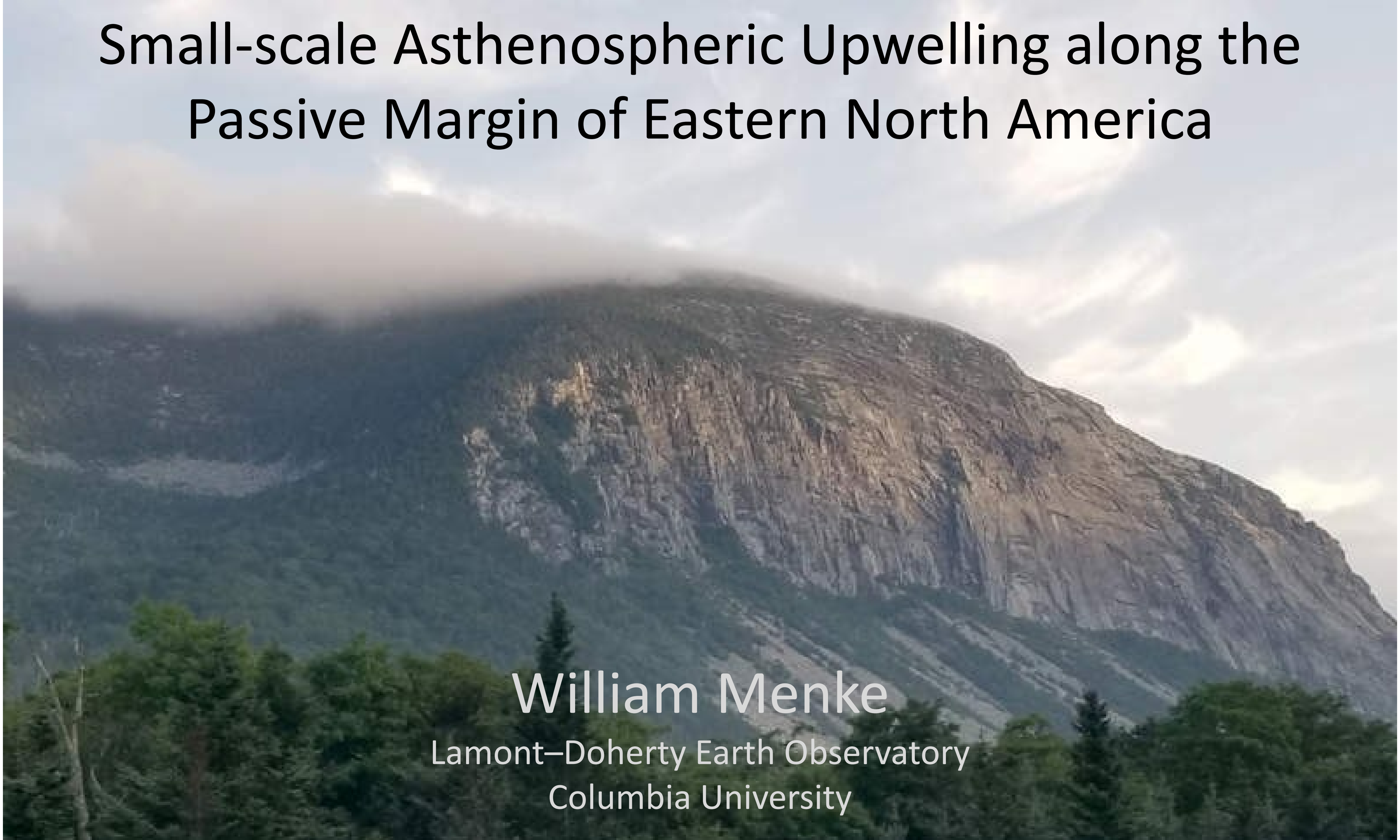
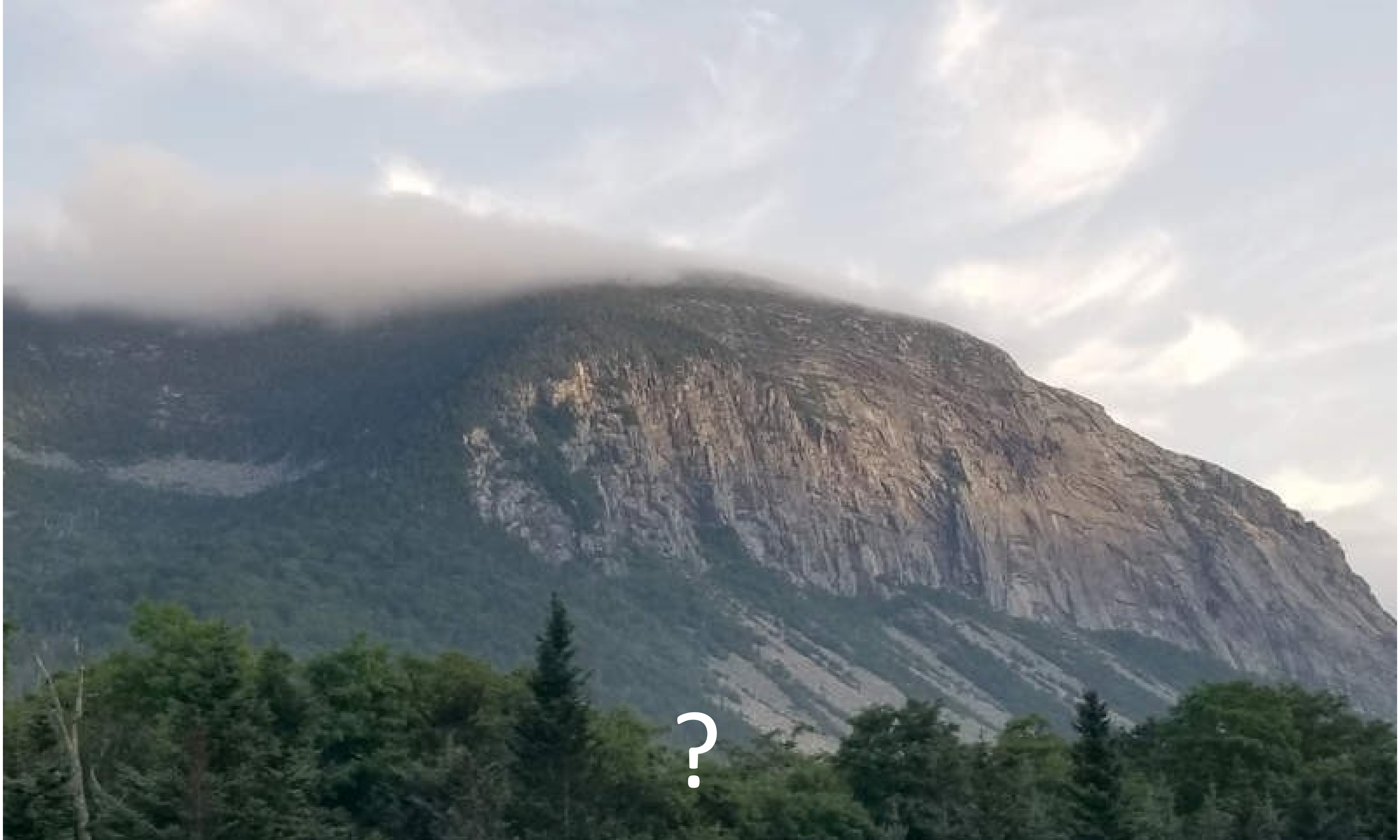
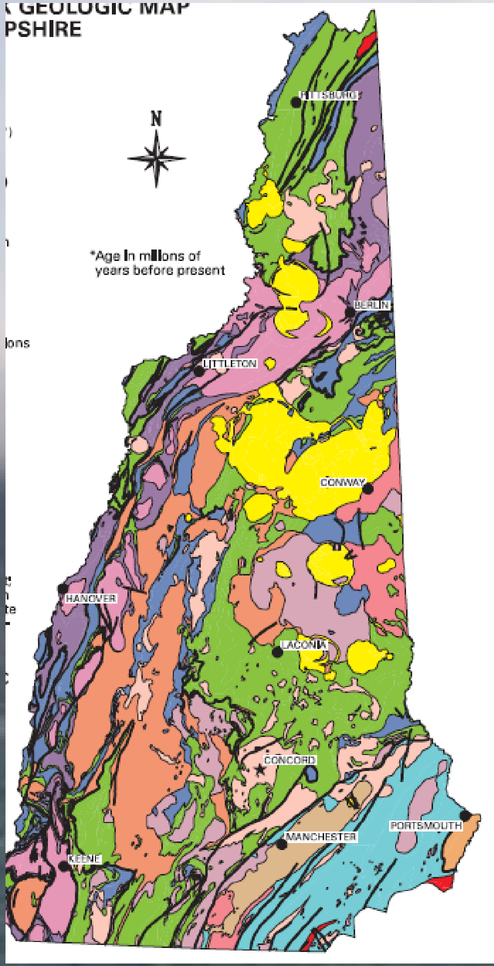


Small-scale Asthenospheric Upwelling along the Passive Margin of Eastern North America

William Menke
Lamont–Doherty Earth Observatory
Columbia University

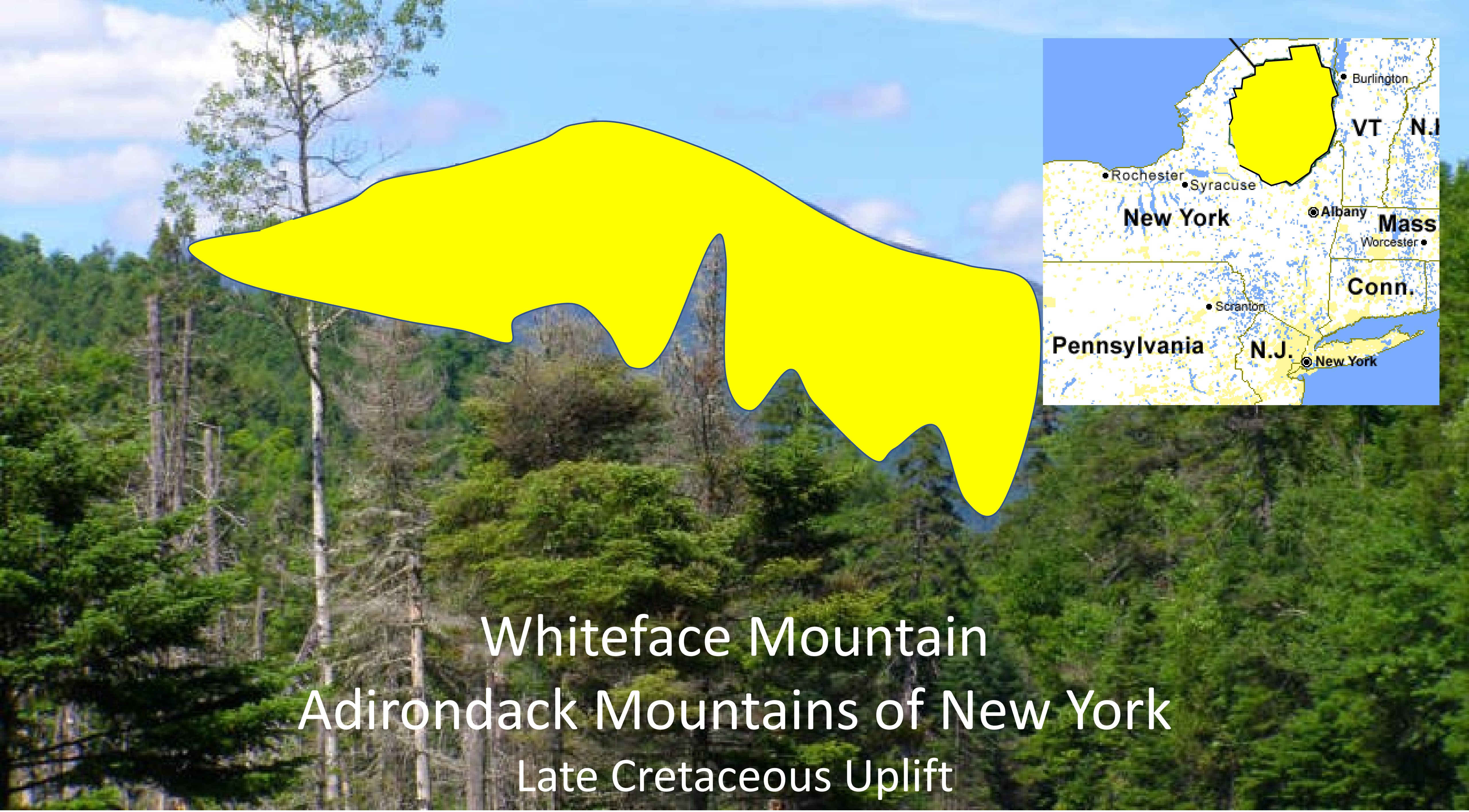


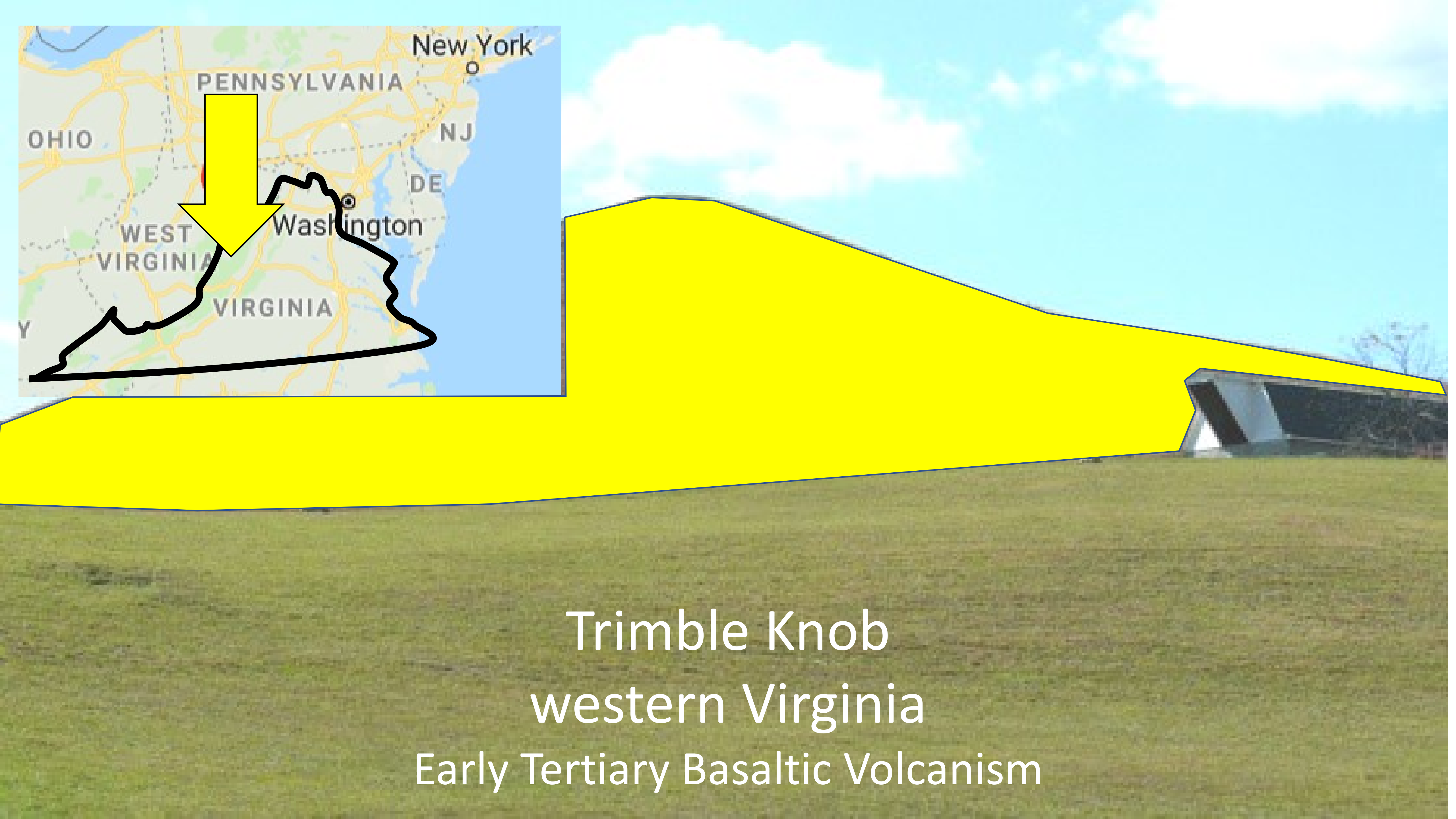


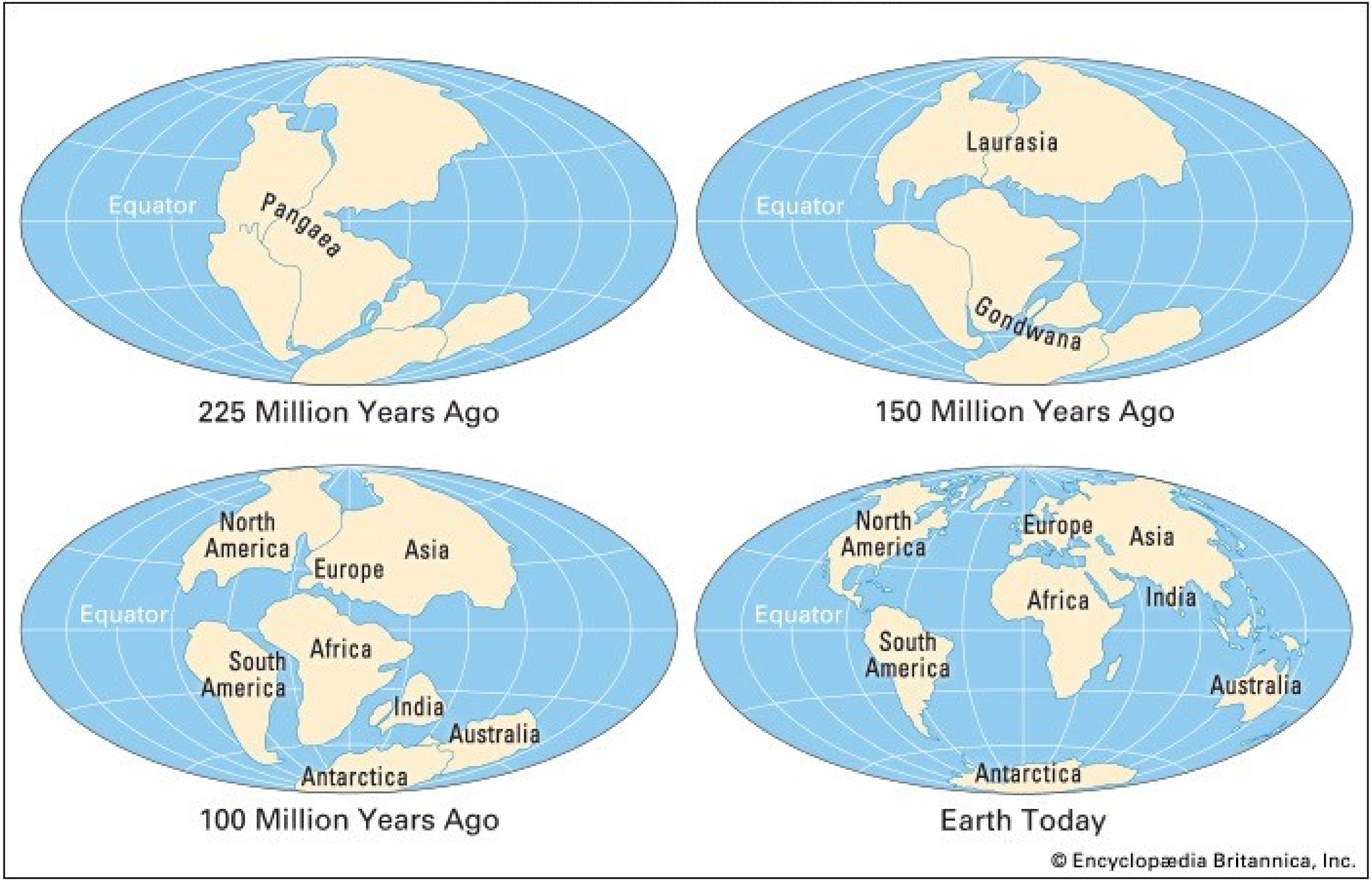
Franconia Notch

White Mountains of New Hampshire

Triassic - Jurassic Granites … Late Mesozoic Uplift


Burlington
VT
N.H
Rochester
Syracuse
New York
Albany
Mass
Worcester
Conn.
Scranton
Pennsylvania
N.J.
New York
Whiteface Mountain
Adirondack Mountains of New York
Late Cretaceous Uplift


New York
PENNSYLVANIA
OHIO
NJ
DE
Washington
WEST
VIRGINIA
VIRGINIA
Trimble Knob
western Virginia
Early Tertiary Basaltic Volcanism


Equator
Pangaea
225 Million Years Ago
Laurasia
Equator
Gondwana
150 Million Years Ago
North America
Asia
Europe
Equator
Africa
South America
India
Australia
Antarctica
100 Million Years Ago
North America
Europe
Asia
Equator
Africa
India
South America
Australia
Antarctica
Earth Today
© Encyclopædia Britannica, Inc.

