in Figure 1 leaves the CR slab 100 m.y.  
576 too early to be consistent with the widely held idea of (northern) Farallon plate subducting since its  
577 inception (~180 Ma) under North America. Prior to 80 Ma, the NAM margin in Figure 1 traverses the  
578 slab-free zone to the northeast of CR, which for tomotectonics implies no trench along the margin.  
579 Finally, CR2, an isolated slab as deep as CR, is present just offshore the present-day west coast in Figures  
580 3a and b – further west than the margin ever was – so that CR2 cannot be due to vertical sinking under a  
581 margin-hugging trench.

582  
583 The inevitable conclusion is that CR and CR2 cannot have been deposited into a margin-hugging trench  
584 by vertical sinking, unlike FN. Therefore, prior to about 80 Ma, the northern Farallon trench must have  
585 sat *offshore* the NAM west coast, or in absolute coordinates, NAM sat well east of the stationary Farallon  
586 (CR) trench. Jointly, FN and CR are voluminous enough to account for the observed 180 m.y. of  
587 northern Farallon spreading and subduction.

588  
589 Hence, by coincidence, FN is not only the upper-mantle part of the northern Farallon slab, but also the  
590 part that was deposited by an Andean-style (Cascades) trench. CR, the lower-mantle Farallon slab, was  
591 deposited by an intra-oceanic trench. The geometric complexities at intermediate depths of CR  
592 presumably reflect the prolonged, oblique override of by NAM <80 Ma that gradually “accreted” the CR  
593 Farallon trench. This tomotectonic prediction of an offshore Farallon trench in the Pacific Northwest  
594 >80 Ma has many implications, including that Baja-BC terranes could have shuffled northward *inboard* of  
595 this trench (section 5).

596  
597 In terms of trench lines for Figure 5, the deep slab wall of CR is easy to transcribe (compare to Fig. 3b).  
598 For the dipping FN slab, paleo-coastlines were equated to trench lines since a margin-hugging trench has  
599 been inferred. The intermediate-depth (turquoise) trenches above the fragmented, rotating slab were  
600 drawn as best guesses/interpolations, and they are almost certainly too simplistic. The strikes of trenches  
601 drawn above W are guesswork since the slab lacks a clear strike, and we do not fully understand W’s  
602 functioning relative to CR. The very deepest (magenta, grey) trench levels of CR are also guesswork –  
603 were the two separate slab walls originally connected into one long, E-W striking slab (Sigloch &  
604 Mihalyuk 2013)? The strike and shape of the offshore CR fragment is not well imaged. The overall  
605 complexity of the Western Group is real and not an imaging shortfall – much of its paleo-geographical  
606 meaning remains to be deciphered.

607  
608

### 609 4.3 Tomotectonic reconstruction of the Eastern Slab Group

610

#### 611 4.3.1 FS slab – southern Farallon slab in the transition zone and lower mantle

612

613 The Eastern Slab Group consists of FS, MEZ and ANG slabs. FS should have subducted more recently  
614 than MEZ and ANG, due to its more westerly and shallower position. The paleo-coastline of Figure 1  
615 traverses FS from ~130 Ma ( $\pm 15$  Ma) to ~75 Ma ( $\pm 10$  Ma?), so deposition must have concluded by the  
616 later date. The slab occupies the same depths as lower FN and intermediate CR, for which we have  
617 inferred similar dates.

618

619 FS slab features a linear, sharp truncation towards its southwest, where the mantle becomes slab free.  
620 This truncation (yellow line in Fig. 1, the “Big Break”) approximately coincides with the strike of the

621 paleo-coastline at 75 or 80 Ma. The simplest explanation for this coincidence is that the FS trench was  
622 built on the margin, and that (vertical) deposition into this marginal trench suddenly stopped at 75-80 Ma.  
623 The slab's elongation in WSW-ENE direction, which is the direction of margin advance, likewise suggests  
624 that FS was deposited beneath the migrating NAM margin.

625

626 In Figure 3b, FS slab tends to deepen toward the east (and the south), albeit irregularly. This also points  
627 to deposition below the migrating margin: easterly FS slab regions have had more time to sink. The gentle  
628 overall dip of FS suggests that its trench migrated relatively rapidly: FS slab geometry best corresponds to  
629 Figure 4H, where the slab flattens in and below the transition zone.

630

631 An eastward-subducting, margin-hugging trench during Cretaceous times, just south of the northern  
632 Farallon system, must be another Farallon trench. The reason is cartooned in Figure 6. When Farallon-  
633 Pacific (FAR-PAC) spreading had just started (time 170 Ma), the associated spreading ridge segment is  
634 short (as recorded by Pacific isochrons), so the CR slab is wide enough latitudinally to account for the  
635 young Farallon plate (fig. 6a). But over Cretaceous times and by 80 Ma (fig. 6b), the FAR-PAC ridge had  
636 extended southward (Atwater, 1989; Engebretson et al., 1985), too far to be accounted for by CR slab  
637 only – since CR slab visibly did not grow southward. Hence an additional Farallon trench segment must  
638 have developed to the south of CR. In fact, FS slab exactly mirrors the lengthening of the Farallon  
639 spreading ridge by a commensurate lengthening of the trench: FS starts out very narrow at the 130-Ma  
640 coastline but widens southward to underlie much of the U.S. and Mexican paleo-margins before the 80-  
641 Ma coastline reaches the Big Break.

642

643 In summary, all aspects of FS point to subduction of the southern Farallon plate over the Cretaceous  
644 period (roughly 130-75 Ma), beneath the NAM margin. Fig. 6b sums up Farallon subduction shortly  
645 before the Big Break: beneath the continental margin of Mexico and California, but still offshore in the  
646 Pacific Northwest.

647

#### 648 4.3.2 Slab-free window between the present-day margin and FS slab

649

650 Next we consider the significance of the slab free area southwest of the Big Break in fig. 1, extending  
651 from FS slab to the current margins of southern California and Mexico. South of the northern  
652 Farallon/Cascadia trench, a dextral transform plate boundary runs along the *present-day* margin (the San  
653 Andreas system). From Pacific isochrons, Atwater (1970) inferred this transform system back to ~30 Ma,  
654 to the reconstructed “landfall” of the PAC-FAR spreading ridge on the margin.

655

656 Tomotectonics can diagnose the existence of this same transform regime from the absence of slab  
657 beneath the present-day margin (indicating that it is not a trench; and a continent-ocean boundary cannot  
658 be a spreading ridge either). However, Figure 1 shows that the slab-free window extends eastward from  
659 the coast not only to the 30-Ma paleo-coastline, but all the way to the Big Break, which corresponds to  
660 the ~75-80 Ma coastline. Hence tomotectonics hindcasts that a transform plate boundary has held sway  
661 along the Californian and Mexican margin since ~75 Ma, when the margin-hugging southern Farallon  
662 (FS) trench suddenly shut down in the Big Break event.

663

664 Slab W (traversed by the coast ~20-50 Ma) might signal a localized, temporary interruption of this  
665 transform regime, but it is unlikely. We noted that slab W is deep and blends into the overall geometries  
666 of CR, hence it likely represents older subduction. If slab W does not interrupt the subduction-free period  
667 after the Big Break, then the current San Andreas regime along the margin is in full spatial and temporal  
668 continuity with the transform regime of ~50-80 Ma that was inferred from rock paleomagnetism to have

669 transported the Baja-BC microcontinent northward (Kent & Irving 2010). This is a straightforward  
670 consequence of the wide slab-free window, combined with the vertical sinking hypothesis.

671

#### 672 4.3.3 MEZ and ANG slab walls

673

674 MEZ slab is among the longest and most voluminous slabs in the whole mantle. It is a gigantic slab wall  
675 that runs from northeast Canada to Florida under the NAM eastern seaboard, and from there on to Peru  
676 (Fig. 1). MEZ wall is >1,000 km “high” under Florida (occupying depth levels ~1800 km to ~800 km in  
677 the mantle column, Fig. 3), but only ~300 km “high” under Nova Scotia (occupying ~1800-1500 km  
678 depth).

679

680 MEZ lies in spatial eastward continuation of the southern Farallon (FS) slab and continues the eastward-  
681 deepening trend, although at a dramatically steeper angle than FS. The intuition might thus be that MEZ  
682 represents Farallon plate older than FS. Tomotectonics indicates that this cannot be the case.

683

684 The deposition of a voluminous, linear slab wall requires a trench that remains stationary above MEZ for  
685 a long time (Fig. 4D). By contrast, the paleo-coastline in Figure 1 marches right across MEZ (and ANG)  
686 without dwelling on the slab and without showing any correspondence with the slab’s shape. In reverse  
687 time, NAM leaves behind FS slab by ~130 Ma. By 150 Ma, the margin leaves behind the eastern  
688 promontory of MEZ slab wall and traverses only slab-free mantle until 170 Ma – the temporal limit of  
689 our study, when the NAM east coast has reunited by with Pangaea and the Central Atlantic closed (see  
690 Fig. 6a).

691

692 The swift and oblique march of the west coast across MEZ means that a *margin-bugging* Farallon trench  
693 could not have deposited the slab wall by vertical sinking. What about a stationary, offshore Farallon  
694 trench, as observed in the case of CR? The problem with eastward (Farallon) subduction into MEZ is that  
695 it would prevent NAM from moving westward, away from Pangea, between 170 Ma and the moment it  
696 reaches MEZ (which is ~150 Ma at the MEZ promontory, and later further south). The slab-free zone  
697 between MEZ and NAM at 170 Ma is occupied by seafloor at the paleo-surface, and this seafloor must  
698 subduct in order to let NAM move westward (Fig. 6a). The only slab available to subduct into is MEZ,  
699 which means *westward* subduction of the seafloor between Pangaea and MEZ, into MEZ trench.

