Three Dimensional Delamination of Mantle Lithosphere in the Southern Sierra Nevada Region

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Introduction

We present an overview of geologic and seismic evidence for the removal of cool mantle lithosphere that constitutes the fossil mantle wedge that formed beneath the southern Sierra Nevada batholith in the Cretaceous. Based on mantle xenolith data the Cretaceous wedge consists of two principal units, eclogitic cumulates genetically related to the overlying batholith, which we term arclogites (after Anderson, 2005), and underlying enriched and partially volatized peridotites. The arclogites accumulated from ~40 to 75 km depths in the wedge, and the underlying peridotites are know to have extended to at least ~125 km depths beneath the batholith. To this we add a review of the thermo-mechanical model published in Le Pourhiet et al. (2006) and Saleeby et al. (2012) that explores the dynamics and surface manifestations of the removal process along a NE-SW transverse section across the batholith and wedge. We then review geological observations of volcanism, heat flow, rock and surface uplift, and tectonic subsidence that reflect the predictions of our preferred thermomechanical model along the transverse model trace, as well as reveal a time transgressive pattern in the three-dimensional removal process.

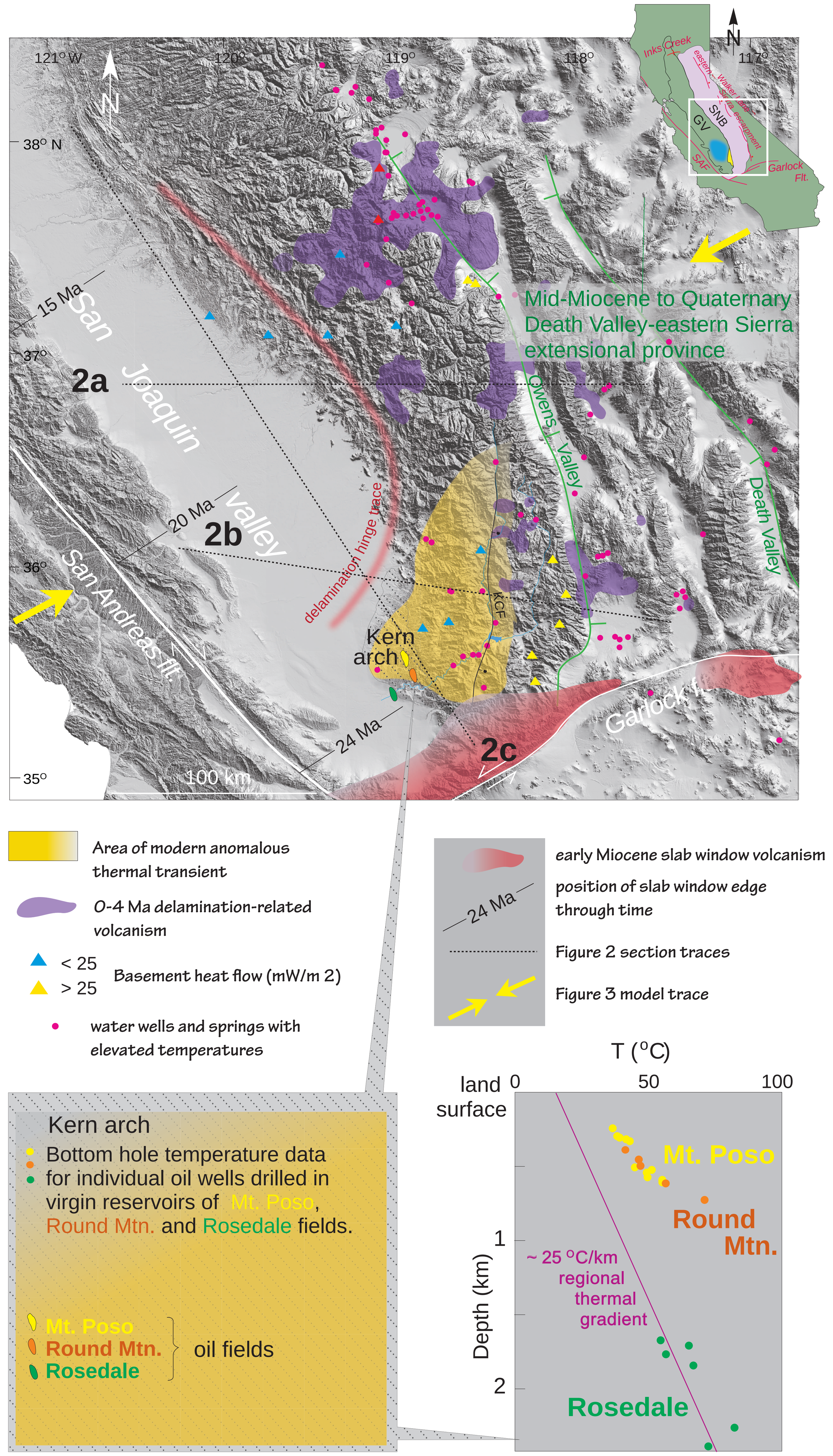


Figure 1. Generalized map showing the southern Sierra Nevada-San Joaquin Basin area highlighting surface features interpreted to reflect the three-dimensional pattern in mantle lithosphere removal. As shown in Figures 2 and 3 the