Dynamic Subsidence and Uplift of the Colorado Plateau

Supplementary Material

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Method and model description

The adjoint method is a gradient-based inverse algorithm, which constrains the initial condition of mantle structure by predicting the present mantle seismic structure through a set of forward and backward calculations (e.g. Bunge et al., 2003). In practice, we started with present-day mantle structure inferred from seismic tomography, and attempted to reconstruct subduction of the Farallon plate back to the Late Cretaceous. Density anomalies associated with the slab and upper and lower mantle viscosities are allowed to vary, which are then constrained by fitting the evolving continental-scale Late Cretaceous marine inundation, sediment isopachs and borehole tectonic subsidence within the Western Interior seaway. More details concerning the method and the determination of our preferred and alternative models through fitting to data can be found in Liu et al. (2008) and Spasojevic et al. (2009).

The model of Farallon subduction that best fits multiple observational constraints in the Late Cretaceous (Liu et al., 2008) recovers a phase of flat slab subduction beneath the western U.S. (Fig. DR1). From 96 Ma, a portion of thickened slab starts to subduct at the latitude of California and moves inland at shallow depths. During this period, the putative slab to the north (Washington, Oregon, Idaho and Montana) sinks faster, and forms a geographically isolated flat slab around 84 Ma with its center largely overlapping with the Colorado Plateau. At 76 Ma, the flat slab stops moving eastward and switches to a northeastward motion. The slab accelerates toward the northeast after 72 Ma and gradually sinks deep into the mantle (Fig. DR2).