700

701 MEZ slab could, therefore, not have hosted an eastward subducting trench at the same time, meaning no  
702 Farallon trench, not even an intra-oceanic one. This is the decisive argument against MEZ as a Farallon  
703 slab. Westward subduction into MEZ solves other problems: the huge latitudinal extent of MEZ does not  
704 match the short isochron segment of the FAR-PAC spreading ridge recorded for Jurassic times (Fig. 6a).  
705 The FS slab, narrowing then disappearing to the east, already explains the history of southern Farallon  
706 growth.

707

708 By contrast, the north-south extent of MEZ is of the correct length and strike to let all of North America  
709 break free from Pangaea at once, and to start moving west ~170 Ma. The northern MEZ segment from  
710 Nova Scotia to Florida closely matches the Central Mid-Atlantic spreading ridge in length and strike, and  
711 from 170 Ma to today. The situation is cartooned in fig. 6a, which highlights (in blue) the seafloor west of  
712 NAM that needs to subduct into MEZ (and ANG). ANG slab served the same role as MEZ, enabling  
713 NAM to move west. MEZ trench pulled on the NAM margin at U.S. and Mexican latitudes, whereas  
714 ANG pulled on the B.C. margin. As required for this functioning, ANG slab wall is the spatial  
715 northwestward extension of MEZ, and very similar in character. ANG strikes oblique to the paleo-  
716 margin, and it reaches far to the west. This means that the margin took a very long time to override ANG

717 slab – in Figure 6b, its trench is still pulling on the northern margin at 80 Ma, when MEZ has long been  
718 overridden.

719

#### 720 4.4 Chronological sequence of archipelago override

721

722 Pulling all tomotectonic inferences together, we play forward the “movie” of continent-trench collisions,  
723 using Figures 1,3, 5 and 6. All trenches start up around the same time (same depth of ~1800-2000 km),  
724 while NAM is still with Pangea, i.e., sometime before 170 Ma (Fig. 6a). All trenches are originally intra-  
725 oceanic in the proto-Pacific basin west of Pangea, where they are free to remain stationary and to build  
726 the observed slab walls MEZ, ANG and CR.

727

728 MEZ and ANG trenches are exerting a westward pull on the NAM plate, whose western plate boundary  
729 is not the continental margin but an ocean basin (the “Mezcalera-Angayucham Ocean” in Fig. 6a). From  
730 ~200-170 Ma, the Central Atlantic rifts along a line parallel to northern MEZ slab. Central Atlantic rifting  
731 transitions to proper spreading ~170 Ma (recorded by Atlantic isochrons, e.g., Seton et al. 2012). The  
732 Atlantic opens at the expense of the Mezcalera-Angayucham Ocean, which narrows by westward  
733 subduction into MEZ and ANG slabs.

734

735 Around 155 Ma, the NAM west coast at U.S. latitudes starts to collide with the northern MEZ trench,  
736 under-riding the MEZ arc and deforming the margin (orange barbs in Fig. 1). The collision gradually  
737 spreads in latitude as broader swaths of MEZ arc (and later ANG arc) are overridden (Fig. 1, coastlines at  
738 130, 110 Ma). The gradual override of northeastern MEZ slab ~155-110 Ma is recorded by the westward  
739 shallowing slab “ramp” it forms in Fig. 3a: under the 150-Ma paleo-coastline, the slab had 150 Ma to sink  
740 since the end of subduction, and its upper truncation now lies ~1500 km deep (red level of the 3-D  
741 isosurface in Fig. 3a); under the 110 Ma-line, its shallowest part lies 1100 km deep (yellow level) and has  
742 been sinking for 110 m.y. (This ramp is among the best opportunities to estimate slab sinking rate,  
743 Sigloch and Mihalynuk, 2013). In Figure 5, the slab ramp translates to trench lines on northern MEZ  
744 “retreating” westward, from pink to red to yellow levels: no more trench where the Mezcalera Ocean has  
745 disappeared.

746

747 At conterminous U.S latitudes, subduction cannot cease with the consumption of all Mezcalera Ocean  
748 lithosphere because NAM continues to be pulled westward, by still-active trenches of northern ANG and  
749 southern MEZ. NAM is pulled into the area presently underlain by eastern FS slab, which forced the  
750 ocean lithosphere occupying this absolute position beneath the advancing U.S. west coast, depositing FS  
751 slab. Hence subduction polarity flips along the California/Mexico margin: NAM margin turns into the  
752 overriding plate (green barbs in Fig. 1), with Farallon plate subducting underneath it. MEZ and ANG  
753 trench segments shrink while FS trench grows along the margin. CR trench (northern Farallon) sat in the  
754 same stationary, intra-oceanic position the entire time.

755

756 At 80 Ma (Fig 6b), these override events have run their course and things are about to change. The  
757 southern Farallon (FS) trench on the margin abruptly shuts down ~80-75 Ma and will never be re-  
758 established (Big Break of FS slab). A transform system takes over that evolves into the present San  
759 Andreas transform (slab-free corridor). The reason for this shutdown of the continental arc is not  
760 obvious, perhaps related to the beginning, oblique collision of NAM with northern Farallon (CR) arc. (Or  
761 to plateau subduction (Livaccari et al., 1981; Humphreys et al., 2024) which cannot be inferred purely  
762 tomotectonically). At the end of a protracted override (fragmentation of upper CR slab), the seafloor that  
763 remained between CR trench and NAM in Figure 6b has been squeezed out, and the northern Farallon

764 trench has “accreted” (by ~50 Ma). It continues as the margin-hugging Cascades trench that is still active  
765 today (FN slab).

766

767 In the far north, ANG arc is under-ridden by NAM very gradually and obliquely into Cenozoic times,  
768 always by westward subduction. Once ANG subduction is completed, the northern margin turns into the  
769 transform system that continues to the present day.

770

## 771 5. The match between tomotectonic arcs and geologic arcs

772

773 So far, we have used only the tomotectonic observables of slab geometries and quantitative plate  
774 reconstructions for making the paleogeographic inferences of Section 4; these are linked together by the  
775 null hypothesis of slabs sinking in place. Geological observables remain untapped and an independent  
776 data set for testing the tomotectonic hypothesis and its predictions.

777

778 The principal link for hypothesis testing is the volcanic arc, which is an inevitable surface manifestation of  
779 any subduction zone. Tomotectonics hindcasts absolute paleo-arc locations. If the tomotectonic method  
780 works properly, every paleo-arc predicted from slab observations should have an actual counterpart in the  
781 accretionary orogen. The converse is equally important: every geologically observed arc should be  
782 matchable to a suitable “tomotectonic arc”, that is, to a slab.

783

784 Figure 7 shows the large-scale assemblage of arc terranes since ~170 Ma that need to be explained along  
785 the present-day west coast of North America (left part of the map). Figure 7 also schematically  
786 reconstructs the paleo-arc terranes above their matched slabs and paleo-trenches. The chosen set of  
787 slab/arc matches will arguably yield the “correct” solution, in the sense that the archipelago override  
788 sequence hindcast by tomotectonics in Section 4.4 will terminate with the spatial configuration of today’s  
789 Cordilleran accreted terranes. The slab/arc associations must also satisfy the geologically known timing  
790 constraints during the arc accretion sequence. In Figure 7, the current and former instances of arcs are  
791 grouped into superterranes and linked by their unchanging colors over time: Farallon arcs and slabs in  
792 green, Insular (INS) & Guerrero (GUE) microcontinents in orange; Intermontane (IMS) microcontinent  
793 in purple; and Central Alaskan arcs in red. Our slab/arc matches are justified in sections 5.1 and 5.2.

794

### 795 5.1 Northern and southern Farallon arcs (eastward subduction)

796

797 Upper-mantle FN slab must be matched with the Cenozoic, still active Cascades arc (du Bray et al, 2014;  
798 Tepper and Clark, 2024; though a continuous arc axis is only apparent since ~40 Ma, see Fig. 1 of  
799 Glazner, 2022; or ~45 Ma, Humphreys and Grunder, 2022). This match is straightforward in terms of  
800 latitudinal extent, timing, polarity, and continental character.

801

802 It is less clear which arc terranes to associate with older northern Farallon subduction, i.e., with the  
803 voluminous lower-mantle CR slab, schematically drawn as a deep green patch in Figure 7 in its stationary,  
804 slab-wall position and strike. Expected to be intra-oceanic in character and accreted inboard of today’s  
805 Cascades arc, CR arc may well be best preserved in the subsurface beneath Vancouver Island (Clowes et  
806 al., 1987) as the downdip extent of the Pacific Rim terrane (“PR” in Fig. 7; Sigloch & Mihalyuk 2013,  
807 2017).

808

809 In addition, parts of CR arc may have been entrained and transported north with BajaBC and the  
810 successor transform regime that continues to today (e.g., Baranov-Leech River hypothesis of Cowan,



811 2003; Garver and Davidson, 2015). That such a big and old slab has only fragmentary arc relics illustrates  
812 some practical challenges in making slab/arc matches. However, this is equally true for any accounting of  
813 pre-Cascades subduction in the Pacific Northwest from geology or plate tectonics alone. FAR-PAC  
814 isochrons record Farallon spreading towards the Pacific Northwest since 180 Ma, irrespective of mantle  
815 evidence. If the pre-Cascades arc were postulated to have grown on the margin, the problem of the  
816 “missing” arc would be aggravated because such an arc should not be displaced as easily as the intra-  
817 oceanic CR arc inferred from tomotectonics.

818

819 Another straightforward match is the association of FS slab with the arc that built the Sierra Nevada  
820 Batholith (SNB, essentially ~120-80 Ma, Paterson and Ducea, 2015). FS slab fits the timing, subduction  
821 polarity and continental nature of the SNB arc. Figure 7 shows this arc in translucent lime green,  
822 originating at the eastern tip of FS slab, in the inner corner between MEZ and ANG slab walls. The  
823 dashed, retreating trench lines schematically represent the subsequent, southwestward migration of this  
824 arc with the NAM margin while the FS slab grows below it. Besides the SNB and allied arc segments, FS  
825 slab must also be associated with the Cretaceous arc on INS, which lay north of the Sierra Nevada and  
826 has since been translated by Baja-BC shuffling (northward by ~1950 km; Enkin, 2006).

