Farallon Subduction Reconstructed by Inverse Dynamic Models: Stratigraphy Verifications and Geophysical implications

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Abstract

Using an inverse mantle convection model that assimilates seismic structure and plate motions, we reconstruct Farallon plate subduction back to 100 Ma. Stratigraphy including paleoshorelines, sediment isopachs and borehole tectonic subsidence are used to constrain the depth dependence of mantle viscosity: Our best model has a lower mantle viscosity 1.5×10^{22}Pas, upper mantle viscosity 10^{21}Pas and a present-day effective temperature anomaly associated with the Farallon remnants at 160 ºC. In Late Cretaceous, the recovered Farallon subduction underneath North America was characterized by an elevated flat-lying oceaninc lithosphere surrounded by an extensive zone of shallow dipping subduction extended beyond the flat-lying slab farther east and north by up to 1000 km. Both shape and location of the flat-lying slab correlate well with the geologically inferred Laramide fault zone, and this limited region of flat subduction is consistent with the notion that subduction of an oceanic plateau caused the slab to flatten. Besides predicting the formation of the Western Interior Seaway, our model also suggests a two-stage post-Cretaceous uplift process for the Colorado Plateau, during which the Plateau changed its downward tilting direction from NE in Eocene to SW in Oligocene.

- **Forward model:** $\nabla\cdot\vec{u}=0;\ \nabla P+\nabla\cdot(\eta\nabla\vec{u})=\rho_m\alpha\Delta T\vec{g};\ \frac{\partial T}{\partial t}+\vec{u}\cdot\nabla T=\kappa\nabla^2T$

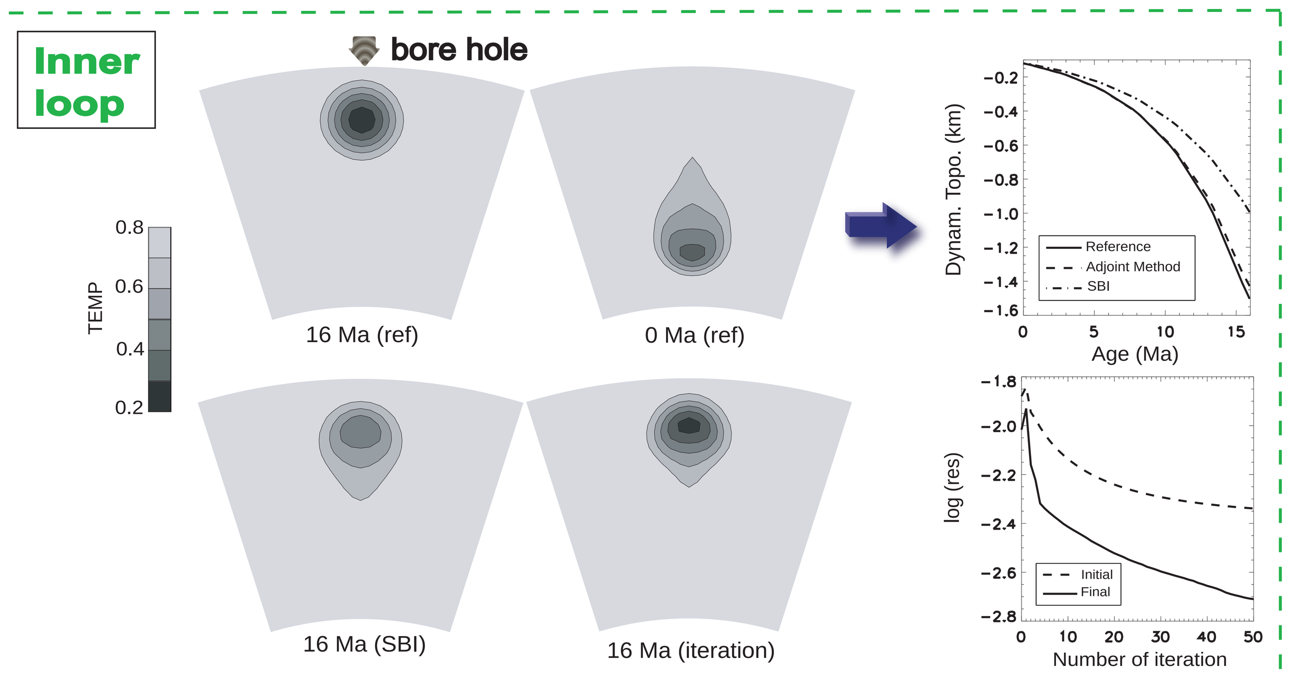
  Adjoint model: $\frac{\partial\lambda}{\partial t}+\vec{u}\cdot\nabla\lambda+\kappa\nabla^2\lambda=0$

