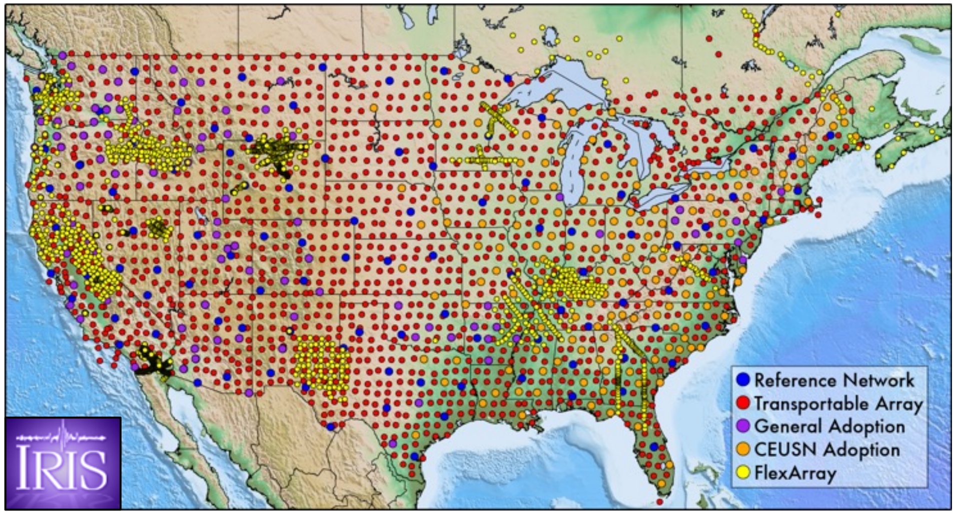
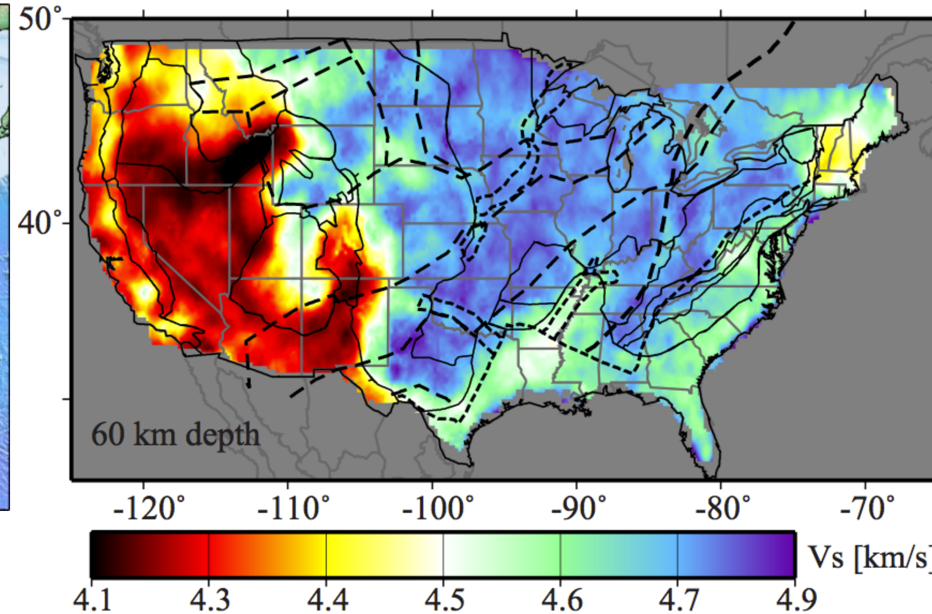
Seismic structure beneath USArray and implications for tectonic and magmatic activity away from plate boundaries





Brandon Schmandt

THE UNIVERSITY of NEW MEXICO

Help from friends:

Fan-Chi Lin, University of Utah

Steve Hansen, University of New Mexico

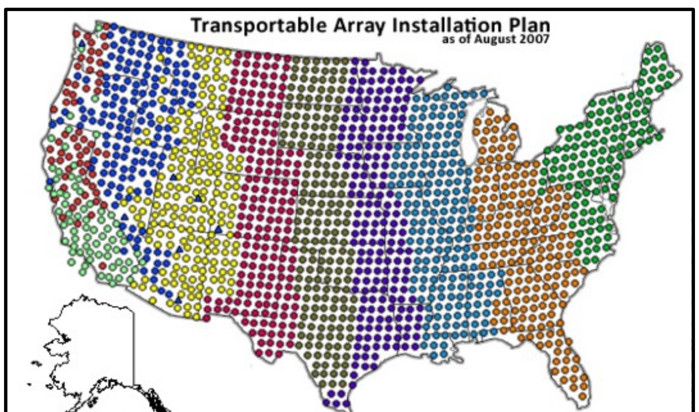
Ken Dueker, University of Wyoming

Supported by NSF EAR-1554908

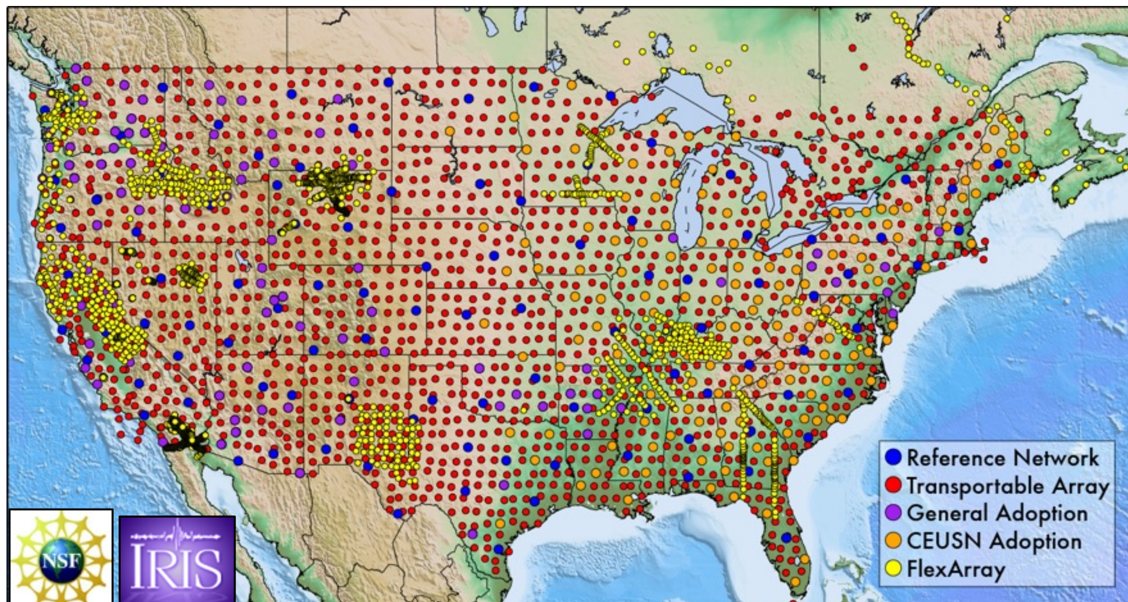
Seismic structure beneath USArray and implications for tectonic and magmatic activity away from plate boundaries

- Yellowstone Hotspot: clearest (~only) example of super-adiabatic upwelling
- Long-lived magmatic scars and small-scale convection in the eastern U.S.
- Supporting topography of young and old orogens

The plan



Broadband data at the IRIS DMC



1. The Yellowstone Hotspot,
The clearest (only?) example of ongoing super-adiabatic upwelling

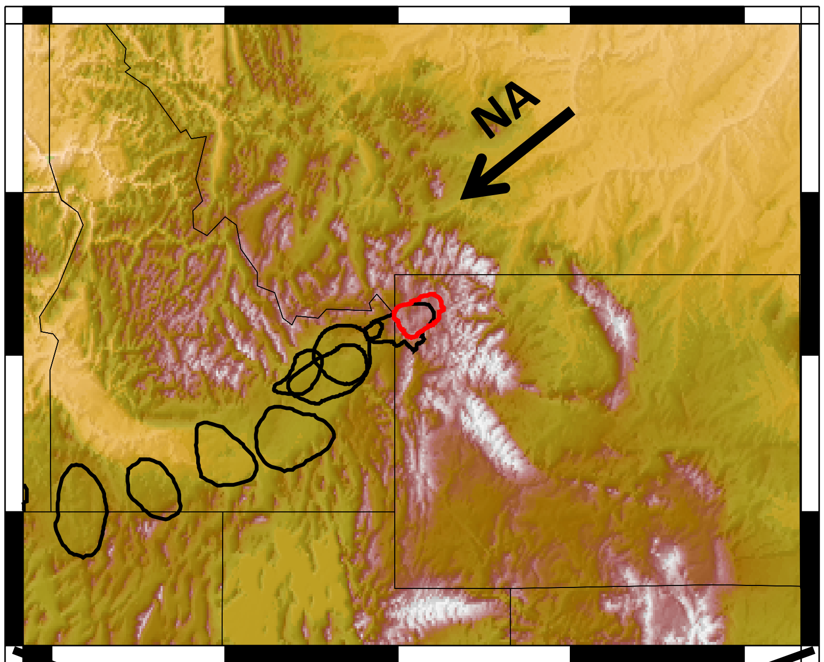
The Yellowstone Hotspot

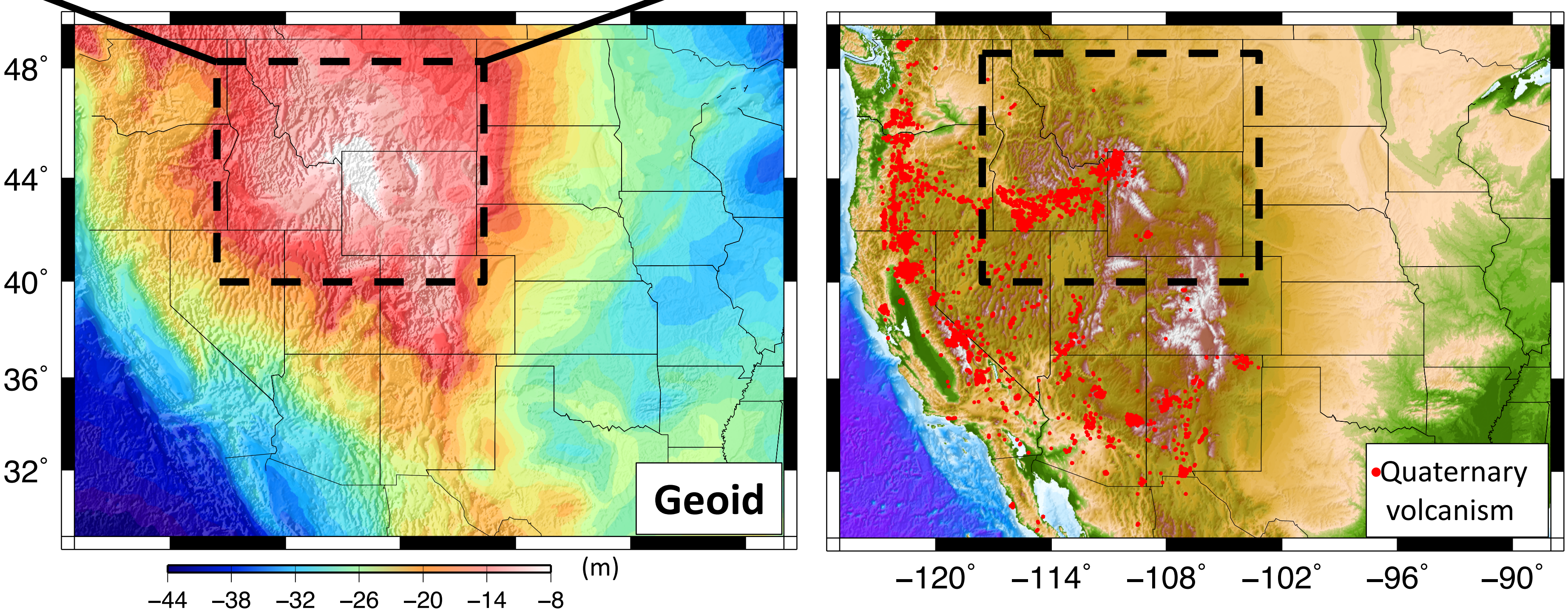
- High $^3He/^4He$ (Graham et al., 2009), up to ~18 R/Ra

