Small-scale Asthenospheric Upwelling along the Passive Margin of Eastern North America

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Franconia Notch
White Mountains of New Hampshire
Triassic - Jurassic Granites ... Late Mesozoic Uplift
Whiteface Mountain
Adirondack Mountains of New York
Late Cretaceous Uplift
Trimble Knob
western Virginia
Early Tertiary Basaltic Volcanism
Armchair Thinking ...
Armchair Thinking ...  

Significant geologic events have occurred since rifting
Armchair Thinking ...

Probably not “Plate Tectonics” per se
Armchair Thinking ...

Too energetic to involve just the “crust” or even just the “lithosphere”
Armchair Thinking ... So probably involve interaction with the asthenosphere
Armchair Thinking ...

What’s the nature of the interactions?
Armchair Thinking ...

Is there a unifying principle involved?
Armchair Thinking ...

Are these events just “things of the past” or are they continuing today?
Taylor & Toksoz 1979

$\Delta V_p (\%)$
Comparable In Intensity to Area Around Rio Grande Rift (New Mexico)
The Asthenosphere: 200 km depth, Vs

Northern Appalachian Anomaly
Central Appalachian Anomaly
Southern Coastal Anomaly
Northern Gulf Anomaly

Schmandt and Lin (2014)
The Asthenosphere: ~100 km depth $V_r$ at 100s period

Jin and Gaherty (2016)
Northern Appalachian Anomaly
Central Appalachian Anomaly
Southern Coastal Anomaly

Northern Gulf Anomaly

Vs at ~100 km depth

Some Primary Data: Teleseismic S Delays

(C) $\Delta T_s$ (km)

(D) $\Delta T_s$ (km)
76 seconds

300 km

Normal asthenosphere

Vs 4.5 km/s
Normal asthenosphere

300 km

S wave S wave S wave S wave S wave

76 seconds

Vs 4.518 km/s

Hot asthenosphere

S wave S wave S wave S wave S wave S wave

5% slow

76+4 seconds

Vs 4.275 km/s
Estimate of temperature change $\Delta T$

\[ V_s(200) = 4.518 - (5.596 \times 10^{-4}) \Delta T \]

Cammarano et al. 2003

\[ V_s = 4.275 \text{ km/s} \quad \text{implies} \quad \Delta T = 430 \text{ degC} \]
Can we be sure the NAA is in the asthenosphere?
Can we be sure the NAA is in the asthenosphere?
Parallax is about 200 km

Feature is about 200 km deep (asthenospheric)
Can we be sure these anomalies are thermal?

\[ \frac{\Delta V_p}{\Delta T} \]

\[ \frac{\Delta V_s}{\Delta T} \]

\[ \frac{\Delta V_p}{\Delta V_s} = 1 \]

Cammarano et al. 2003
Can we be sure the really thermal?

\[ \frac{\Delta V_p}{\Delta T} \]

\[ \frac{\Delta V_s}{\Delta T} \]

\[ \frac{\Delta V_p}{\Delta V_s} = 1.8 \]

Compositional

\[ \frac{\Delta V_p}{\Delta V_s} = 1 \]

Thermal

Cammarano et al. 2003
$$\frac{\Delta V_s}{\Delta V_p} \text{ not the same as } \frac{\Delta T_s}{\Delta T_p}$$

$$\frac{\Delta T_p}{T_{po}} = -\frac{\Delta V_p}{V_{po}} \quad \text{Percent change equal and opposite}$$

$$\frac{\Delta T_s}{\Delta T_p} = - \left(\frac{V_{p0}}{V_{po}}\right)^2 \frac{\Delta V_s}{\Delta V_p}$$

**Thermal**

$$\frac{\Delta V_s}{\Delta V_p} = 1 \text{ then } \frac{\Delta T_s}{\Delta T_p} = 3.35$$