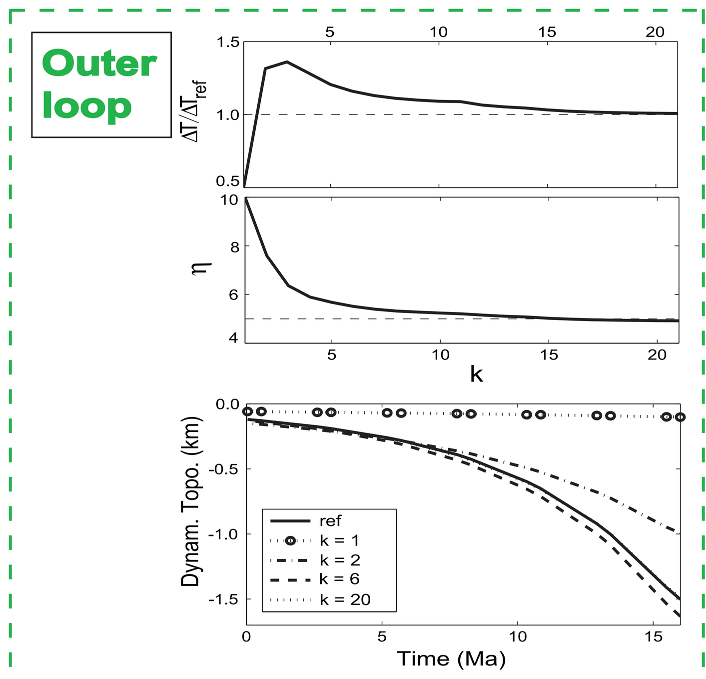
  u: velocity; *P*: pressure; η: viscosity; α: thermal expansion; *T*: temperature; ρ_m: mantle density; g: gravity acceleration; κ: thermal diffusivity; λ: adjoint temperature.

- ***Uncertain mantle properties:*** Application of the adjoint method to real geophysical problems requires a better understanding of mantle rheology and buoyancy which are crucial to mantle dynamics. This can be overcome by assimilating the surface dynamic topography associated with mantle buoyancy into the time-dependence of mantle convection.

(A) One layer mantle: $h(t)=\zeta(t)\Delta T;\ \dot{h}(t)=\frac{\xi(t)}{\eta}h_1^2$

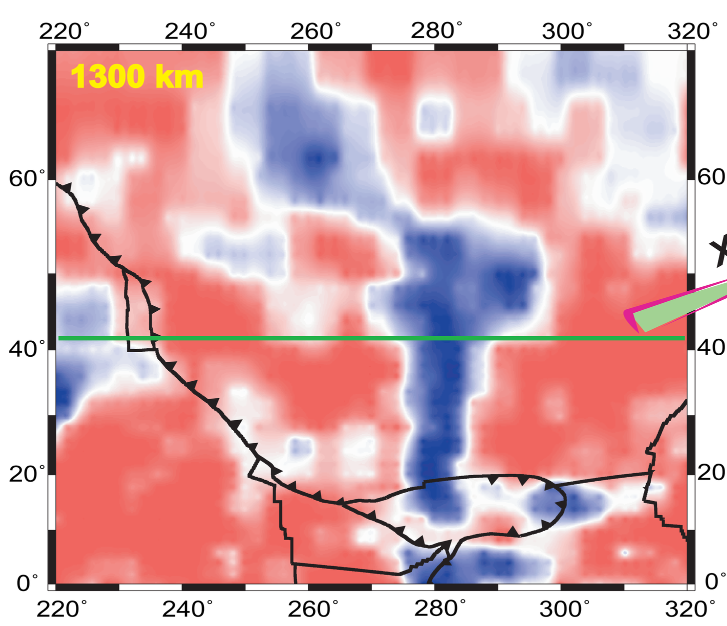
h: dynamic topography; ΔT: temperature anomaly; η: viscosity; ζ, ξ: numerical coefficients.