principal removal mechanism that effects surface geology is the delamination of the arclogite root from the base of the felsic crust. Based on the Figure 2 synthesis of seismic data we designate the locus of separation of the root from the crust as the delamination hinge, which is projected onto the map surface as the hinge trace. The 0-4 Ma delamination volcanics consist of a bimodal suite with basaltic members variably enriched in lithospheric components. The anomalous thermal transient corresponds to the area of spatial overlap between extremely low basement heat flow, typical of the axial to western Sierra Nevada, and the occurrence of numerous warm and hot springs and wells in the exposed batholith, and hot oil fields in the basin.

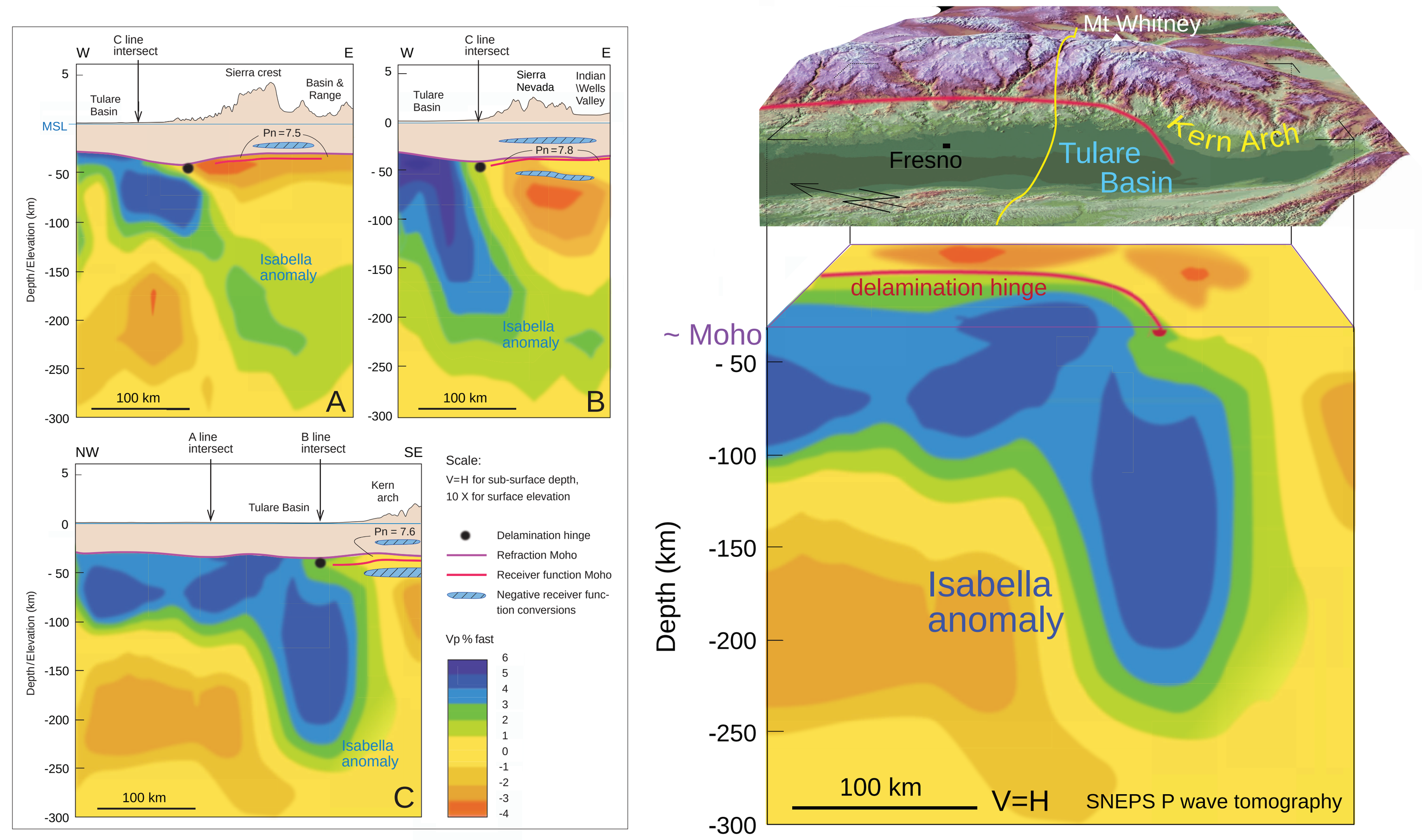
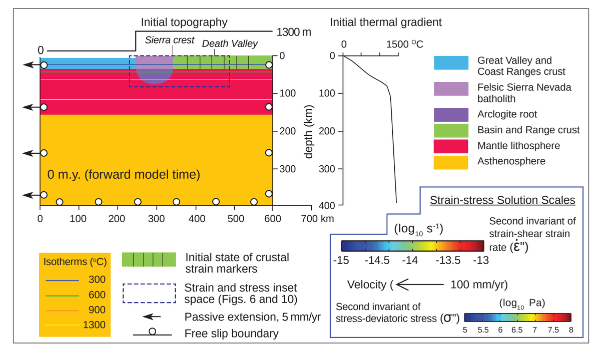