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 …

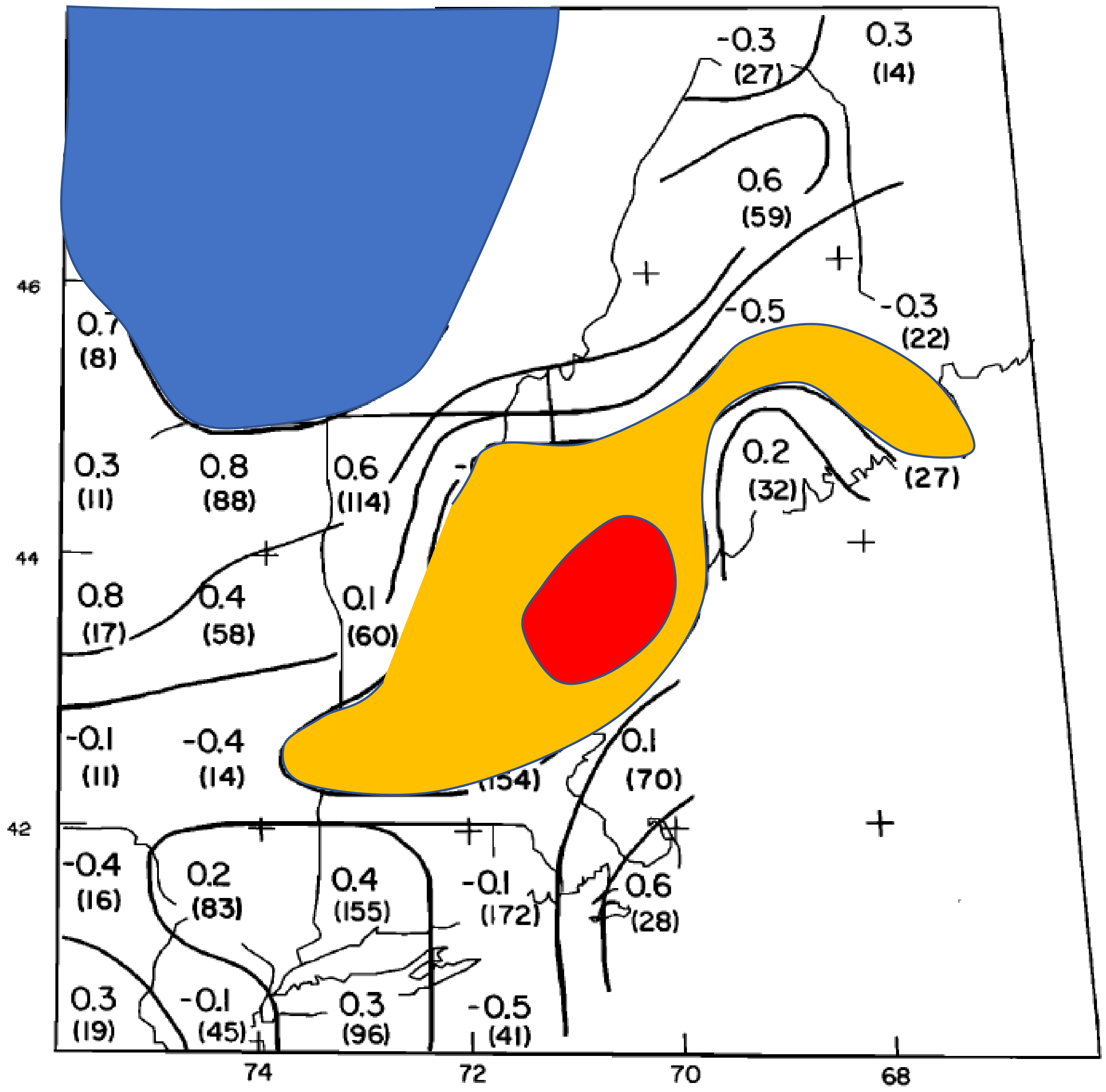
What’s the nature of the interactions?

Armchair Thinking …

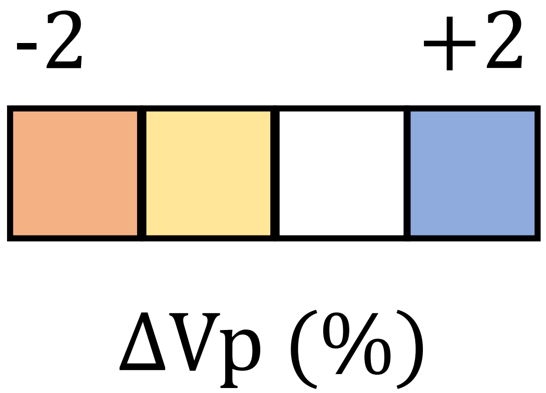
Is there a unifying principle involved?

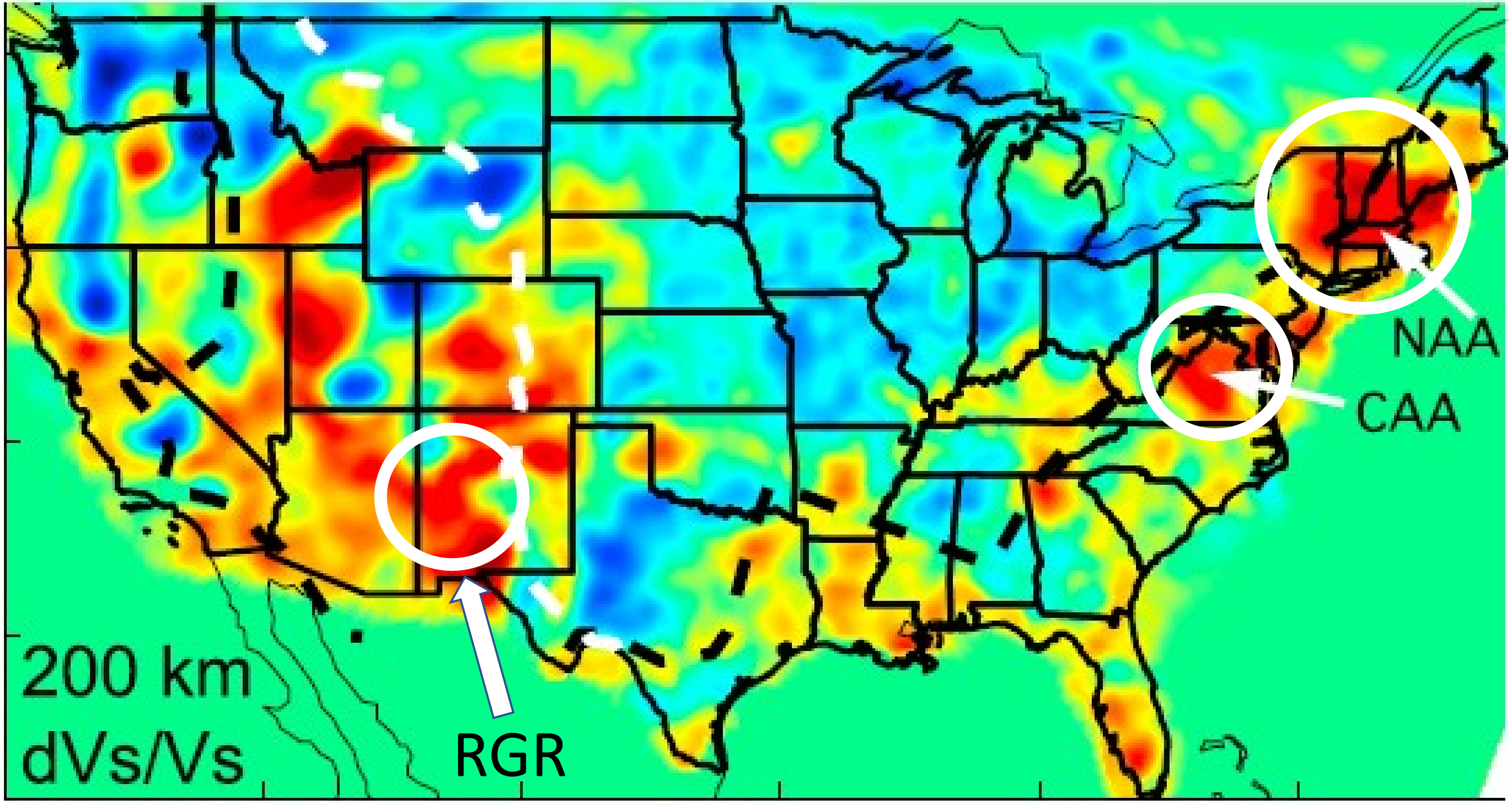
Armchair Thinking …

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



Taylor & Toksoz 1979 !

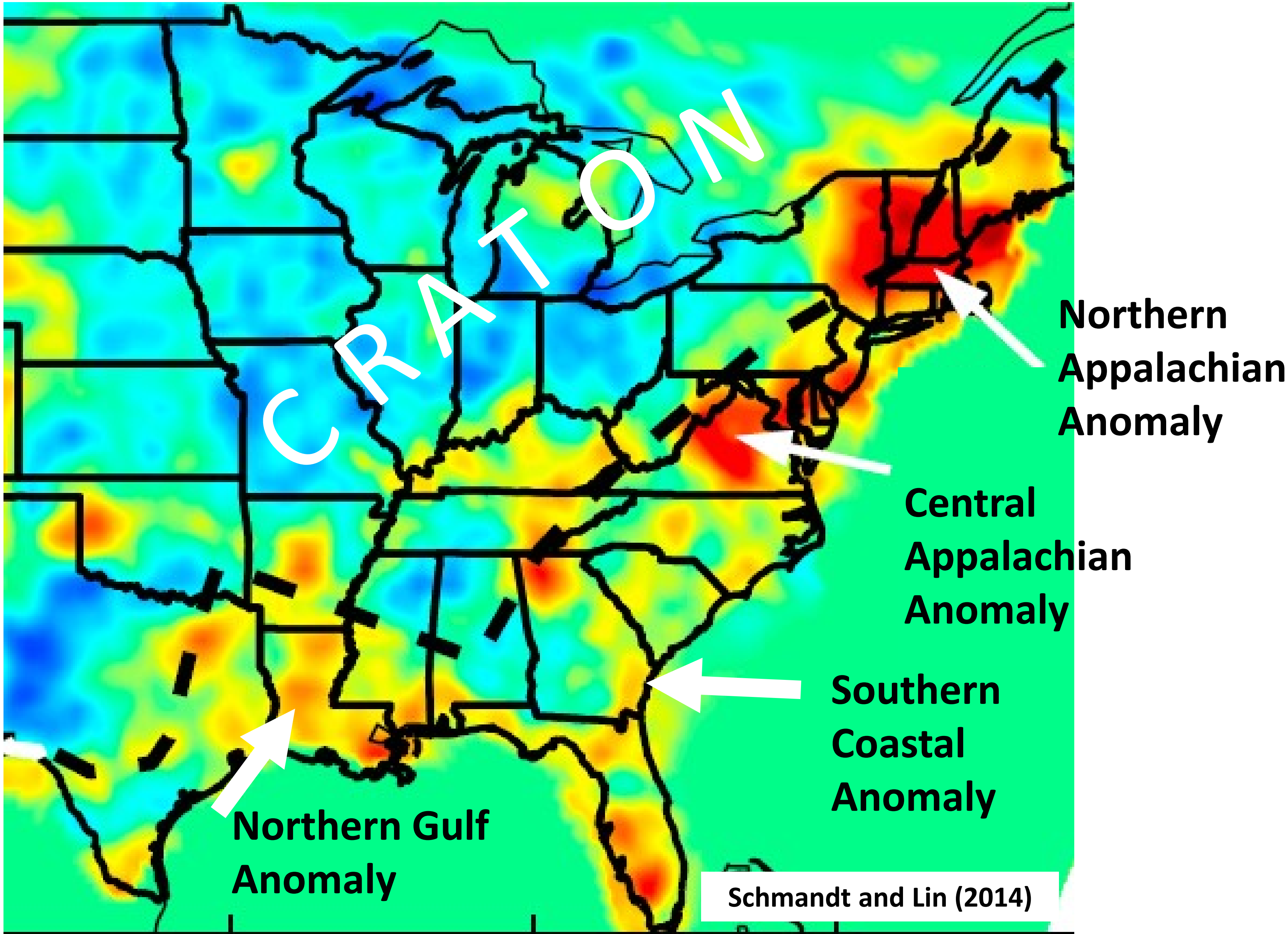




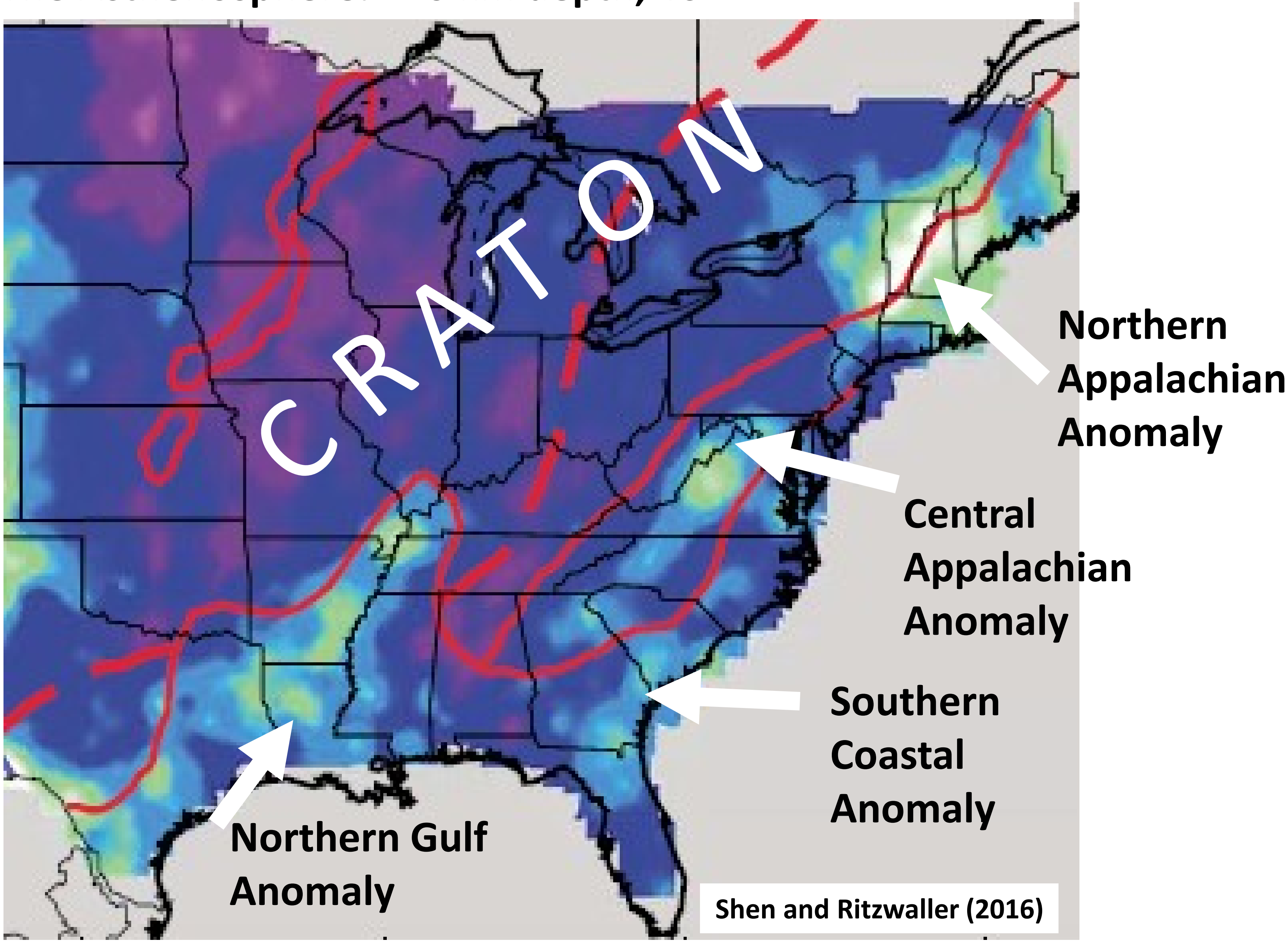
Schmandt and Lin (2014)

Comparable In Intensity to Area Around Rio Grande Rift (New Mexico)

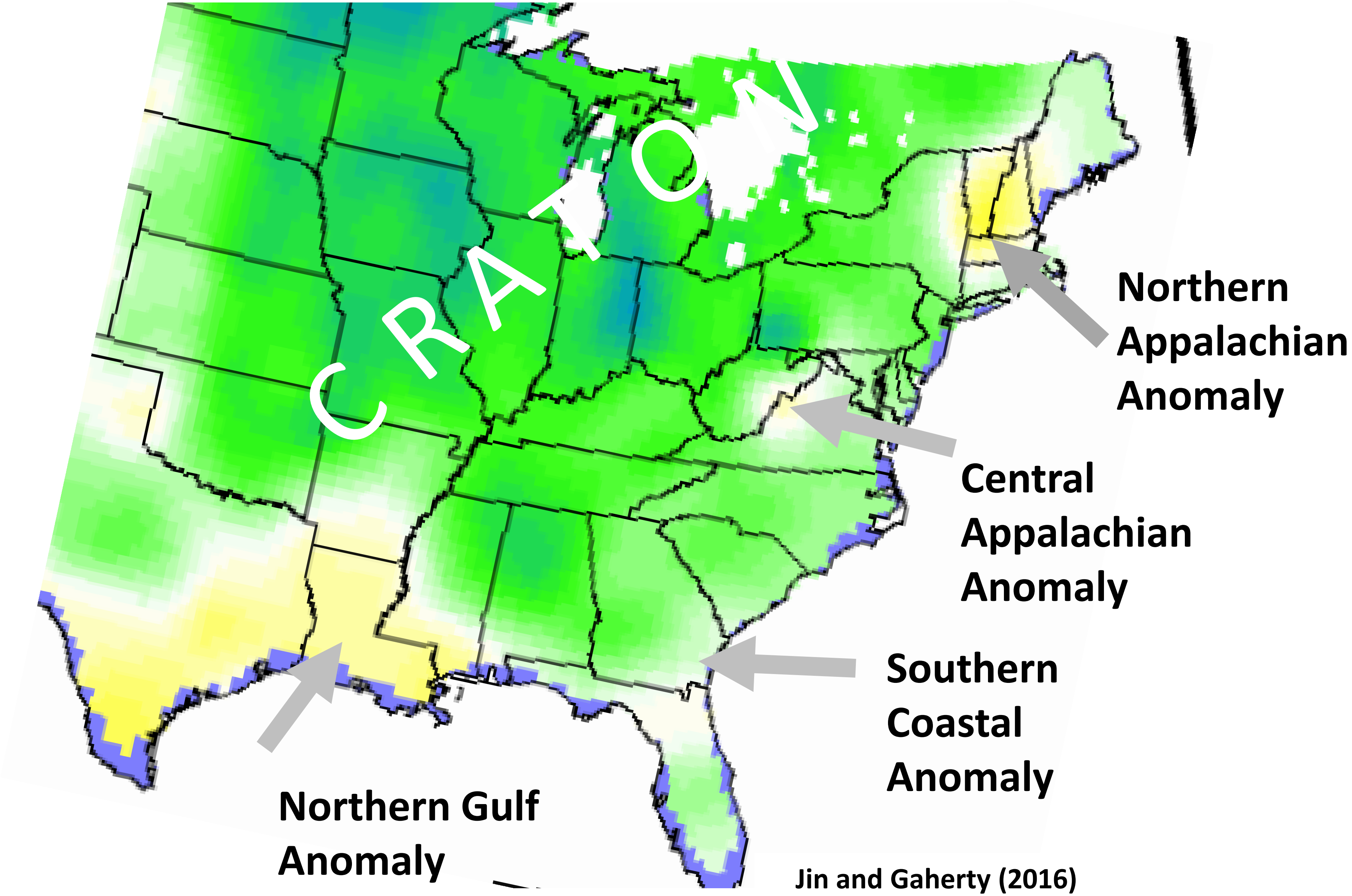
The Asthenosphere: 200 km depth , Vs



The Asthenosphere: 120 km depth, Vs

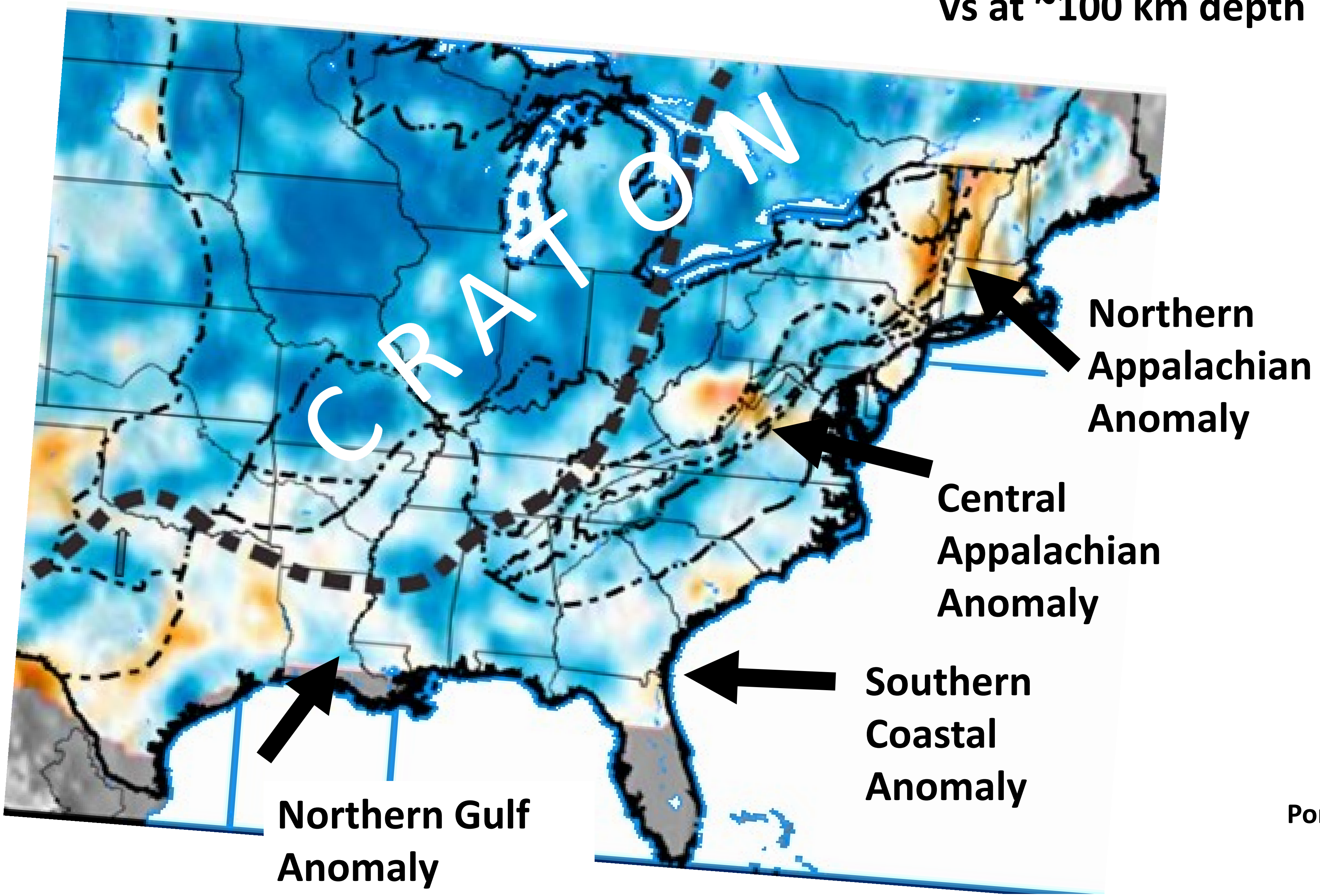


The Asthenosphere: ~100 km depth Vr at 100s period



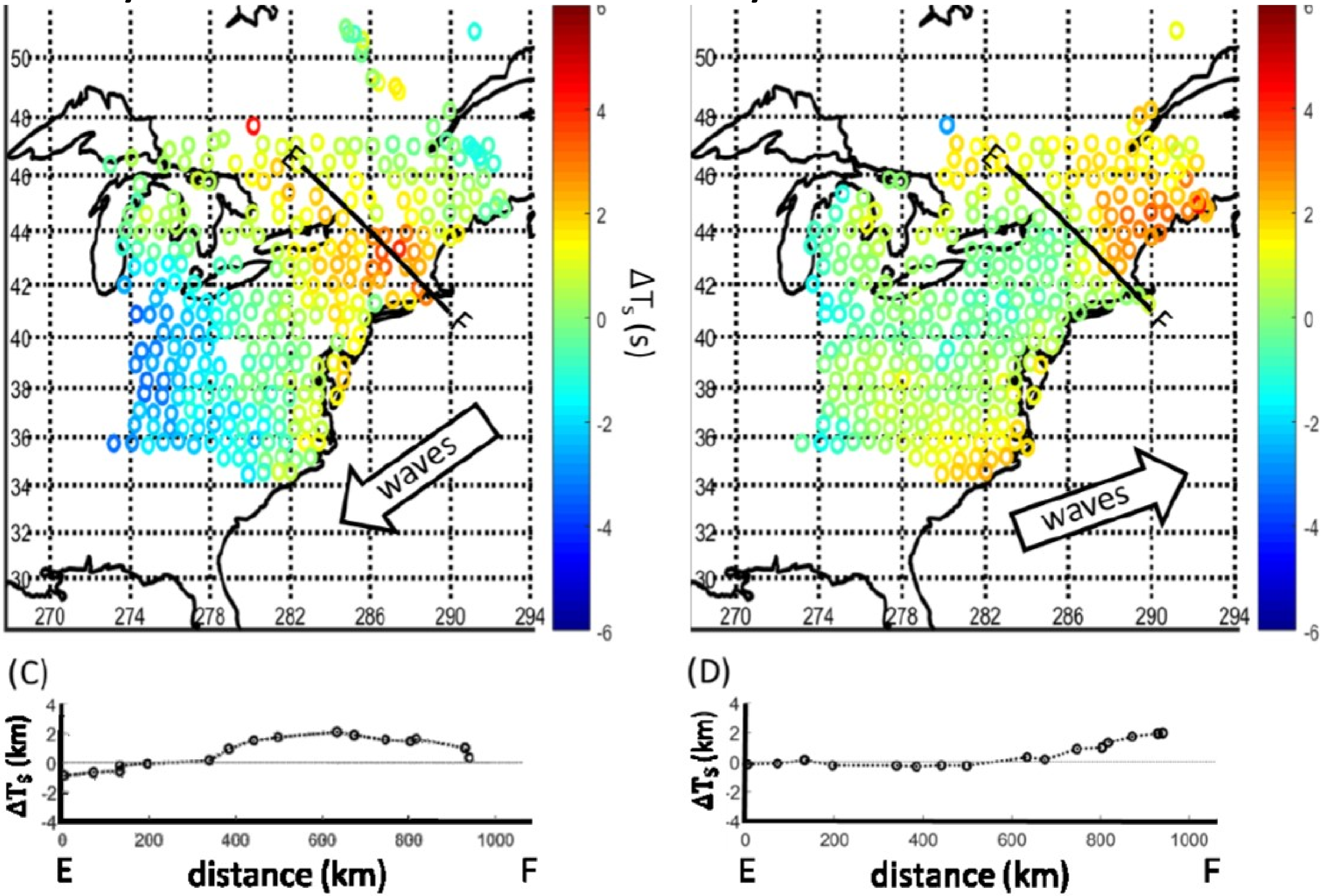
Jin and Gaherty (2016)