- Radially symmetric geoid high, ~1000 km radius

- voluminous basalt intrusions have densified the Snake River Plain crust

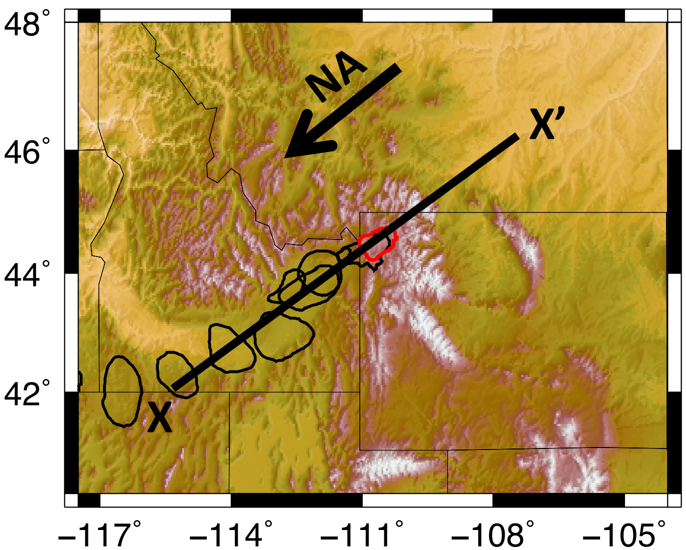
*clearly not in isolation of tectonic conditions favorable to volcanism, but its buoyancy and melt productivity are execptional

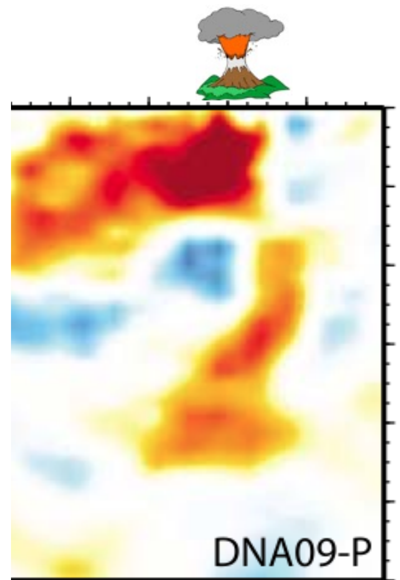




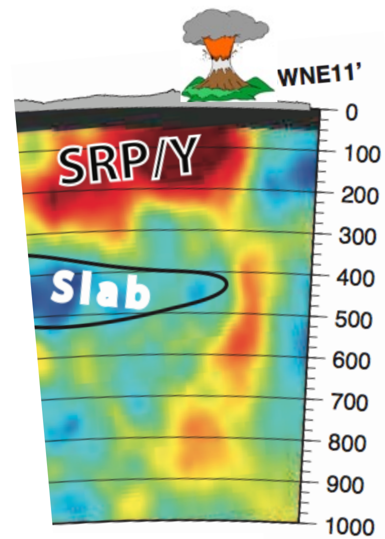
USArray tomography beneath Yellowstone

A vertically heterogeneous low-velocity anomaly extending into the lower mantle in all USArray tomography models. Three examples:

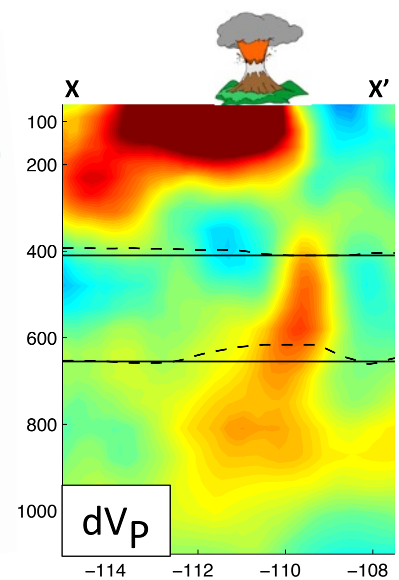




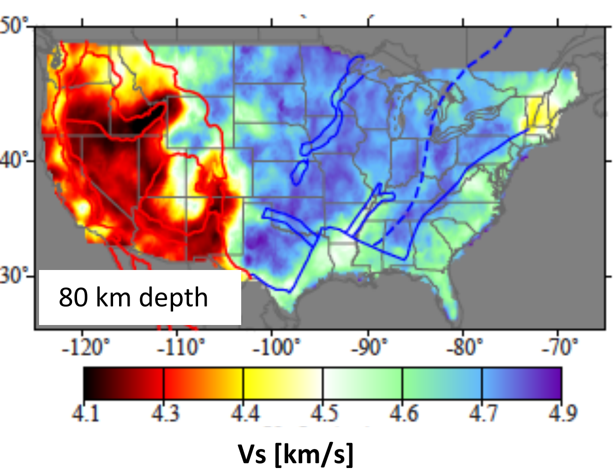
(Obrebski et al., 2010)



(James et al., 2011)

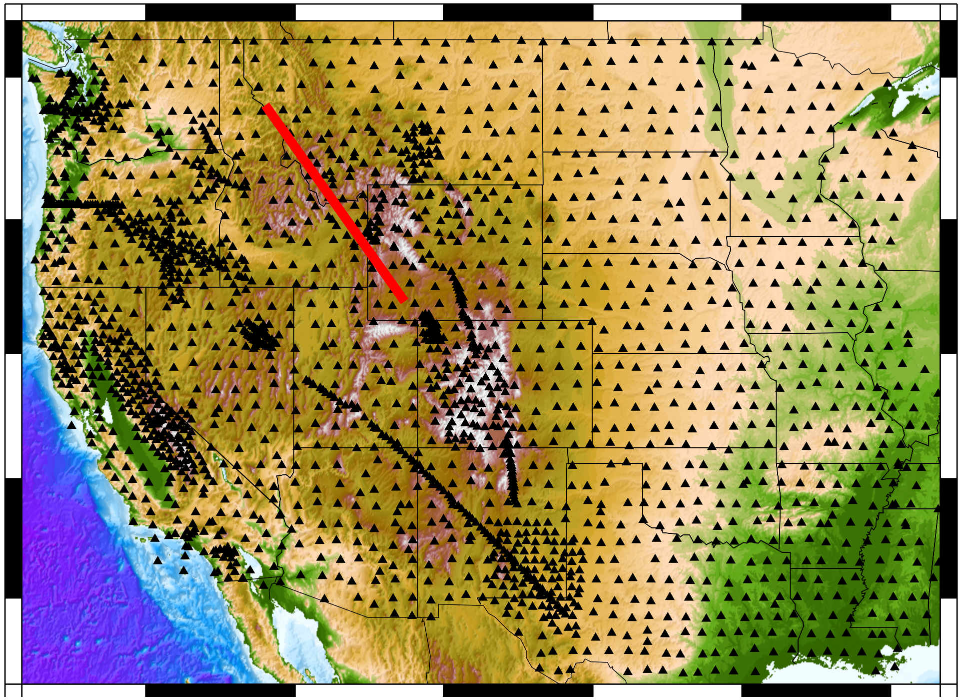


(Schmandt et al., 2012)

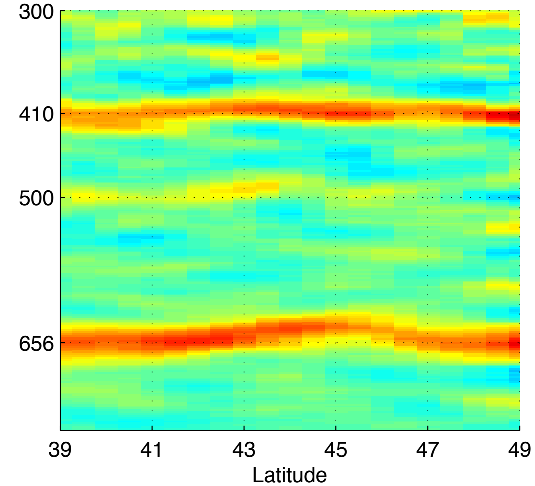


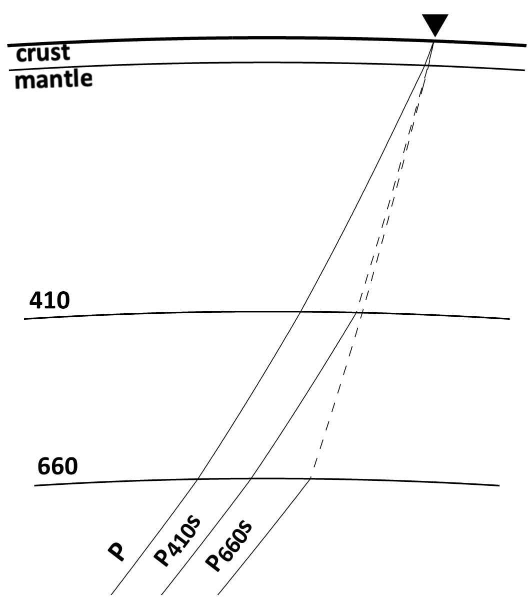
Lowest shear velocities found beneath eastern Snake River Plain, ~3.9 km/s.
Slower than beneath East Pacific Rise at same depth [e.g., Schutt and Dueker, 2008].