Figure 2. Synthesis of seismic P-wave tomography, refraction and receiver function data along transverse (A), oblique (B) and longitudinal (C) profiles (Fig. 1) as compiled in Saleeby et al. (2012). We interpret the dVp>4% fast volume as arising from a compositionally controlled anomaly arising from the arclogite root, and the dVp 1-4% fast volume as a thermally controlled velocity anomaly arising from the Rayleigh-Taylor instability that the delaminating arclogite root is nested in. The dVp<-1% volume is interpreted as incipiently melted ascended asthenosphere with the negative rf conversions reflecting melt concentrations. D is a three-dimensional render-



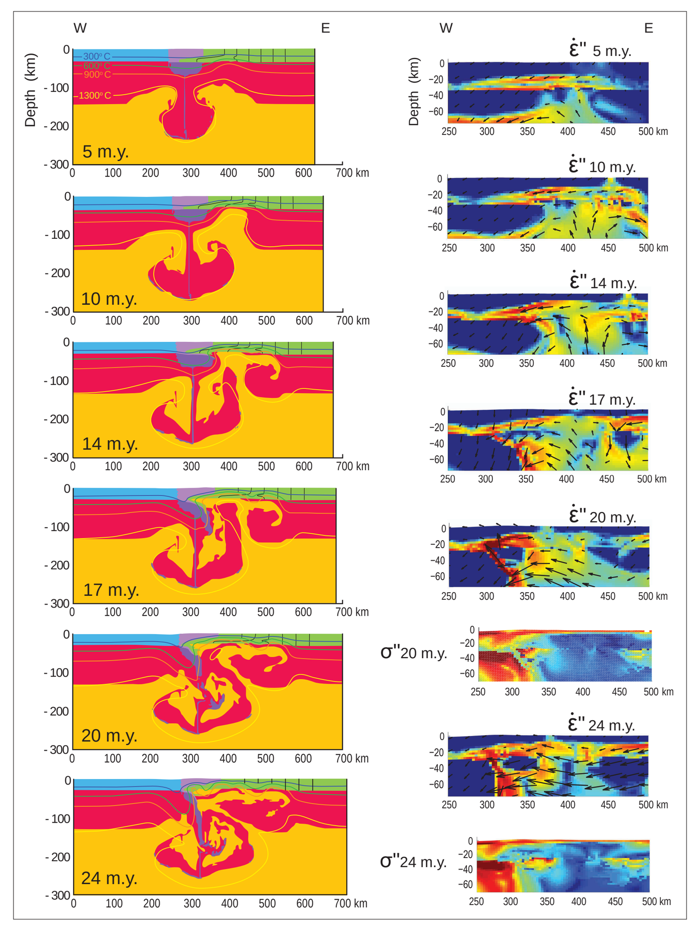


Figure 3. Preferred thermo-mechanical model results. The model is intended to simulate a thermal perturbation to the base of the cooled lithosphere by the northward opening of the Pacific-Farallon slab window Ma (Fig. 1). A) summary of initial and boundary conditions. B) Preferred model results through forward model time. Essential features are initial mobilization as an RT instability, lithospheric break-off in the Death Valley area at ~10 m.y., suction of a lower crust into the lower Sierran crust by root loading, and then rapid W to E root delamination starting at ~14 m.y., which we correlate to 7-5 Ma geologic time.

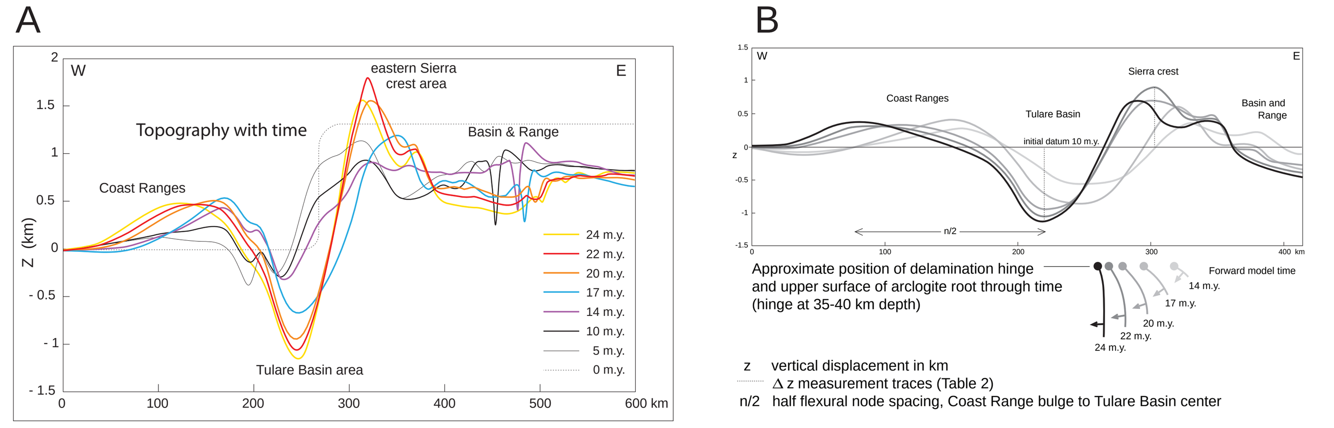
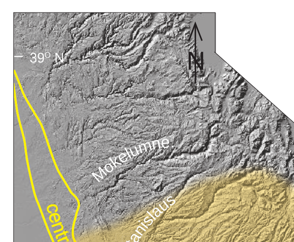


Figure 4. Predictions for vertical displacements in the Earth's surface from preferred model. These translate into rock/surface uplift with no exhumation and tectonic subsidence. A) Results for entire model run with initial topographic step along west side of batholith (Fig. 3A). B) Results for post-10 m.y. displacements hung on 10 m.y. profile from A, as to simulate uplift and subsidence patterns following lithospheric break-off formation of Sierran microplate dated geologically at 10 2 Ma.