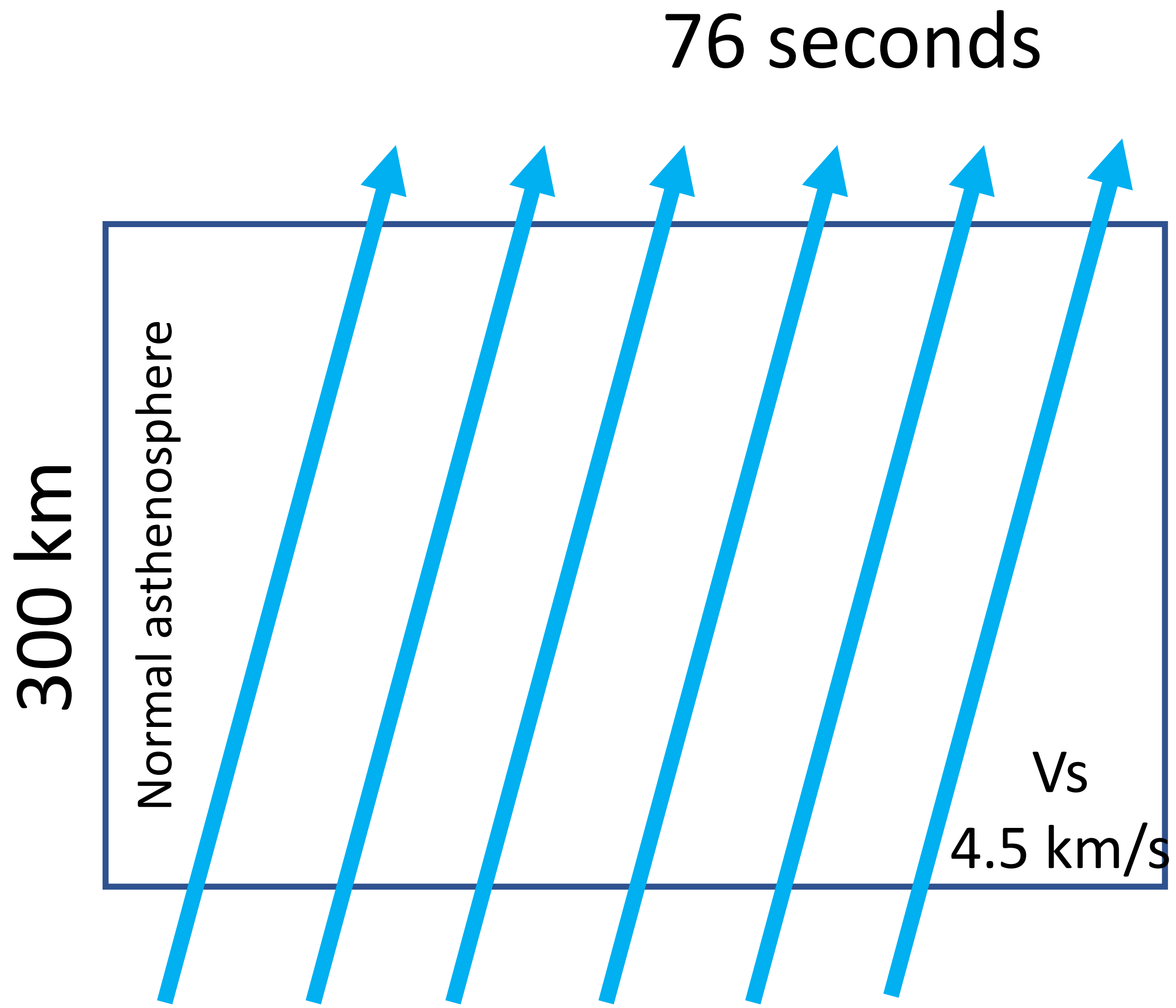
Vs at ~100 km depth

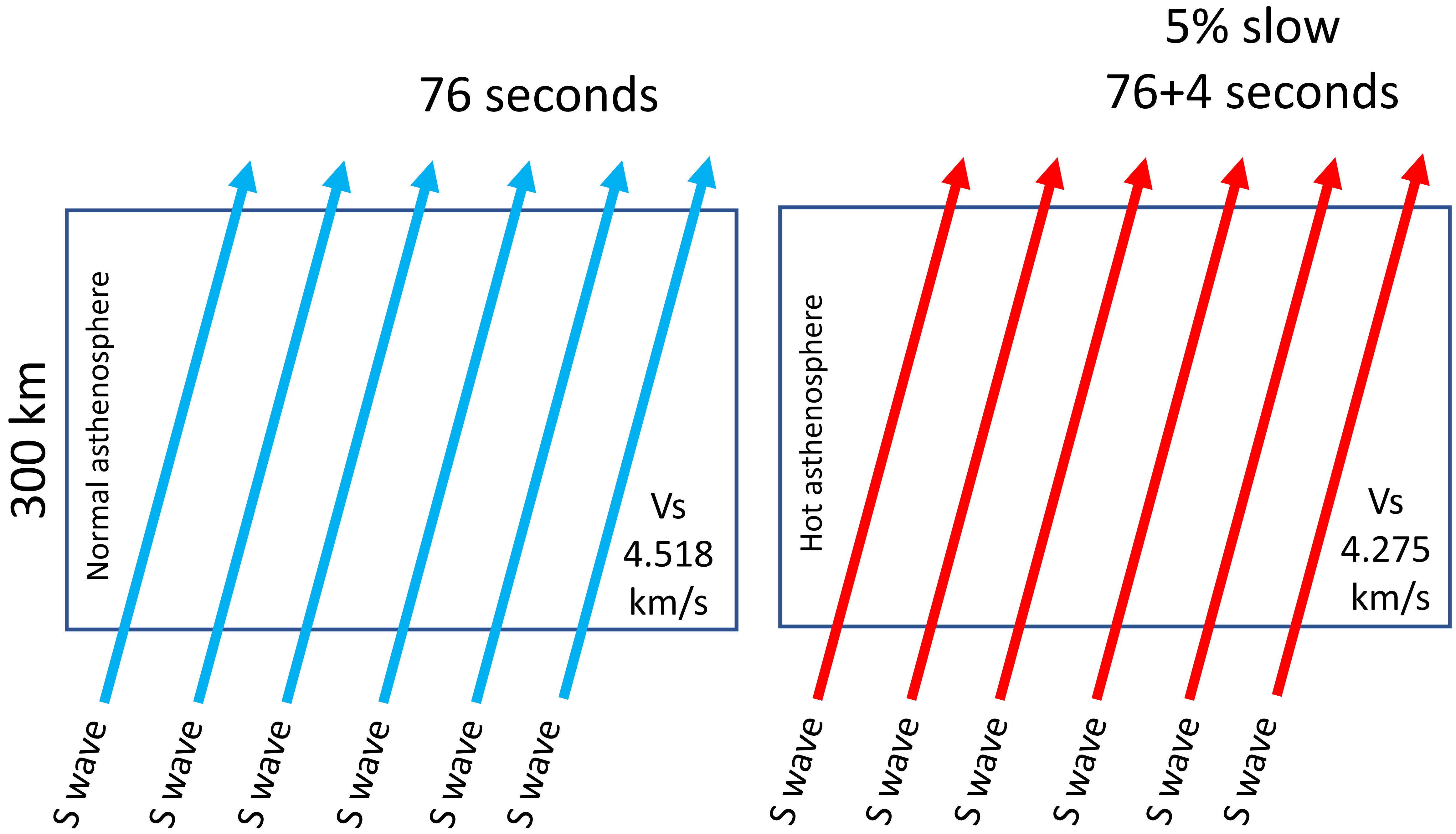


Porter et al (2015)

Some Primary Data: Teleseismic S Delays




76 seconds
300 km
Normal asthenosphere
Vs
4.5 km/s


5% slow
76 seconds
76+4 seconds
300 km
Normal asthenosphere
Hot asthenosphere
Vs
4.518
km/s
Vs
4.275
km/s
S wave
S wave
S wave
S wave
S wave
S wave
S wave
S wave
S wave
S wave
S wave
S wave

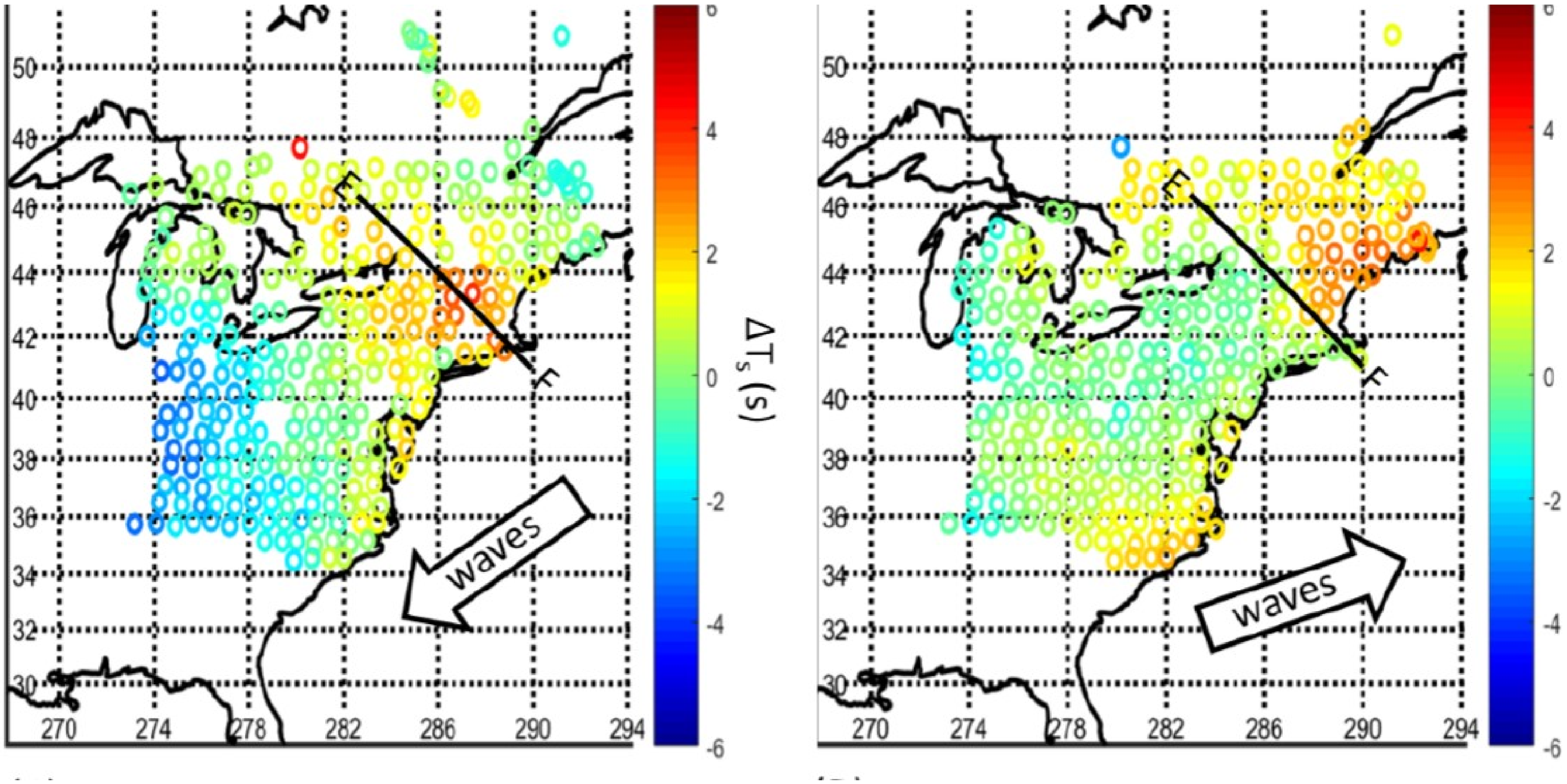
Estimate of temperature change ΔT

$$V_S(200) = 4.518 - (5.596 \times 10^{-4})\,\Delta T$$

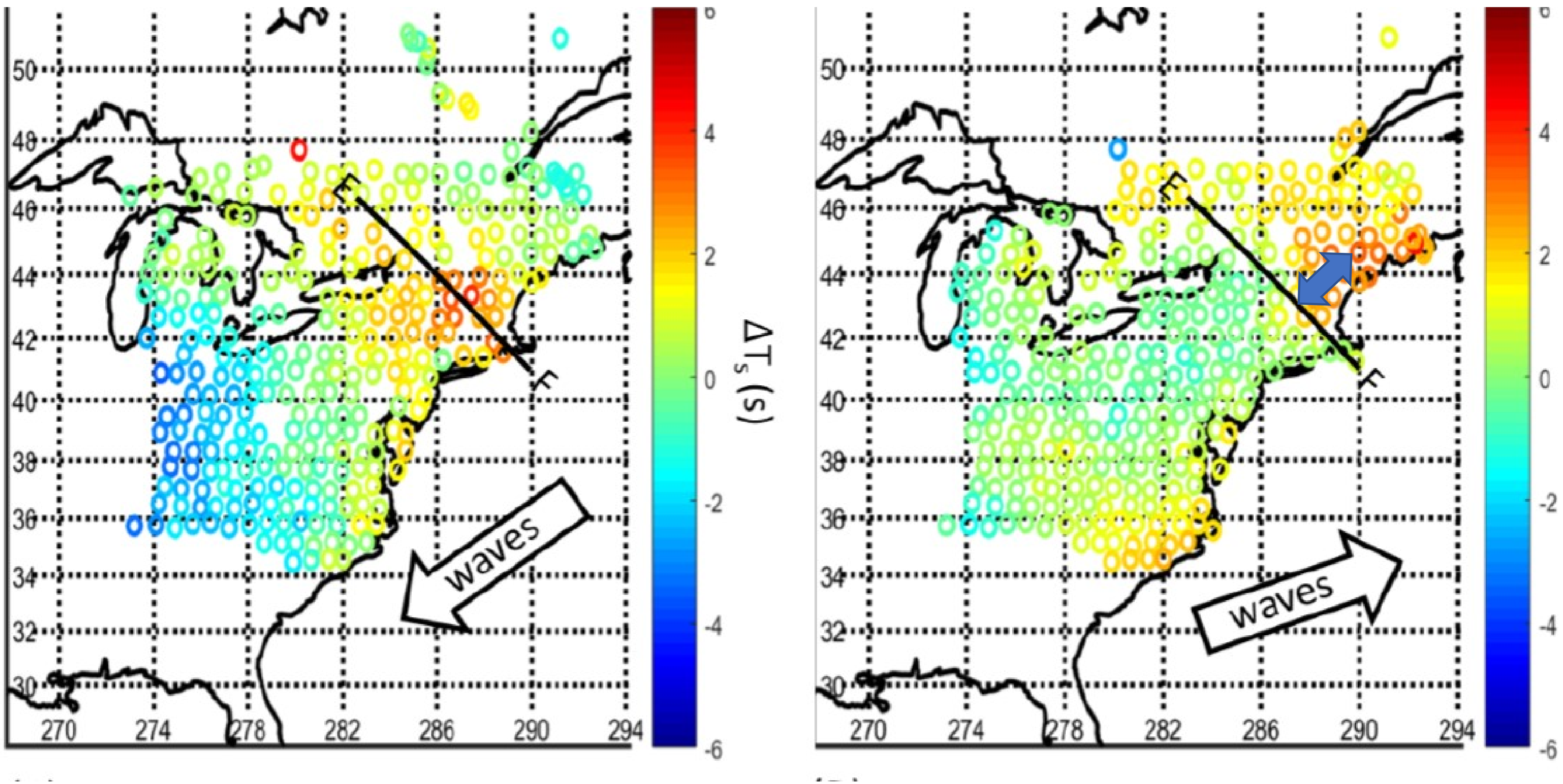
Cammarano et al. 2003

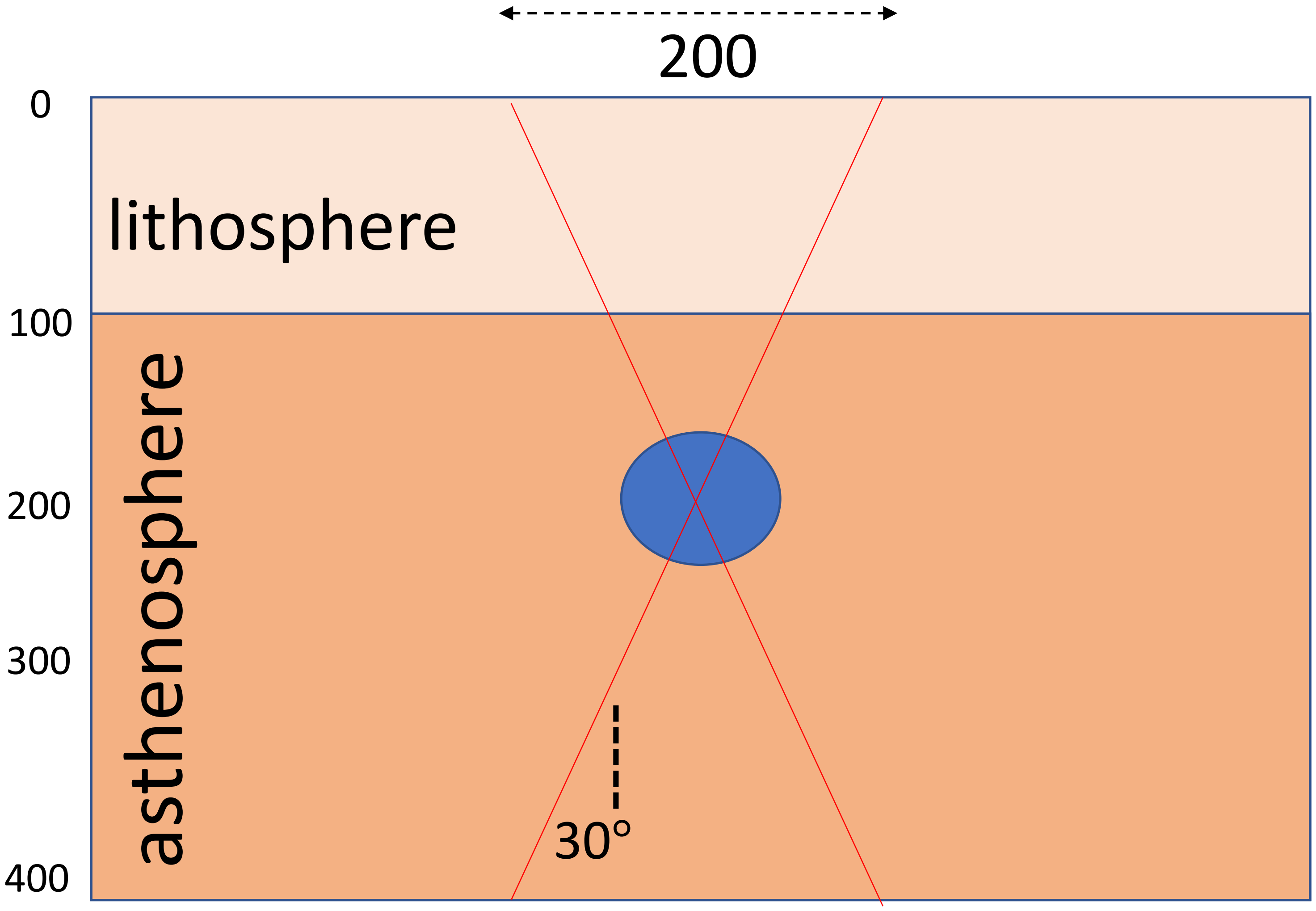
Vs = 4.275 km/s implies $\Delta T = 430$ degC

Can we be sure the NAA is in the asthenosphere?



Can we be sure the NAA is in the asthenosphere?