Converted wave imaging of the mantle transition zone with USArray

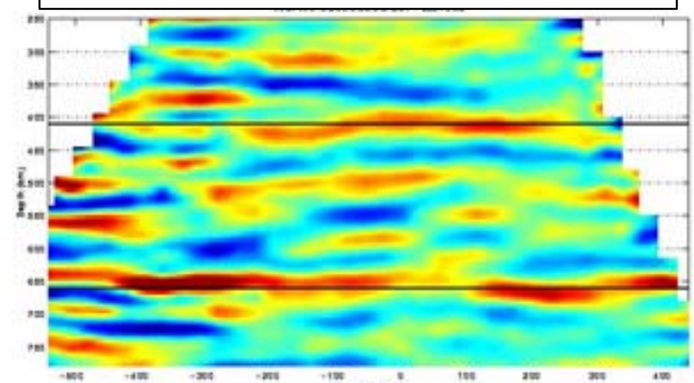


Ps receiver function
CCP image with USArray+PASSCAL Arrays

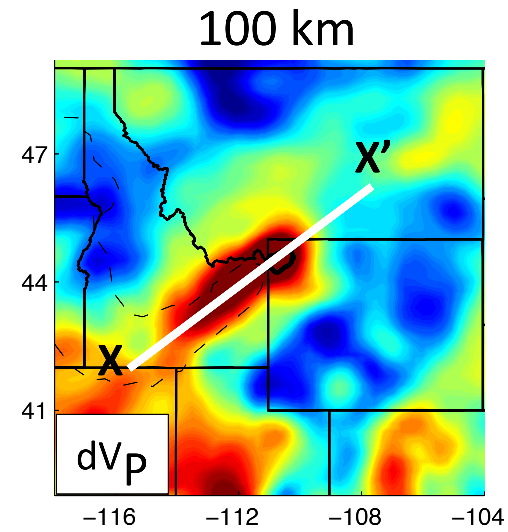


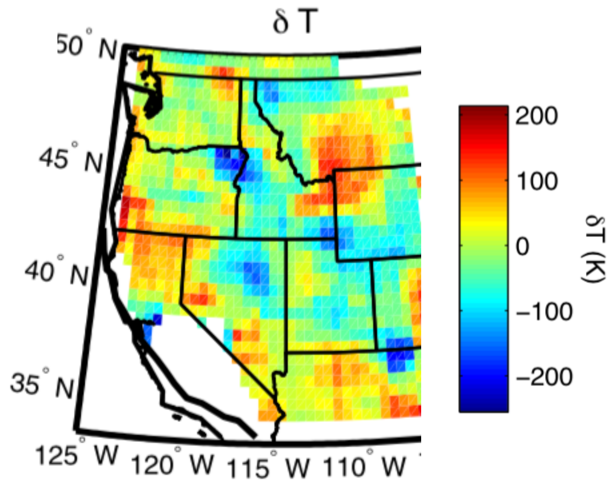


Pre-USArray CCP image
Beneath the Snake River Plane



(Dueker and Sheehan, 1997)





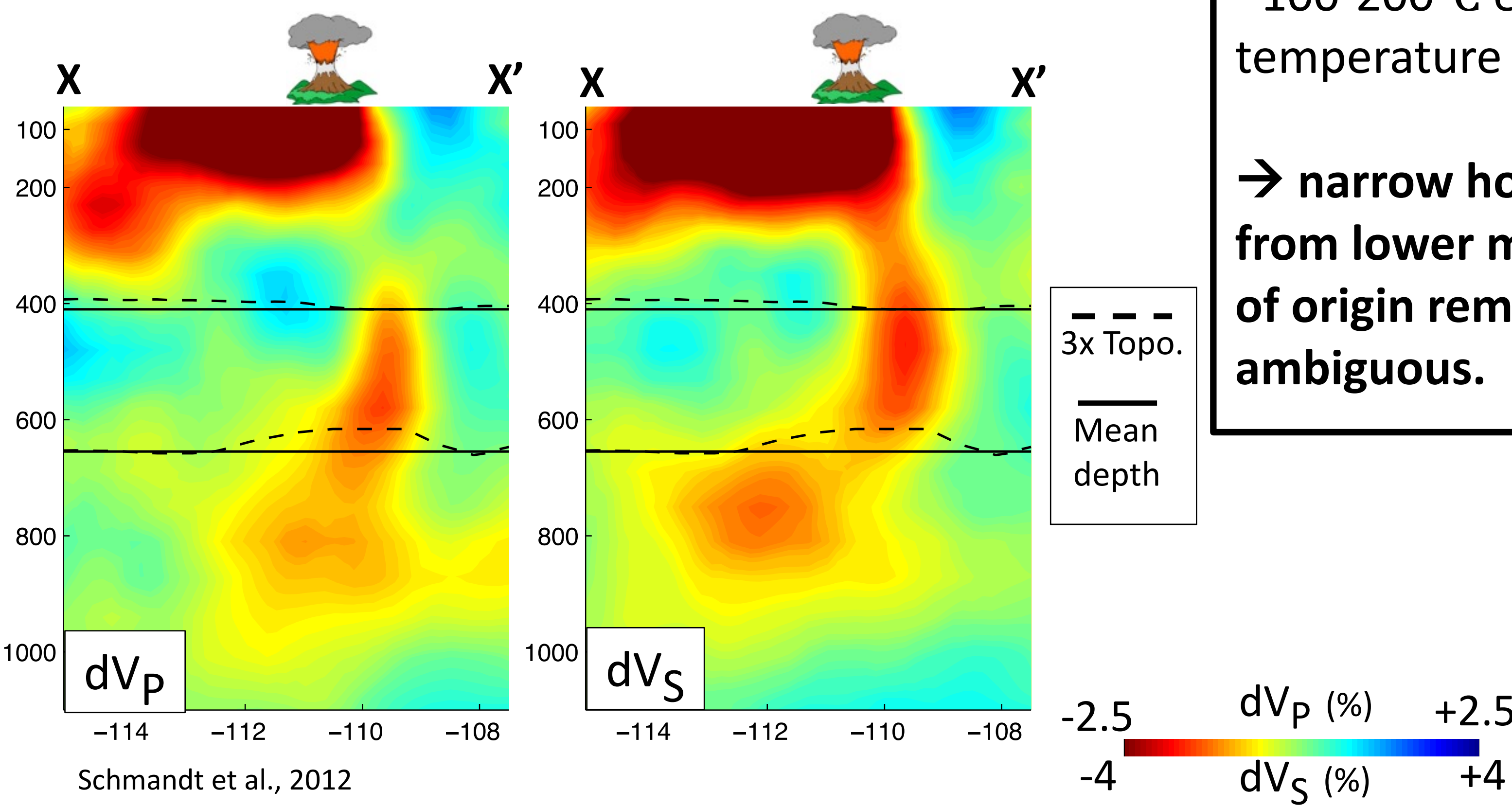
Tauzin and Ricard, 2014

- Uppermost mantle Vs as low as ~3.9 km/s.

- Deeper low-velocity anomaly is correlated with thin MTZ

~100-200°C excess temperature

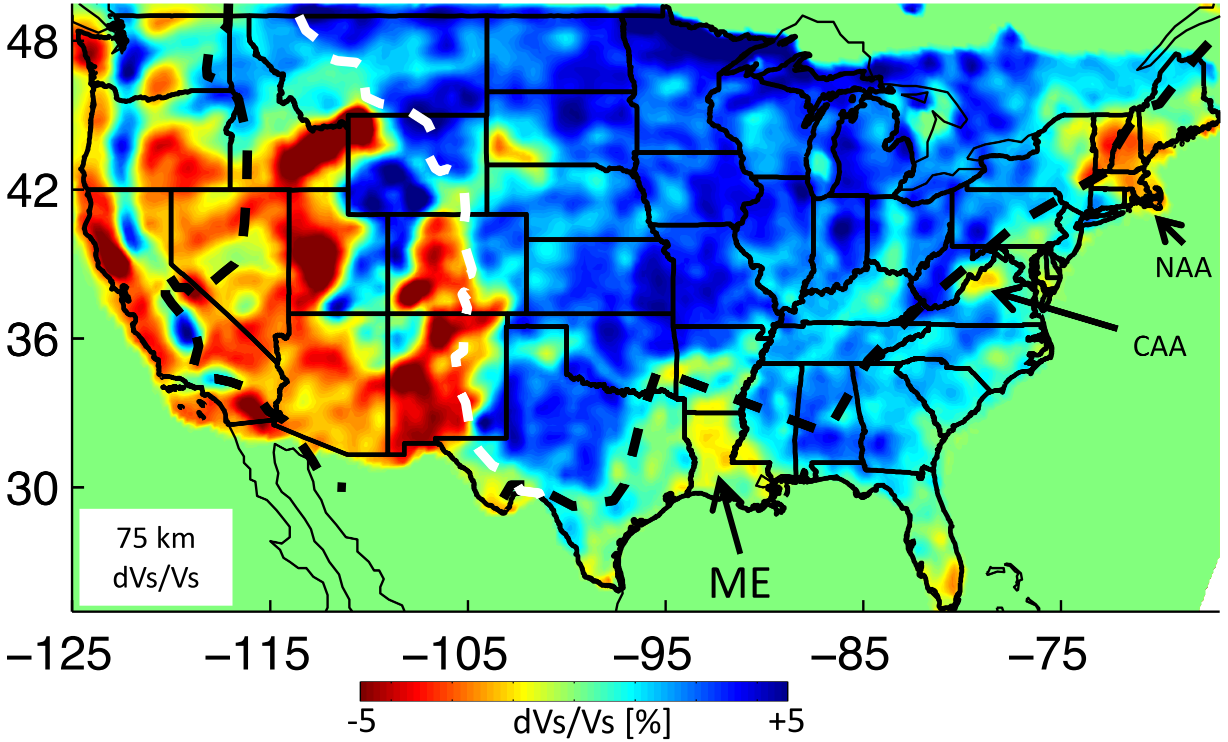
→ narrow hot upwelling from lower mantle. Depth of origin remains ambiguous.



Schmandt et al., 2012

2. Long-lived magmatic scars and small-scale convection in the eastern U.S.

Long-lived magmatic scars in the eastern U.S.



Schmandt and Lin, 2014

Low velocity anomalies along the passive margin [Eaton and Frederiksen, 2007; Villemaire et al., 2012; Pollitz and Mooney, 2016; Menke et al., 2016]

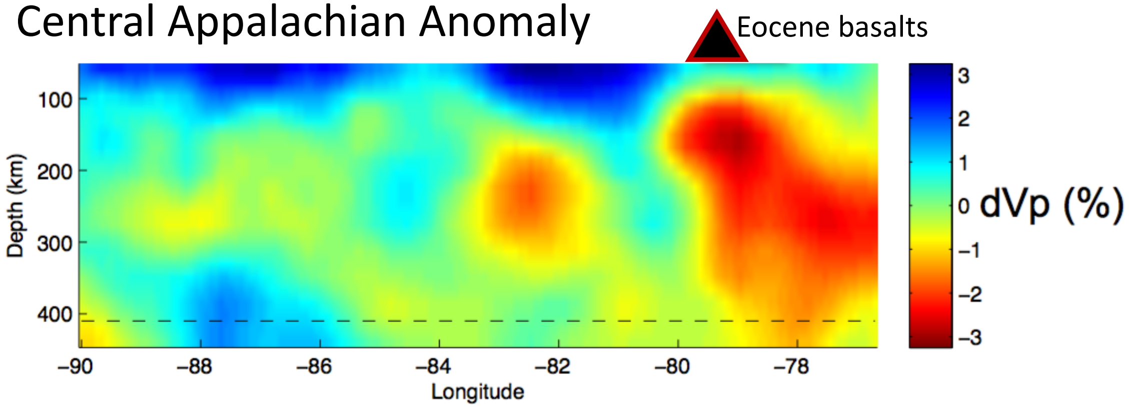
Vs ~4.27 – 4.4 km/s
Similar to lithosphere in western U.S. Faster than most Quaternary volcanic fields.

Generally not slow enough to require partial melt

2 anomalies are spatially linked to post-rifting magmatic events [e.g., Mazza et al., 2014; Eby, 1987; Heaman and Kjarsgaard, 2000]

Long-lived magmatic scars in the eastern U.S.

