Rapid Exhumation of the Sierra Nevada in the Cretaceous Related to Shatsky Conjugate Rise Subduction

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1. Introduction and Motivation

The Sierra Nevada batholith (SNB) is the plutonic underpinnings of a long-lived, west-facing "Andean" type Mesozoic arc, which armored the entire western margin of North America during the Cretaceous, much like the modern Andean arc armors the western margin of South America today (Fig. 1). As shown on Figure 1 the NA Mz arc has been segmented into series of distinct exhumed linear batholith segments, part of which still lie beneath active arc segments. Such segmentation has occurred by a combination of oceanic plateau subduction, spreading ridge encounters and large magnitude transform offsets.

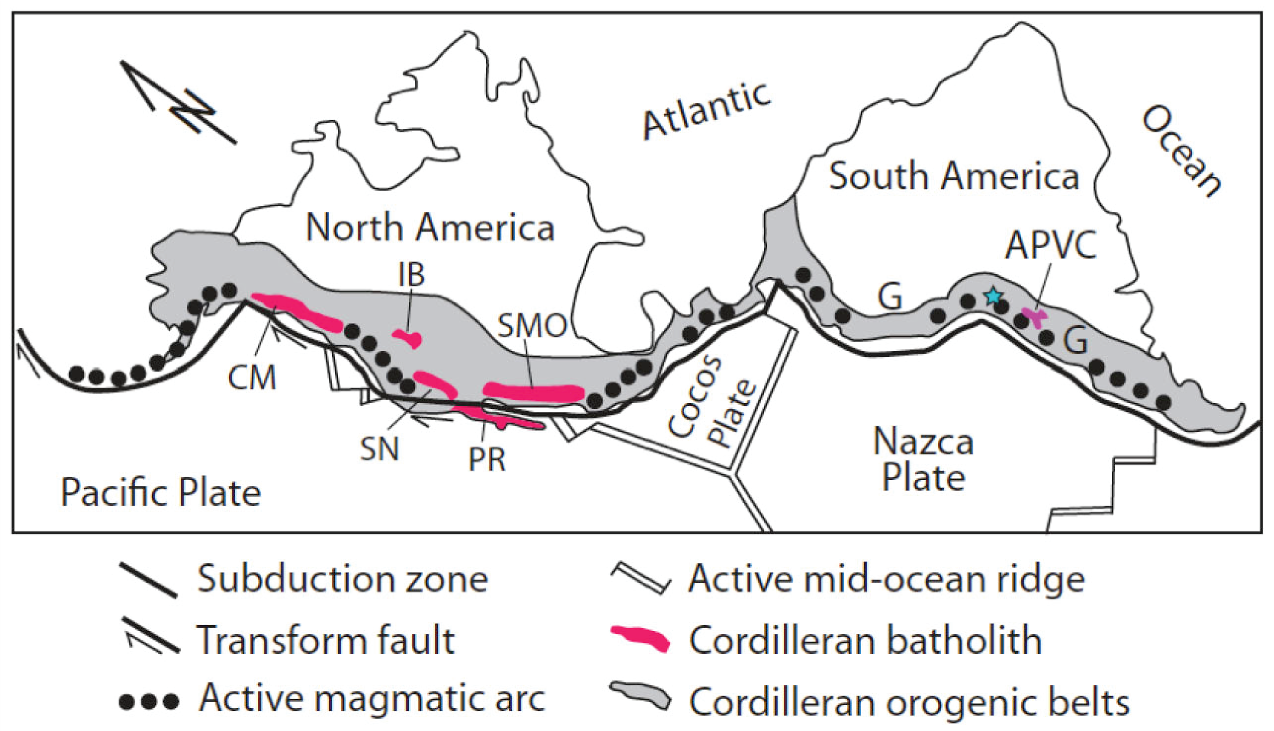

Figure 1

1. Generalized map of the American Cordilleran orogen. Emphasis here is on the Cord. batholiths of NA, which originally formed a continuous Andean type arc in the Cretaceous, but have subsequently been broken into distinct segments by superimposed tectonic events.

