The Isabella anomaly imaged by earthquake and ambient noise Rayleigh wave dispersion data: A composite anomaly of Sierra Nevada batholith root foundering and Pacific Plate slab-flap translation ?

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Sierra Nevada Earthscope Project (SNEP) and Earthscope Transportable Array (TA) Rayleigh wave dispersion data are inverted for a shear velocity model to constrain the geometry of the sub-crustal Isabella anomaly beneath the San Joaquin valley. The Rayleigh wave dispersion dataset was measured using the two-plane wave method with earthquake records and using the parametric Bessel-zeros method (Ekstrom et al., 2009) with correlated ambient noise records. Two starting velocity models have been tested: a uniform (4.4 km/s) starting model and a starting model with the Moho mapped by Pn station time terms (Buehler and Shearer, in review). We find that over most of our sampling, a uniform starting velocity model inversion can be used to estimate the Moho depth as the depth of the maximum velocity gradient.

Our image of the Isabella anomaly is provisionally interpreted to manifest a composite anomaly consisting of a Pacific plate slab-flap (Monterrey microplate) and the foundering roots of the southern Sierra Nevada batholith. The pros and cons of this composite interpretation will be discussed. The slab flap is identified as the 4.4-4.6 km/s NW-SE striking 150 km wide planar anomaly imaged at 60-100 km depth beneath the San Joaquin valley. The foundering southern Sierra batholithic root is identified as the N-S trending 4.1-4.4 km/s high velocity region beneath the southern Sierran foothills. This anomaly is bowed down beneath the high standing southern Sierra block to form a wedge filled with 4.1-4.2 km/s which is interpreted as in-flowed asthenosphere.

Comparison of our velocity model with another ambient/earthquake dispersion data image (Moschetti et al., in review) finds that the two models are well correlated. Comparison of our velocity model with teleseismic body wave images reveals substantial differences in the geometry and depth extent of the Isabella anomaly related to wave resolution differences. P-wave receiver function crustal thickness maps agree in about 70% of their jointly sampled area.

Summary

1. Both the uniform starting models (4.4 km/s) with no imposed moho and a imposed moho using the Pn time-terms from Beuhler and Shearer (in review) give very similar images especially with respect to the geometry of the subcrustal Isabella velocity anomaly.

2. The Isabella velocity anomaly can be explained as a composite anomaly associated with a N-S oriented foundering batholithic root from the southern Sierras and a NW-SE oriented anomaly that could be interpreted as a vertically oriented slab-flap extending beneath the continental margin associated with an inboard extension of the stalled Monterrey mricoplate.

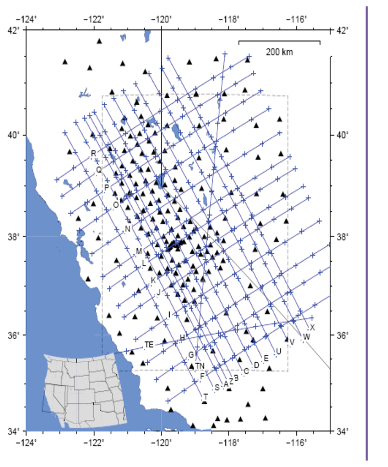
3. In 70% of our shear velocity image using a uniform starting velocity model (no imposed moho), the depth of the moho can be estimated as the depth of the maximum vertical velocity gradient. This method does not work in the Coast Range province.

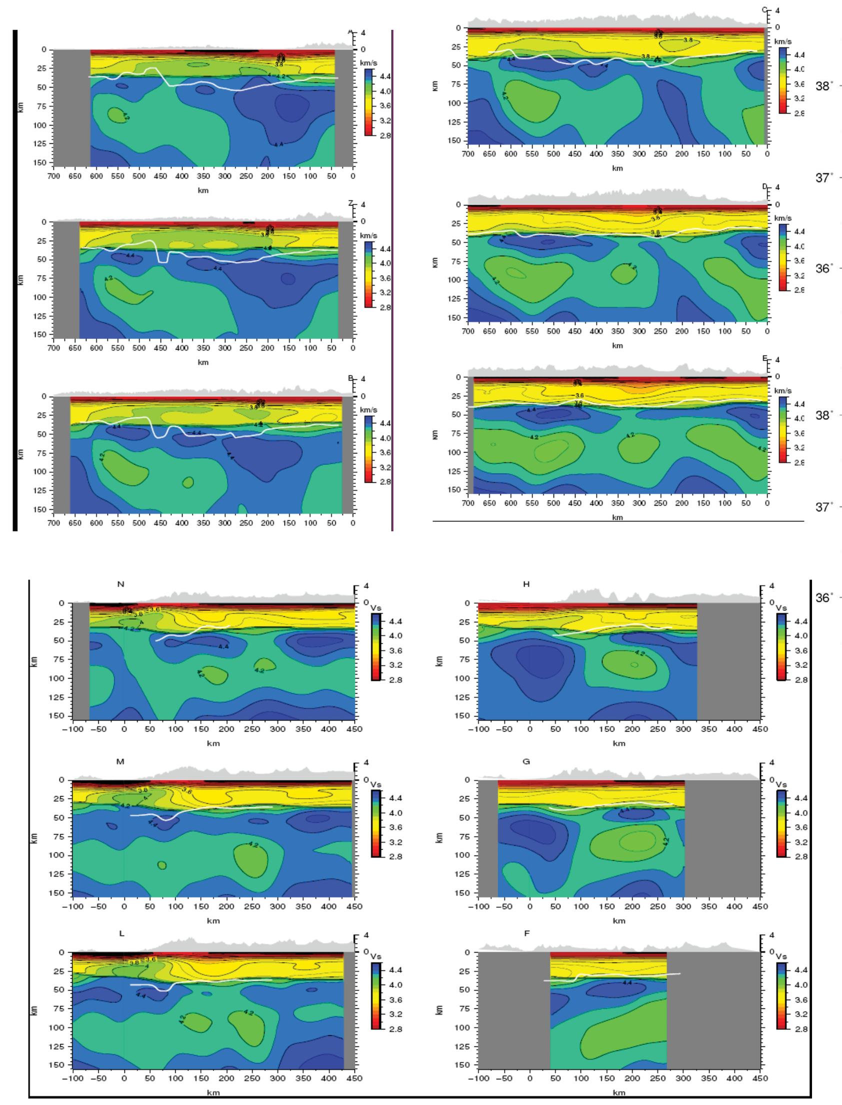
Pn time-term moho starting velocity model

