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Supplementary Materials

The role of oceanic plateau subduction in the Laramide Orogeny

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Reconstruction of subducted oceanic plateaus from plate tectonics

We assume that the Shatsky Rise formed at the Pacific-Farallon-Izanagi triple junction[1,2] between ~145-130 Ma[2] with conjugates on the Farallon and Izanagi plates. The Hess Rise and its conjugate formed along the Pacific-Farallon ridge at ~110 Ma. An ellipsoidal configuration is assumed for these conjectured plateaus, with contours representing estimated maxima and minima extent of the now subducted plateau conjugates. Positions of the conjugate plateaus are inferred based on the geometry of the preserved plateaus, the age of the underlying ocean lithosphere and the associated mid-ocean ridge system. The Pacific-Farallon ridge was reconstructed by deriving stage rotations from half-stage rotations with an assumption of spreading symmetry[3]. Reconstruction of the Pacific-Izanagi-Farallon triple junction additionally followed principles of triple junction closure[4]. The absolute reference frame used for the Pacific plate is based on a hybrid moving Indian-Atlantic hotspot[5] and a fixed Pacific hotspot reference frame for times prior to 83.5 Ma[6]. Although motion between hotspots in the Indian-Atlantic and Pacific domains has been recognized[7-9], moving Pacific hotspots have not been incorporated into our model as there are no published rotations available. Instead, we test two alternative fixed Pacific hotspot reference frames for times prior to

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83.5 Ma[6,10] and find a difference of < 300 km between models at 90 Ma. We do not anticipate significantly more than 300 km of motion using a moving hotspot reference model over this 6.5 million year period (from 83.5-90 Ma) as this would require higher rates of motion of the Pacific plate for which there is no evidence.