Central Appalachian Anomaly

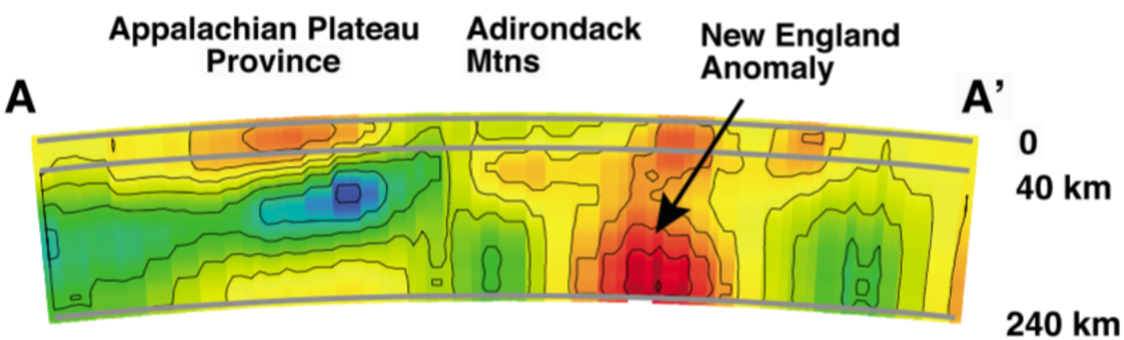


Schmandt and Lin, 2014

~48 million years since magmatism [Mazza et al., 2014]

Very close spatial correlation

Northern Appalachian or New England Anomaly



Pollitz and Mooney, 2016

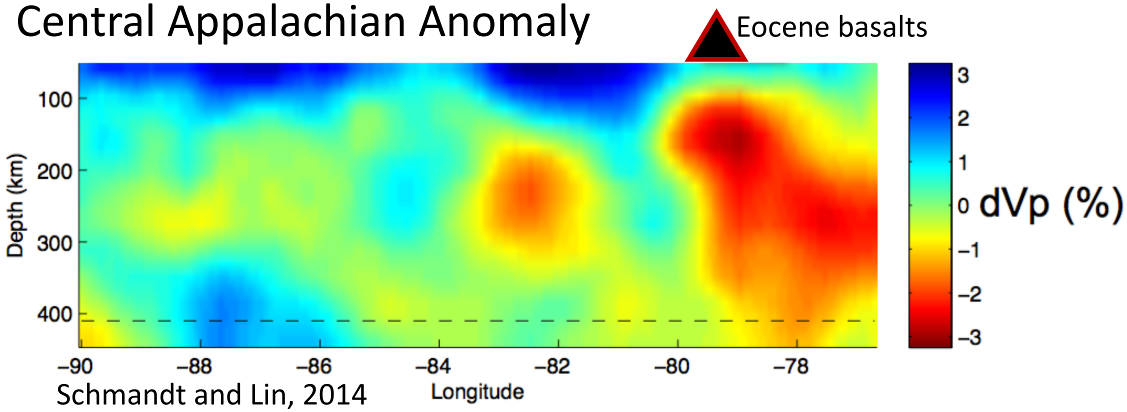
~100 million years since magmatism [e.g., Eby, 1987]

Potential association with hotspot track [Eaton and Freriksen, 2007; Villemaire et al., 2012]

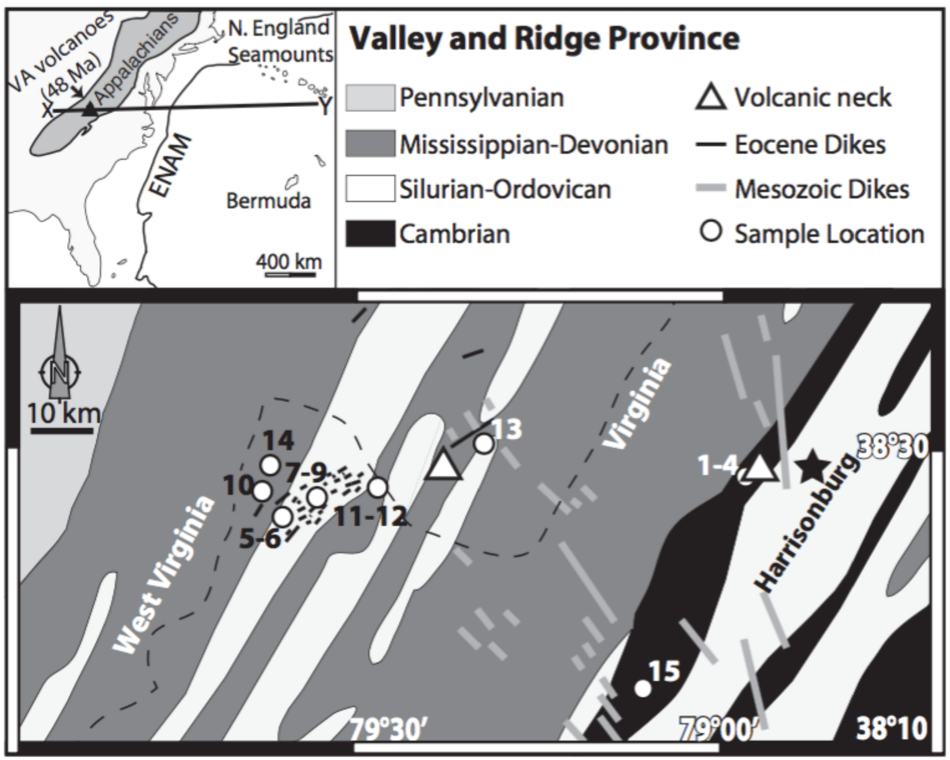
More ambiguous spatial correlation [e.g., Eaton and Frederiksen, 2007; Menke et al., 2016]

Long-lived magmatic scars in the eastern U.S.

Central Appalachian Anomaly



Schmandt and Lin, 2014



Mazza et al., 2014

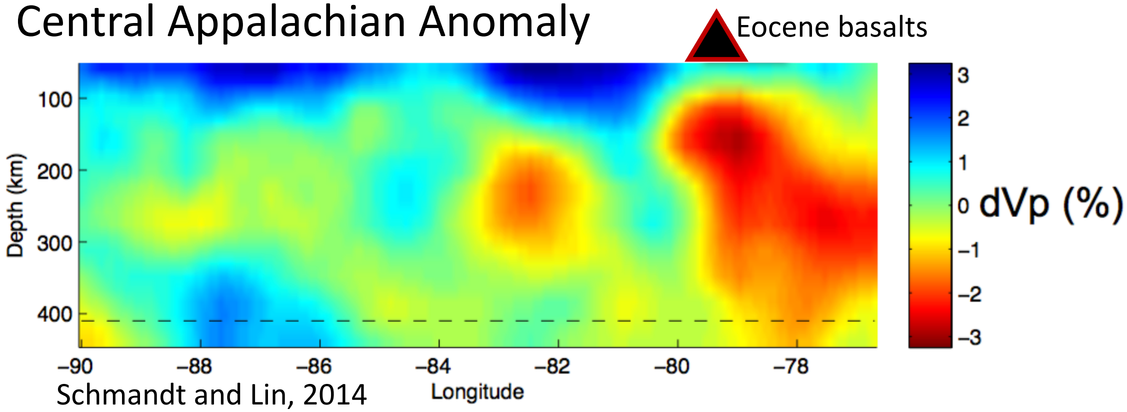
If TA spacing was much greater than 70 km we might have missed it

~48 million years since magmatism [Mazza et al., 2014]

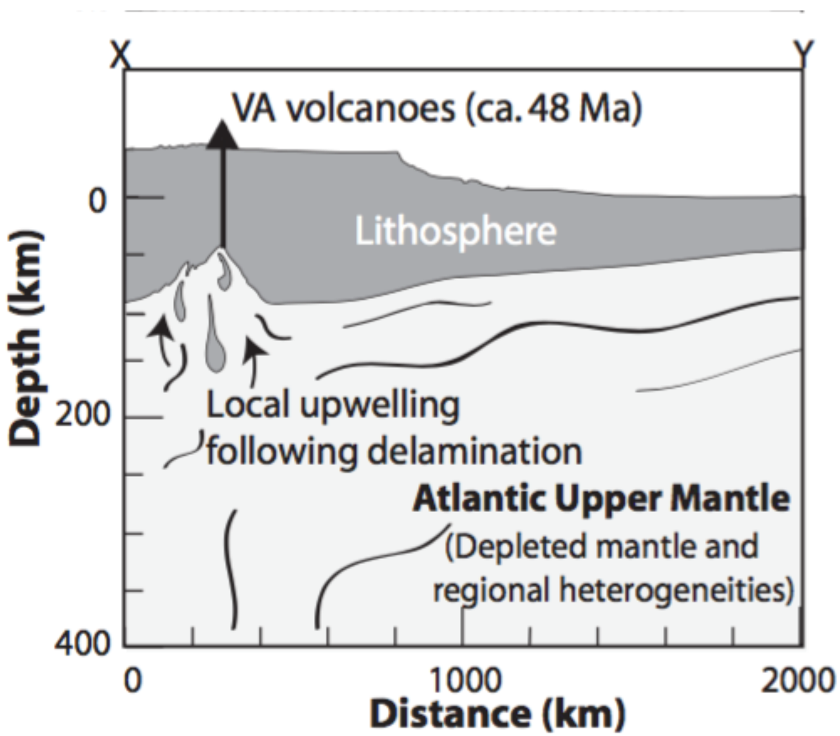
Basalts consistent with decompression melting along dry solidus ~70-90 km depth [Mazza et al., 2014]

Long-lived magmatic scars in the eastern U.S.

Central Appalachian Anomaly



Schmandt and Lin, 2014



Mazza et al., 2014

Potential origins:

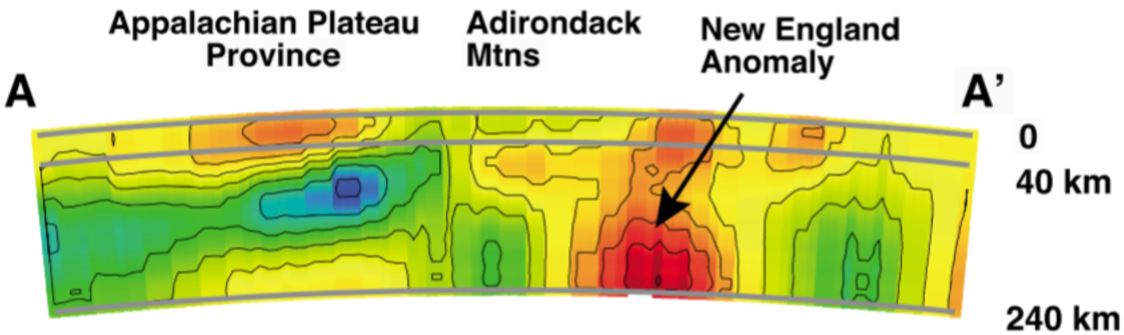
Delamination [Mazza et al., 2014]

Edge convection [e.g., King and Anderson, 1998]

Revised hotspot track [Chu et al., 2012]

Long-lived magmatic scars in the eastern U.S.

