National Science Foundation
WHERE DISCOVERIES BEGIN

Earthscope Illumination of Melts, Volatiles, Dynamics and Structure of a Continent

Tony Lowry

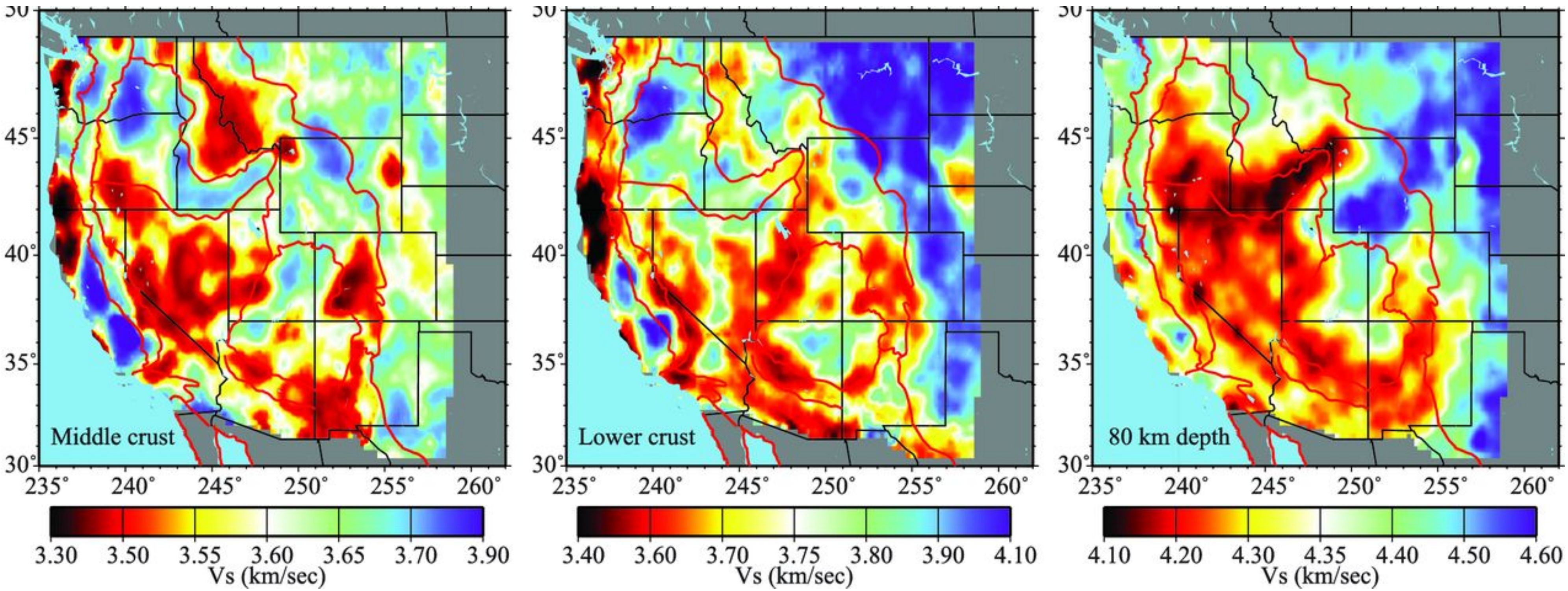
with thanks to: Thorsten Becker, Michael Berry, Janine Buehler, Fan-Chi Lin, Xiaofei Ma, Marta Pérez-Gussinyé, Brandon Schmandt, & Derek Schutt

UtahStateUniversity

	Hot? Wet?	Higher H_2O	Property		Higher Temp.	Cold? Dry?
	Slow	↓	Seismic Velocity		↓	Fast
	High	↑	Electrical Conductivity		↑	Low
		↓	Mass Density	!	↓	
		↓	Flow Strength	!	↓	
		↑	Partial Melt	!	↑	

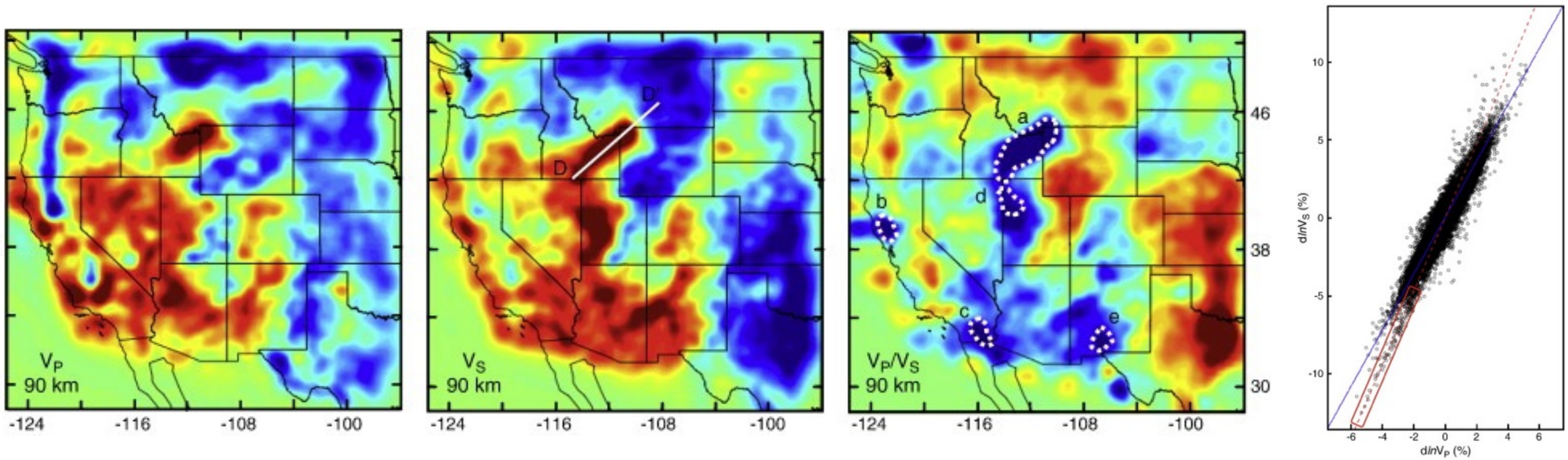
These are important for the dynamics…

Shear wave velocity…



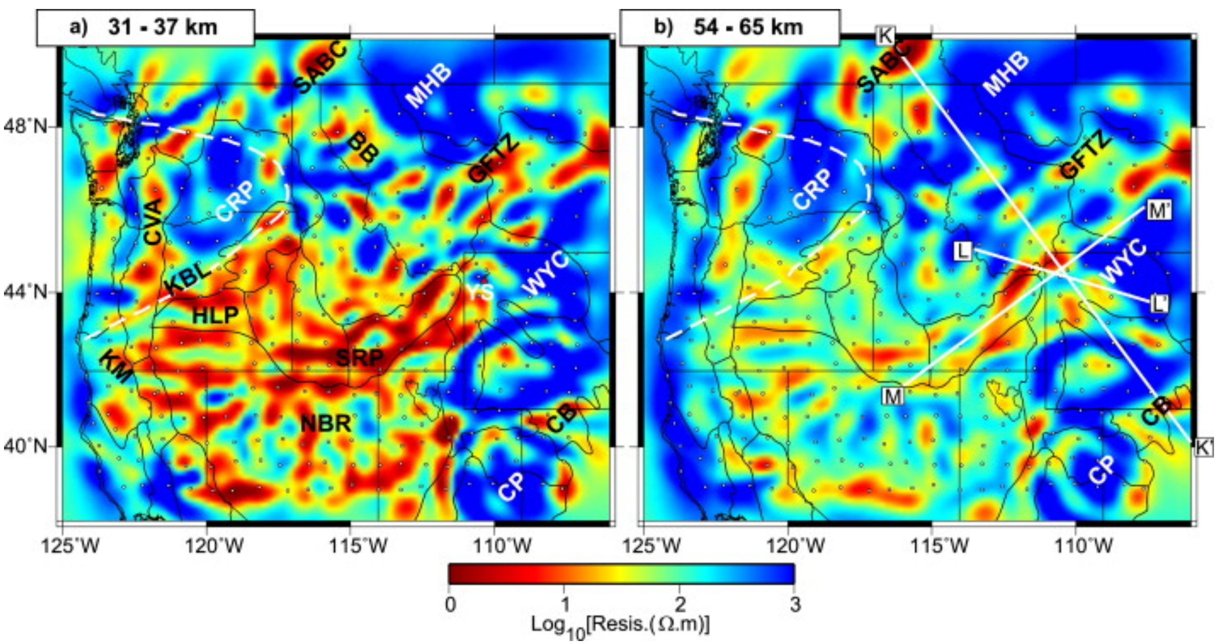
Lin et al., *Geophys. J. Int.* (2014)