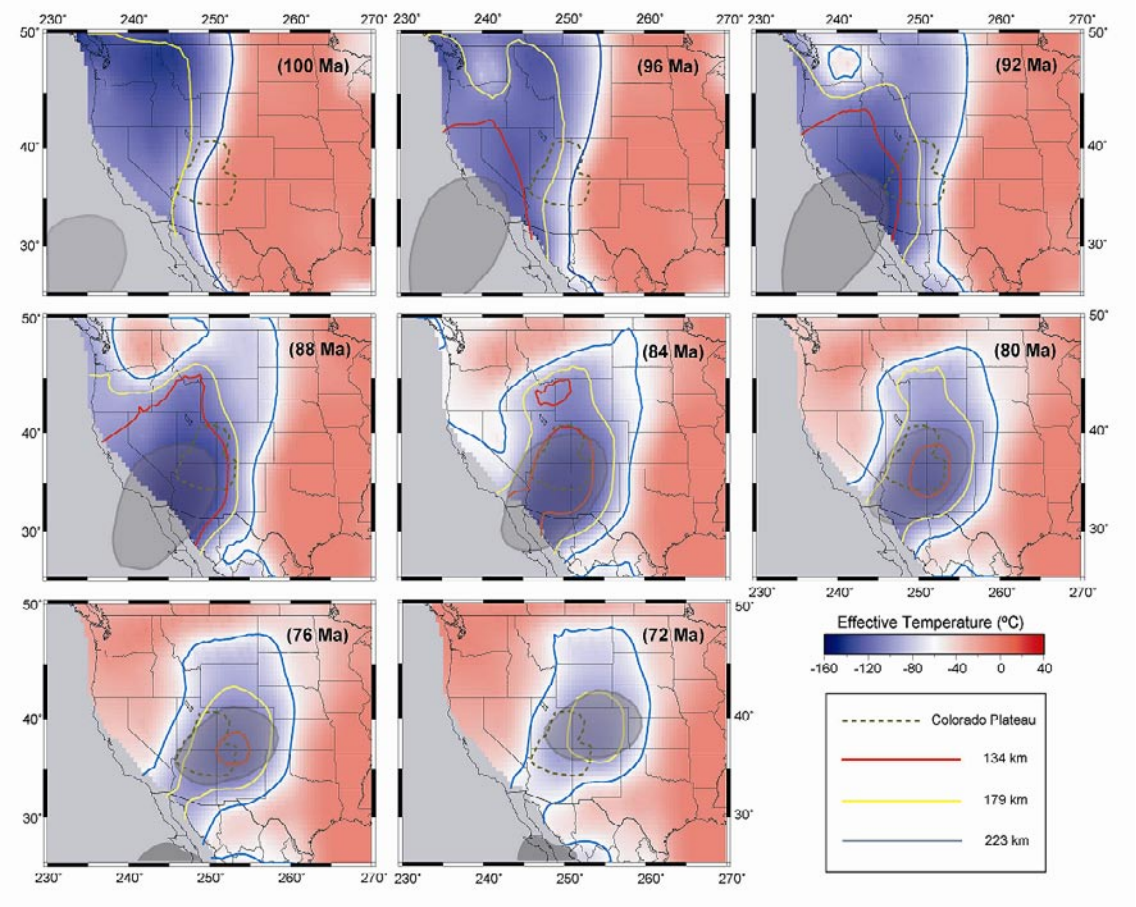

Fig. S1: Migration of the Shatsky conjugate plateau with respect to the North American continent during the Late Cretaceous based on an inverse convection model[11,12]. The background shows temperature at 220 km depth, while color contours denotes isotherms of temperatures 60 °C lower than the ambient mantle at different depths. The grey area (tracer distribution) indicates the thickest part (core) of the Shatsky conjugate plateau. A secondary grey area along north Mexico after 76 Ma represents the arrival of the Hess conjugate.

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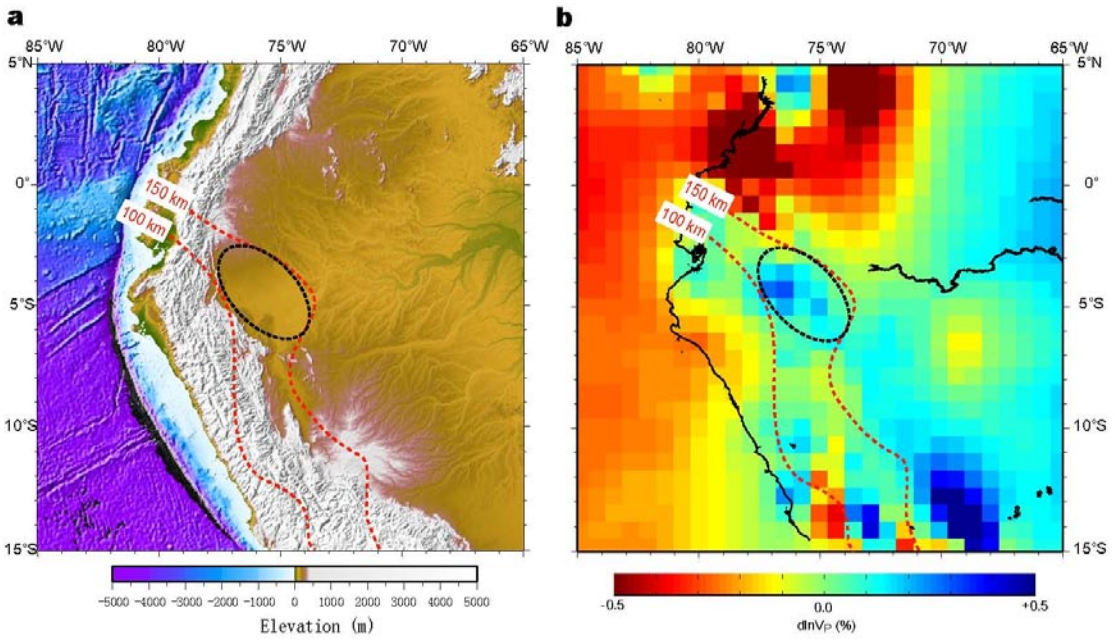

Fig. S2: Surface topography (a) and seismic tomography[13] at 120 km depth (b) of western South America. The dashed red lines indicate slab contours[14] at 100 and 150 km depth, respectively. The dashed black ellipse represents the putative Inca plateau subducting beneath Peru[14]. Note the topography low (presumably subsidence) above the Inca plateau which shows up as a fast seismic anomaly in b. Both surface subsidence and flat-slab formation associated with the subducting Inca plateau makes it a present-day analogy of our model where subduction of the Shatsky conjugate plateau caused the slab to flatten while simultaneously inducing surface subsidence above the plateau during the Late Cretaceous.