We focus the initial segmentation of the SNB due to the Late K subduction of the conjugate massif to the Shatsky Rise of the NW Pacific plate. As this conjugate massif was subducted beneath the southern California region, it severely disrupted the corresponding southern California segment of the arc, driving early Laramide orogeny deformation as it progressed inland (Fig. 2). Disruption of the southern California arc segment entailed: **(1)** the shearing off of its mantle wedge, at paleo-Moho depths; and **(2)** thrust imbrication and rapid erosional exhumation to mid-crustal depths, followed by large magnitude trench-directed extension and lower crustal exhumation as the trailing edge of the massif was subducted. ***Our studies of the SNB and its Great Valley (GV) forearc indicate that the SNB-GV segment of the system also underwent a profound exhumation synchronous with Shatsky conjugate subduction to the south. We posit that the broad northern shoulder that is observed off the northern flank of the Shatsky Rise also had a conjugate on the Farallon plate, and that its subduction drove the regional erosional event of the SNB-GV.***

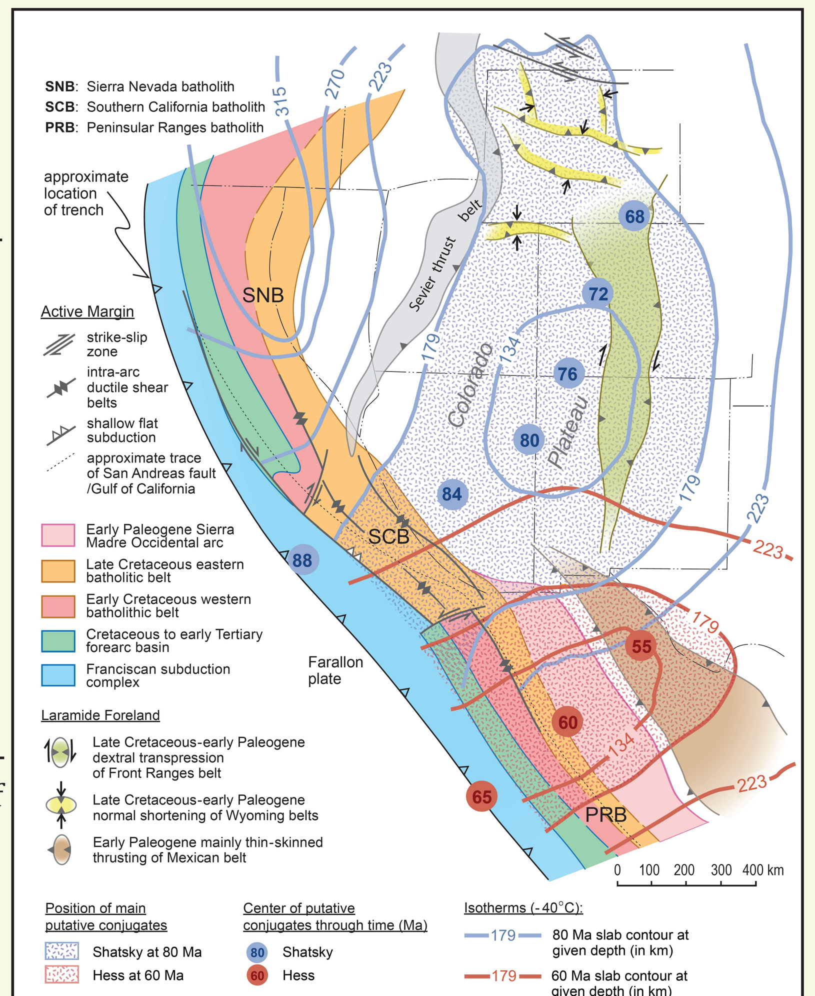

Figure 2 (Liu et al., 2010)

2. Generalized Map of the Laramide deformation corridor plotted on a pre-Neogene palinspastic base. The blue stippled area represents the projection of the principal Shatsky conjugate massif in its 80 Ma subducted position (see Fig.12). The SCB, its now vanished forearc, and its transitions into the SNB and PRB are the principal damage zone of Shatsky conjugate shallow slab segment subduction.

