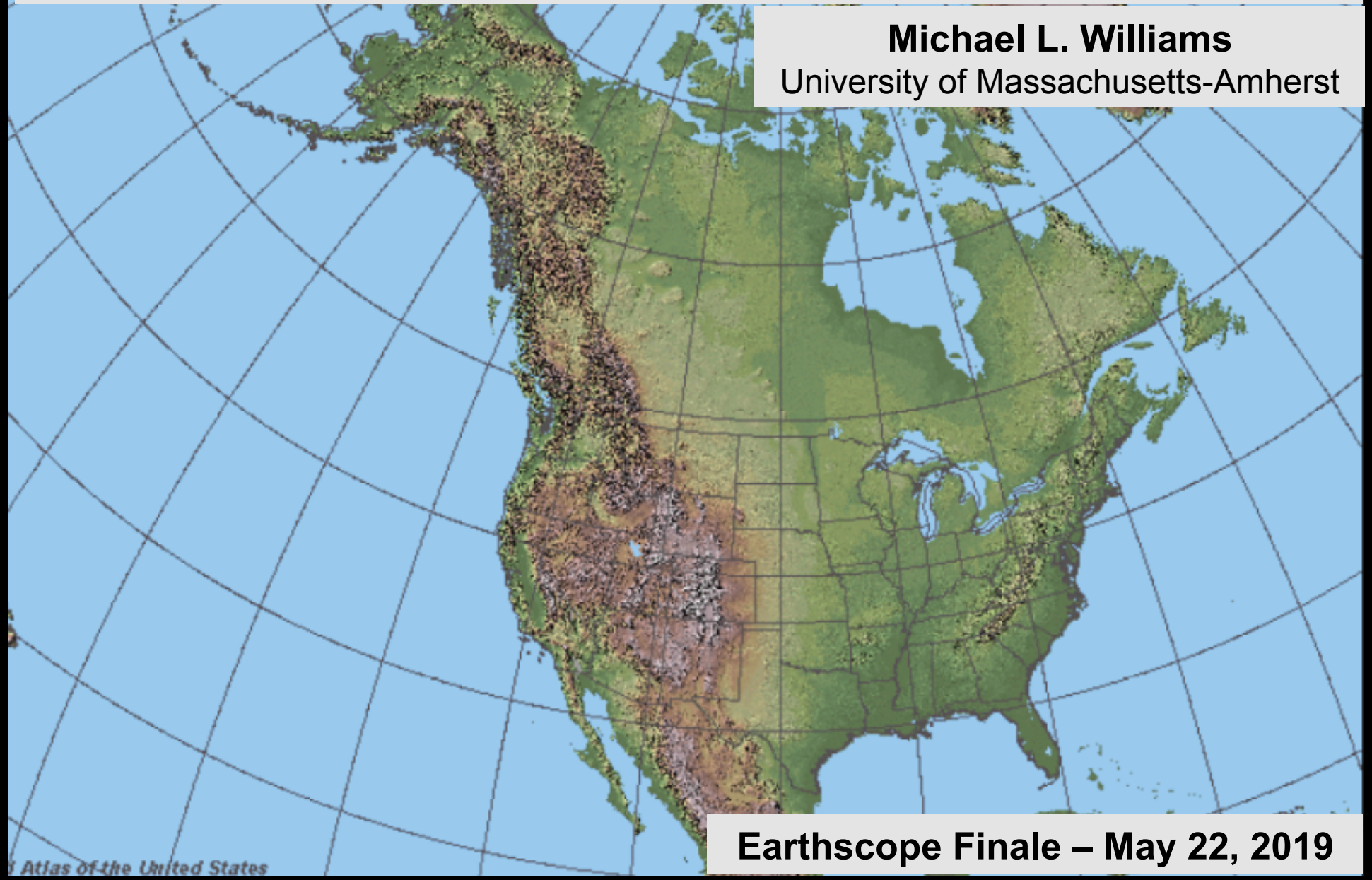
The Second Tectonics Revolution:

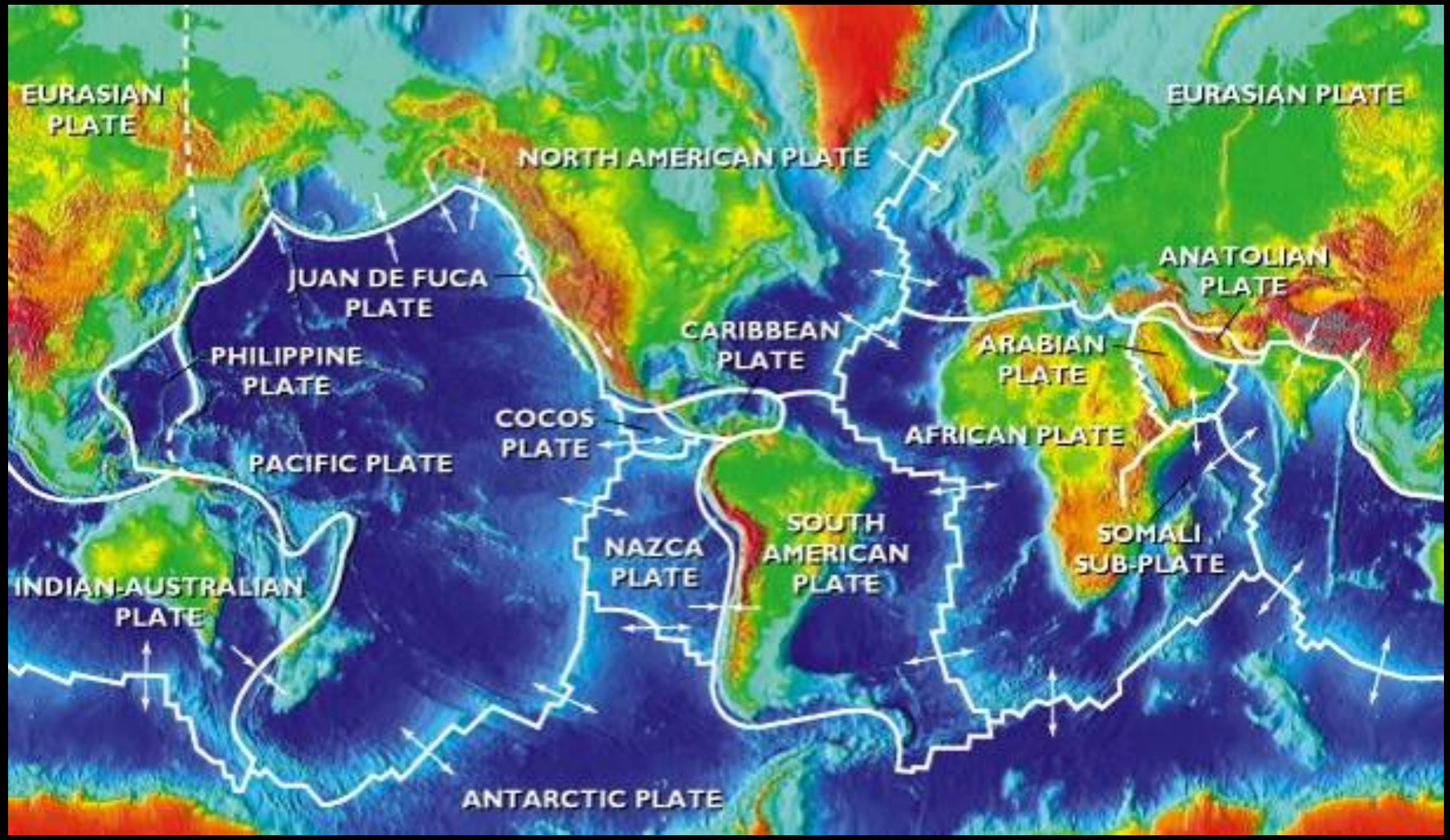
A New 4D Perspective on the History of the North American Continent



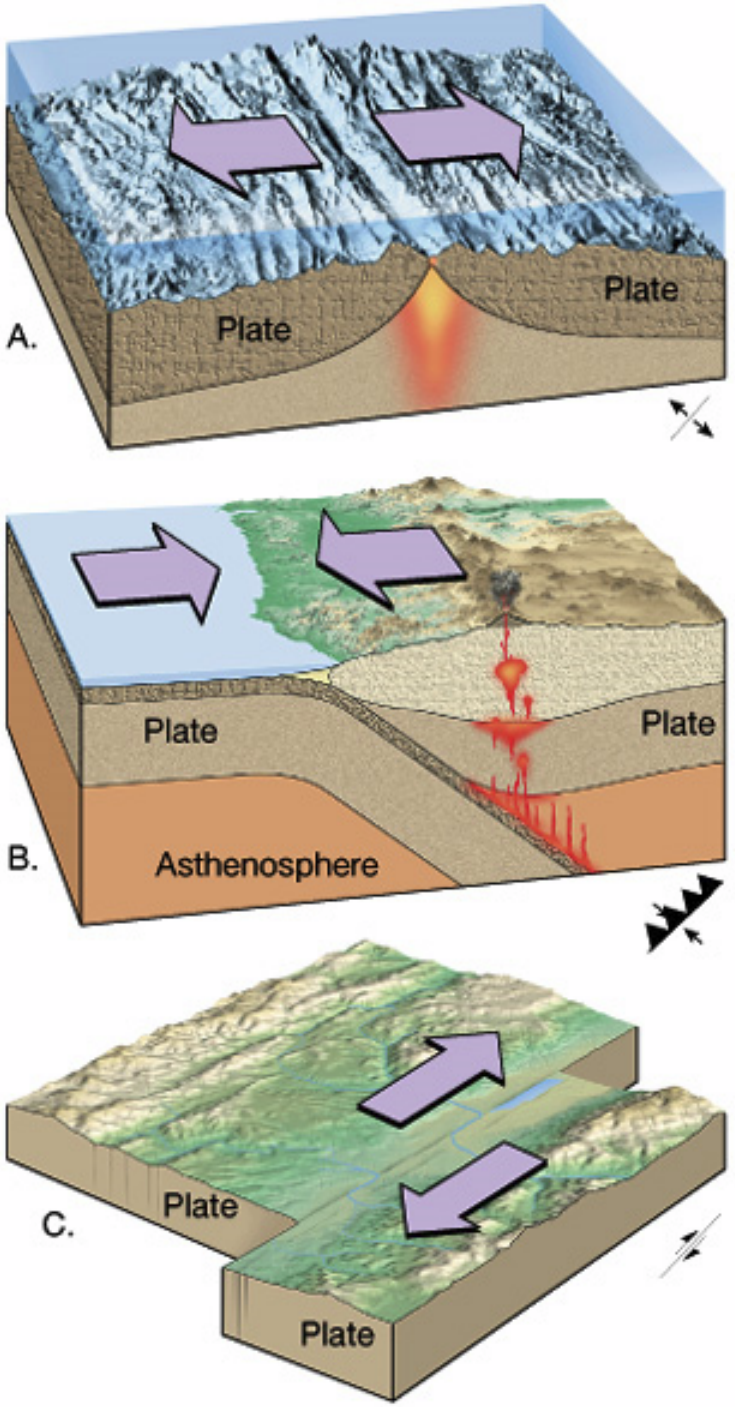
Michael L. Williams
University of Massachusetts-Amherst

Earthscope Finale – May 22, 2019

The Plate Tectonics Revolution



Pete W. Sloss, NOAA-NESDIS-NGDC


A.
Plate
Plate
B.
Plate
Plate
Asthenosphere
C.
Plate
Plate

Mountain Belts and the New Global Tectonics

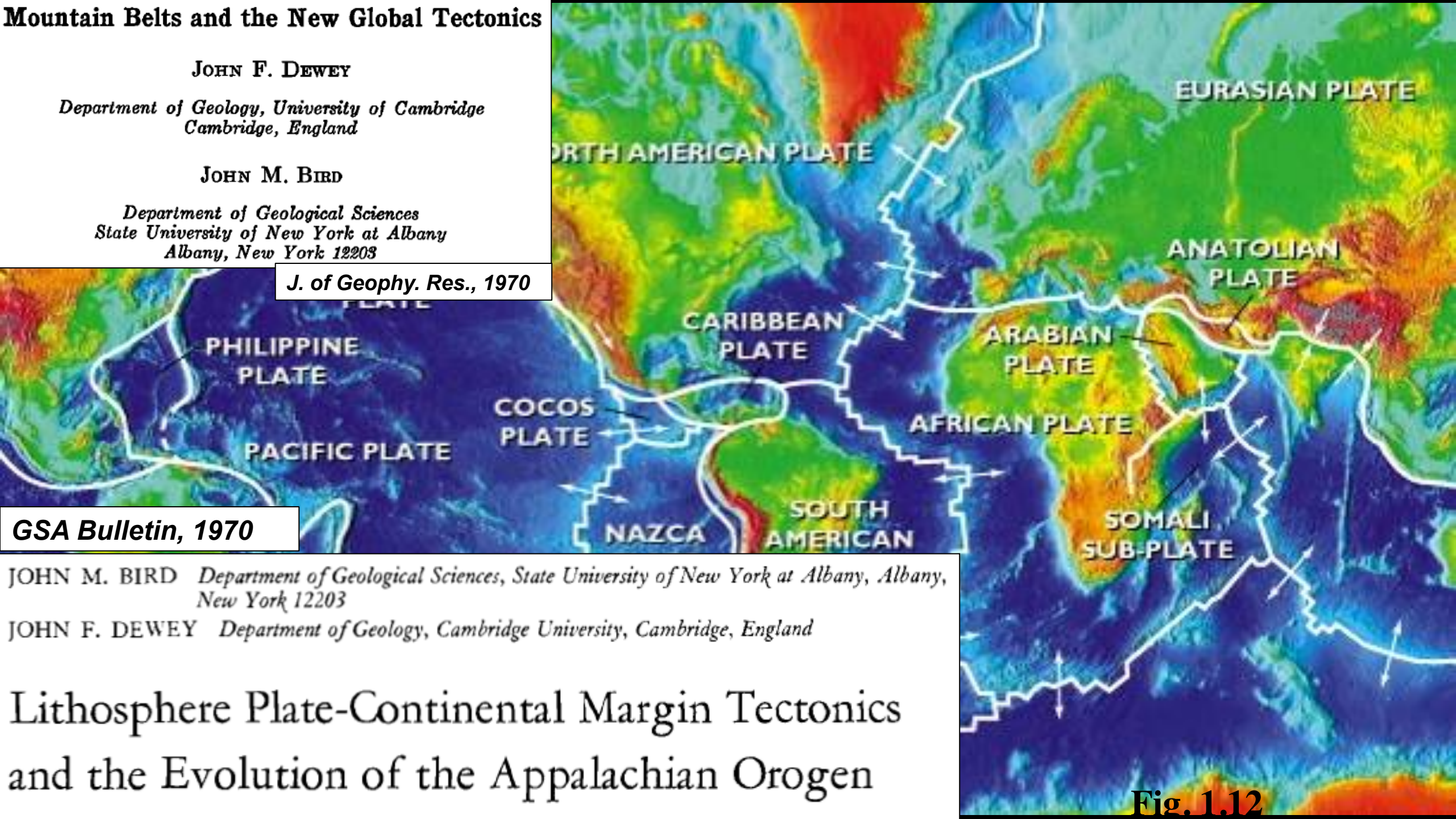
JOHN F. DEWEY

Department of Geology, University of Cambridge
Cambridge, England

JOHN M. BIRD

Department of Geological Sciences
State University of New York at Albany
Albany, New York 12203

J. of Geophy. Res., 1970



GSA Bulletin, 1970

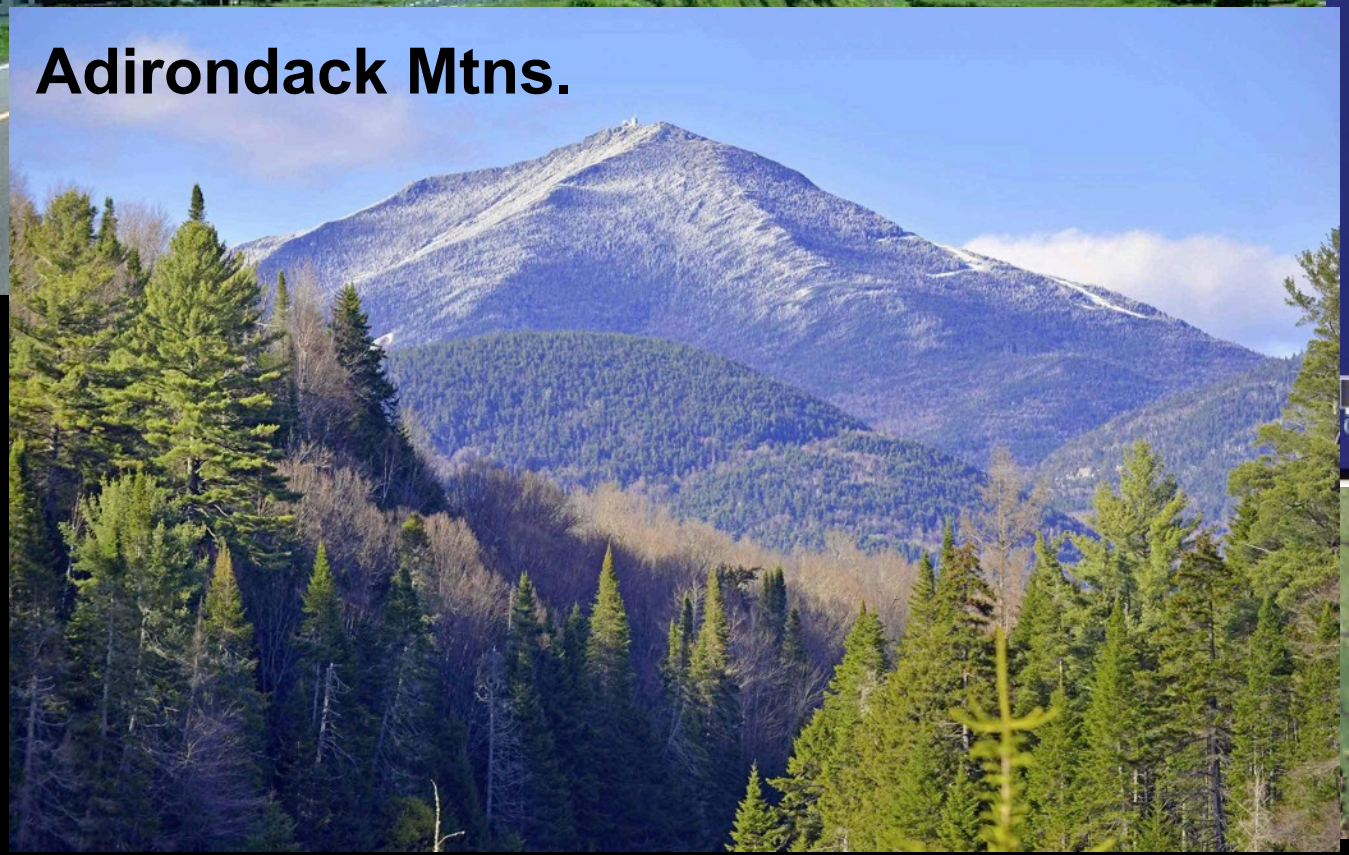
JOHN M. BIRD *Department of Geological Sciences, State University of New York at Albany, Albany, New York 12203*

JOHN F. DEWEY *Department of Geology, Cambridge University, Cambridge, England*

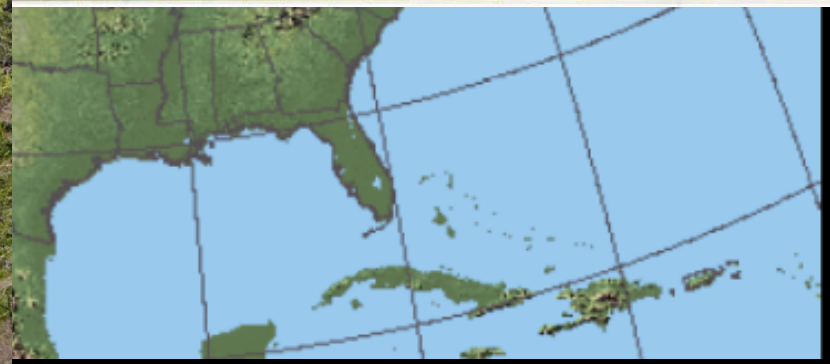
Lithosphere Plate-Continental Margin Tectonics and the Evolution of the Appalachian Orogen

Fig. 1.12

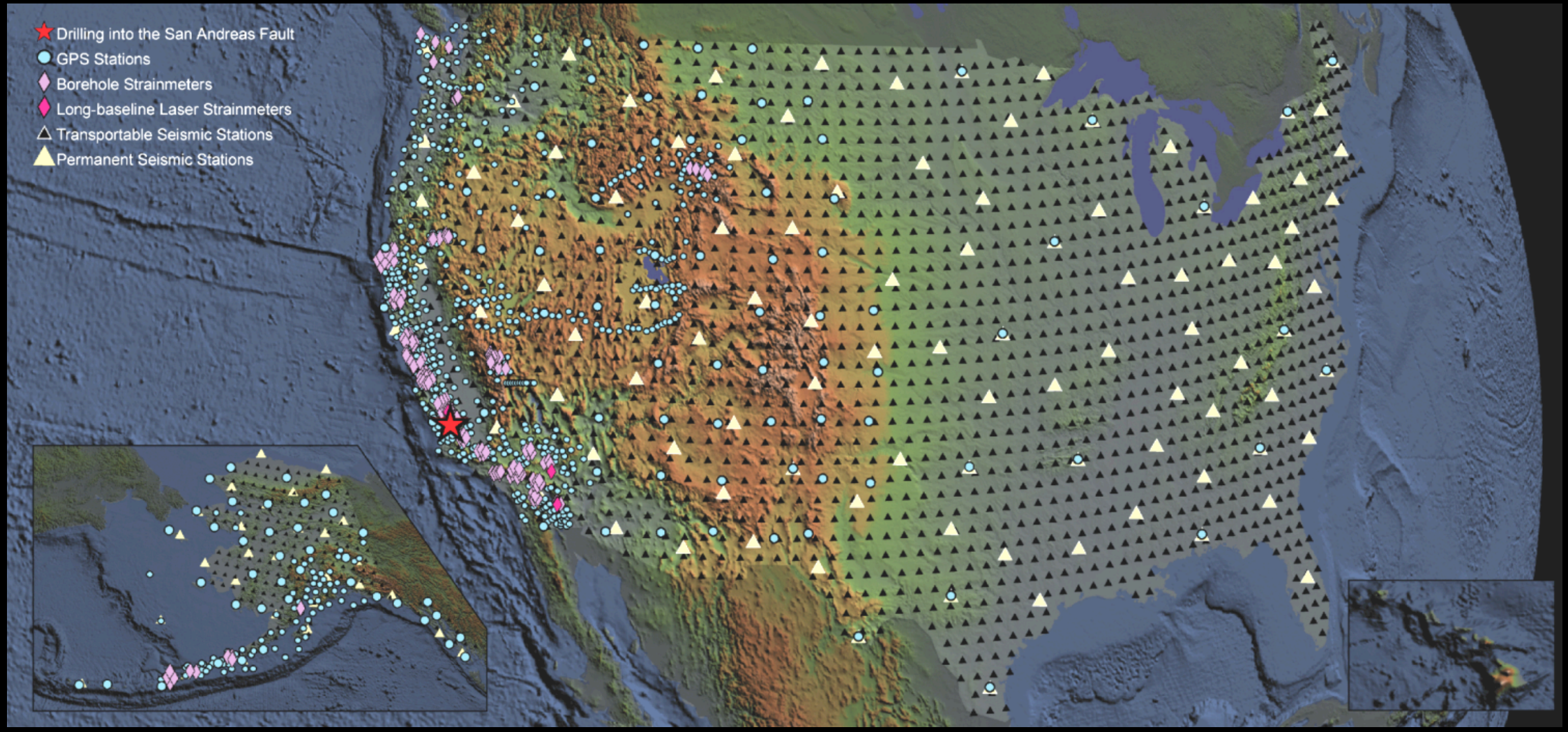

Virginia


Adirondack Mtns.

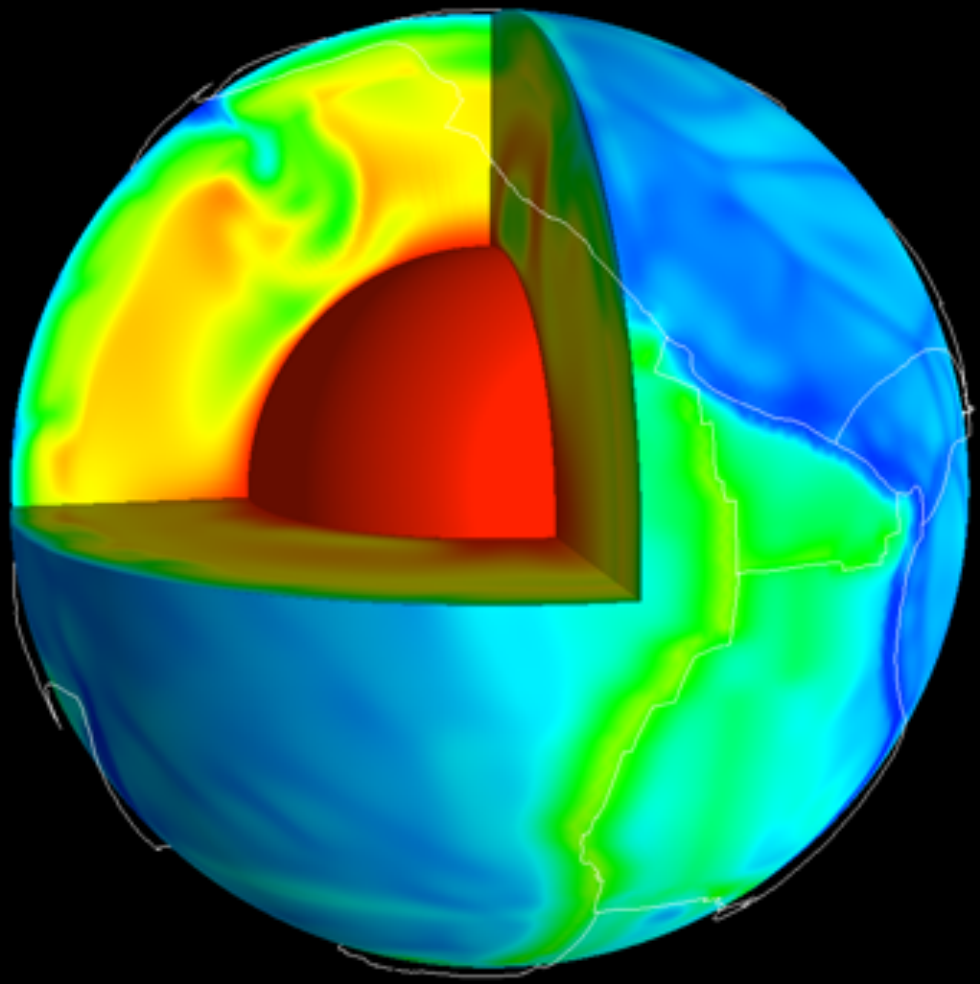

0
1000
2000
3000
4000
ELEVATION (m)



Earthscope

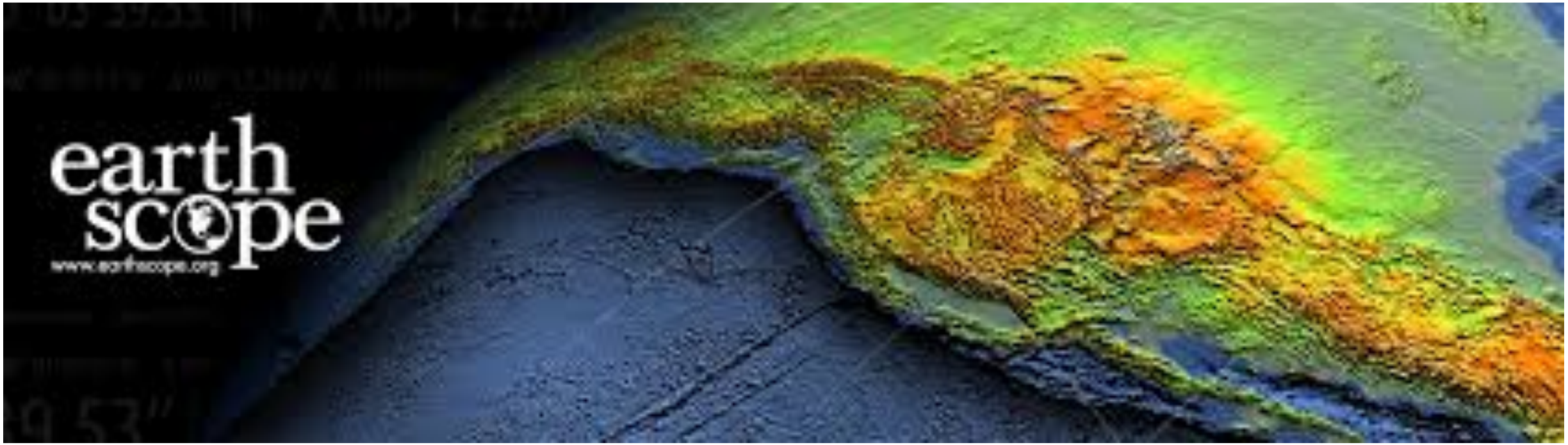


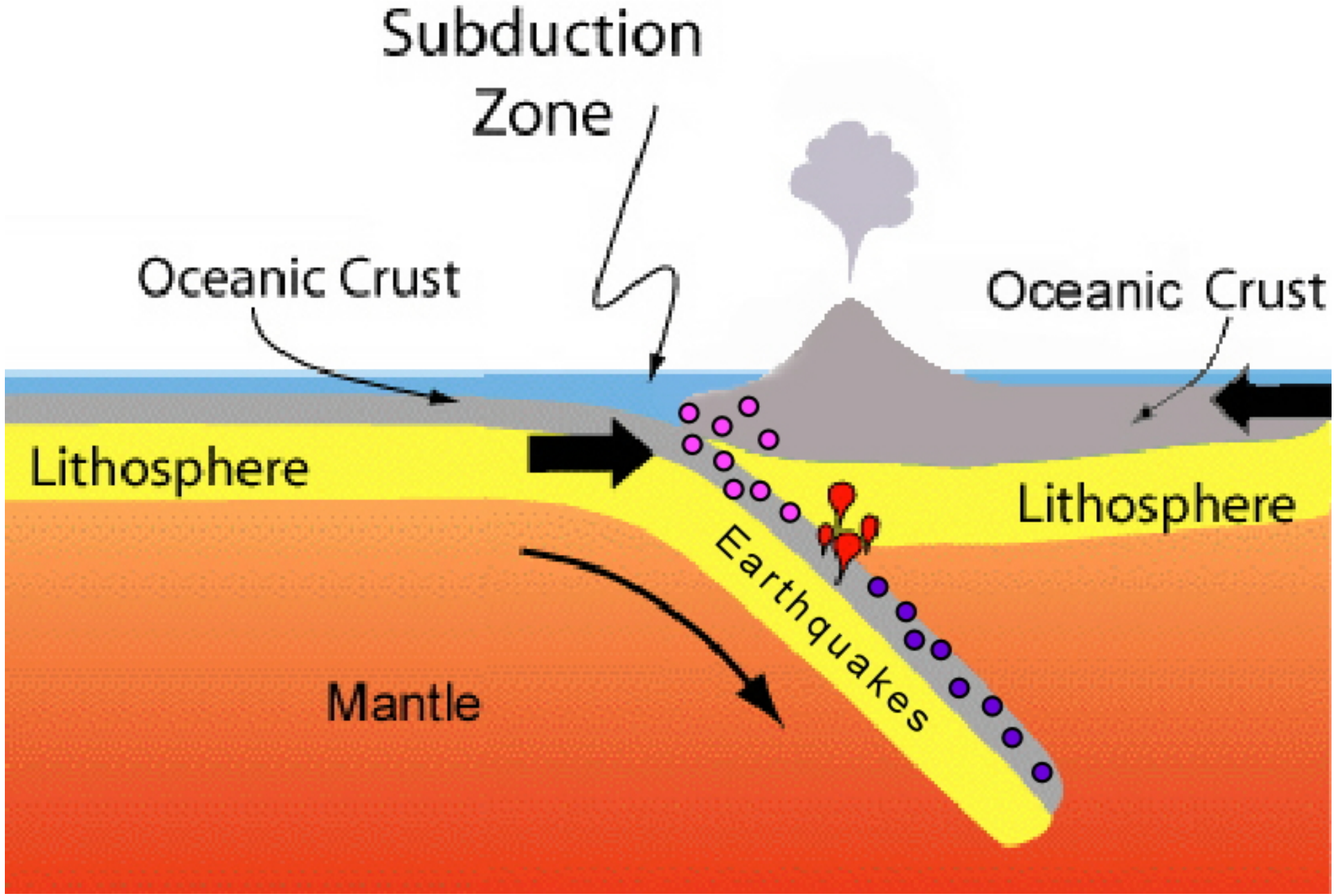
Exploring the Structure and Evolution of the North American Continent

