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Sigloch, K., and Mihalynuk, M.G., 2017, Mantle and geological evidence for a Jurassic–Cretaceous suture spanning North America: GSA Bulletin, doi:10.1130/B31529.1.

DATA REPOSITORY

Supplementary Figure DR1

Farallon subduction beneath the Cascadia subduction zone, from trench to ~1500 km depth. Three-dimensional, oblique elevation view from the southwest; topography and bathymetry of the western U.S. are shown as translucent surface (elevations strongly exaggerated; same surface is also shown schematically translated to 1000km depth for spatial reference). Seismically fast domains according to the tomographic P-velocity model of Sigloch (2011) are iso-contoured in 3-D where wave velocities are dVp/Vp > 0.35% faster than average (as in Figs. 2 and 3, and using same rainbow color scale to indicate depth). Fast velocities that are clearly separate from this continuous system are masked out, including cratonic root and transition zone slab to the east, and lower-mantle slabs CR2 and K to the north and west (the latter are visible in Figs. 2 and 3 and Movie M1). The slab dips eastward, but extends not farther east than the Rocky Mountain front (see also Figs. 3A/B). The slab's lower-mantle parts, termed "CR" or "Cascadia Root" in the text, are much more massive than in the uppermost mantle; slab thickening happens mostly in the transition zone (light blue level, 400–600 km). Comparison to the different perspectives of Figures 2A and 3A reveals a rotation in deposition direction. The base of CR at the red/yellow levels strikes NW-SE (almost perpendicular to this viewing angle) and is built steep and wall-like. From the blue-green level (~800 km) up, the slab is less massive, heavily fragmented, and shows a clear slope toward the trench, i.e., westward-shallowing; the strike of this material is more N-S, c.f. Figure 2A. (We interpret this upper-mantle slab as deposited after CR trench had accreted and while it was dragged westward as an Andean-style trench, i.e., post-ca. 60 Ma. This matches a clockwise rotation of conjugate magnetic isochrons on the Pacific plate from NW-SE to more N-S, recording the fracturing of the Vancouver fragment from the northern Farallon ca. 52 Ma, as discussed in Sigloch 2011.)

Supplementary Figure DR2

Volcanic arc and trench migrations west of Jura-Cretaceous North America over time and space: summary of the four-dimensional paleo-reconstruction of Supplementary Movie M1.

Colored lines are absolute trench positions over time, with respect to the lower mantle, as inferred from slab geometries. Colors are chosen to match the depth-to-color mapping used to visualize the 3-D tomography model in Figures 2 and 3, and Movie M1. At depth increments of 100 km, trench geometries were inferred from the geometries of "actively growing" slabs, as explained in the caption of Movie M1. A slab-wall sinking rate of 10.5 mm/a, which is estimated from slab geometries rather than just assumed, produces a mapping of slab depth to trench age; see the color bar. This mapping is derived from the geometries of the MEZ, ANG, and CR slab walls (c.f. Section 2.7); such "supported" trenches are drawn as solid lines. Barbs on trench lines point in direction of subduction; barb colors denote the ocean basin origin of subducting lithosphere: Farallon (dark green), Mezcalera (orange), Angayucham (red), or Pacific (maroon).

Slabs that sank slower or faster than 10 ± 2 mm/a are marked by dotted or dashed trench lines, respectively, and their deviating sinking styles are expected and discussed in the caption of movie M1. Arguments for MezAng suturing do not depend on these younger Farallon slabs. Slab outlines at 1400 km and 800 km depth are given for reference, as are continent locations in a lower-mantle frame at 170 Ma, 80 Ma, and present day, with accreted belt shaded beige. (Additional times are omitted in order to avoid clutter. The movie reconstructs 3-D slab deposition, continental drift, and seafloor isochrons in time increments of 5 m.y., from 200 Ma to present.)

The first-order contrast in trench evolution is that of old, stationary trenches (solid lines clustered above steep slab walls), versus younger, westward-dispersed trenches. In all locations, the transition from clustered to dispersed trench lines marks the collision of westward-migrating North America with intra-oceanic, formerly stationary trenches, which forces subduction zones, slab depo-sites and volcanic arcs to the west. More easterly sites are overridden earlier, as expected. Northern MEZ segment shows the full override sequence most clearly: stationary trench of westward-subducting Mezcalera Ocean at magenta and dark red slab levels (Late Jurassic); westward retreat combined with trench line shortening (arc extinction due to override) at orange/yellow levels (Early Cretaceous); incipient subduction of an eastward-dipping Farallon beneath west coast terranes at orange/yellow levels, and subduction hand-over into same at yellow/light green levels (no more MEZ deposition from here on); followed by rapid westward migration of the Andean-style Farallon trench (green to blue levels associated with slab L1). Similar rainbow-colored sequences of westward-migrating trenches are evident along southern MEZ; and later along CR, the westerly, intra-oceanic Northern Farallon trench that becomes westward-migrating Farallon-Gorda (G) trench after continental override at light blue levels. Westward dipping subduction into ANG slab gradually shortens, i.e., goes extinct from SE to NW.