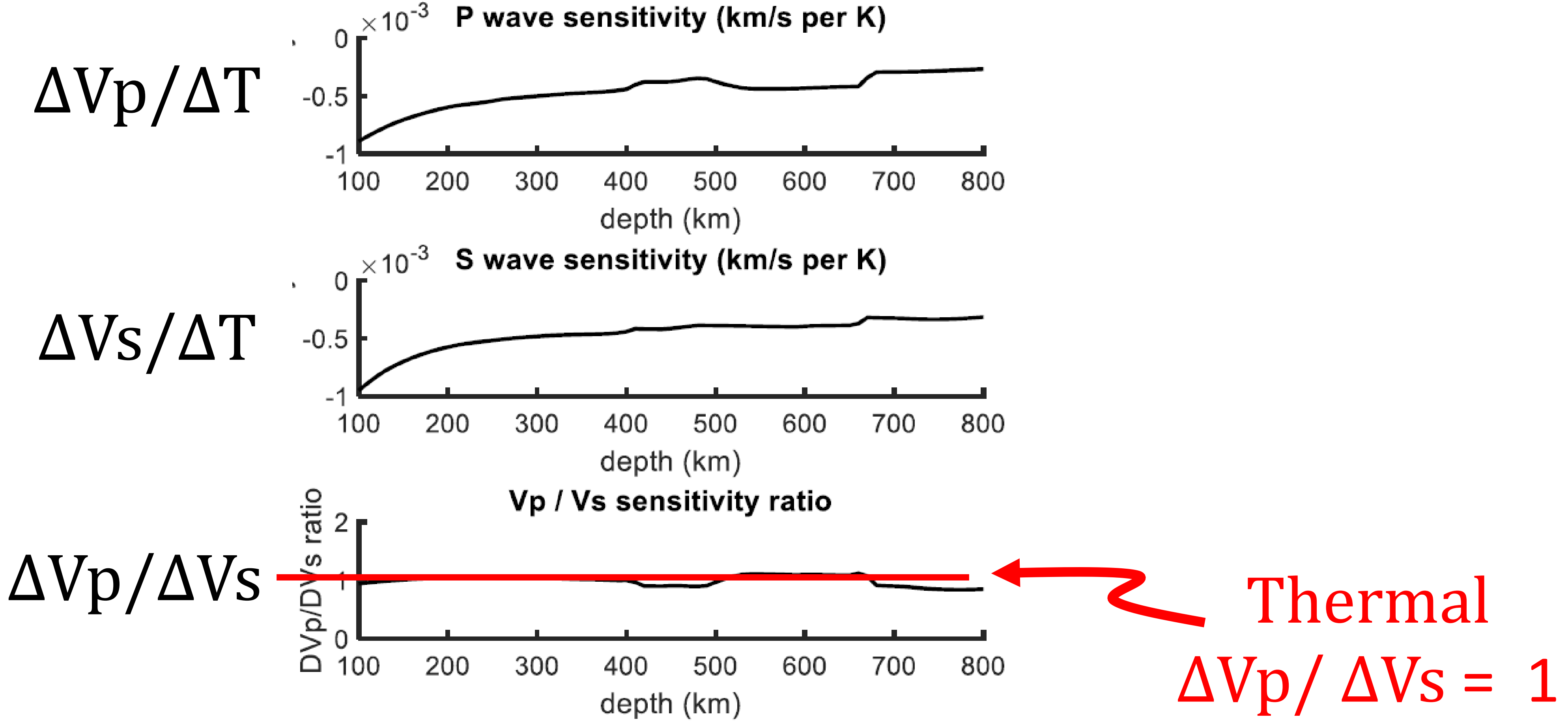




Parallax is about 200 km

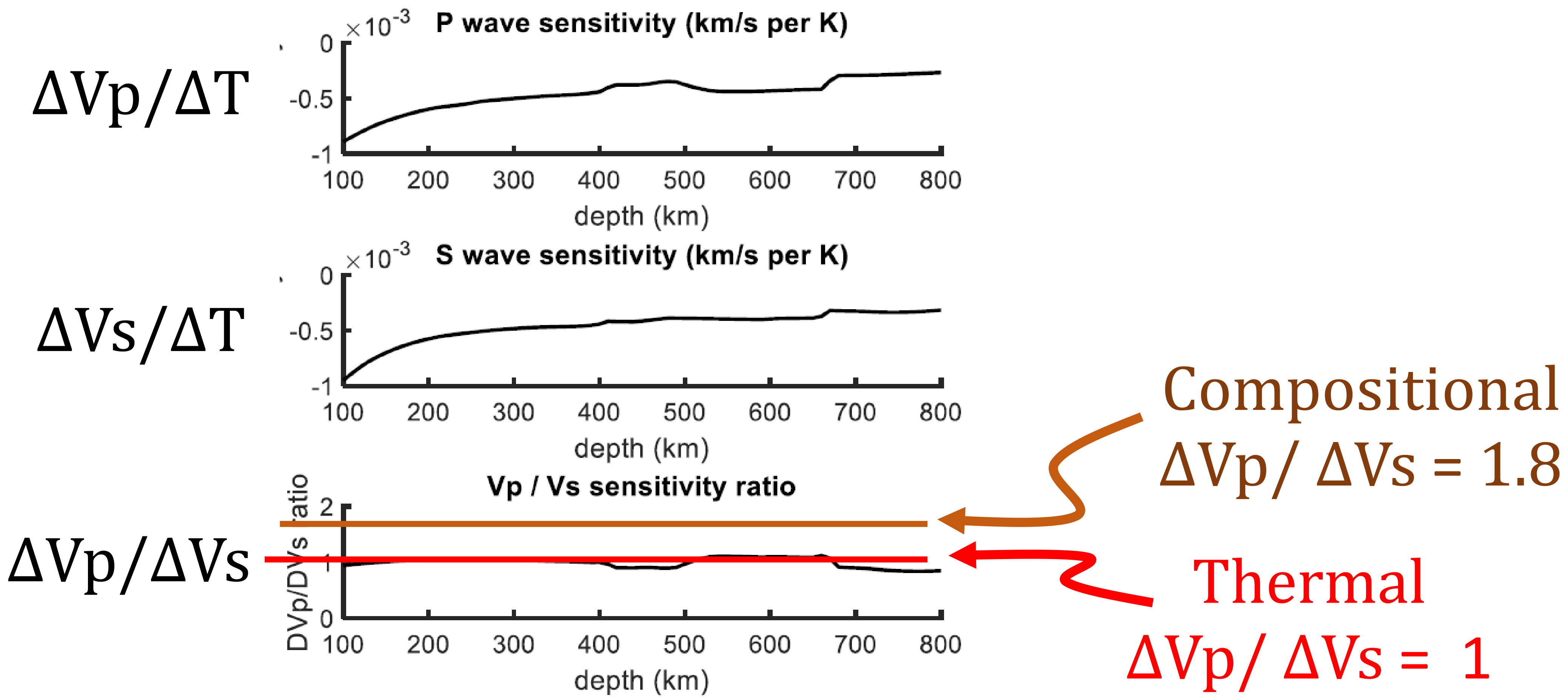
Feature is about 200 km deep (asthenospheric)

Can we be sure these anomalies are thermal?



Cammarano et al. 2003

Can we be sure the really thermal ?



Cammarano et al. 2003

$\Delta Vs/\Delta Vp$ not the same as $\Delta Ts/\Delta Tp$

$\Delta Tp/Tpo = - \Delta Vp/Vpo$ Percent change equal and opposite

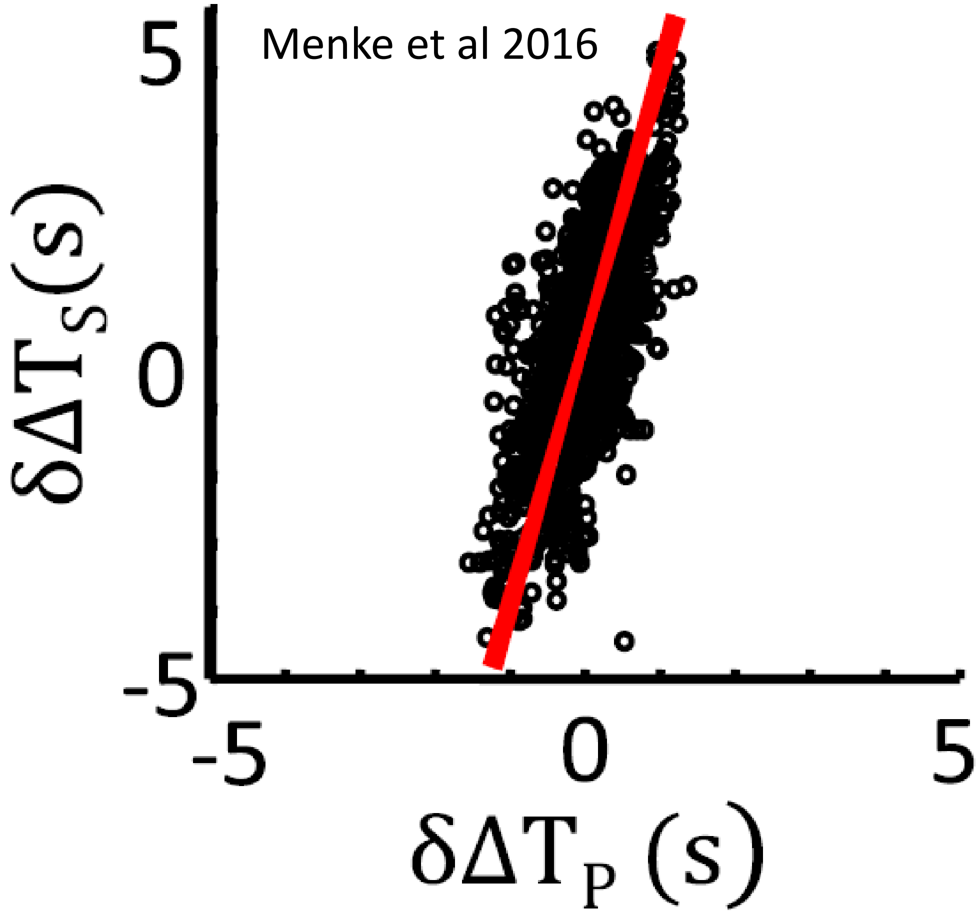
$\Delta Ts/ \Delta Tp = - (Vp0 /Vpo)^2 \Delta Vs/ \Delta Vp$

Thermal

$\Delta Vs/\Delta Vp = 1$ then $\Delta Ts/\Delta Tp = 3.35$

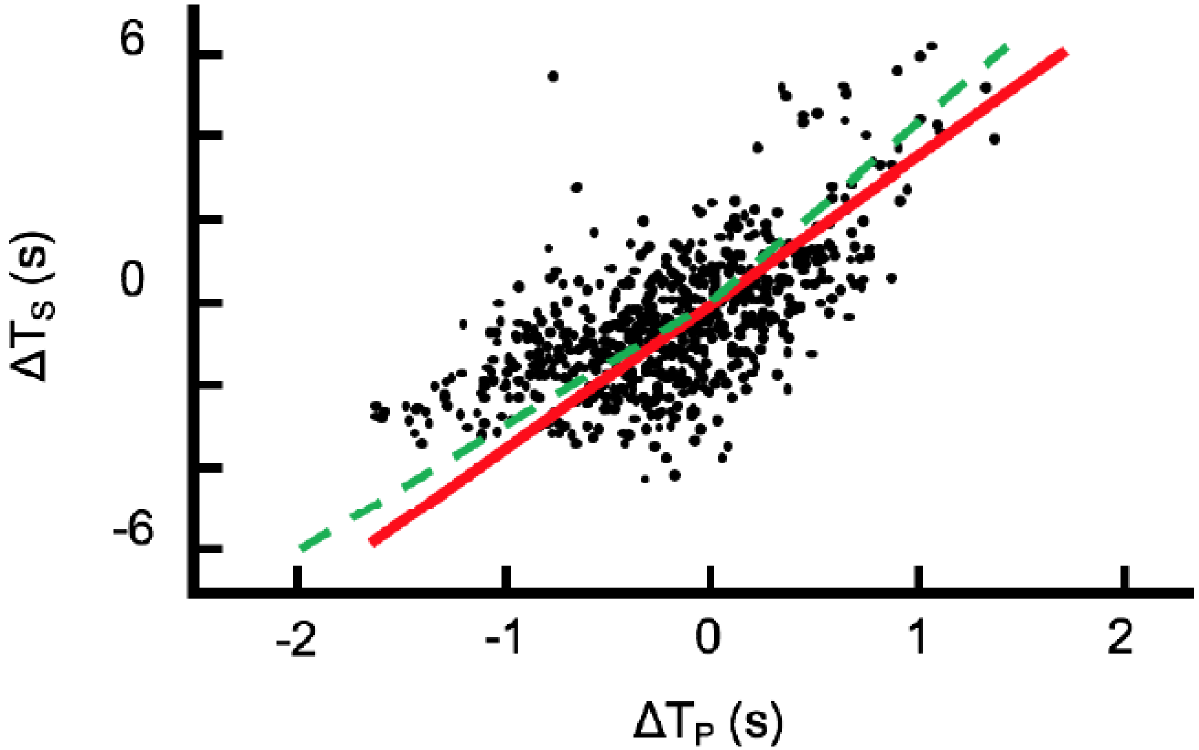
Compositional

$\Delta Vs/\Delta Vp = 1/1.83$ then $\Delta Ts/ \Delta Tp = 1.83$



NAA
Northern Appalachian Anomaly
Slope: 3.98 ± 0.26 (95 %)

Clearly thermal

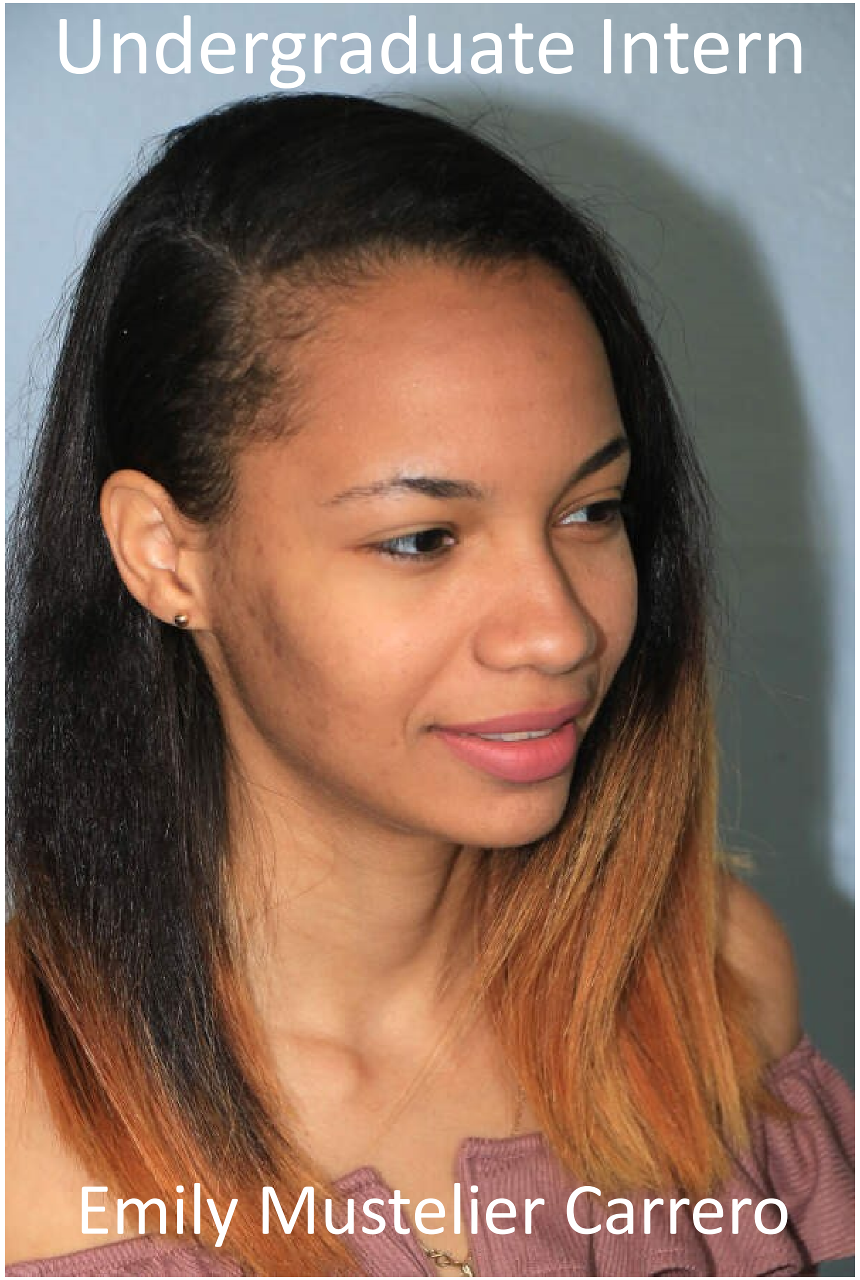


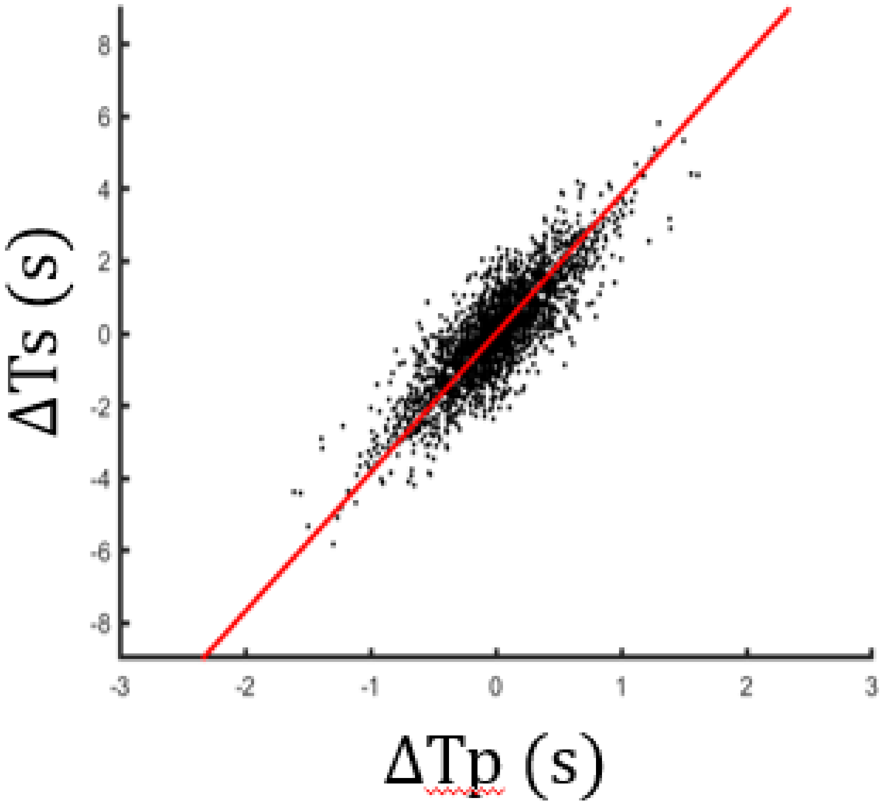
NGA

Northern Gulf Anomaly

Slope: 3.48 ± 0.69 (95 %)

Clearly thermal





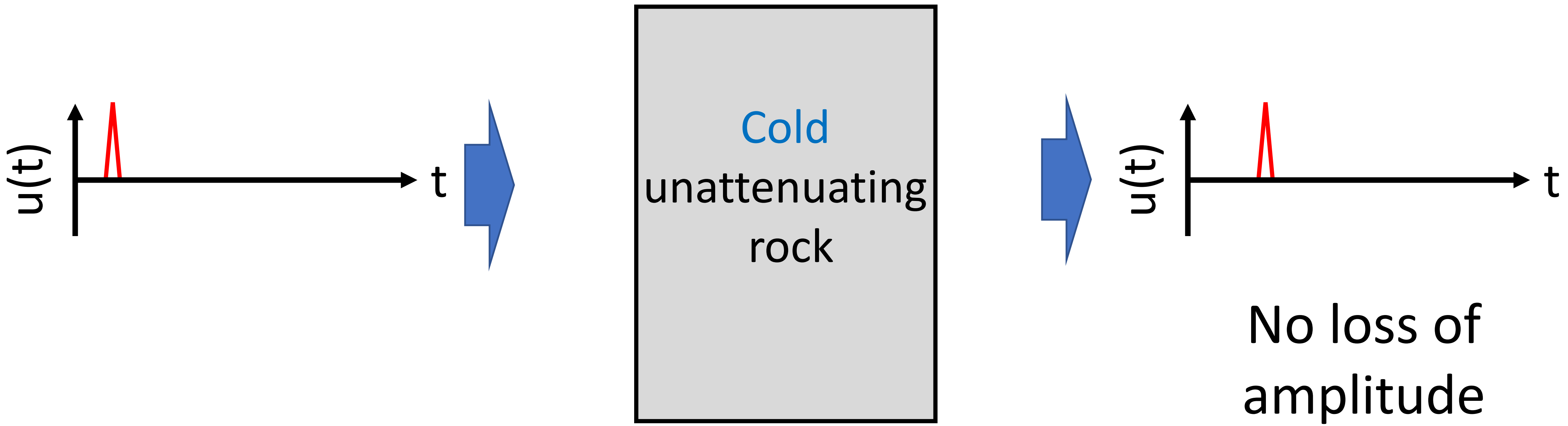
SCA

Southern Coastal Anomaly

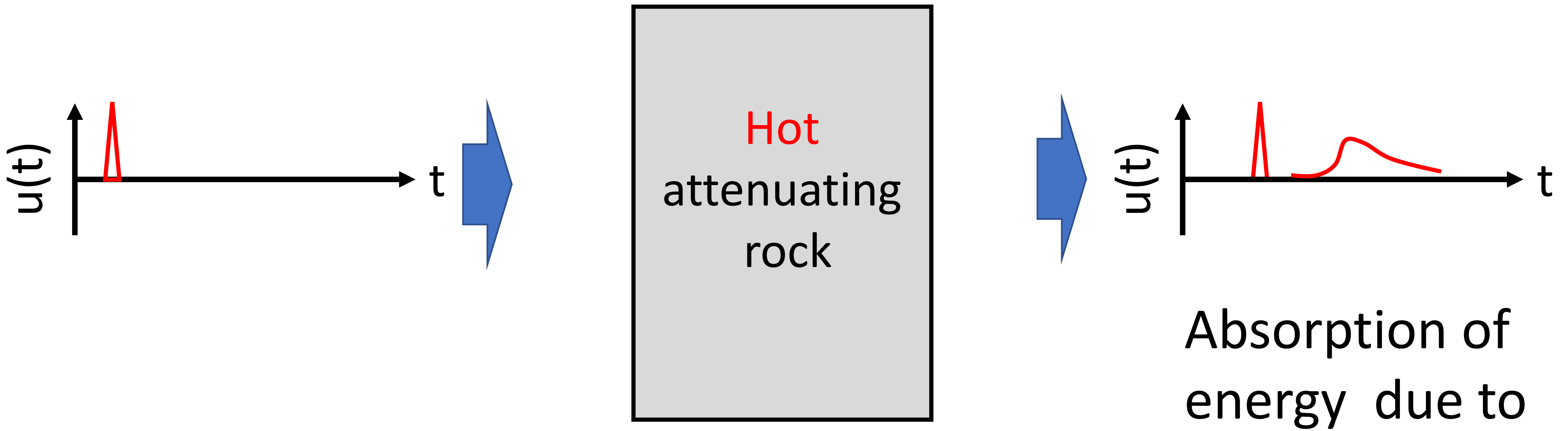
Slope: 3.84 ± 0.20 (95 %)