Northern Appalachian or New England Anomaly

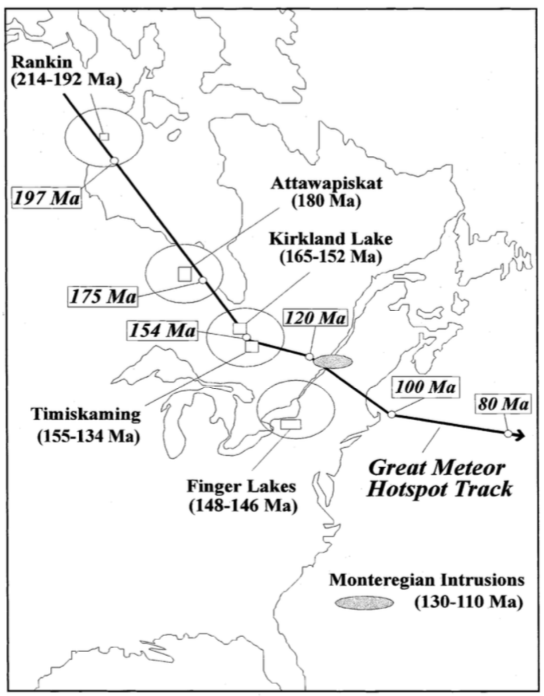


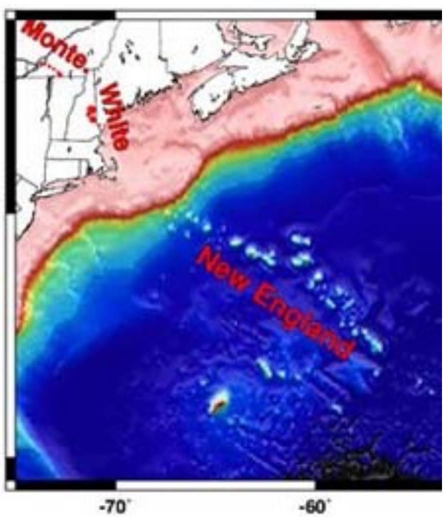
Pollitz and Mooney, 2016

~100 million years since local magmatism [e.g., Eby, 1987]

Potential association with hotspot track

More ambiguous spatial correlation [e.g., Eaton and Frederiksen, 2007; Menke et al., 2016]

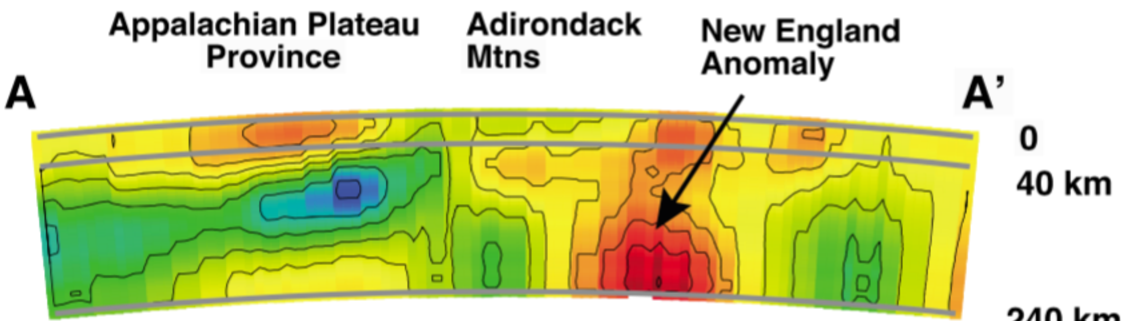




New England seamount chain
Possible older continental extension in kimberlite magmatism
[Heaman and Kjarsgaard, 2000]

Long-lived magmatic scars in the eastern U.S.

Northern Appalachian or New England Anomaly

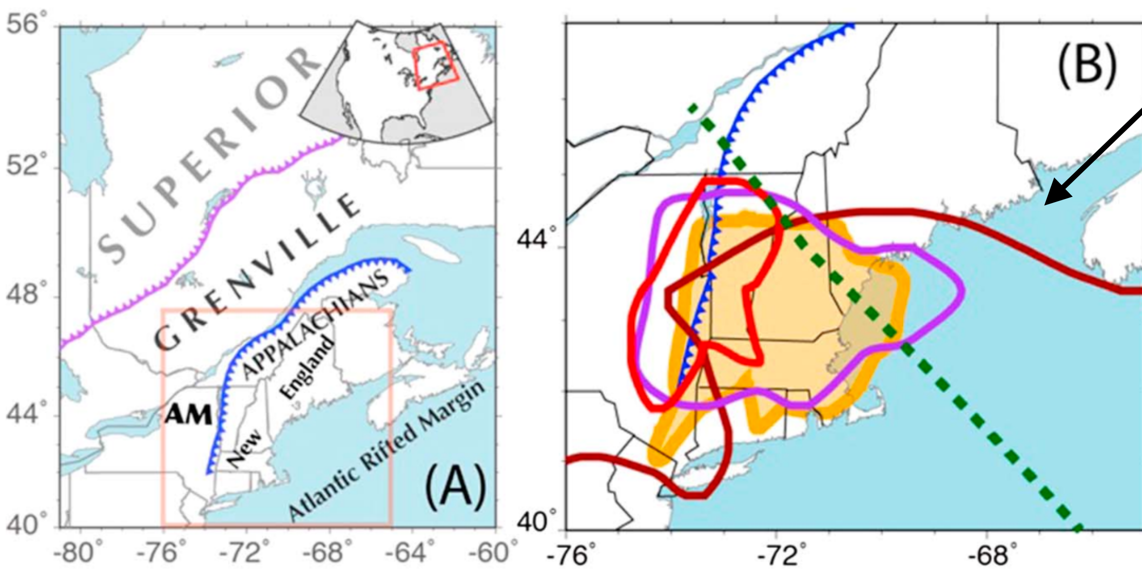


Pollitz and Mooney, 2016

~100 million years since magmatism [e.g., Eby, 1987]

Potential association with hotspot track

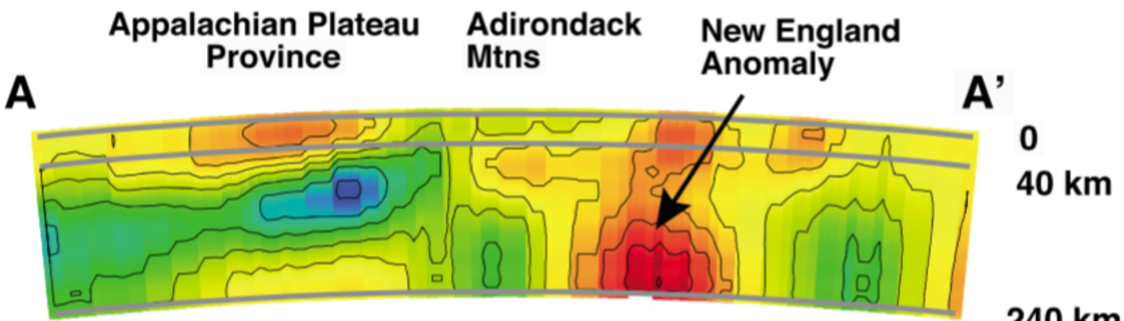
More ambiguous spatial correlation [e.g., Eaton and Frederiksen, 2007; Menke et al., 2016]



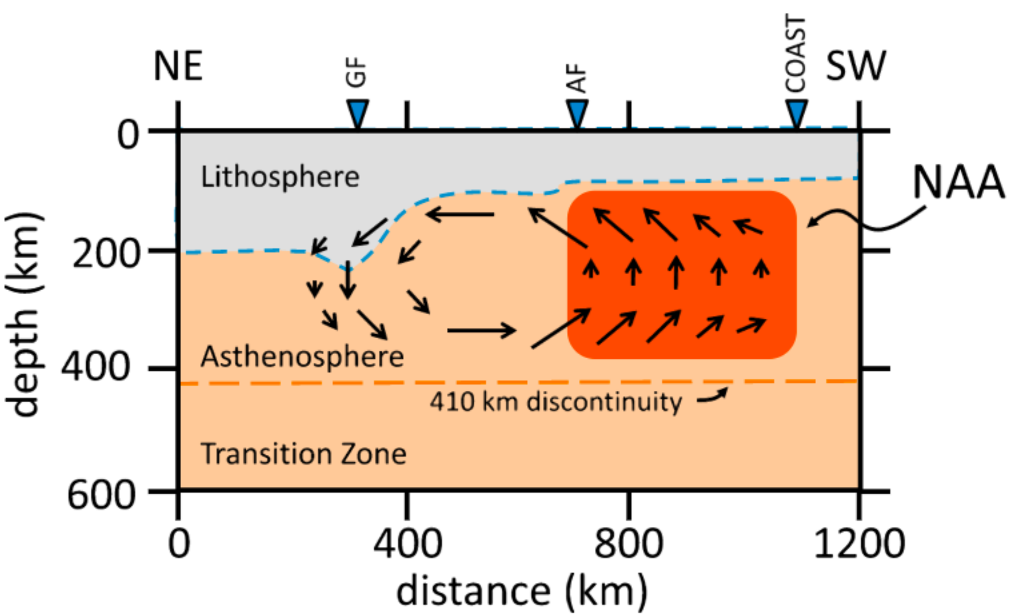
Menke et al., 2016

Long-lived magmatic scars in the eastern U.S.

Northern Appalachian or New England Anomaly



Pollitz and Mooney, 2016



Menke et al., 2016; King and Anderson, 1998

~100 million years since magmatism [e.g., Eby, 1987]

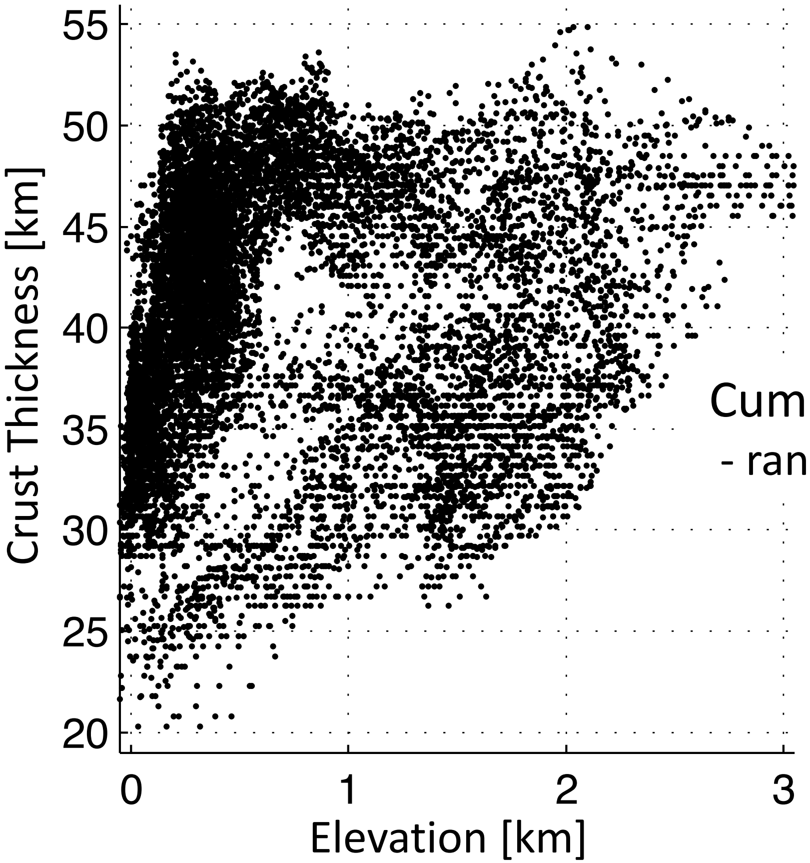
Potential association with hotspot track

More ambiguous spatial correlation [e.g., Eaton and Frederiksen, 2007; Menke et al., 2016]

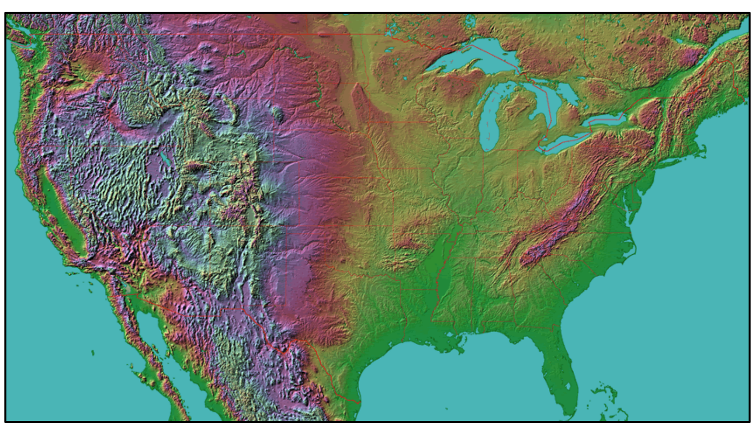
Edge convection, possibly unrelated to Cretaceous magmatism [Menke et al., 2016]