2. Western extent of the Sierra Nevada batholith

The SNB is commonly perceived of as simply the large mass of plutonic rock with cover strata to the west in the Great Valley (GV) constituting its forearc basin. Our detailed studies of the GV subsurface by core sample petrology and geochemistry, seismic imaging and potential field analysis (Fig. 3) show, however, that Early K rocks of the SNB constitute most of the GV basement (Fig. 4). Our GV subsurface studies also show a regional, Late K exhumation event (of ~2 kb/7km, based on phase and textural relations of basement cores) of the now-buried SNB rocks, expressed in the subsurface as a nonconformity between Upper K marine strata and 115-140 Ma batholithic rocks of the GV (Fig. 5) Regional exhumation patterns of the exposed SNB indicate that 90-115 Ma batholithic rocks of the western to axial Sierra Nevada were exhumed ~ 2 kb greater than the 80-90 Ma aged plutons of the eastern SNB (Fig. 6), which were still undergoing magmatic construction and feeding large volume ignimbrites at the time. Zircon and apatite (U-Th)/He thermochronometric data summarized in this poster indicate that the excessive exhumation event along the western to axial Sierra was contemporaneous with the exhumation of the GV batholithic rocks.

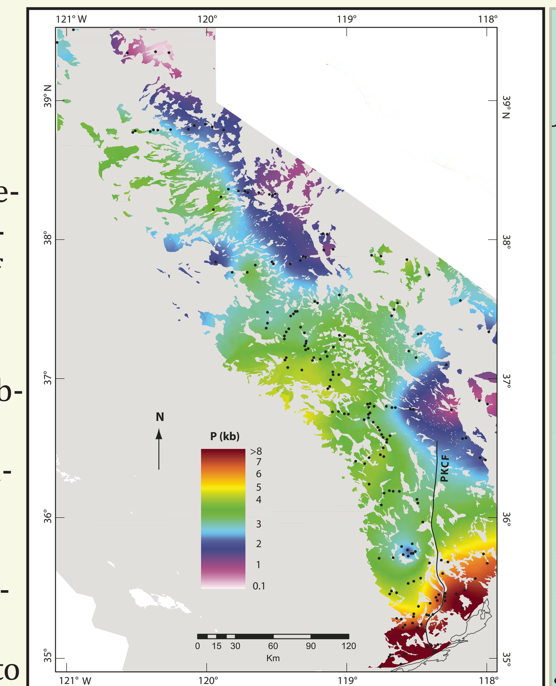

Figure 6 (Nadin and Saleeby, 2009)

5. Age of basal strata lying on regional nonconformity across exhumed Early K GV batholithic rocks. Early phase rapid exhumation ages for SNB coded by same color scheme as nonconformity surface. 6. Igneous equilibration pressures of the SNB. The strong exhumation gradient in the south is directly related to the shallow subduction of the Shatsky conjugate, and a more modest transverse gradient related to differential erosion.

3. Structure contour map of GV basement surface with core locations. Also shown are coupled gravity-magnetic anomalies and seismic lines used in crustal structure studies. SN is outlined in blue. 4. Map showing age-composition belts of the SNB.