Clearly thermal

Further corroboration that they are thermal

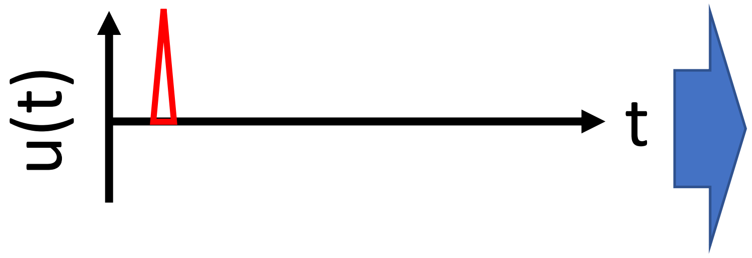


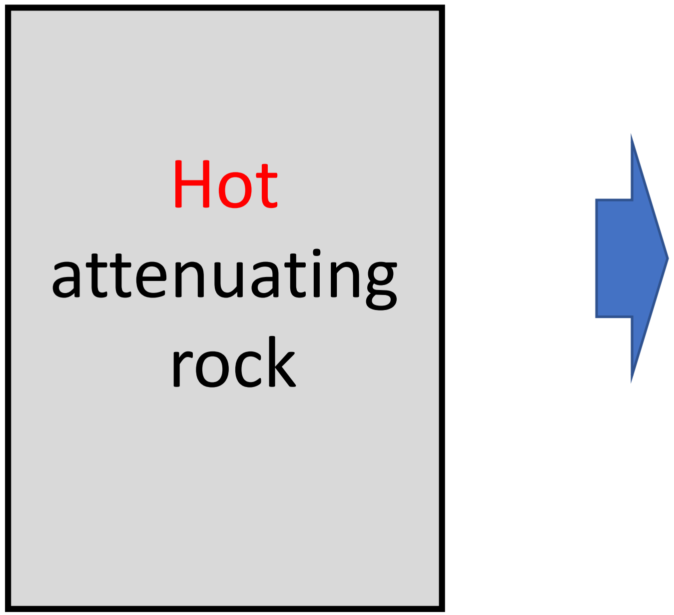
Further corroboration that they are thermal

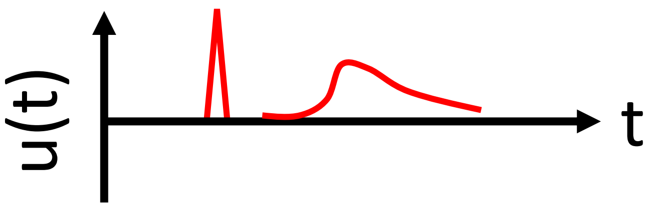


Absorption of energy due to internal friction

Further corroboration that they are thermal





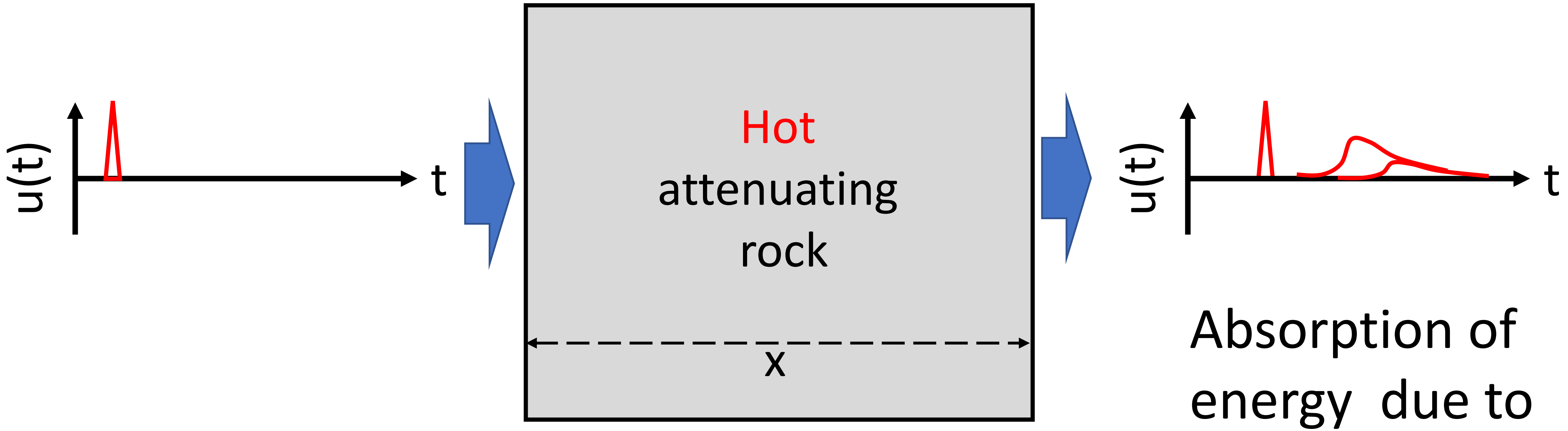


quality factor, Q(f)

Absorption of energy due to internal friction

LOW Q = HIGH Attenuation

Further corroboration that they are thermal



Absorption of energy due to internal friction

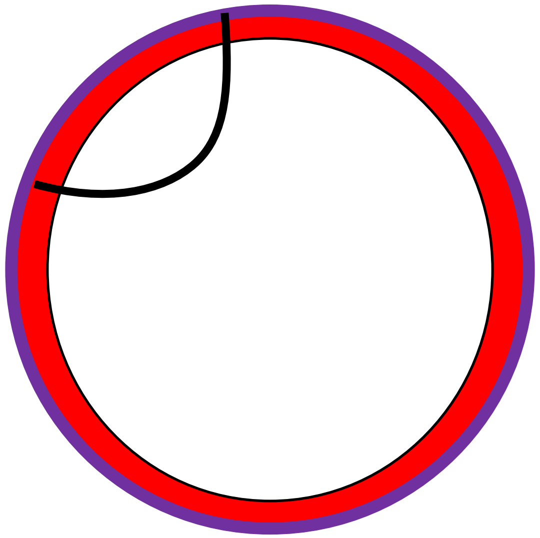
Attenuation depends on distance x travelled

What you actually measure is tee-star

$t^* = x / (v\,Q)$

HIGH t^* = HIGH Attenuation

t* of teleseismic S wave



average asthenospheric Qs=80

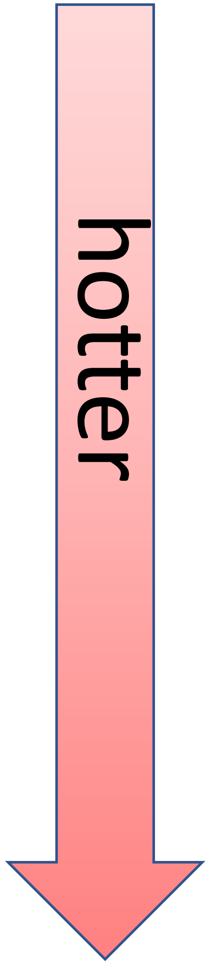
thickness of asthenosphere H=300 km

shear wave velocity of asthenosphere Vs=4.5 km/s

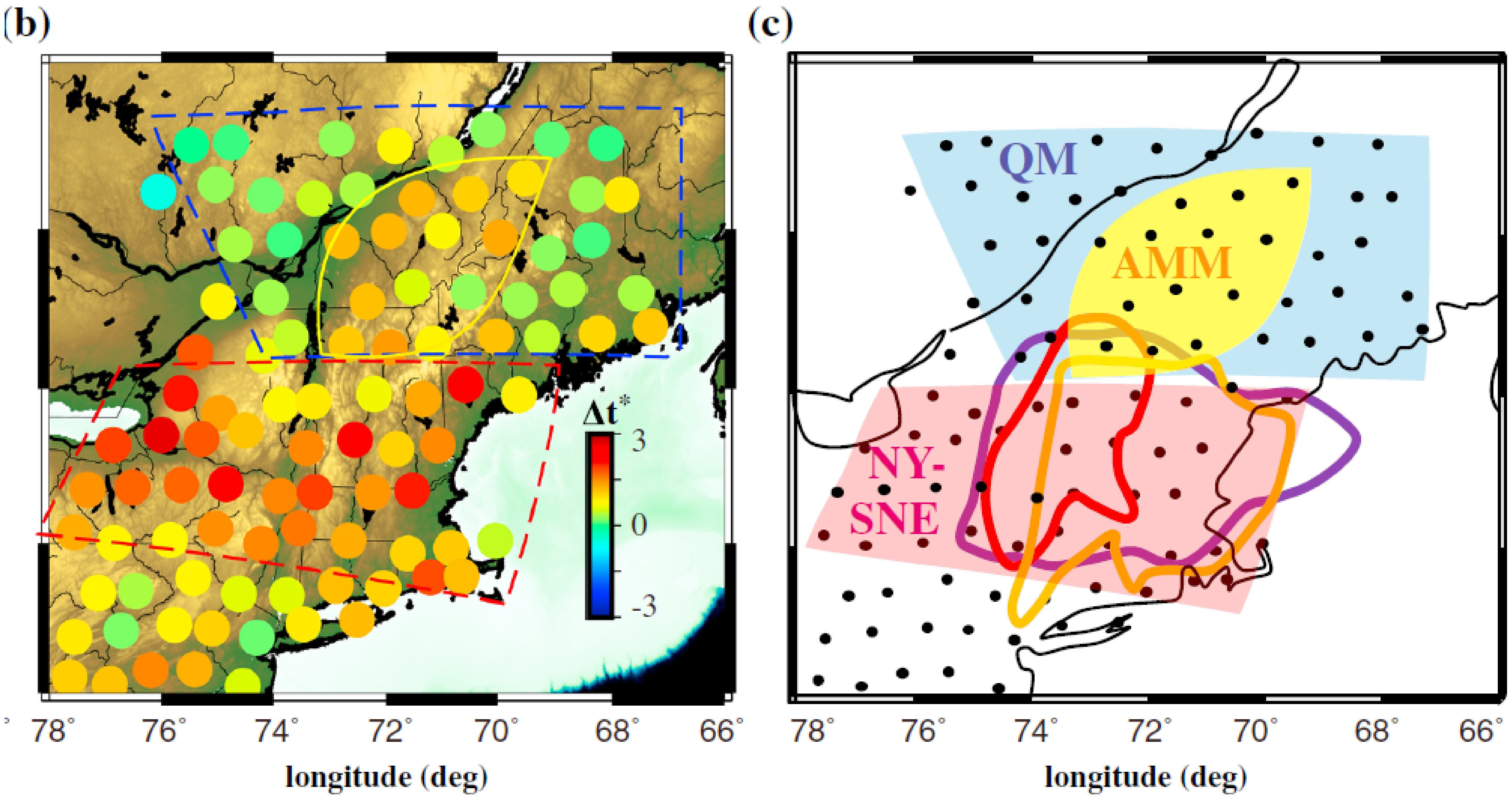
Assuming asthenosphere is primary source of attenuation

t* = (2 x 300) / (80 x 4.5) = 1.7 s

attenuation increases with temperature

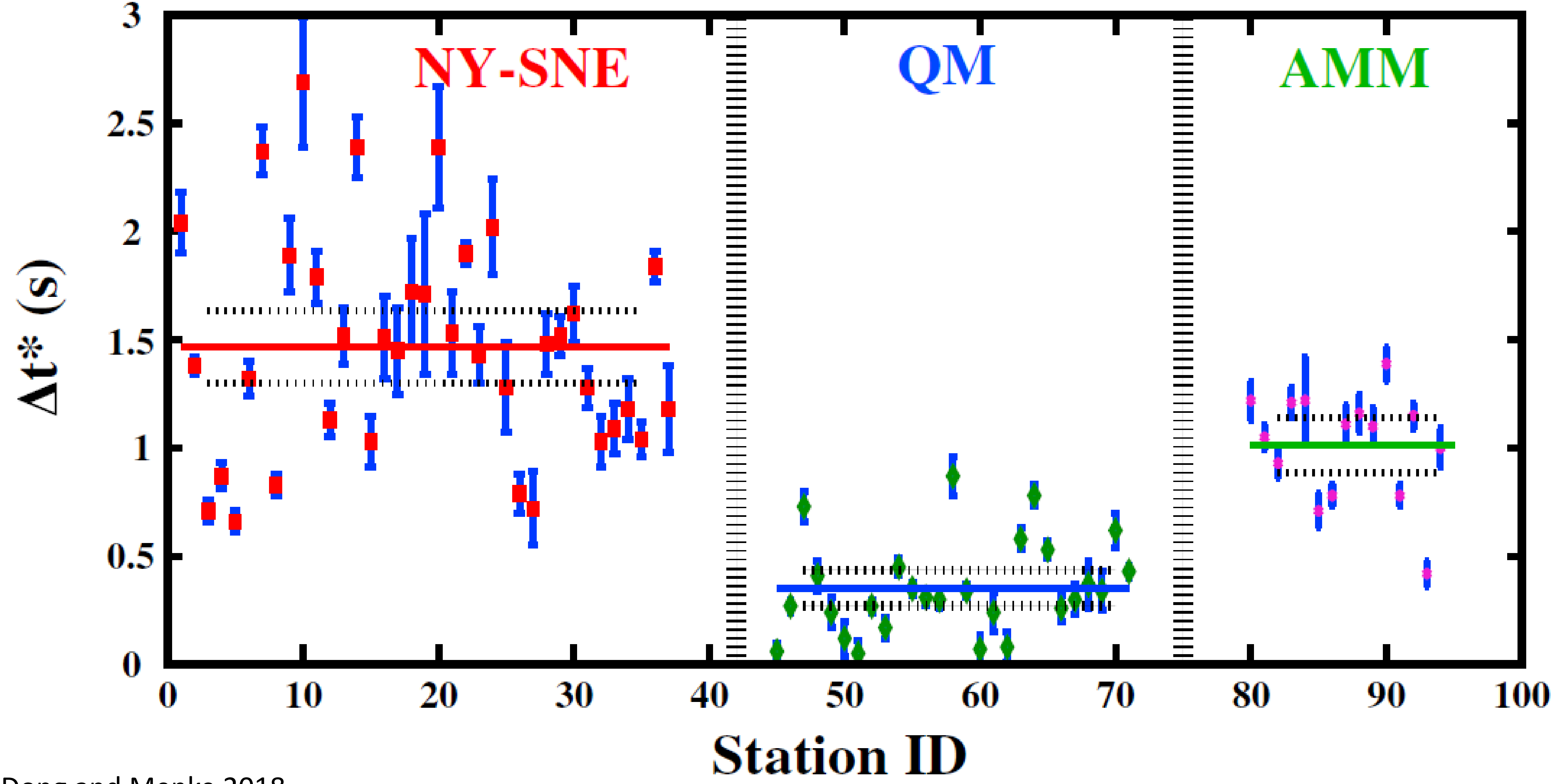


	Qs	t* (200)
Average lithosphere	800	0.06
Average asthenosphere	80	0.6
Really hot asthenosphere	20	2.2
Partially molten	10	4.4

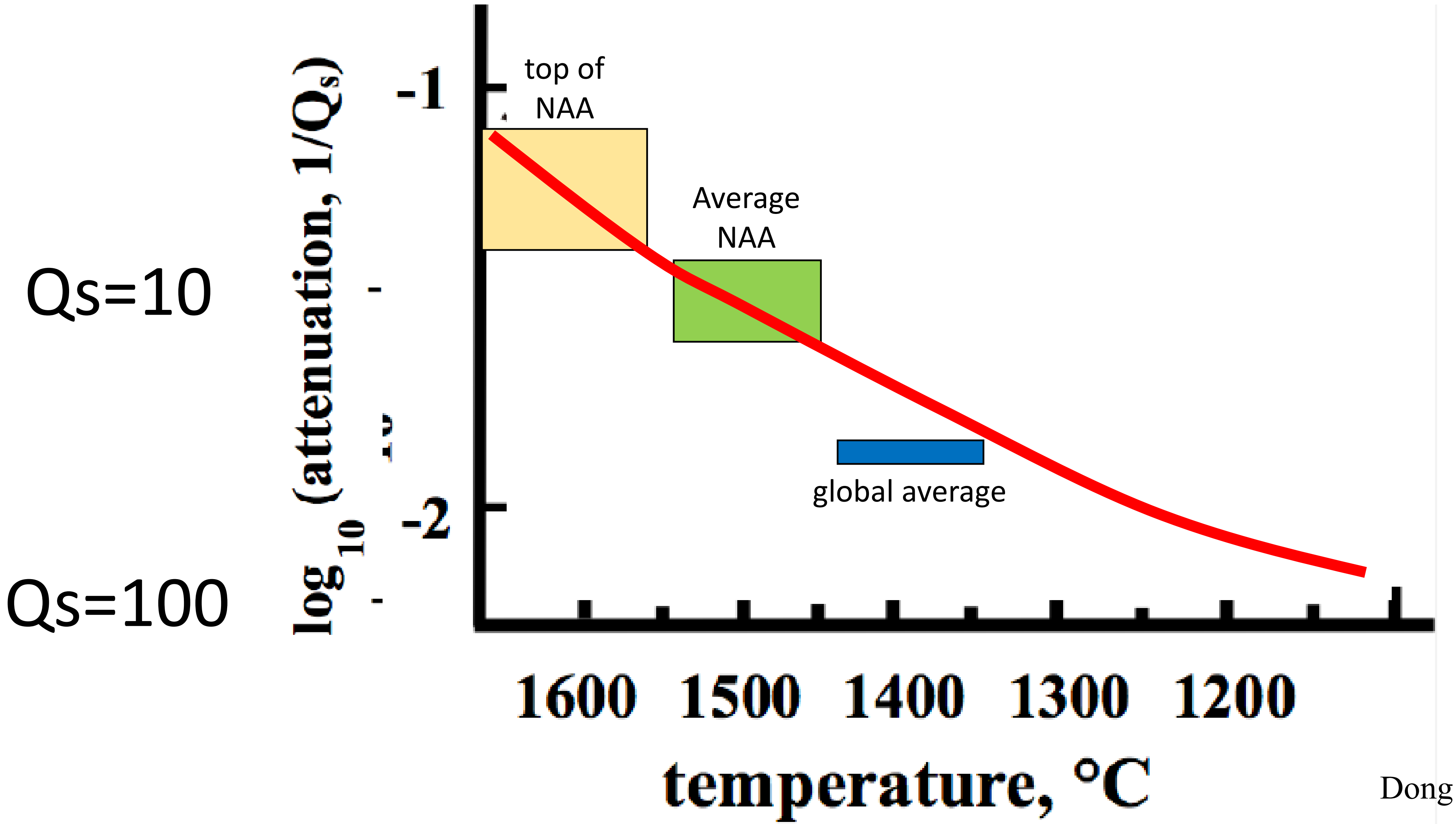


Dong and Menke 2018

regionalized t*

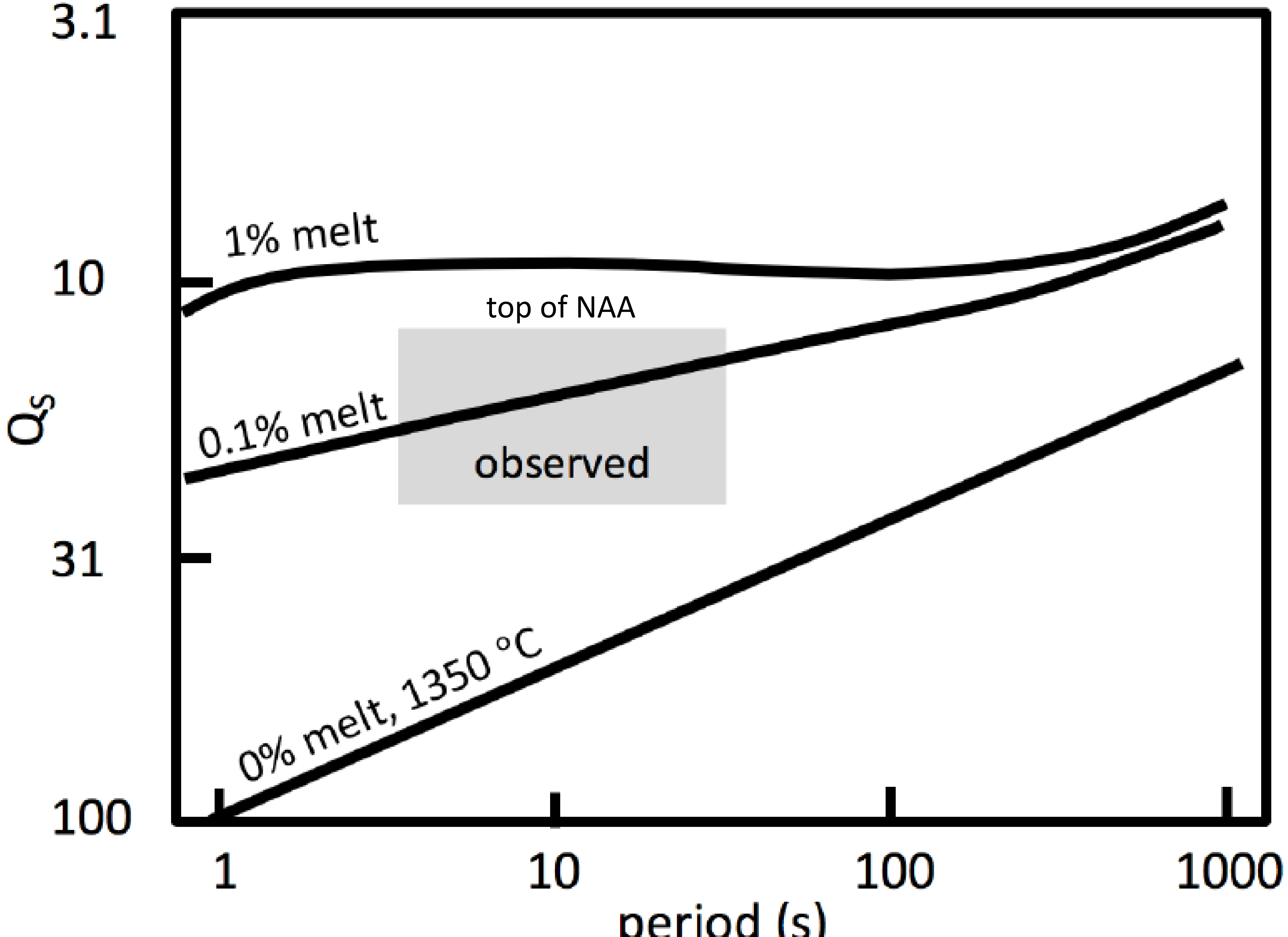


Dong and Menke 2018



Dong and Menke 2018

Jackson and Faul (2010)