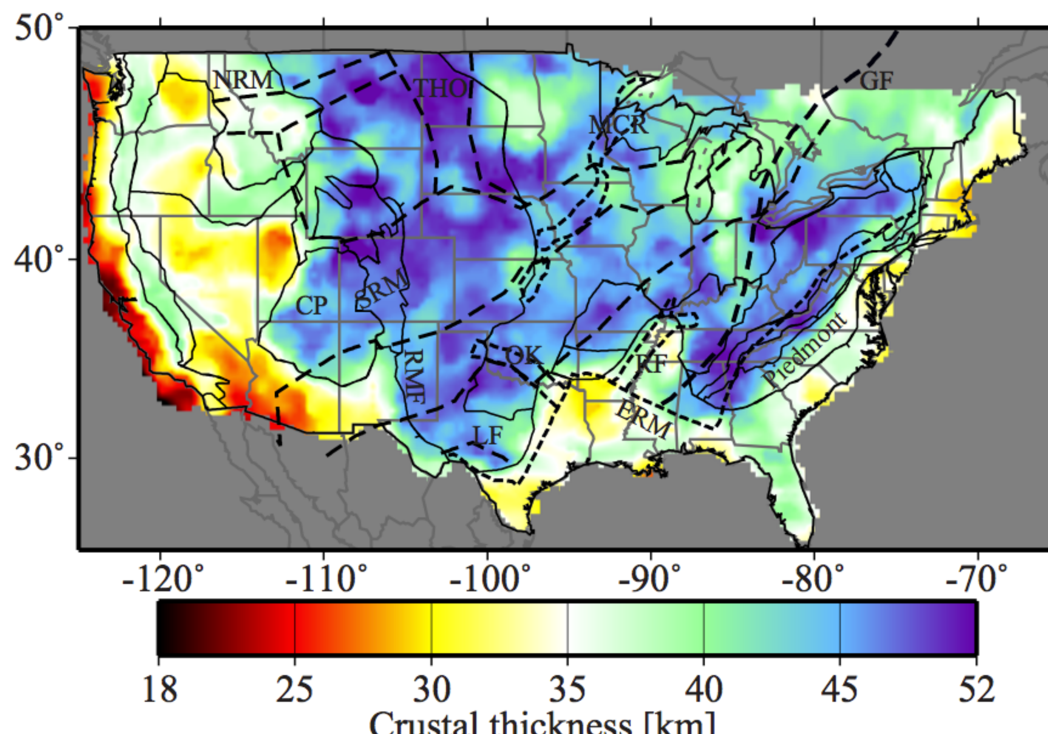
3. Isostatic support for topography in young and old orogens

U.S. Crust thickness versus elevation

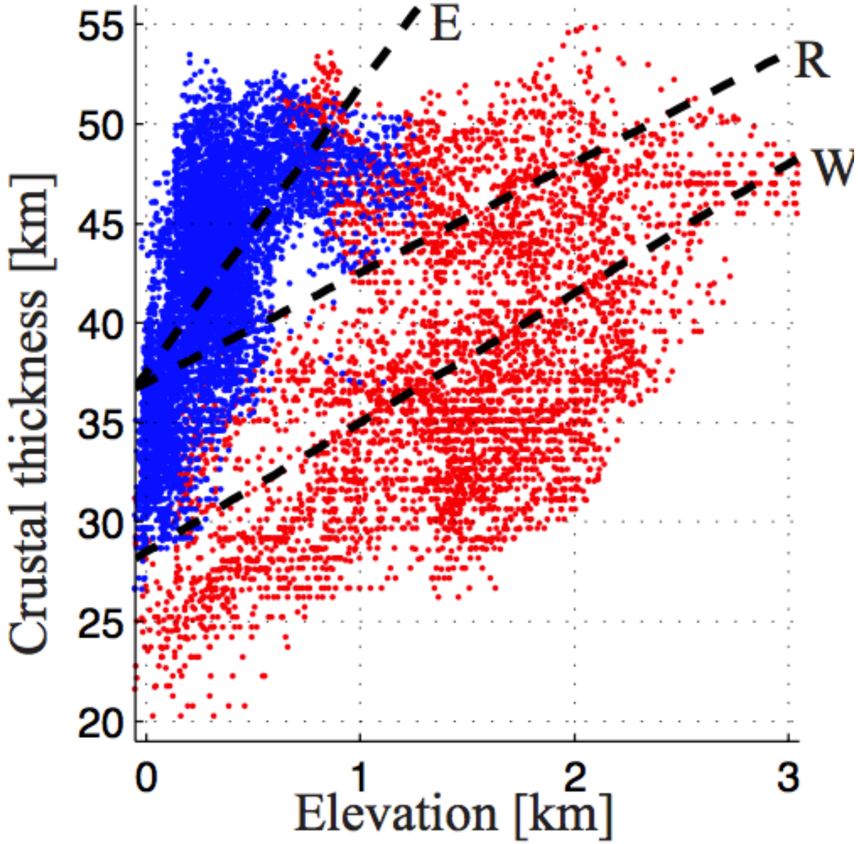


Cumulative U.S. correlation coefficient = 0.14
- random numbers often better





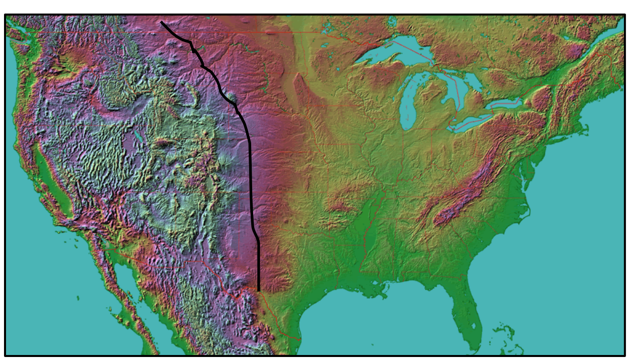
U.S. Crust thickness versus elevation

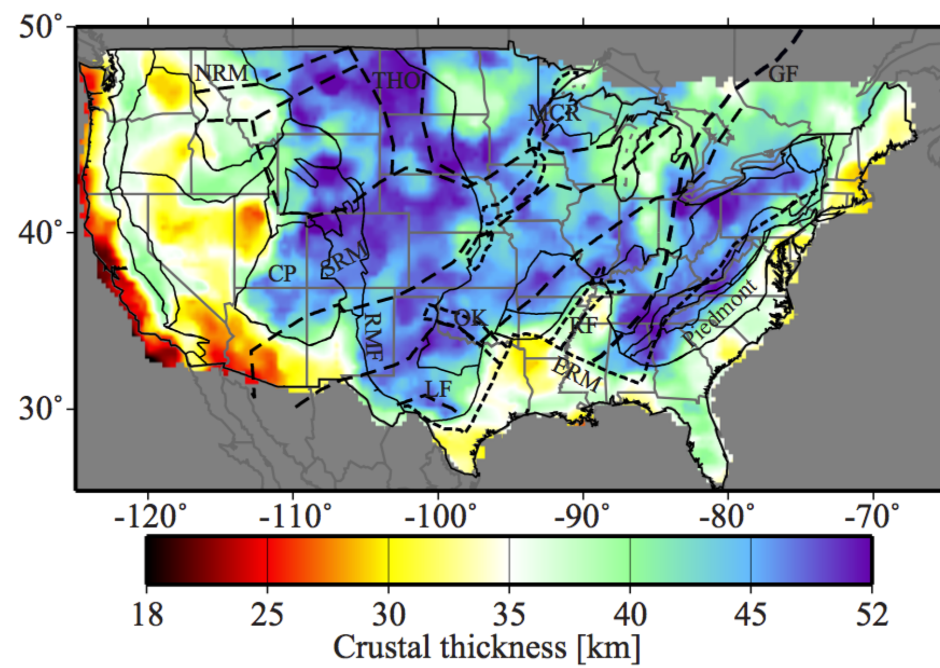


West of Rocky Mountain Front (red), correlation = 0.51

East of RMF (blue), correlation = 0.61

→2 distinct populations east/west of RMF with much greater correlation
→Greater scatter west of RMF