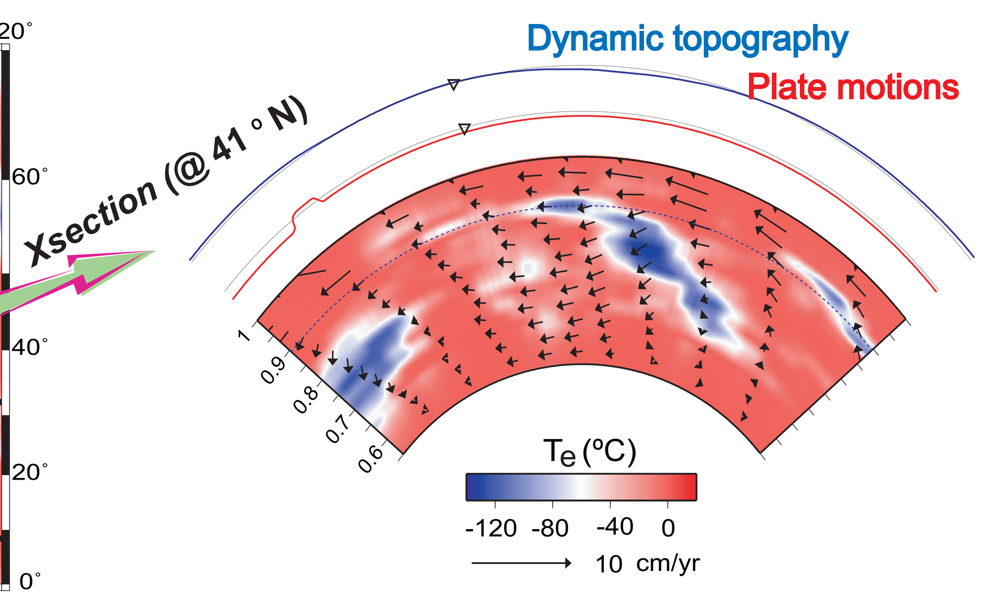




Tomography

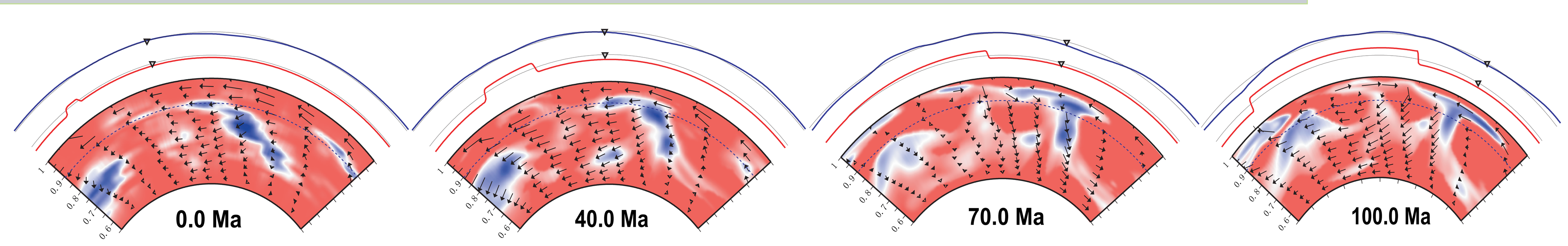
Global shear wave sesimic tomography (Grand, 2002)