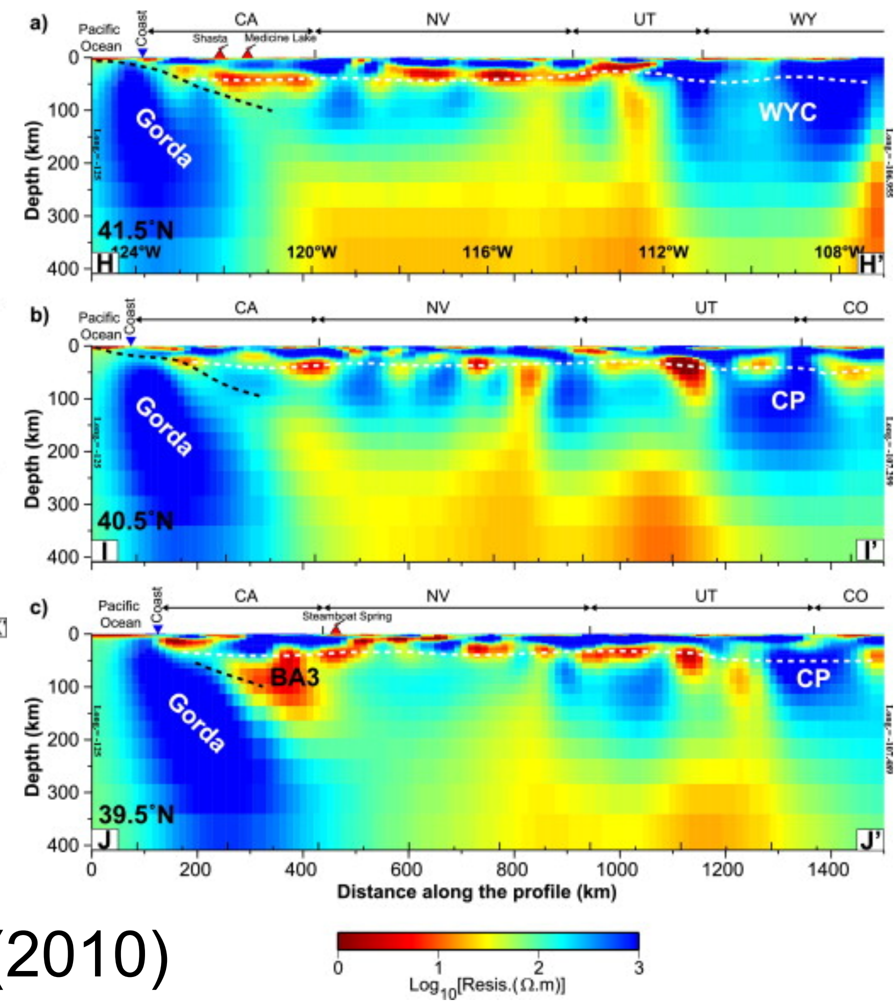
Mantle melts from v_P/v_S...



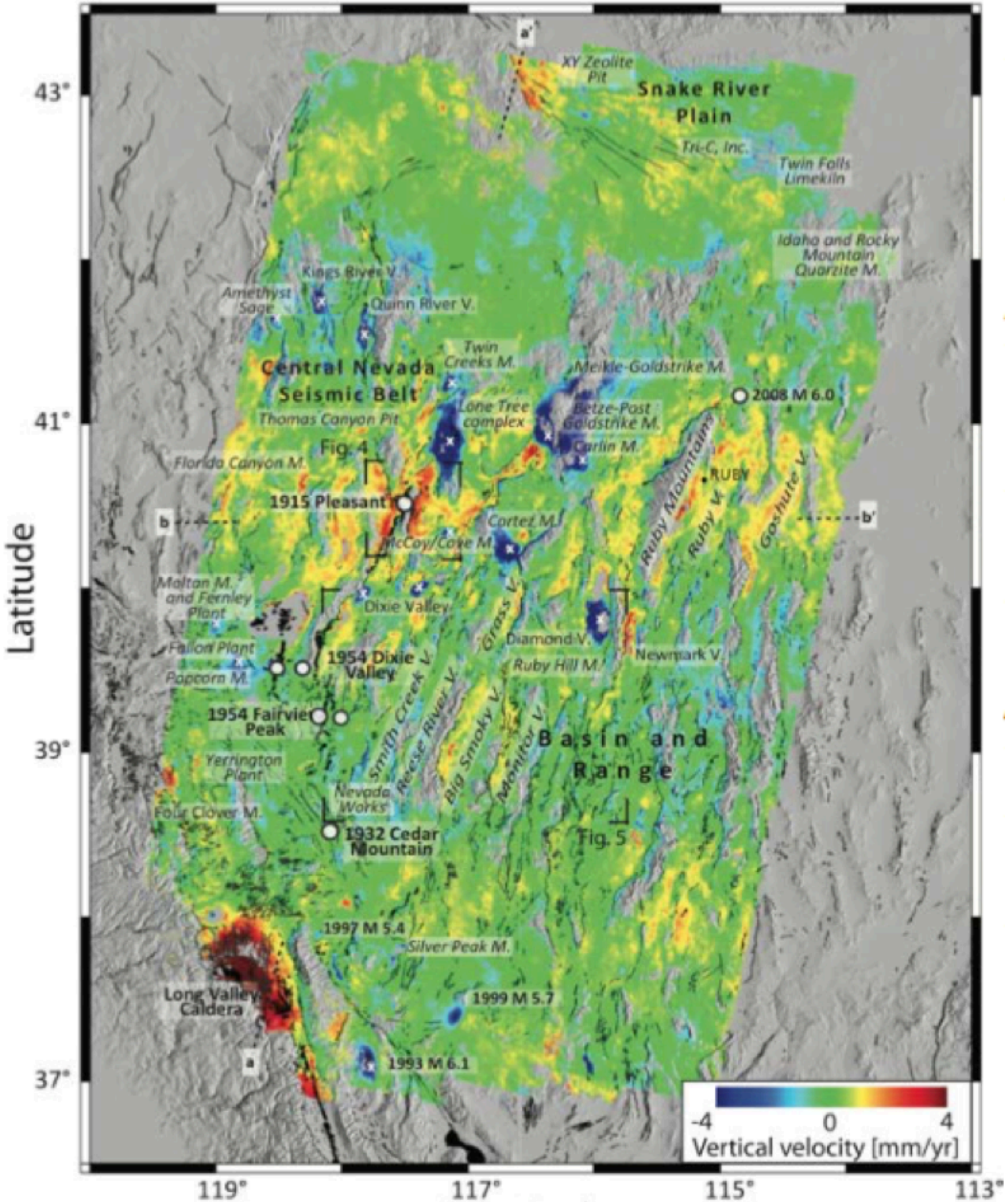
Schmandt & Humphreys, *Earth Planet. Sci. Lett*. (2010)

Lower crustal melts from MT...