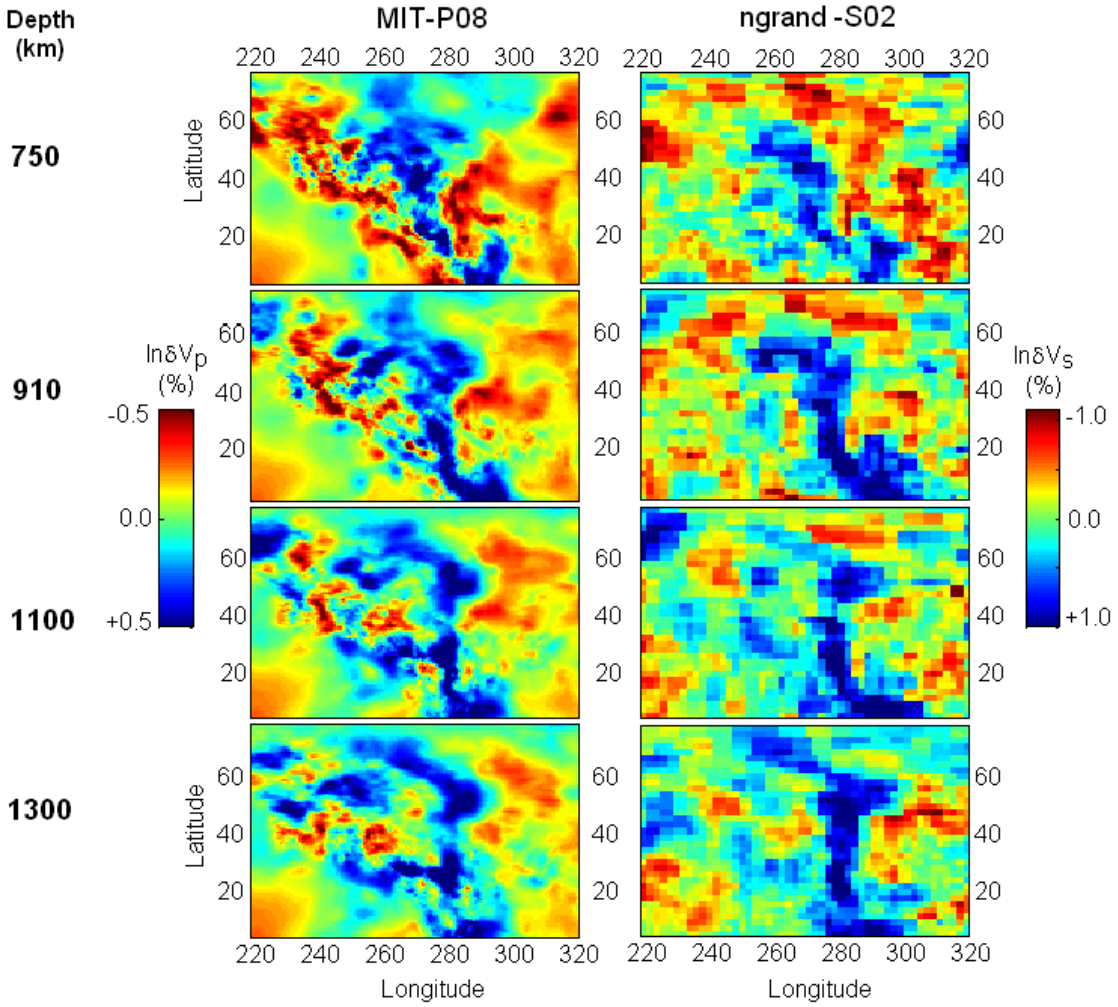

Fig. S3: Comparison of the Farallon slab remnants revealed by both a P wave[13] (left) and an S wave[15] tomography (right). Seismic structures at four different depths under North America are shown. Note the similarity of the two models, especially those of the Farallon remnants (high seismic velocity anomalies).

