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Vertical slab sinking and westward subduction offshore of Mesozoic North America

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Subducted slabs in the mantle, as imaged by seismic tomography, preserve a record of ancient subduction zones. Ongoing debate concerns how direct this link is. How long ago did each parcel of slab subduct, and where was the trench located relative to the imaged slab position? Resolving these questions will benefit paleogeographic reconstructions, and restrict the range of plausible rheologies for mantle convection simulations.

We investigate one of the largest and best-constrained Mesozoic slab complexes, the “Farallon” in the transition zone and lower mantle beneath North America. We quantitatively integrate observations from whole-mantle P-wave tomography, global plate reconstructions, and land geological evidence from the North American Cordillera. These three data sets permit us to test the simplest conceivable hypothesis for linking slabs to paleo-trenches: that each parcel of slab sank only vertically shortly after entering the trench That is, we test whether within the limits of tomographic resolution, all slab material lies directly below the location where it subducted beneath its corresponding arc.

Crucially and in contrast to previous studies, we do not accept or impose an Andean-style west coast trench (Farallon-beneath-continent subduction) since Jurassic times, as this scenario is inconsistent with many geological observations. Slab geometry alone suggests that trenches started out as intra-oceanic because tomography images massive, linear slab “walls” in the lower mantle, extending almost vertically from about 800 km to 2000+ km depth. Such steep geometries would be expected from slabs sinking vertically beneath trenches that were quasi-stationary over many tens of millions of years. Intra-oceanic trenches west of Mesozoic North America could have been stationary, whereas a coastal Farallon trench could not, because the continent moved westward continuously as the Atlantic opened.

Overlap of North American west-coast positions, as reconstructed in a hotspot reference frame, with elongate slab walls predicts where and when the intra-oceanic trenches would have been overridden by the westward-moving continent. Land geology plays the role of a validating data set: trench override is predicted to coincide with accretion of buoyant arc terranes, deformation of the continental margin and slab window volcanism. We find excellent agreement between predicted and observed accretion episodes, validating both vertical sinking (within observational uncertainties of a few hundred kilometers laterally), and westward subduction beneath an archipelago of island arcs west of Jura-Cretaceous North America. Amalgamation of the arcs with North America occurred as the intervening ocean crust was consumed. Implied slab sinking rates are of 10$\pm$2 mm/a, uniformly for three different slab walls. We conclude that the hypothesis of essentially vertical slab sinking produces a self-consistent model that explains first-order observations of 200 Ma – 50 Ma Cordilleran geology. By contrast, the standard scenario of a continental Farallon trench requires massive amounts of slab to be laterally displaced by 1000+ km after subduction, and offers no explanation for a long series of Cretaceous terrane accretions.