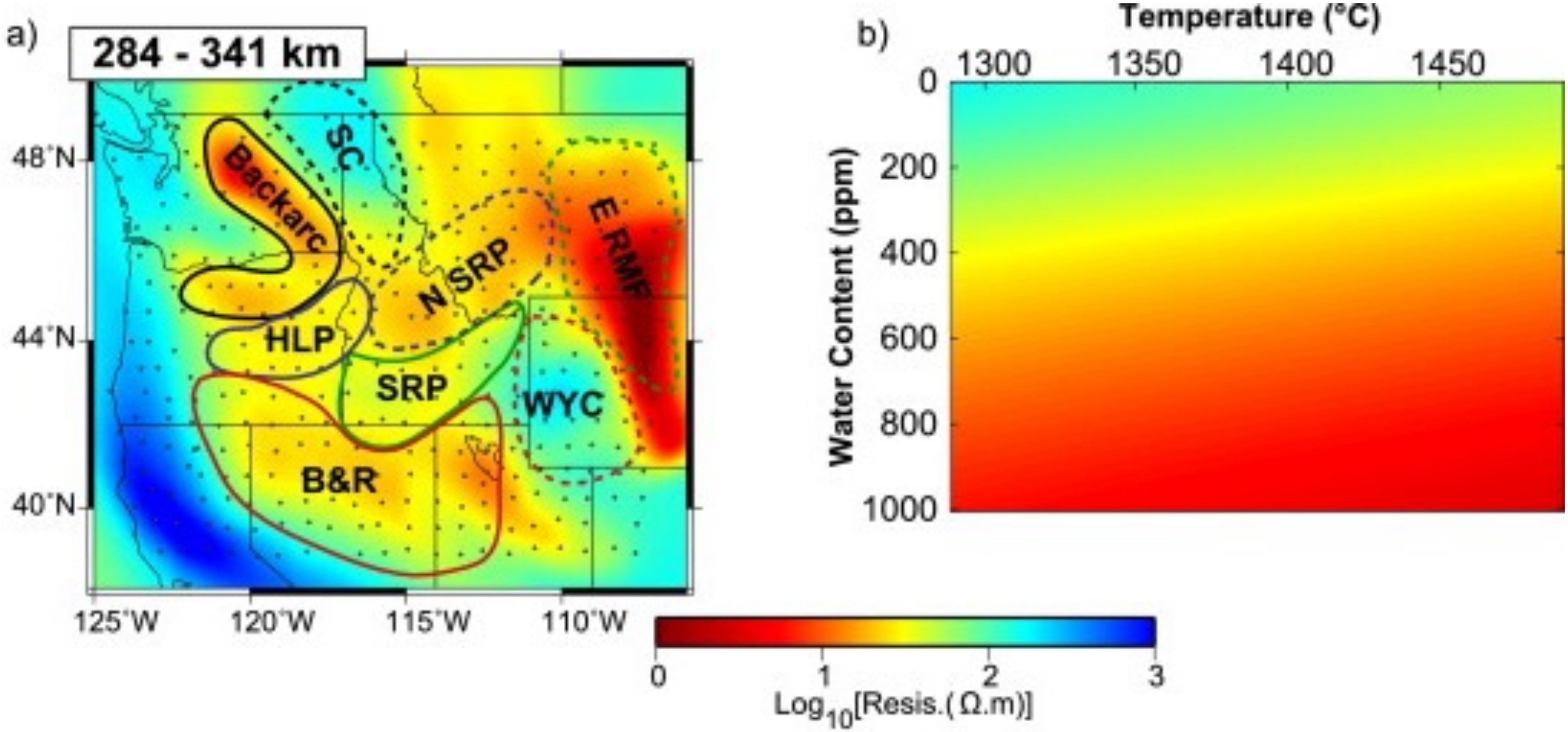


Meqbel et al., *Earth Planet. Sci. Lett*. (2010)



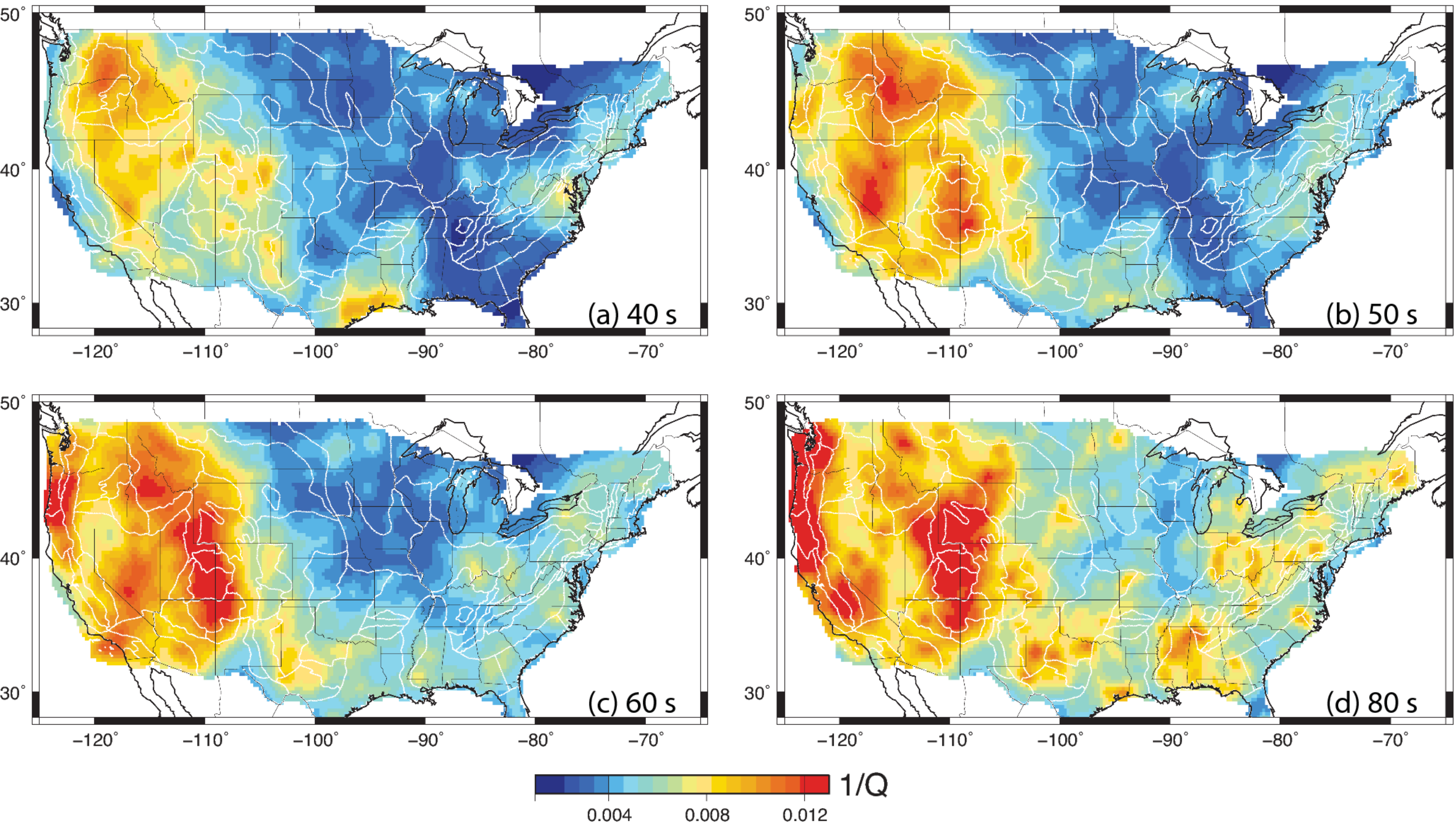
Greene, PhD Diss.
University of Miami
(2014)