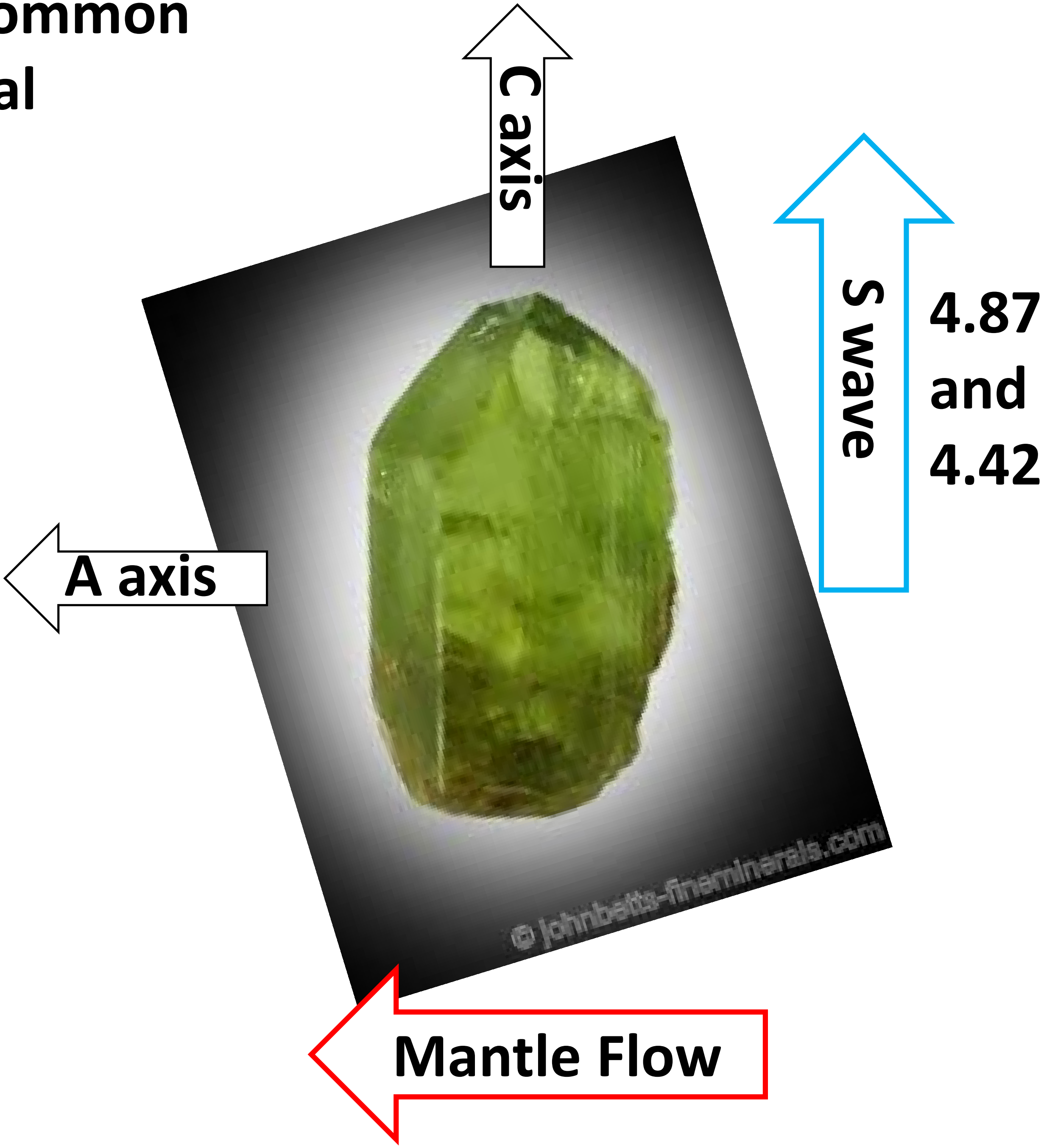


Dong and Menke 2018

Faul et al. [2004]

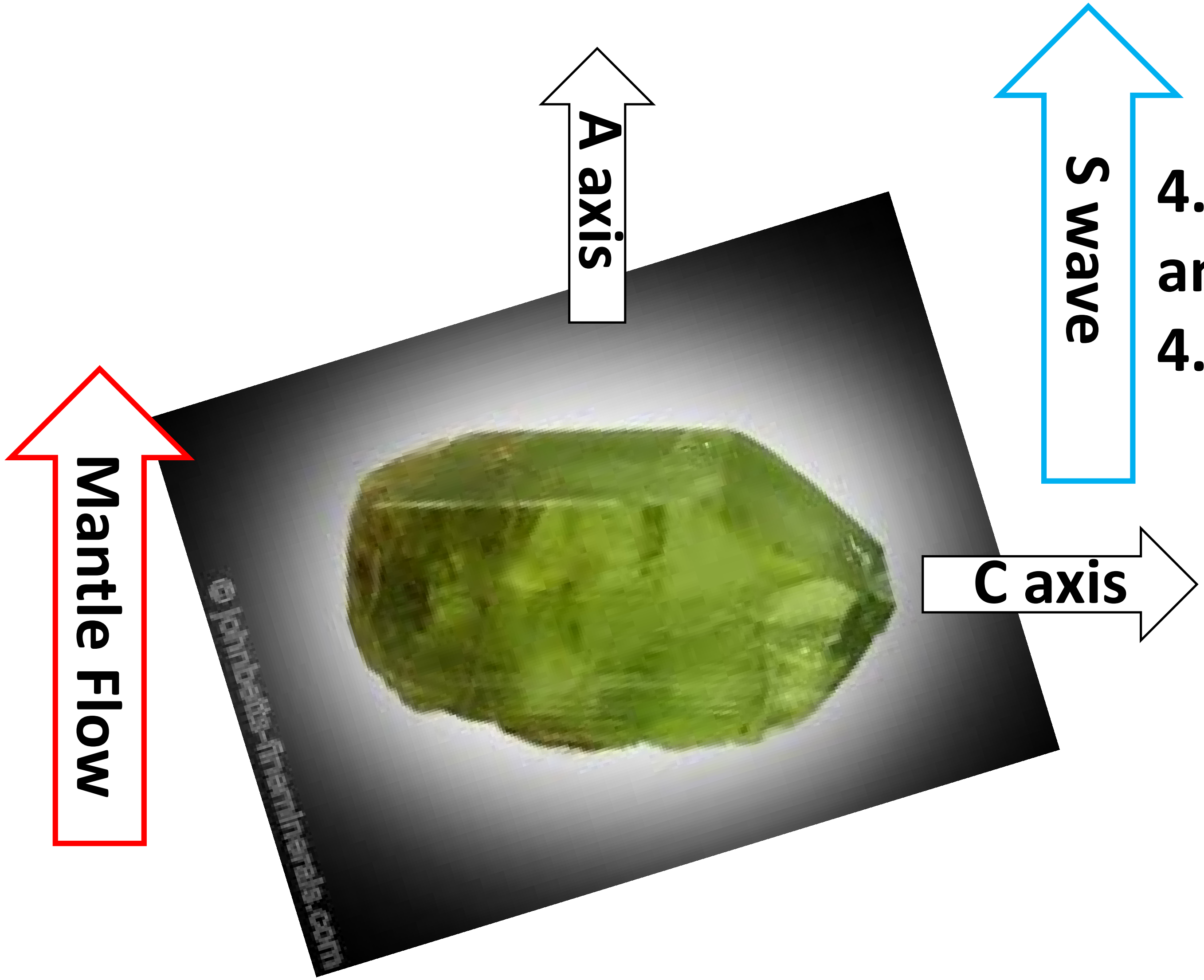
Is the asthenosphere flowing upward beneath the NAA and other anomalies?

Olivine – the most common upper mantle mineral



Strong
Splitting

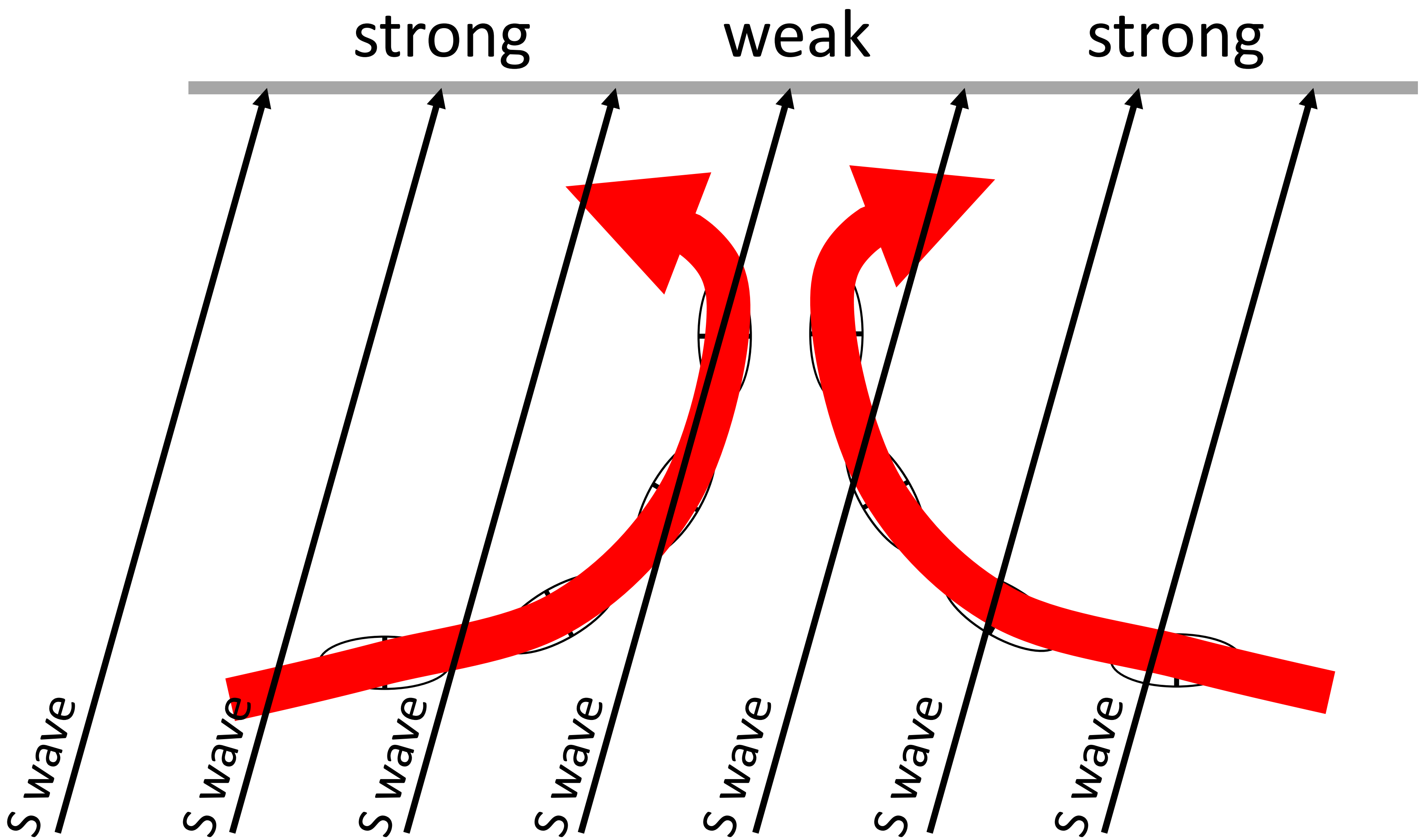
Olivine – the most common upper mantle mineral



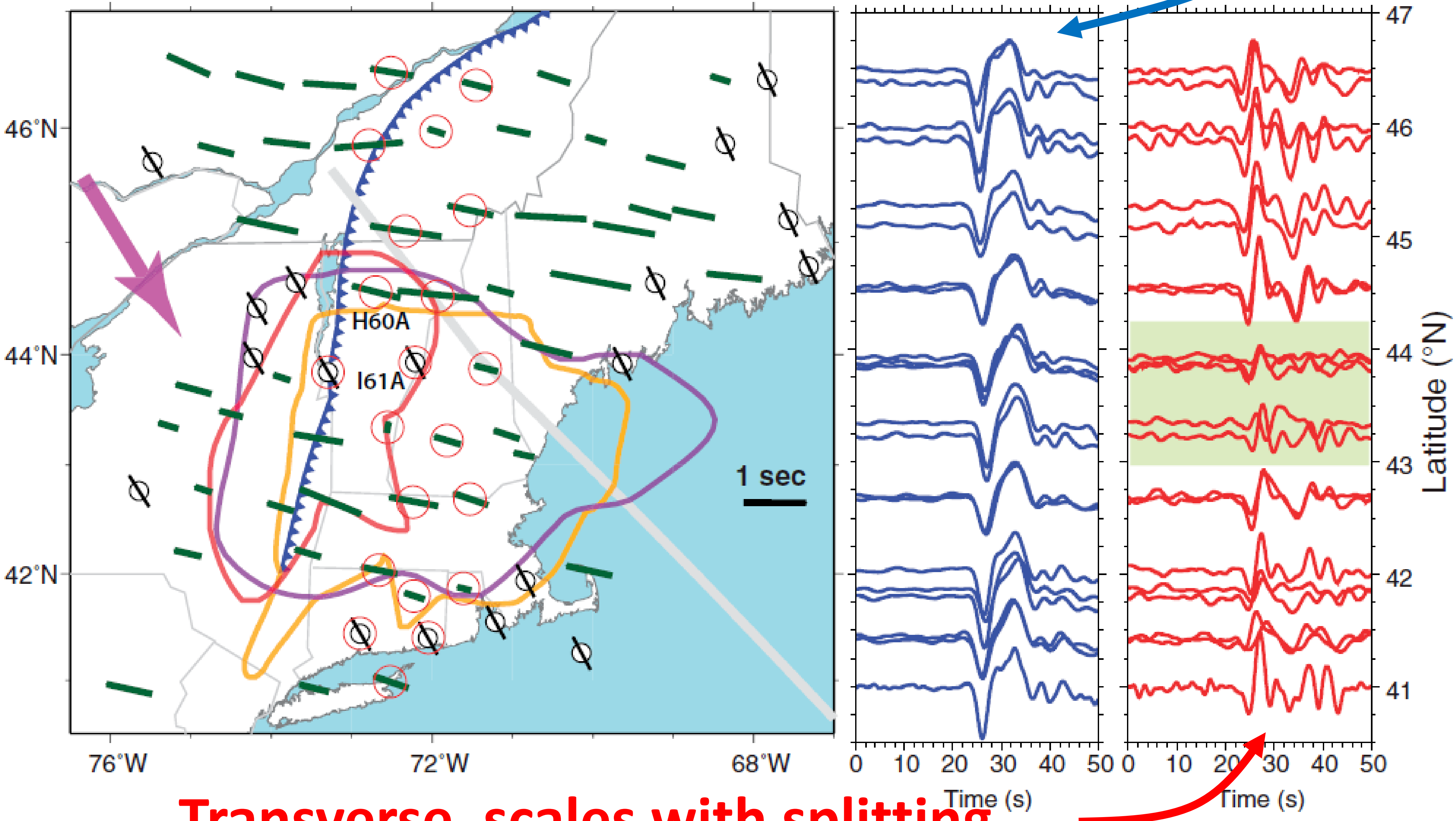
4.89
and
4.87

Weak
Splitting

Explained by Olivine Alignment Along Flow



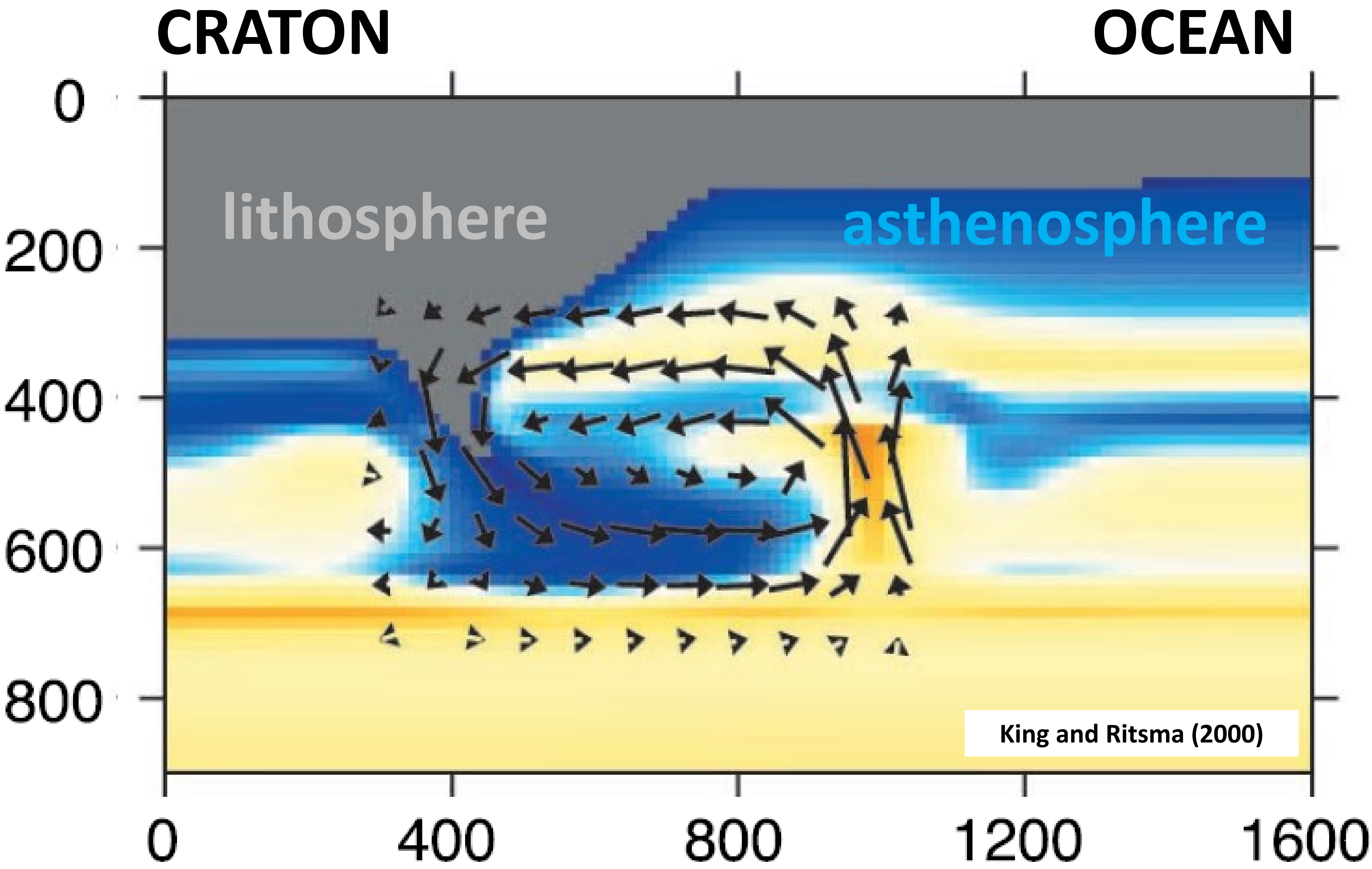
Radial, all the same, measure of data quality