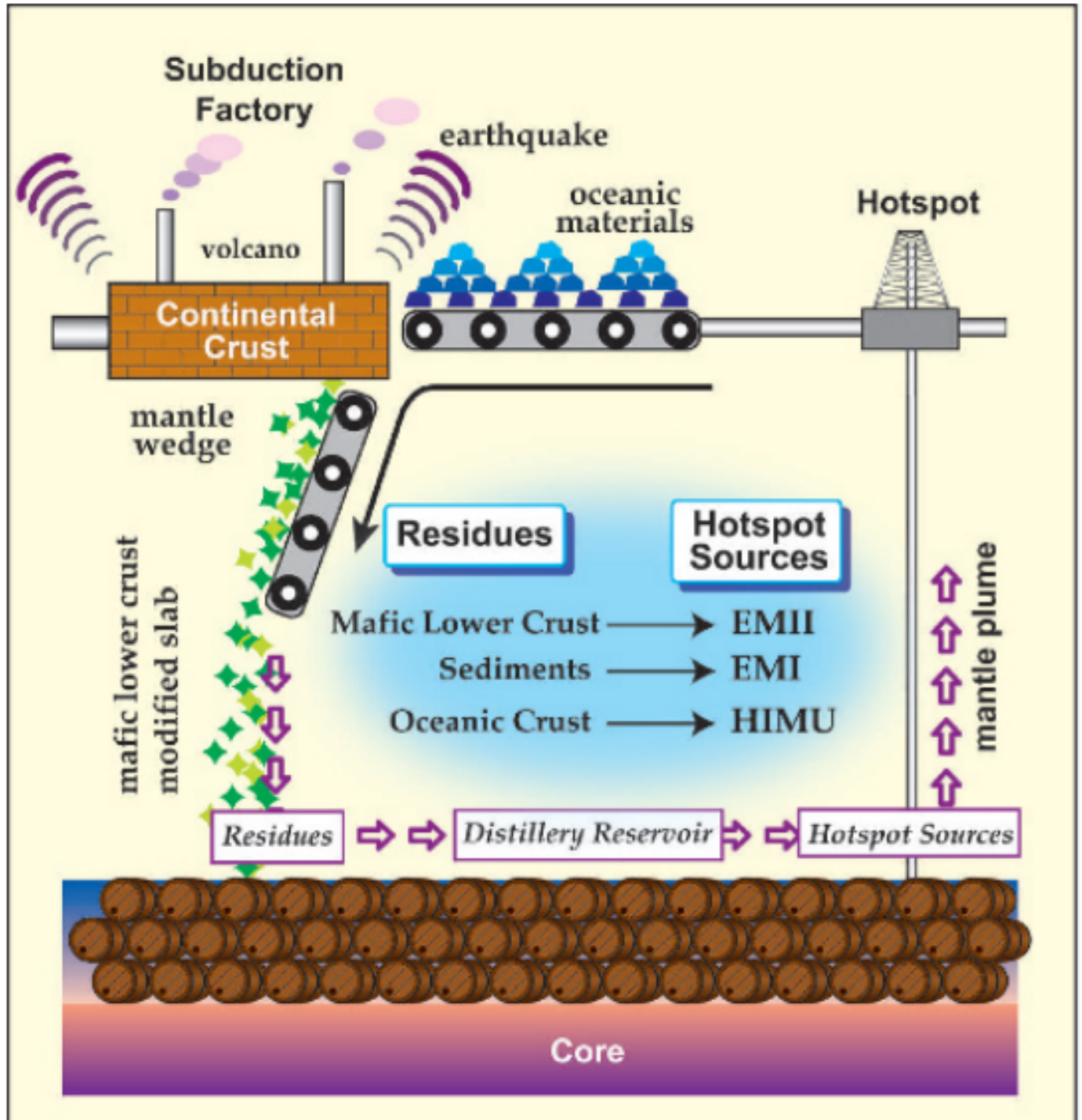


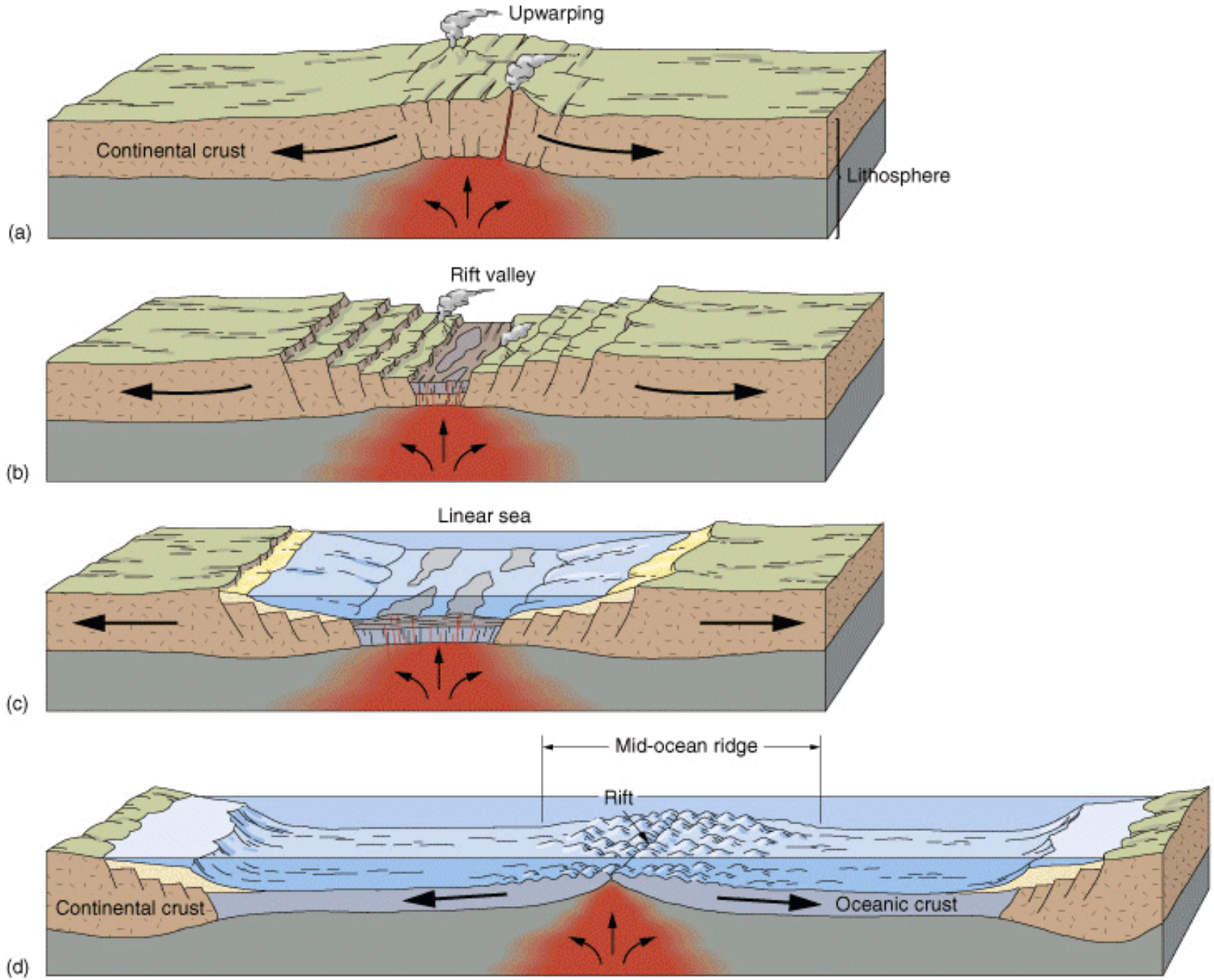
The Second Tectonics Revolution

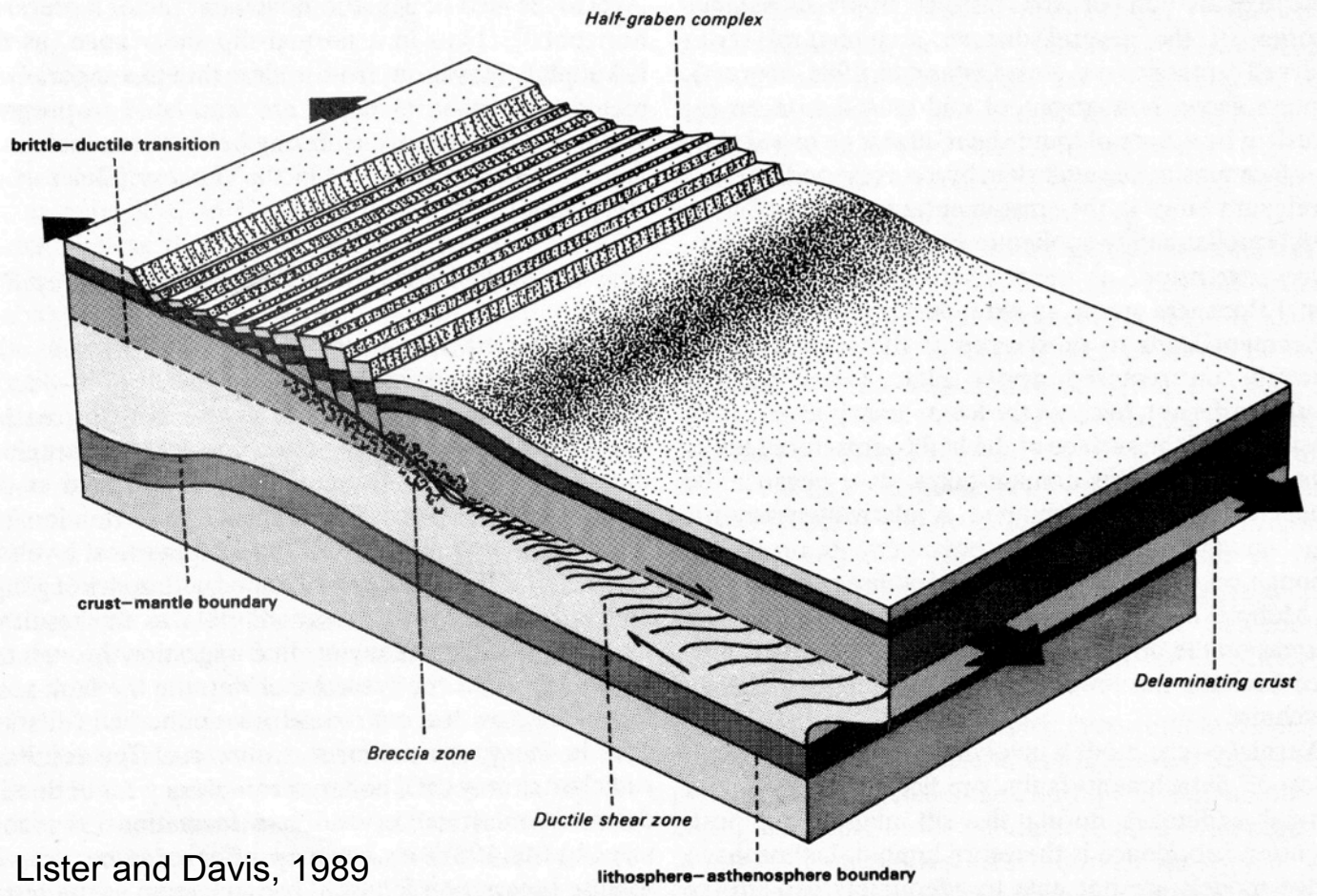
A New View of Plate Interaction



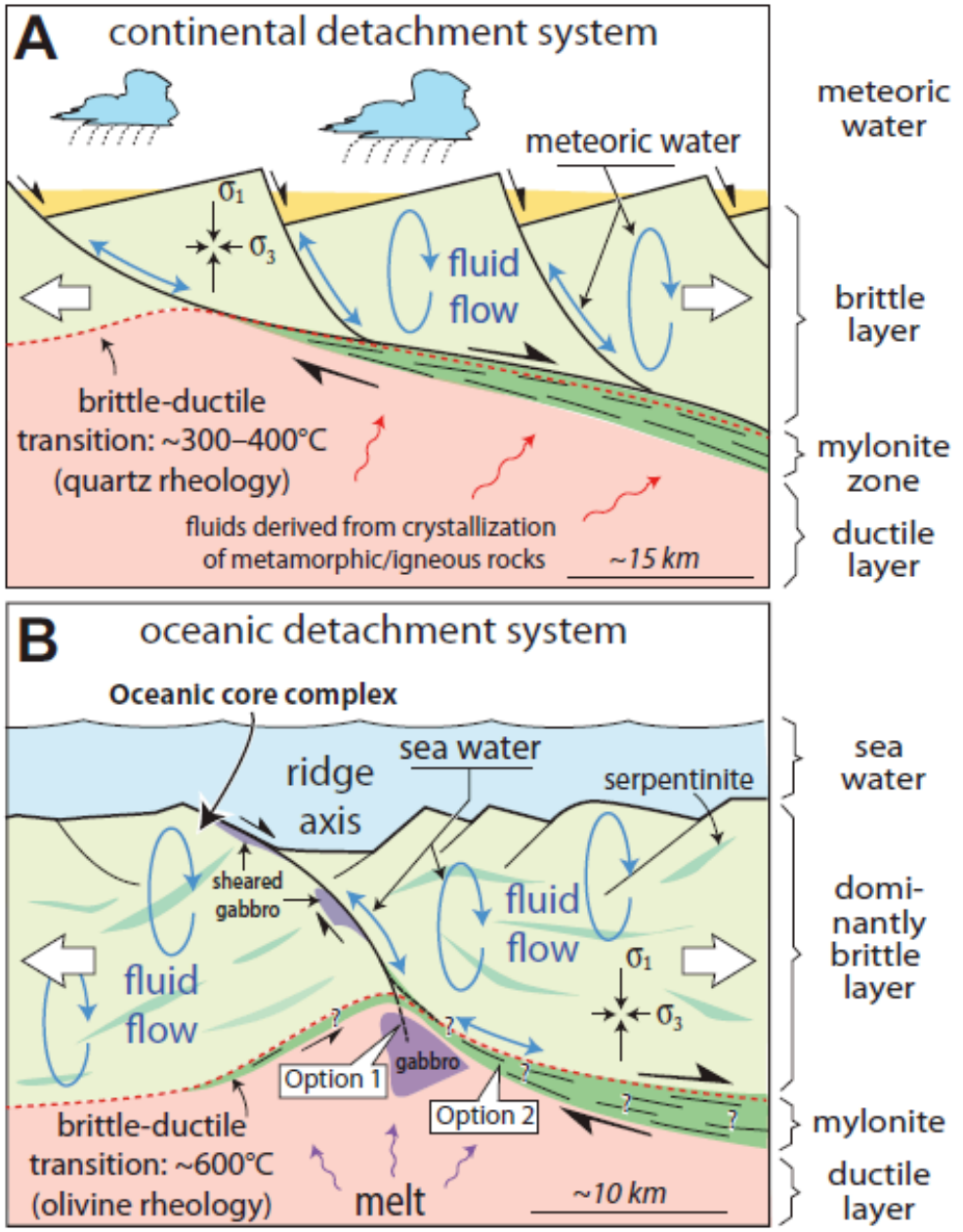

Subduction
Zone
Oceanic Crust
Oceanic Crust
Lithosphere
Lithosphere
Earthquakes
Mantle


Subduction Factory
earthquake
volcano
oceanic materials
Hotspot
Continental Crust
mantle wedge
Residues
Hotspot Sources
Mafic Lower Crust → EMII
Sediments → EMI
Oceanic Crust → HIMU
mafic lower crust modified slab
mantle plume
Residues
Distillery Reservoir
Hotspot Sources
Core

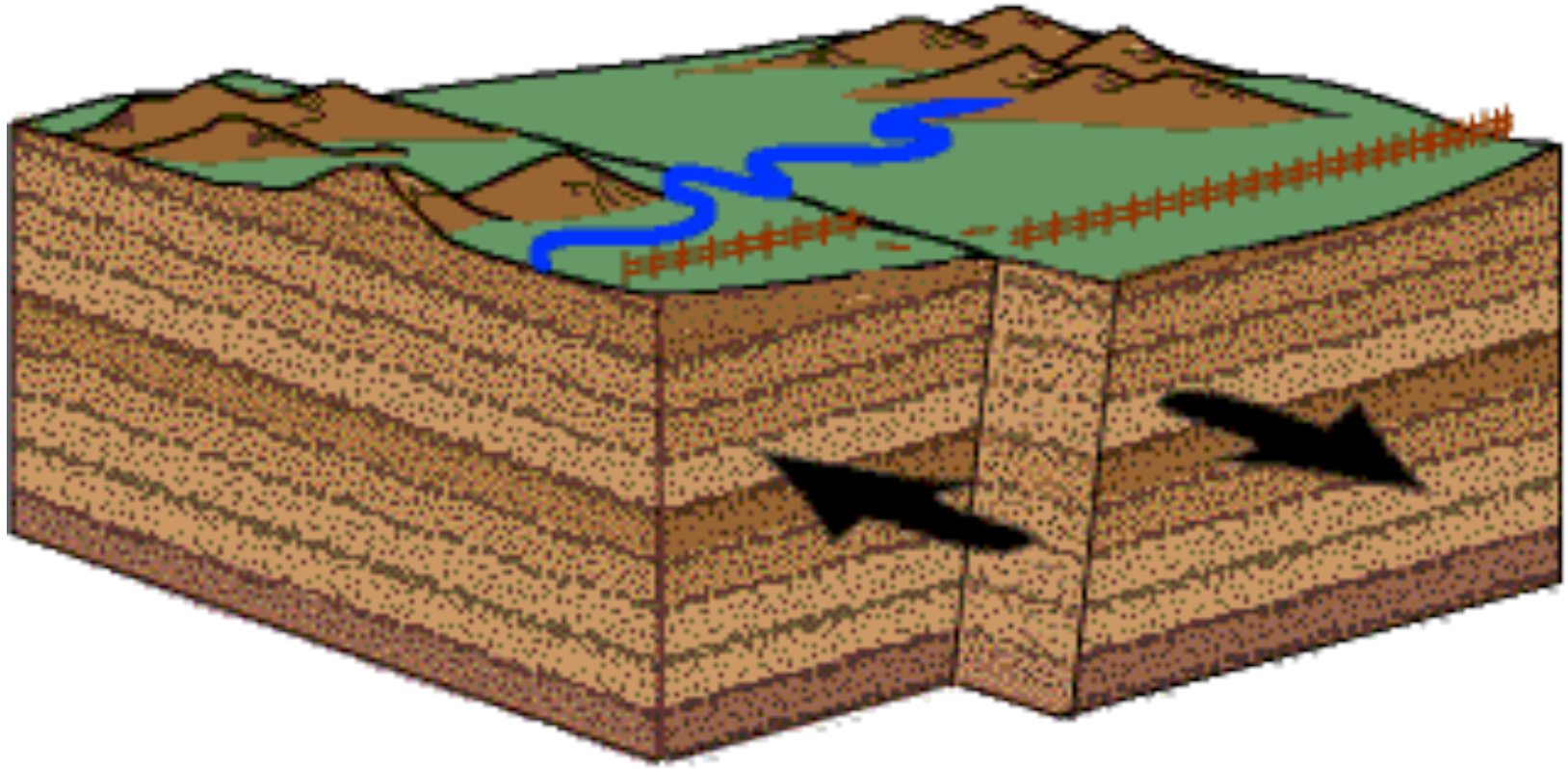

Upwarping
Continental crust
Lithosphere
(a)
Rift valley
(b)
Linear sea
(c)
Mid-ocean ridge
Rift
Continental crust
Oceanic crust
(d)



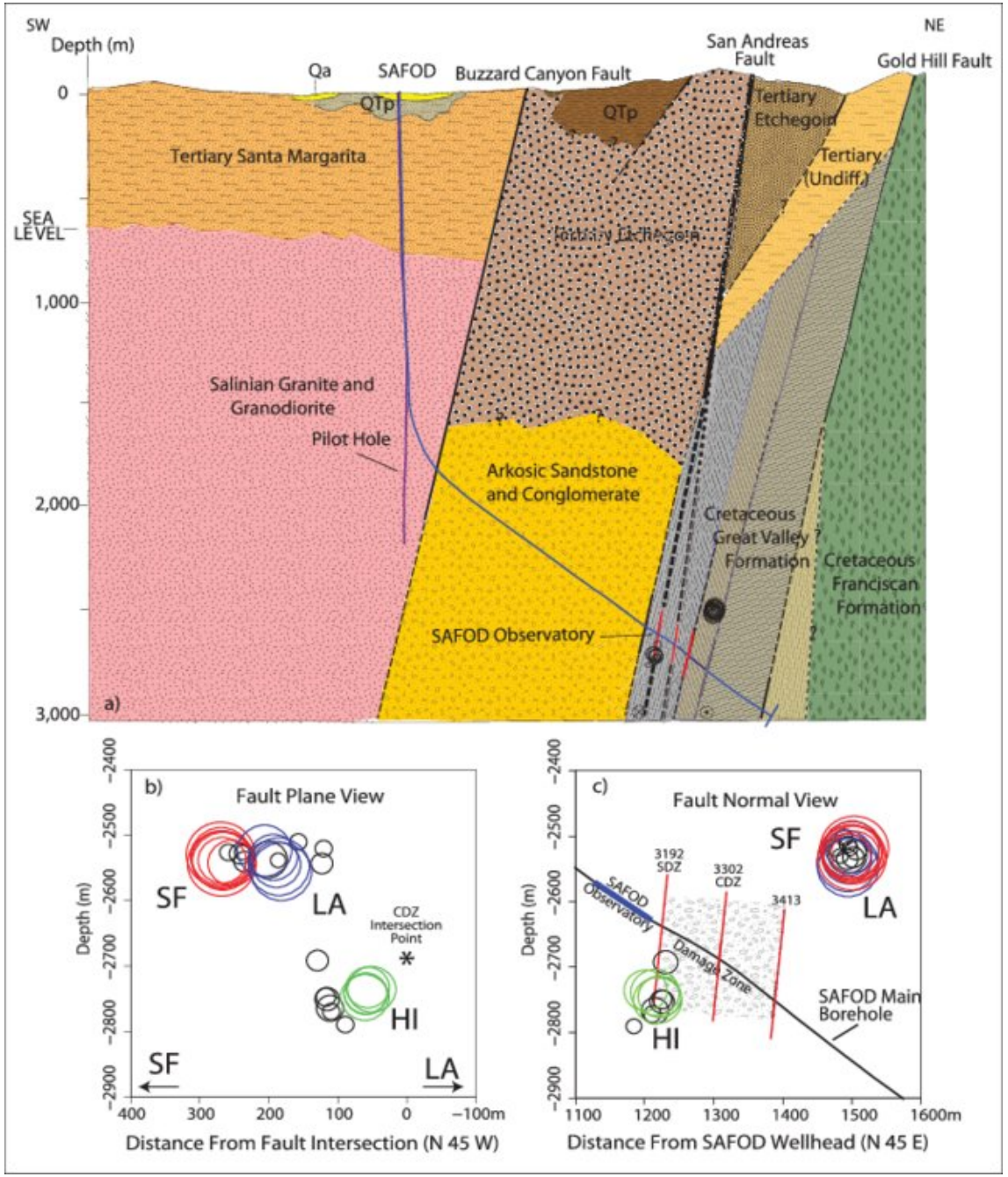
Lister and Davis, 1989

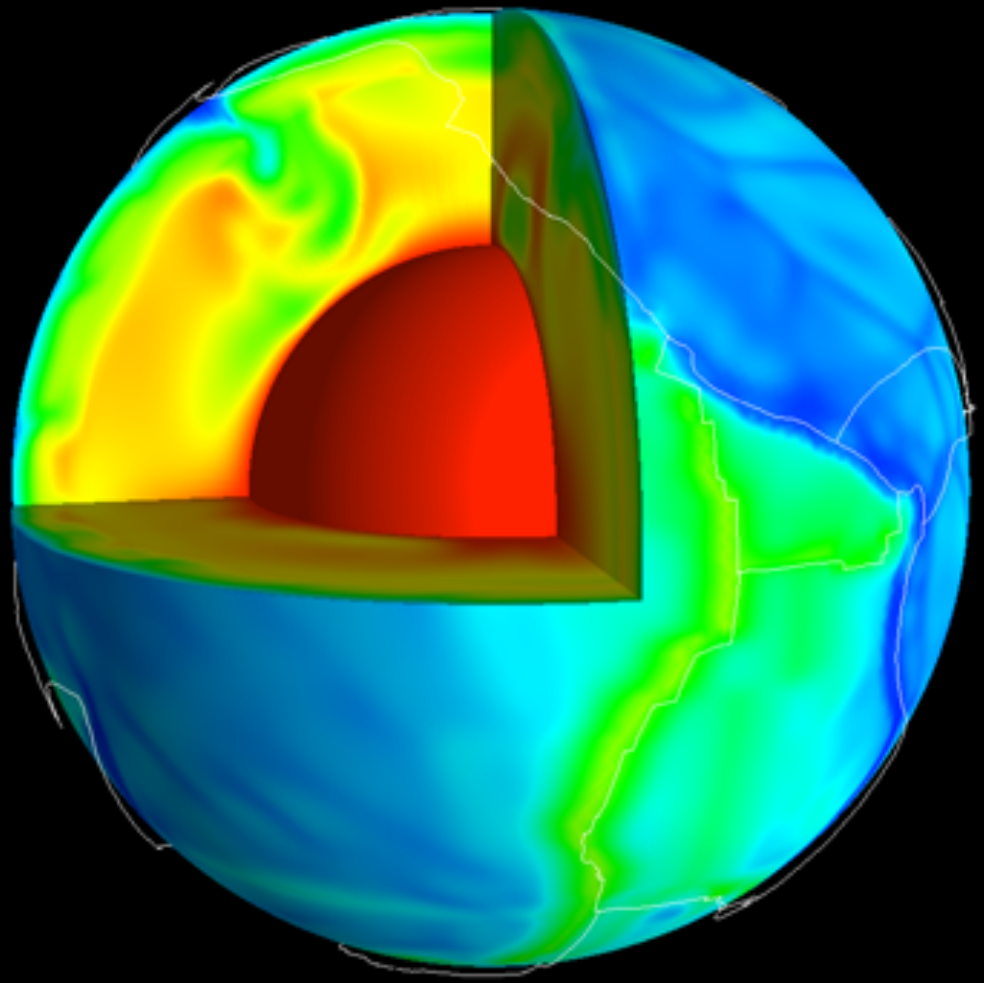


Whitney et al., 2013




North American Plate
1906 M 7.8
San Francisco
1989 M 6.9
1966 M 6.0
SAFOD (Parkfield)
1857 M 7.9
San Andreas Fault
48 mm/yr
Los Angeles
Pacific Plate

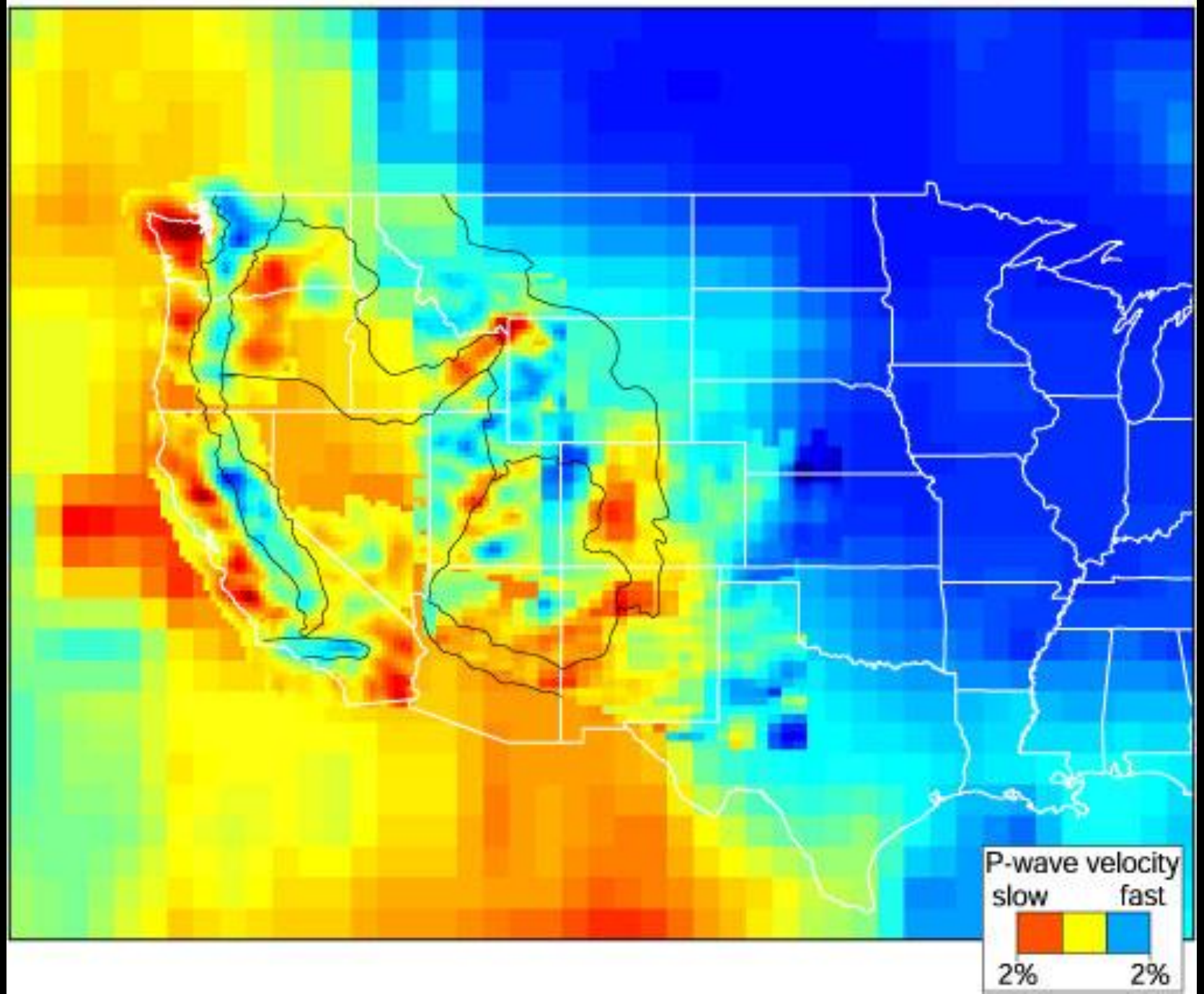

SW
NE
Depth (m)
Qa
SAFOD
Buzzard Canyon Fault
San Andreas Fault
Gold Hill Fault
QTp
Tertiary Etchegoin
Tertiary (Undiff.)
Tertiary Santa Margarita
SEA LEVEL
Salinian Granite and Granodiorite
Pilot Hole
Arkosic Sandstone and Conglomerate
Cretaceous Great Valley ? Formation
Cretaceous Franciscan Formation
SAFOD Observatory
a)
b)
Fault Plane View
SF
LA
CDZ Intersection Point
HI
Distance From Fault Intersection (N 45 W)
c)
Fault Normal View
3192 SDZ
3302 CDZ
3413
SAFOD Observatory
Damage Zone
SAFOD Main Borehole
Distance From SAFOD Wellhead (N 45 E)