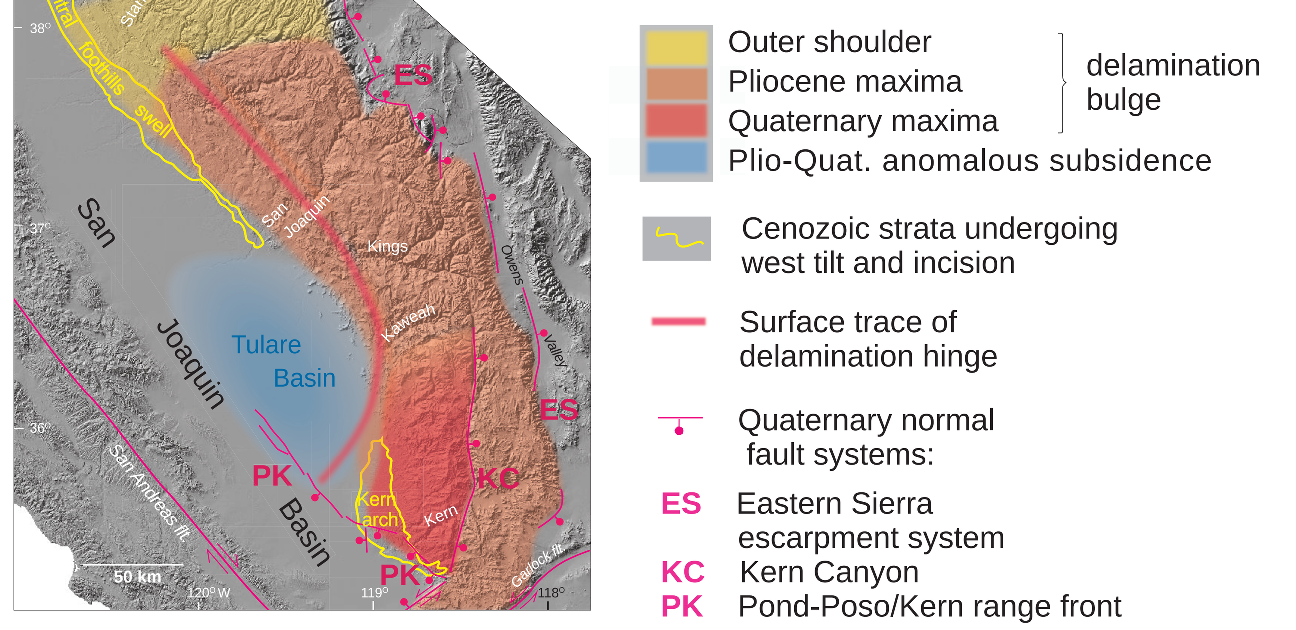


Figure 5. Summary of constraints for the timing of principal late Cenozoic rock and surface uplift for southern Sierra Nevada region in relation to active normal faulting, anomalous subsidence and delamination hinge trace. Resolved rock uplift over the region of the delamination bulge is at 1000 m scale.

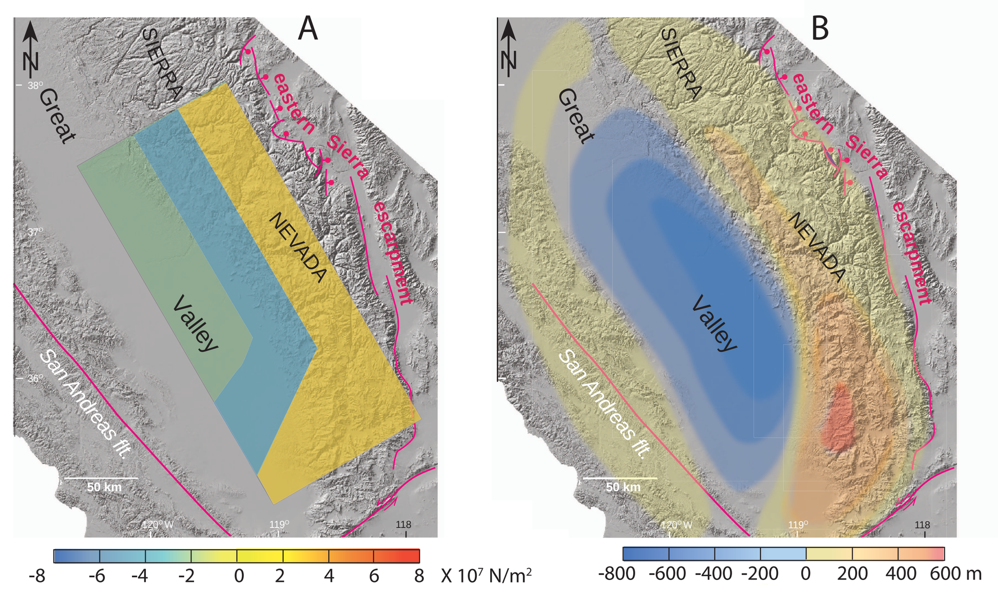


Figure 6. Three-dimensional flexural model arising from current configuration of the arclogite root load (Fig. 2) as attached beneath Tulare Basin (Figs. 1 & 5). A) Root loading geometry. B) Resulting flexural anomaly.