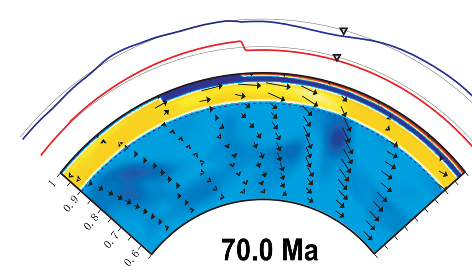
Dynamic models I:

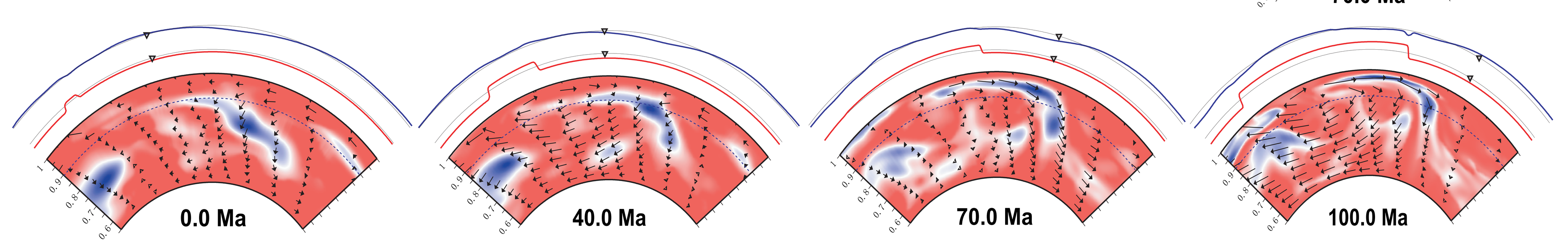
A standard convection model with imposed plate motions will not lead to a geophysically reasonable subduction geometry. This problem can not be solved either with different radial viscosity structure or with more adjoint iterations.



Dynamic models II:

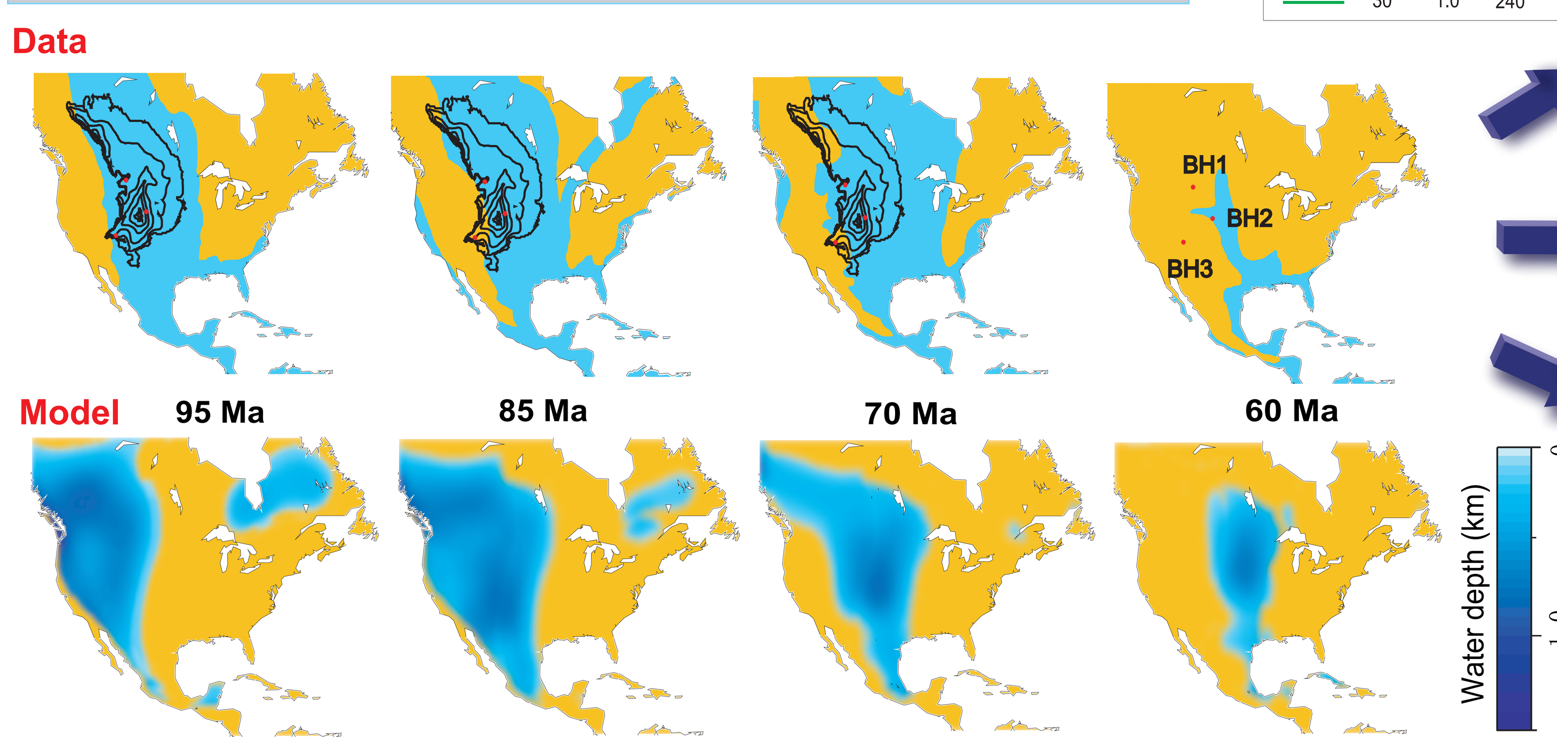
Since we hypothesize that this problem is due to a missing upper mantle slab that connects present day lower mantle Farallon remnants to the oceanic plate on the surface, we implement a simple stress guide under the North America plate in which the Farallon slab preferentially attaches to the oceanic plate as it rises up to the surface. This leads to a reasonable subduction geometry.