The Second Tectonics Revolution

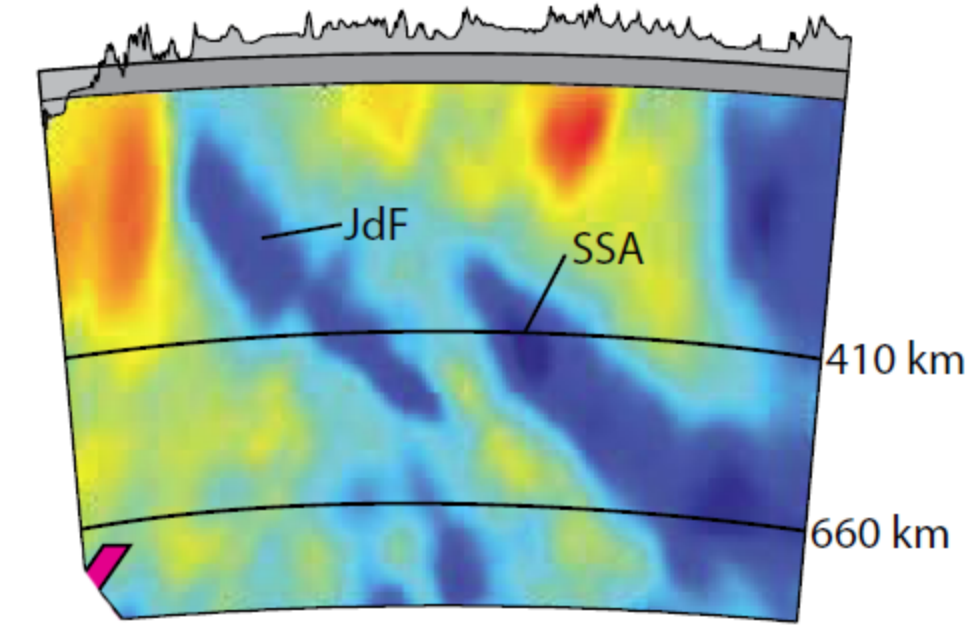
Slabs, Drips, Plumes and More

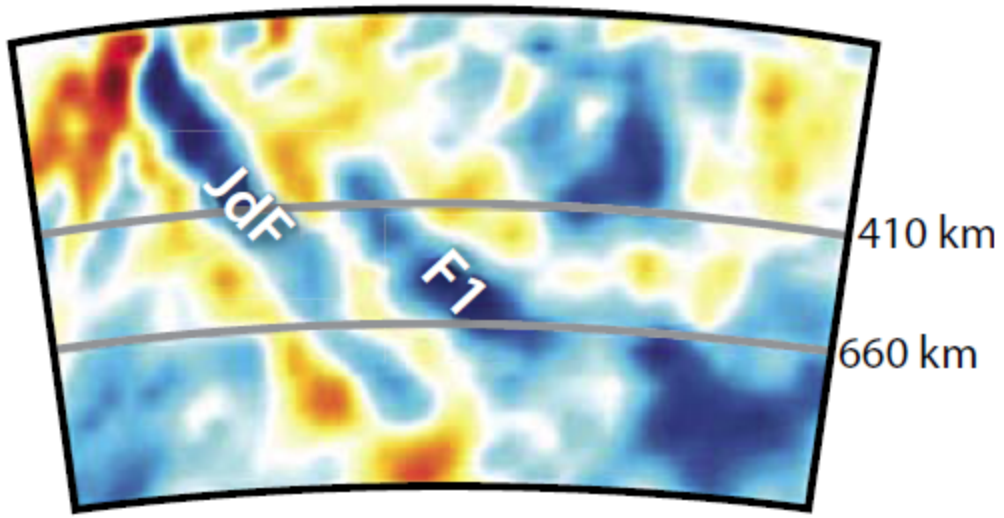
Velocity at 100 km depth



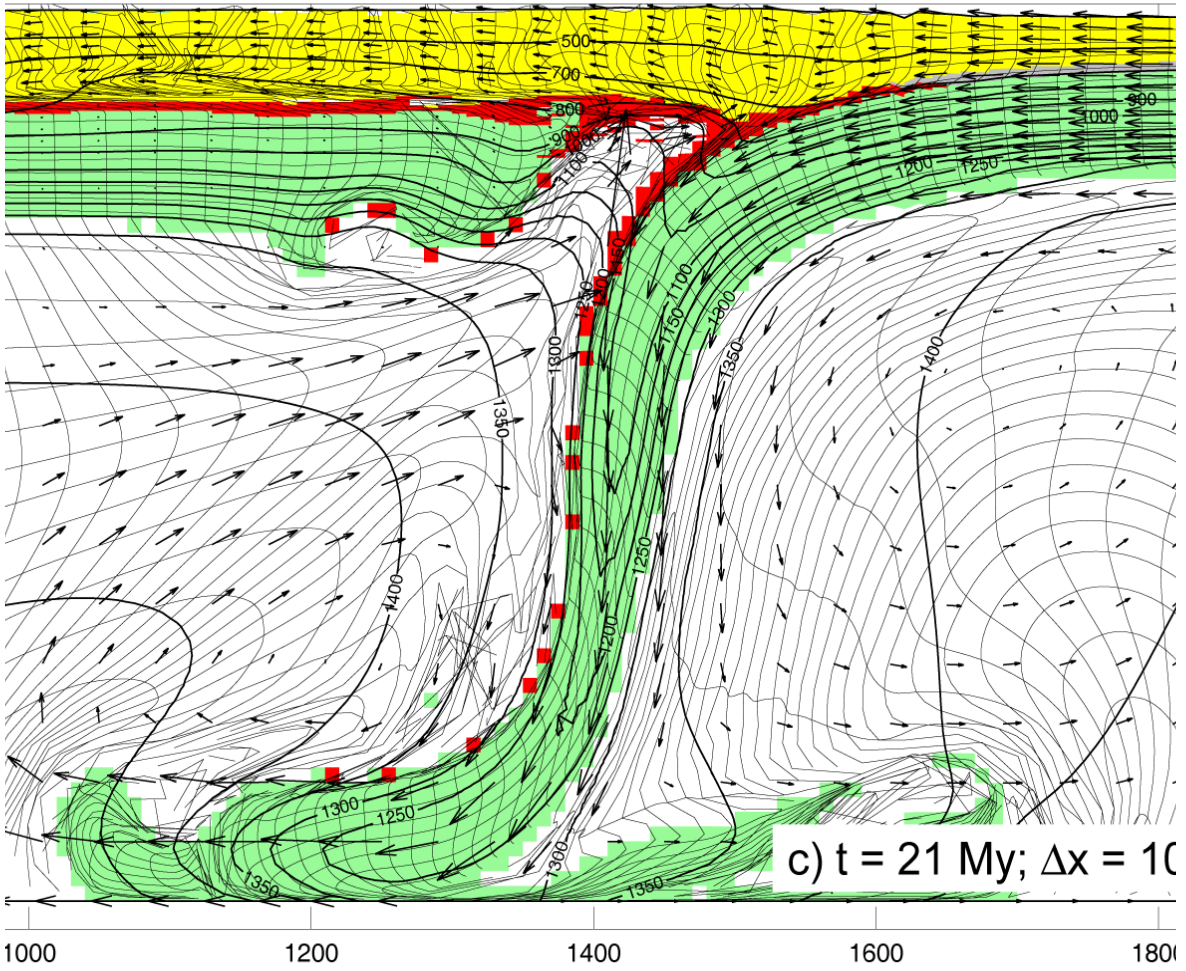
Slabs

Roth et al., 2008

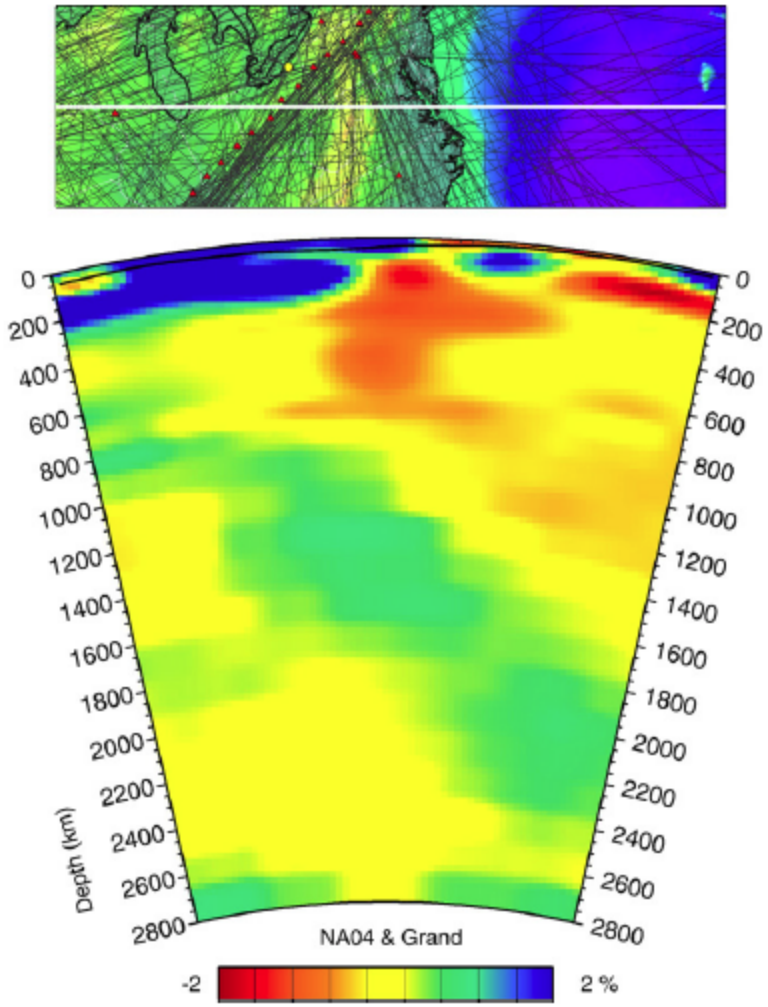


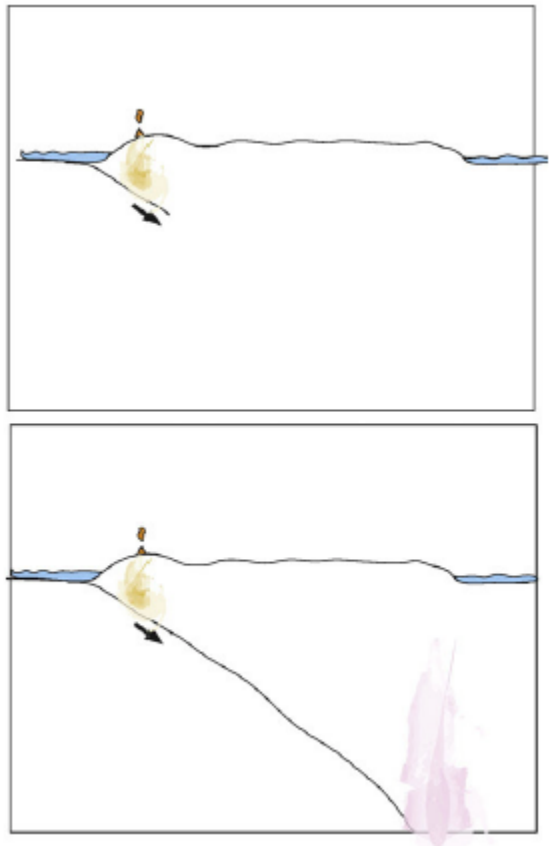


Obrebski et al., 2010



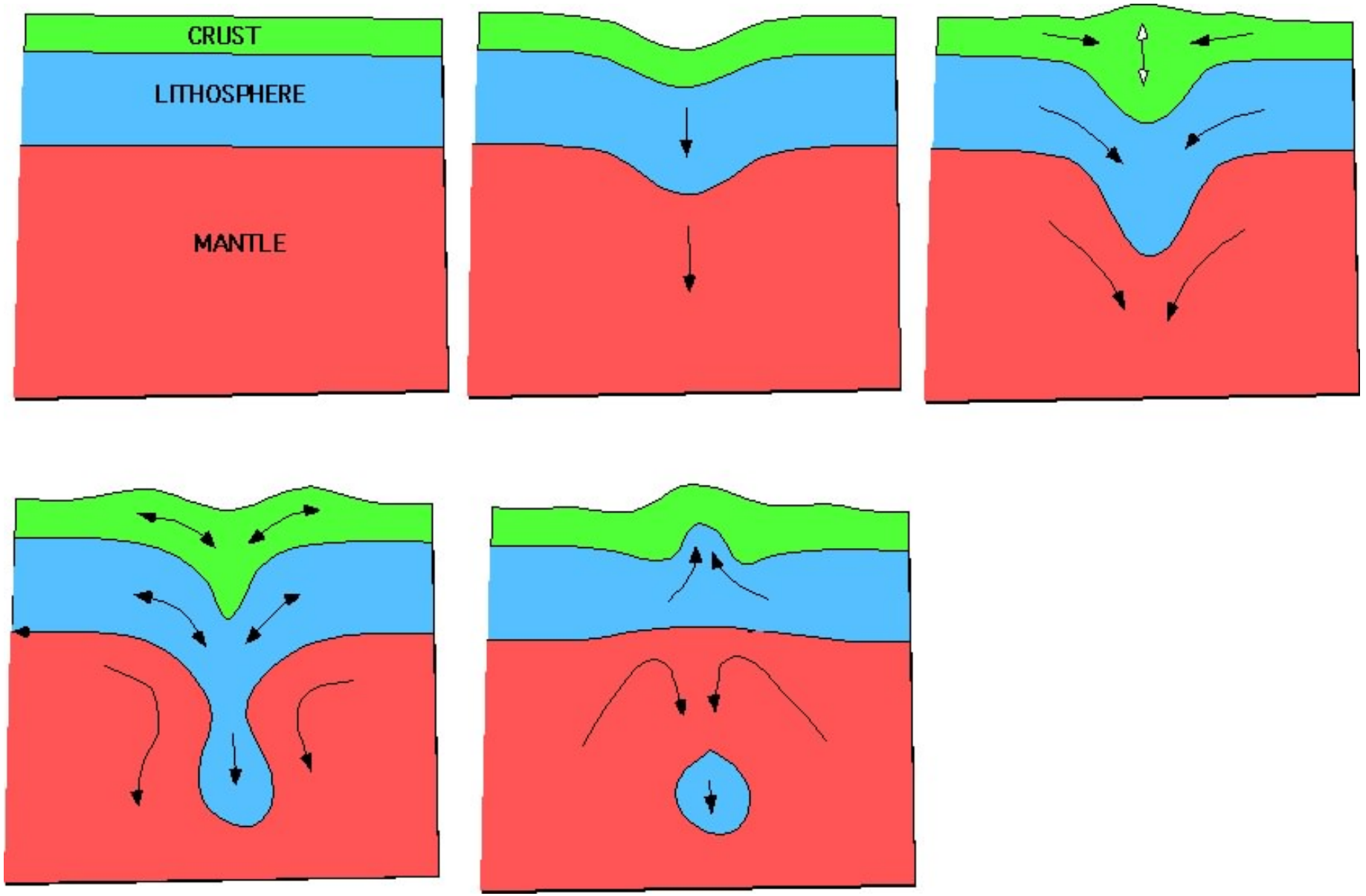
C. Beaumont, personal communication





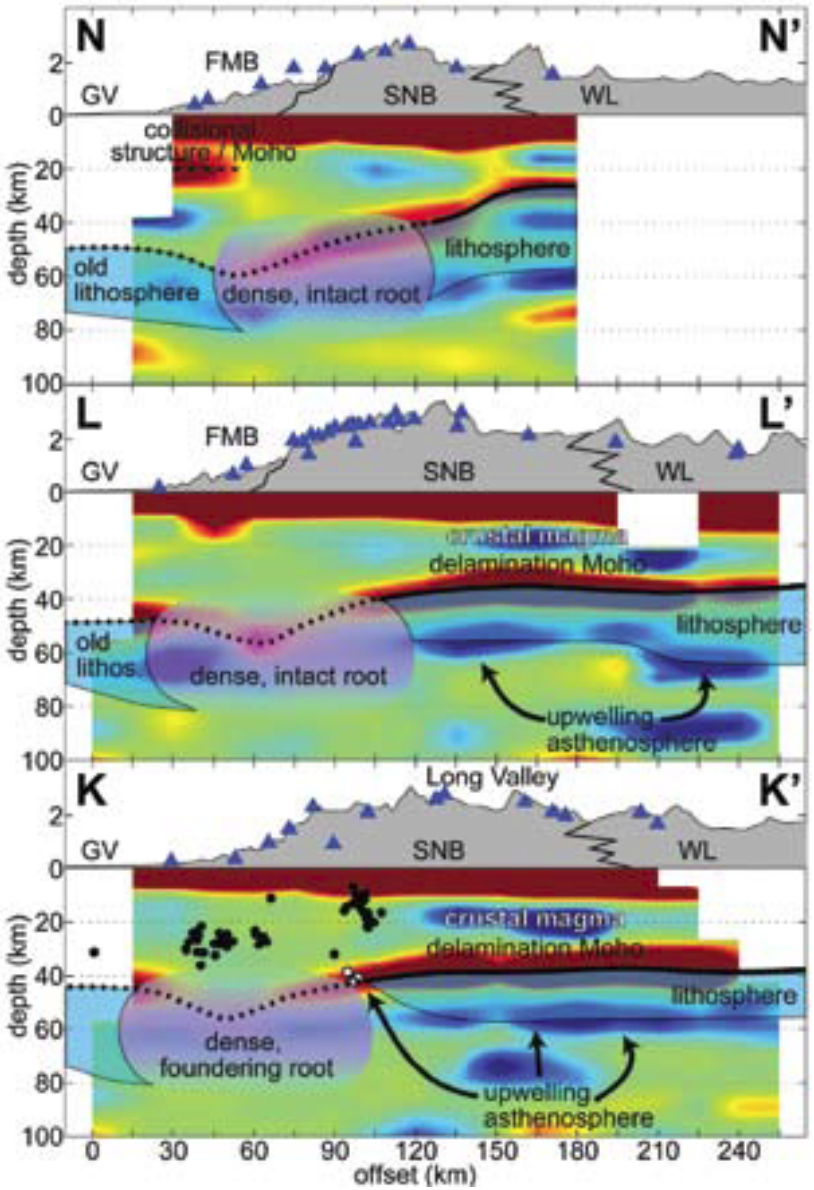
Van der Lee, Regenauer-Lieb, Yuen, 2008, The role of water in connecting past and future episodes of subduction, Earth and Planetary Science Letters 273, 15–27.

Drips

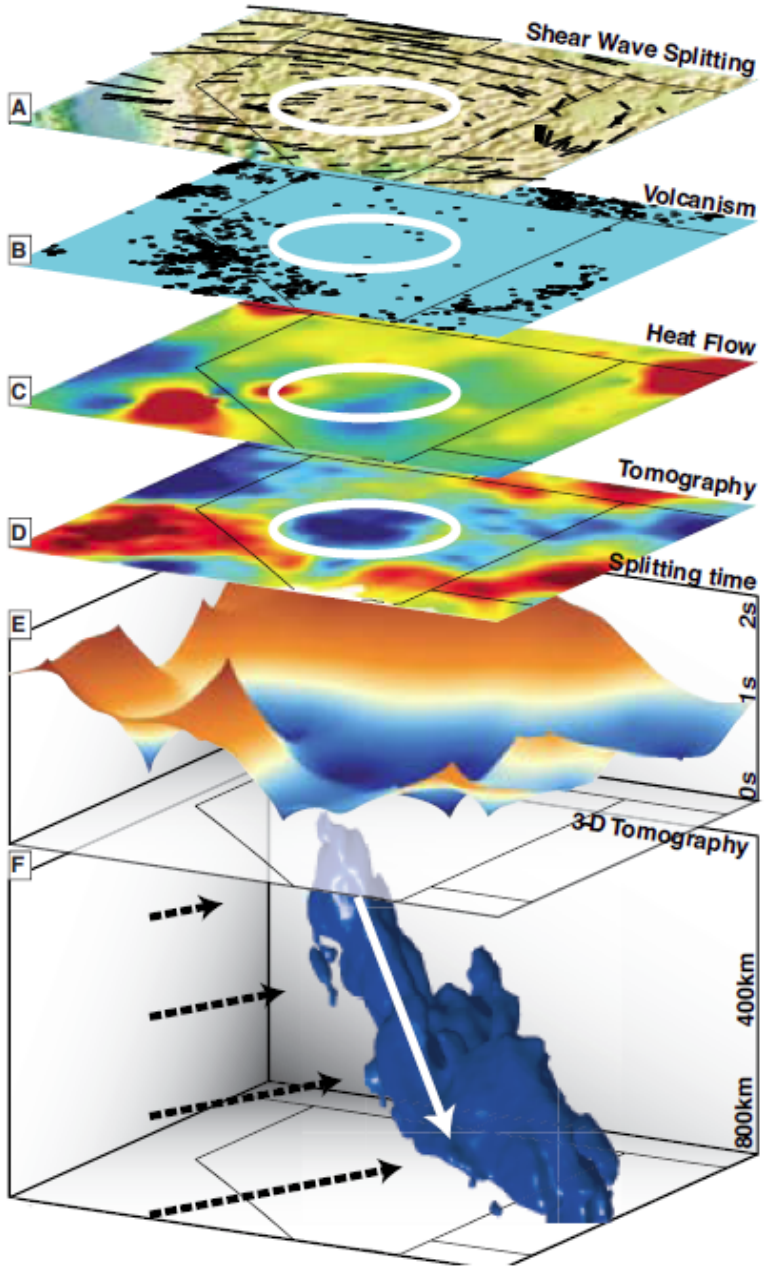


Drips

Sierra Nevada



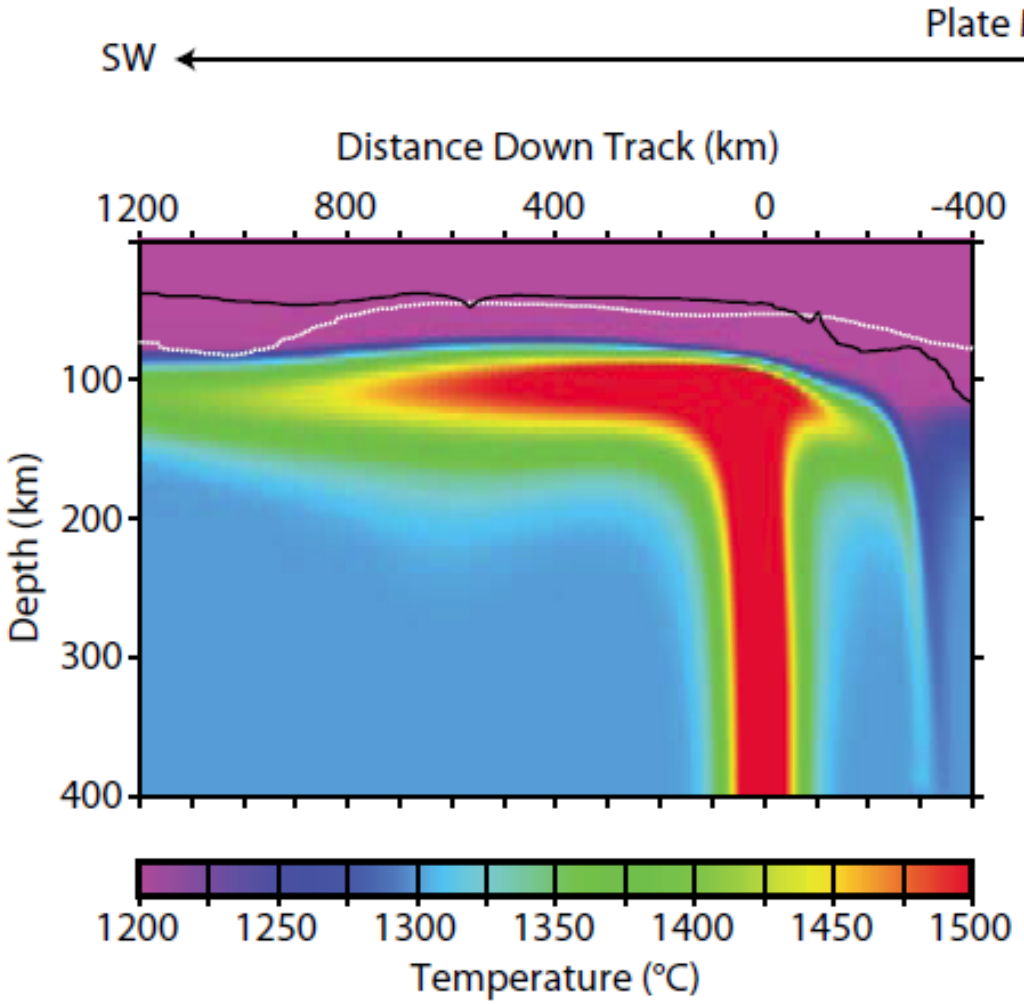
Frassetto et al., 2009



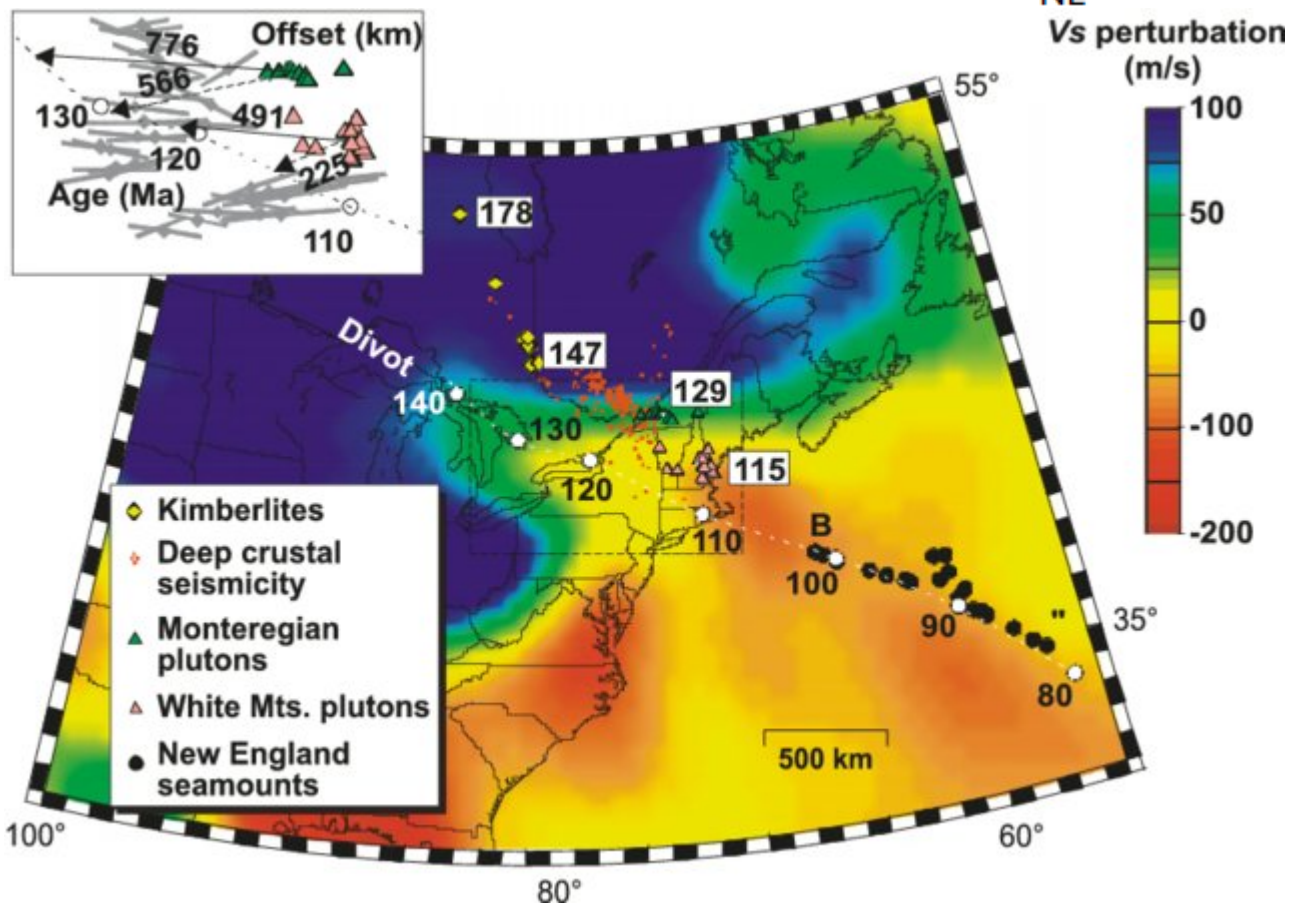
West et al., 2009

Nevada

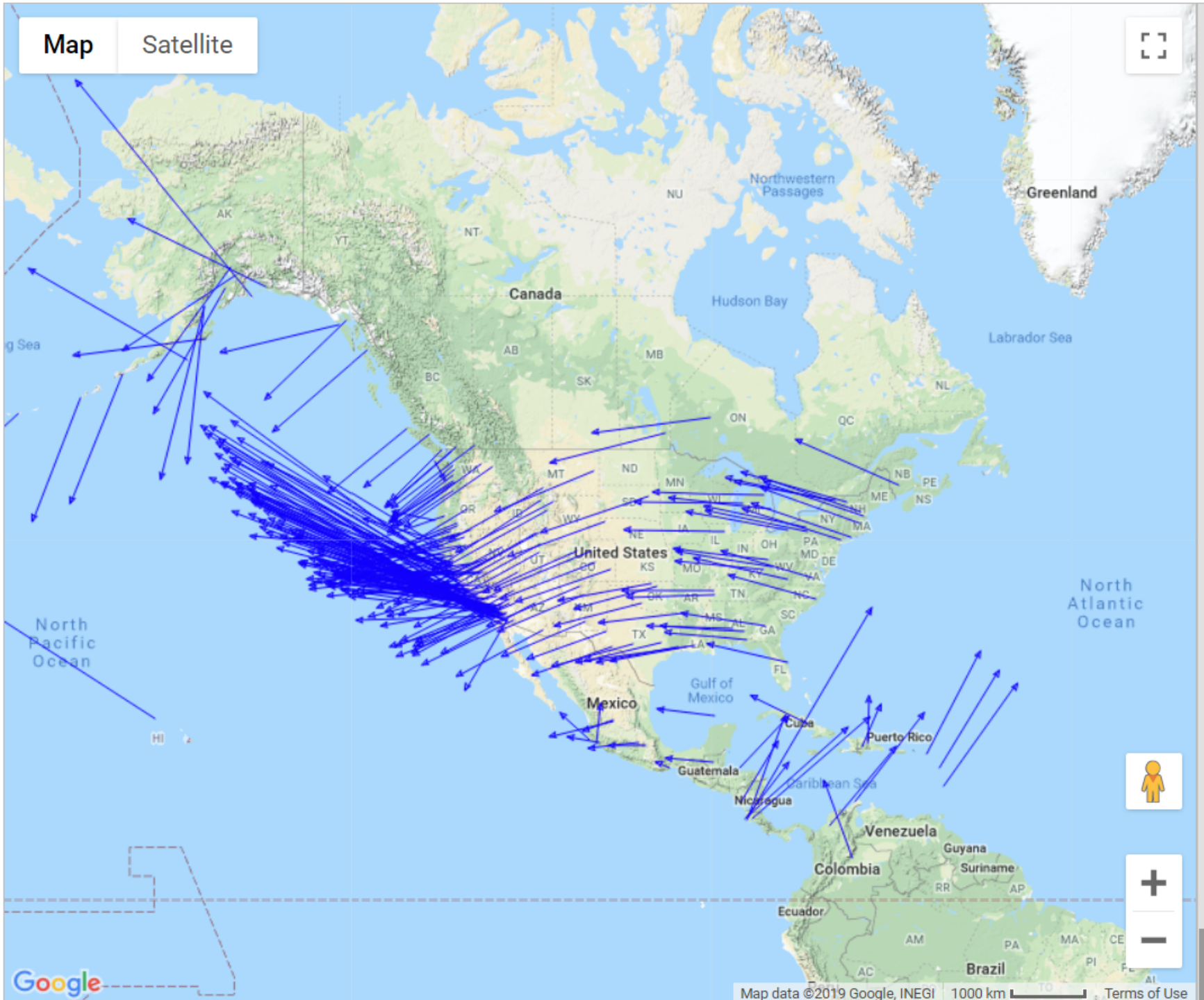
Plumes



Lowry et al., 2000



Bostock et al., 2010



GNSS velocity vectors

GNSS Data source:
N. America, IGS08/NNR, UNAVCO

- [x] Display vectors

Vector color:
blue

Vector length (scaling):
1x

- [ ] Station labels and data download
- [ ] Display error ellipses
- [ ] Display vertical rates