827

828 For times younger than the SNB arc, no clear arc axis is observed in the southern U.S. sector, which is  
829 consistent with the slab-free region southwest of FS slab. Post-SNB volcanism and magmatism in the  
830 region are spatially diffuse instead of linearly aligned, not of typical arc chemistry (see Glazner, 2022).

831

832 For completeness, the Pacific plate subducts northward beneath southern Alaska today. This subduction  
833 zone has been building the upper-mantle Aleutians slab (Gorbatov, et al., 2000; van der Meer et al., 2018),  
834 associated with the Aleutians arc since at least 46 Ma (Jicha and Kay, 2018). This obvious match is  
835 mentioned here because Baja-BC shuffling events transported southern Alaska terranes (Insular  
836 Superterrane) to its present resting place by ~50 Ma (e.g., Kent and Irving, 2010), just before Aleutians  
837 subduction initiated and the Aleutian arc started to grow on and outboard of those newly arrived terranes  
838 (northward translation of outermost INS is still happening due to coupling across the active dextral  
839 transform margin). Earlier Kula subduction events in that region (presumably matched with KI slab in  
840 figs. 5 and 3, (Sigloch & Mihalynuk 2017) do not directly pertain to the present study.

841

## 842 5.2 Arcs associated with Mezcalera/Angayucham westward subduction

843

844 Section 5.1 has matched all eastward (Farallon) arcs inferred by tomotectonics with actually observed  
845 geological arcs. The tomotectonically inferred arcs (i.e., slabs) remaining to be matched are MEZ and  
846 ANG. Conversely, five geological arc systems of Cretaceous and Jurassic age remain to be matched to  
847 slabs (Fig. 7), from north to south: the Cretaceous arcs of Central Alaska (Koyukuk); the arcs on the  
848 Insular Superterrane (INS: Wrangellia, Alexander and Peninsular terranes); arcs on the Intermontane  
849 Superterrane (IMS: Stikine and Quesnel); the Native Triassic-Jurassic arc in the southwestern U.S.; and  
850 the Cretaceous arc on the Guerrero Superterrane in Mexico.

851

852 At times preceding the main SNB flare-up 125-85 Ma (Paterson and Ducea, 2015), arc volcanism was  
853 built on Insular Superterrane (INS) (205-165 Ma, younging eastward; Canil and Morris, 2024). According  
854 to paleomagnetic evidence (Kent & Irving 2010), INS lay at latitudes of the southern U.S. and northern  
855 Mexico when its Jurassic arc was active, but now occupies an outboard position along the margins of B.C.  
856 and southern Alaska – hence the name “Baja-BC” (Irving, 1985) for the margin-parallel shuffling that  
857 achieved the displacement between 90 and 50 Ma.

858

859 Construction of the “Native Triassic-Jurassic arc” (256 Ma (latest Permian) to 175 Ma) on the cratonic  
860 margin of the southwestern U.S. was followed (~170 Ma) by a period of transpression and formation of  
861 Middle Jurassic ophiolites (Saleeby and Dunne, 2015). Most workers refer to the Jurassic magmatic rocks  
862 as parts of an extensional continental arc (Tosdal and Wooden, 2015; Saleeby and Dunne, 2015; Busby  
863 and Centeno-García, 2022), that transitions southward to the opening Gulf of Mexico. What proportion  
864 of these arc-type volcanic and plutonic rocks (which typically display extensive interaction with the  
865 Proterozoic crust) are true arc versus decompression melts related to extension, is an open question.  
866 Zircon geochemistry shows elevated Th/U ratios of Sierra-Nevada-derived Jurassic detrital zircons of  
867 southeast California (180-160 Ma, Barth et al., 2013) are atypical of arc zircons from both older, Triassic,  
868 and younger, Cretaceous, Sierra Nevadan magmatic rocks, and may be from asthenospheric sources  
869 (Tosdal and Wooden, 2015).

870

871 Intermontane Superterrane (IMS) in British Columbia, located inboard of INS, hosted another long chain  
872 of Triassic-Jurassic arcs (Stikine & Quesnel) that went extinct and were accreted by ~174 Ma (Mihalynuk  
873 et al., 2004). Before accretion, IMS presumably formed the offshore, northwestward extension of the  
874 Native arc in western USA, judging by their geographic and geological relationship (e.g. Mihalynuk and  
875 Diakow, 2020) and their almost simultaneous demise or change to extensional regime between ~170 and  
876 ~180 Ma (Barth et al., 2013; Tosdal and Wooden, 2015, see above).

877

878 The slab wall of northern MEZ lies in spatial and temporal continuity with FS slab, which was built  
879 ~130-80 Ma (fig. 1). Hence the Native arc would be too ancient for a match to MEZ slab, and as a  
880 margin-hugging arc it must necessarily have been eastward-subducting, whereas MEZ slab  
881 accommodated westward subduction (section 4.3, 4.4). IMS arcs cannot be directly paired with MEZ for  
882 the same timing reasons: they do not reach to as young as 130 Ma.

883

884 The geologic arc to associate with MEZ slab can therefore only be the Jura-Cretaceous arc on INS. This  
885 is plausible because INS is not part of stable North America but rather an accreted microcontinent.  
886 Hence westward subduction beneath INS is possible *a priori*, but paleo-seafloor east of INS would need  
887 to be demonstrated, as a match for the tomotectonically inferred Mezcalera Ocean.

888

889 Towards the east, INS is indeed separated from IMS by a belt of “collapsed basins” of oceanic character.  
890 Sigloch & Mihalynuk (2013, 2017) made detailed geological arguments why these collapsed basins are  
891 suitable to represent the suture of the tomotectonically inferred Mezcalera-Angayucham Ocean (light blue  
892 in fig. 7). A dozen collapsed basins are shown on their present-day positions (also light blue in fig. 7), and  
893 named in the legend. They have the correct ages (sufficiently young from detrital zircon dating), spatial  
894 extent (spanning the length of the NAM margin) and character (mantle slivers outcropping in half of the  
895 basins) in order to represent the suture of the Mezcalera-Angayucham Ocean that closed west of MEZ  
896 slab by westward subduction.

897

898 MEZ slab wall runs south to Mexican latitudes. There are suitable geological matches in the Cretaceous  
899 arc on Guerrero Superterrane, a southern correlate of INS Superterrane (fig. 7). The collapsed basin  
900 representing the Mezcalera ocean (and its suture) to the west of Guerrero is the Arperos basin, adopting  
901 an interpretation of Tardy et al. (1992) and Dickinson and Lawton (2001). An additional Mexican arc, the  
902 Early Cretaceous Alisitos arc that preceded Farallon subduction (accreted outboard of Guerrero arc) is  
903 considered out of spatial scope but is matched to slab by Clennett et al. (2020).

904

905 The Cretaceous arcs of Central Alaska are a straightforward match with ANG slab wall. Figure 1 shows  
906 how NAM underrode ANG slab very slowly over Cretaceous times and into the Cenozoic – a prolonged,  
907 oblique collision that would have slowly plucked the originally linear, >3,000 km long arc off its slab and

908 crumpled its slivers into the tightly folded oroclinal folds seen in figure 7 (in red). The northerly latitude of  
909 ANG slab ensures that Central Alaska accretes north of all Farallon and MEZ arcs, as observed. This  
910 huge slab provides a satisfying placement for Central Alaskan terranes that have been difficult to place or  
911 to relate to more southerly events in reconstructions based purely on geology (e.g. Patton and Box, 1989)  
912 or purely on plate reconstructions (e.g., Seton et al. 2012).

913

914 With this, all arcs back to ~170 Ma are matched to slabs, and all slabs in figure 1 are matched to arcs. The  
915 two oldest candidate arcs, Native arc and IMS (Stikine, Quesnel), remain unmatched to slab. This is  
916 unsurprising in light of our tomotectonic inference that the Archipelago to 1800 km depth records events  
917 since Pangaean breakup and Atlantic spreading. The ~170 Ma extinction of a long, linear chain of  
918 Native/Intermontane arcs, and its sudden replacement by the even more vast MEZ and ANG arcs, must  
919 be a consequence of hemispheric reconfiguration of the time. Sigloch & Mihalynuk (2017, 2020)  
920 speculatively matched slab below the Atlantic to the Native/IMS arc, albeit not directly below the 170-Ma  
921 position of NAM in fig. 1. The uncertainties of absolute paleo-positioning multiply into Jurassic times,  
922 with neither surviving seafloor nor hotspot tracks available, and lingering questions about True Polar  
923 Wander (Fu & Kent, 2018).

924

925

### 926 5.3 Archipelago override sequence replayed with arc terranes

927

928 We replay the archipelago override sequence of Section 4.4 with the matched geologic arc terranes. The  
929 most relevant figures are figures 7, 6 and 5. Events are narrated with an emphasis on slab pull as the  
930 driving force. This is justified by the observation that 90% of present-day plate motions can be explained  
931 by trench configurations: plates mainly seem to move because they are pulled perpendicularly into  
932 subduction zones where dense slab is sinking into the mantle (Forsyth & Uyeda, 1975).