"SN" marks the (younger) Sierra Nevada arc, associated with Farallon slab L1. Early Sierra Nevada arc was part of the Native arc (stars on the 170-Ma continent position), which went extinct by 170 Ma. Wedged between these two arcs is MEZ arc material (Section 3.6). The unfilled arrow west of "SN" approximates the location and east-west extent of Shatsky Rise Conjugate accretion, which extinguished the SN batholith.

Supplementary Movie M1

Four-dimensional reconstruction of seafloor isochrons, North American drift, and deposition of subducted lithosphere over the past 200 million years. Evolution of 2-D surface and 3-D subsurface structure is shown in time increments of 5 million years. Isochron and plate reconstruction by Seton et al. 2012 in the lower-mantle (i.e., hybrid hotspot/true polar wander, HHS-TPW) reference frame of Steinberger and Torsvik 2008. In pink, North American position at 170 Ma, when new Atlantic seafloor begins to form during breakup of Pangea. Present-day coastlines in light gray, current extent of accreted terrane belt shaded dark gray. Magnetic seafloor isochrons in light blue, spreading ridges in yellow.

Seismically faster-than-average material from the finite-frequency P-wave tomography of Sigloch 2011 is iso-contoured in 3-D at $dVp/Vp = 0.25\%$ and colored in depth increments of 200 km, as in article. Slabs are added at a rate of 10.5 mm/a or 10.5 km/m.y., for which the color bar gives the relationship between current slab depth and deposition age. From the moment of deposition, slabs are shown at their current depths, i.e., we make no attempt to depict their gradual sinking. Continuous slab "deposition" in the movie stops at 40 Ma, when all seismically fast material at and below 400 km depth is visible. The applied sinking rate of 10.5 mm/a (or rather, 10 ± 2 mm/a) was estimated from the westward-shallowing of the upper truncation surfaces of MEZ and ANG slab walls, as discussed in Sections 2.6 and 2.7. (For completeness, slab between 300 and 400 km depth appears in the 20-Ma slide, but contamination by lithospheric structure becomes apparent, and no depth-age relationship is implied.)

Interpreted trenches are superimposed on the evolving slabs as colored lines with barbs pointing in direction of subduction: Farallon trenches in green, Angayucham trenches in red, Mezcalera trenches in orange, Pacific (Aleutians) trench in maroon. Trench line styles indicate the type of slab. Solid lines with filled barbs indicate "supported" slabs, essentially the lower-mantle slab walls used to estimate sinking rates (and yielded consistent rates of 10 ± 2 mm/a). Since the depicted deposition rate of 10.5 mm/a is correct for these slabs, trench lines will overlie a slab (only) while it is still "growing", i.e., adding material from one time slice to the next.

This is not the case for two other slab types that must have sunk at different rates. Dotted lines indicate trenches where the slab seemingly continues to grow after the trench must have gone extinct (because the area was overridden by North America). These very slow sinkers (<10.5 mm/a) are 'stagnant' transition-zone slabs L1 and G, deposited under an Andean-style, marginal Farallon trench. Dashed trenches with unfilled barbs indicate slabs that appear earlier than its trench could have been active, i.e., the slab must have sunk more rapidly than 10.5 mm/a. For details see discussion items (iii) and (iv) below. Supplementary Figure DR2 provides a summary of the evolving trenches shown in this movie.

Our study focuses on the diachronous extinction, between ca. 150 Ma and ca. 50 Ma, of westward subduction into MEZ-ANG trenches due to override by North America; all implied trenches are consistent with 10.5 mm/a sinking. MEZ subduction is gradually replaced by eastward subduction into margin-hugging Farallon trenches, although intra-oceanic Farallon subduction was ongoing before this hand-over, and was always more segmented and shifting than MEZ-ANG subduction. Accretion of the intra-oceanic Farallon trench segment above Cascadia Root (CR)/Gorda (G) slab in the Pacific Northwest occurred as late as 60–50 Ma, ending the sequence of Archipelago override.