**Compositional**

$$\frac{\Delta V_s}{\Delta V_p} = 1/1.83 \text{ then } \frac{\Delta T_s}{\Delta T_p} = 1.83$$
NAA
Northern Appalachian Anomaly
Slope: $3.98 \pm 0.26$ (95 %)

Clearly thermal
NGA
Northern Gulf Anomaly
Slope: 3.48 ± 0.69 (95 %)
Clearly thermal
SCA  
Southern Coastal Anomaly  
Slope: $3.84 \pm 0.20$ (95 %)  
Clearly thermal
Further corroboration that they are thermal

No loss of amplitude
Further corroboration that they are thermal

Absorption of energy due to internal friction
Further corroboration that they are thermal

Absorption of energy due to internal friction

LOW Q = HIGH Attenuation
Further corroboration that they are thermal

What you actually measure is tee-star

\[ t^* = \frac{x}{(v Q)} \]

HIGH \( t^* \) = HIGH Attenuation
t* of teleseismic S wave

average asthenospheric Qs=80

thickness of asthenosphere H=300 km

shear wave velocity of asthenosphere Vs=4.5 km/s

Assuming asthenosphere is primary source of attenuation

\[ t^* = \frac{2 \times 300}{80 \times 4.5} = 1.7 \text{ s} \]
attenuation increases with temperature

<table>
<thead>
<tr>
<th></th>
<th>Qs</th>
<th>t* (200)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average lithosphere</td>
<td>800</td>
<td>0.06</td>
</tr>
<tr>
<td>Average asthenosphere</td>
<td>80</td>
<td>0.6</td>
</tr>
<tr>
<td>Really hot asthenosphere</td>
<td>20</td>
<td>2.2</td>
</tr>
<tr>
<td>Partially molten</td>
<td>10</td>
<td>4.4</td>
</tr>
</tbody>
</table>
Qs=10

Qs=100

\( \log_{10}(\text{attenuation, } 1/Q_s) \)

Temperature, °C

Dong and Menke 2018
Jackson and Faul (2010)
Is the asthenosphere flowing upward beneath the NAA and other anomalies?
Olivine – the most common upper mantle mineral

Mantle Flow

Strong Splitting

S wave

4.87 and 4.42

A axis

C axis
Olivine – the most common upper mantle mineral

- A axis
- C axis
- Mantle Flow
- S wave
- 4.89 and 4.87
- Weak Splitting
Explained by Olivine Alignment Along Flow

strong  weak  strong
Radial, all the same, measure of data quality

Levin et al. 2017, Fig 2
“Edge Convection” is a Plausible Driver of the Upwelling
King and Ritsma (2000)
However SCA spatially larger NAA more intense in $\Delta V_s$
Is the NAA asthenosphere interacting with the lithosphere?
Proxy for lithospheric velocity

Rayl. 40s

Ekstrom 2017
peak at 65 km

Nettles & Dziewonski, 2008
The NAA’s asthenospheric signal is huge

Can we be sure it is not causing an artifact within the lithospheric signal?
The NAA’s asthenospheric signal cannot account for the lithospheric signal.

A decrease in lower – but not upper – lithospheric velocities best fits the data.
lithosphere thinner
asthenosphere hotter
heat flow higher

30% increase in geothermal gradient
30% increase in heat flow
time needed for the top part lithosphere to conductively warm

\[ \kappa = 5 \times 10^{-7} \text{ m}^2/\text{s} \]

50 km

67 my
Mt Washington, White Mts area

B) QTQt Inverse Model

Best-fit thermal histories for samples V14-V17

95% credible interval

Amidon et al. 2016
Fluids could reach the surface faster,
Without uniformly warming the surrounding rock ...
New Mindset for eastern North American Geology

Post-rift Activity is Presumed to be Related to Small-scale Asthenospheric Upwelling Until Proven Otherwise
Critical Questions

How stable are the positions of the convection cells over tens of millions of years?

What percent of lithosphere has been altered?

Is the lower lithosphere really dense enough that its removal causes uplift?