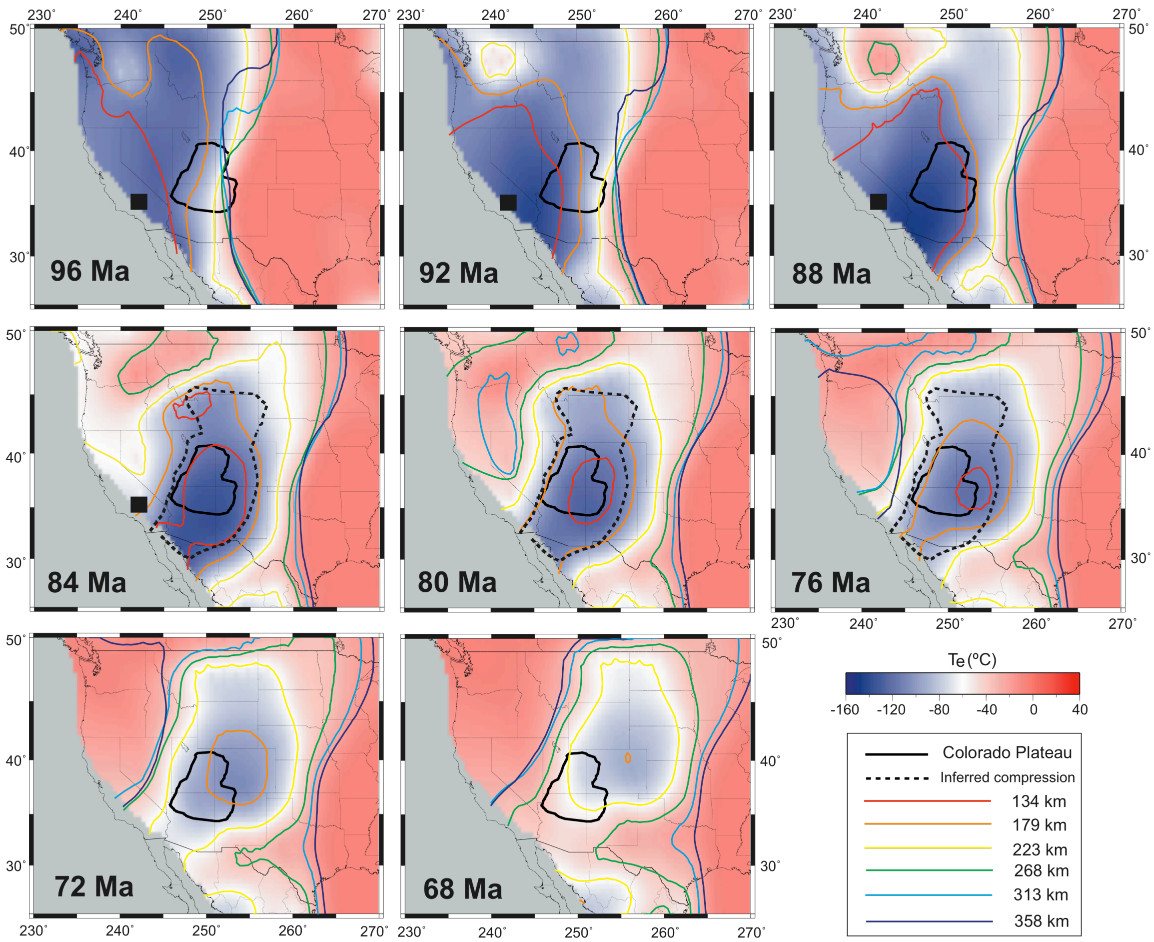

Figure DR1. Three dimensional delineation of the recovered Farallon subduction during the Late Cretaceous from the preferred model in Liu et al. (2008): color contours depict an isotherm at various depths (these isotherms are 40°C lower than the ambient mantle which represent the edge of the Farallon slab at these depths); the background temperature field is shown for 223 km depth. All time snapshots are projected onto the North American plate. The black square in Southern California represents the location of southernmost Sierra Nevada batholiths during the exhumation event described by Saleeby et al. (2007). The black dashed contour outlines the geologically inferred Laramide compression zone (Saleeby, 2003).

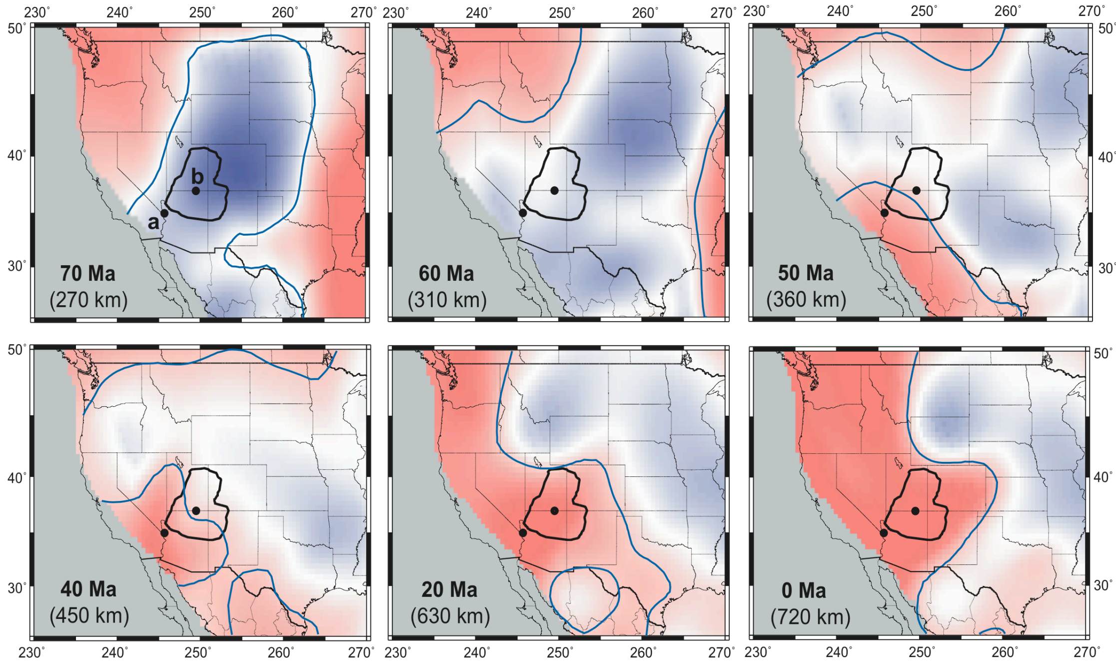

Figure DR2. Migration of the Farallon slab inside the mantle beneath the Colorado Plateau after the Late Cretaceous flat subduction from the preferred model in Liu et al. (2008). Each time snapshot corresponds to a different depth where the Farallon slab is best resolved. The blue contour represents an isotherm of 30 °C lower than the ambient mantle. Temperature scale is the same as Fig. 1. The two points are the same as in Fig. 1.