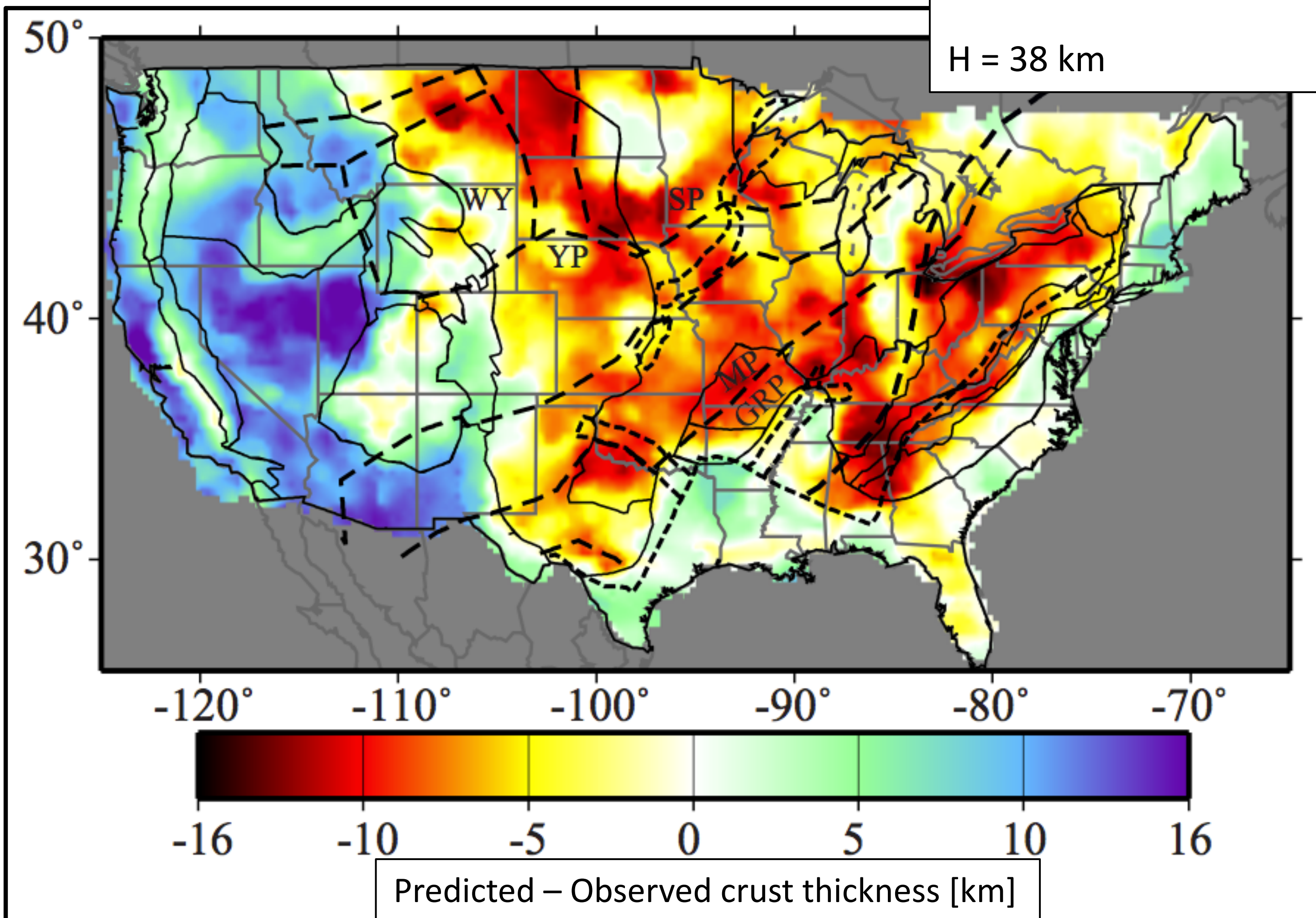


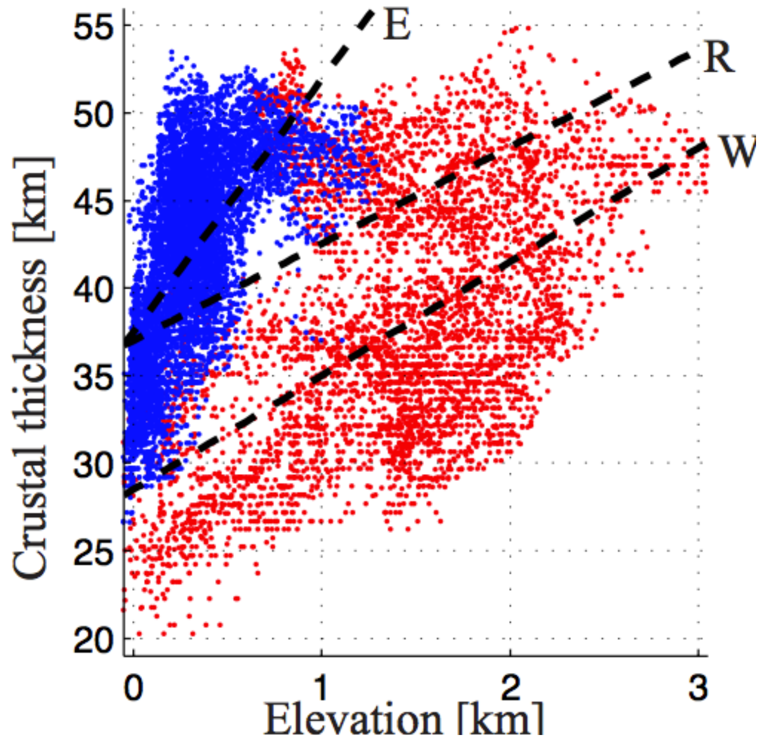
Evaluating Airy Isostasy with global reference densities

$$\text{Airy Crust thickness} = H + \left(\frac{\rho UC}{\rho UM - \rho LC} \right) \text{Elevation}$$

$\rho UC = 2.6\ g/cm^3$
$\rho LC - 2.9\ g/gm^3$
$\rho UM - 3.38\ g/cm^3$
PREM [Dziewonski and Anderson, 1981]

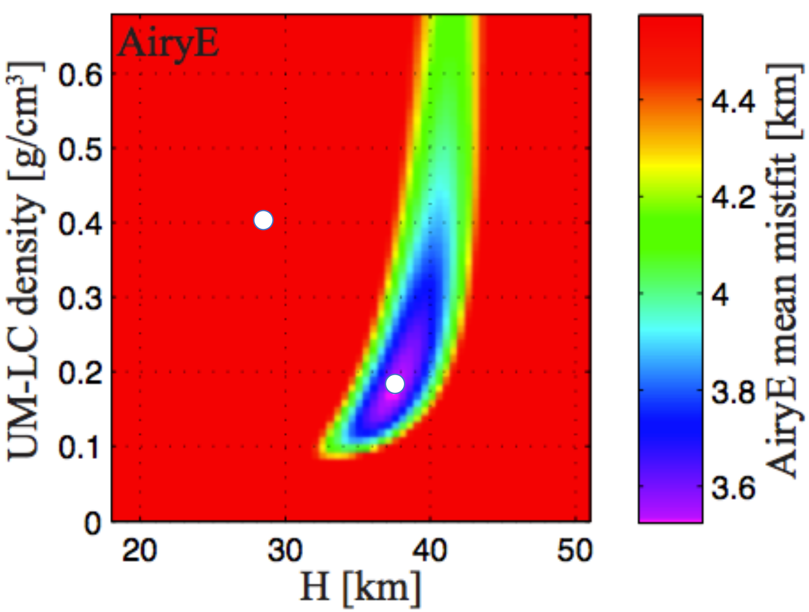
H = 38 km

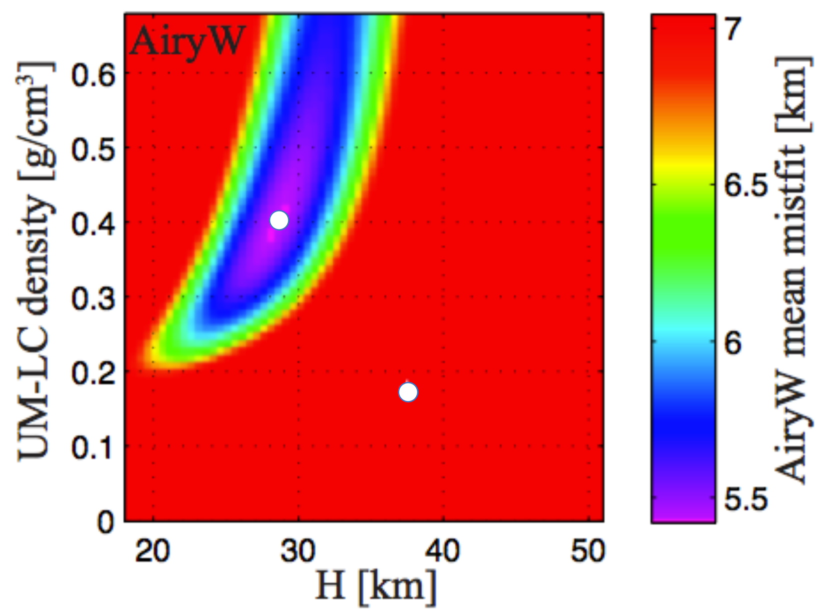




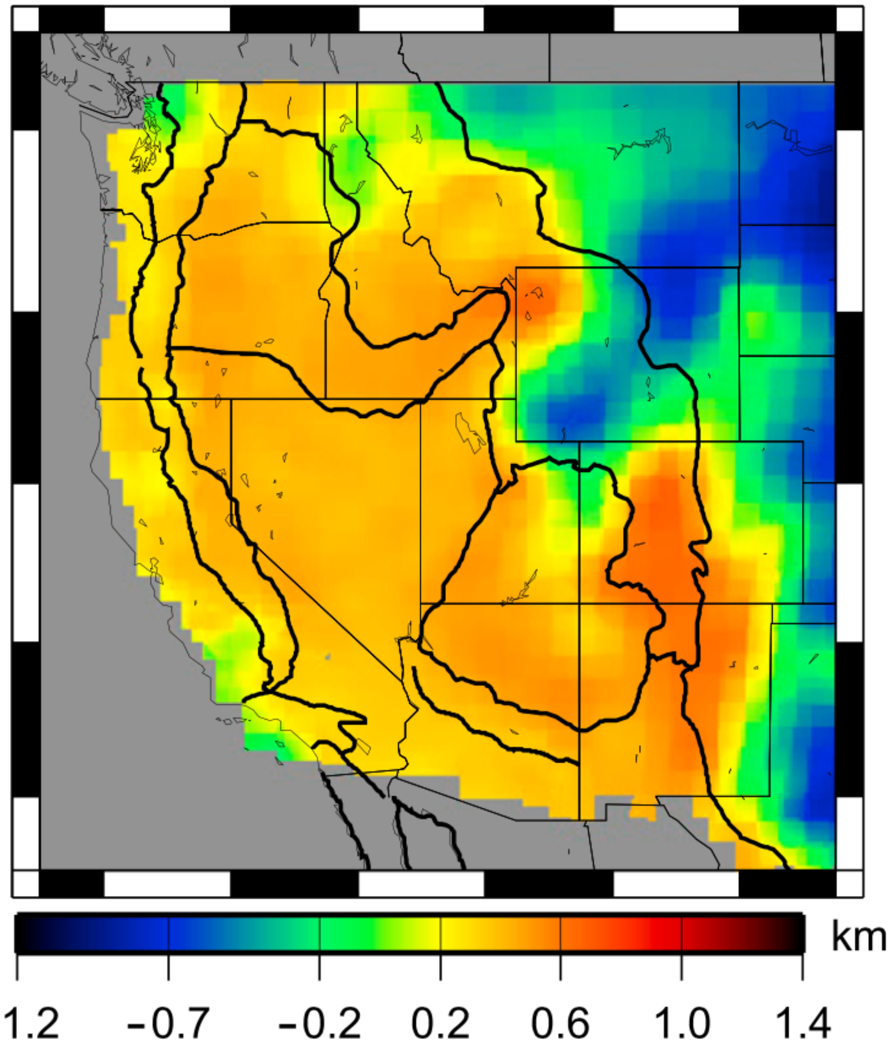
What density structure can explain the trends east and west of the Rocky Mountain Front?

$$\text{Airy Crust thickness} = H + \left(\frac{\rho UC}{\rho UM - \rho LC}\right)\text{Elevation}$$





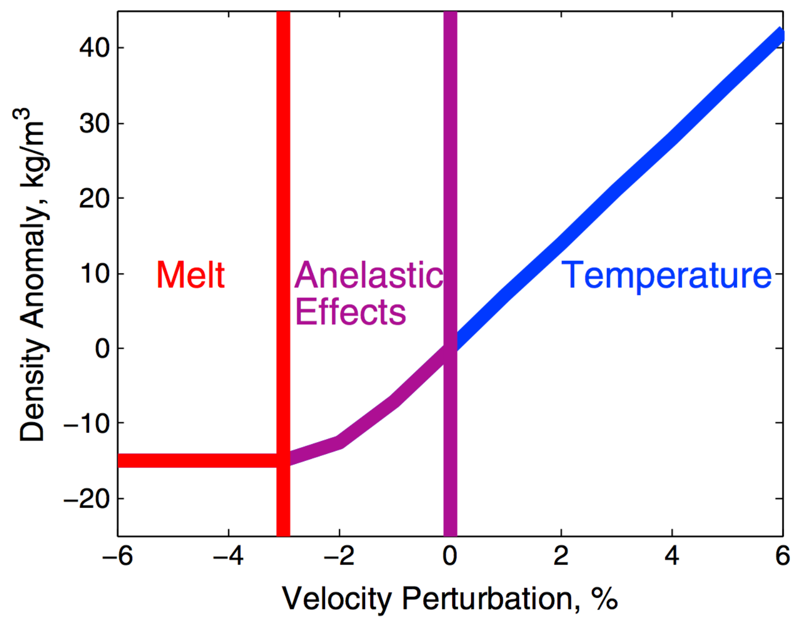
Lower reference crust thickness value reflects long-wavelength mantle buoyancy, consistent with thermal origin