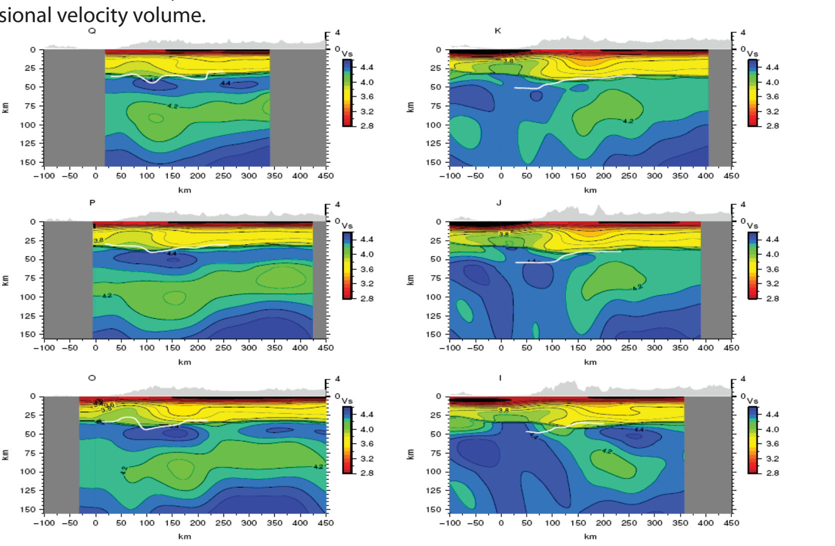
Dispersion measurement of fundamental mode Rayleigh waves was performed using ambient noise (J. Stachnik) and earthquakes (H. Gilbert). The two plane wave method was used to measure dispersion from the earthquakes and the parametric Bessel-zeros method (Ekstrom et al., 2009) was used to measure dispersion from the ambient noise correlation functions.

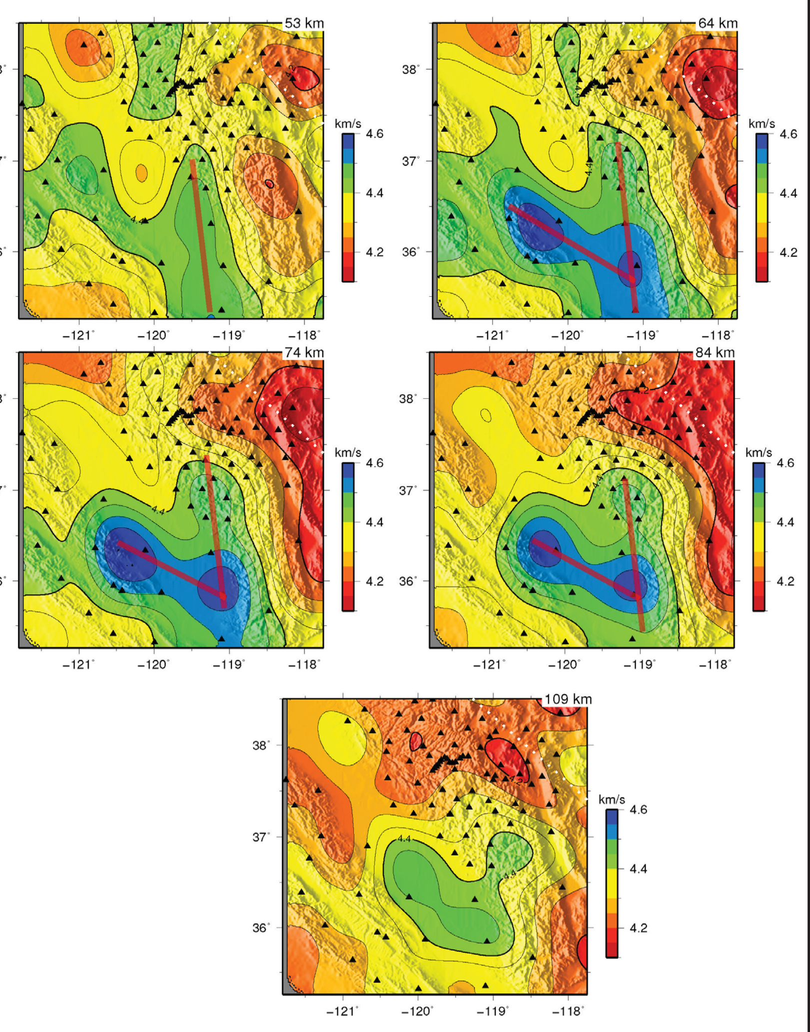
The starting velocity model for the velocity model in this box is a 3.7 km/s crust and a 4.4 km/s mantle halfspace. The moho is imposed using the Pn-time terms provided by Beuler and Shearer (in review).