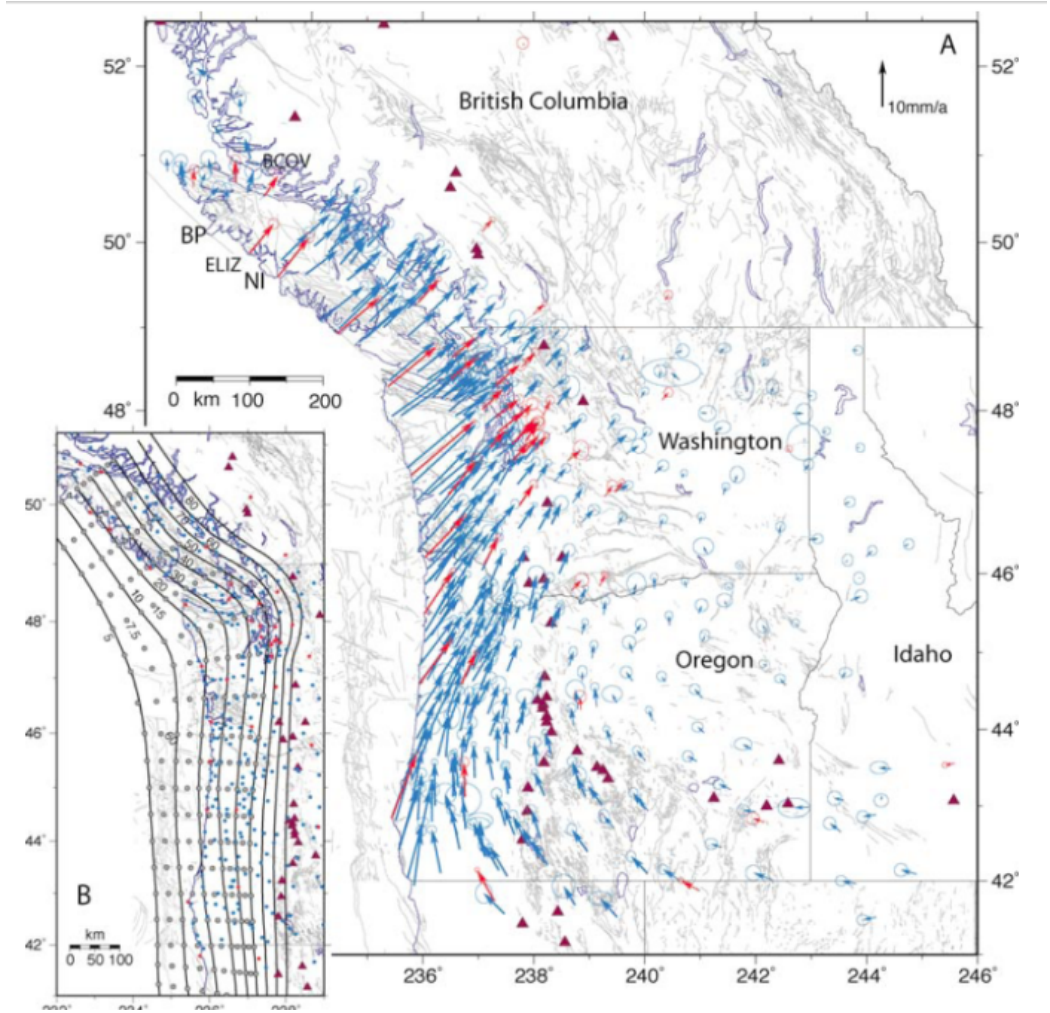
How many markers displayed:
Show one in twenty

More types of data

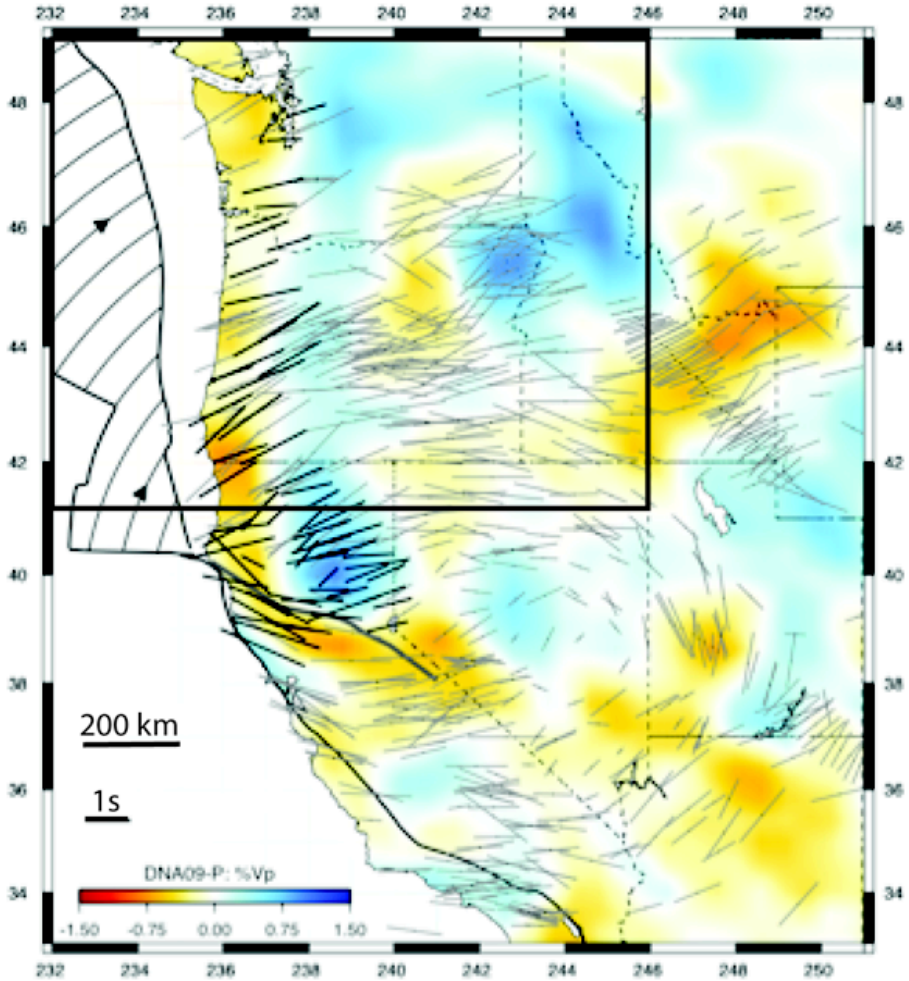
- [ ] Display volcanic centers
- [ ] Display volcano labels
- [ ] Display plate boundaries
- [ ] Display earthquakes

Earthquakes area:
North America

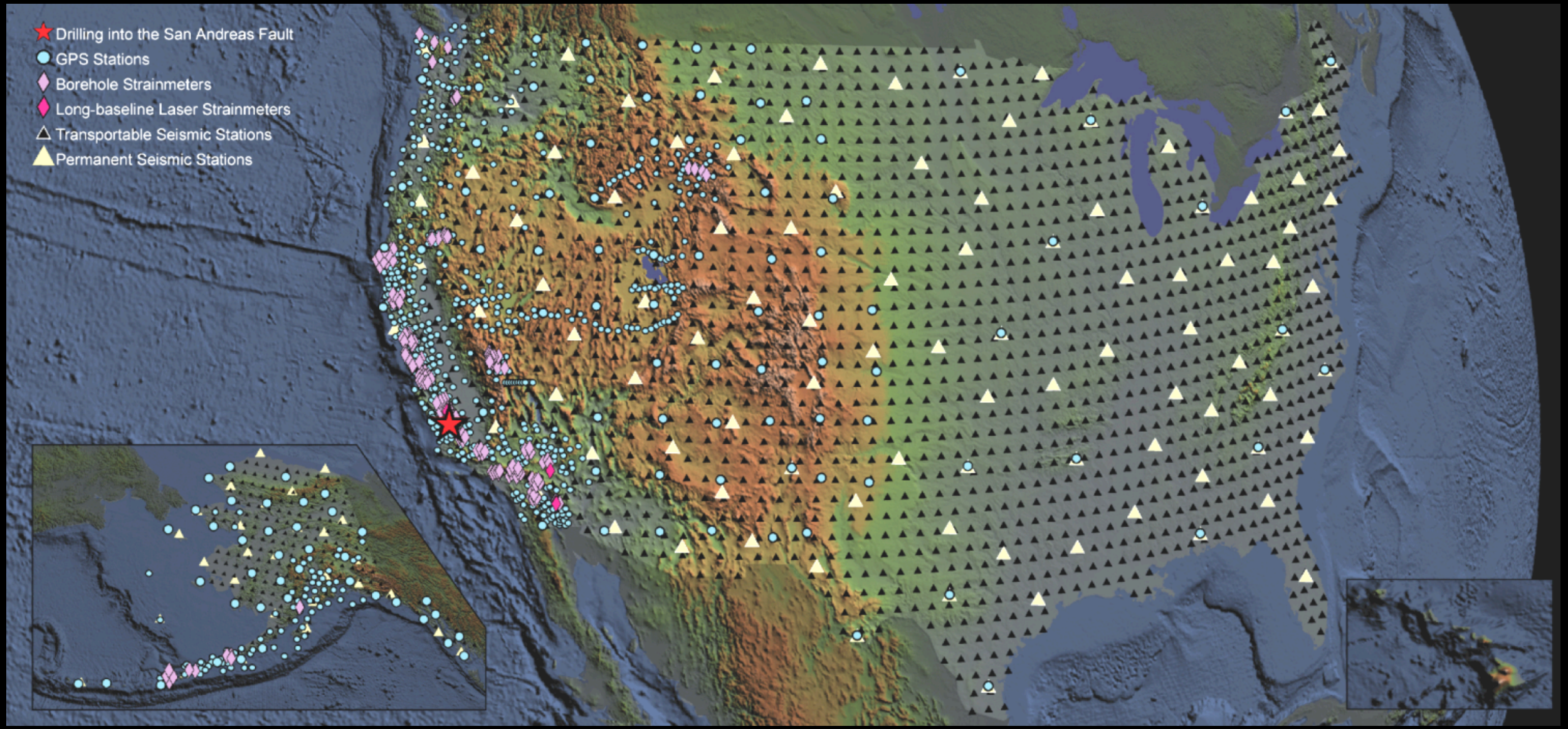
Draw Map Start Over

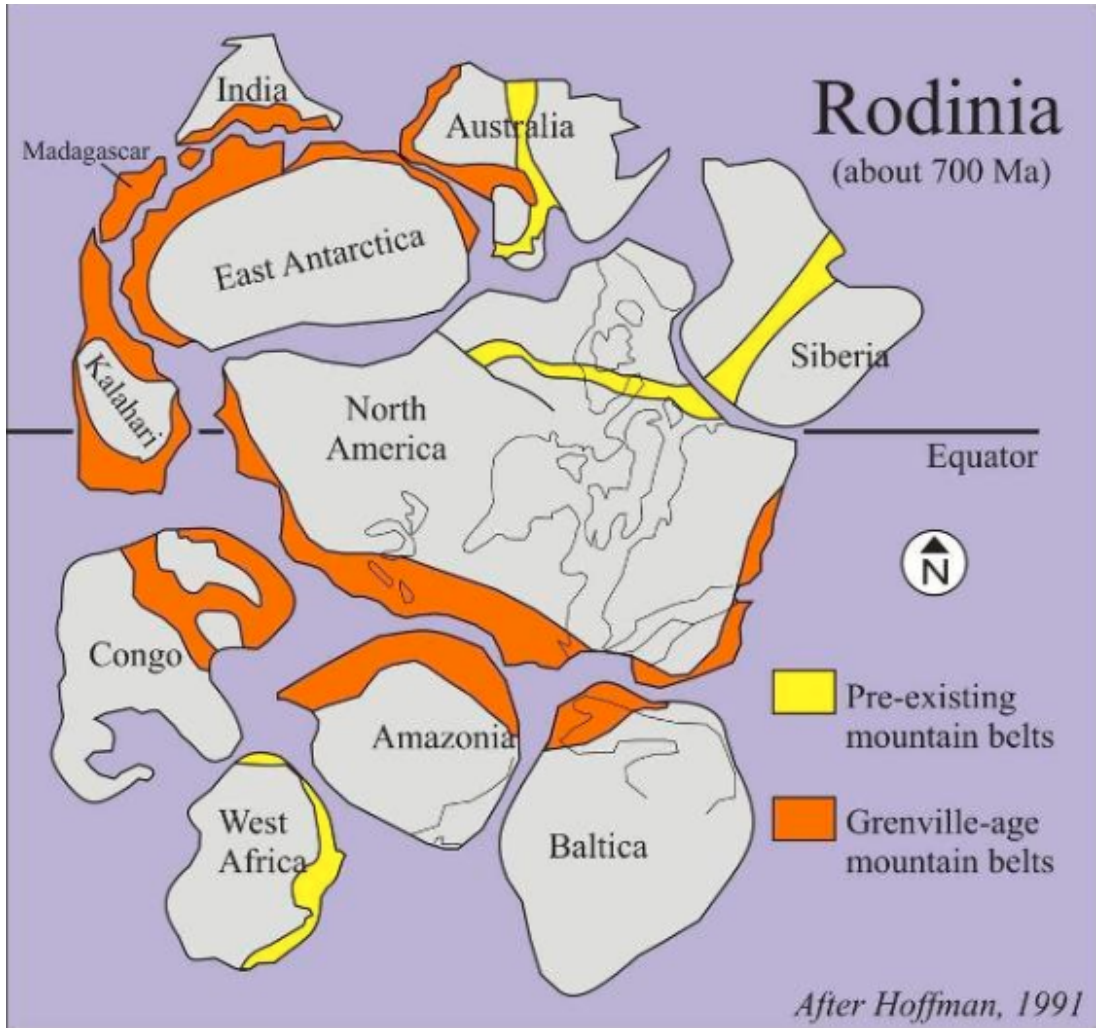


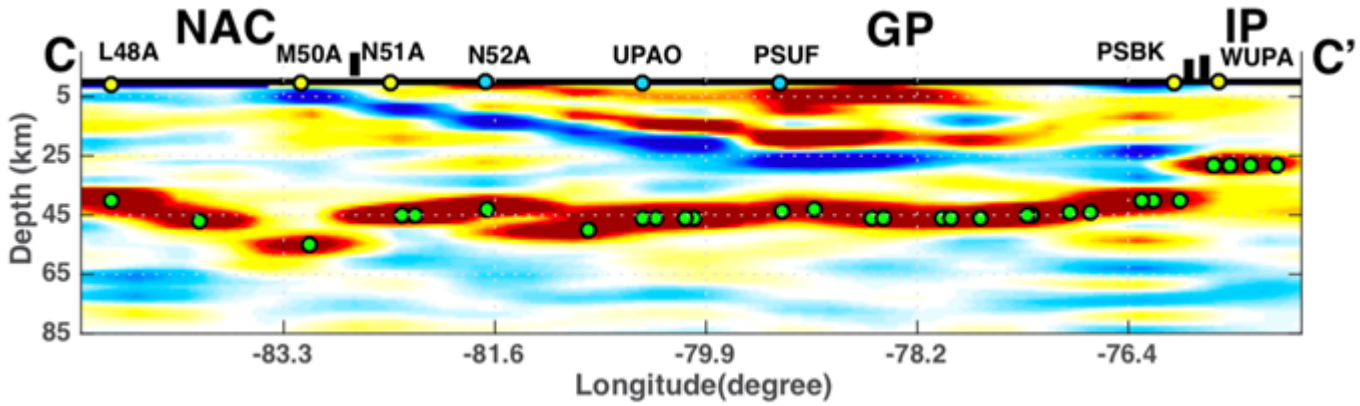
McCaffrey et al., 2007

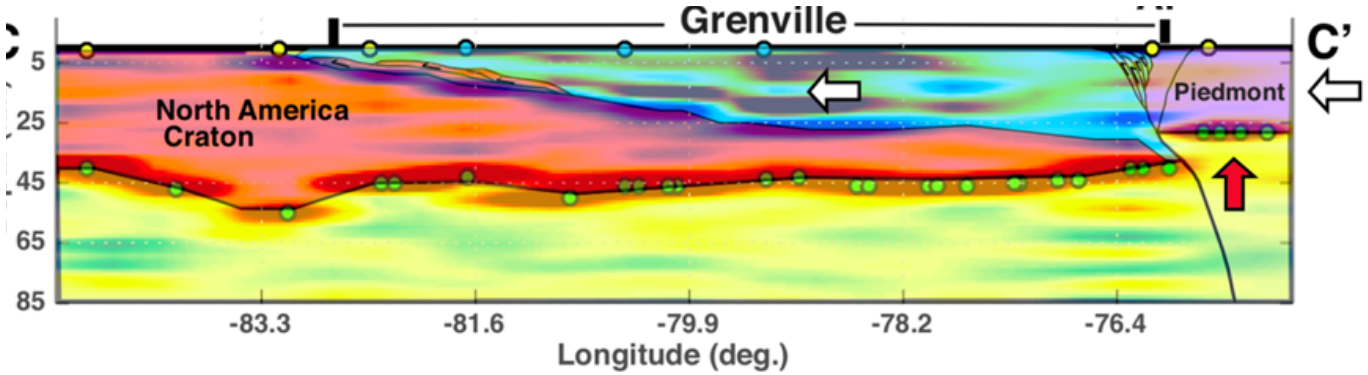


Eakin et al., 2010

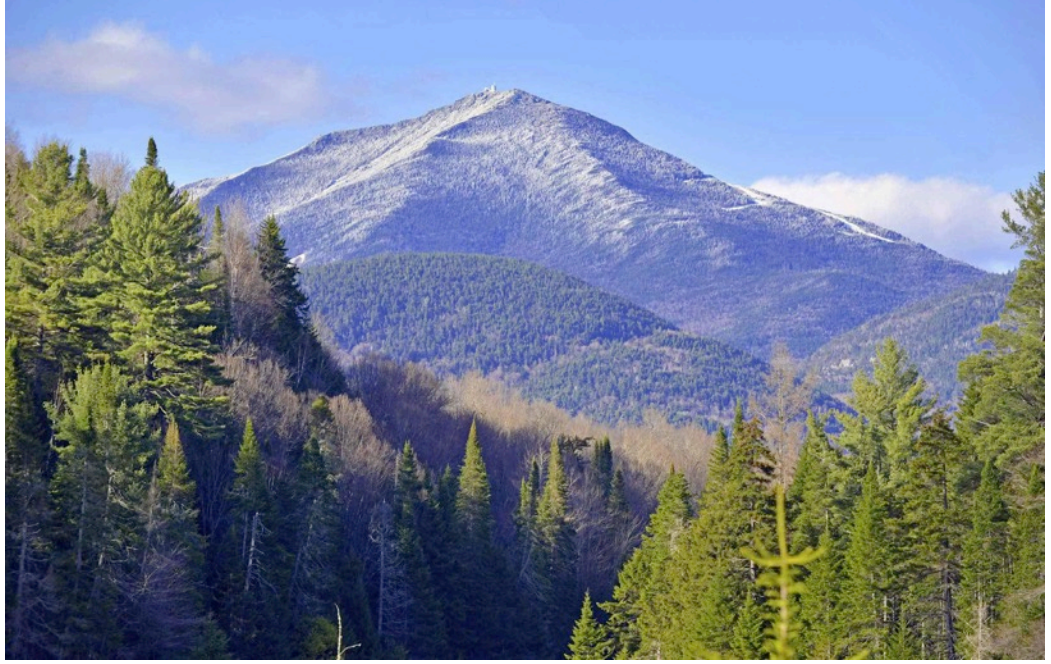

Drilling into the San Andreas Fault
GPS Stations
Borehole Strainmeters
Long-baseline Laser Strainmeters
Transportable Seismic Stations
Permanent Seismic Stations

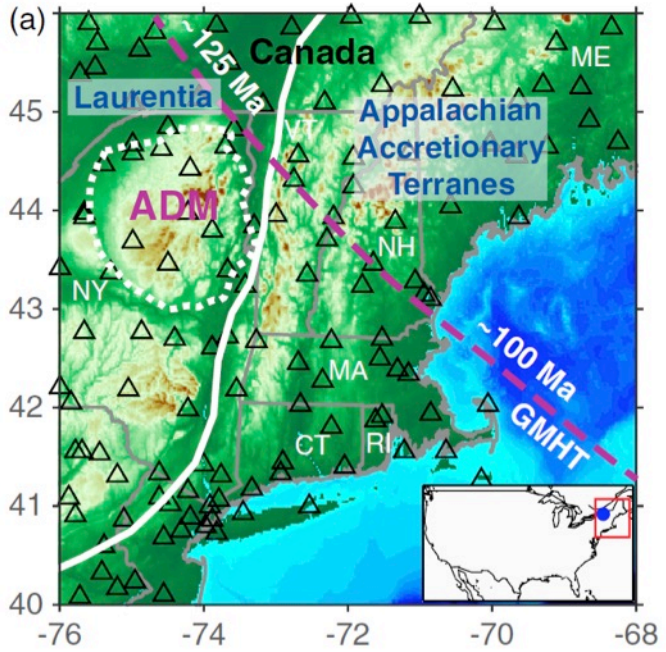


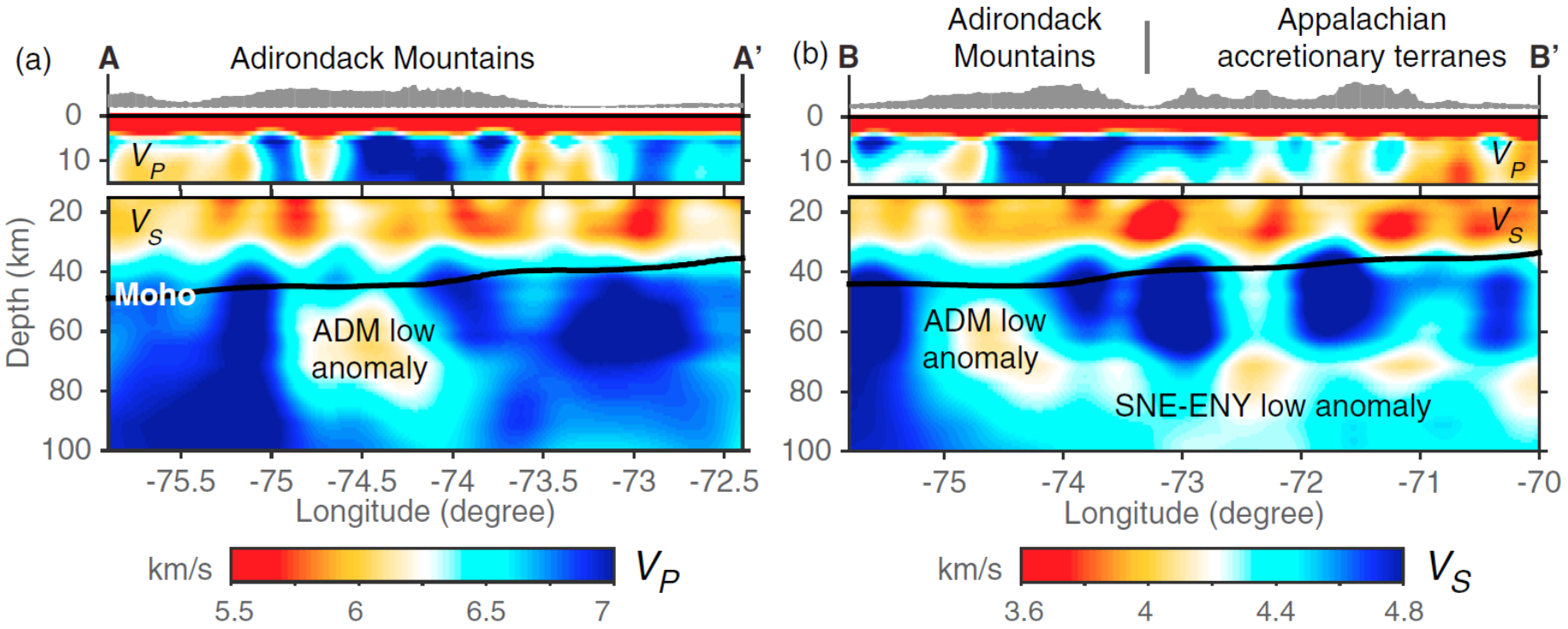




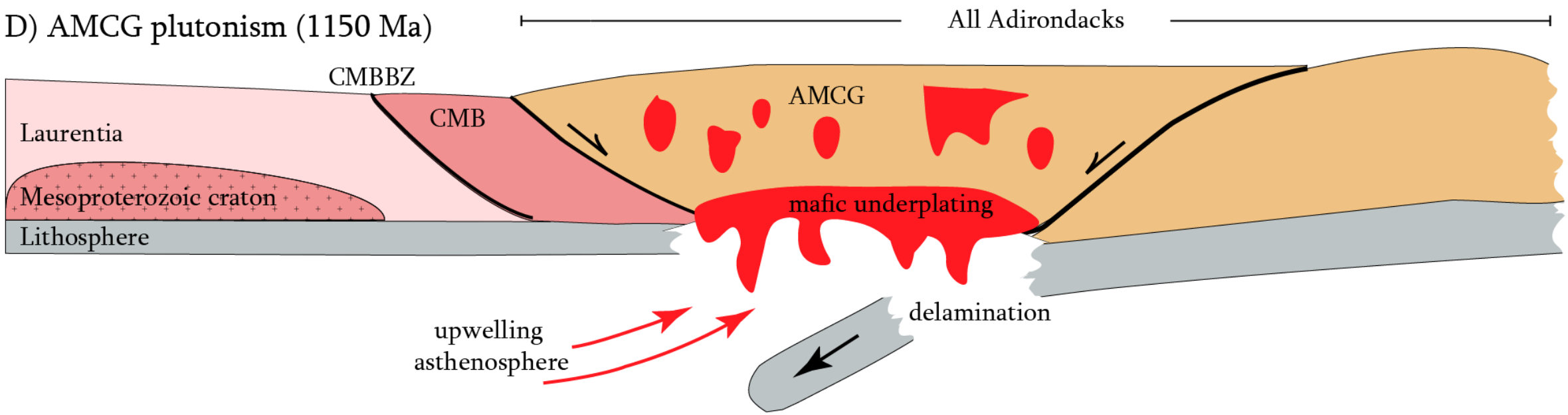
Li et al., in prep., 2019

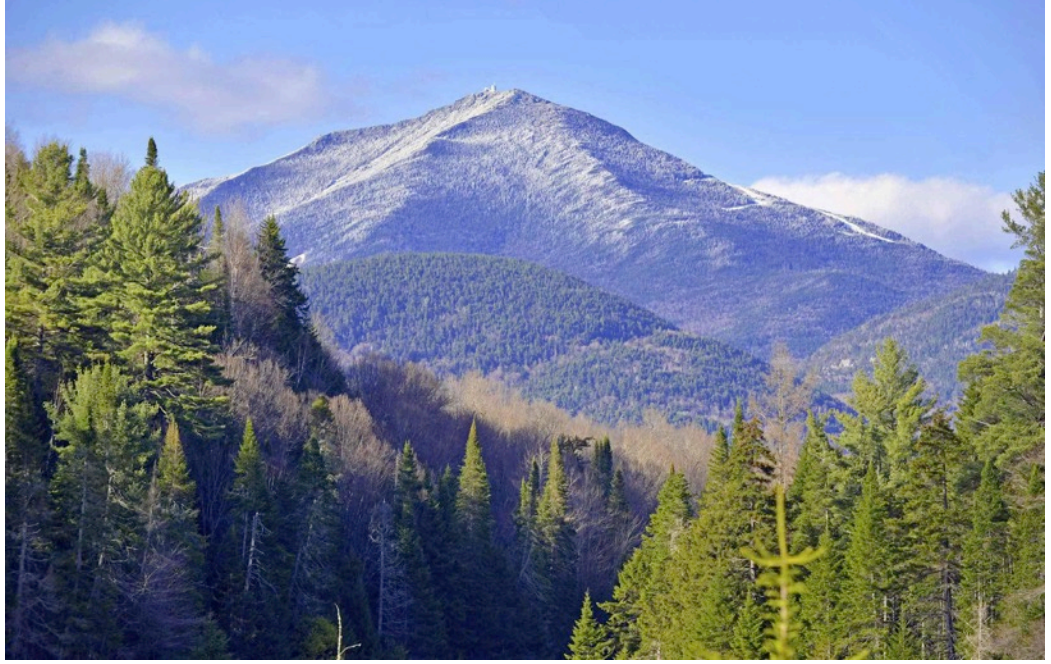


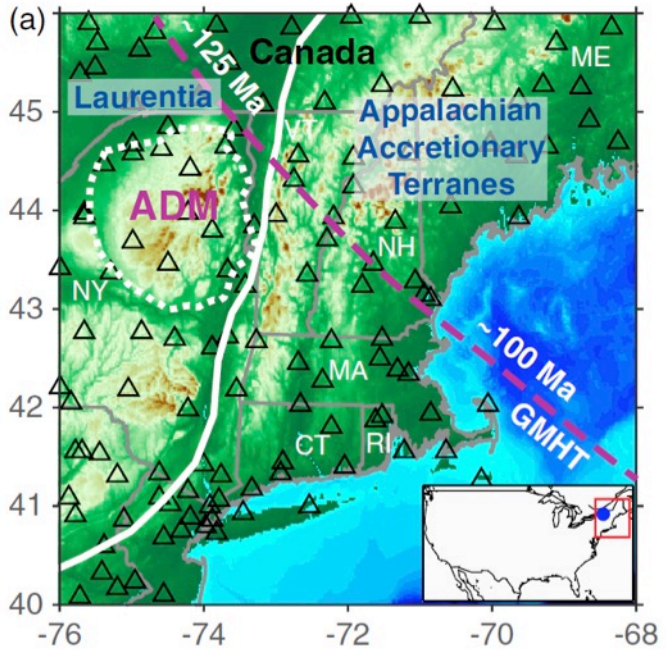


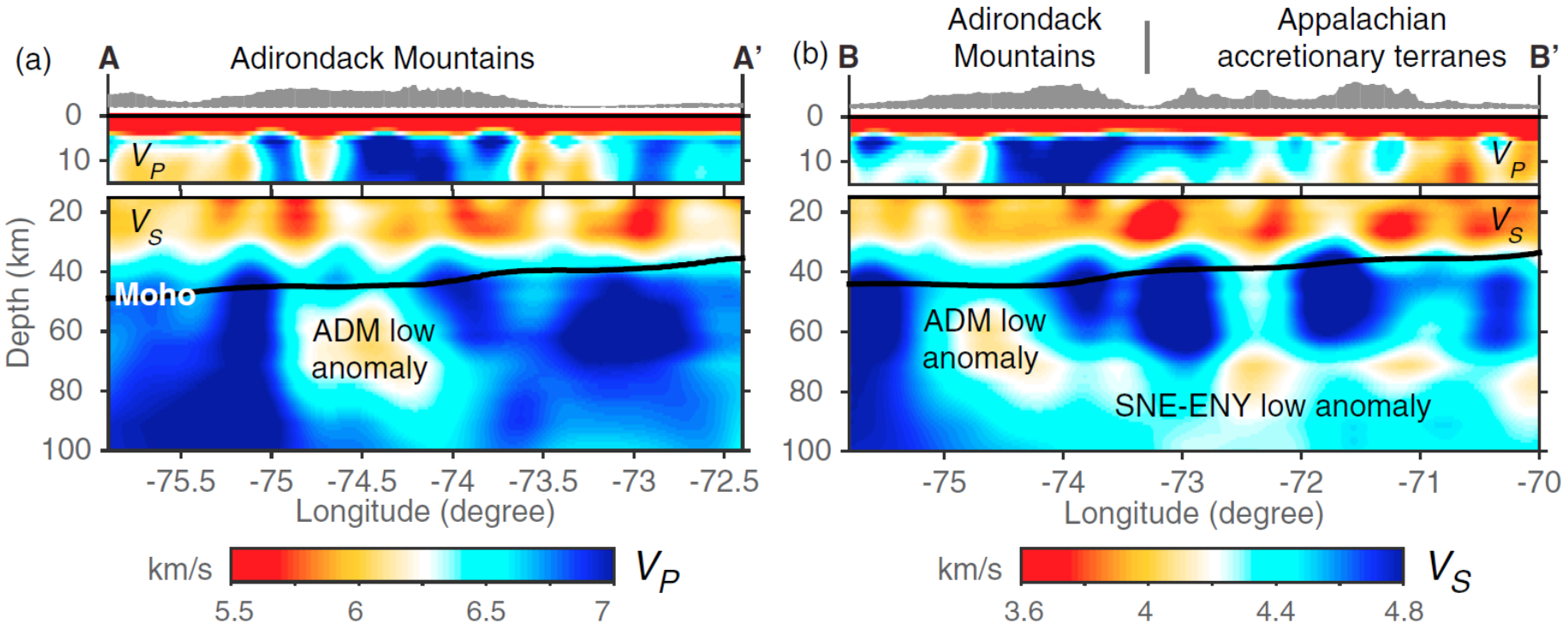


Yang and Gao, 2018, GRL


D) AMCG plutonism (1150 Ma)
All Adirondacks
CMBBZ
CMB
AMCG
Laurentia
Mesoproterozoic craton
mafic underplating
Lithosphere
delamination
upwelling
asthenosphere