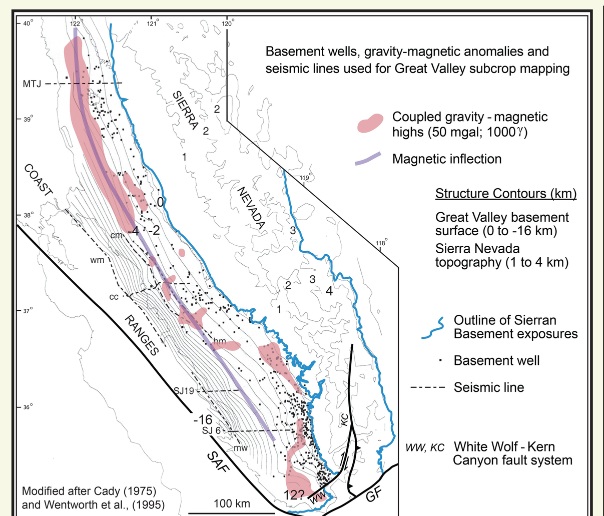

Figure 3

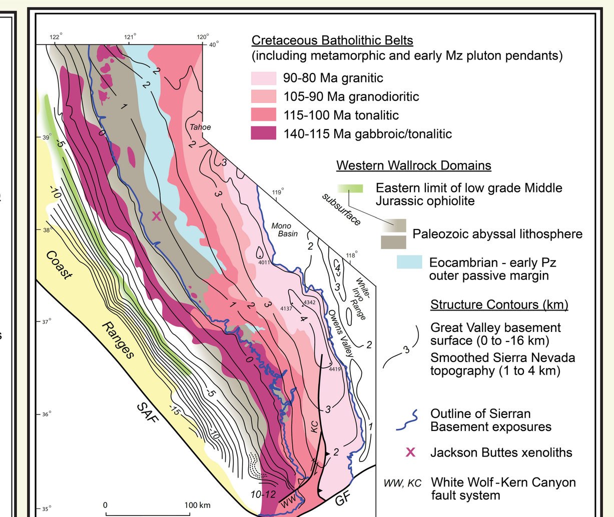

Figure 4

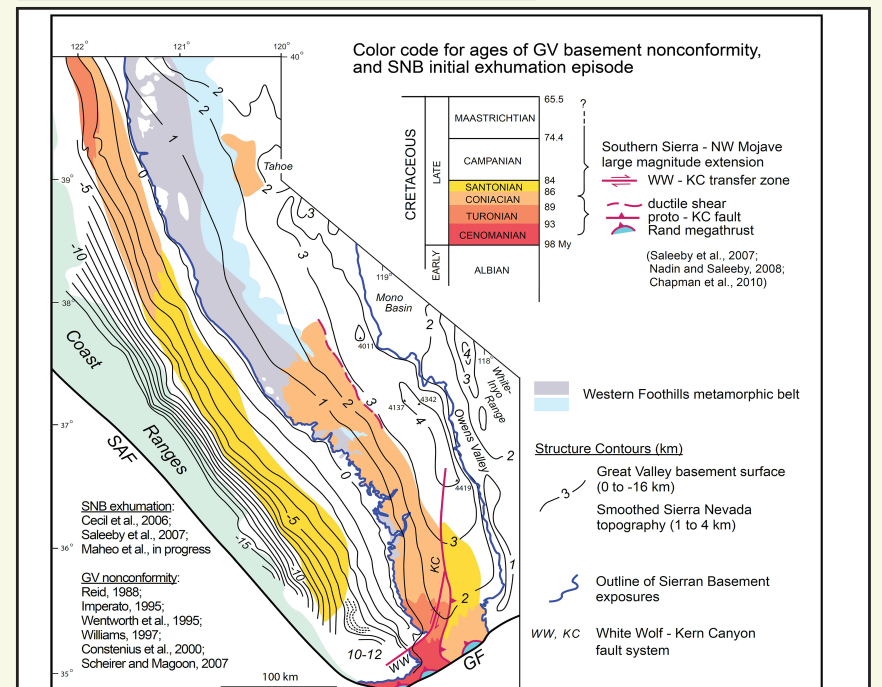

Figure 5

3. Regional patterns in thermochronometry and basement exhumation

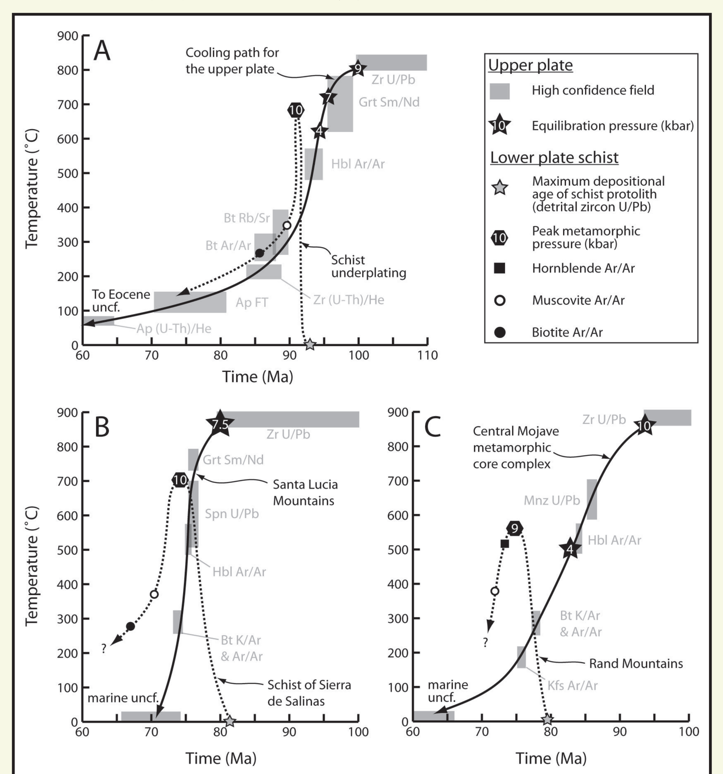

Figure 7 (Saleeby et al., 2007)

7. T-t plots of the southernmost SNB, and adjacent So. California batholith (northern Mojave-Salinia) reflecting rapid exhumation by a combination of erosion and large magnitude extension during the subduction and passage of the Shatsky conjugate.