The shear wave images are made in three steps: 1) a phase velocity map inversion at 4-100 s periods; 2) a vertical velocity inversion on a 20 km grid sampled from the phase velocity maps; 3) an interpolation of the 1-dimensional velocity models into a three dimensional velocity volume.







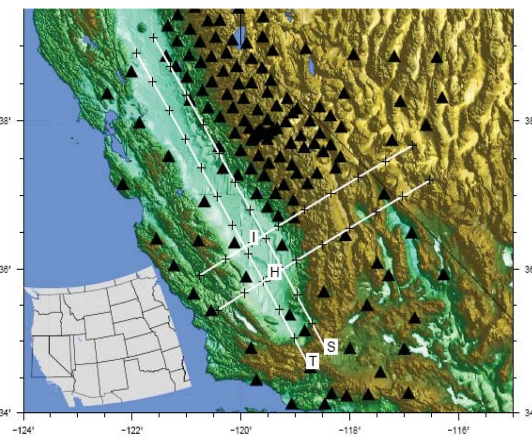


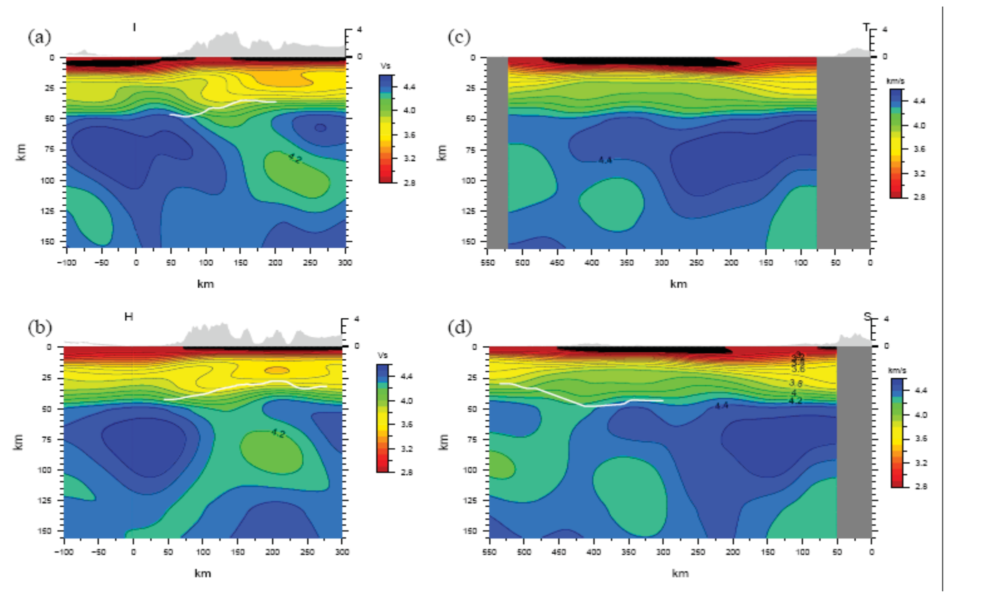
Uniform starting velocity model

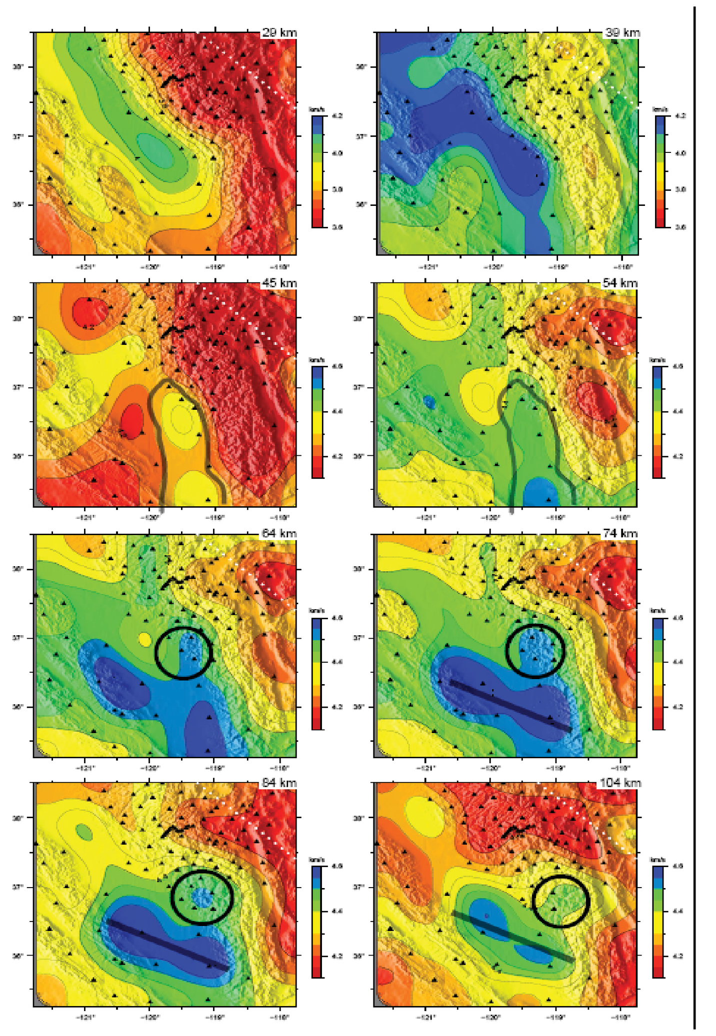
Dispersion measurement of fundamental mode Rayleigh waves was performed using ambient noise (J. Stachnik) and earthquakes (H. Gilbert). The two plane wave method was used to measure dispersion