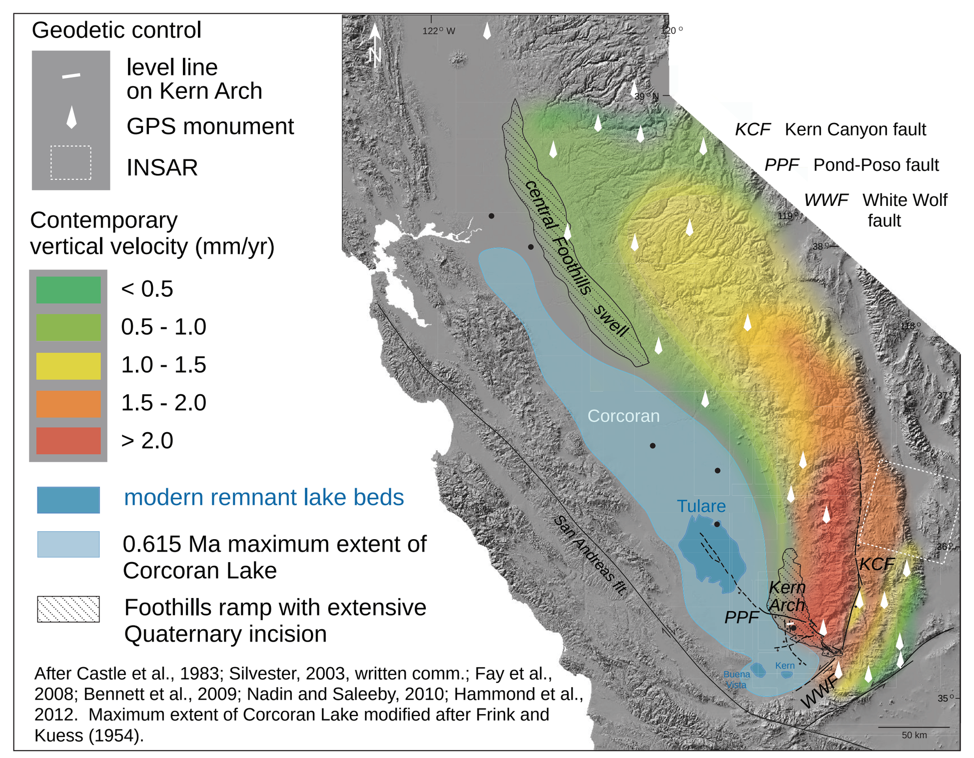


Figure 7. Contemporary vertical velocity field across the southern Sierra Nevada as determined by GPS monuments, INSAR, and level line data, and late Quaternary exhumation rates in Cenozoic strata along western Sierra Foothills (Fay et al., 2008; Sylvester, 2008; Hammond et al., 2010; and Cecil et al., 2012). Also shown is distribution of late Quaternary lake beds of the San Joaquin Basin.