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References:

1. W. W. Sager, D. W. HandschumacheTr,. W. C. Hilde, & D . R. Bracey, Tectonic evolution of the northern Pacific plate and Pacific-Farallon-Izanagi triple junction in the Late Jurassic and Early Cretaceous (M21-M10), *Tectonophysics* **155**, 345-364 (1988).

2. M. Nakanishi, W. W. Sager & A. Klaus, Magnetic lineations within Shatsky Rise, northwest Pacific Ocean: Implications for hot spot-triple junction interaction and oceanic plateau formation *J. Geophy. Res*. **104**, B4, 7539-7556 (1999).

3. R. D. Müller, M. Sdrolias, C. Gaina & W.R. Roest, Age, spreading rates, and spreading asymmetry of the world's ocean crust, *Geochem. Geophys. Geosys.* **9**, doi: 10.1029/2007GC001743 (2008).

4. D. P. McKenzie & J. Morgan, The evolution of triple junctions, *Nature* **224**, 125-133 (1969).

5. C. O'Neill, R.D. Müller & B. Steinberger, On the uncertainties in hotspot reconstructions, and the significance of moving hotspot reference frames, *Geochem., Geophys., Geosys.* **6**, 35, doi:10.1029/2004GC000784 (2005).

6. P. Wessel Y. Harada & L. W. Kroenke, Toward a self-consistent, high-resolution absolute plate motion model for the Pacific, *Geochem*. *Geophys*. *Geosys*. **7**, Q03L12, doi:10.1029/2005GC001000 (2006).

7. P. Molnar & Tanya Atwater, Relative motion of hot spots in the mantle, *Nature* **246**, 288-291 (1973).

8. J.A. Tarduno, H.-P. Bunge, N. Sleep & U. Hansen, The bent Hawaiian-Emperor hotspot track: Inheriting the mantle wind, *Science* **324**, 50-53 (2009).

9. J.A. Tarduno, R.A. Duncan, D.W. Scholl, R.D. Cottrell, B. Steinberger, T. Thordarson, B.C. Kerr, C.R. Neal, F.A. Frey, M. Torii & C. Carvallo, The Emperor

Seamounts: Southward motion of the Hawaiian Hotspot plume in Earth's mantle, *Science* **301**, 1064-1069 (2003).

10. P. Wessel & L. W. Kroenke, Pacific absolute plate motion since 145 Ma: An assessment of the fixed hot spot hypothesis, *J*. *Geophys*. *Res*. **113**, B06101 (2008).

11. L. Liu, S. Spasojevic, & M. Gurnis, Reconstructing Farallon plate subduction beneath North America back to the Late Cretaceous, *Science* **322**, 934-938 (2008).

12. S. Spasojevic, L. Liu & M. Gurnis, Adjoint models of mantle convection with seismic, plate motion, and stratigraphic constraints: North America since the Late Cretaceous, *Geochem*. *Geophys*. *Geosys*. **10**, Q05W02, doi: 10.1029/2008GC002345 (2009).

13. C. Li, R. D. van der Hilst, E. R. Engdahl & S. Burdick, A new global model for P wave speed variations in Earth's mantle, *Geochem. Geophys. Geosys.* **9**, 10.1029/2007GC001806 (2008).

14. M-A Guscher, J.-L.Olivet, D. Aslanianb, J.-P. Eissen & R. Mauryd, The "lost Inca Plateau": cause of flat subduction beneath Peru? *Earth Planet. Sci. Lett.* **171**, 335-341 (1999a).

15. S. P. Grand, Mantle shear-wave tomography and the fate of subducted slabs, *Philos. Trans. R. Soc. London* A **360**, 2475-2491 (2002).