Mantle hydration state from MT…



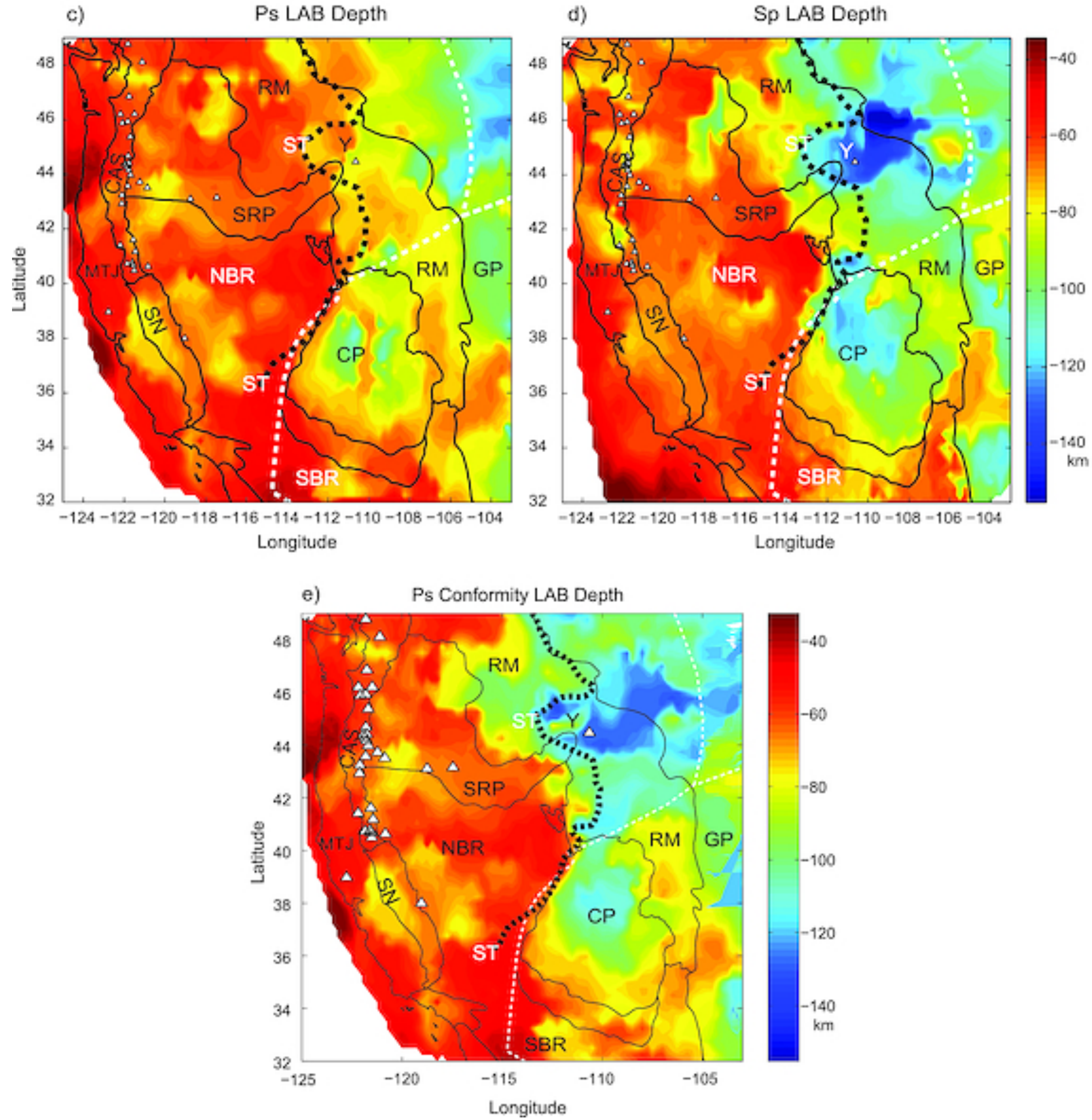
Meqbel et al., *Earth Planet. Sci. Lett*. (2014)

Rheology? from attenuation...



Bao et al., *Geophys. J. Int.* (2016)

Rheology? from seismic LAB…

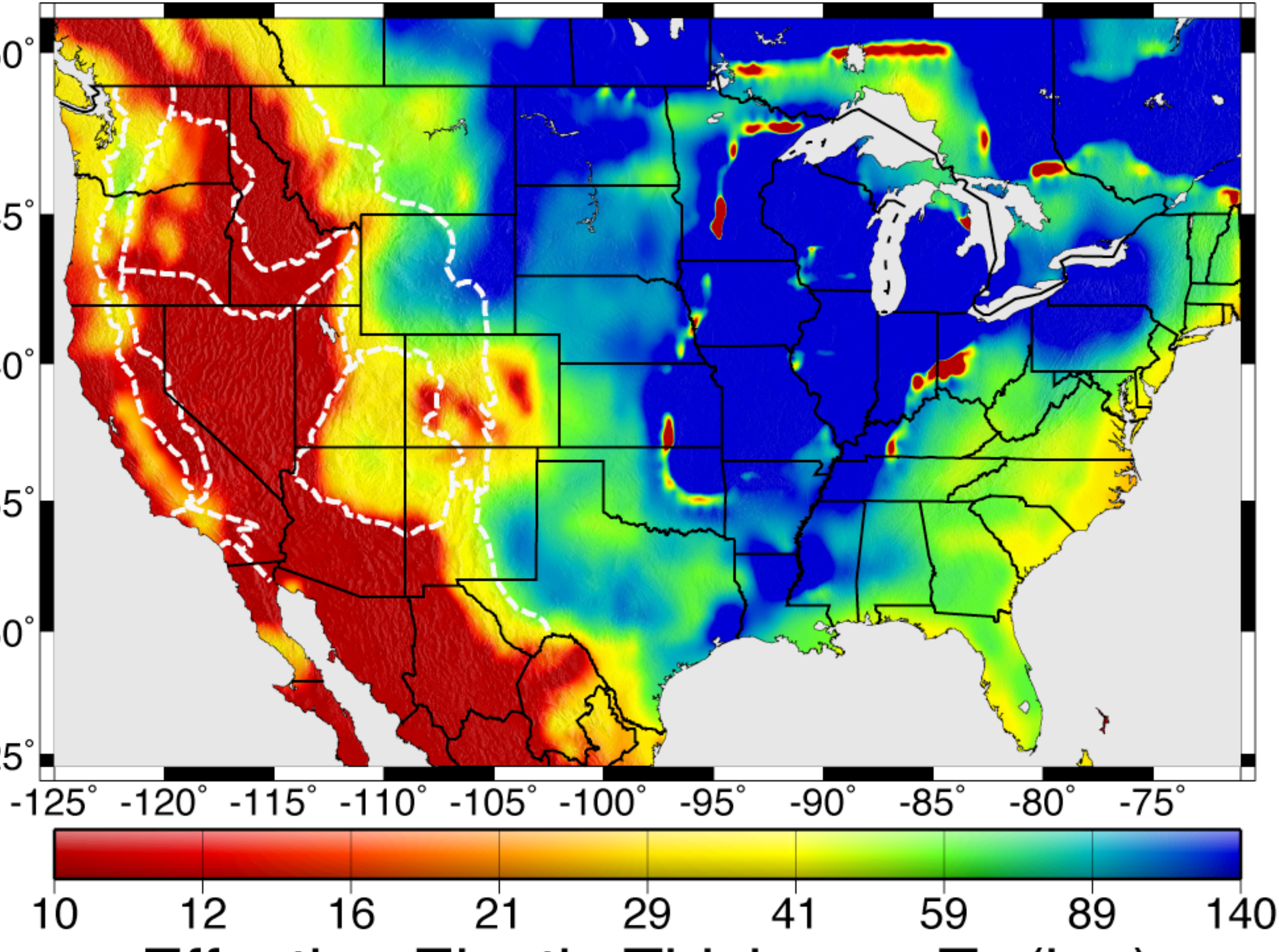


Levander & Miller *Geochem. Geophys. Geosys*. (2012)

So, to state the obvious…

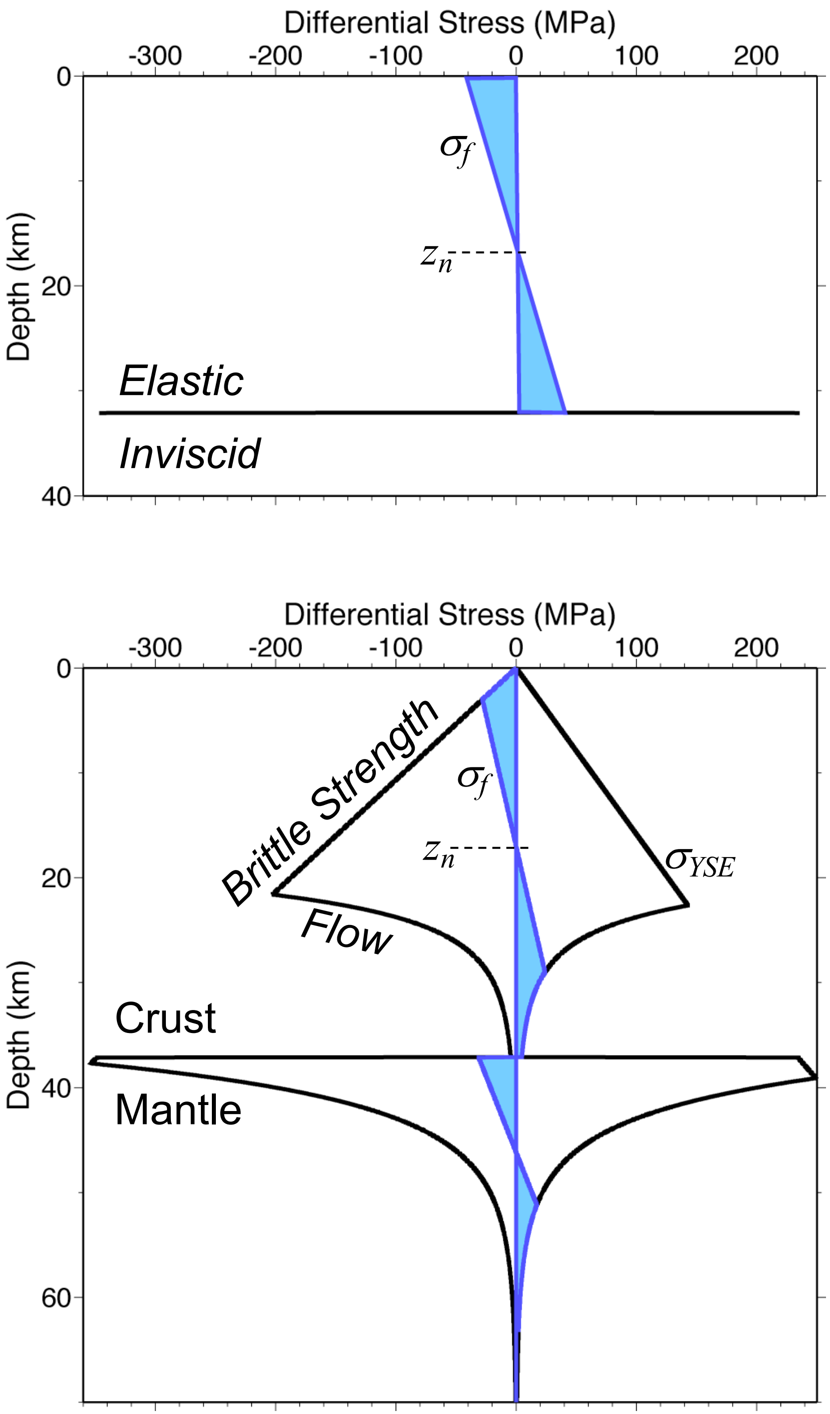
Separating temperature, compositional, melt and volatile flux in deformation processes will require:

- Integration of multiple data sets
- With mineral physics
- And careful assessment of uncertainties

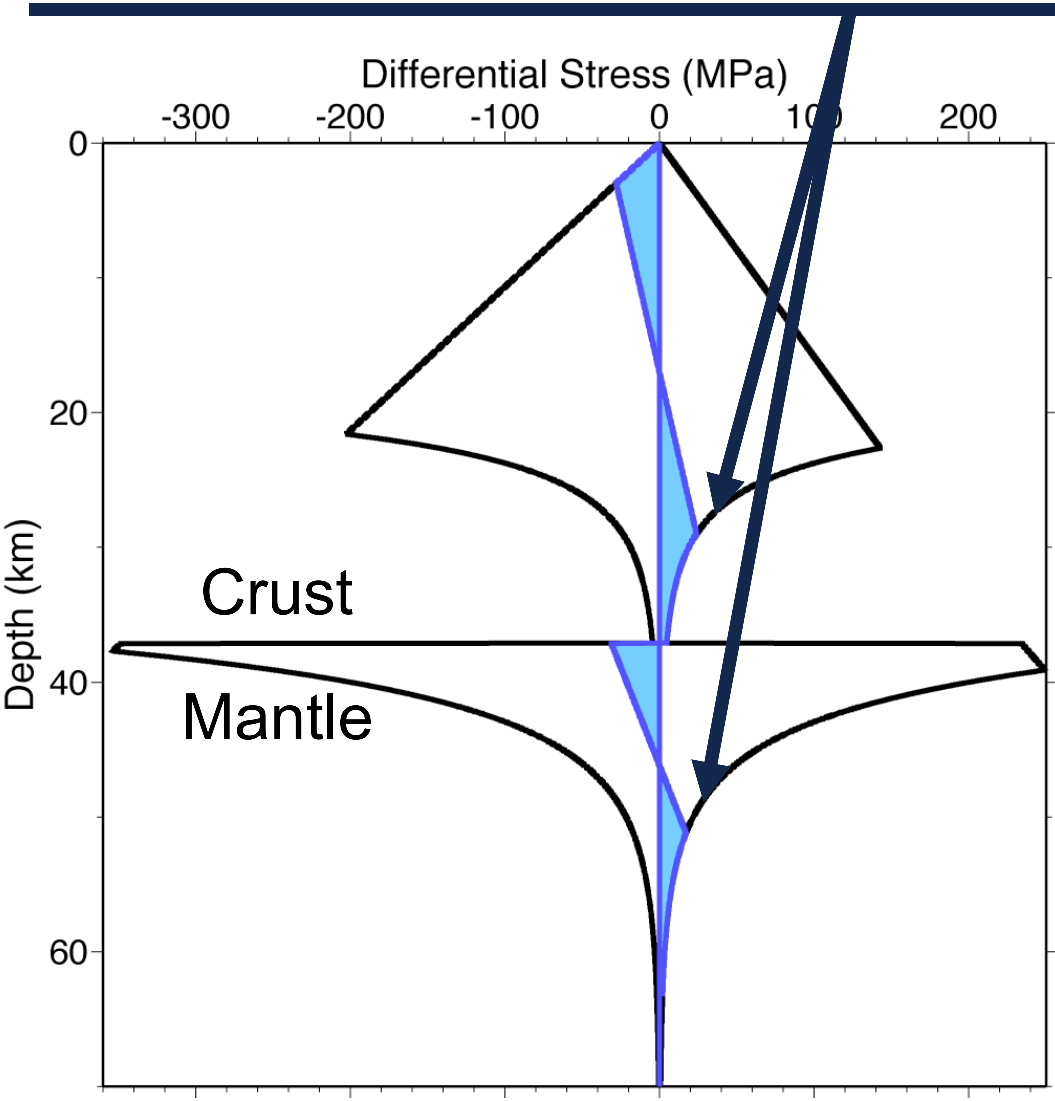


Lowry & Pérez-Gussinyé, Nature 2011

T_e and Strength



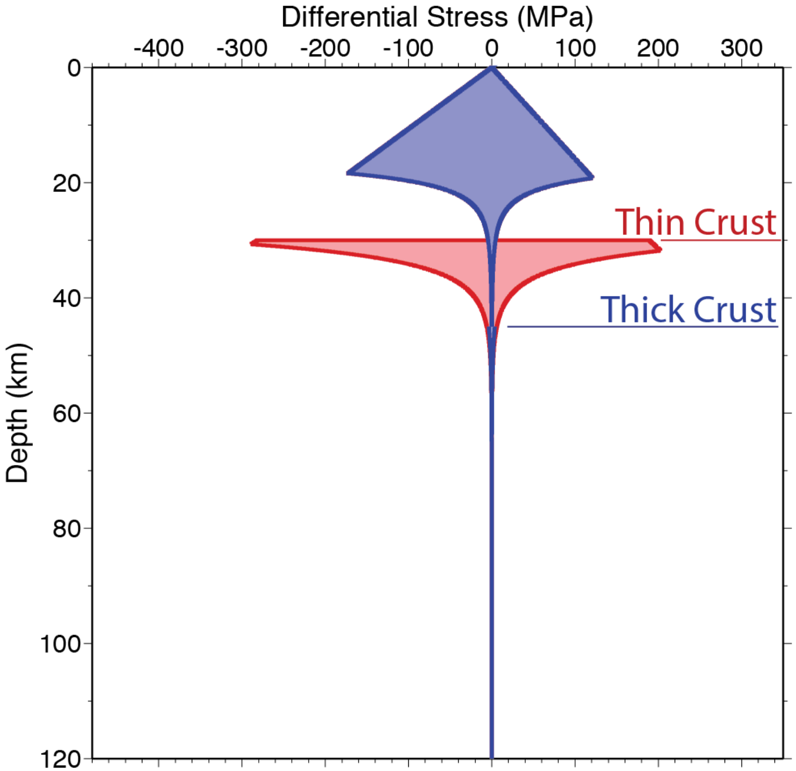
Flow Strength...



depends on:

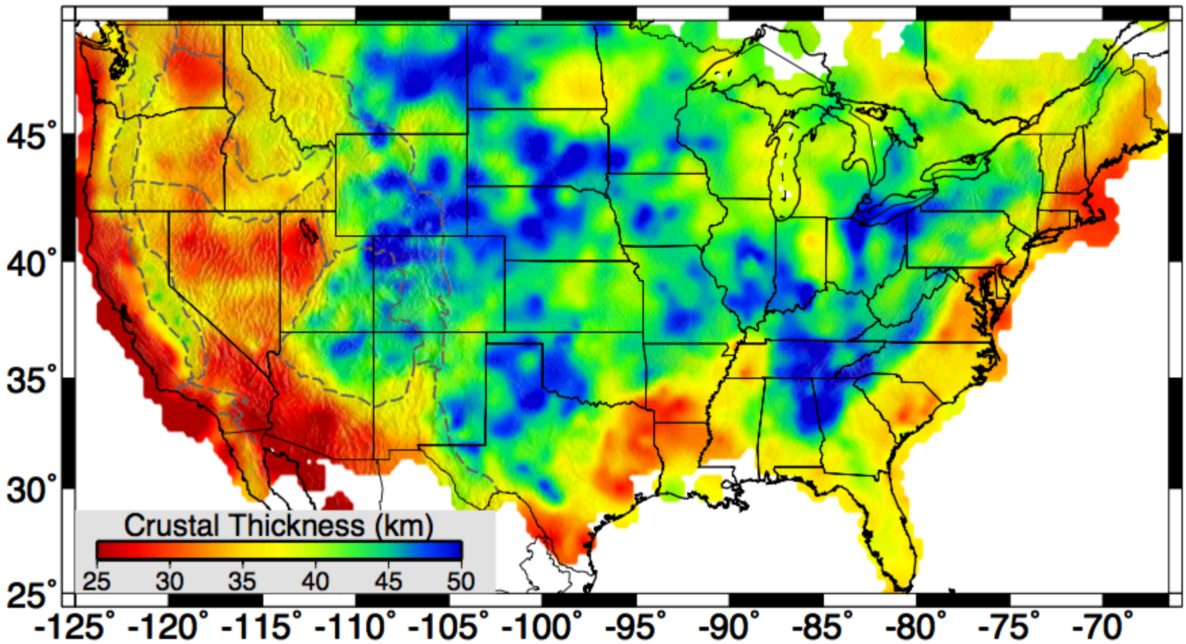
- **Temperature**
- **Mineralogy**
  (pyroxene > olivine > feldspar > quartz)
- **Hydration state**

Flow Strength...



depends mostly on:

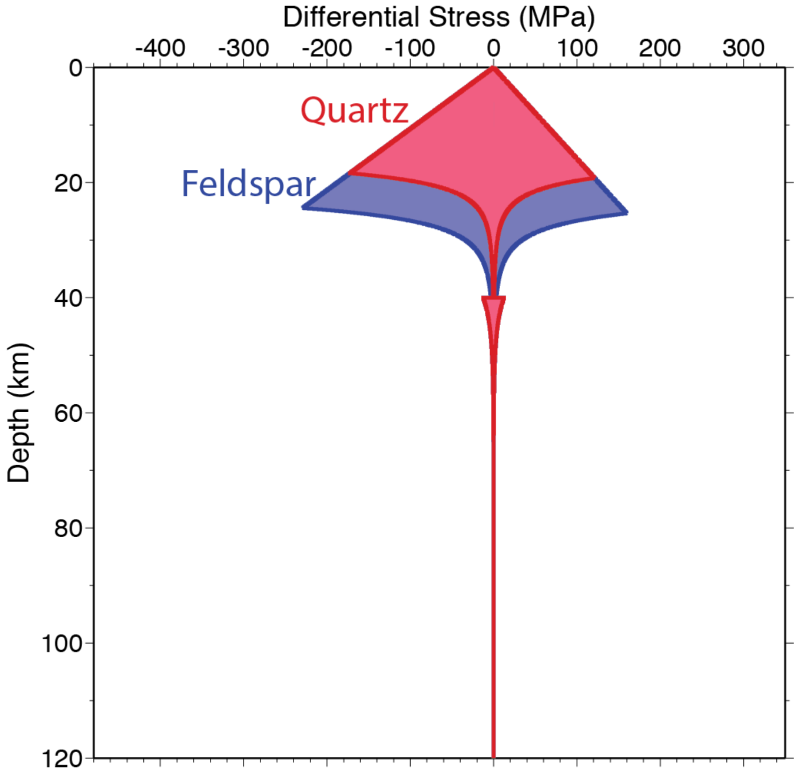
- **Mineralogy** (crust thickness) ✔
- **Temperature**
- **Hydration**

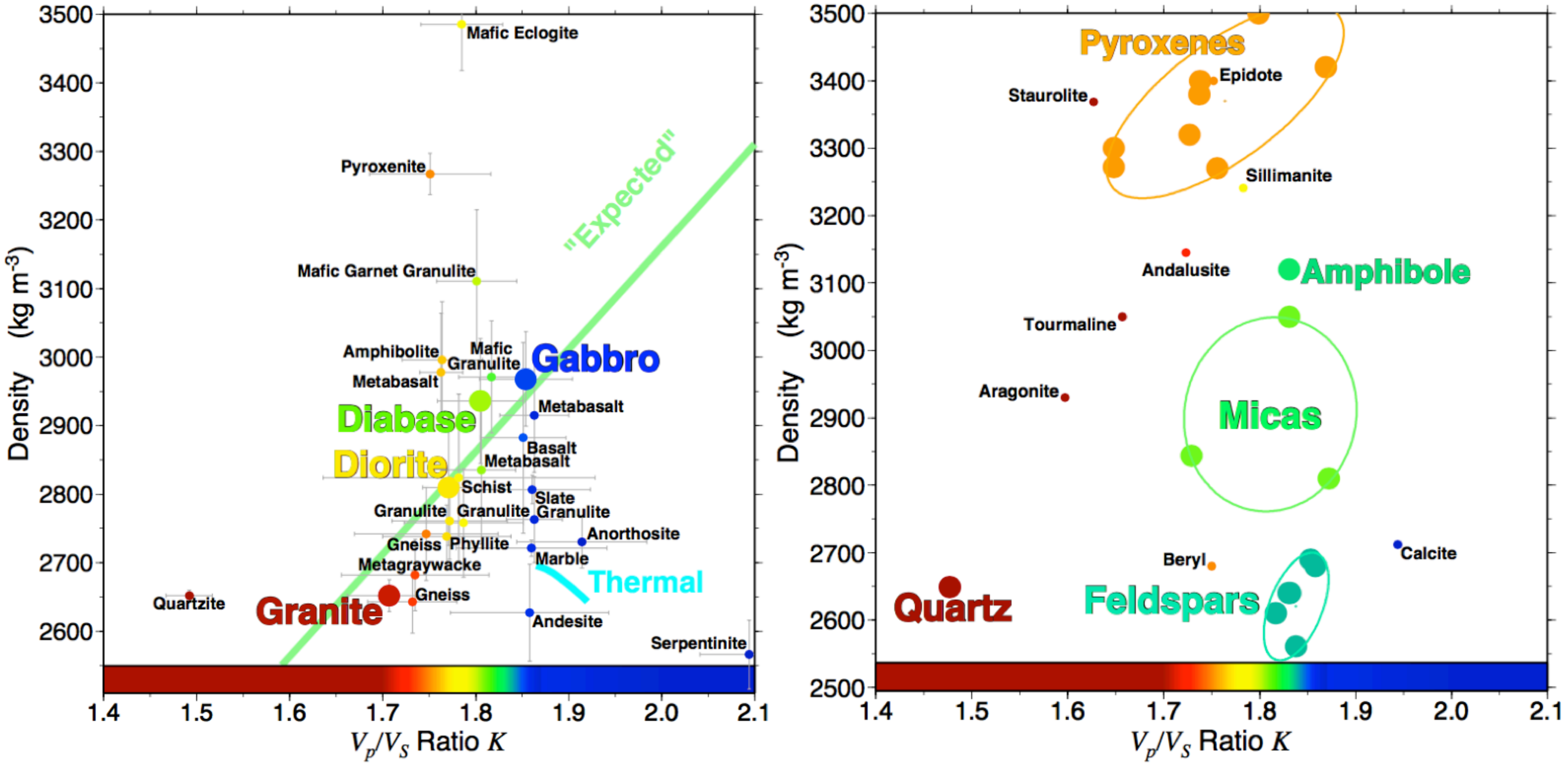


Flow Strength...

depends mostly on:

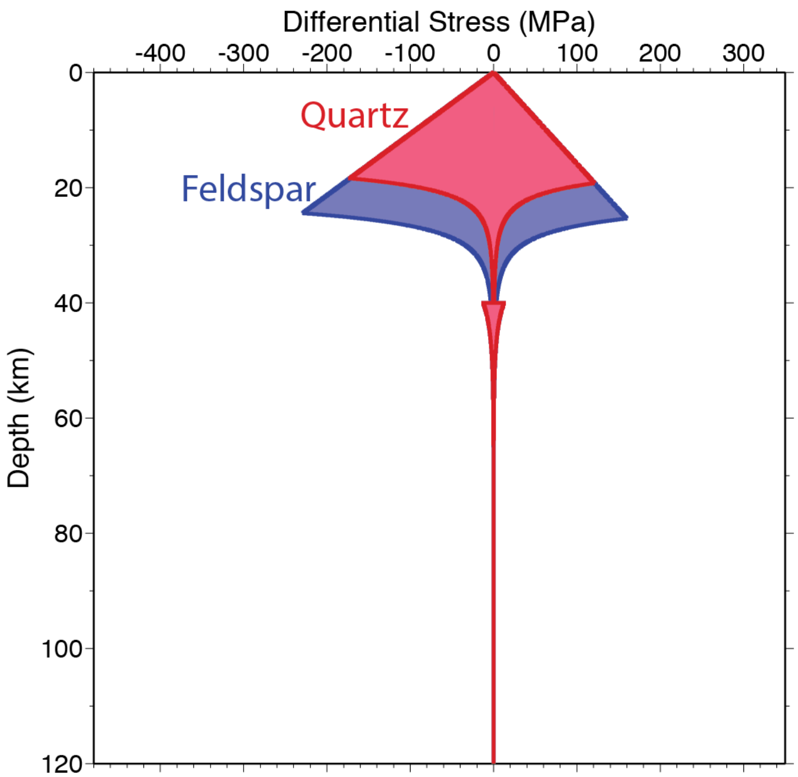
- **Mineralogy** (Qtz or Fsp?)
- **Temperature**
- **Hydration**





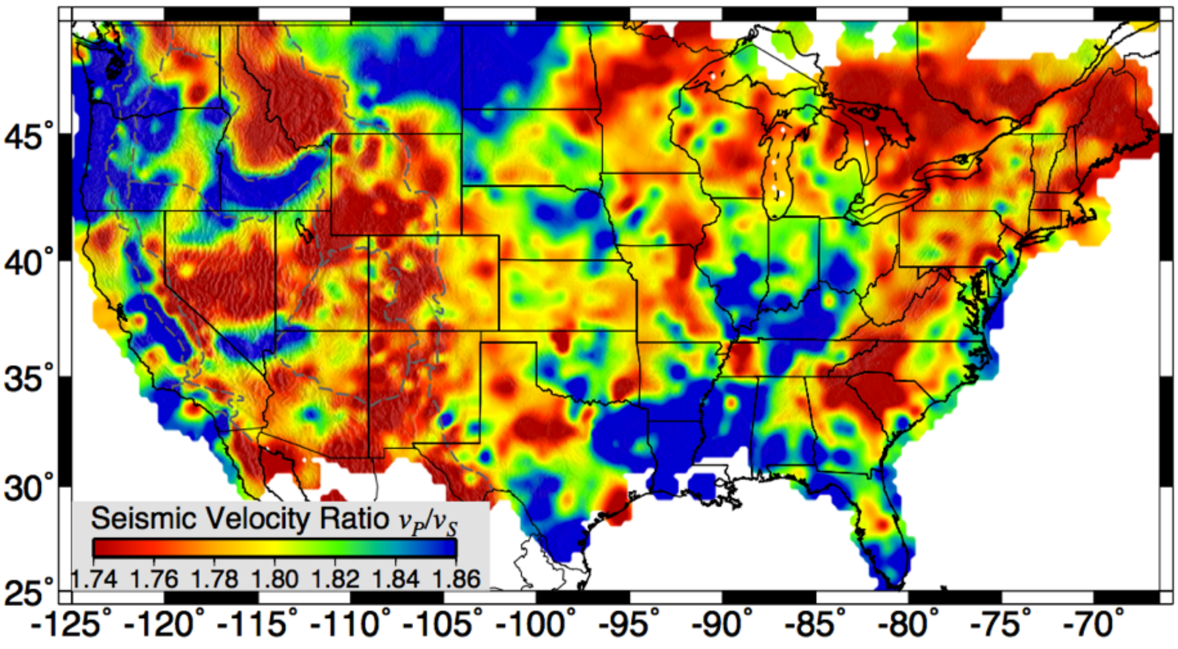
Density (kg m-3)
Vp/VS Ratio K
Mafic Eclogite
Pyroxenite
"Expected"
Mafic Garnet Granulite
Amphibolite
Mafic Granulite
Gabbro
Metabasalt
Diabase
Diorite
Basalt
Schist
Slate
Granulite
Anorthosite
Gneiss
Phyllite
Metagraywacke
Marble
Thermal
Quartzite
Granite
Andesite
Serpentinite
Pyroxenes
Epidote
Staurolite
Sillimanite
Andalusite
Amphibole
Tourmaline
Aragonite
Micas
Beryl
Calcite
Quartz
Feldspars

Flow Strength...



depends mostly on:

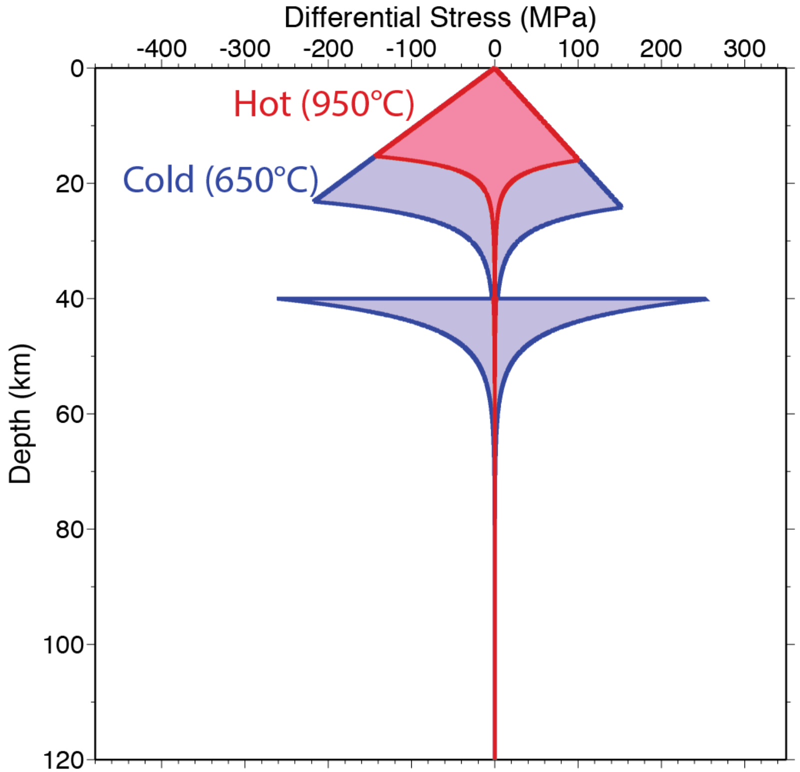
- **Mineralogy** (Qtz or Fsp?)
- **Temperature**
- **Hydration**