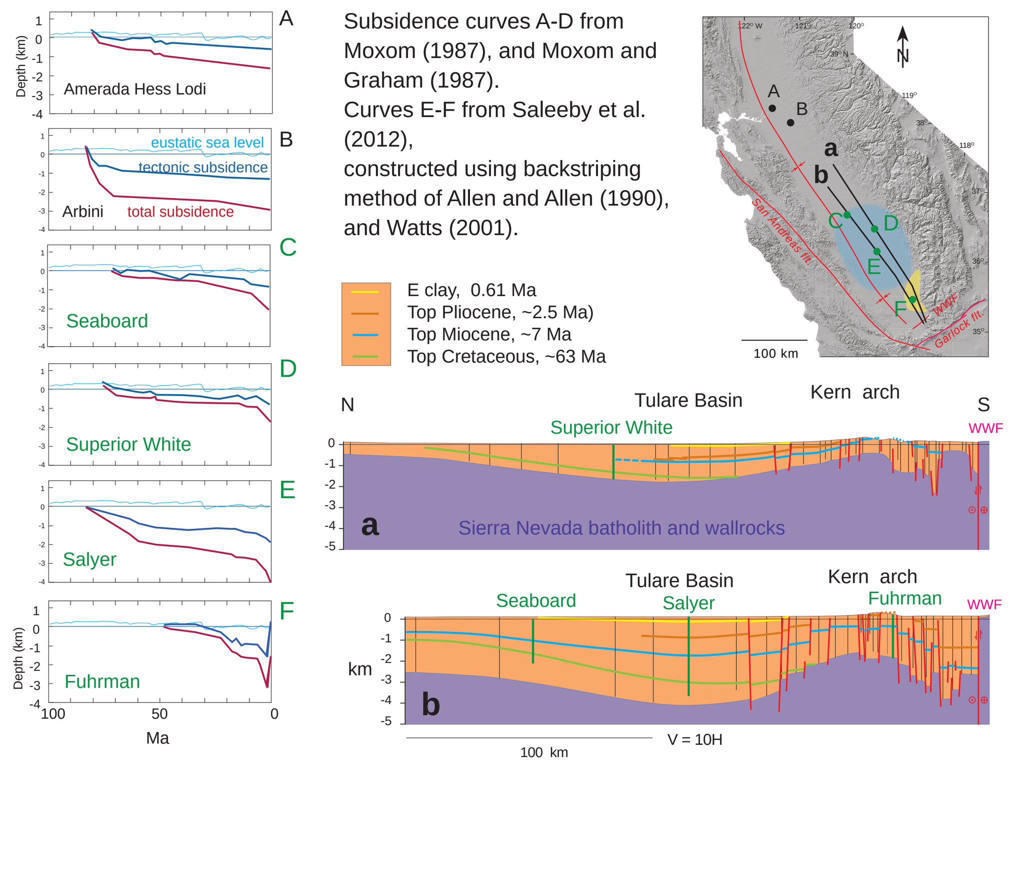
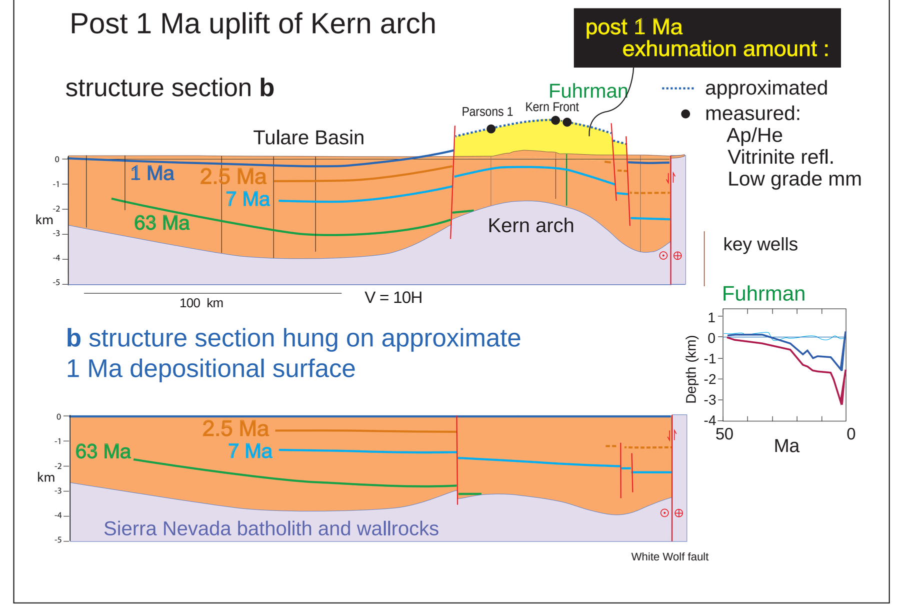


Figure 8. Longitudinal structure sections for eastern (a) and axial (b) San Joaquin Basin highlighting anomalous subsidence related to root load. Selected subsidence curves display anomalous subsidence (C-F) in comparison to regional Great Valley patterns (A & B). Note that basement beneath Kern arch consists of normal fault block tilted into Tulare Basin analogous to southern Sierra Nevada fault controlled tilt into Tulare Basin.

Figure 9. Simplified structure sections along Figure 8b trace with (a) showing constraints on post-1 Ma exhumation across Kern arch from subsurface data as well as 1 Ma depositional interface adjacent to the Kern arch, and (b) retro-deformed state of the basin at 1 Ma