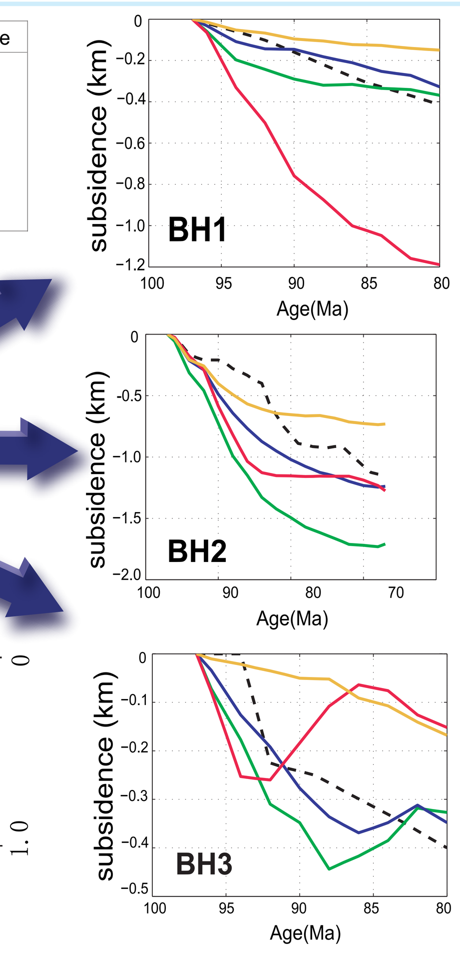




Stratigraphic constraining:

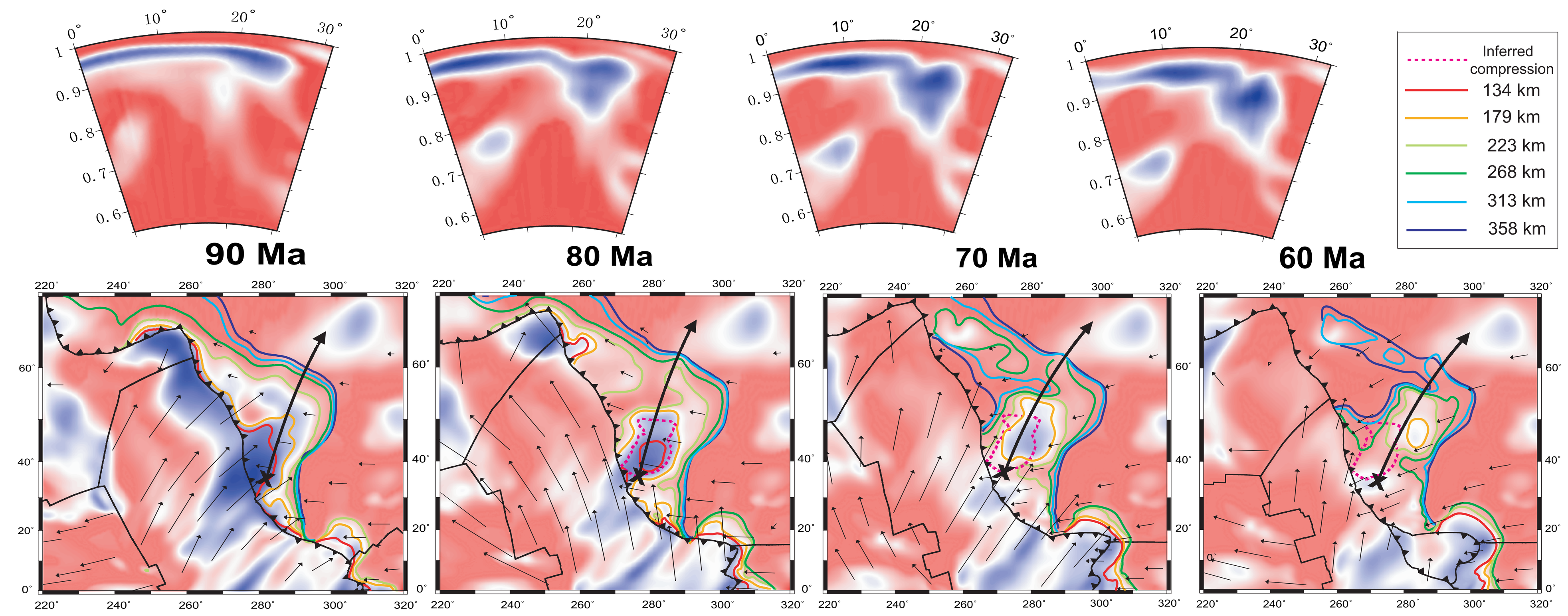
Predicting the Late Cretaceous paleo-shorelines and borehole tectonic subsidence rates in western U.S. constrains both mantle viscosities and slab buoyancy: the best fit model has η_{LM}=1.5x10^{22}Pas, η_{UM}=10^{21}Pas and dT=160˚C.