933

934 In the proto-Pacific basin, a vast grouping of intra-oceanic arcs starts up relatively simultaneously  
935 between 205-180 Ma. This new Archipelago sits >1,000 km west of NAM and consists of arcs that built  
936 the Insular-Guerrero Superterrane, a Mesozoic-Paleozoic microcontinent; and future Central Alaskan  
937 arcs, striking NW-SE along a >3,000 km trench. Further to the west, the new Farallon arc parallels the  
938 strike of the Alaskan (ANG) arcs over ~2,000 km length, sitting ~1,500 km south of them. On and close  
939 to the NAM margin, a long chain of older arcs is shutting down (Native & IMS), are overprinted, or  
940 transition southward into extensional volcanic fields (e.g. Saleeby and Dunne, 2015; Tosdal and Wooden,  
941 2015; Busby and Centeno-García, 2022). NAM is exposed to westward pull because the seafloor west of  
942 it, which forms part of the NAM plate, is now subducting westward beneath the INS-GUE and Central  
943 Alaskan arcs (MEZ & ANG slabs). A rift zone between eastern NAM and west Africa transitions to full-  
944 blown westward drift by ~170 Ma, opening the Central Atlantic along a spreading ridge that is parallel to  
945 the INS-GUE trench.

946

947 Thus North America breaks away from Pangaea and is pulled into the Archipelago, with INS-GUE  
948 trench consuming the seafloor immediately west of NAM, the Mezcalera Ocean. Around ~150 Ma, NAM  
949 first collides with northern INS at conterminous U.S. latitudes (?northern California): at the easternmost  
950 point of the Archipelago, the Mezcalera Ocean has closed and collapsed into a suture. This continent-  
951 microcontinent collision deforms the margin locally (Nevadan orogeny), and the accreted (obducted) INS  
952 loads the continental margin, which develops topography that sheds sediments inland (Passage Beds of  
953 B.C. and Alberta) ~155 Ma. The collided segment of INS arc is extinguished.

954

955 NAM continues to be pulled into the Archipelago by the still-subducting segments of the Mezcalera and  
956 Angayucham Oceans, south and north of the collided segment. As NAM rides into the interior of the  
957 Archipelago, the seafloor sitting there is forced to subduct under the continental margin, i.e., eastward. In  
958 response a new arc is constructed above the lithosphere now subducting eastward beneath the continental  
959 margin. This is the SNB arc, the batholithic roots of which intrude and overprint the two older arcs: the  
960 accreted, extinct INS arc and the Native Triassic-Jurassic arc on stable NAM (extinct since ~170 Ma).  
961 The evolution of the override sequence and the three juxtaposed arcs are shown in Figure 8a.  
962

963 NAM continues to be pulled west by the southern MEZ and by ANG subduction zones. They are  
964 trenches on a suicide mission: the continent collides with wider and wider (in latitude) swaths of INS-  
965 GUE arc segments, which go extinct and are replaced by SNB and allied arc forming above east  
966 subducting Farallon plate. From ~110 Ma, NAM also collides with future Central Alaskan arcs along  
967 ANG slab (Fig. 1). At latitudes of the CR (Fig. 1) ANG trench segments are not polarity-flipped due to  
968 the intervening Orcas micro-plate (Orcas basin in Fig. 1), which can slide out of the way rather than  
969 subduct.  
970

971 Progressive accretion of arc segments intensifies the deformation of the margin and widens it in latitude  
972 into the Sevier and Columbian (in Canada) orogenies. Progressive closure of the Mezcalera Ocean  
973 between INS and NAM forms the collapsed basins of Figure 7, predicted by tomotectonics (Fig. 1) to  
974 have closed from ~150 Ma (in the U.S.) to ~100 Ma (in MX), as INS diachronously collided with NAM  
975 or with IMS (where IMS was pre-accreted to NAM).  
976

977 Around 100 Ma, the Insular-Guerrero arc was extinct even in Mexico – the end of westward subduction  
978 at MX, US and southern BC latitudes. The Yukon margin and northern BC continued to be pulled into  
979 the Koyukuk arc. Farallon eastward subduction now reigned in the south: the SNB and allied arc on the  
980 margin (FS slab) had expanded south along the Mexican margin to form the Peninsular arc (Dickinson  
981 and Lawton, 2001). The northern Farallon arc (Pacific Rim terrane, and more) remained offshore, but by  
982 90 Ma probably felt the approach of the NAM margin, now impinging on the Orcas microplate, which  
983 became substrate for both northern Farallon arc and the Koyukuk arc construction.  
984

985 Around 80 Ma, the SNB arc on the margin suddenly shuts down (Big Break), probably related to  
986 disruption from initial override of the CR arc further north, and/or the collision of the Hess-Shatsky Rise  
987 conjugate plateau along FS trench (Livaccari et al., 1981; Humphreys, 2009; Humphreys et al., 2015, this  
988 volume). This sudden demise of the long-lived and margin-hugging FS trench decoupled the Sierra  
989 Nevada-Peninsular segment from the margin. The segment also included the accreted INS and IMS at  
990 U.S. latitudes, then located north of the Sierra Nevada batholith. The Farallon plate transitions into  
991 transform motion (transpression) relative to NAM, and the transform boundary runs inside the soft  
992 continental lithosphere (speculatively mainly along the yellow line in Fig. 9a/b). The slivered-off parts of  
993 accreted INS and IMS (“Baja-BC”) were free to move rapidly northward, as parts of the southern  
994 Farallon plate, and then as parts of the Orcas plate (Fig. 9b). Since the northern Farallon arc still sits  
995 offshore, Baja-BC can move north relatively unimpeded and *inboard* of the northern Farallon arc, assisted  
996 by the small, moveable Orcas microplate (as spelled out in section 6.2).  
997

998 This transform corridor stays open for some tens of m.y. (recorded by disruption and retreat of upper CR  
999 slab), until by ~50 Ma the Orcas plate has gone, the northern Farallon trench has obliquely accreted to  
1000 the Pacific Northwest margin, and established a new arc on the margin (Cascades arc). This margin-  
1001 hugging new Farallon arc acts like a roadblock that ends the free passage of Baja-BC terranes.  
1002

1003 The transform margin along the Sierra Nevada sector (San Andreas) continues to present, still slivering  
1004 off continental fragments and transporting them north (Baja California, Salinian block, Transverse  
1005 Ranges...) but only until they reach the impasse of the Juan de Fuca (northern Farallon) plate and its  
1006 Cascades arc.

1007  
1008 In the far north, the Koyukuk arcs that have been crumpling against the NAM margin (Fig. 9b, at 85 Ma),  
1009 are further impacted by arrival of Baja-BC from the south, and Baja-BC gets wedged against the backstop  
1010 of the Koyukuk arcs. As the Orcas microplate gets squeezed away or subducts, the INS and Central  
1011 Alaskan arcs are compressed into the big terrane agglomerate that is Alaska (Fig. 9b).

1012  
1013 Once the Koyukuk arc is completely extinct (ANG slab largely overridden by 50 Ma), the margin  
1014 becomes turns transform. It remains a transform boundary to the present-day, still carrying parts of INS  
1015 northward, albeit more slowly, at ~41 mm/yr (Leonard, et al., 2007).

## 1016 6. Discussion

1017  
1018 We first address the most common objections to the archipelago model. We then discuss the range of  
1019 collision styles encountered (mainly ~150 to 80 Ma), followed by a discussion of margin-parallel  
1020 translations (“Baja-BC”, since ~80 to 50 Ma).

1021

### 1022 6.1 Objections to the archipelago model based on the nature of the Insular- 1023 Intermontane suture

1024

1025 Objections to the archipelago model (and the ~15 m.y. period of westward-only subduction at  
1026 conterminous U.S. latitudes) have centered on supposedly discrepant geological characteristics of the  
1027 Jura-Cretaceous suture between under-riding NAM and overriding Insular Superterrane.

1028 Critics have pointed towards the lack of old detrital zircon sources in the archipelago, in order to explain  
1029 the observed flooding of INS with old zircons, given that the Mezcalera Ocean originally (Fig. 6a) was of  
1030 substantial width (1000-2000 km at its narrowest). Another criticism has concerned the lack of a  
1031 persistent sedimentary basin on the leading edge of the subducting NAM plate.

1032

1033 Detrital zircons have been pointed to as a ‘crucial test’ of the archipelago model (LaMaskin et al., 2022).

1034 In this ‘crucial test’ zircons derived from cratonic NAM and the Native Triassic-Jurassic arc built upon its  
1035 margin, should be absent in the overriding Insular Superterrane. Yet we have pointed to modern  
1036 analogues for continent-beneath-arc collisional zones (Sigloch and Mihalynuk, 2017, 2019) where  
1037 sediments derived from the continent and its margin are EXPECTED to be an increasingly predominant  
1038 component during arc-continent convergence.

1039 In modern examples of collision between continental margins and the arcs beneath which they subduct  
1040 (Australia-Banda forming Timor, China-Luzon forming Taiwan), sediments containing zircons derived  
1041 from the continent are observed on both the fore and back sides of the converging arc. Both Timor (e.g.  
1042 Harris, 2011) and Taiwan (e.g. Beyssac et al., 2007) are comprised primarily of continentally-derived  
1043 sediment, some of which transits the arc and is carried onto the overriding plate. Even isotopically  
1044 primitive igneous rocks of the Luzon arc are overwhelmed by old, inherited zircons from the Chinese  
1045 cratonic margin, prompting some workers propose an unexposed continental fragment underpinning the  
1046 Luzon arc (Shao et al., 2015). In the case of the Insular Superterrane, objections based on lack of old  
1047 zircons may be moot because basement of the superterrane itself includes possible sources of Early  
1048 Paleozoic strata with abundant Precambrian zircons (e.g. Beranek et al, 2012; and noted, but discounted  
1049 by LaMaskin et al., 2022). Hence the observed abundance of old continental zircons on INS does not

1050 constitute a ‘crucial test’ against continent-beneath-arc collision, as proposed by LaMaskin et al. (2022);  
1051 the modern-day analogues demonstrate quite the opposite.