8. Palinspastic map of southern SNB, and adjacent So. California batholith (northern Mojave-Salinia) which form a regional metamorphic core complex with underplated schists in lower plate position. Note structure contours on shallow level subduction megathrust-eduction surface, and their descent beneath the southern Sierra Nevada. Black arrows show eduction transport directions determined for underplated schists.

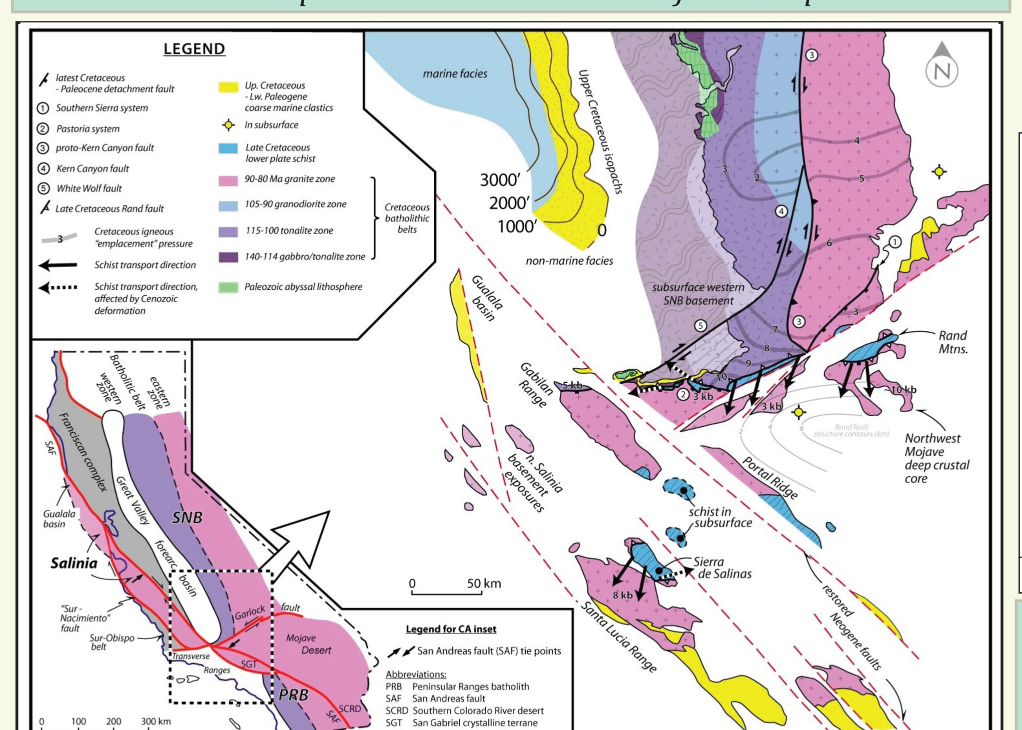

Figure 8 (Chapman et al., 2010)