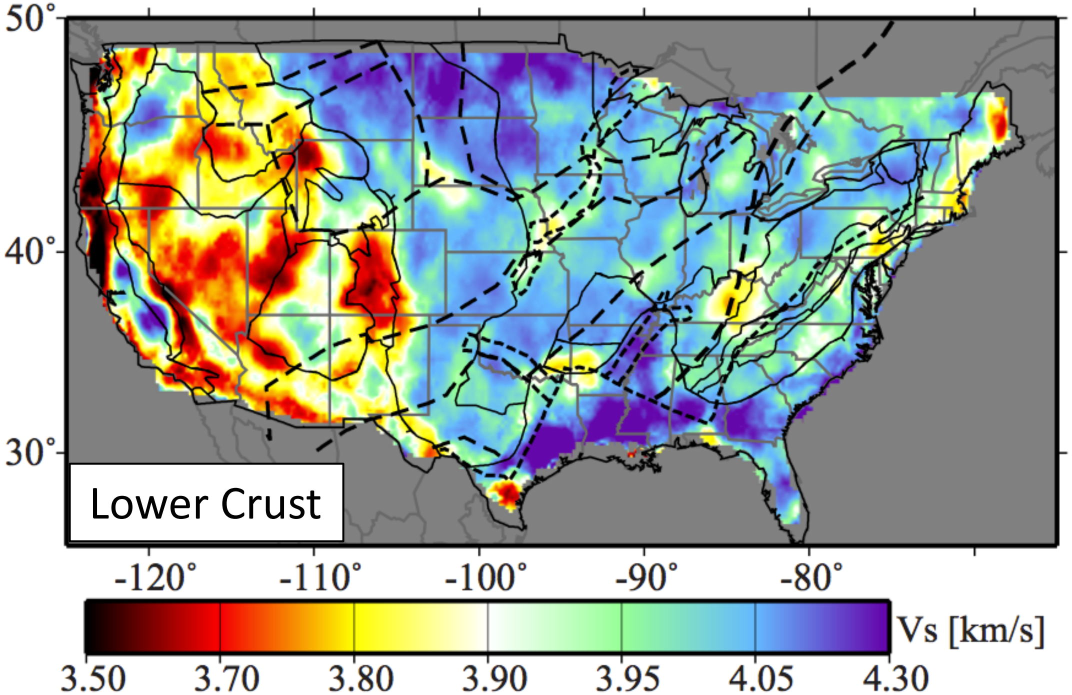
Levandowski et al., 2014

~500-700 m of thermal support from upper mantle

Extreme low velocity areas (< ~4.25) are truncated to address partial melts effects [Levandowski et al., 2014]

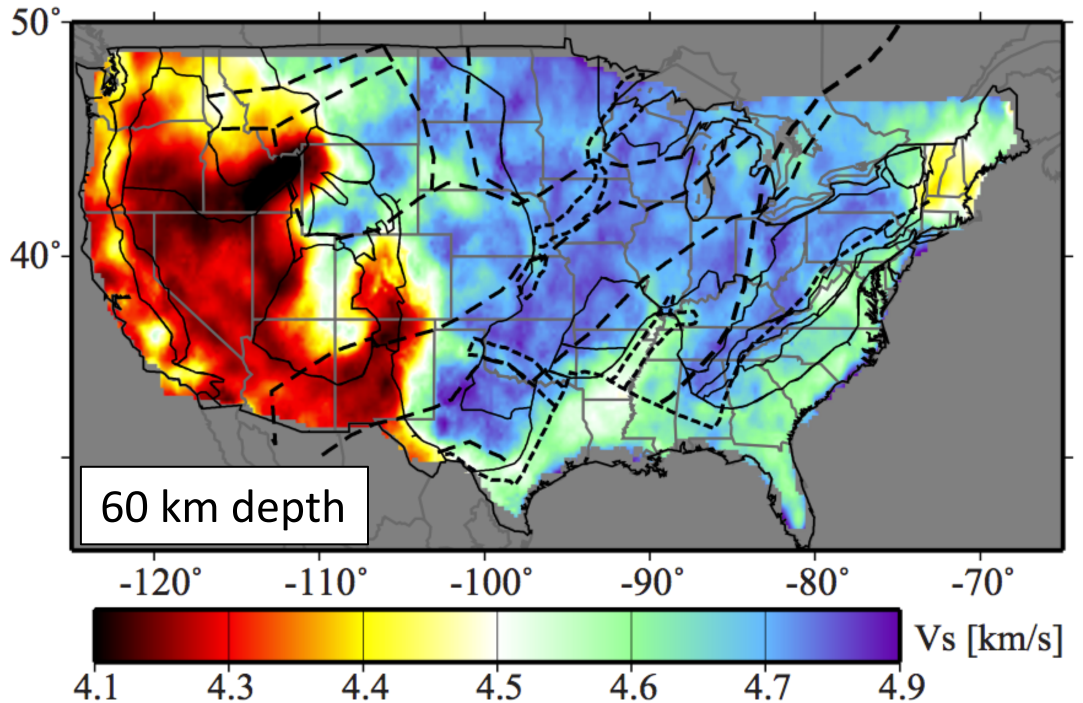


Is the lower crust or uppermost mantle primarily to blame?

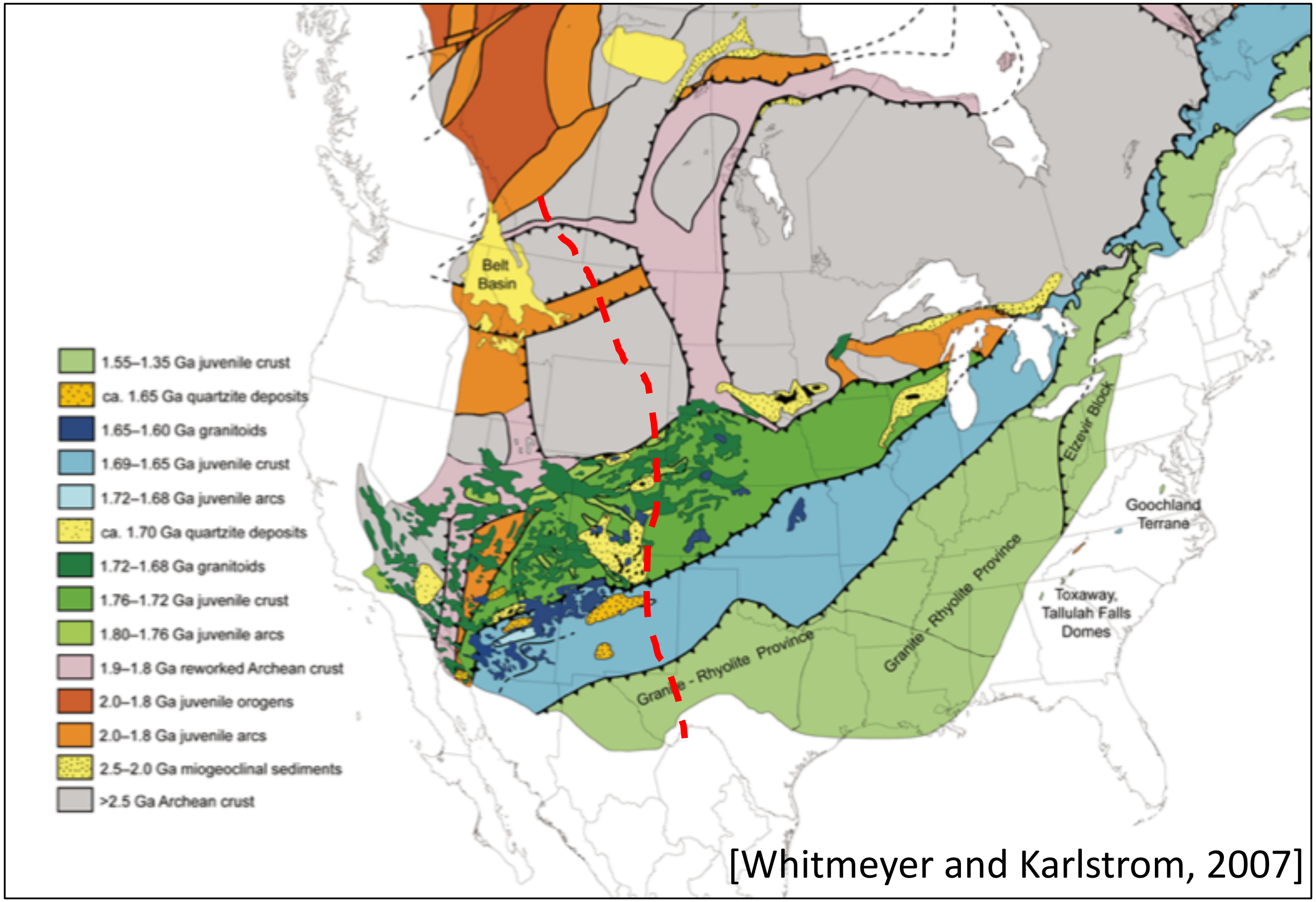


ρUM – ρLC west of the RMF (0.4 g/cm³) is about double that east of the RMF (0.18 g/cm³)

If ρUM west of the RMF is less than or equal to that east of the RMF, then the difference must be primarily attributed to the lower crust



Location of contrast at the RMF implies reduction of lower crust densities by Laramide to post-Laramide processes (heating, hydration?, delamination) rather than a product of Precambrian inheritance



[Whitmeyer and Karlstrom, 2007]

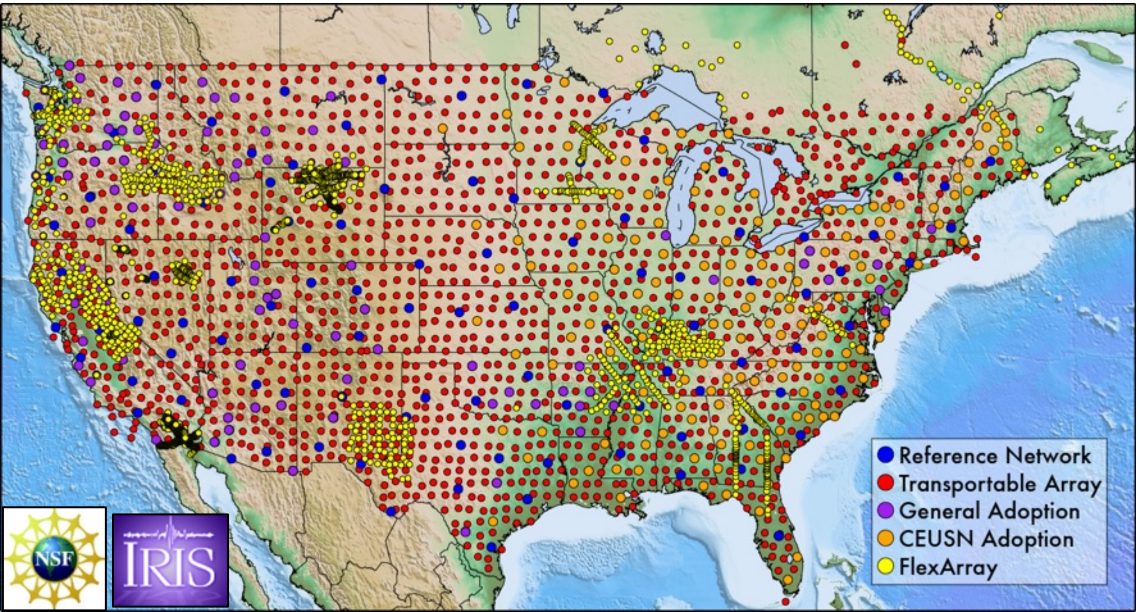
Links between seismic structure and tectonic & magmatic activity across the continent

- Yellowstone Hotspot: clearest (~only) example of super-adiabatic upwelling

- Long-lived magmatic scars and small-scale convection in the eastern U.S.
  - Ongoing edge convection and/or localized delamination

- Supporting topography of young and old orogens
  - Larger crust/mantle density contrast west of Rocky Mountain Front
  - Pervasive Laramide and post-Laramide modification of lower crust
  - Small density contrast east of Appalachian, Grenville difficult to explain without mafic lower crust

Broadband data at the IRIS DMC



Outstanding data resources.
Lots left to test and explore!