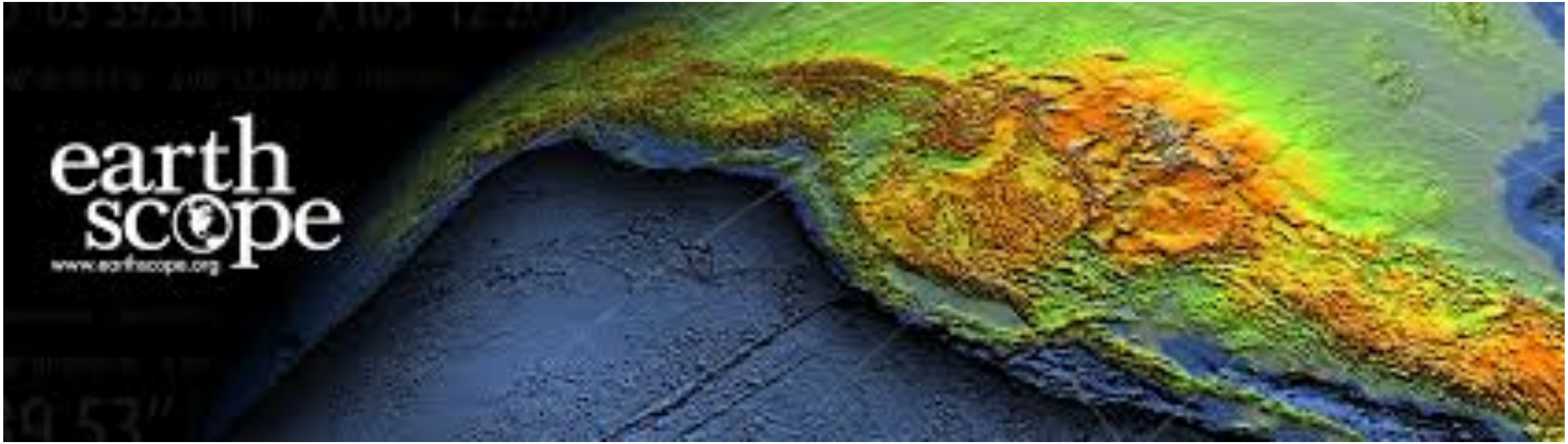
Yang and Gao, 2018, GRL

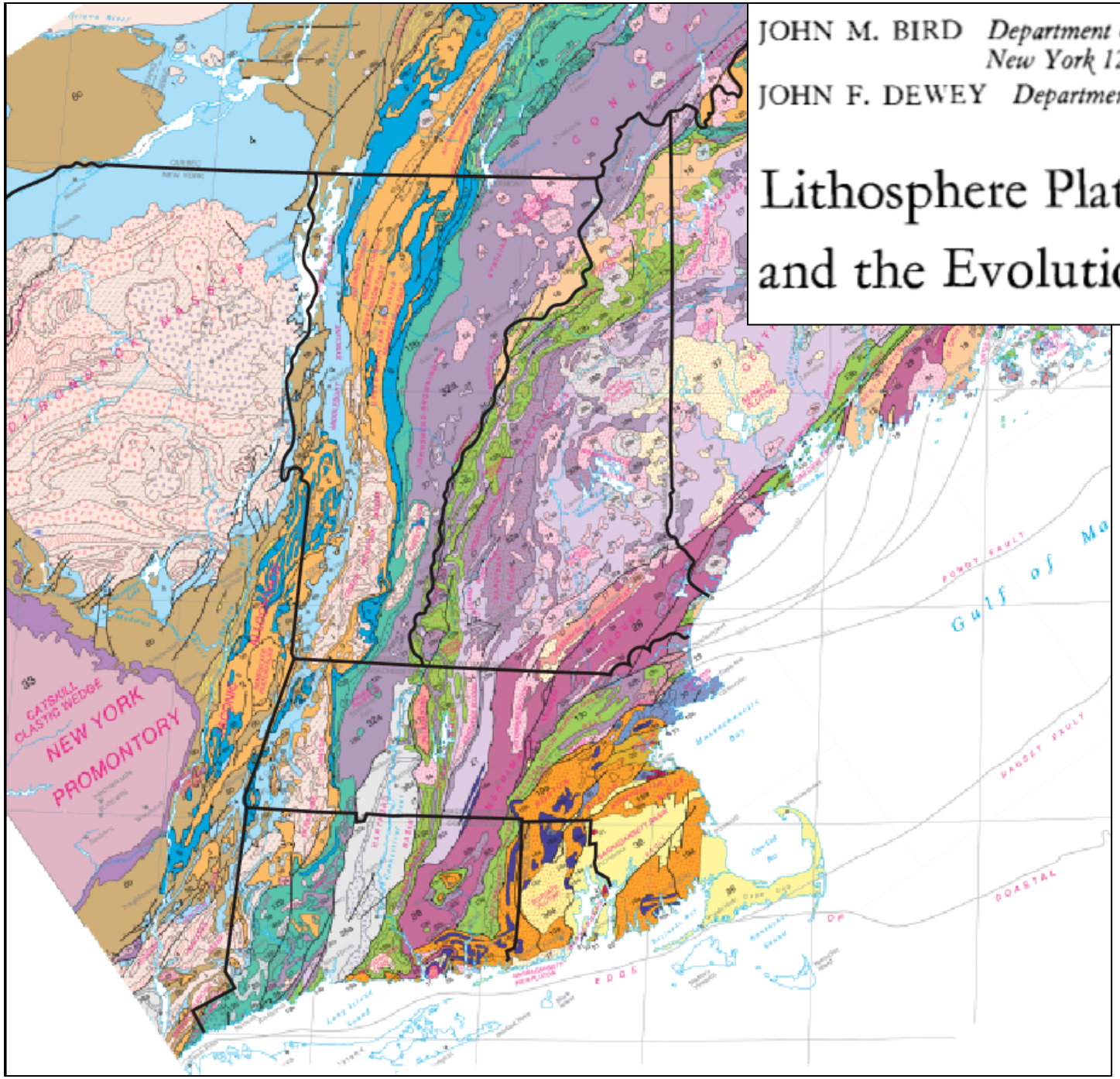
Example - Geology-Geophysics Integration:

A 4D, Data-driven Approach to Investigating Earth Tectonics

Credits

- Ian Hillenbrand, M.S. Student, UMass
- Earthscope Synthesis Workshop – 4D Tectonics, Nov. 2016



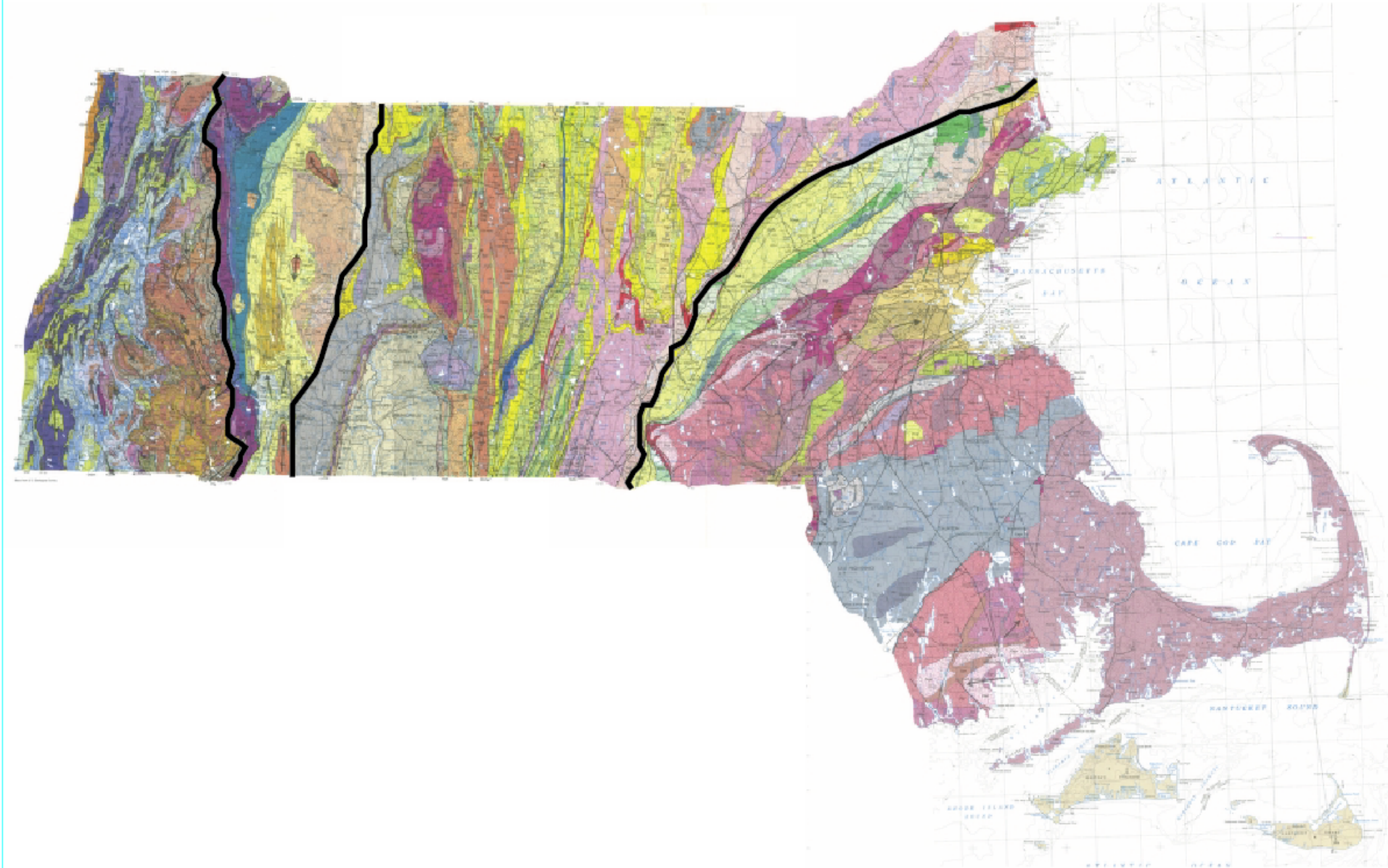


JOHN M. BIRD *Department of Geological Sciences, State University of New York at Albany, Albany, New York 12203*

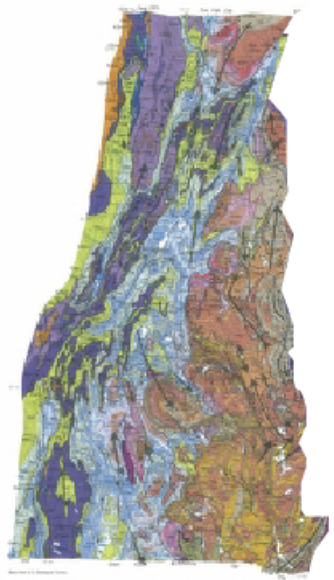
JOHN F. DEWEY *Department of Geology, Cambridge University, Cambridge, England*

Lithosphere Plate-Continental Margin Tectonics and the Evolution of the Appalachian Orogen

Bedrock Geology Map of Massachusetts



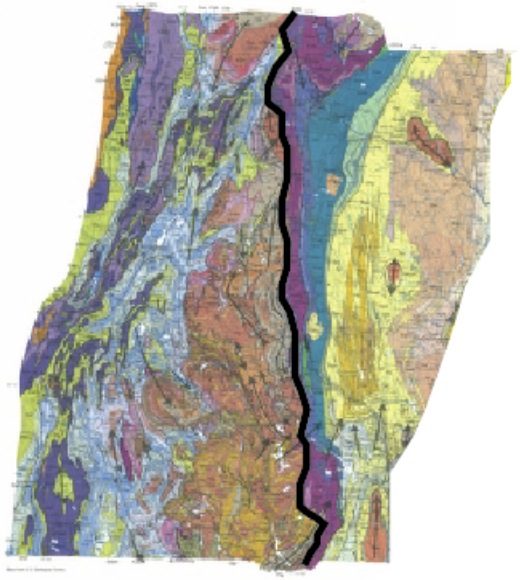
Bedrock Geology Map of Massachusetts



"Laurentia"