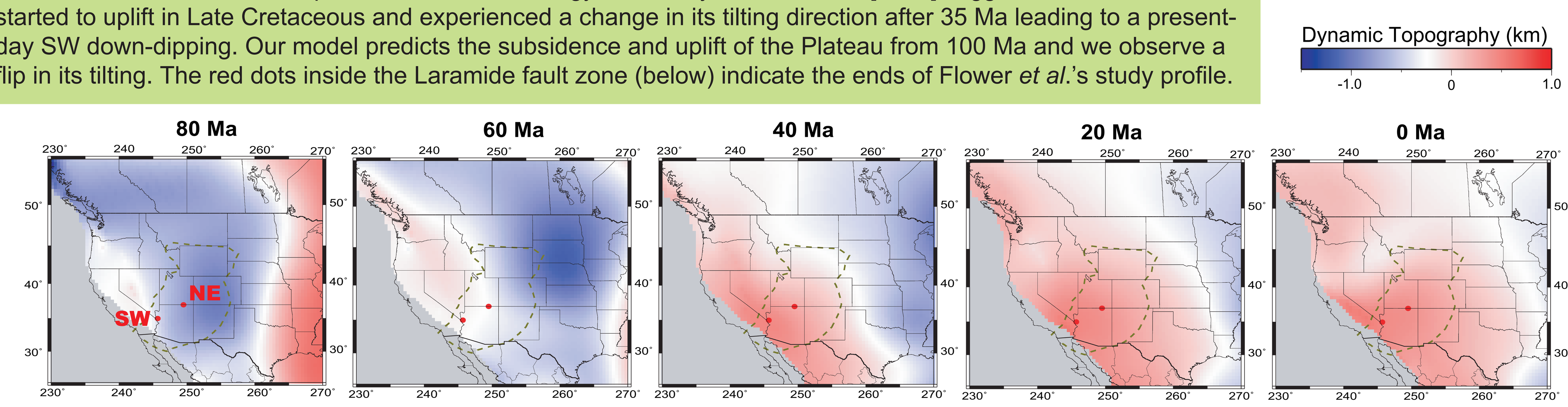
Farallon subduction

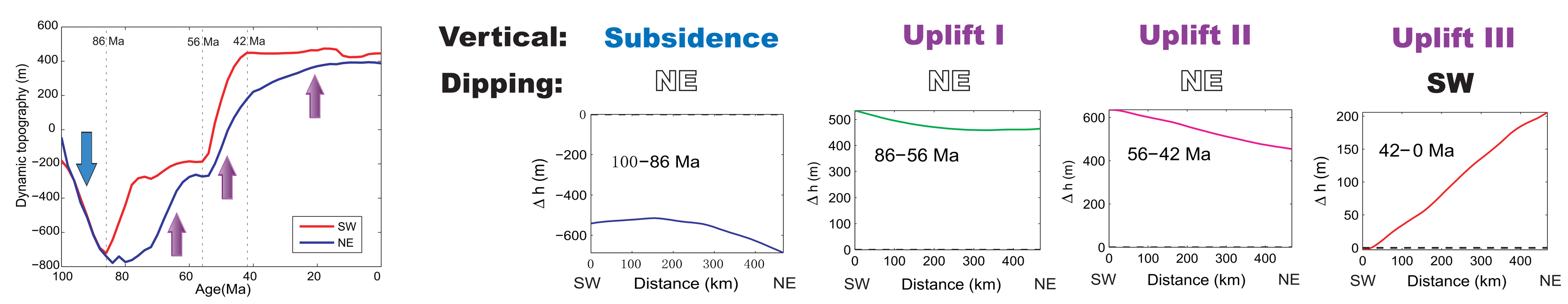
3-dimensional evolution of the flat slab: folding and shortening lead to demise of flat subduction.



Colorado Plateau

Causes and timing of subsidence and uplift of the Colorado Plateau has been controversial. Recent low temperature thermo-chornogy studies by Flowers *et al.* [2008] suggest that the Plateau started to uplift in Late Cretaceous and experienced a change in its tilting direction after 35 Ma leading to a present-day SW down-dipping. Our model predicts the subsidence and uplift of the Plateau from 100 Ma and we observe a flip in its tilting. The red dots inside the Laramide fault zone (below) indicate the ends of Flower *et al.*'s study profile.





1. Inverting for Farallon subduction with the adjoint method provides a new way to constrain basic mantle properties, including viscosity and mantle buoyancy.
2. The Farallon flat subduction is a natural result of inverting tomography while predicting various stratigraphic observations. The flat slab reconstructed by adjoint models correlates well with the flat slab inferred from basement cutting Laramide-type faults in the western US.
3. During Late Cretaceous, byond the flat portion of the Farallon slab, a vast range of shallow dipping slab segments emnate east and northward with an extent up to 1000 km, which have caused a much broader range of dynamic subsidence over the North America Craton than previously thought to be within Colorado and Wyoming.
4. Demise of the flat subduction is marked by a vertical sinking of the flat slab into the mantle, rather than an east to west delamination or a centrally located instability.
5. Inverting seismic structure from present day mantle to the past provides unexpected insights to tectonic events.