Discussion of Shortcomings of the Movie and Model

(i) Uncertainties of absolute reference frame. Among all absolute reference frames investigated by Sigloch and Mihalynuk (2013), the choice of the HHS-TPW frame for this movie results in the youngest ages for Archipelago override. Eastward-protruding MEZ slab is seen to be overridden only after 130 Ma (retreat/extinction of yellow trench). This contrasts with geological evidence pointing to onset of collision by ca. 155 Ma (Nevadan orogeny), which we consider a more reliable time marker of first override. 130 Ma is however within the cumulative uncertainty of 146 ± 24 Ma calculated by Sigloch and Mihalynuk (2013). It is not only due to uncertainty in absolute lower-mantle frame prior to Indo-Atlantic hotspot activity, but also to uncertainty in the shape and westward extent of the continental margin prior to accretion of the Insular-Guerrero micro-continent, c.f. item (ii). We chose the HHS-TPW reference frame due to its wide adoption in contemporary studies of plate reconstructions, its quantification of (paleomagnetic) constraints prior to hotspot activity, and its ready availability in the GPlates software used for creating the movie.

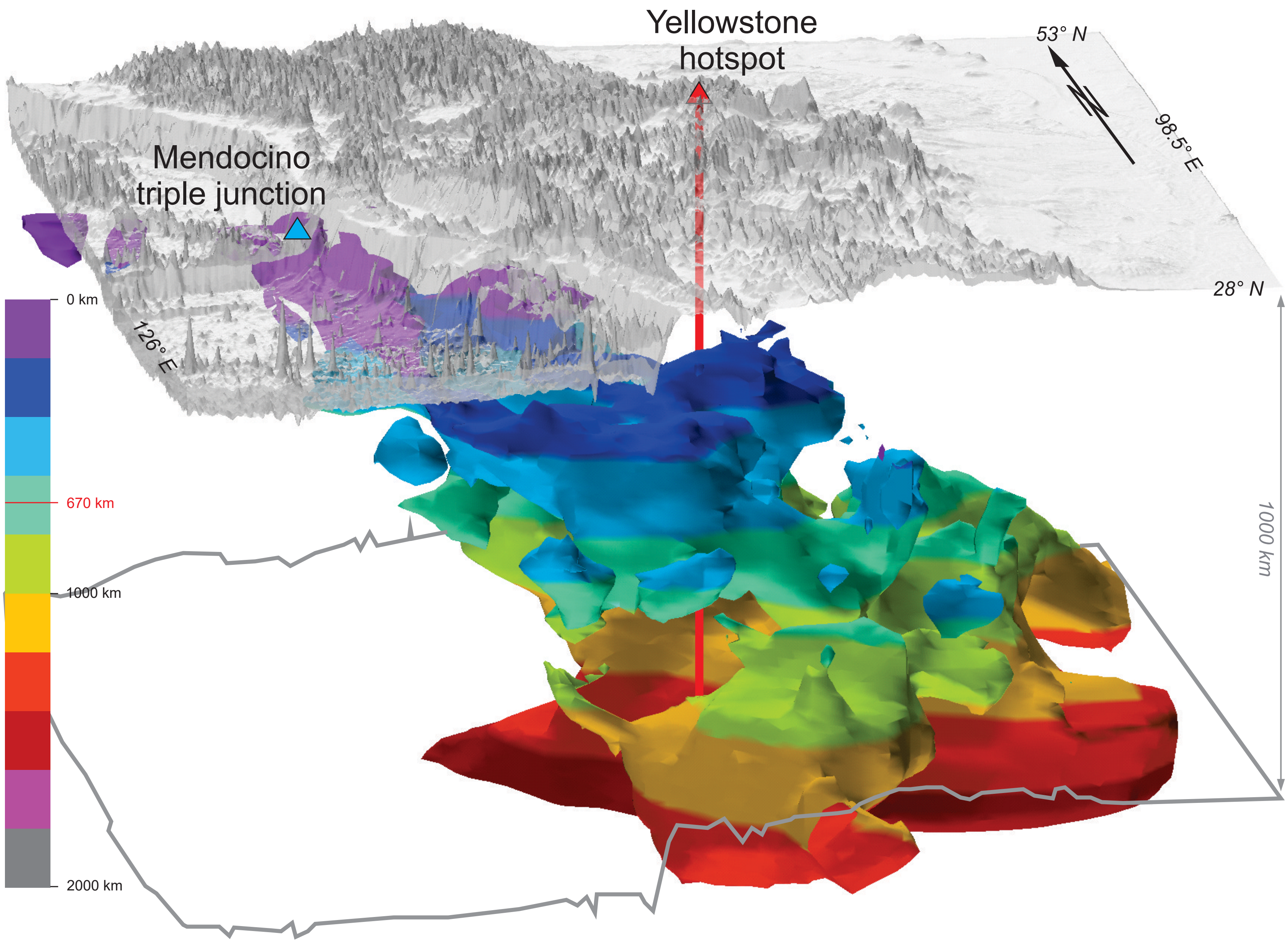
(ii) Uncertainty in the westward extent of the paleo-margin over time. A gray-shaded belt along the (present-day) continental margin shows the speculative extent of the mobile belt including the pre-accreted Intermontane microcontinent at ca. 170 Ma, i.e., we suspect that just before first collision with MEZ arcs, the western margin extended approximately as far west as it does today (relative to the craton). Large uncertainties in this width translate into timing uncertainties of first collision with the MEZ arcs (Insular-Guerrero microcontinent), c.f. item (i). More generally, constraining the location over time of tectonic blocks that lay along or slightly off of the margin of North America prior to ca. 50 Ma is subject to contentious debate in a vast body of literature. This involves reconstructing the widths of all microcontinents before and after accretion; restoration of Sevier and Laramide shortening; northward translation of microcontinents post-accretion (e.g., "Baja-BC controversy"); restoration of post-orogenic Basin and Range extension. Instead of arguing for one configuration or another, Sigloch and Mihalynuk (2013) attempted to quantify cumulative uncertainties, but these inevitably trade off with uncertainties in absolute reference frame, c.f. item (i).