from the earthquakes and the parametric Bessel-zeros method was used to measure dispersion from the ambient noise correlation functions.

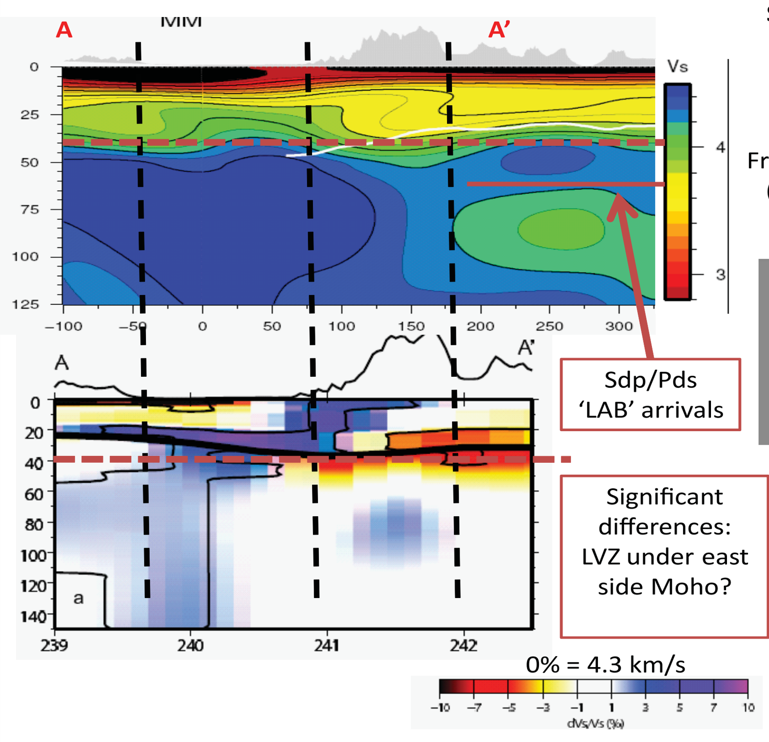
In contrast to the shear wave model to the left of this text, a uniform velocity starting model was used: i.e., a 4.4 km/s halfspace.

The white lines at moho depths are moho depth estimates from receiver functions (Frassetto et al., in review)



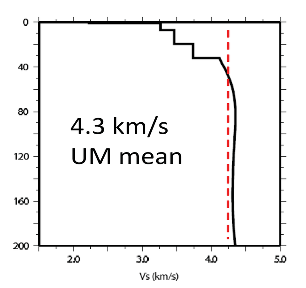






Shear velocity comparison
Moschetti et al. (in revew): versus our model

Moho depth comparison
Frassetto (white line) vs. Gilbert (black line) vs. Stachnik (4.0 km/s contour)