1052

1053 Likewise, criticisms based on the lack of sediment load on the leading edge of the subducting continental  
1054 plate are at odds with fundamental features of modern continent-beneath-arc collision zones. In both the  
1055 Taiwan and Timor examples, amphibolite-grade metamorphic rocks are exhumed continentward of the  
1056 colliding arc because the arc acts as a backstop for strata scraped off the subducting continental plate (fig.  
1057 8d). In the case of Taiwan, the subducting continental (China) margin is interpreted as a relict Andean-  
1058 type arc (Cui et al., 2021), analogous to the extinct, Native-Jurassic arc that formed the leading edge of  
1059 NAM in its collision with INS. Thus, the modern Luzon-China collision may be the best modern  
1060 analogue for initial impingement of western NAM (California) with the Mezcacala arcs at ~155 Ma. A  
1061 shortcoming of this analogy is the difference in the topography of the subducting plate. In the case of  
1062 Taiwan, the eroded arc was older than 85 Ma when blanketed by Cenozoic sediments of the South China  
1063 Sea, and the interface varies in depth by less than ~2400 m (Cui et al., 2021). In the North American case,  
1064 only ~15 m.y. elapsed between cessation of active continental margin arc magmatism and collision of the  
1065 archipelago (Sigloch and Mihalynuk, 2017, 2020), so rather than a broad submerged margin, one that had  
1066 considerable relict topography is likely (e.g. Dickinson, 2018), and when deformed, produced confusing  
1067 juxtapositions of basement and overlying strata.

1068

1069 We acknowledge that the creation of a plate model showing terrane motion paths and accurate  
1070 relationships with other terranes while preserving recognizable terrane outlines is a challenge. With these  
1071 constraints, our models (Henderson et al., 2014; Clennett et al., 2020) have not yet generated satisfactory  
1072 motions for Klamath terranes (as pointed out by LaMaskin, et al., 2022), and this clearly requires future  
1073 work. However, whether the Mezcacala suture lies between *bona fide* intra-oceanic arc of the Rogue-  
1074 Chetco arc (Yule et al., 2006) bounded by the Orleans Fault, or includes arc, ophiolite, and mélange belts  
1075 (e.g. Rattlesnake Creek terrane as used by Wyld and Wright, 1988) as far east as the North Fork terrane  
1076 (as defined by Snoke and Barnes, 2006), does not alter the fundamental mantle underpinnings of the  
1077 continental-scale suture between INS and NAM/IMS.

1078

## 1079 6.2 Double-sided subduction caused and shaped all collisions since 150 Ma

1080

1081 Much of the Archipelago debate has been framed in terms of eastward versus westward subduction. In  
1082 reality, all arc collisions in the Archipelago were shaped by double-sided subduction, which defined the  
1083 Archipelago from its inception (Fig. 6a). When the three major intra-oceanic arcs of MEZ, ANG and  
1084 Farallon (CR, CR2) sprang into being all around the same time (at 1800-2000 km depth, corresponding to  
1085 early Jurassic times), they reconfigured the eastern proto-Pacific from scratch. The earth favored double-  
1086 sided subduction – with Farallon (CR, CR2) trenches pulling in lithosphere from the southwest, and  
1087 directly facing off with ANG subduction, which sourced seafloor from the northeast. The CR and ANG  
1088 trenches and slabs were parallel, with the Orcas microplate as a passive spacer between them. MEZ  
1089 subduction, pulling in lithosphere from the east, worked in concert with ANG, although striking more  
1090 obliquely to CR (fig. 6a). The “function” of this geometry is to permit two large ocean domains (Farallon  
1091 Ocean and Mezcacala-Angayucham Ocean) to subduct simultaneously, in a configuration that could  
1092 remain stable over long time scales, which presumably is an efficient mode of cooling the mantle. In  
1093 support of this speculation of Archipelagoes as preferred modes of mantle convection, a close analogue  
1094 to the Cordilleran Archipelago currently exists in the southwest Pacific (Sigloch & Mihalynuk, 2017). The  
1095 Pacific Ocean and the Indian (formerly Tethys) Ocean subduct into this region from opposite sides  
1096 without much mutual disruption. The interior of the archipelago – the region bounded by the Sunda arc,  
1097 Papua-New Guinea, the Coral Sea arcs, and the Izu-Bonin and Mariana arcs – is complex in detail, with

1098 shifting configurations of minor trenches. Yet the basic functioning, of letting two big oceans subduct  
1099 from the exterior, is robust. Slab walls are observed below the bounding trenches, indicating their  
1100 stationarity (e.g., Hosseini et al., 2020).

1101

#### 1102 6.2.1 Southern U.S. and Mexico: heads-on collision with subduction flip

1103

1104 In the first stage of Archipelago collisions, North America collided “only” with an eastward-protruding  
1105 part of MEZ arc, while continuing to be pulled west by more southerly segments of MEZ and by all of  
1106 ANG. It is crucial to not limit consideration of this collision along a singular 2-D cross section, as  
1107 cartooned in Fig. 8a for 140 Ma, but also in and out of the plane (e.g., at Mexico and B.C. latitudes),  
1108 where westward subduction kept pulling the NAM plate westward even after this direct trench pull had  
1109 ceased at the point of collision on the U.S. margin ~155 Ma. Override of MEZ arc (INS and Guerrero  
1110 superterrane) led to a gradual, orderly polarity flip along the collided segments, diachronous from  
1111 northern California to Mexico. Intra-archipelago “southern Farallon” lithosphere (FS) was forced beneath  
1112 the overriding continental margin, in the override sequence shown in Figures 1 and 5. A close analogue is  
1113 the trench flip underway at the northern margin of Australia (Papua-New Guinea), which has breached  
1114 the previously uninterrupted chains of Sunda and Coral Sea arcs and keeps getting pulled further  
1115 northward by the surviving segments of those two arcs (Sigloch & Mihalynuk 2017).

1116

1117 The NAM-MEZ collision was thus succeeded by a sizable margin-hugging FS arc, along which the SNB  
1118 and Peninsular batholiths coalesced, and beneath which was deposited an east-dipping slab (FS slab).  
1119 However, FS slab is limited in space and time to this one discrete subduction episode from which  
1120 Andean-style Farallon subduction has been extrapolated across the margin

1121

1122 The FS arc shut down suddenly, as recorded in the slabscape by the Big Break ~80 Ma (Fig. 1, yellow  
1123 line). It is difficult to isolate specific causes in an interconnected plate-mantle system, but ultimately the  
1124 SNB arc may have died because the motivating force, of slab pull into the Archipelago, diminished due to  
1125 MEZ-ANG override. Arrival of the Hess-Shatsky plateau conjugate on the Farallon plate ~90 Ma, which  
1126 was difficult to subduct (Livaccari et al. 1981), was likely another cause, or even the main cause, for the  
1127 arc shutdown as FS subduction became flat beneath the continent, resisting the entry of more lithosphere.  
1128 (Humphreys et al., 2015). In the tomotectonic interpretation, the plateau-arrival event is a transition of  
1129 southern Farallon subduction from the regime of Figure 4F to 4H, caused by a strong decrease in sinking  
1130 rate.

1131

1132 Given the lack of slab west of the Big Break, we interpret that the southwestern U.S. remained free of a  
1133 continental arc after 80 Ma. The observed, spatially diffuse sweeps of “arc-like” magmatism across the  
1134 western U.S. noted by various workers (see summary in Glazner, 2022) likely represent slab-window  
1135 magmatism, when NAM lithosphere, continuing westward and pre-hydrated from below by the flat FS  
1136 slab it had recently traversed, encountered the asthenosphere of the slab-free window. In absolute  
1137 coordinates, the upper mantle region traversed by western NAM during the diffuse magmatic sweeps  
1138 would have last been overlain by Baja-BC, which had however shuffled north most recently, events that  
1139 may have further disturbed the upper mantle. While we cannot account for the spatial details of the  
1140 magmatic sweep, we argue that the event looks unsurprising in the context of the region’s upheaval, and  
1141 that there is no compelling reason to interpret the sweep as “true” arc magmatism caused by subducting  
1142 lithosphere. After the buoyant coupling of Farallon/Shatsky to NAM (~70 Ma), the continent’s westward  
1143 drift slowed by more than half for the next 40 m.y. (fig. 1).

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1145 6.2.2 Pacific Northwest, B.C., Alaska and “Baja-BC”: 115-50 Ma collisions with double-sided subduction  
1146 on the Orcas plate

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In the late stage of arc collisions, NAM overrode the opposing ANG and CR trenches simultaneously and obliquely. ANG was overridden from ~115 Ma by North America moving parallel to the slab (Fig. 1, gold arrow), causing collisions at almost 90° angle with the ANG (Koyukuk) arcs, which had been welded into the Orcas microplate for as long as the archipelago existed, but which now crumpled into oroclinal (terrane-wreck style; Johnston, 2008) to form the nucleus of Alaska.

The Orcas microplate was moveable due to its small size and seems to have diverted west- or northwestward when it felt the force of NAM approaching. This is recorded by the perturbed and westward-shallowing CR geometries of post-100 Ma times (green levels in Fig. 2), contrasting with the deeper, simple slab wall geometry of CR (red/yellow levels). Thus, the Orcas plate does not seem to have subducted under NAM, which it might have, analogous to the way that southern Farallon (FS) lithosphere started to subduct eastward after NAM had overridden MEZ arc (Fig. 8). Instead, the small Orcas plate was apparently squeezed out toward the (north)west. Ultimately, Orcas microplate had to subduct somewhere, and it may have quickly subducted into the small upper-mantle slab that strikes east-west under southern Saskatchewan, Alberta and B.C. (dark blue in Fig. 3a). This slab is not part of the sloping continuity of the northern Farallon group but rather seems to rest on top of it. Its location in Figure 9b is marked by the gray oval and two “??”.

The Orcas microplate might be more aptly named “Alaska plate” because by 80 Ma, the components of future Alaska (except for Arctic Alaska), were all fringing this plate, as detailed by Figure 9b. They would be brought into contact and assembled by ~50 Ma, through the disappearance of the intervening Orcas lithosphere. Hence the northward “sprint” of Baja-BC must be a manifestation of the mobility and rapid demise of the Orcas plate during this squeeze phase. The northern Farallon (CR) arc could only make landfall on the continent (as Cascades continental trench since ~50 Ma) as and when the Orcas plate, into which the CR arc had always been welded (e.g., Pacific Rim terrane, now spread from Vancouver Island to southern Alaska), disappeared into the mantle.

