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

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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

Broadband data at the IRIS DMC

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

- High $^3$He/$^4$He (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 exceptional
USArray tomography beneath Yellowstone

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

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

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

- ~48 million years since magmatism [Mazza et al., 2014]
- Very close spatial correlation

Northern Appalachian or New England Anomaly

- ~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.

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]

Mazza et al., 2014
Long-lived magmatic scars in the eastern U.S.

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

~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.

~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]

Pollitz and Mooney, 2016

Menke et al., 2016
Long-lived magmatic scars in the eastern U.S.

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

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

\rho_{UC} = 2.6 \text{ g/cm}^3
\rho_{LC} = 2.9 \text{ g/gm}^3
\rho_{UM} = 3.38 \text{ g/cm}^3

PREM [Dziewonski and Anderson, 1981]

H = 38 \text{ km}
What density structure can explain the trends east and west of the Rocky Mountain Front?

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.

~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?

\[ \rho_{UM} - \rho_{LC} \text{ west of the RMF (0.4 g/cm}^3) \text{ is about double that east of the RMF (0.18 g/cm}^3) \]

If \( \rho_{UM} \) 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.

60 km depth
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!