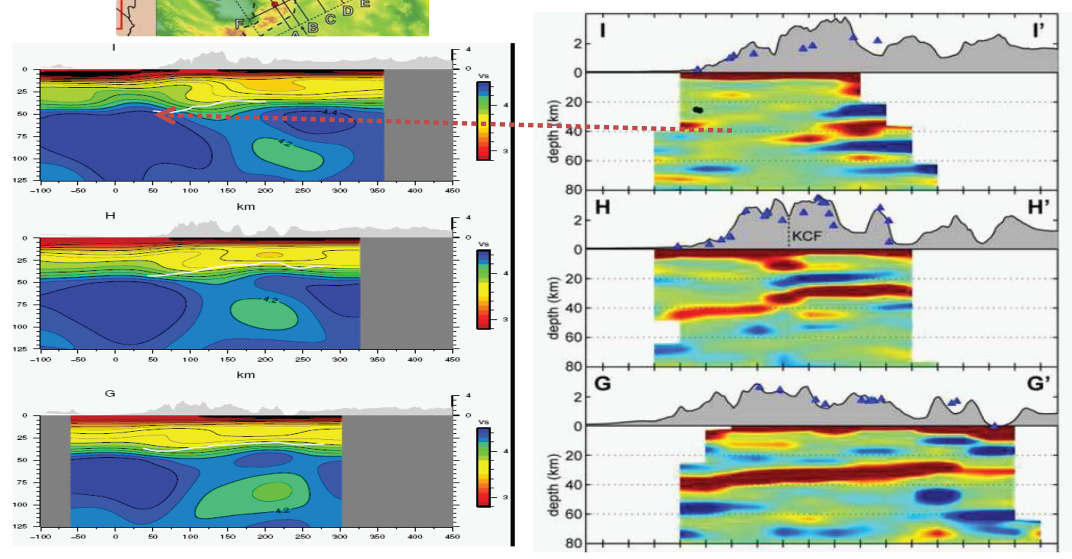


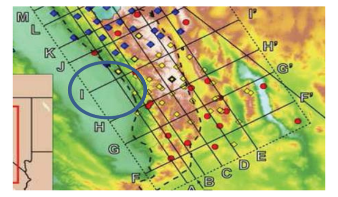
Sdp/Pds 'LAB' arrivals

Significant differences: LVZ under east side Moho?

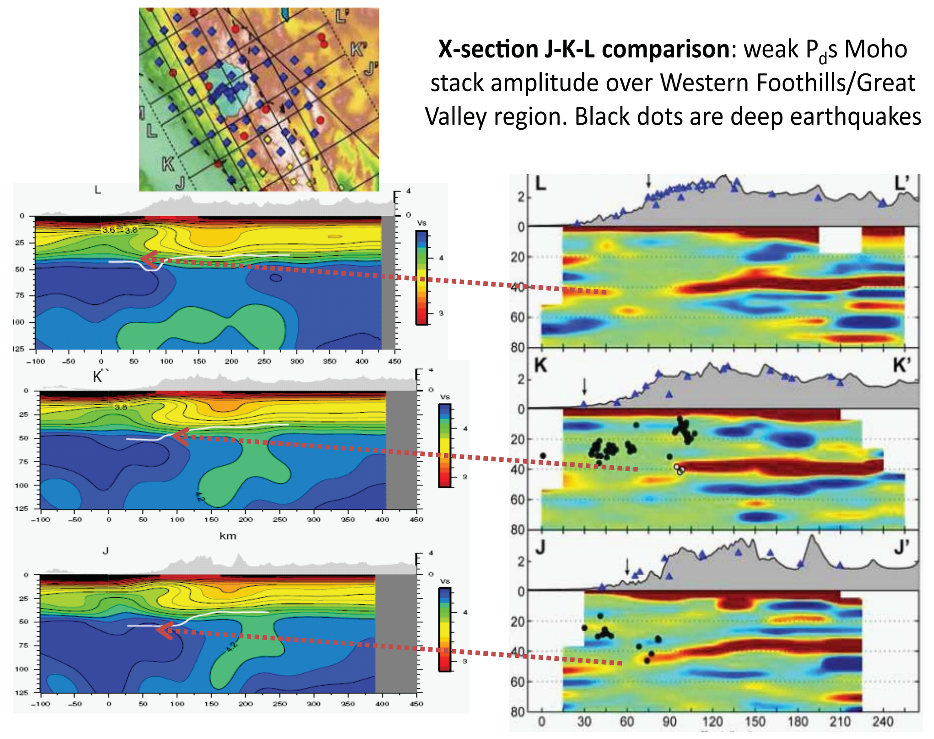
0% = 4.3 km/s

Moho depth/amplitude From P_ds stacking (Frassetto et al., in review): G-H-I x-sections through Whitney Block

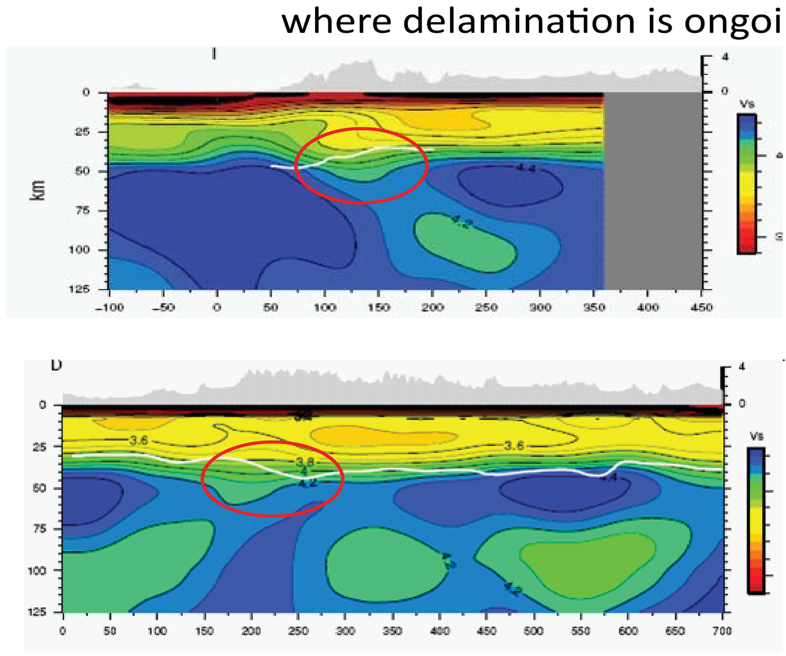




X-section J-K-L comparison: weak P_ds Moho stack amplitude over Western Foothills/Great Valley region. Black dots are deep earthquakes