We note that kinematically, the final demise stage (60-50 Ma) of the long-lived Orcas plate must be equated with the Cenozoic Resurrection plate (in an ironic mismatch of naming). This short-lived, Cenozoic microplate ordering B.C. and southern Alaska had been inferred from magmatic sweeps along the margin (Haeussler et al. 2003, Miller et al. 2023), and confirmed from upper-mantle geometries of the Farallon (FN) and Aleutian slabs by Fuston & Wu (2021).

### 6.2.3 Tomotectonic hypothesis testing on the three Sierra Nevada arcs

The field geologic record of the arc extinction / trench flip sequence is complex, because (at least) two arcs are produced in the same place (Fig. 8a). For MEZ, westward subduction ahead of the first-colliding margin segment (U.S. Sierra Nevada segment) was of decent duration, from MEZ/INS arc inception ~180 Ma(?) to first collision ~155 Ma. However, the geologic record of this INS arc is obscured by a later, overprinting arc, the Sierra Nevada Batholith arc (Fig. 8a, bottom). This overprinting is not an unlucky coincidence but an inevitable consequence of the arc collision / trench flip sequence. It is systematically predictable here and elsewhere (e.g., Papua-New Guinea or Taiwan).

Tomotectonics can help to frame geologic field studies and the generation of realistic hypotheses that guide predictive mapping. In the Sierra Nevada case above, the prediction would include a suture between a collapsed continental margin and outboard arc. Specifically the Calaveras mélangé belt, the collapsed Mariposa basin that flanks it (Fig. 7), and that plutons produced by westward-subduction (INS) should be found only *outboard* of this Mezcalera Ocean suture. Following suturing, the later Sierra Nevada arc



1196 magmatism could thermally overprint the suture and produce plutons both inboard and outboard of the  
1197 suture.

1198

1199 Testing this hypothesis requires precise timing constraints, where the biggest challenge is to reliably  
1200 distinguish plutons that are strictly of arc character (i.e., caused by mantle-wedge fluxing above the down-  
1201 going Mezcalera plate and thus really recording the westward subduction episode), from plutons that are  
1202 due to post-arc flare-up or to prograde or decompression remelting of older arc crust. On a continental  
1203 arc margin (with abundant Native Triassic-Jurassic and Permian arc contributions) opportunities for  
1204 confounding magmatic arc rock relationships are omnipresent (e.g. consider the Taiwan analogy, Fig. 8b)

1205

1206 Further confounding geologic relationships is the structural overprint during Baja-BC translation. For  
1207 example, the north-south ordering of MEZ suture basins in Figure 7 is almost certainly not the same as  
1208 their original north-south ordering, prior to translation. Our tomotectonic-constrained prediction would  
1209 place the Sierra Nevada segment near the oldest MEZ suture (~155 Ma), and the Guerrero segment near  
1210 the youngest MEZ suture (~110 Ma), with neither segment transported north to a significant degree.

1211 Locations that sutured between these original latitudinal limits of INS accretion are predicted  
1212 intermediate suturing dates, but these basins have since been transported to British Columbia and  
1213 southern Alaska. Hence, we cannot naively predict that northern basins should have older sutures than  
1214 southern ones, even though that is what the override sequence of MEZ slab in Figure 1 would suggest.  
1215 Baja-BC events must be restored before interpreting the older accretion record.

1216

### 1217 6.3 Tomotectonics infers BajaBC displacements, independent of paleomagnetism

1218

1219 “BajaBC” is a long-standing hypothesis developed to explain paleomagnetic measurements on Cordilleran  
1220 terrestrial rocks, reproduced many times (Enkin 2006, Kent & Irving 2010), which indicate that Insular  
1221 microcontinent and western parts of Intermontane microcontinent (Stikinia) originally accreted far south  
1222 of their current locations, relative to NAM. Southern INS, now located in southern British Columbia,  
1223 originally occupied Baja Californian (Mexican) latitudes (Irving 1985, Kent & Irving 2010). Alaskan parts  
1224 of INS should accordingly have accreted at conterminous U.S. latitudes. The northward shuffle of 1500-  
1225 2000 km happened between 80 Ma and ~50 Ma because rocks magnetized around 90 Ma show the full  
1226 latitudinal offset, and rocks across most of British Columbia that were magnetized after 50 Ma show no  
1227 significant offset relative to the North American craton. The 50 Ma to present history of northwest-most  
1228 British Columbia and southern Alaska is much different. There, the evolving transform margin and its  
1229 transition into the Aleutian arc accommodated significant northward offset from 50 Ma to present (see  
1230 Hillhouse and Coe, 1994; Murphy, 2018).

1231

1232 INS constitutes the largest part of Baja-BC, and tomotectonic constraints require INS to have undergone  
1233 large-scale northward displacement since its accretion, in an argument completely independent of rock  
1234 magnetism. Figure 1 hindcasts that first accretion of INS to NAM at ~150 Ma occurred at conterminous  
1235 U.S. latitudes (northern California). This first collision involved northeastern promontory of MEZ slab,  
1236 hence northern INS arc. Today, northernmost INS arc (Peninsular/Alexander terranes) is not abutting  
1237 the conterminous U.S. but rather the southern Alaskan margin. Thus from tomotectonics arises the  
1238 prediction that since its accretion, northern INS must have moved north relative to stable NAM, from  
1239 conterminous U.S. latitudes to Alaskan latitudes. This amount of displacement is consistent with  
1240 paleomagnetic data mainly from *southern* INS (southern B.C., Washington state), with an inferred original  
1241 location at northern Mexican latitudes. Tomotectonics therefore provides remarkably straightforward  
1242 support for paleomagnetic measurements that have still not gained widespread acceptance within the  
1243 Cordilleran geoscience community.

1244

1245 Figure 9a shows the trajectories over time of the half dozen most robust paleomagnetic data sets that  
1246 gave rise to the Baja-BC hypothesis. Data from many more sites support the timing of the northward  
1247 sprint but are less robust. The blue/green trajectories follow the paleomagnetic sample sites back in time  
1248 and space to where and when they were magnetized: Carmacks at 70 Ma, Churn Creek/Mount Tatlow at  
1249 95 Ma, 103 Ma for Spences Bridge, etc. (Enkin, 2006). All positions are given in absolute coordinates  
1250 relative to the lower mantle. The Baja-BC sites are implemented to move northward rapidly between 70  
1251 Ma and 50 Ma. This timing is biased by paleomagnetic data; tomotectonic constraints permit translation  
1252 any time between ~105 Ma (migration of the continental margin past ANG), and ~50 Ma  
1253 (reestablishment of subduction leading to Cascade magmatism, evident by 45 Ma; Humphreys and  
1254 Grunder, 2022).

1255

1256 The yellow line is our speculated location of the main Baja-BC transform fault ran. It is necessary to  
1257 commit to a location when building a quantitative model like Clennett et al. (2020). We run the main Baja-  
1258 BC shear inboard of all displaced sites of Figure 9a, but no more inboard than necessary (a conservative  
1259 solution), and in locations that can plausibly hide a major fault. Mainly we run the fault through  
1260 Intermontane terranes now located in B.C. and through presumed, left-behind IMS correlatives in the  
1261 U.S. (in or west of the Blue Mountains; Mihalynuk & Diakow 2020, Tikoff et al. 2023).

1262

1263 In B.C., we speculate that the fault runs through the Cache Creek accretionary complex, sliding Stikinia  
1264 past Quesnellia (as in Fig. 9b at 70 Ma). Displacement of Quesnellia is inferred to have been much less  
1265 than Stikinia; however, paleomagnetic data on layered Mesozoic volcanic rocks of Quesnellia that are not  
1266 compromised by resetting and pass all confidence tests, have yet to be obtained. Hence, we position the  
1267 main Baja-BC shear zone conservatively between Quesnellia and Stikinia; in the intensely imbricated and  
1268 poorly exposed Cache Creek terrane which separates them and could well hide this shear zone. In the  
1269 Pacific Northwest U.S., its offset must be distributed somewhere between the dashed and the non-dashed  
1270 line.

1271

1272 In California, we run the fault slightly outboard of the NAM-INS suture (identified with the Calaveras  
1273 mélangé belt and Mariposa collapsed basin in the Sierra Nevada; Fig. 7). The rationale is that not much of  
1274 INS should be left in California if it is now found mainly in B.C. In practice, this means that we run the  
1275 fault under the Central Valley, inspired by Wright and Wyld (2007), but we continue it *inboard* of the  
1276 Klamaths, in order to implement ~1000 km northward translation of the Klamaths (Housen and Dorsey,  
1277 2005), past the stationary Sierra Nevada), which is recorded by Ochoco basin strata correlative with the  
1278 Hornbrook Formation (Surpless and Beverly, 2013) that straddle the Klamath block (Housen, 2018). At  
1279 the regional scales considered in this study, the uncertainties about the exact location of the fault(s) do  
1280 not change any conclusions.

## 1281 7. Conclusions and outlook

1282

1283 We have explained the tomotectonic method on a fully worked example for NAM. The method is based  
1284 on a very simple, predictive, falsifiable null hypothesis, and a separation of geophysical (slab and plate  
1285 tectonic) observations for making predictions, from geological observations for testing the predictions.  
1286 The link between tomotectonics and geology is made by volcanic arcs above subducted paleo-lithosphere  
1287 (slabs).

1288

1289 Since breaking away from Pangaea in early Jurassic times, North America has overridden a vast  
1290 archipelago of intra-oceanic subduction zones and their arc terranes. This is supported by robust evidence

1291 in the mantle and at the surface. An archipelago is an oceanic area bounded by trenches that are oriented  
1292 to pull in seafloor from opposite sides: a large-scale zone of plate convergence. All arc and  
1293 microcontinent collisions of Cordilleran North America since ~150 Ma have been shaped by this double-  
1294 sided nature of subduction. Different collision and deformation styles have occurred depending on the  
1295 spacing of the two opposing trenches, and the angle at which North America collided with their arc  
1296 terranes.