Temporal relations of basement exhumation across the Shatsky conjugate damage zone are shown in Figure 7. These plots show that b/w roughly 90 and 80 Ma the So. SNB was exhumed rapidly to lower crustal depths. During this time, trench sediments were underplated beneath the disrupted batholithic rocks, in place of their mantle wedge which was sheared off by a shallow slab segment that formed over the subducting Shatsky conjugate (Fig. 2). The retrograde path of the underplated sediments (schists) reflect rapid eduction back out the shallow subduction zone, leading to the extensional development of a regional metamorphic core complex(Fig. 8). (U-Th)/He data from the intact western to axial SNB (Figs. 9 and 10) indicate rapid initial exhumation in the Late K, followed by slow erosion through much of the Cenozoic.

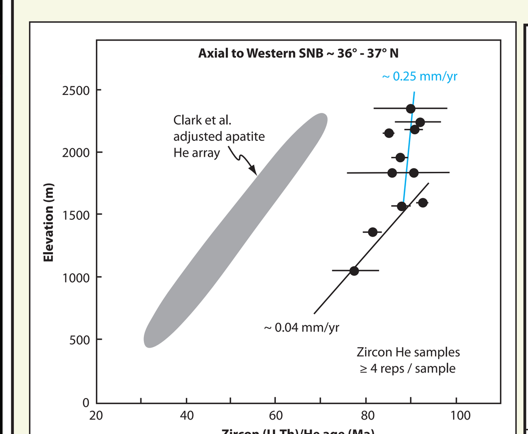

Figure 9

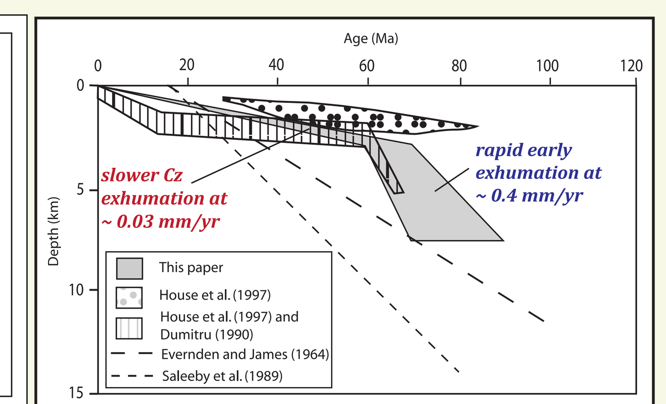

Figure 10 (Cecil et al., 2006)

9. Age-elevation relationship for (U-Th)/He zircon ages for SW SNB showing initial rapid exhumation at 80-85 Ma followed by slower exhumation that continues into apatite He age array of the greater SNB (Clark et al., 2005 field). 10. Exhumation of the No. SNB from (U-Th)/He thermochronometry, showing rapid exhumation from ~ 80 - 65 Ma, followed by slower exhumation through the Cenozoic.

4. A plausible teconic driving mechanism for the early phase erosional exhumation event

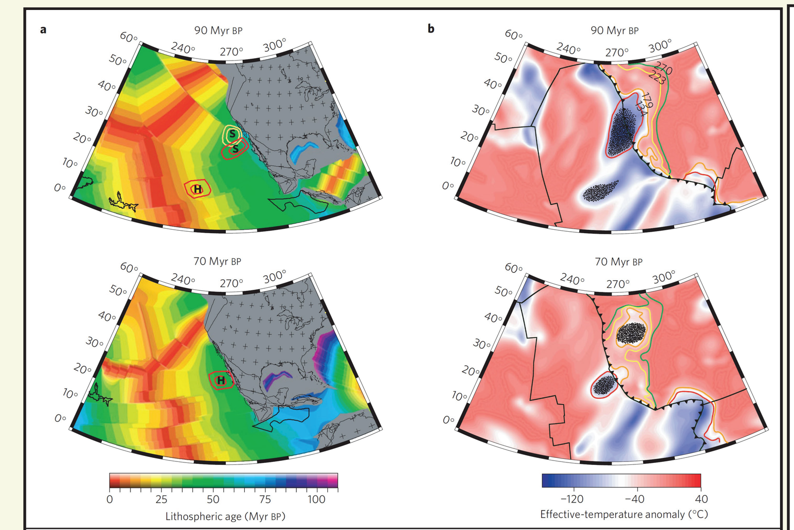

Figure 11 (Liu et al., 2010)

11. Plate kinematic (a) and dynamic (b) models of the paths of the Shatsky and Hess Rise conjugates as they encroach upon and subduct beneath western North America. Dynamic model based on inverse tomography of putative mantle anomalies arising from subducted positions of conjugate massifs.