Precambiran North America

Bedrock Geology Map of Massachusetts



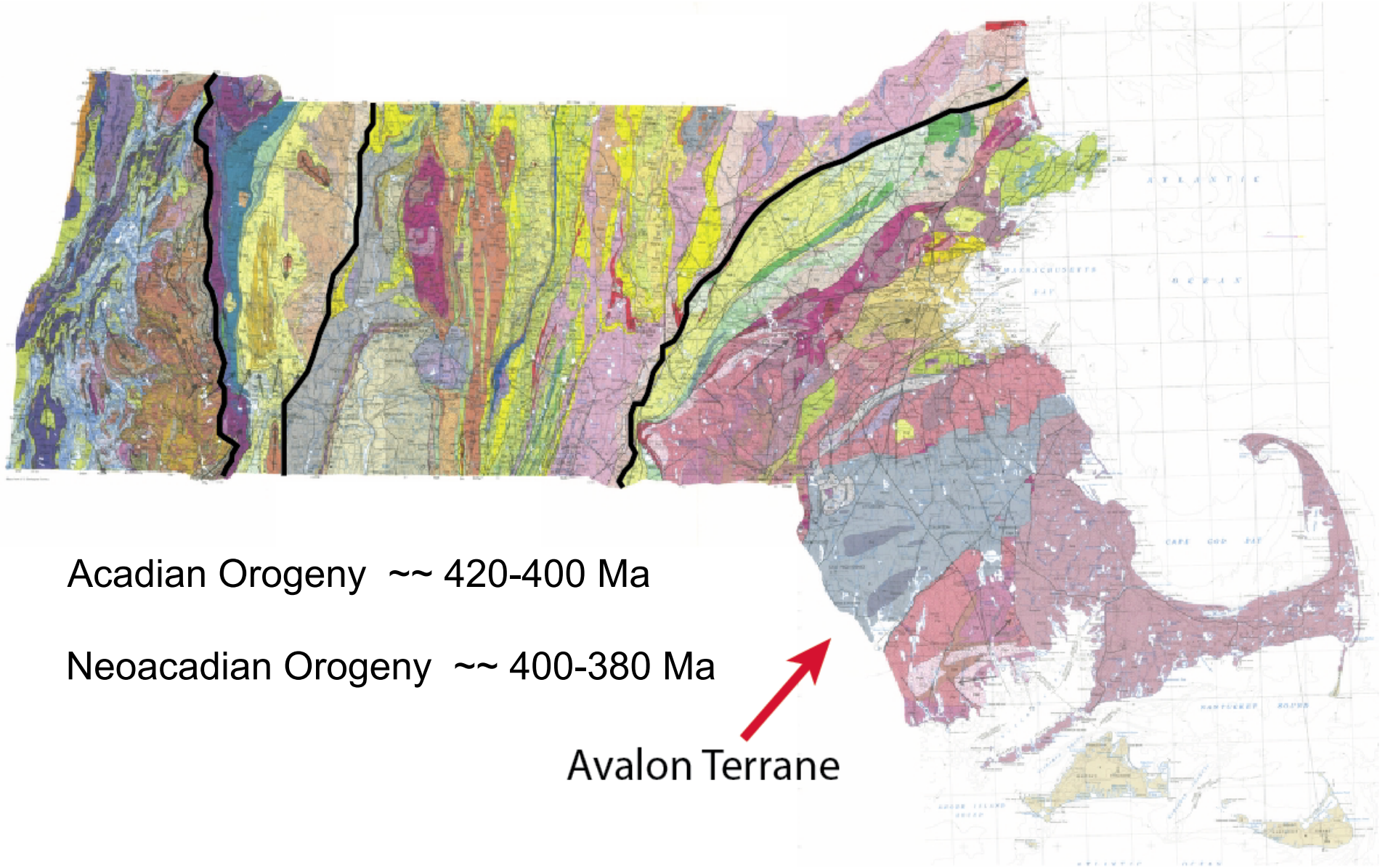
Shelbourne Falls Arc

Taconic Orogeny ~~ 480-450 Ma

Bedrock Geology Map of Massachusetts

Salinic Orogeny ~~ 440-420 Ma

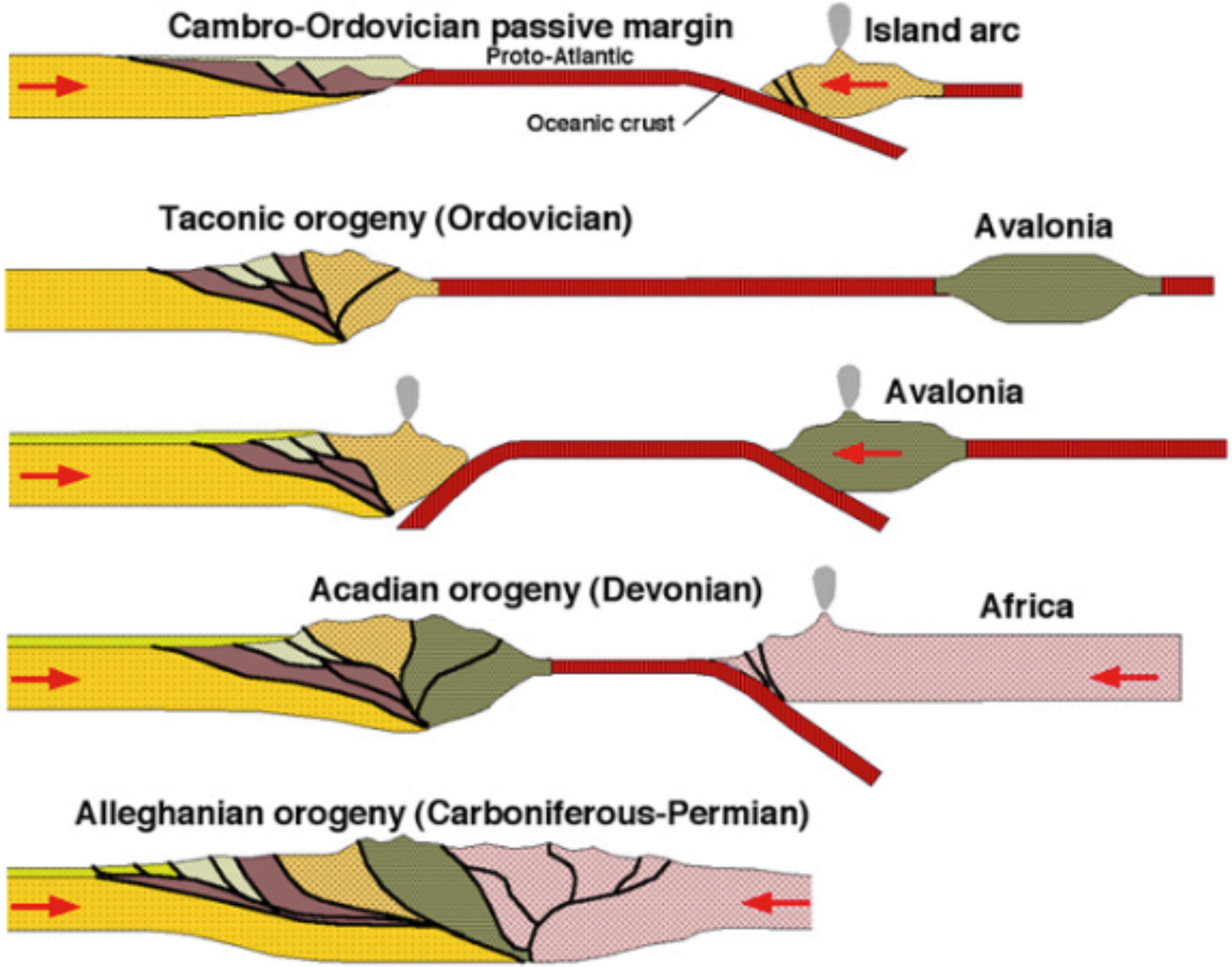
Bedrock Geology Map of Massachusetts

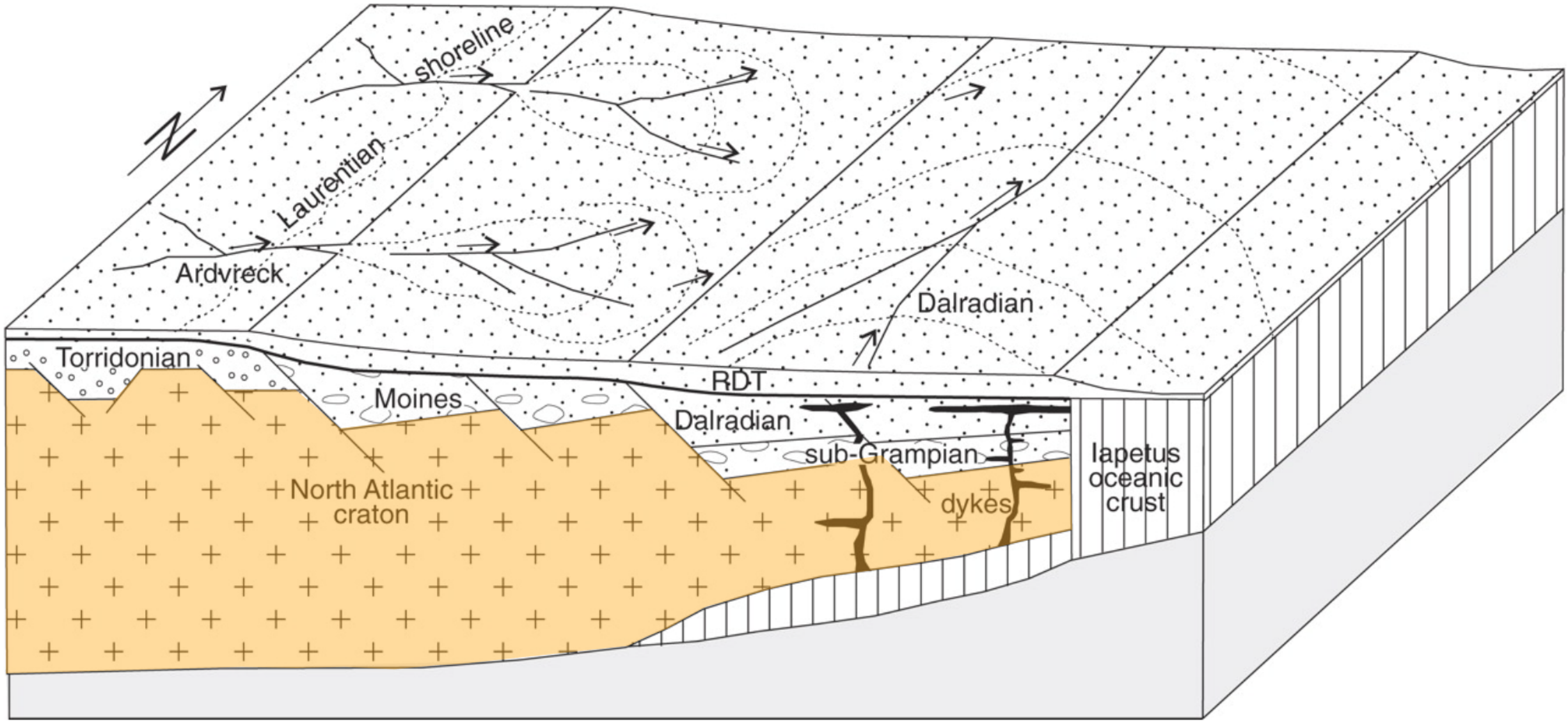


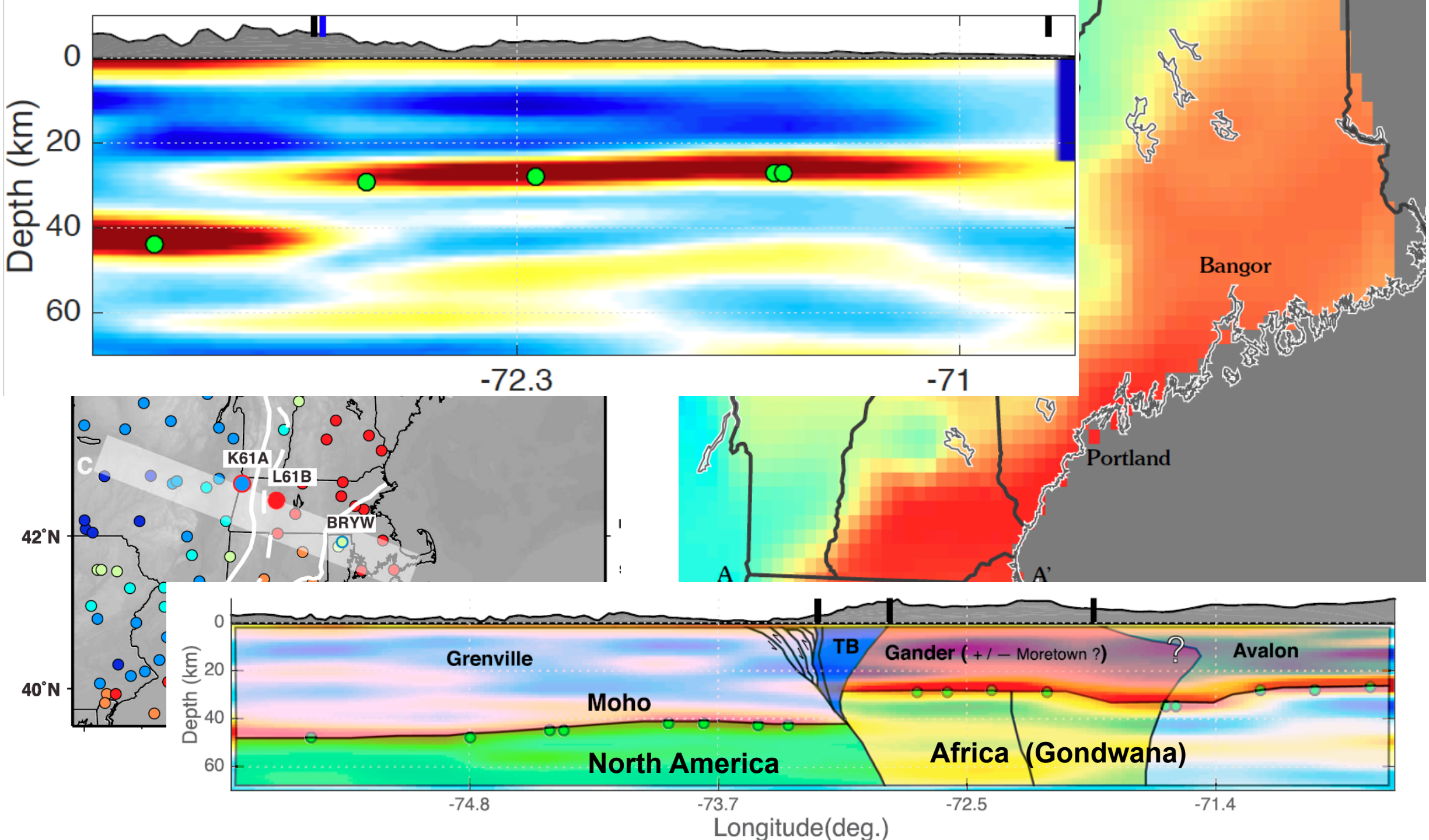
Acadian Orogeny ~~ 420-400 Ma

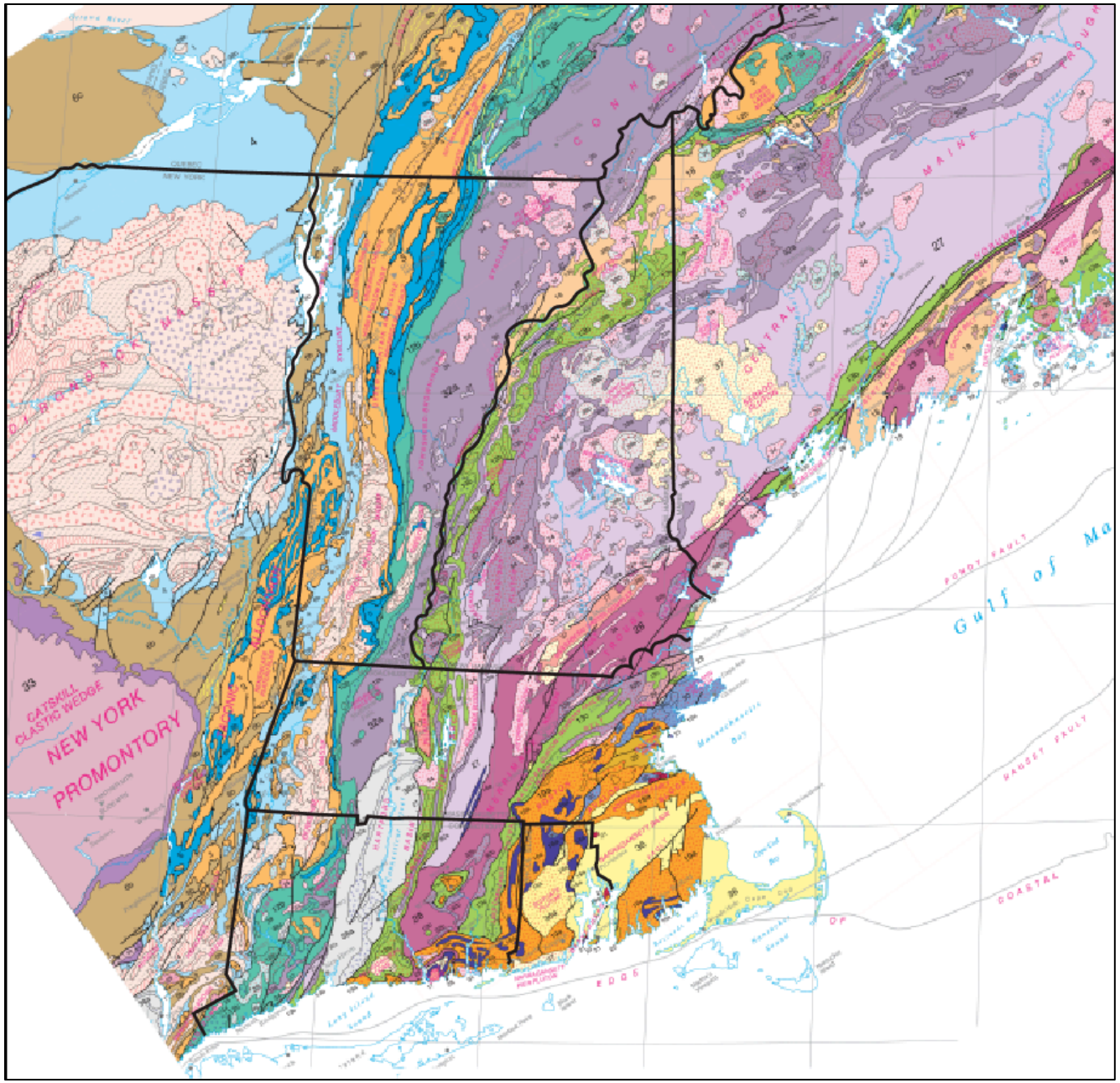
Neoacadian Orogeny ~~ 400-380 Ma

Avalon Terrane

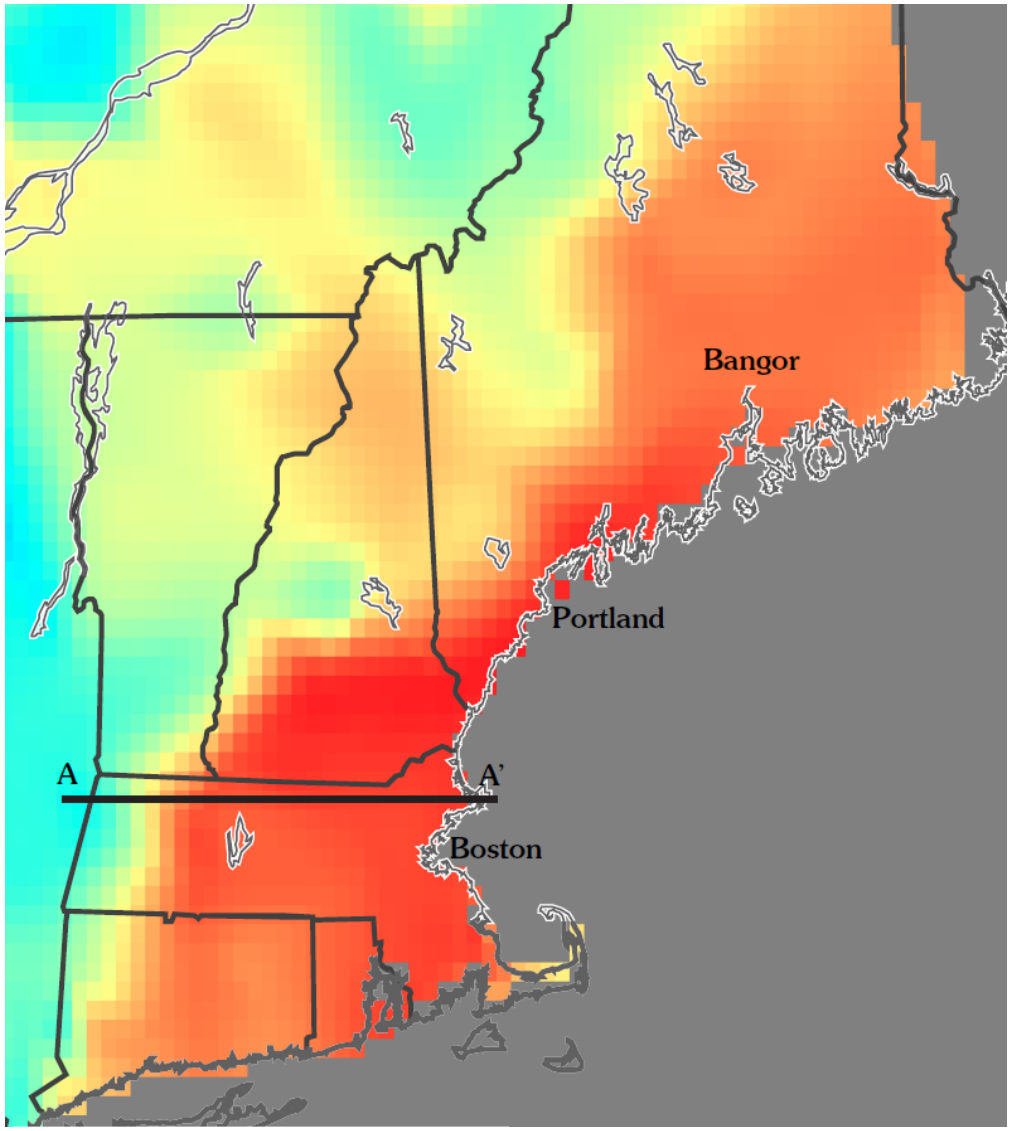

Cambro-Ordovician passive margin
Proto-Atlantic
Island arc
Oceanic crust
Taconic orogeny (Ordovician)
Avalonia
Avalonia
Acadian orogeny (Devonian)
Africa
Alleghanian orogeny (Carboniferous-Permian)

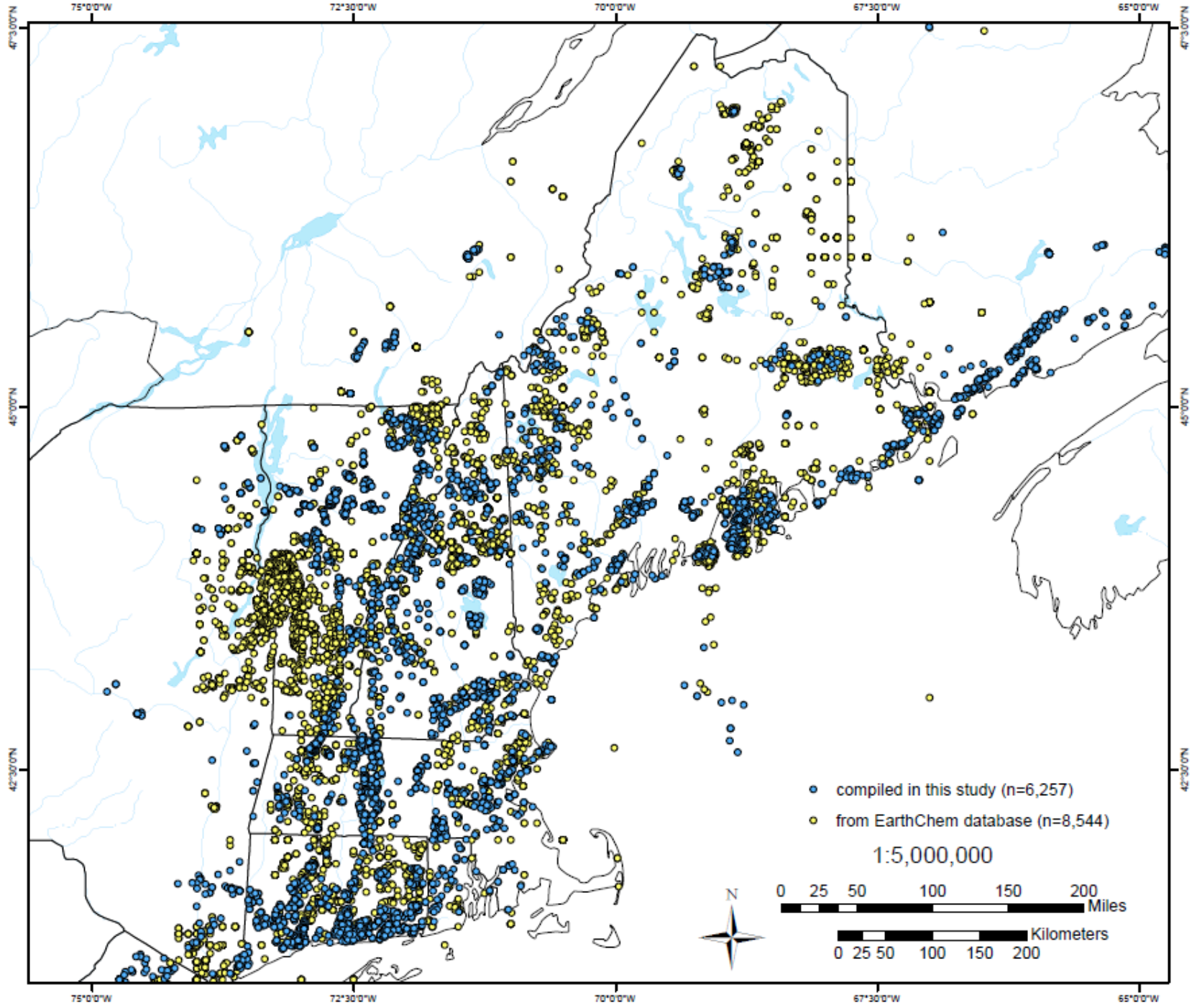

shoreline
N
Laurentian
Ardvreck
Dalradian
Torridonian
RDT
Moines
Dalradian
sub-Grampian
North Atlantic
craton
dykes
Iapetus
oceanic
crust


Depth (km)
0
20
40
60
-72.3
-71
Bangor
Portland
A
A'
C
K61A
L61B
BRYW
42˚N
40˚N
Depth (km)
0
20
40
60
Grenville
Moho
North America
TB
Gander (+ / — Moretown ?)
?
Avalon
Africa (Gondwana)
-74.8
-73.7
-72.5
-71.4
Longitude(deg.)


CATSKILL CLASTIC WEDGE
NEW YORK PROMONTORY
Gulf of Ma
BOSTON BLOCK
EDGE

4D Database

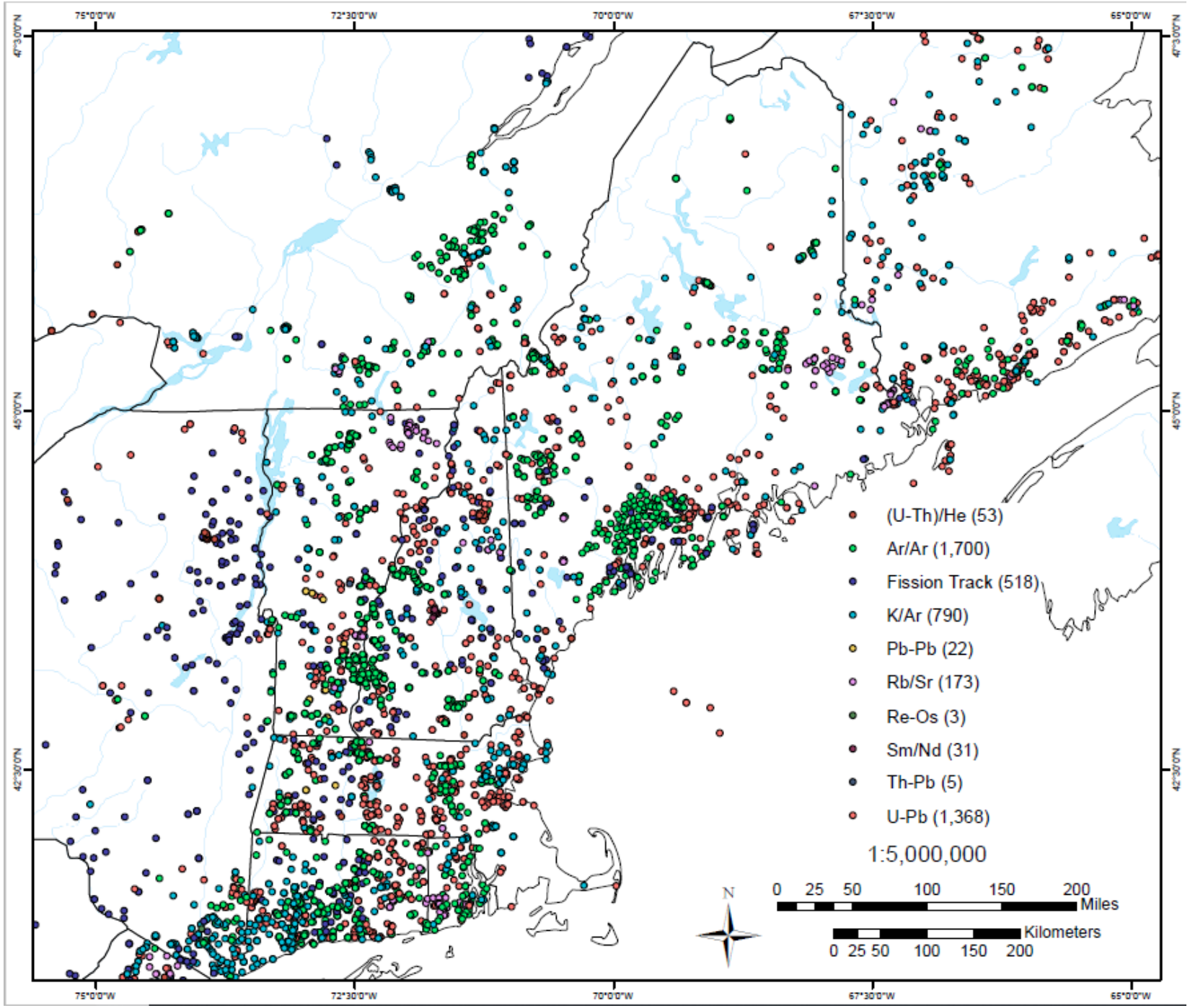

Bangor
Portland
A
A'
Boston



Geochemical Analyses

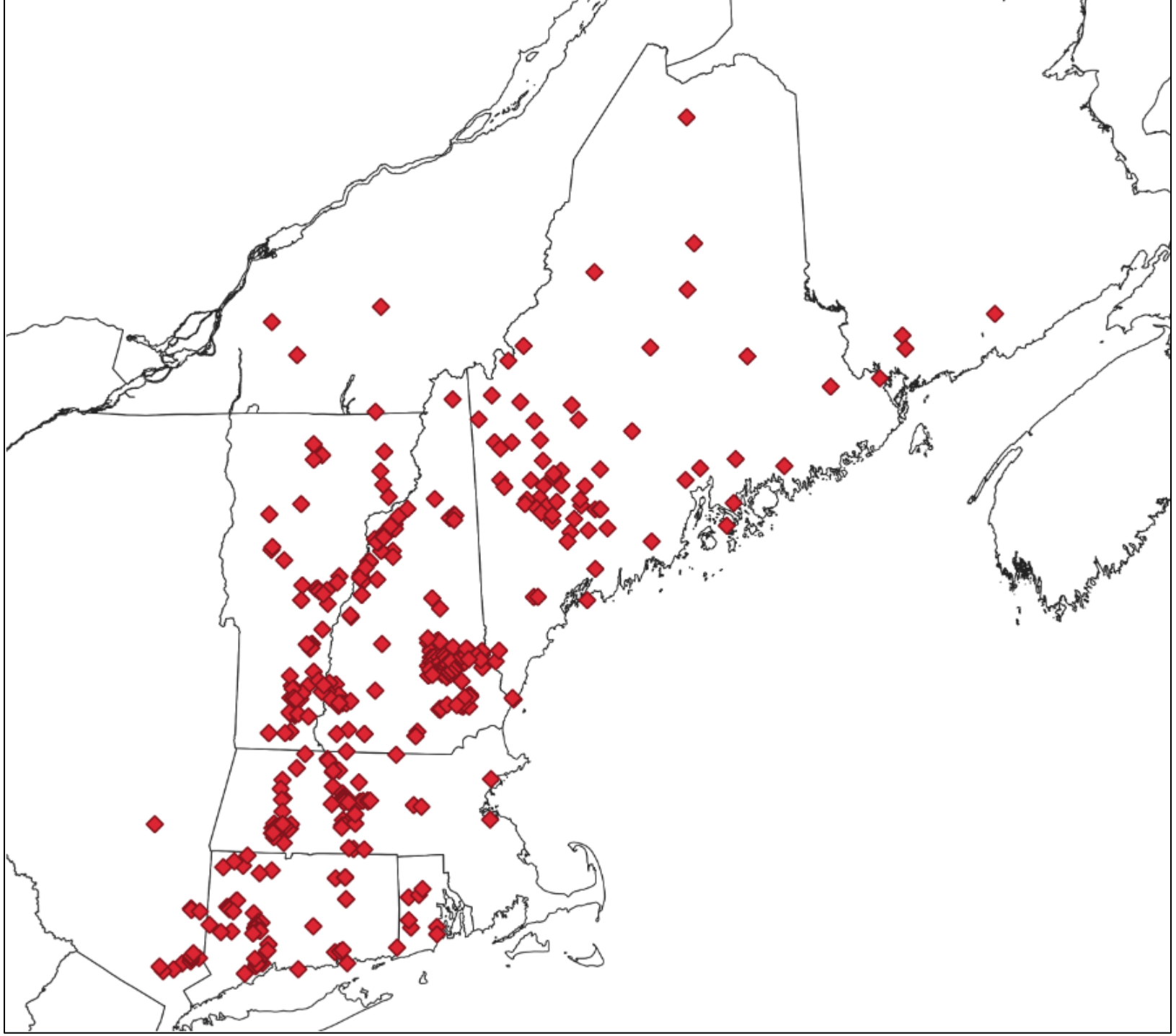
>6000 analyses compiled

With access to >8000 analyses from EarthChem Database



Geochronologic Data

~6000 dates

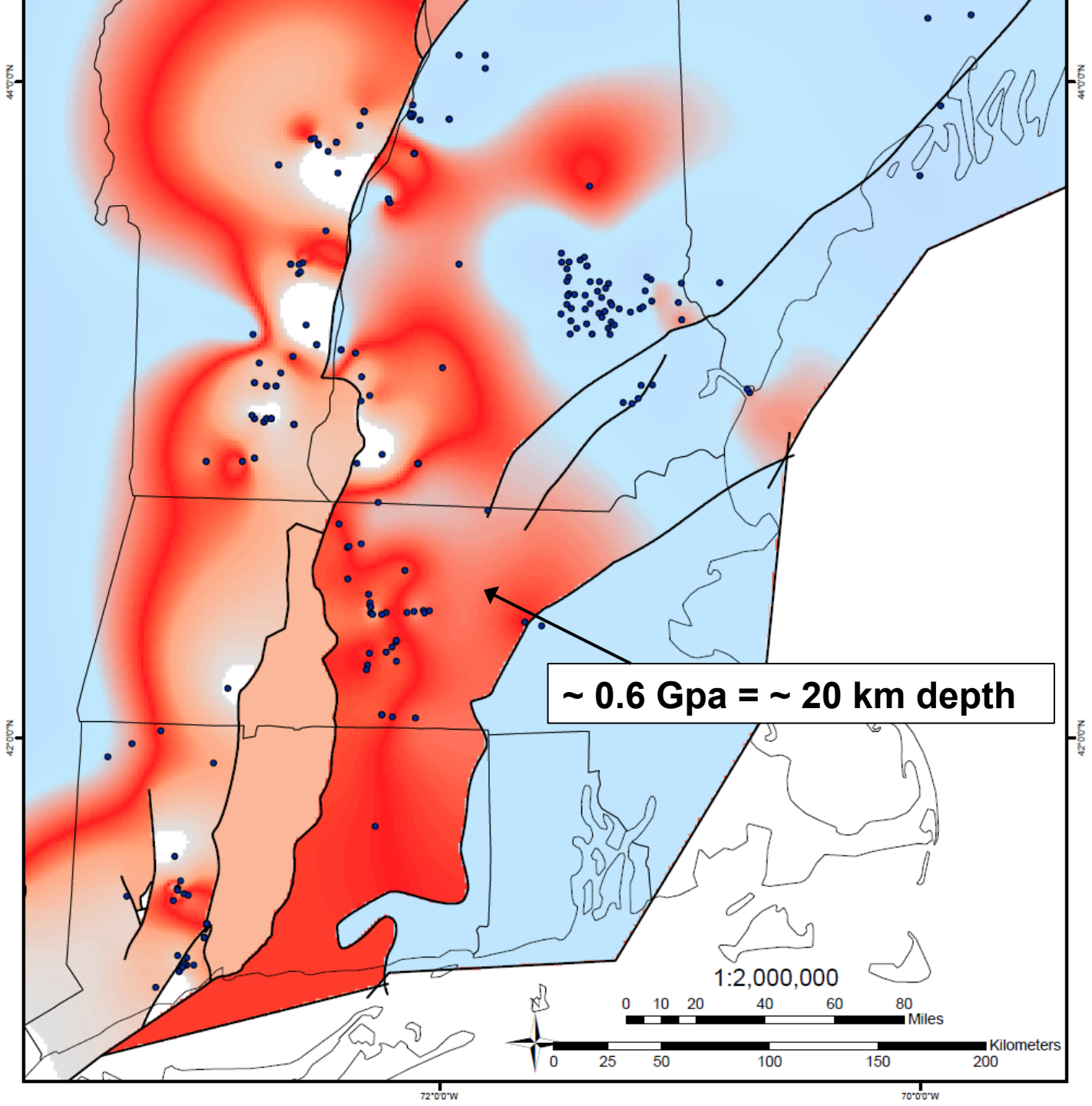


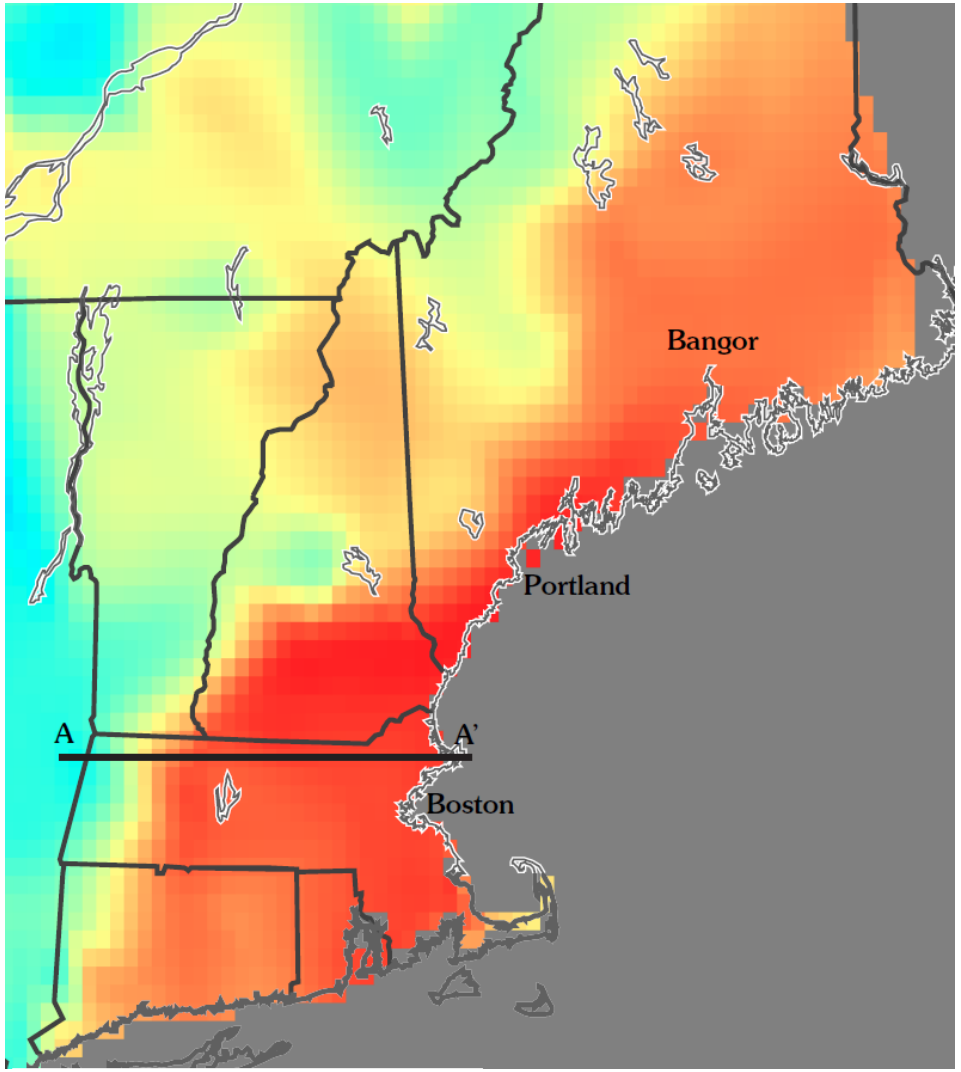
Metamorphic Data

>600 calculations of:
- Temperature
- Pressure (depth)

Metamorphic Pressure - 400-380 Ma

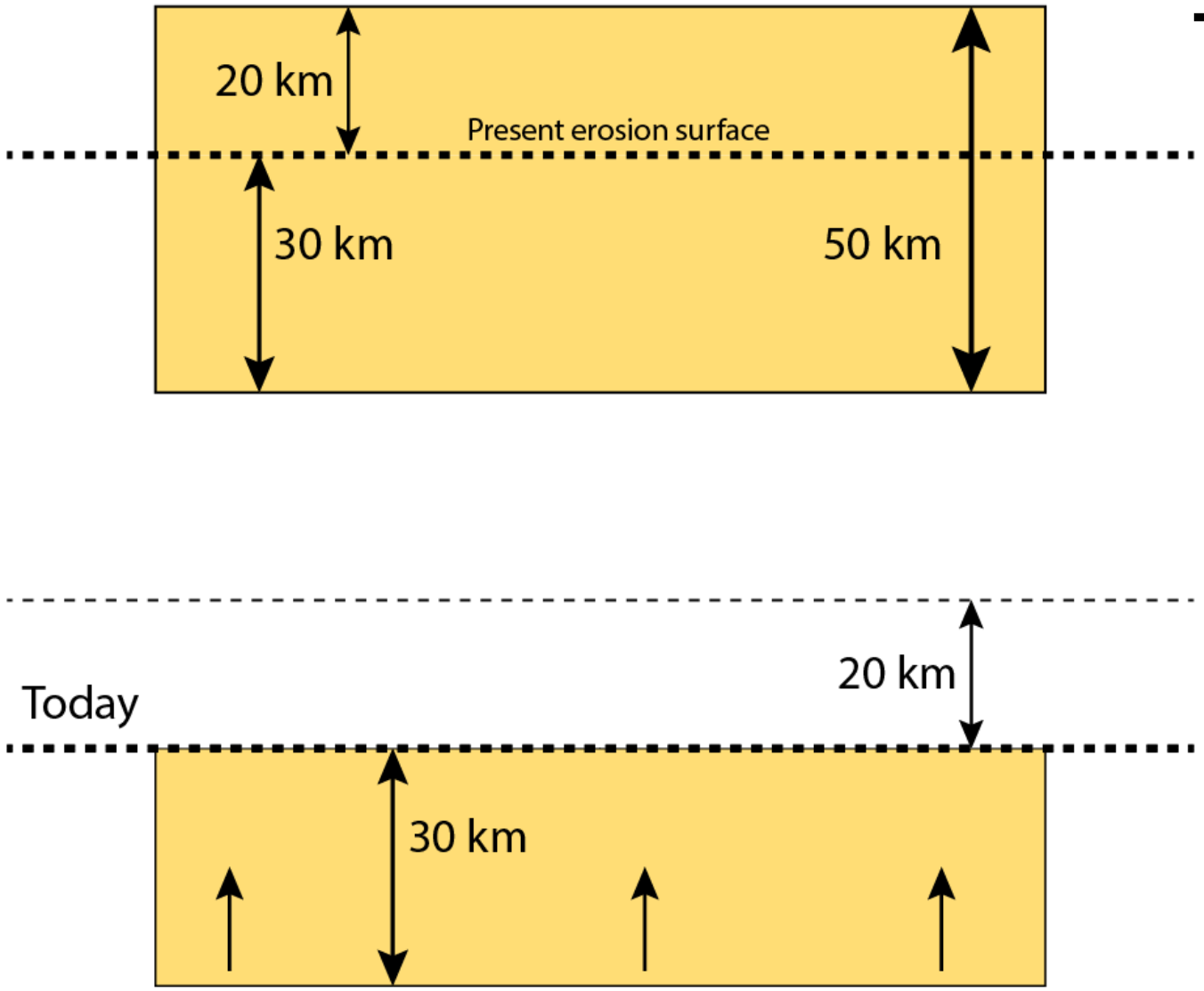
"*Central Mass. Metamorphic High*"