Lower crust advection to west under Whitney Block where delamination is ongoing



- Not an inversion pathology as this wide Moho gradient is not found elsewhere in model.
- Delamination requires weak lower crust to decouple sub-Moho flow (Gurnis paper).
- Mushroom's east side has bent downwards to bring up asthenosphere as Ducea and Saleeby (1998) found.
- North Owens valley and Long Valley volcanics correlation with upwelling asthenosphere.

Plate tectonic History off-shore California

As the Farallon spreading ridge approached the coastline and first made contact in Baja California at 24 Ma, the Farallon plate segmented into four micro-plates: the Magdalena, Guadalupe, Arguello, and Monterrey plates. The same style of slab segmentation is happening to the Juan de Fuca plate today with its two microplates: the Gorda and Explorer plates.

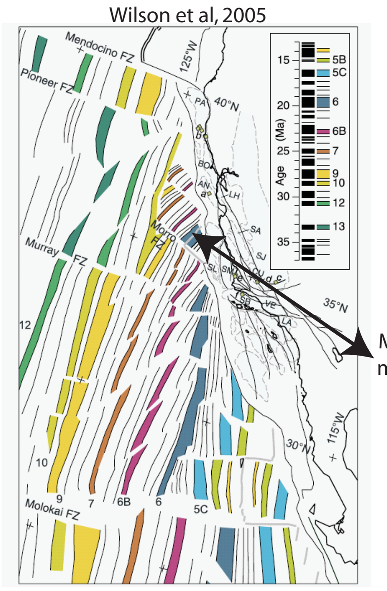
A first order question is how the microplates are segmented from their subducting portions as the spreading ridge ceases. This depends on how the micrplate segment from their subduction portions; two possibilities exist.

1. Do the microplates viscously neck at the base of the seismogenically locked zone from its subducted portions (Andrews and Billens, 2009) ?

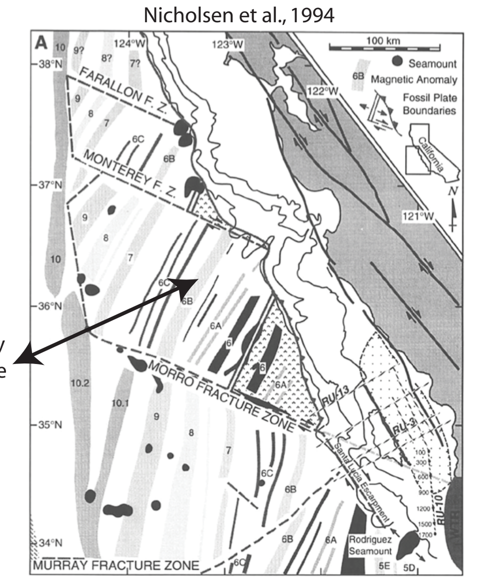
2. Do the microplates nucleated a 'tear' that propagates laterally along the slab to disconnect the subducted portions from the 'dead' microplate? : e.g., as maybe happening in the zone of NE-SW left lateral faulting at the Mendocino triple-junction.

How far inboard the microplates segment from their subducted portions will determine how much of a slab-flap may initially extend beneath the margin to exert tractions at the base of the lithosphere/crust as the Pacific plate and its inherited microplates translates to the NW. After segmenting, the slab flab may bend downwards due to eclogite loading as the microplates basaltic crust is thermally watered.