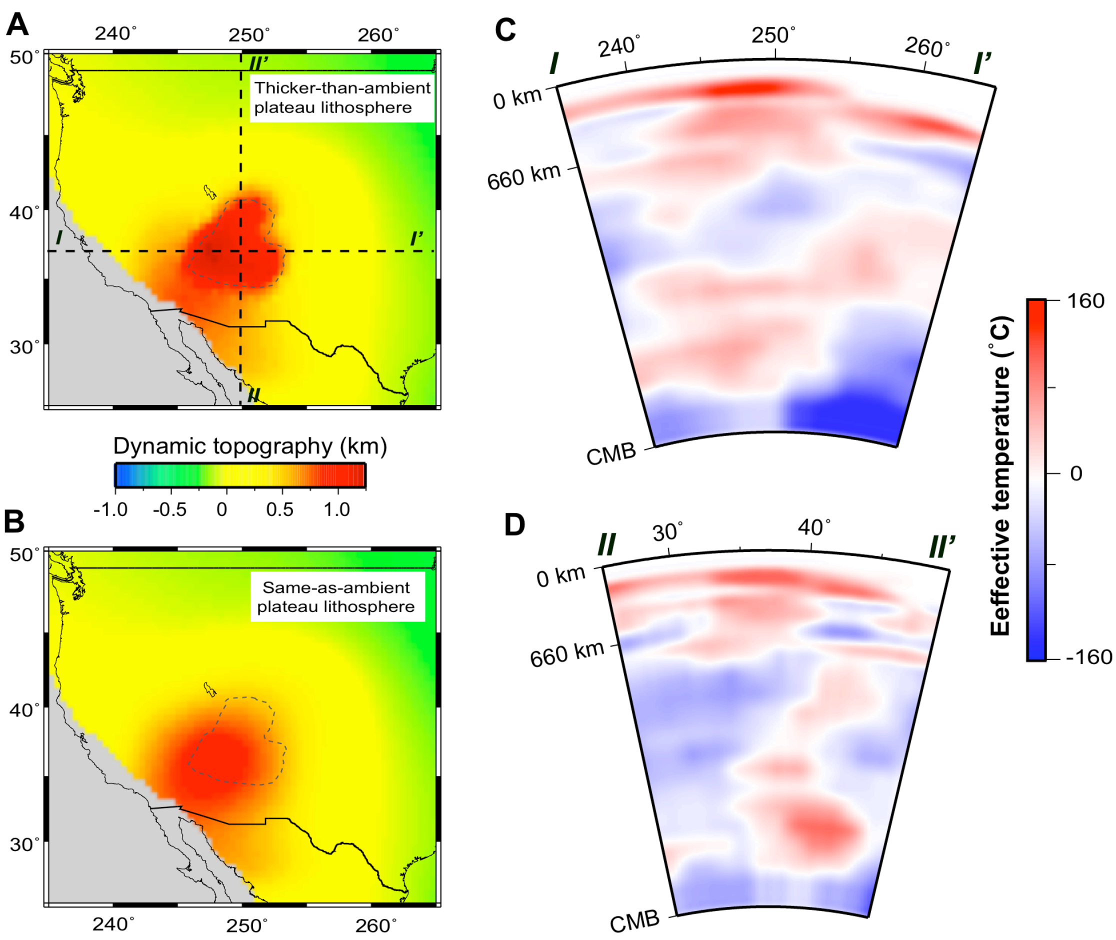

Figure DR3. Active upwellings beneath western U.S. and associated surface dynamic topography. A: Predicted present-day dynamic topography by model M4 where the plateau lithosphere is thicker (130 km) than ambient (90 km). Two red lines *I-I'* and *II-II'* indicate cross-sections shown in C and D, respectively. B: Predicted present-day dynamic topography by model M4 where the plateau lithosphere thickness is the same as ambient (90 km). C: East-west vertical profile across the plateau showing the effective temperature anomaly based on the scaling factor constrained by Liu et al. (2008). D: Same as C, but along a north-south vertical profile. In C and D, both the top 150 km signal and that associated with the North American craton are removed.

References

1. Bunge, H.-P., C. R. Hagelberg, and B. J. Travis, 2003, Mantle circulation models with variational data assimilation: Inferring past mantle flow and structure from plate motions histories and seismic tomography, *Geophys. J. Int.*, v. 152, p. 280-301.

2 . Liu, L., S. Spasojevic and M. Gurnis, 2008, Reconstructing Farallon Plate Subduction Beneath North America Back to the Late Cretaceous, *Science*, v. 322, p. 934-938.

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

4. Saleeby, J., 2003, Segmentation of the Laramide Slab-evidence from the southern Sierra Nevada region, *GSA Bulletin,* v. 115, p. 655-668.

5. Saleeby, J., Farley, K. A., Kistler, R. W., Fleck, R. J., 2007, Thermal evolution and exhumation of deep-level batholithic exposures, southernmost Sierra Nevada, California, *in* GSA special paper 419, p. 39-66.