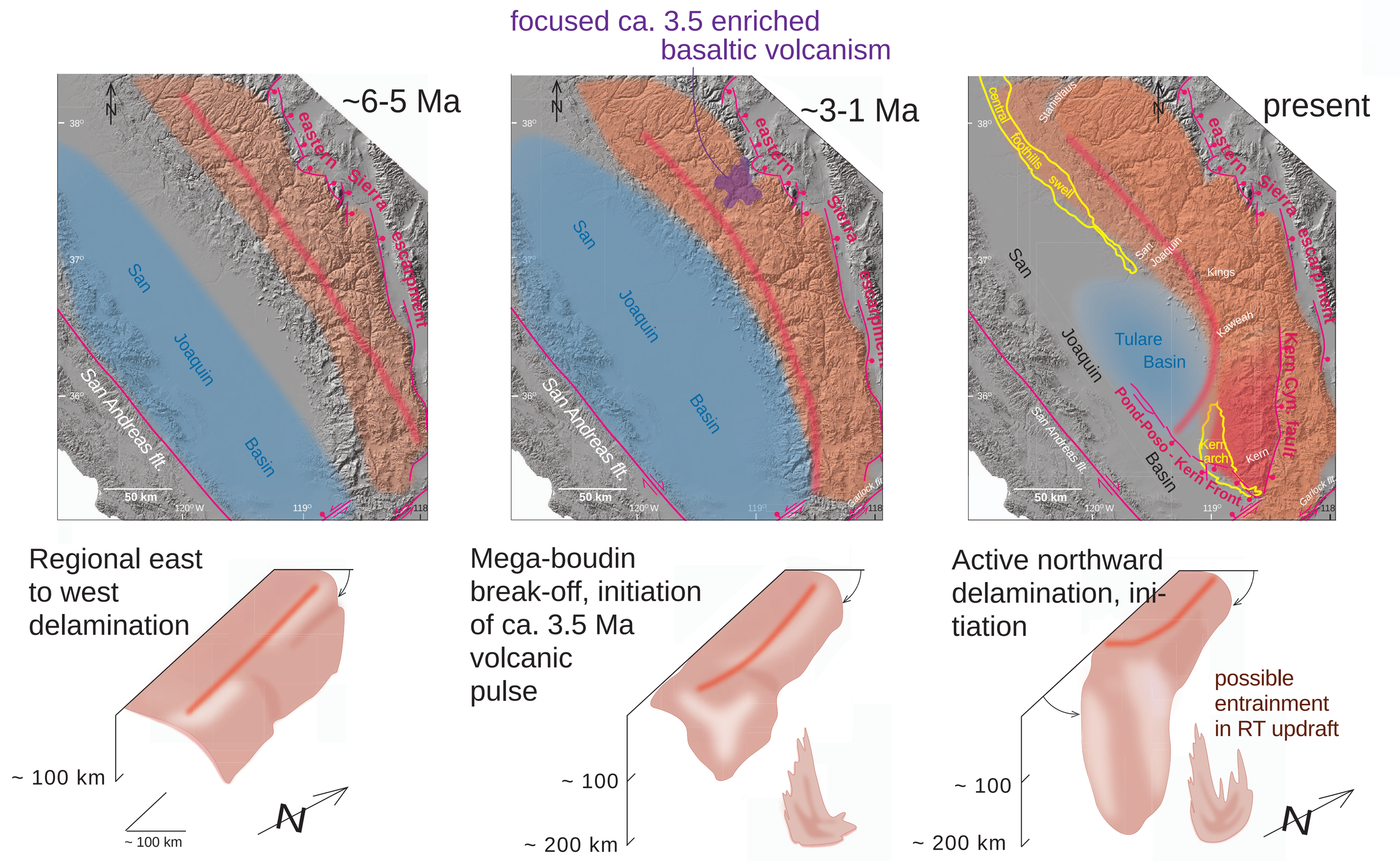


Figure 10. Simplified reconstruction of the progression in three-dimensional delamination across the southern Sierra Nevada region. A) Mio-Pliocene (6-5 Ma, ~14 m.y. model time) showing principal E to W phase of delamination with resulting Sierra Nevada uplift and San Joaquin Basin subsidence, including area over the future Kern arch. B) continued E to W delamination over late Pliocene-early Quaternary time (3-1 Ma, ~17-20 m.y. model time) with partial necking of root fragment promoting focused ca. 3.5 Ma enriched basaltic volcanism by melting of descending root fragment plus entrained lithospheric peridotite and possible felsic crust. Necking event focuses residual root load to south instigating the S to N pattern of delamination. C) Late Quaternary (<1 Ma) phase of S to N root delamination with rapid epeirogenic uplift of Kern arch as root separates from underlying lower crust, and the resulting partitioning off of the contemporary Tulare Basin.