1297  
1298 The accretion of Insular Superterrane, including the Sierra Nevada orogeny and arc succession was a case  
1299 of subduction flip within the spacious interior of the archipelago. Oroclinal collapse of the Central  
1300 Alaskan arcs against the continental margin, by westward subduction, was possible in the lee of the  
1301 nearby, opposite-facing Farallon trench. The northward sprint of Baja-BC and its collapse against Central  
1302 Alaska was a product of the same setting of closely spaced, opposing trenches.

1303  
1304 Tomotectonics infers the large-scale northward displacement of Insular Superterrane (relative to stable  
1305 North America) since it was accreted. This inference is completely independent of the paleomagnetic  
1306 argument for Baja-BC, and supportive of it. A good understanding of these large-scale margin-parallel  
1307 displacements between 80-50 Ma is crucial for the correct interpretation of the older accretions that pre-  
1308 date Baja-BC, including the evidence for westward subduction. Slabs can be used to unscramble this  
1309 record because they have stayed in their absolute paleo-positions, while surface elements have been much  
1310 more mobile.

1311  
1312 The tomotectonic null hypothesis, of subducted lithosphere sinking essentially vertically once it has  
1313 entered its trench, is holding up so far. With very few degrees of freedom, the tomotectonic method  
1314 capably predicts the known regional tectonic regimes (subduction, compression, transform) and their  
1315 changes along various sectors of the NAM west coast from ~170 Ma to today. A useful contribution to  
1316 tomotectonic hypothesis testing would be the development of tools for unequivocally discriminating  
1317 igneous rocks formed in an arc above subducting lithosphere from similar magmatic rocks formed in  
1318 other environments.

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## 1587 Figure captions

1588

1589 **Figure 1.** Roadmap figure for this study: the superposition of subducted lithosphere (slabs) in the mantle  
1590 with continental drift, reconstructed with respect to the mantle. Coloured polygons show outlines of  
1591 major slabs under North America from teleseismic P-wave tomography (Sigloch 2011). Slabs inferred to  
1592 have been deposited by westward subduction are coloured in orange, those generated by eastward  
1593 (Farallon) subduction in green. Darker colour shades are applied to lower-mantle slabs (MEZ, ANG and  
1594 CR/CR2/W; light shades to shallower slabs: FS (400-1000 km deep), FN (0-700 km), and to the shallow  
1595 western end of ANG. Superimposed are time snapshots tracking the westward migrating margin of North  
1596 America, reconstructed in a mantle reference frame, which is constrained between 0-120 Ma by moving  
1597 hotspots (Dubrovine et al., 2012) and 120-170 Ma by true polar wander-corrected paleomagnetic data  
1598 (Torsvik et al., 2019). Colored arrows connecting the northern end points of the paleo-coastlines highlight  
1599 three distinct episodes of absolute plate motion.

1600 If the slabs sank vertically in place then a continental margin overlying a slab indicates a continent-arc  
1601 interaction – because a slab constrains a paleo-subduction zone, which must have hosted a paleo-arc.  
1602 Symbols on the paleo-margins indicate the nature of the tectonic regime along the margin, as inferable  
1603 from the tomotectonic principles developed in the text. Orange barbs: NAM-beneath-arc collision  
1604 (westward subducting slab located underneath). Green barbs: subduction beneath NAM (eastward  
1605 subduction), with arc built on NAM. Light blue lines and arrows: transform boundary along the margin  
1606 (no slab underneath). Black line: (quasi-)passive continental margin (no slab underneath, and no pre-  
1607 existing plate boundary along the margin). Yellow line traces the sharp western edge of FS slab, associated  
1608 with a sudden transition from eastward subduction to transform margin  $\sim 80$  Ma. The starting point of  
1609 our inference is  $\sim 170$  Ma, the time when North America separated from Pangaea, and when absolute  
1610 paleo-positioning in plate reconstructions becomes reasonably reliable.

1611 Slab abbreviations: MEZ – Mezcalera, ANG – Angayucham, CR & CR2 – Cascadia Root, FN – Farallon  
1612 North, FS – Farallon South. W is a non-interpretive slab name.

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1615 **Figure 2.** Mantle tomography: 3-D isosurface rendering of seismically fast anomalies imaged under the  
1616 western U.S.A., from the surface to  $\sim 1800$  km depth, in the teleseismic P-wave tomography model of  
1617 Sigloch (2011). The isosurface rendering threshold is  $dV_p/V_p > 0.25\%$ . Color signals depth and changes  
1618 in increments of 200 km. This structure represents subducted oceanic lithosphere (slab) of the former  
1619 Farallon plate, dipping eastward down from beneath the Cascades (Juan de Fuca) trench. Surface  
1620 topography of the North American Cordillera and the Pacific basin are overlain in translucent gray, with  
1621 strong vertical exaggeration. Yellowstone (red triangle) and its vertical downward continuation are shown  
1622 for visual reference. Seismically slow anomalies are not rendered (e.g., Yellowstone plume). Shallow fast  
1623 anomalies representing the thick continental lithosphere of NAM are masked out as they would block the  
1624 3-D view on the slabscape. Panels A and B present alternative view angles on the same scene, comprising  
1625 the FN and CR slabs of Figure 1 (subdivided at  $\sim 600$  km depth, where structural breaks are visible  
1626 especially in panel B). Slab W is also visible in the foreground. Deep CR2 slab under the Pacific is not  
1627 rendered.

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1630 **Figure 3.** Three-dimensional isosurface rendering of all seismically fast P-wave anomalies (subducted  
1631 slabs) in the upper and lower mantle beneath North America. Tomography model, rendering threshold  
1632 and color scheme as in Figure 2. (A) Top-down view of fast structure below 400 km (in order to exclude

1633 the overlying lithosphere, which is fast but does not represent slab). Strictly speaking, the view is from  
1634 ~390 km down due to slight interpolation smoothing of the contouring algorithm, explaining why the  
1635 shallowest anomalies appear in dark blue, as part of the 200-400 km layer. (B) Inside-out view of all fast  
1636 structure from the surface down, with the deepest structure (slab walls MEZ, ANG, CR/CR2) emerging  
1637 to the foreground. Imaging limitations include artifacts, especially near the margins of the regional dataset:  
1638 resolution lost into the ocean basins and north of 55°. Two downward smearing artifacts are labeled with  
1639 white x's and are not interpreted.

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1642 **Figure 4.** (A) The tomotectonic null hypothesis of vertical slab sinking, as envisioned by the very first  
1643 cartoon of subduction to be published, by Harry Hess in 1965. Motions are drawn in a mantle reference  
1644 frame, with the overriding plate moving laterally but not the subducting plate. (B)-(I) Range of possible  
1645 slab geometries predicted for when oceanic lithosphere sinks vertically after entering the trench, as a  
1646 function of the parameters  $v_o$ , the velocity of the overriding plate (or arc) on the x-axis, and of  $K$ , a  
1647 measure for the vigor of subduction, on the y-axis. Dashed lines represent the viscosity discontinuity  
1648 between upper mantle (UM) and lower mantle (LM), where the mantle becomes 1-2 orders of magnitude  
1649 more viscous, resisting further slab sinking. Motions are drawn relative to the mantle, and velocity arrows  
1650 are drawn to scale relative to each other.  $v_z$ , the slab sinking velocity in the lower mantle, is kept fixed in  
1651 all panels (a typical value being 10 mm/year). Kinematic ratio  $K = v_{sub}/v_{acc}$  is the ratio of slab length  
1652 subducted per unit time versus the length of accommodation space created for it, by means of the vertical  
1653 sinking away of older slab and the migration  $v_o$  of the trench away from the site of older subduction (see  
1654 Cerpa et al. 2022, eq. 1, for exact definition).  $K > 1$  indicates “traffic jam conditions”, where plate  
1655 convergence is too rapid to be accommodated undeformed, so that slab is forced to thicken (probably by  
1656 folding). The average value observed for present-day trenches is  $K \sim 2.5$  (Cerpa et al. 2022), with the  
1657 associated slab types highlighted by grey shaded panels D, F, H.  $v_o < 0$  (trench advance, panels B & C) is  
1658 practically not observed.

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1661 **Figure 5.** Paleo-trenches in absolute (mantle) coordinates, as predicted by the observed slab geometries  
1662 of Figure 3 if the slabs sank vertically. Slab-to-trench transcriptions are drawn in depth increments of 100  
1663 km, using the same depth-to-colour mapping as Figure 3. Tracks of paleo-trench (or arc) locations are  
1664 shown as thick lines if inferred to be produced by westward subduction, and thin lines if produced by  
1665 eastward subduction or subduction of ambiguous polarity (mostly Farallon). For laterally extended slabs  
1666 (FS, FN, CR, presumably produced as in figs 4F/H), the arc lines are shown as dashed when a locus of  
1667 slab deposition is poorly constrained laterally, for a given depth. The colour bar also shows an indicative  
1668 mapping of slab depth to time of subduction, using 10 mm/year as a typical, heuristic value for slab  
1669 sinking rate. The coastlines of NAM reconstructed at times 170 Ma (black), ~80 Ma (green), and present  
1670 day (grey). Grey polygons indicate slab footprints at 800 km depth (in light grey) and at 1400 km (dark  
1671 grey). Label SN marks the approximate position of the Sierra Nevada batholith; the arrow denotes  
1672 possible extents of the Hess-Shatsky Rise conjugate plateau. Arc abbreviations: A = Aleutian, KI = Kula-  
1673 Izanagi. Purple-grey stars on western NAM mark the previous generation of arcs IMS & NJ, extinct and  
1674 accreted by 170 Ma.