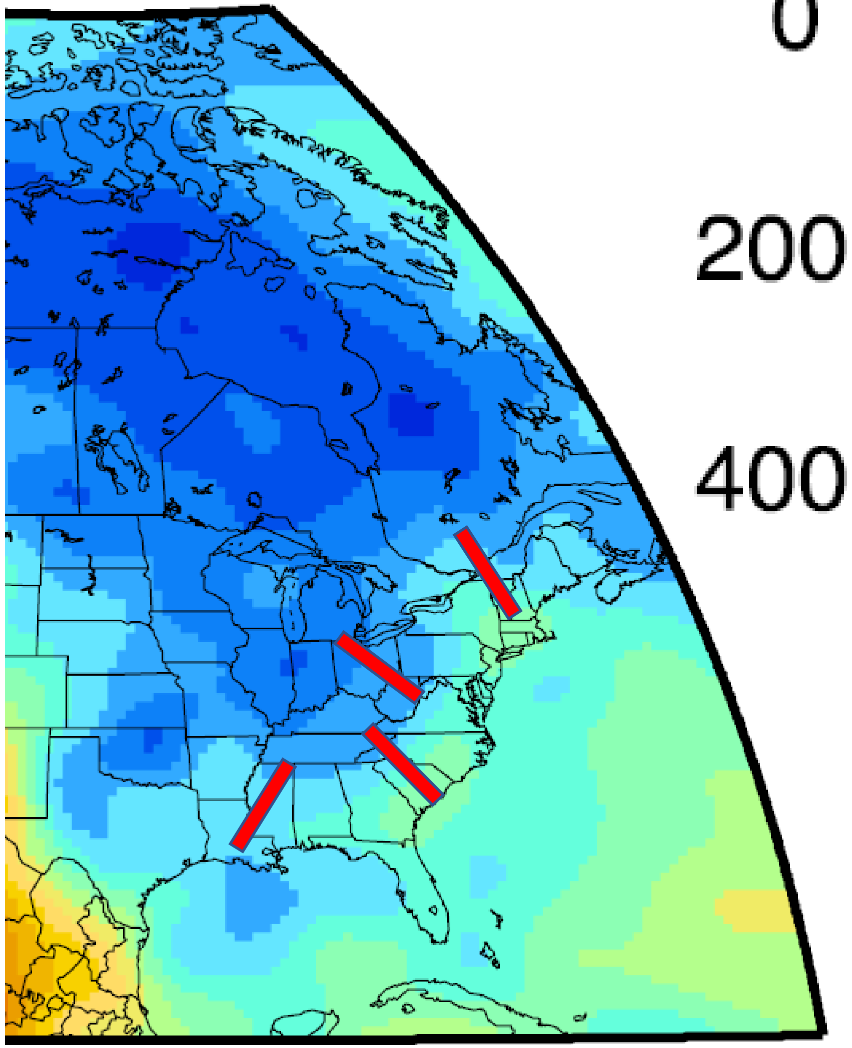


Transverse, scales with splitting

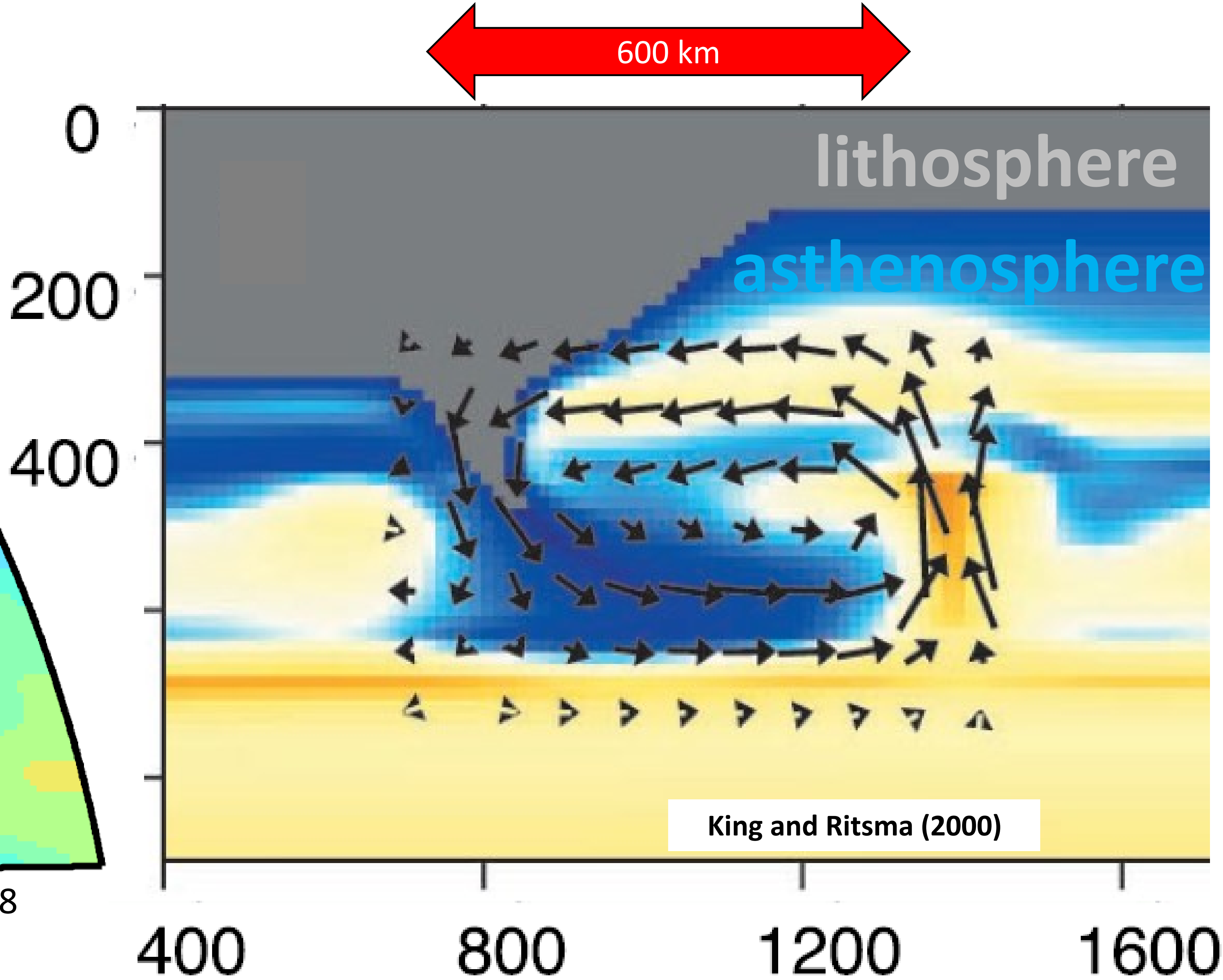
Levin et al. 2017, Fig 2

“Edge Convection” is a Plausible Driver of the Upwelling

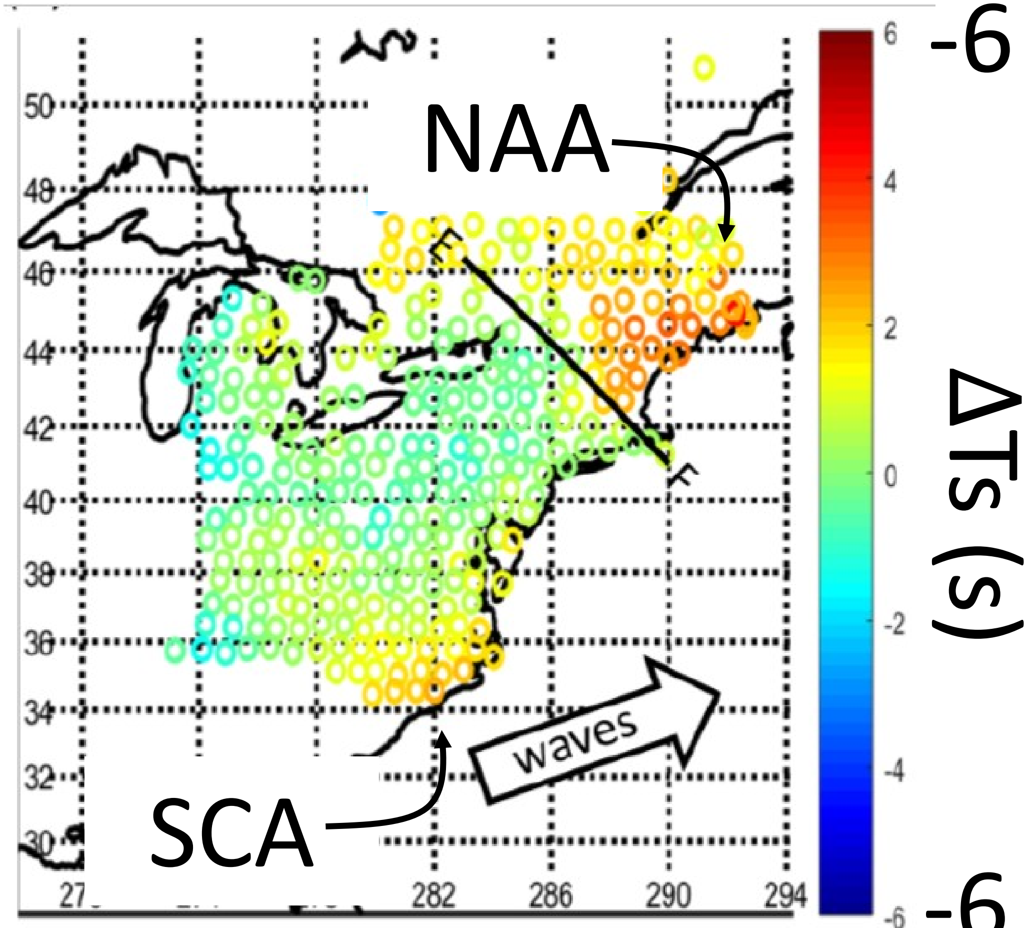

CRATON
OCEAN
lithosphere
asthenosphere
0
200
400
600
800
0
400
800
1200
1600
King and Ritsma (2000)

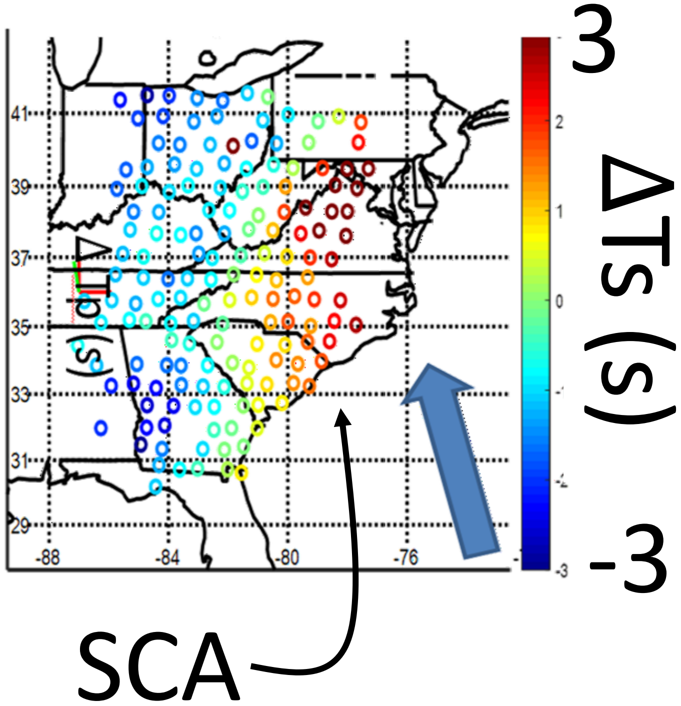


Nettles & Dziewonski, 2008

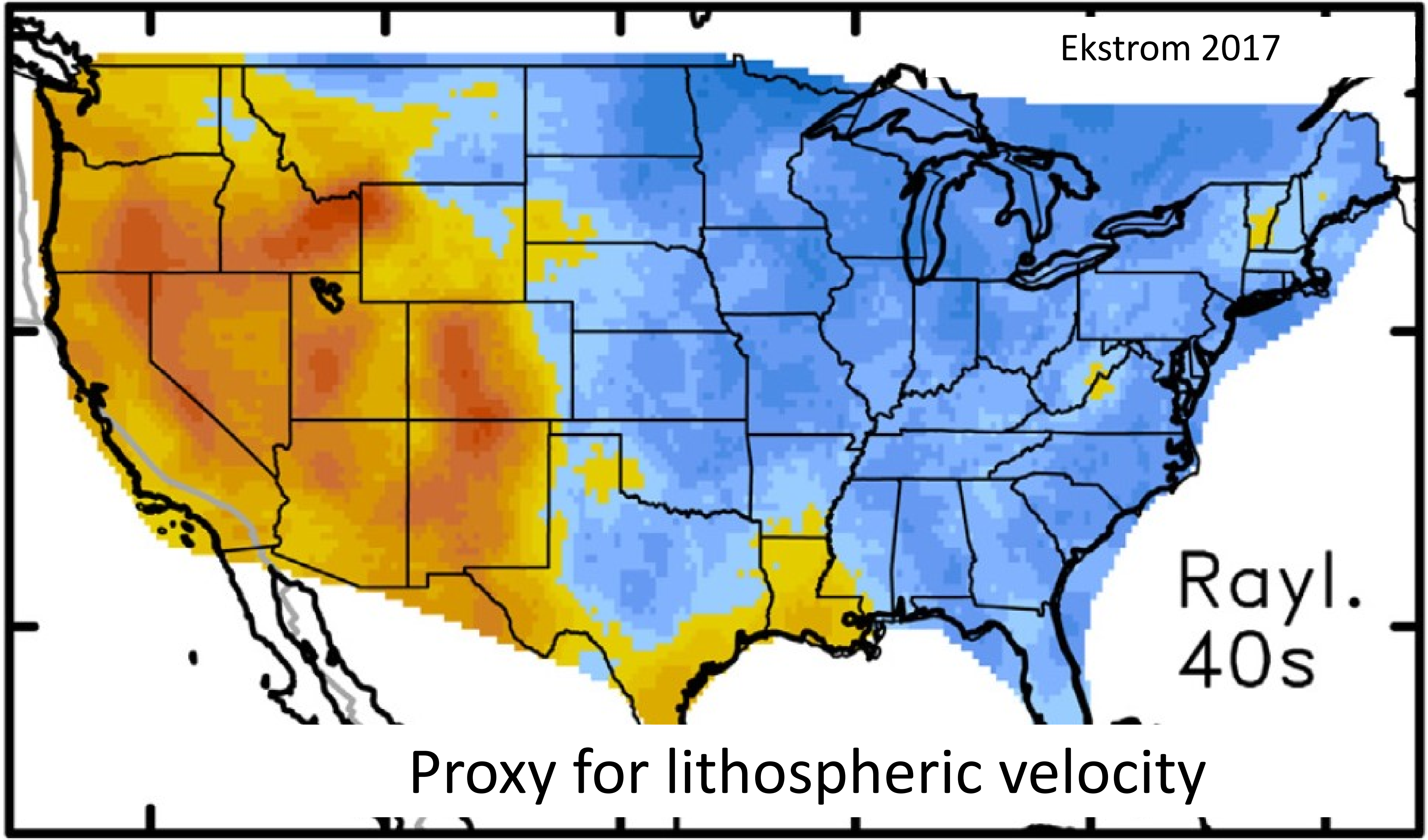


However
SCA spatially larger
NAA more intense in ΔVs

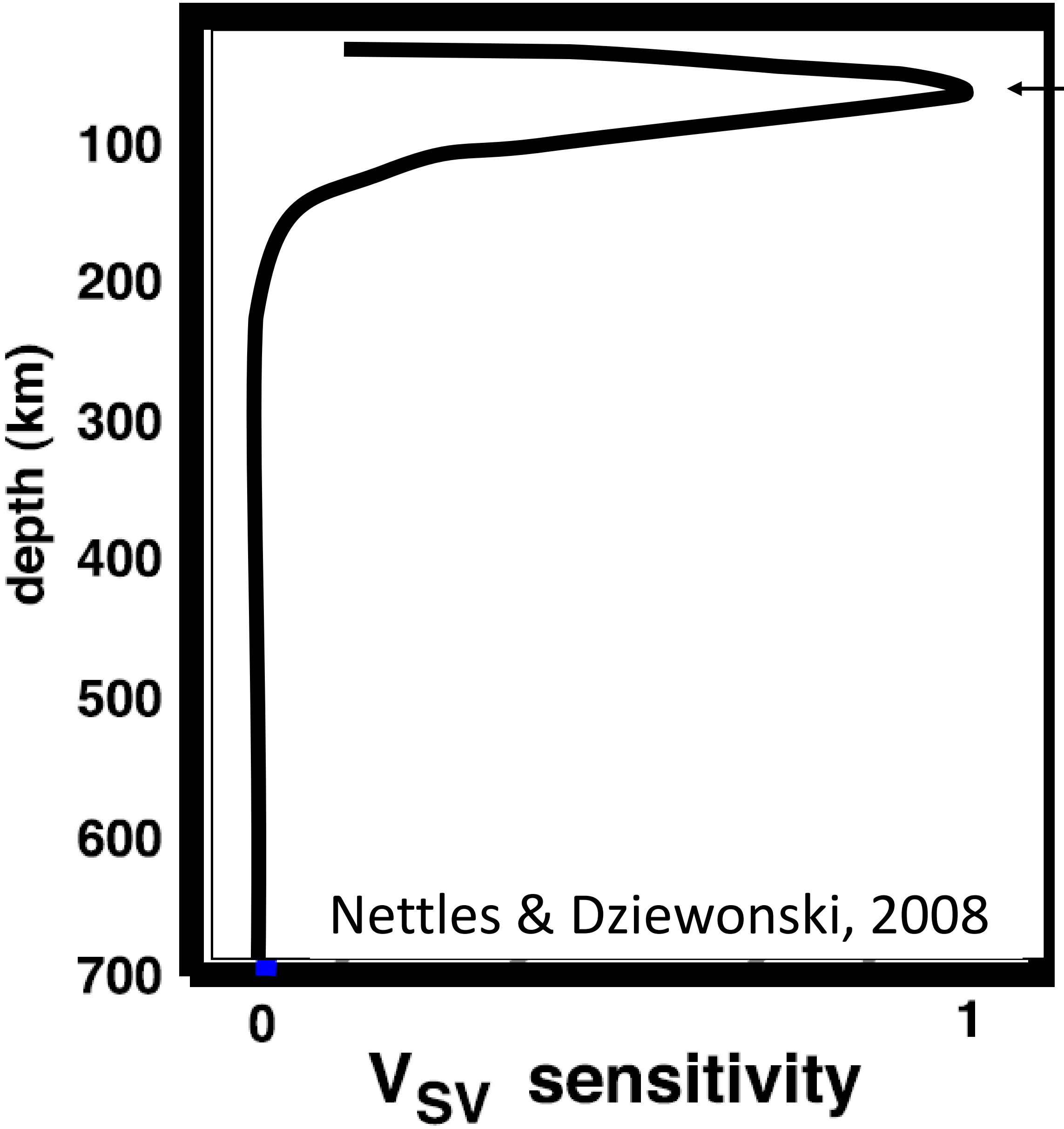




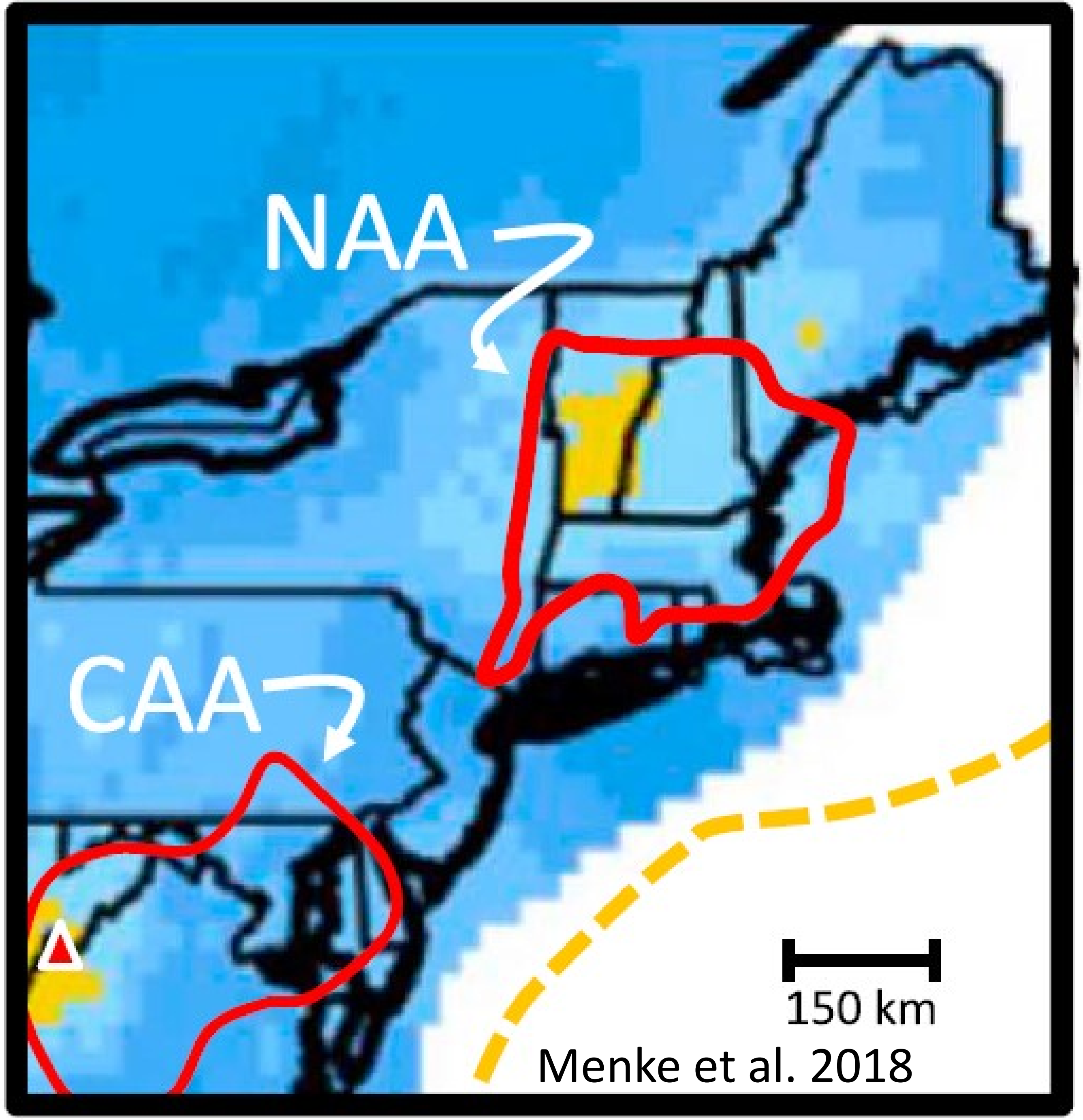
Is the NAA asthenosphere interacting with the lithosphere?



Proxy for lithospheric velocity

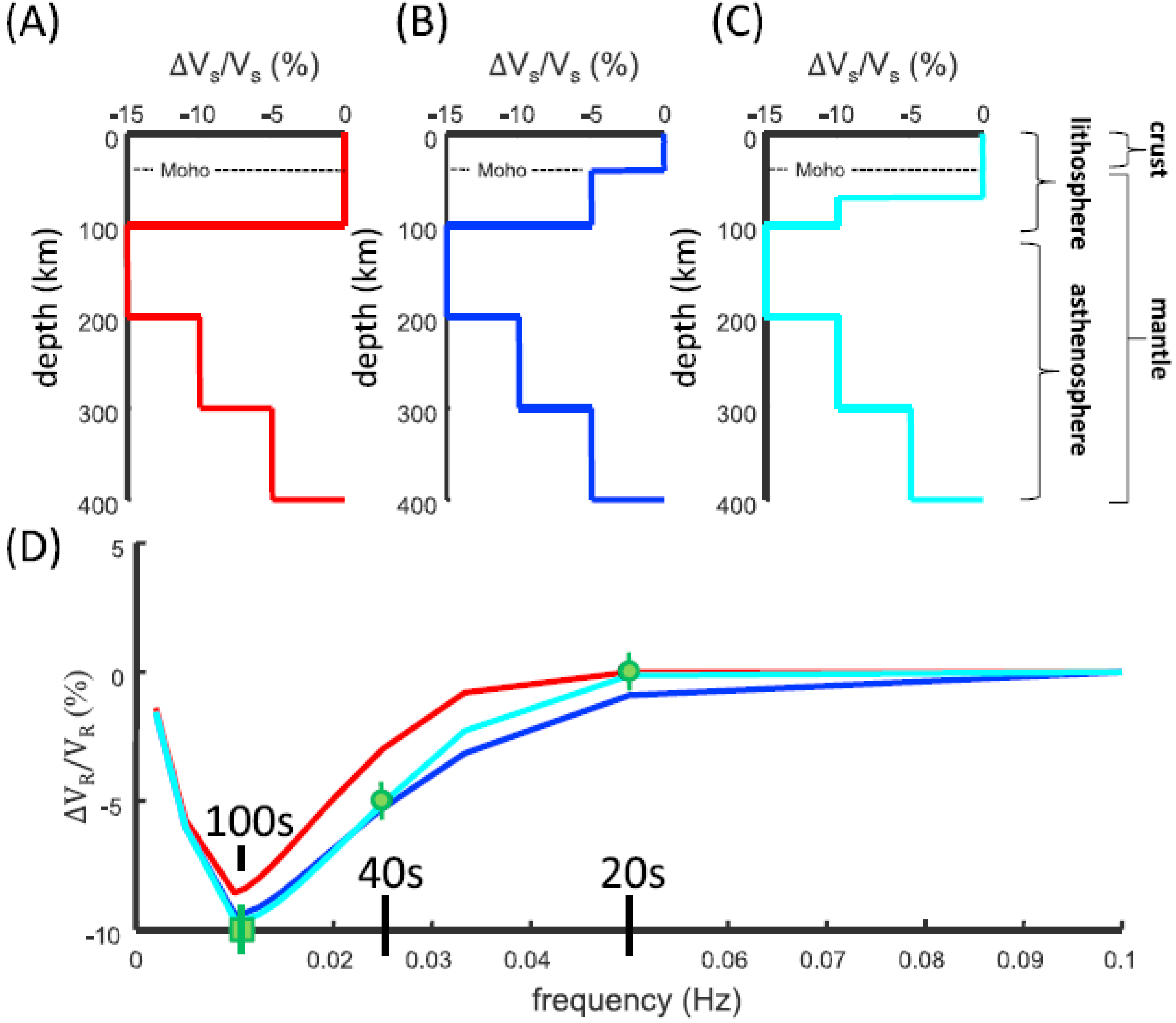

100
200
300
400
500
600
700
depth (km)
0
1
V_{SV} sensitivity
Nettles & Dziewonski, 2008

peak at 65 km


NAA
CAA
150 km
Menke et al. 2018

The NAA’s asthenospheric signal is huge

Can we be sure it is not causing an artifact within the lithospheric signal?