Wilson et al., 2005

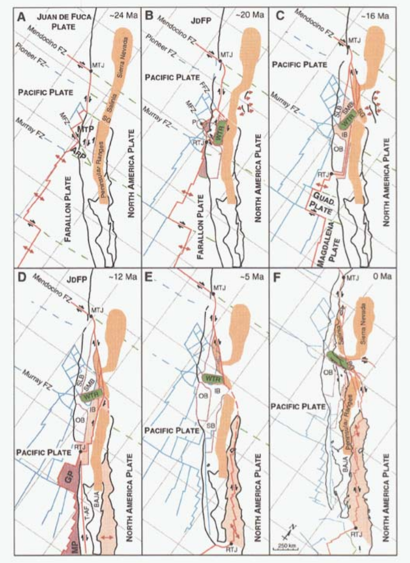


Nicholsen et al., 1994

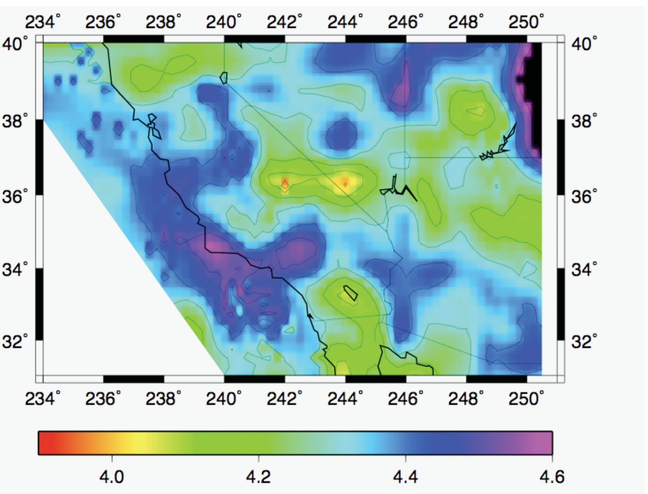


Monterrey microplate

Nicholsen et al., 1994



Shear velocity average at 40-60 km depth from Forsyth (2010)



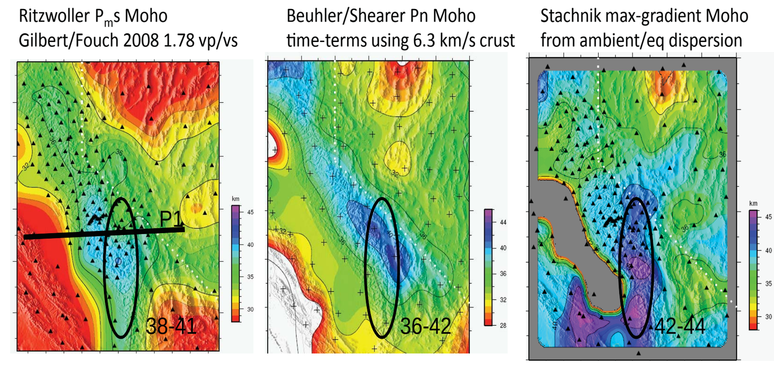
Moho thickness comparison under southern Sierra batholith: aka the Whitney Block

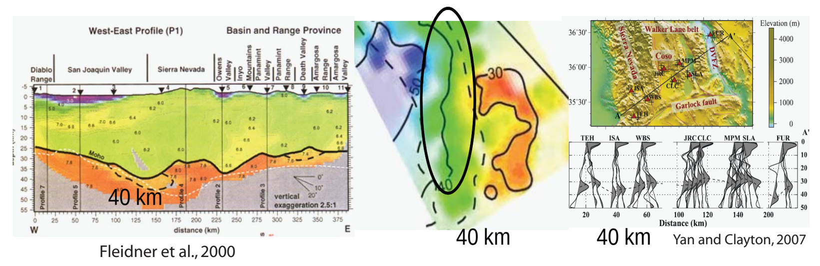
Whitney Block Moho comparisons: 36-44 km range