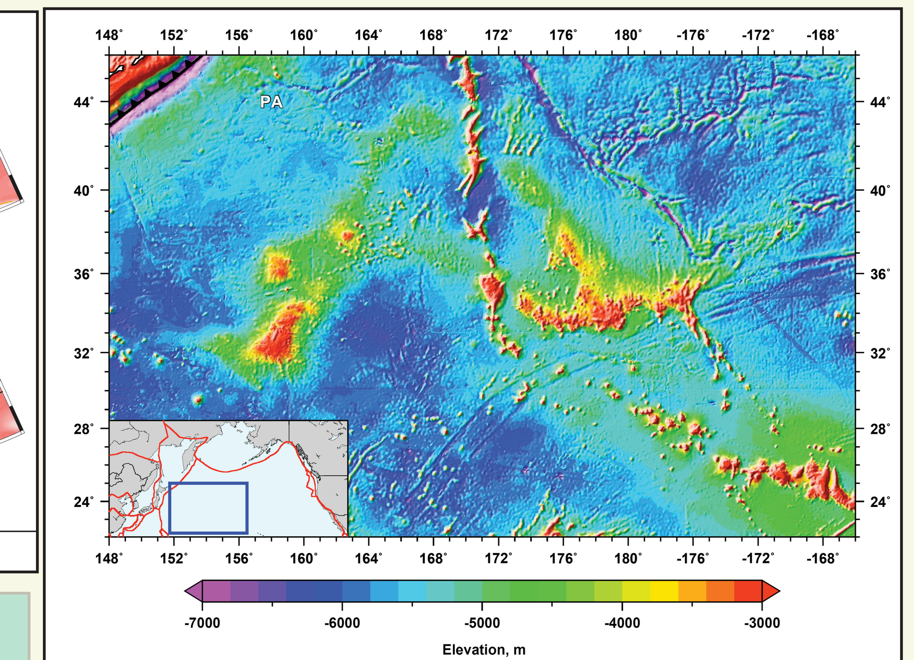

Figure 12 (Liu et al., 2010)

12. Bathymetry of NW Pacific showing Shatsky Rise to the W and Hess rise to the E of the Emperor seamount chain. Note the large shoulder extending NE off the Shatsky Rise.

Figure 11 shows a recent model of Pacific-Farallon-NA plate motions with emphasis on oceanic plateau conjugates and their putative mantle anomalies. Subduction of the Shatsky conjugate is consistent with the reconstruction of the Laramide deformation (Figure 2), and with the rapid exhumation and core complex deformation of the So. SNB (Figs. 7 and 8). Figure 12 shows that the two principal massifs of the Shatsky Rise correspond to the two elliptical bodies impinging on the southern California active margin in Figure 11. Note the large shoulder extending NE off the principal Rise, which is diagrammatically superimposed onto the kinematic reconstruction of Figure 11. Assuming symmetric production of the conjugate massif, the shoulder is in the appropriate location to induce a modest slab flattening component, and to drive forearc and frontal arc uplift and erosional exhumation.

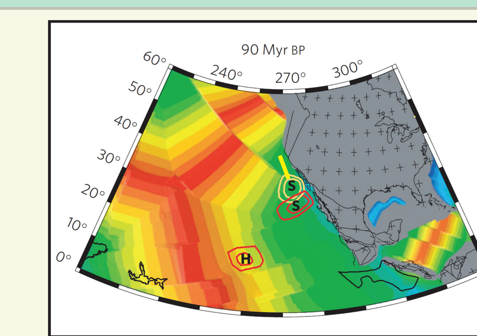

Figure 13

13. Blow-up of Fig. 11, showing shoulder extending off Shaysky Rise (yellow bar).

5. References

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