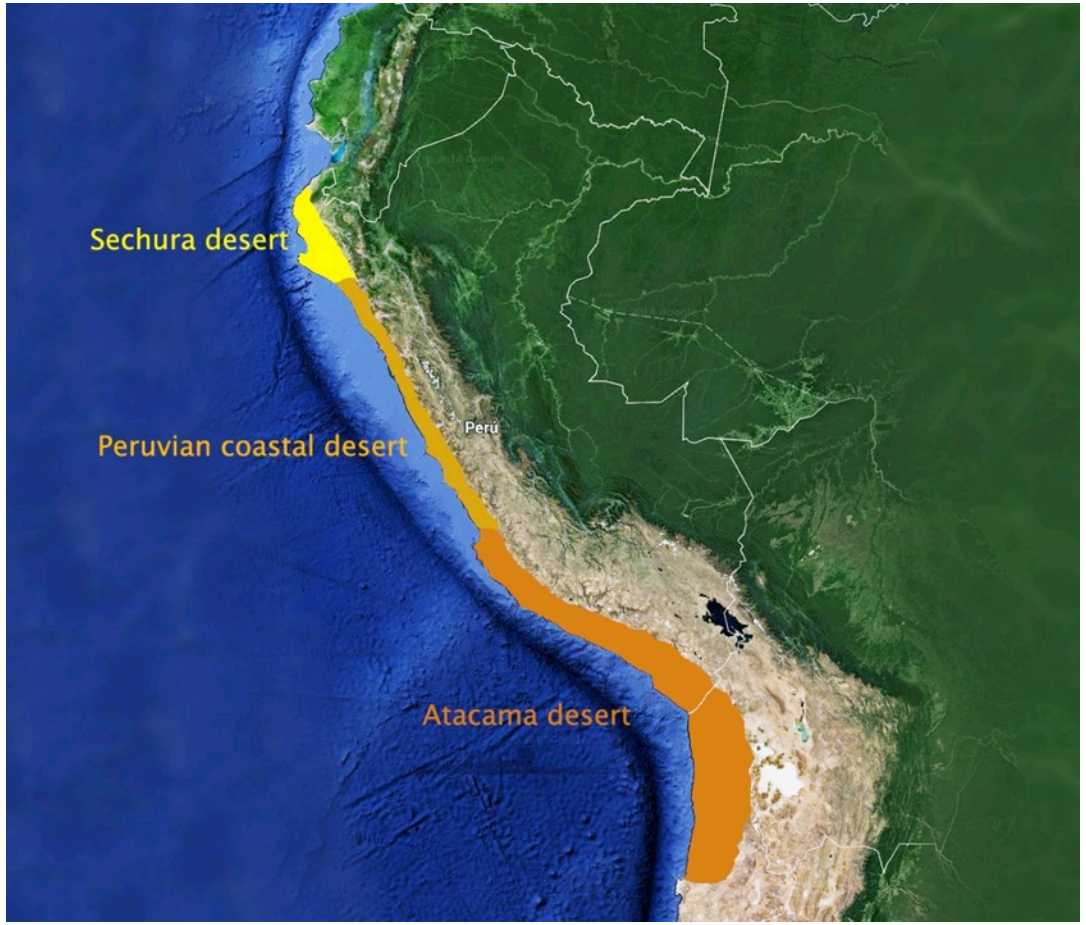


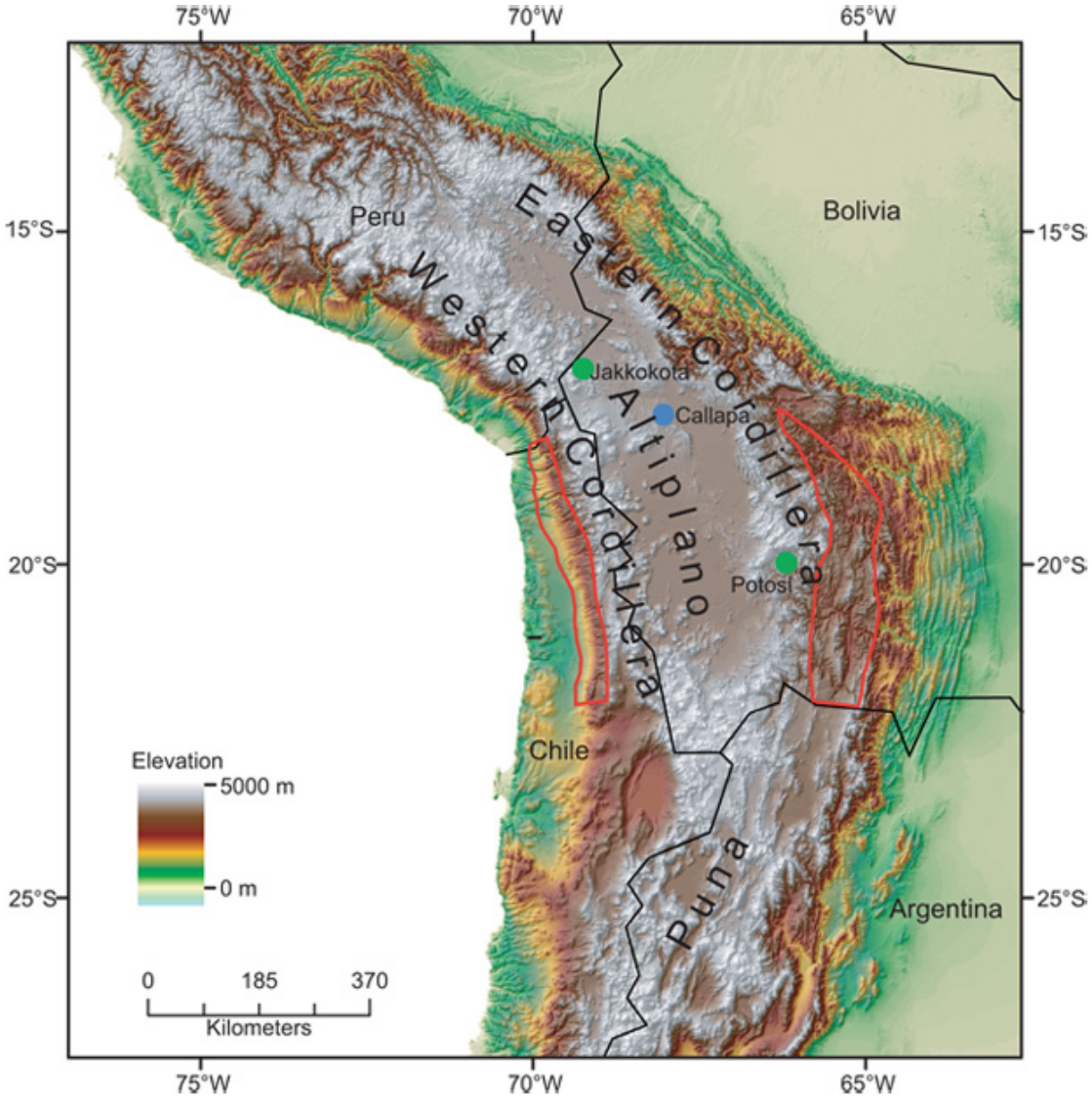


400-380 Ma

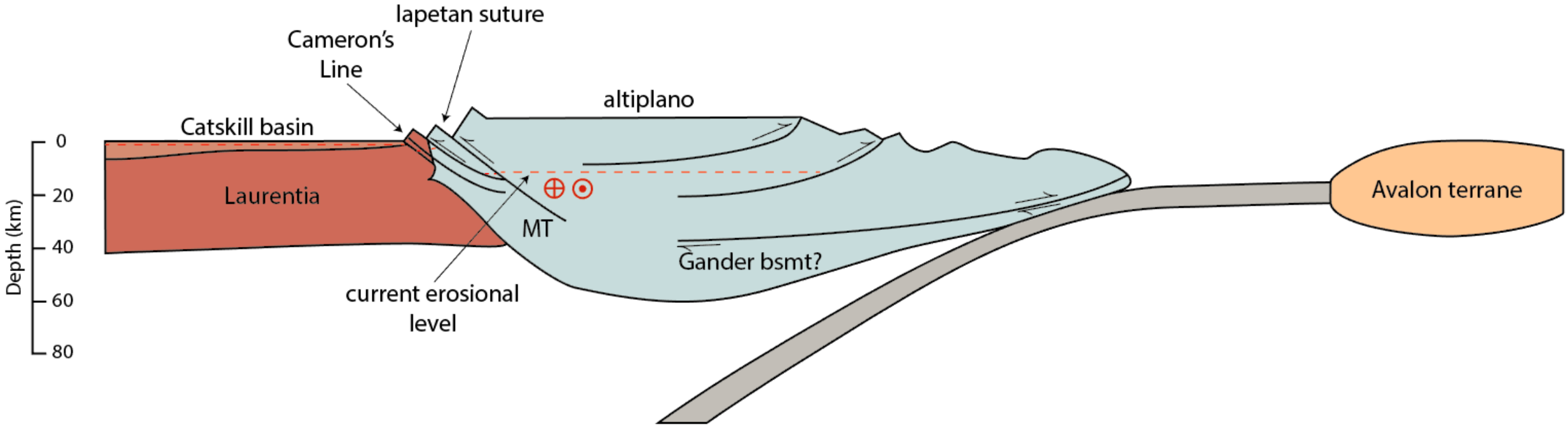
The Acadian Altiplano




Sechura desert
Peruvian coastal desert
Atacama desert
Perú


75°W
70°W
65°W
15°S
20°S
25°S
Peru
Bolivia
Chile
Argentina
Western Cordillera
Eastern Cordillera
Altiplano
Puna
Jakkokota
Callapa
Potosi
Elevation
5000 m
0 m
0
185
370
Kilometers