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1677 **Figure 6.** Tomotectonic constraints on the growth and consumption of ocean basins subducting into the  
1678 Archipelago from opposite sides. (A) Time frame for 170 Ma (early Archipelago before NAM started  
1679 moving west) and (B) for 80 Ma (override far advanced, westward subduction almost overridden).  
1680 Trenches/arcs active at the respective reconstruction times are highlighted with barbs and the colours  
1681 corresponding to their depths, and are plotted on the basemap of Figure 4, which shows all arc tracks

1682 over time. In (A), the lateral gap between the NAM and its nearest slabs (MEZ, ANG) constrains the  
1683 extents of a paleo-ocean at 170 Ma (the Mezcalera-Angayucham Ocean), whose westward subduction into  
1684 MEZ/ANG allows NAM to advance westward. The lateral gap between the reconstructed Farallon  
1685 spreading ridge (isochrons preserved on today's Pacific plate) and its nearest slabs (CR, CR2) constrains  
1686 the extents of another paleo-ocean, the Farallon Ocean. Orcas Basin is an oceanic microplate inferred to  
1687 occupy the space between the double-sided, intra-oceanic CR and ANG trenches. (B) By 80 Ma, lateral  
1688 overlap of NAM with arc tracks indicates accomplished arc collisions and accretions, except in the far  
1689 northwest of the ANG arc. Lateral overlap of NAM with the FS slab indicates that the (southern)  
1690 Farallon trench is flush against the continental margin. The enduring gap between NAM and the CR slab  
1691 further north indicates that the northern Farallon arc continues to sit offshore (but is in the process of  
1692 being overridden and converted into a marginal arc, the future Cascades arc).

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1695 **Figure 7.** Arc terranes matched to slabs. Every substantive slab should be associated with a geologically  
1696 known arc, and every known arc should be associated with a slab. Arc (super-)terranes are shown in their  
1697 present positions in the Cordillera on the left part of the map. The same arc terranes are schematically  
1698 reconstructed above their matched slabs and paleo-trenches, in absolute positions relative to the lower  
1699 mantle. Colour legend gives the interpreted matches of slabs to geologically known arcs. Superterranes,  
1700 slabs, arcs and trenches are coloured green if associated with Farallon Ocean subduction; orange if  
1701 associated with Mezcalera Ocean subduction, and red if associated with Angayucham Ocean subduction.  
1702 The reconstruction time for the arcs and slab walls corresponds to ~170 Ma (before Archipelago override  
1703 began), except in the case of the SW-ward migrating southern Farallon (Sierra Nevada Batholith) arc,  
1704 which is shown in several time snapshots migrating across the area occupied by its associated FS slab.  
1705 North America is reconstructed at 170 Ma, 140 Ma and 0 Ma. Intermontane Superterrane (IMS) and its  
1706 continental prolongation, the Native Jurassic arc (NJ) are coloured purple; by 170 Ma, their arc activity  
1707 had ceased and IMS is shown docked against NAM. The interpreted suture of MEZ arcs (Insular &  
1708 Guerrero Superterranes INS, orange) against IMS/NJ terranes, is represented by a dozen of collapsed  
1709 oceanic basins coloured cyan and numbered/labeled in the legend.

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1711 Abbreviations: Guerrero-Insular arc terranes include WR (Wrangellia), AX (Alexander), PE (Peninsular),  
1712 GU (Guerrero), WF (Western Jurassic, Western Hayfork, Foothills, and related terranes), SA (Santa Ana).  
1713 Terranes are associated with Farallon subduction include CG—Chugach; FR—Franciscan; PR—Pacific  
1714 Rim; SC—Siletz-Crescent; VC—Vizcaino.

1715 IMS Superterrane (purple) includes terranes BM (Blue Mountains, CC (Cache Creek), QN (Quesnel), ST  
1716 (Stikine) and YTT (Yukon Tanana). NJ (Native Jurassic arc) is the onshore continuation of IMS arcs, as is  
1717 presumably its along-strike continuation of extensional magmatism in Mexico (“Nazas arc”), shown by  
1718 purple asterisks.

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1721 **Figure 8.** Collisional deformation since ~155 Ma, when NAM first rode into the intra-oceanic MEZ arc,  
1722 and welded it onto the continent's westward-subducting margin. **(A)** Progression of deformation in three  
1723 time slices before, during and after suturing. **At 160 Ma**, arc magmatism above the westward-subducting  
1724 Mezcalera Ocean, at the leading edge of North America (NAM), adds crust to the Insular Superterrane  
1725 (INS) arc and lithosphere to the MEZ slab wall. Circa 155 Ma, the last of Mezcalera lithosphere is  
1726 consumed between NAM and easternmost INS: NAM collides with INS microcontinent, resulting in the  
1727 Nevadan orogeny **At 140 Ma**, deformation at the California margin and upward truncation of the slab  
1728 wall. As NAM is still being pulled westward (by intact trench segments in and out of the figure plane),  
1729 subduction polarity at the collided segment is forced to flip. **At 100 Ma**, subduction has flipped, to  
1730 eastward beneath the margin. Its slab, deposited by subduction of the Southern Farallon plate), creates an

1731 east-dipping blanket (100 Ma panel) as the trench is forced westward in front of advancing NAM. This  
1732 subduction is building new, margin-hugging arcs that overprint the NAM-INS suture (including the Sierra  
1733 Nevada batholith). Both north and south of the initial collision site, NAM continues to collide with  
1734 microcontinental INS, resulting in widening Sevier deformation (Columbian orogeny in Canada).  
1735 **(B)** Generalized cross-section through a continent-beneath-arc suture, such as between NAM and INS.  
1736 This spatial zoom into the green box in the 140-Ma panel of A is based on a stylized cross section  
1737 through central Taiwan, a modern example of continent-arc collision with subsequent subduction flip  
1738 (after Beyssac et al., 2007; section oriented normal to the suture). Both the Taiwan and the INS-NAM  
1739 sutures show widespread distribution of units containing old detrital zircons, tectonically exhumed forearc  
1740 (tectonically removed), and high grade, rapidly exhumed metamorphic rocks immediately inboard of the  
1741 suture. Kmg is Cretaceous orthogneiss (Chipan gneiss) that has cooled through 240 °C in the past million  
1742 years (Beyssac et al., 2007).

1743  
1744

1745 **Figure 9.** Margin-parallel terrane translations based principally on paleomagnetic data from Late  
1746 Cretaceous and Eocene strata. These data constrain the tomotectonic terrane reconstruction model of  
1747 Clennett et al. (2020), which is modified in the figures. (A) Present-day terrane map shows the current  
1748 locations of a half-dozen units that are very robustly constrained. The green/blue lines, with nodes every  
1749 10 Ma and date labels (in Ma) at key times, represent the spatio-temporal trajectories into the past of these  
1750 units, back to when they were deposited. A 1000-km scale bar is shown for reference. Trajectories are in  
1751 absolute coordinates relative to the lower mantle, according to our Clennett et al. 2020 reconstruction.  
1752 This reconstruction honors the displacement constraints of the most solid paleomag sites, Carmacks &  
1753 Mount Tatlow/Churn Creek, but Spences Bridge is not honored since it does not fully pass the fold test.  
1754 The model is based on globally derived apparent polar wander paths (APWP), which reach the same  
1755 conclusion as for APWP derived solely from North American rock units (Housen, 2021; Tikoff et al.,  
1756 2022). The *main* BajaBC translations are implemented 70-50 Ma along the yellow line, which runs mainly  
1757 through Intermontane terranes (and their left-behind correlatives in the Blue Mountains/U.S.). This Baja-  
1758 BC fault line is necessarily speculative, but it must run inboard of all paleomag sites that show significant  
1759 offsets (details in section 6.2). The trajectory of the Sierra Nevada, illustrative of a non-translated site on  
1760 stable NAM, is shown in dark green. Accreted superterrane packages follow the colour scheme of Figure  
1761 7; additional pericratonic blocks are colored dark and light purple.

1762

1763 (B) Tomotectonic reconstruction of the assembly of Alaska from Baja-BC and Angayucham terrane  
1764 translations. This 85-Ma snapshot of the Clennett et al. 2020 model reconstructs the configuration of Baja-  
1765 BC (comprising at a minimum the terranes west of the yellow line) at the onset of its northward sprint.  
1766 The locations of the Angayucham (red barbs) and northern Farallon trenches (green solid barbs) are  
1767 constrained by the ANG and CR slabs, respectively. The terranes of the then-active ANG arc (Koyukuk,  
1768 future Central Alaska, in red) were welded into the Orcas microplate, but gradually being dislodged and  
1769 rotated by the obliquely colliding NAM – the “Great Alaskan Terrane Wreck” of Johnston (2001). The  
1770 northern Farallon arc terranes (Pacific Rim, PR, and others now underplating INS) were also intruded  
1771 into the Orcas plate and slowly accreted against INS. During its northward sprint, Baja-BC effectively  
1772 became part of the Orcas plate, separated from NAM by the “Baja-BC fault” (yellow line) or collection of  
1773 faults.

1774 Baja-BC passes *inboard* of, and unimpeded by, the CR Farallon trench, which still sits offshore. As NAM  
1775 advances westward, Orcas is squeezed out toward the west or north. It may have subducted into one of  
1776 two small slabs observed under the grey areas (see text). Due to the small size and mobility of the plate,  
1777 its disappearance can be rapid, and the Baja-BC and Central Alaskan terranes on it are transported along  
1778 (the “sprint” phase). As the Orcas seafloor subducts, the northern Farallon trench persists and makes  
1779 landfall on NAM, becoming the continental Cascades arc by ~50 Ma, which shut off this northwestern

1780 passage for shuffling terranes. Baja-BC and Central Alaska collapse against each other and against NAM,  
1781 completing the assembly of Alaska. The angle between the yellow line (paralleling the NAM margin) and  
1782 the ANG slab (red line) sets the angle of the Alaskan orocline.