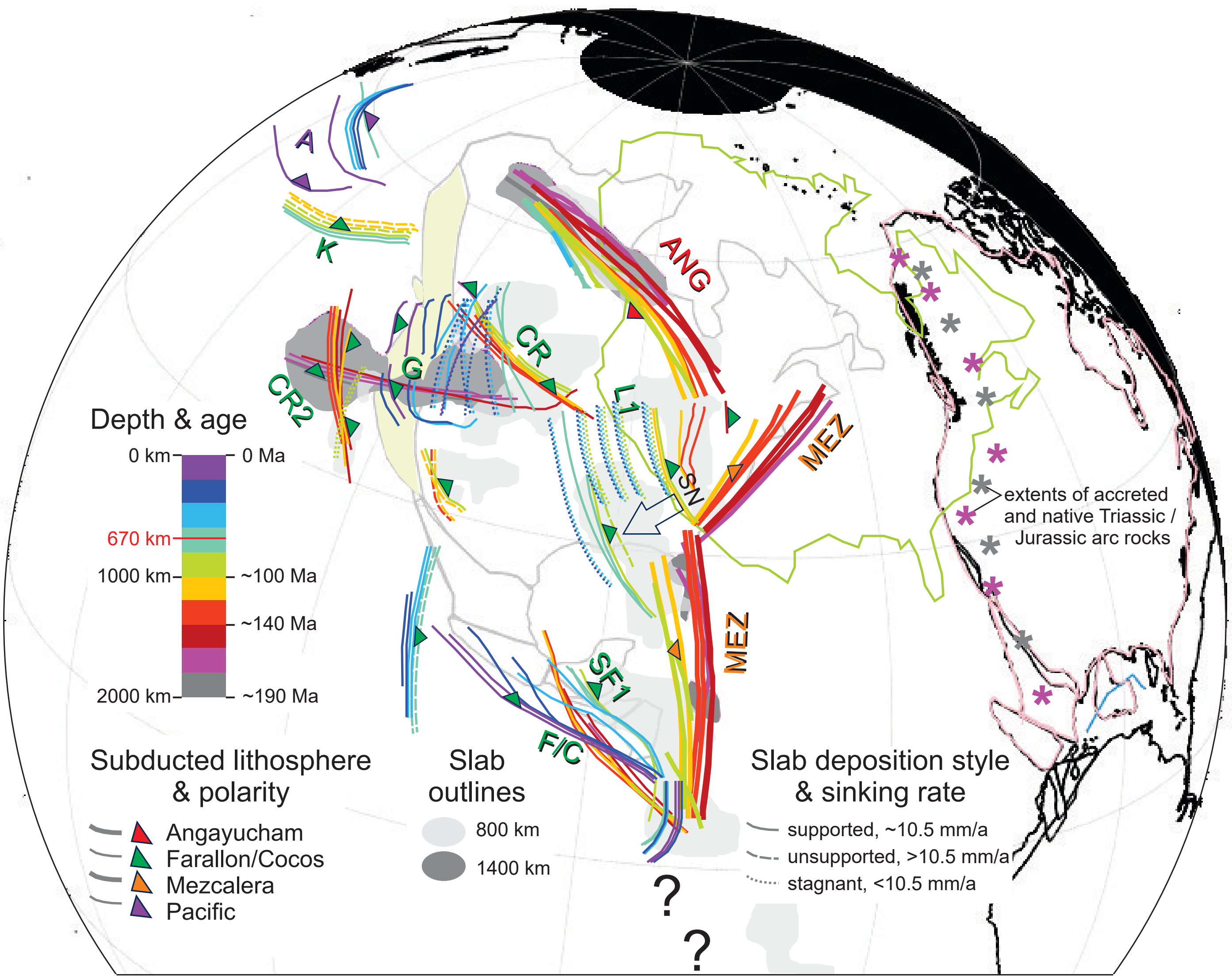
(iii) Slab that sinks at less than 10.5 mm/a (dotted green trench lines): transition zone slabs L1 (Laramide) and G (Gorda), deposited beneath migrating Farallon trenches. These are 'stagnant slabs' of the kind first discovered in the archipelagos of the Southwest and Western Pacific, e.g., review by Fukao et al. 2009. L1 must be due to the migrating, margin-hugging, Farallon trench between ca. 90 Ma and ca. 55 Ma; Gorda slab was deposited beneath the same type of trench (northern Farallon) post-55 Ma. We show presumed trench locations (dotted green lines) migrating with the margin. The slabs appear to continue growing until long after override by the continent(!), which at face value would preclude vertical sinking. We think these slabs did sink vertically but in the style cartooned in Figure 2 panel C2 (which is supported by numerical studies, e.g., Gibert et al. 2012; Čížková and Bina, 2013). Under a migrating trench, slab folds in the transition zone were laid down from east to west rather than from bottom to top. The folds have steep limbs that span a ~400 km depth range. Such thickness instantaneously fills the entire vertical range of the transition zone, rather than linearly adding 10 mm/a. Each fold sank near-vertically, at an upper-mantle rate that probably exceeded 10.5 mm/a, but has since stagnated on the '670' discontinuity due to its elongated aspect ratio, or at least has penetrated the lower mantle after considerable delay caused by the '670's endothermic phase boundary (L1 extends somewhat below the transition zone).