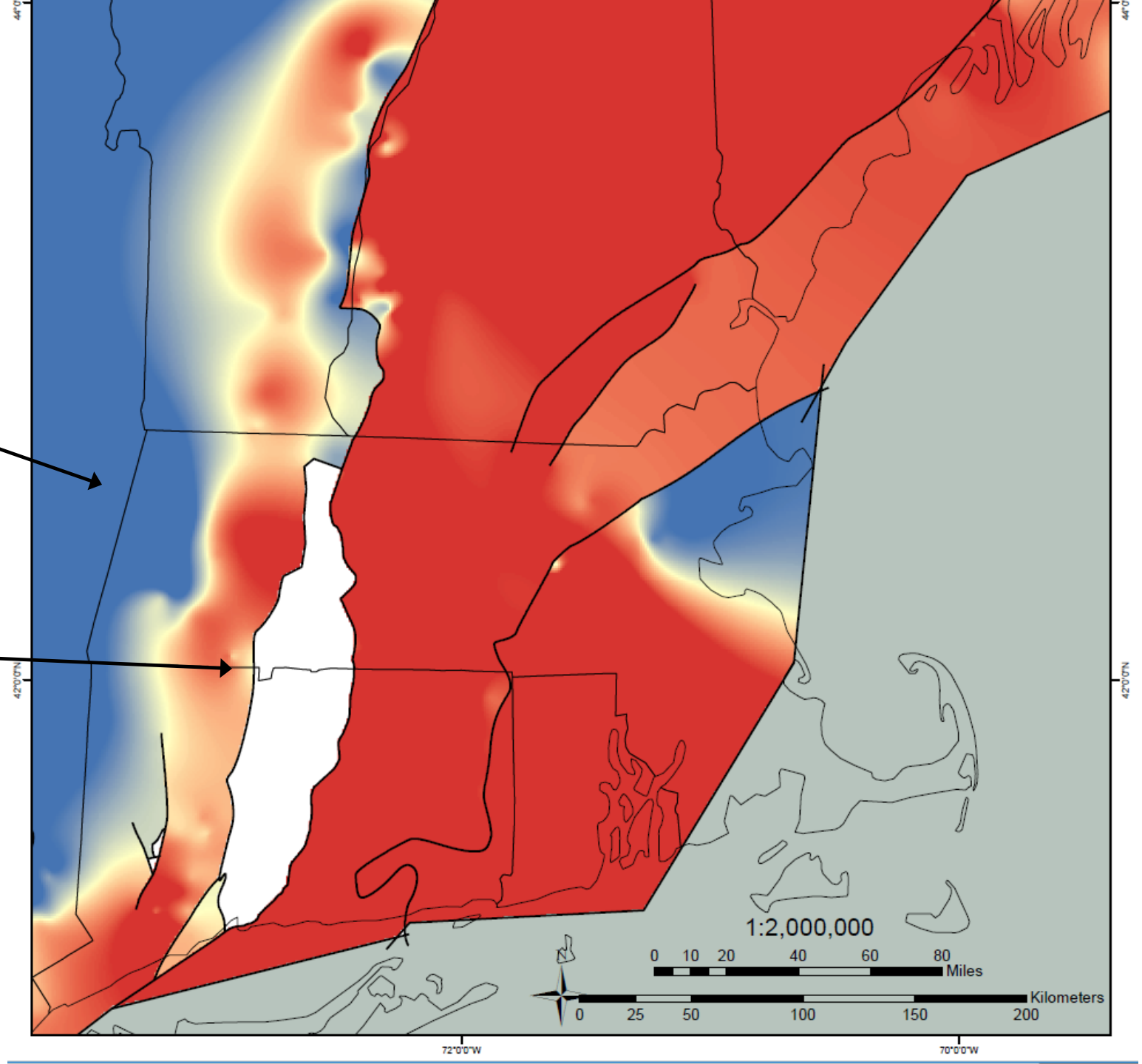
The Acadian Altiplano
~ 380 Ma



Hornblende Cooling Ages
~ 500 C

> 400 Ma

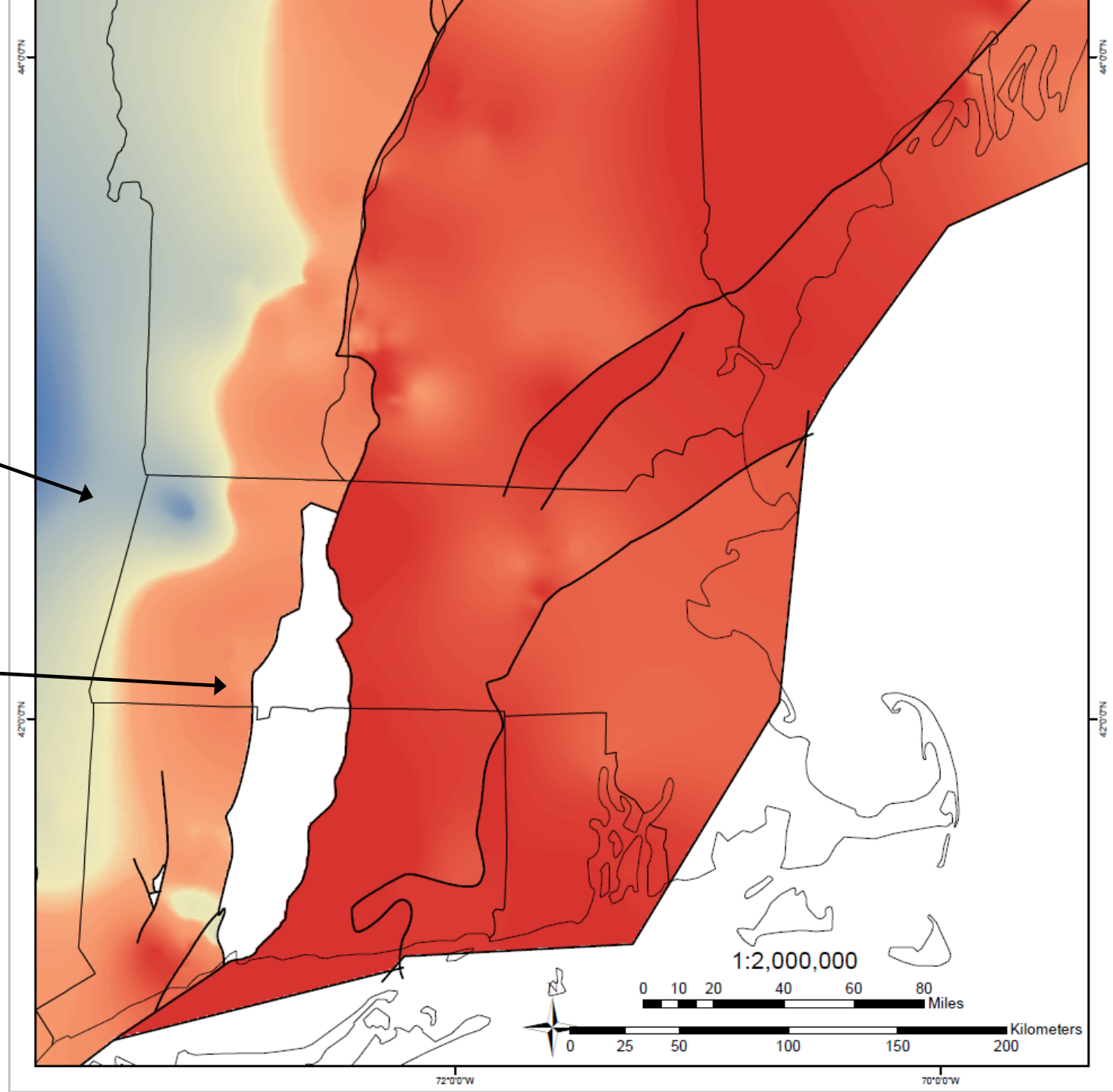
~380 Ma



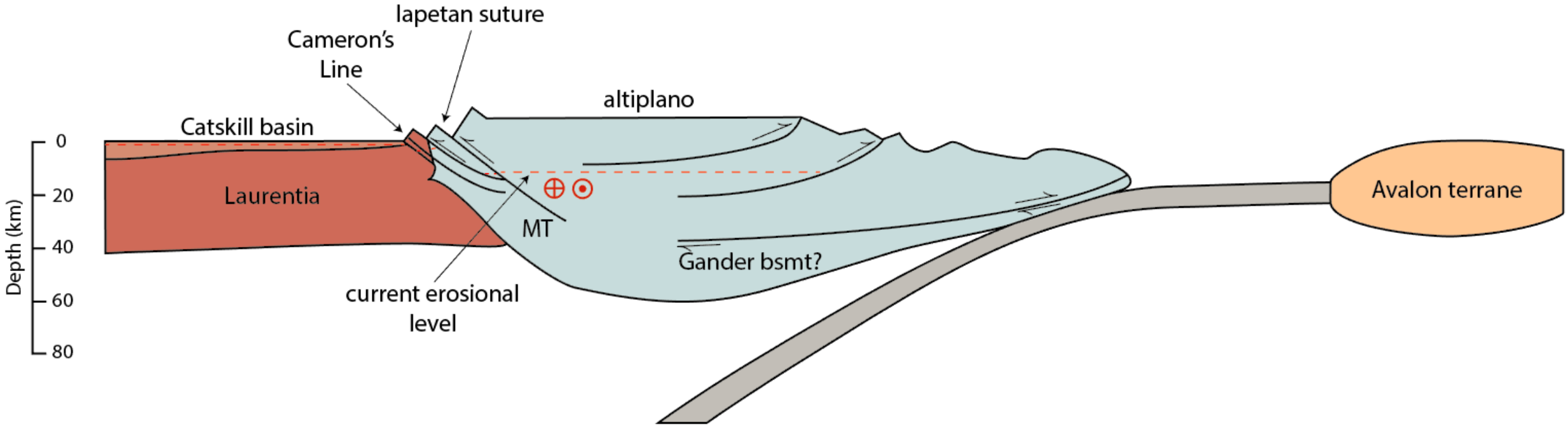
Muscovite Cooling Ages
~ 350 C

> 400 Ma

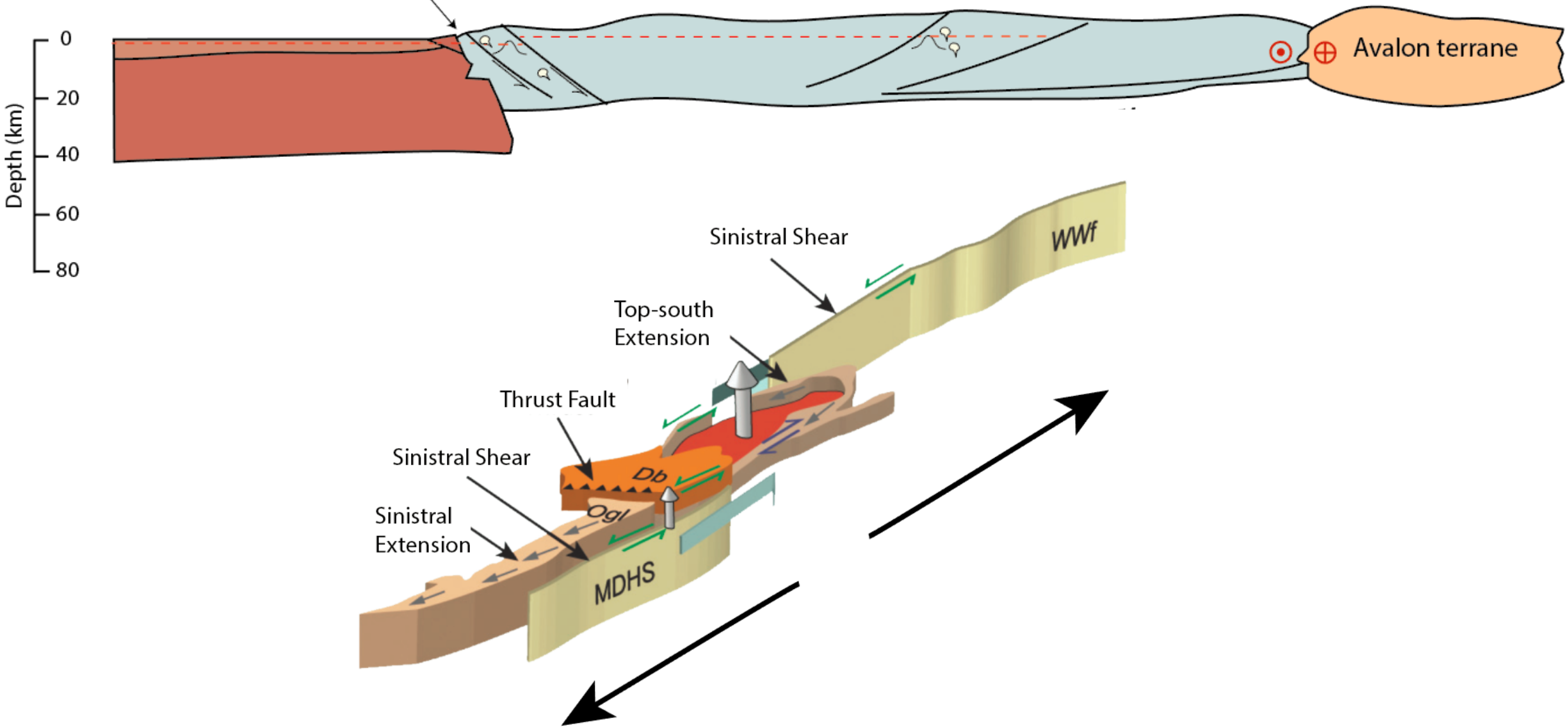
~340-320 Ma



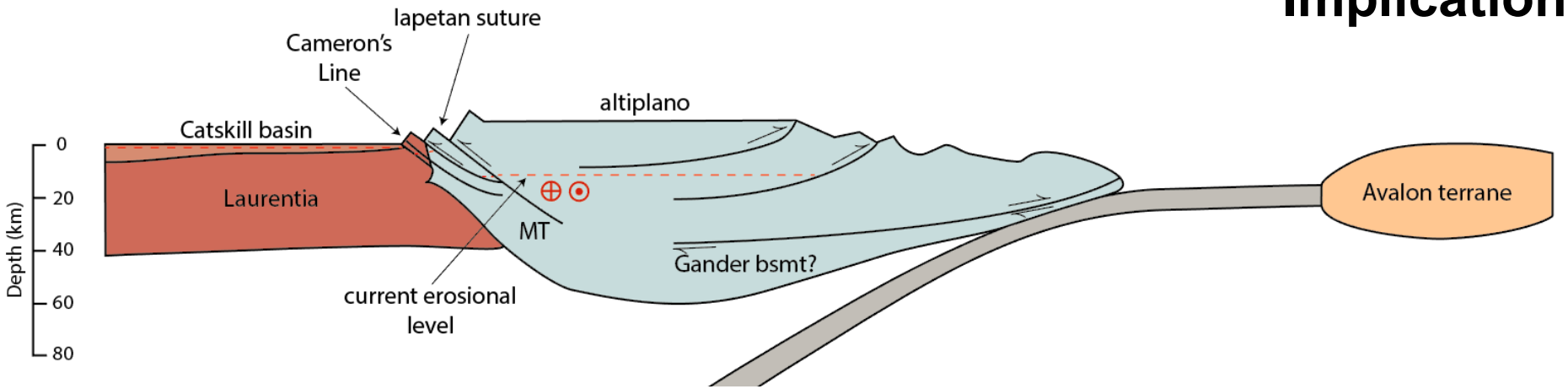
The Acadian Altiplano
~ 380 Ma



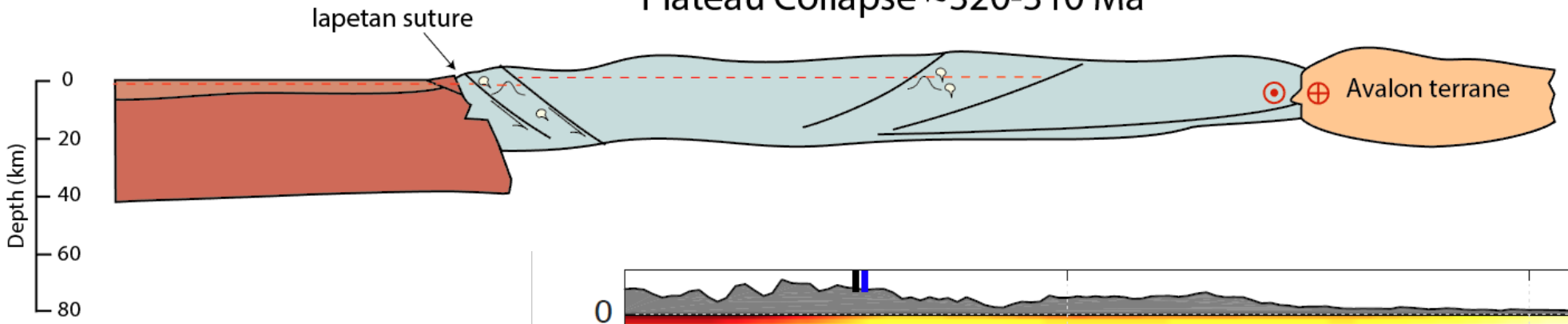
Plateau Collapse ~320-310 Ma

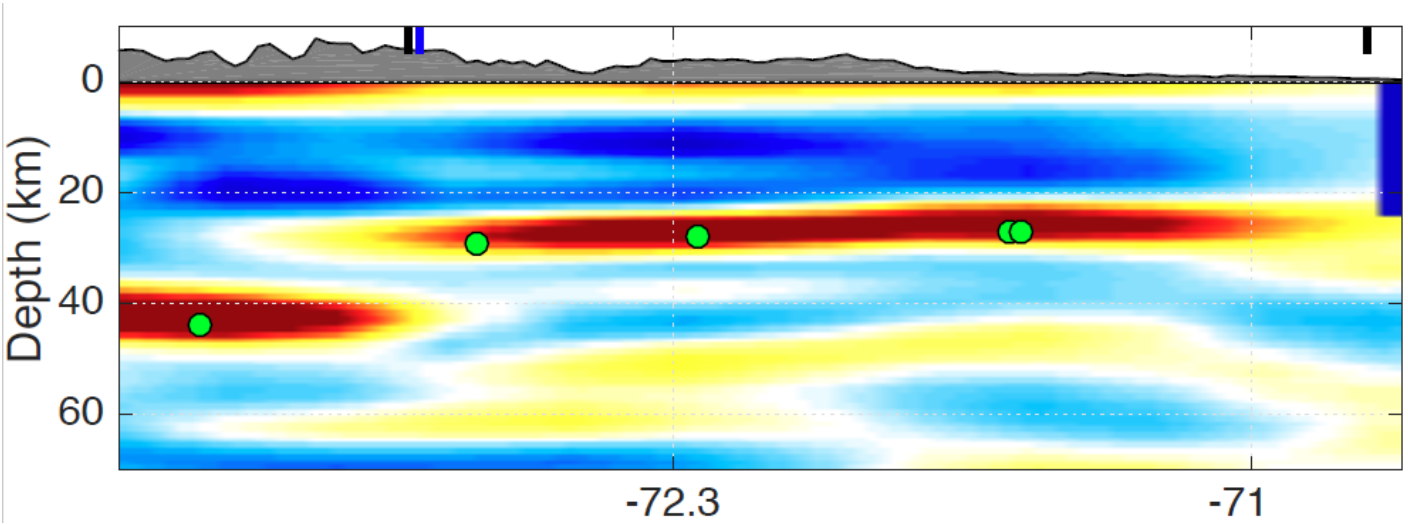


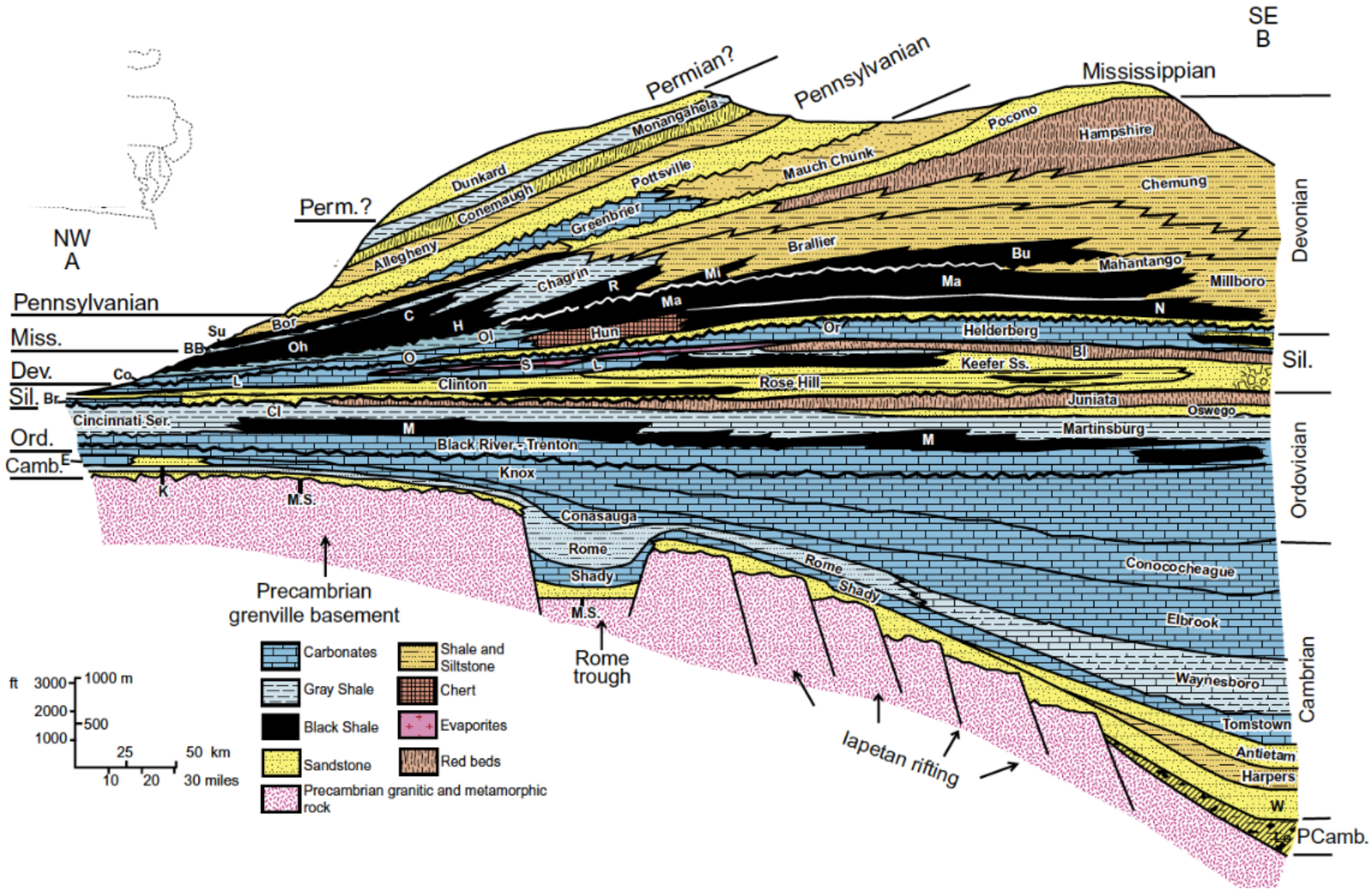
Implications / Connections

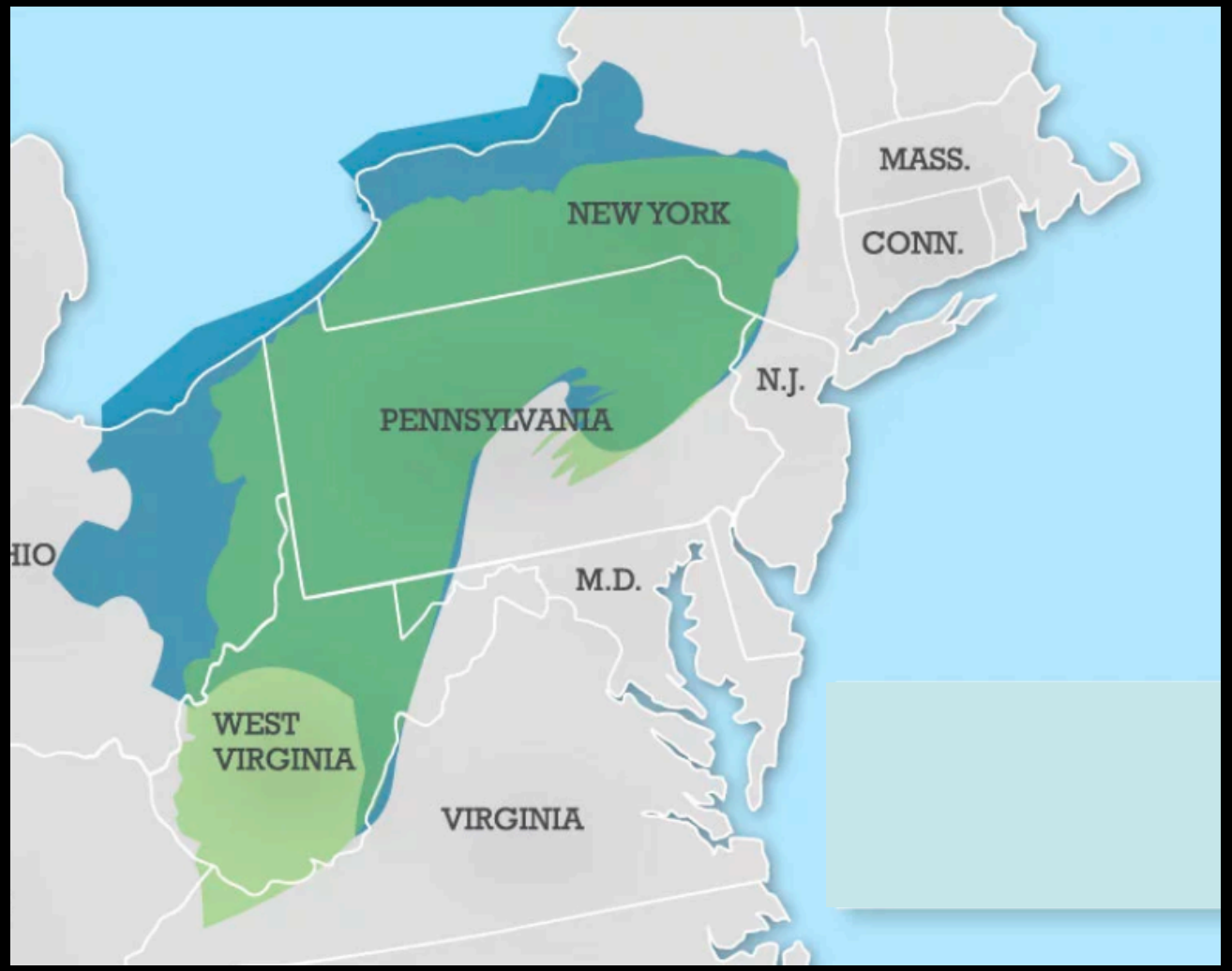


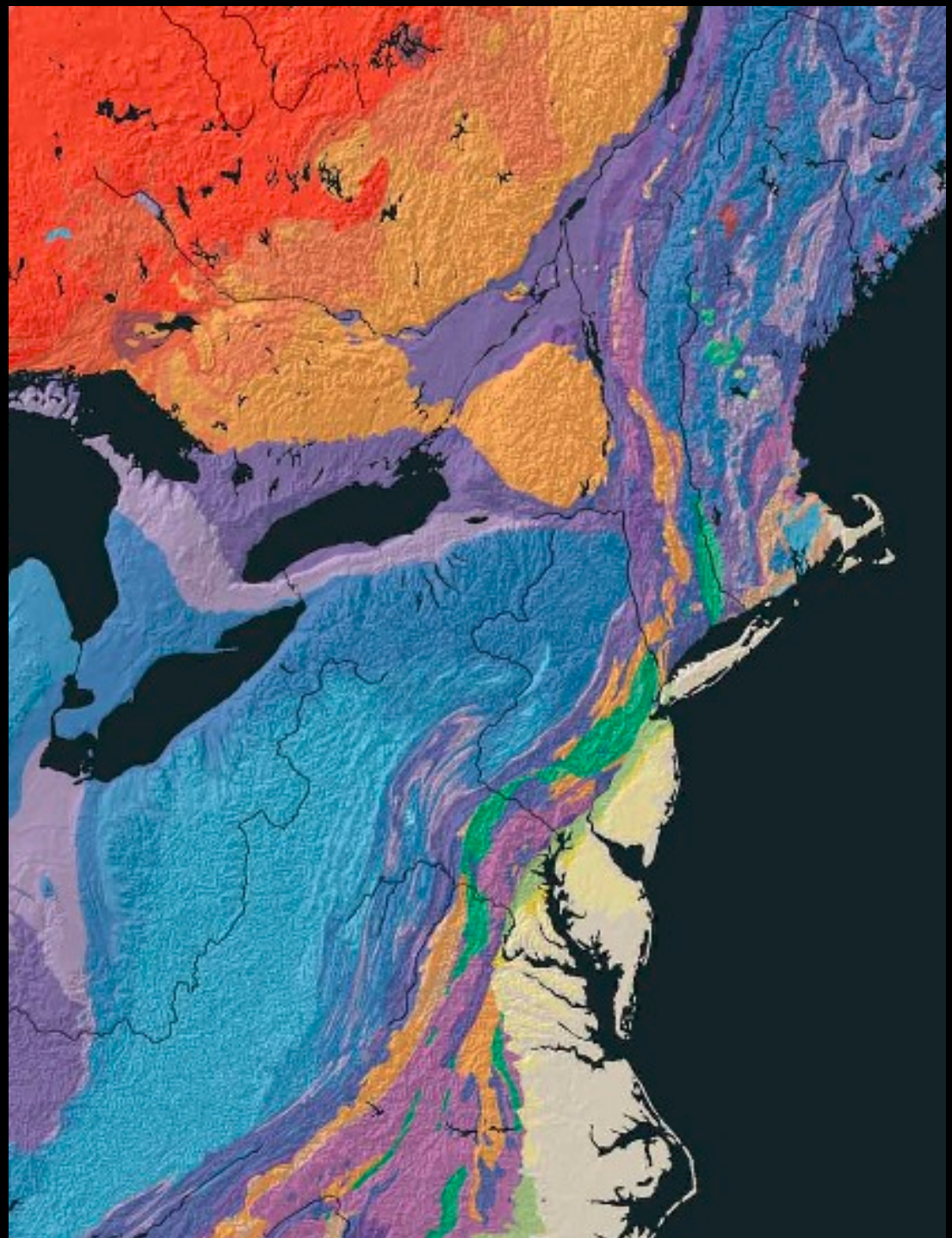
Plateau Collapse ~320-310 Ma



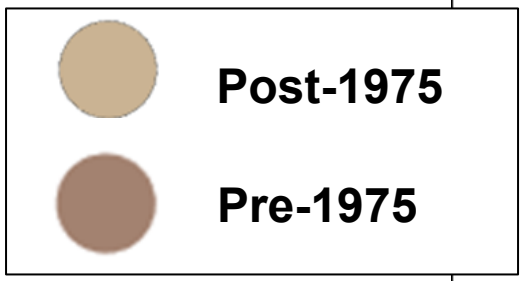


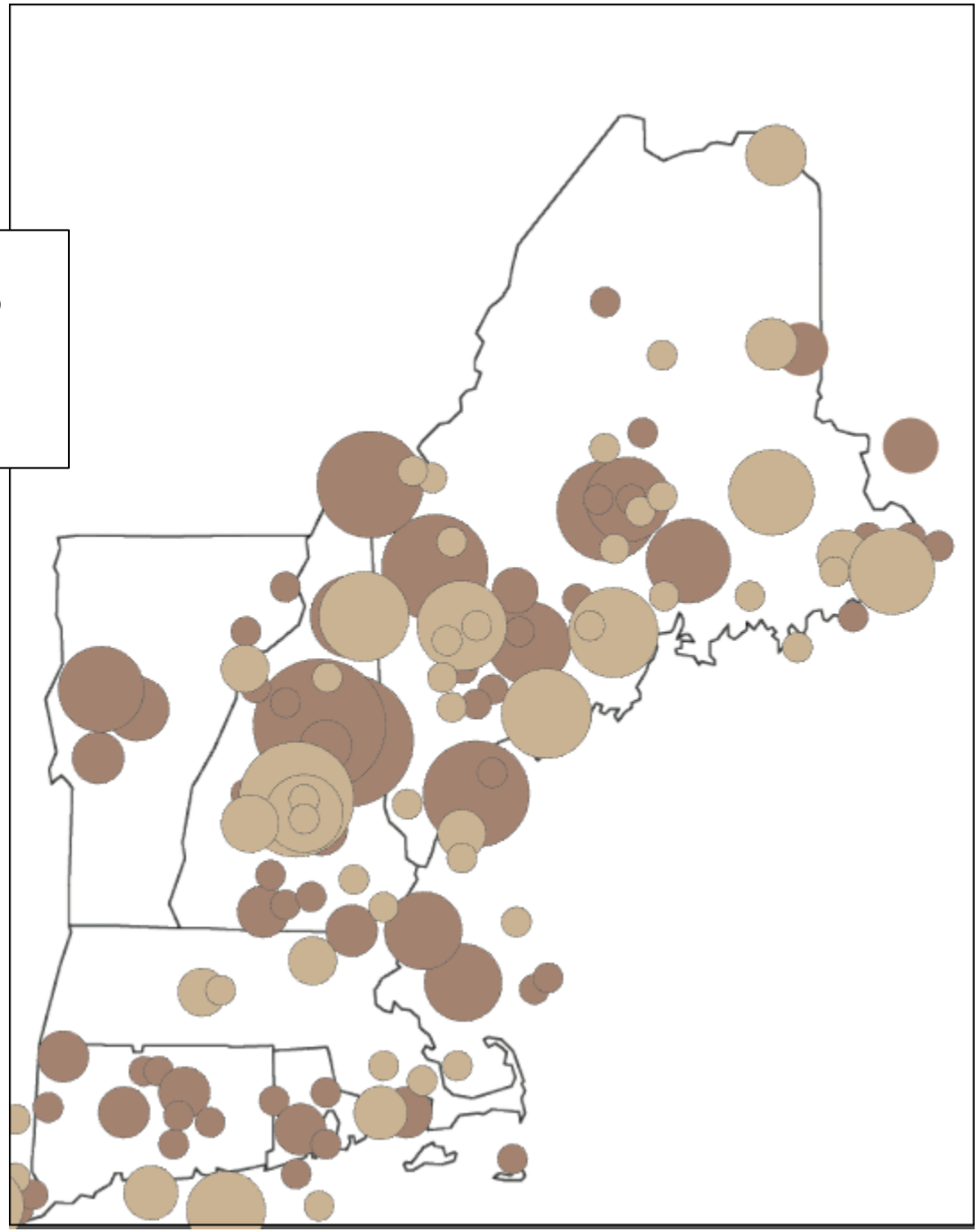

NW
A
SE
B
Perm.?
Permian?
Pennsylvanian
Mississippian
Pennsylvanian
Miss.
Dev.
Sil.
Ord.
Camb.
Devonian
Sil.
Ordovician
Cambrian
PCamb.
Monongahela
Dunkard
Conemaugh
Pottsville
Allegheny
Greenbrier
Mauch Chunk
Pocono
Hampshire
Chemung
Brallier
Chagrin
Bu
Mahantango
Millboro
Ma
Mi
R
N
Holderberg
Bl
Keefer Ss.
Rose Hill
Juniata
Oswego
Martinsburg
Clinton
Cincinnati Ser.
Black River - Trenton
Knox
Conasauga
Rome
Shady
Conococheague
Elbrook
Waynesboro
Tomstown
Antietam
Harpers
W
Precambrian
grenville basement
Rome
trough
Iapetan rifting
Su
Bor
C
H
Ol
Hun
Or
Oh
BB
Co
O
S
L
Br
Cl
M
E
K
M.S.
ft
3000
2000
1000
1000 m
500
25
50 km
10
20
30 miles
Carbonates
Gray Shale
Black Shale
Sandstone
Shale and Siltstone
Chert
Evaporites
Red beds
Precambrian granitic and metamorphic rock

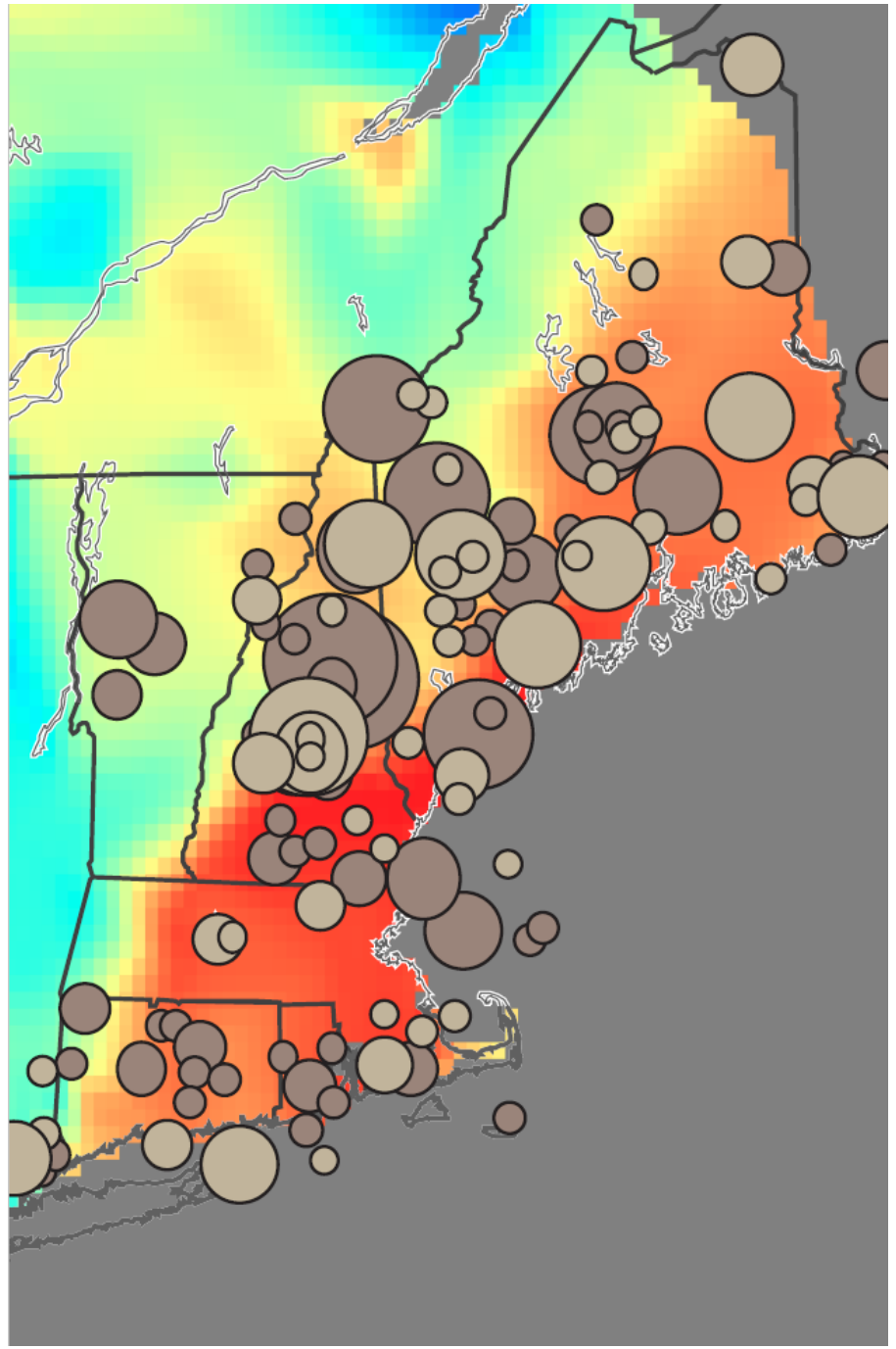

MASS.
NEW YORK
CONN.
N.J.
PENNSYLVANIA
HIO
M.D.
WEST
VIRGINIA
VIRGINIA

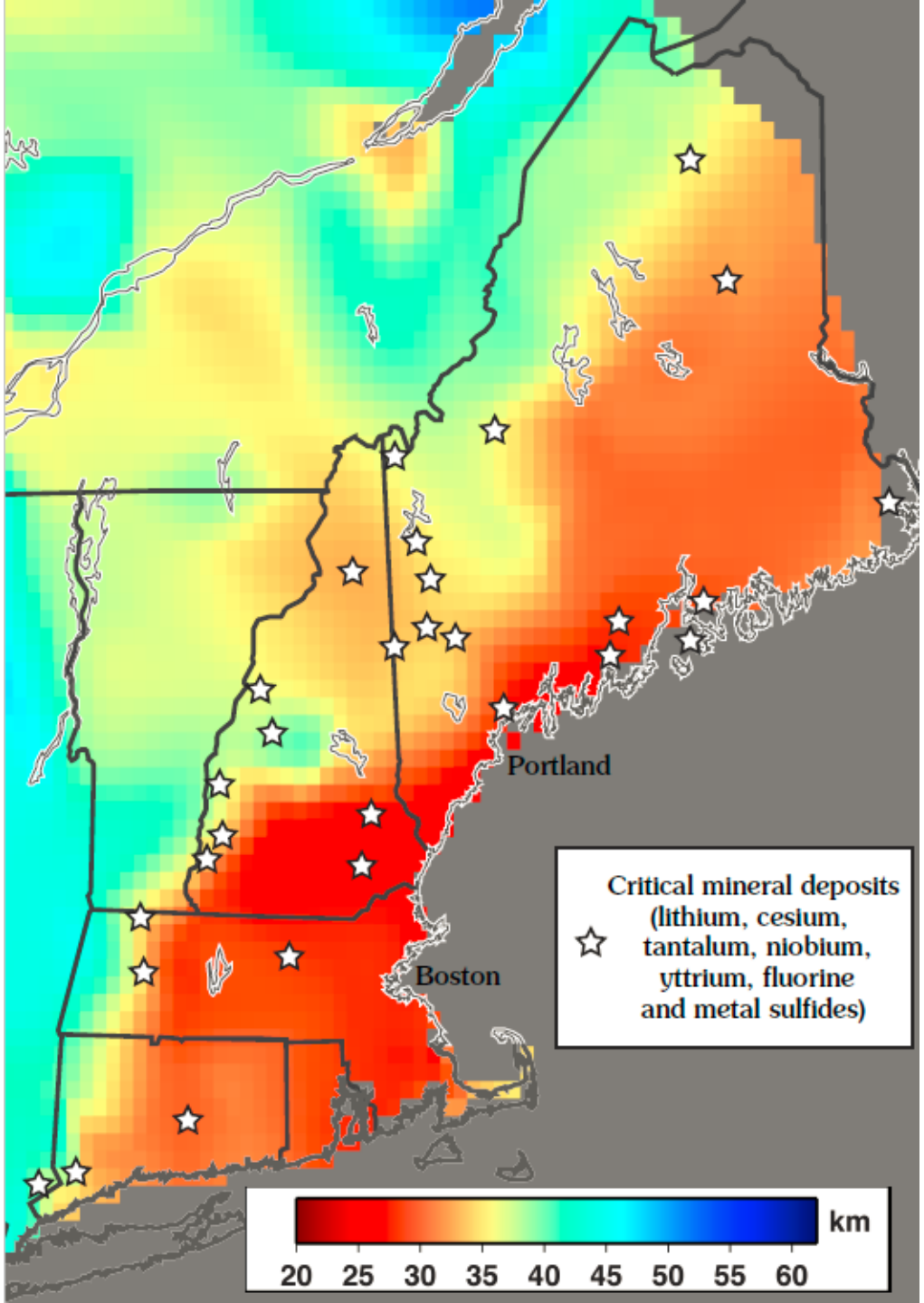


Earthquakes



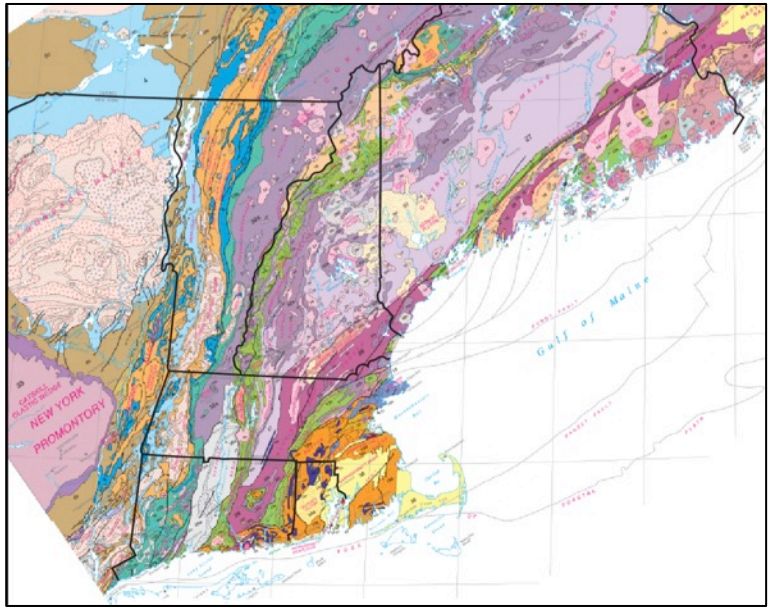


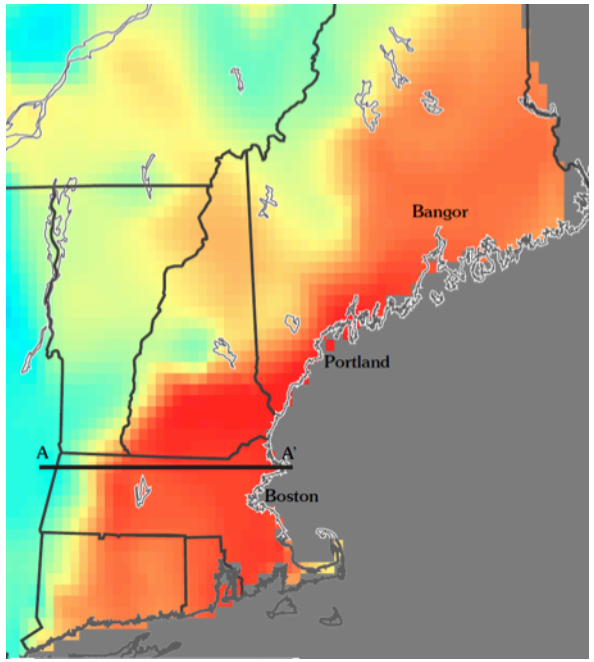


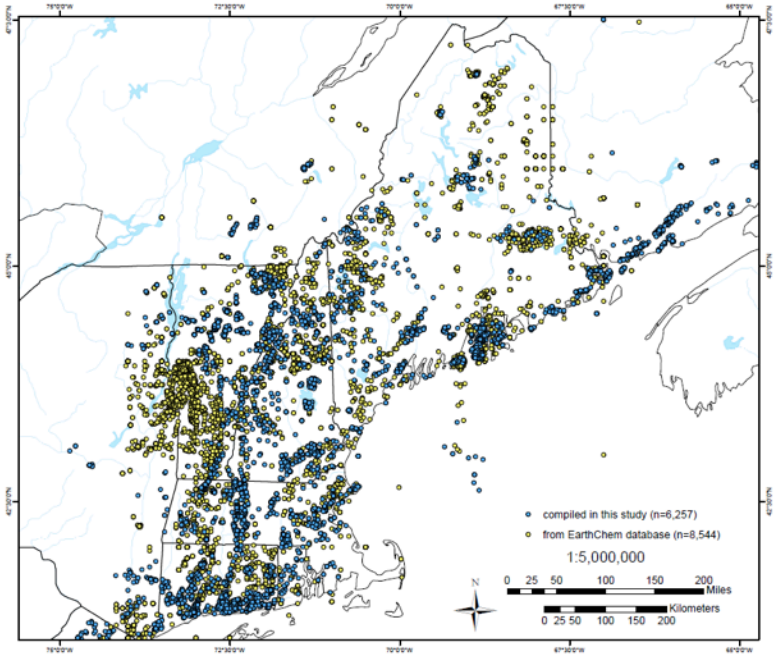


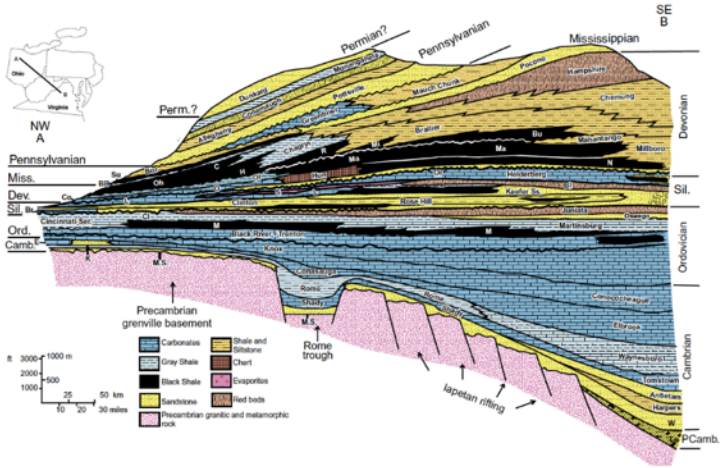
Mineral Deposits

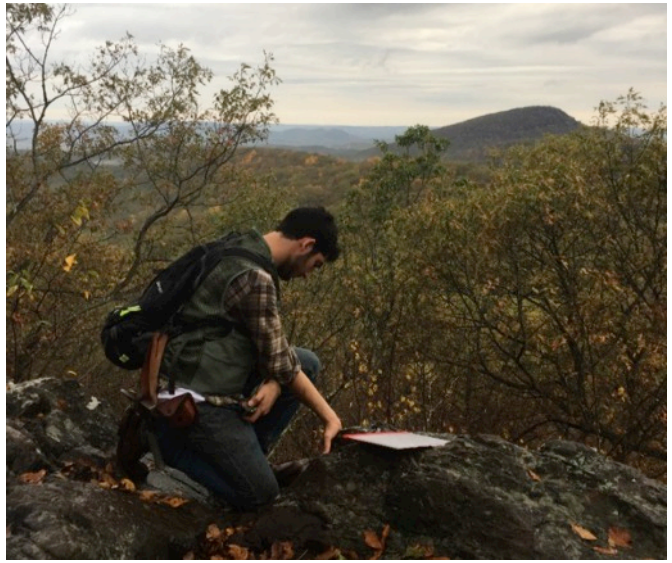
A New Way of Studying the Earth…

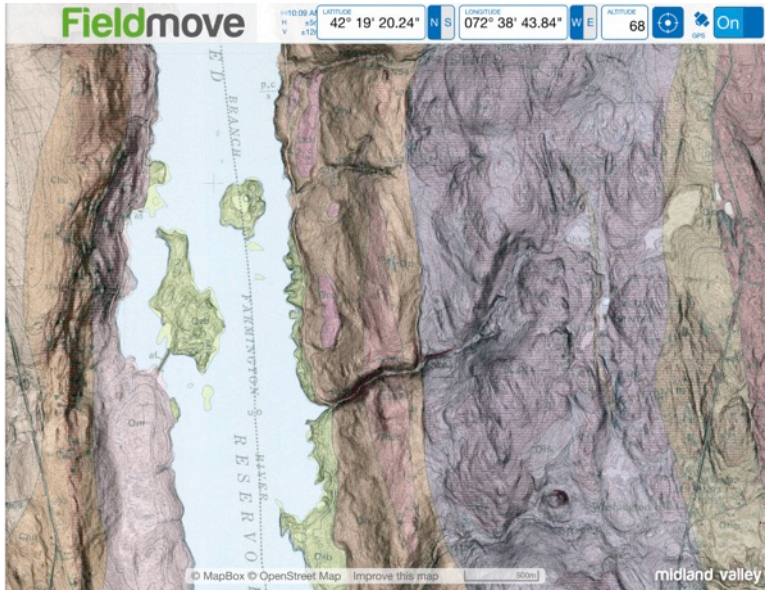


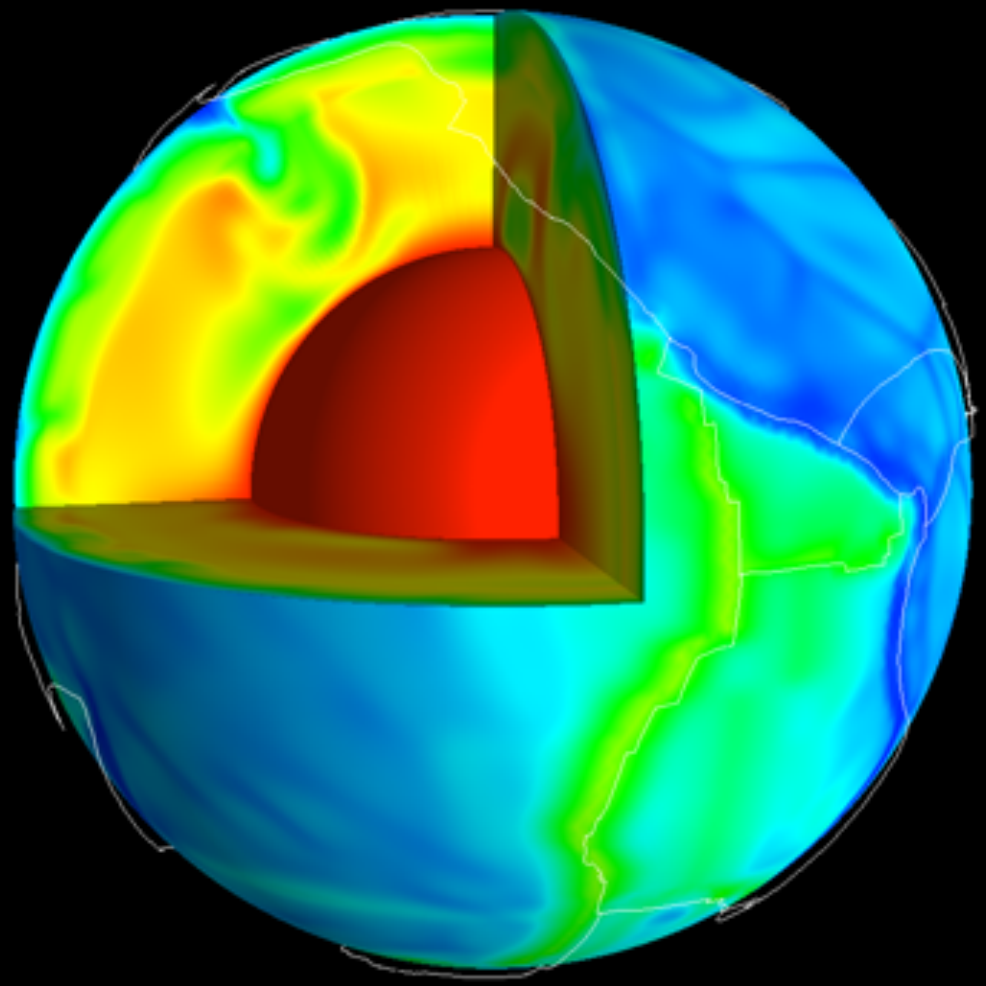












The New Tectonics Revolution