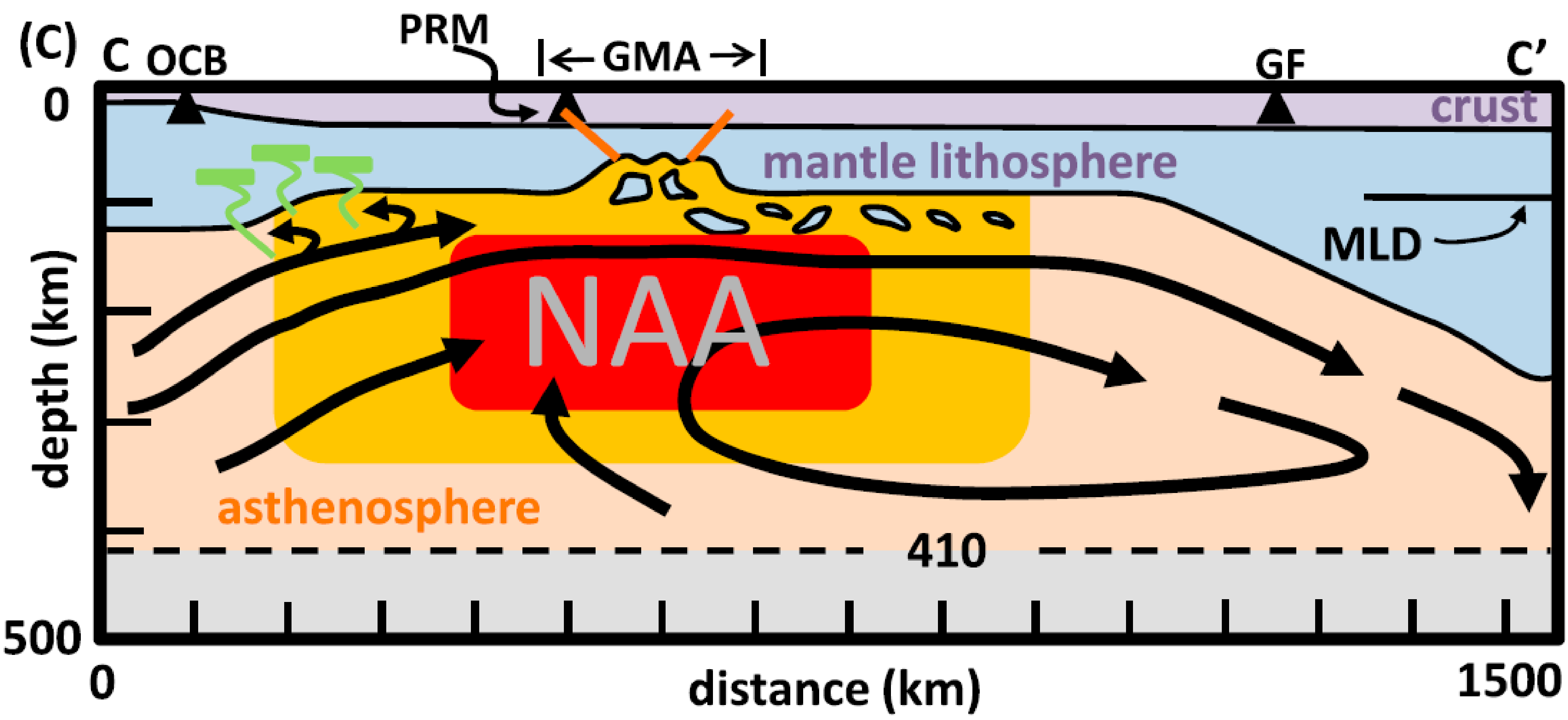


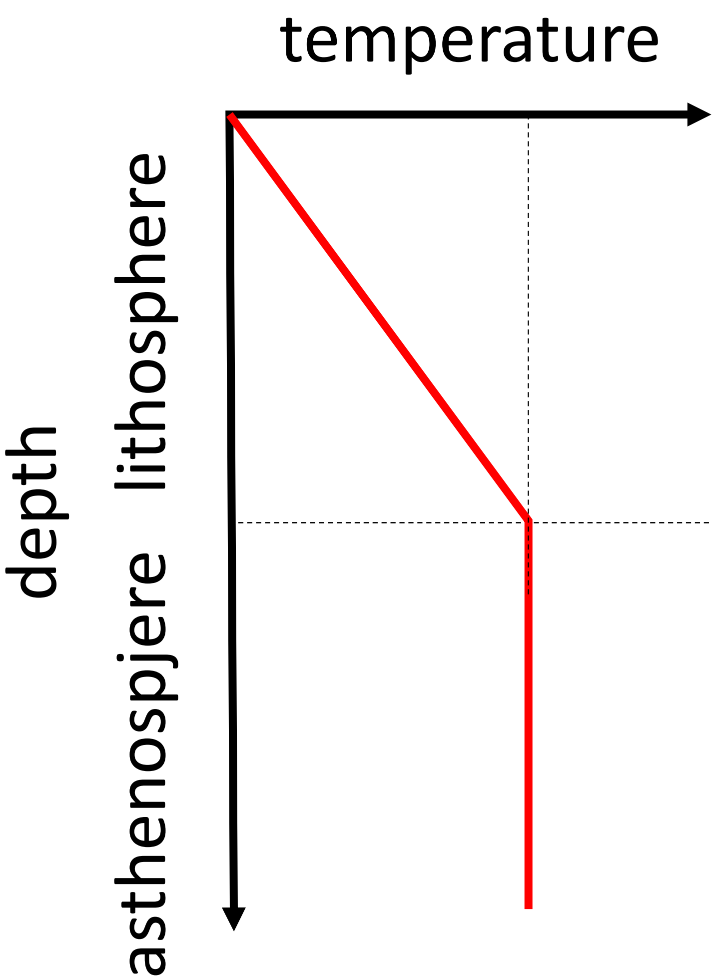
(A)
(B)
(C)
ΔVs/Vs (%)
-15
-10
-5
0
depth (km)
100
200
300
400
Moho
crust
lithosphere
asthenosphere
mantle
(D)
ΔVR/VR (%)
5
-5
-10
100s
40s
20s
0.02
0.03
0.04
0.06
0.07
0.08
0.09
0.1
frequency (Hz)

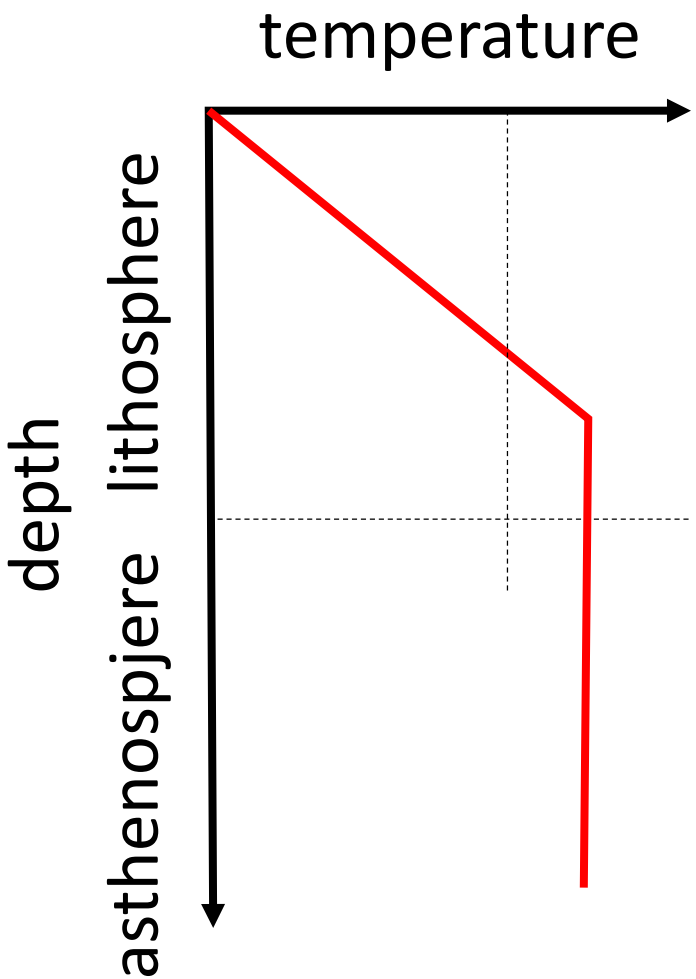
The NAA’s asthenospheric signal cannot account for the lithospheric signal

A decrease in lower
– but not upper –
lithospheric velocities best fits the data

Ocean Craton



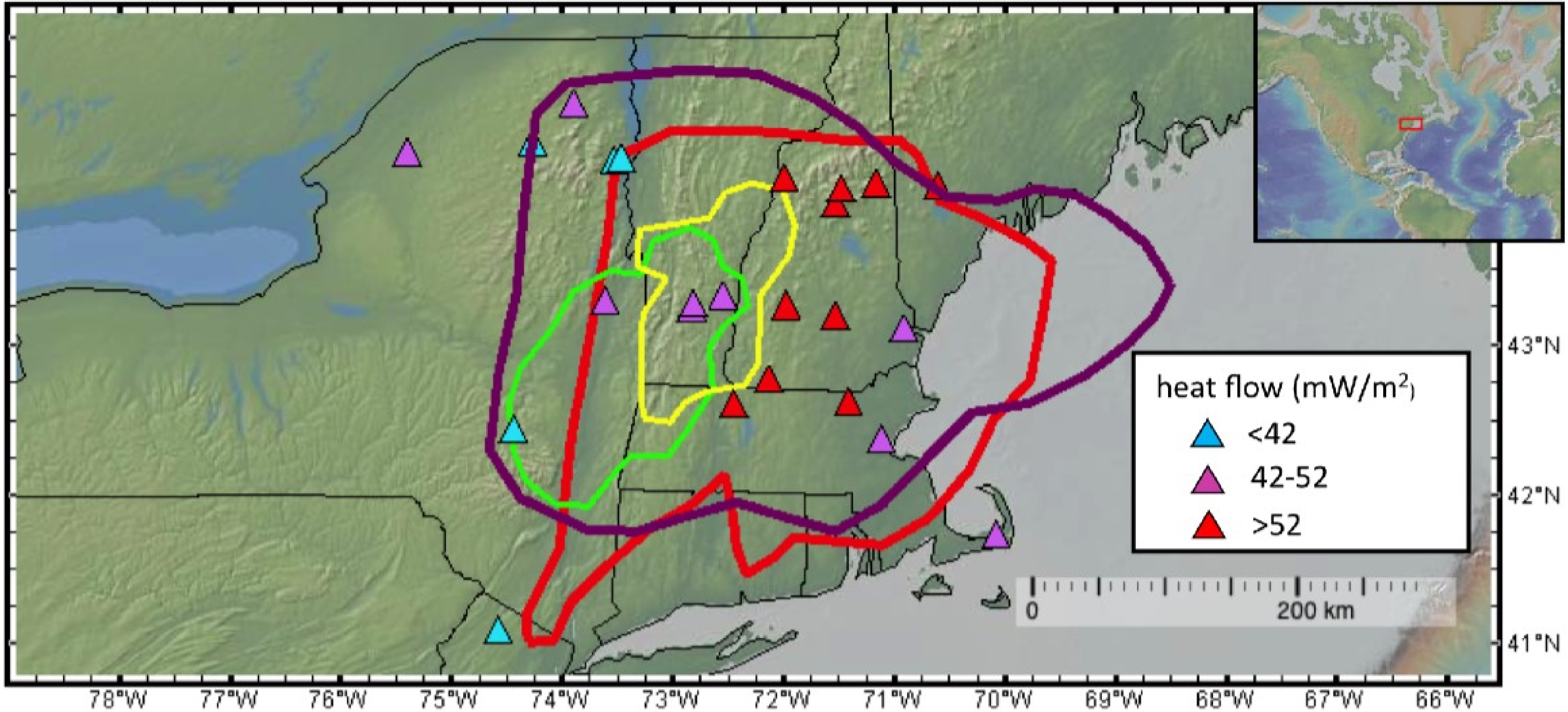




30% increase
in geothermal
gradient

30% increase
in heat flow

lithosphere thinner
asthenosphere hotter
heat flow higher

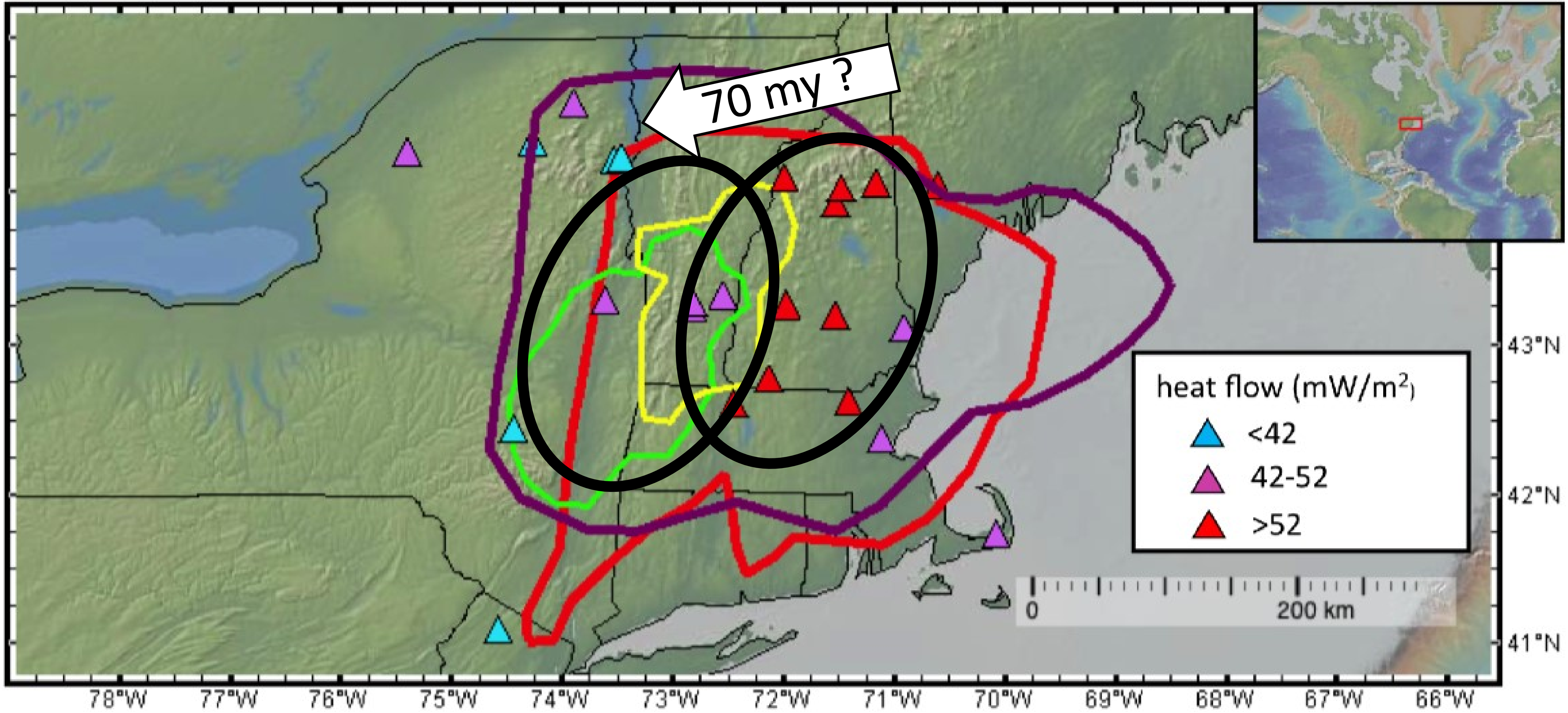

heat flow (mW/m²)
<42
42-52
>52
0
200 km
43°N
42°N
41°N
78°W
77°W
76°W
75°W
74°W
73°W
72°W
71°W
70°W
69°W
68°W
67°W
66°W

time needed for the top part lithosphere to conductively warm

50 km

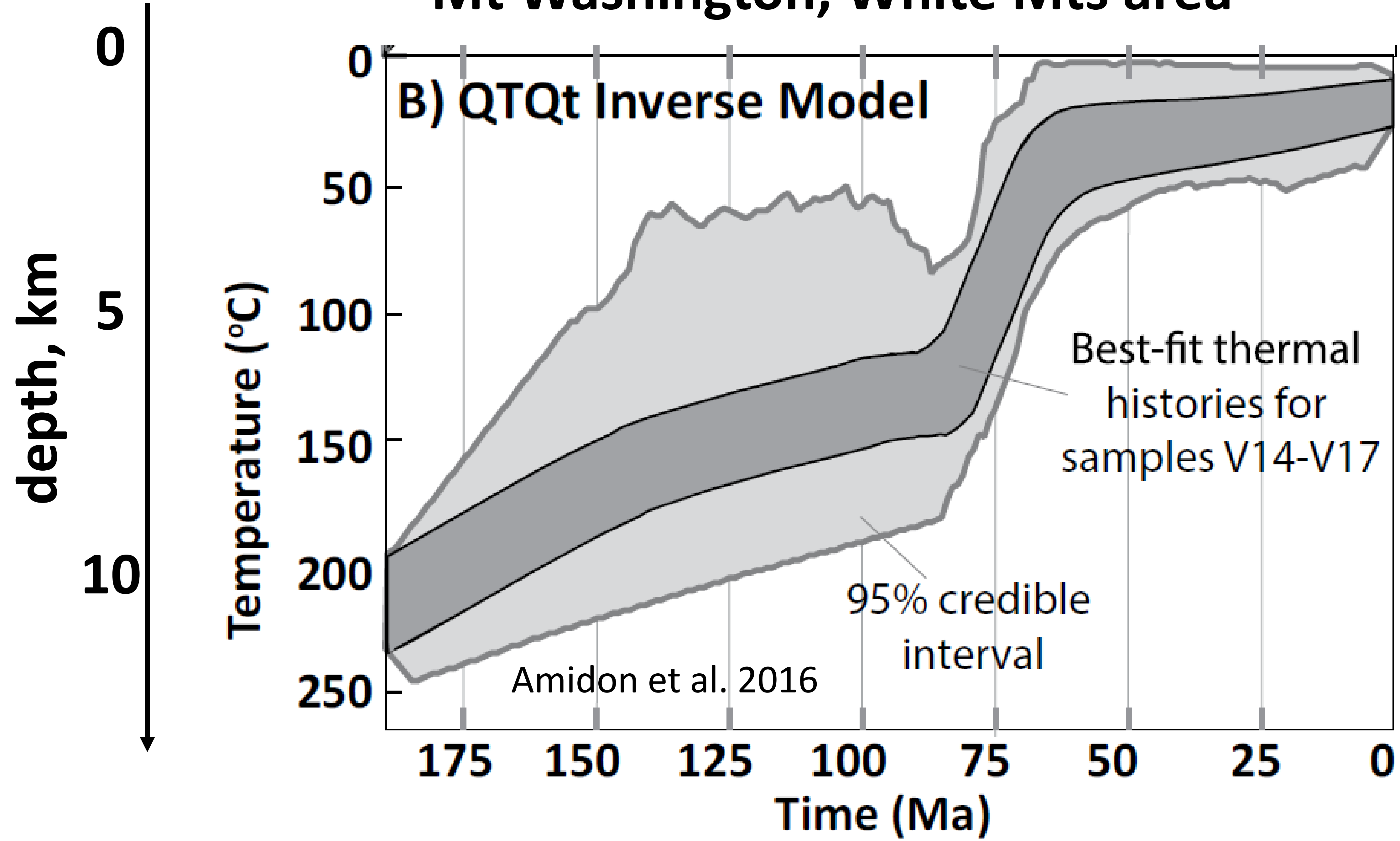
κ= 5x10-7 m^2/s

67 my

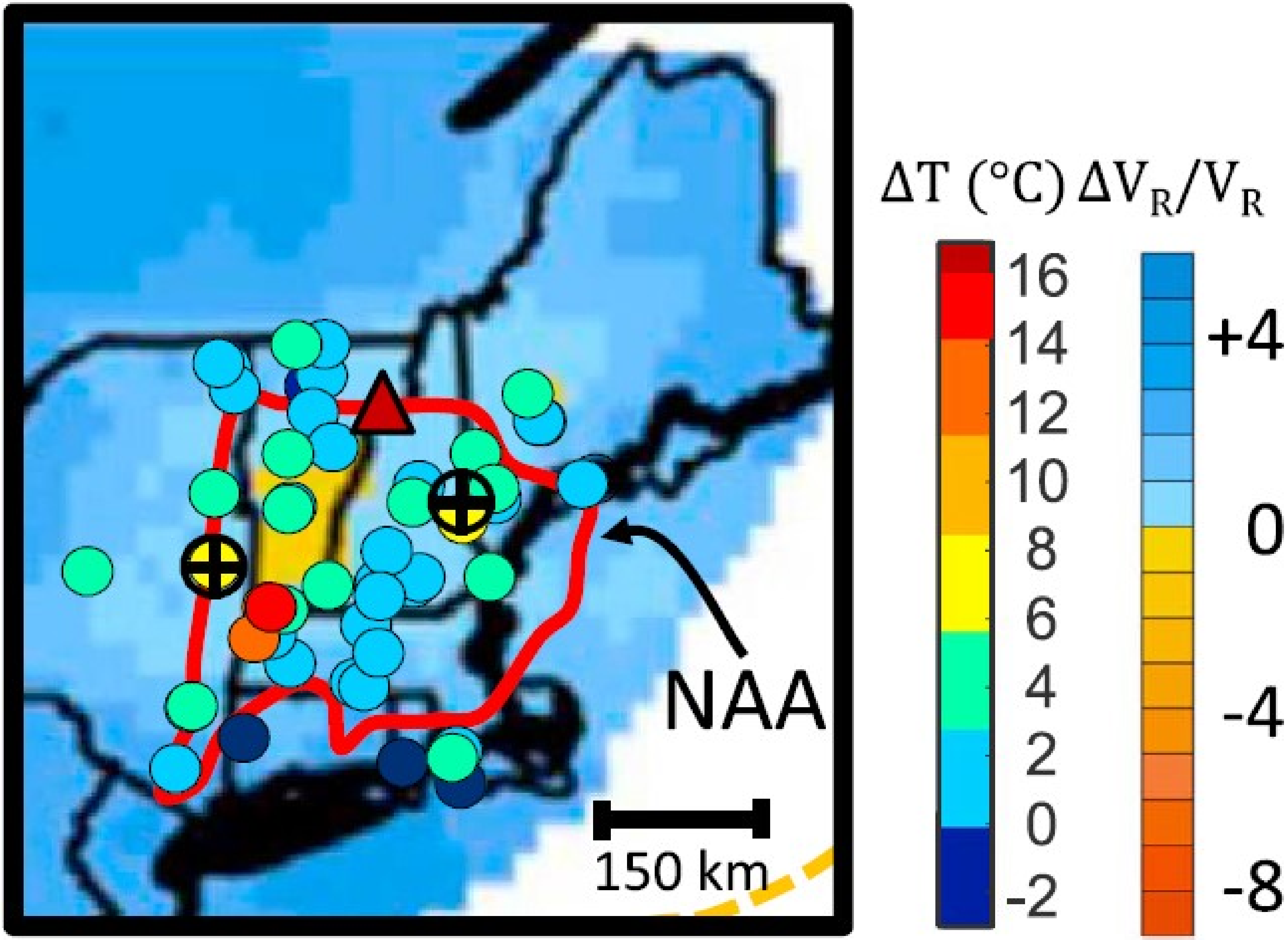


70 my ?
heat flow (mW/m²)
<42
42-52
>52
0
200 km
78°W
77°W
76°W
75°W
74°W
73°W
72°W
71°W
70°W
69°W
68°W
67°W
66°W
43°N
42°N
41°N

Mt Washington, White Mts area



Fluids could reach the surface faster,
Without uniformly warming the surrounding rock …


NAA
150 km
ΔT (°C)
16
14
12
10
8
6
4
2
0
-2
$\Delta V_R/V_R$
+4
0
-4
-8

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?