(iv) Slab that sinks faster than 10.5 mm/a (dashed green trench lines with unfilled barbs): short-lived segments of westerly, intra-oceanic (Farallon) subduction under relatively stationary trenches. These four smaller Farallon slab fragments in the lower mantle appear to show up too early. If actually active during the time slices in which they are marked as dashed with unfilled barbs, these trenches would have operated simultaneously with older but still-active trenches of similar strikes and further inboard (east or south). Instead, these dashed outboard trenches probably replaced their inboard counterparts once the latter became inactive. (Else there would also be a shortfall of trenches to account for more recent Farallon subduction). If this explanation is correct, then slabs beneath dashed trenches sank faster than 10.5 mm/a.

The best-constrained example is "Slab K" south of the Aleutians, discussed in Section 2.4. Located at 900–1200 km depth, the slab would be 90–120 Ma old at 10 mm/a sinking, whereas if it represented Kula lithosphere, the slab would be expected at 850–550 km depth, based on known Kula subduction between 85 and 55 Ma (Woods and Davies, 1982; Engebretson, 1984; Atwater, 1989). Everything else about Slab K fits expectations for Kula subduction: its location relative to CR (Northern Farallon), its east-west strike, and a depth extent of 300 km in the lower mantle, corresponding to a lifespan of 30 m.y.

Relatively faster sinking of K and other dashed slabs is probably due to their limited vertical extents of only a few hundred kilometers. For most of their short lifespans, they could drop quickly through the less viscous upper mantle.. Contrast this to the MEZ/ANG/CR slab walls that fill >1000 km of vertical range: in a mature stage of development, their roots were anchored in the lower mantle, which set the (slow) sinking rate for the entire slab wall, including that for any new material inserted into the (low-viscosity) upper mantle.


Yellowstone
hotspot
Mendocino
triple junction
53° N
98.5° E
28° N
126° E
0 km
670 km
1000 km
2000 km
1000 km



A
K
ANG
CR
G
CR2
L1
MEZ
SN
MEZ
SF1
F/C
?
?
extents of accreted
and native Triassic /
Jurassic arc rocks
Depth & age
0 km
0 Ma
670 km
1000 km
~100 Ma
~140 Ma
2000 km
~190 Ma
Subducted lithosphere
& polarity
Angayucham
Farallon/Cocos
Mezcalera
Pacific
Slab
outlines
800 km
1400 km
Slab deposition style
& sinking rate
supported, ~10.5 mm/a
unsupported, >10.5 mm/a
stagnant, <10.5 mm/a