Ritzwoller P_ms Moho Gilbert/Fouch 2008 1.78 vp/vs

Beuhler/Shearer Pn Moho time-terms using 6.3 km/s crust

Stachnik max-gradient Moho from ambient/eq dispersion



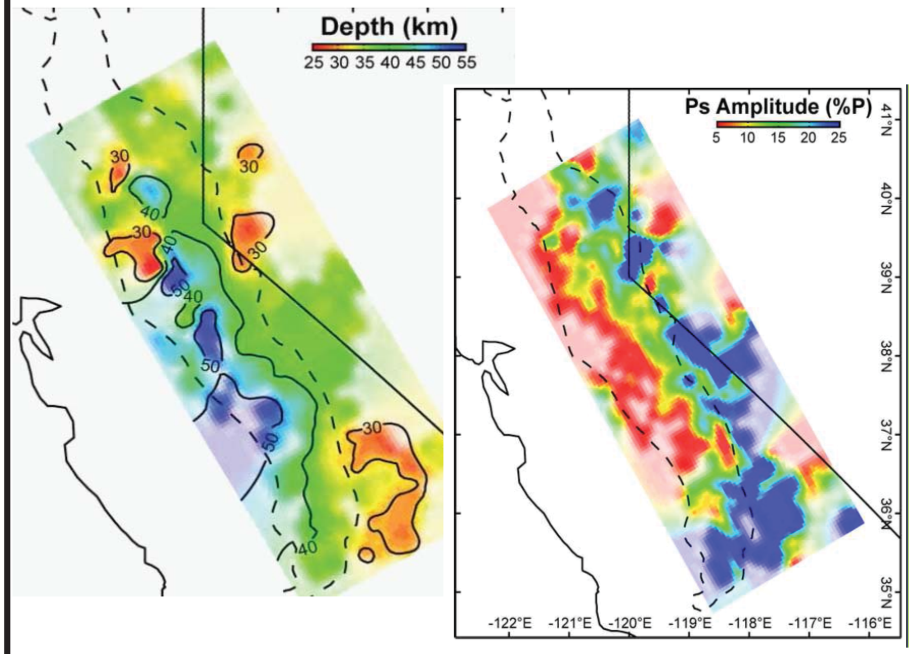


Fleidner et al., 2000

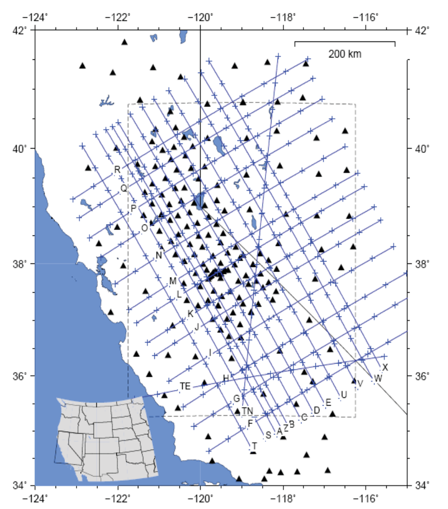
40 km

40 km Yan and Clayton, 2007

Receiver Function Moho Depth and Amplitude
Frassetto et al. in review



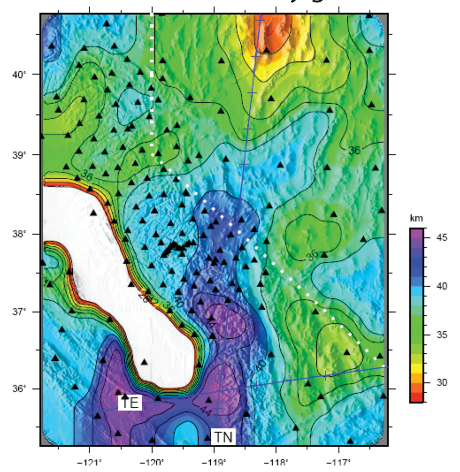
Moho depth calculated from shear velocity image velocity gradient



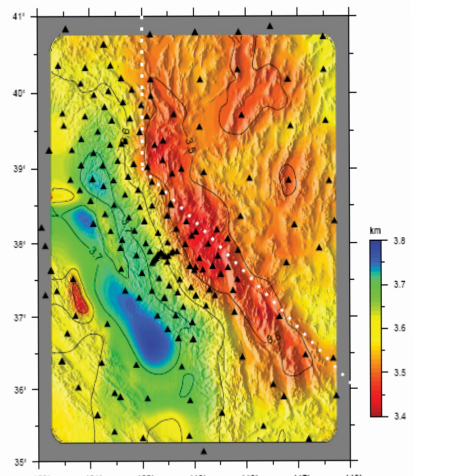
We estimate the depth to the moho by picking the maximum velocity gradient from our shear velocity images constructed using the uniform (4.4 km/s) starting velocity model.

This moho depth picking method gives good results in most regions except the Coast Range region where the crustal thickness of 44 km is clearly errant. We attribute the failure to find the correct moho depth here due to two factors: 1) reduced seismic sampling, and 2) complicated velocity structure below the Moho associated with understuffed subduction material and a serpentized upper mantle.

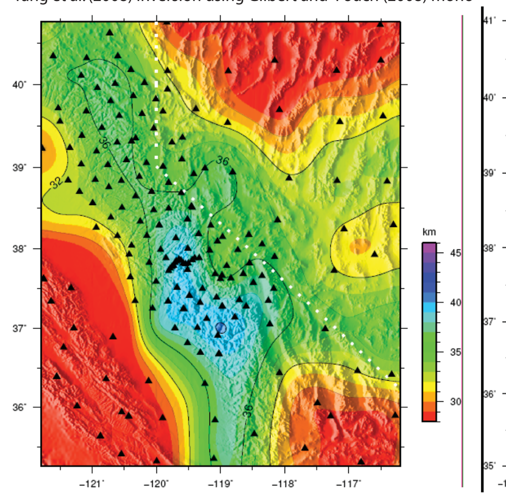
Moho depth from surface wave model maximum velocity gradient



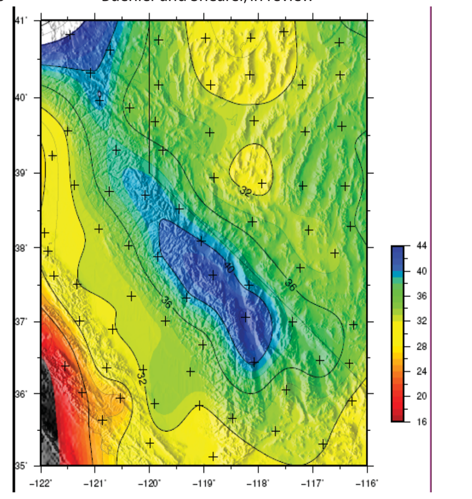
Mean crustal shear velocity from our surface wave model



Colorado Univ. Moho
Yang et al. (2008) inversion using Gilbert and Fouch (2008) moho



Pn time-term Moho
Buehler and Shearer, in review



Uniform starting velocity model cross sections

white line = Frassetto et al. moho

Velocity gradient from surface wave model
dotted line= maximum gradient
dashed line = Frassetto et al. moho

Receiver Function Moho common conversion point image

Frassetto et al., in review