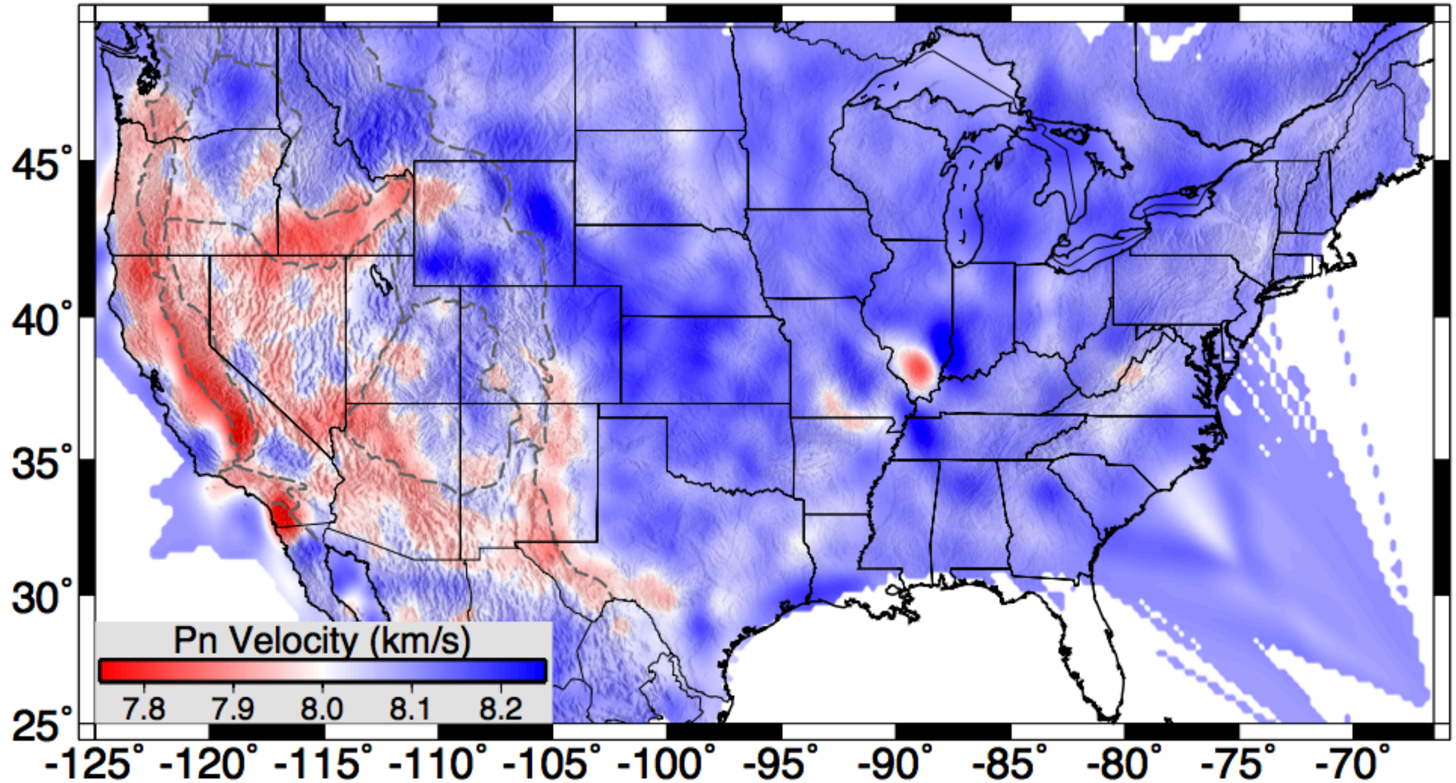


Flow Strength...

depends mostly on:

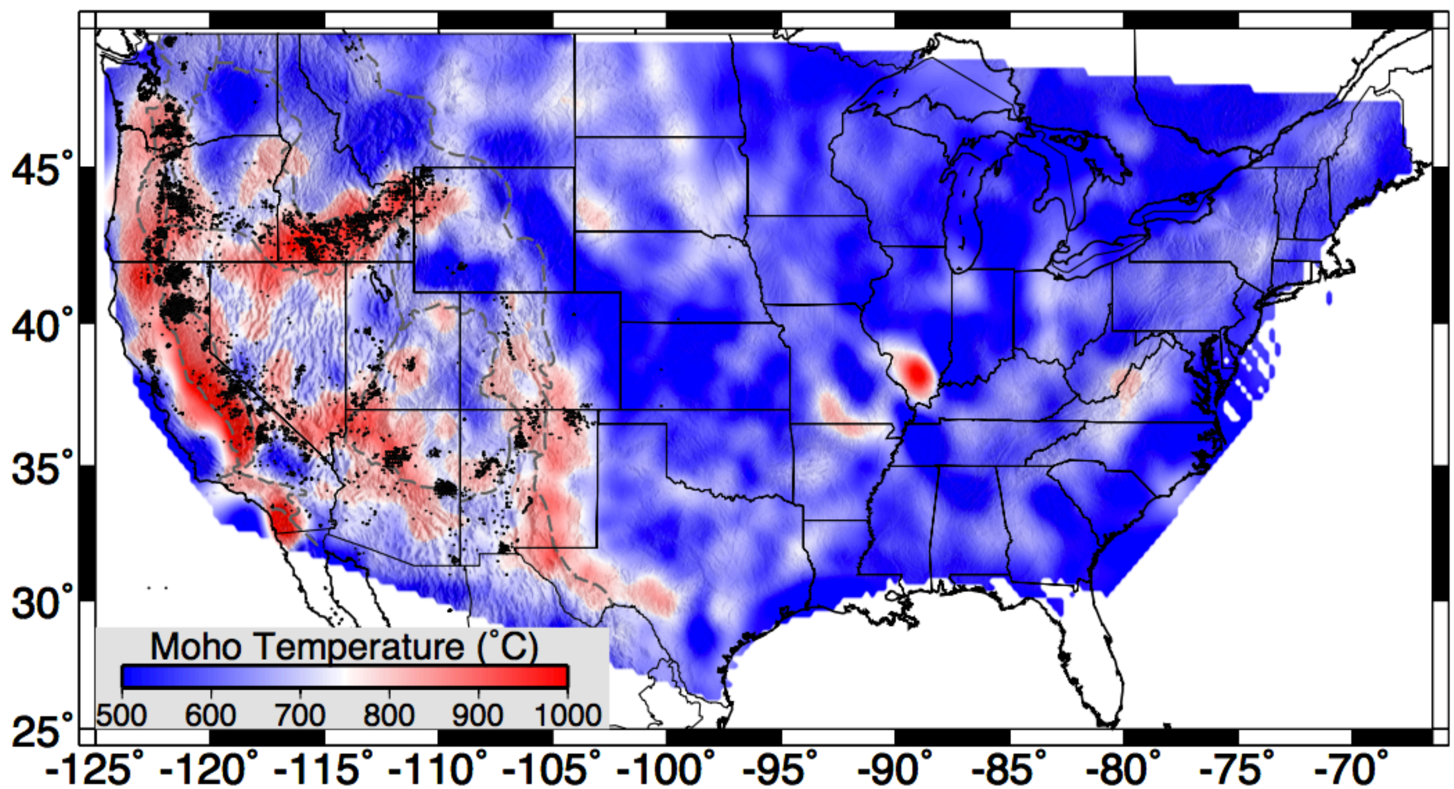
- **Mineralogy**
- **Temperature**
- **Hydration**





Pn (refracted Moho phase) tomography

Buehler & Shearer, *J. Geophys. Res.* (2017)



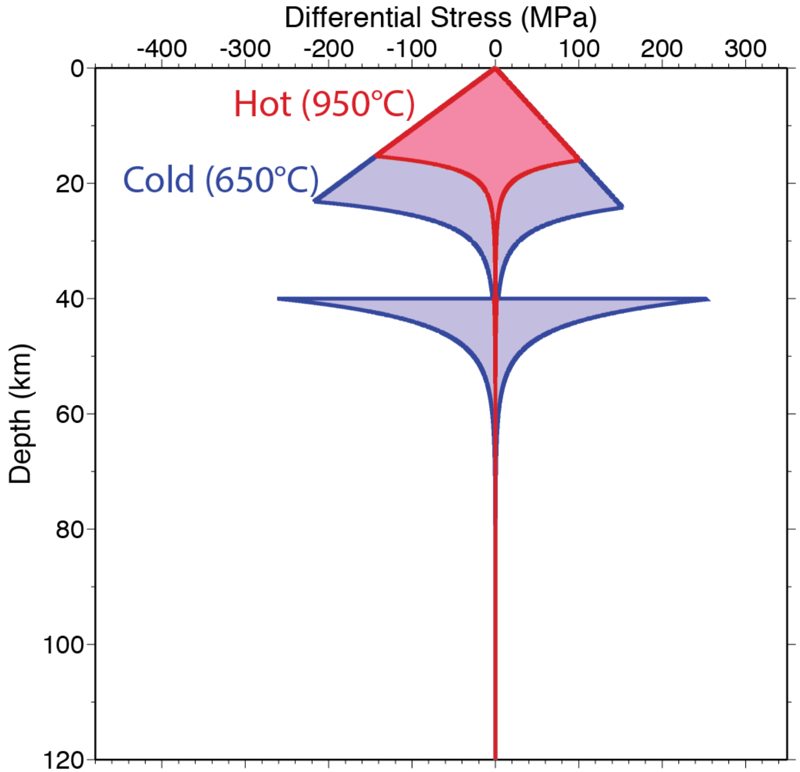
Moho temperature (from Pn & mineral physics)

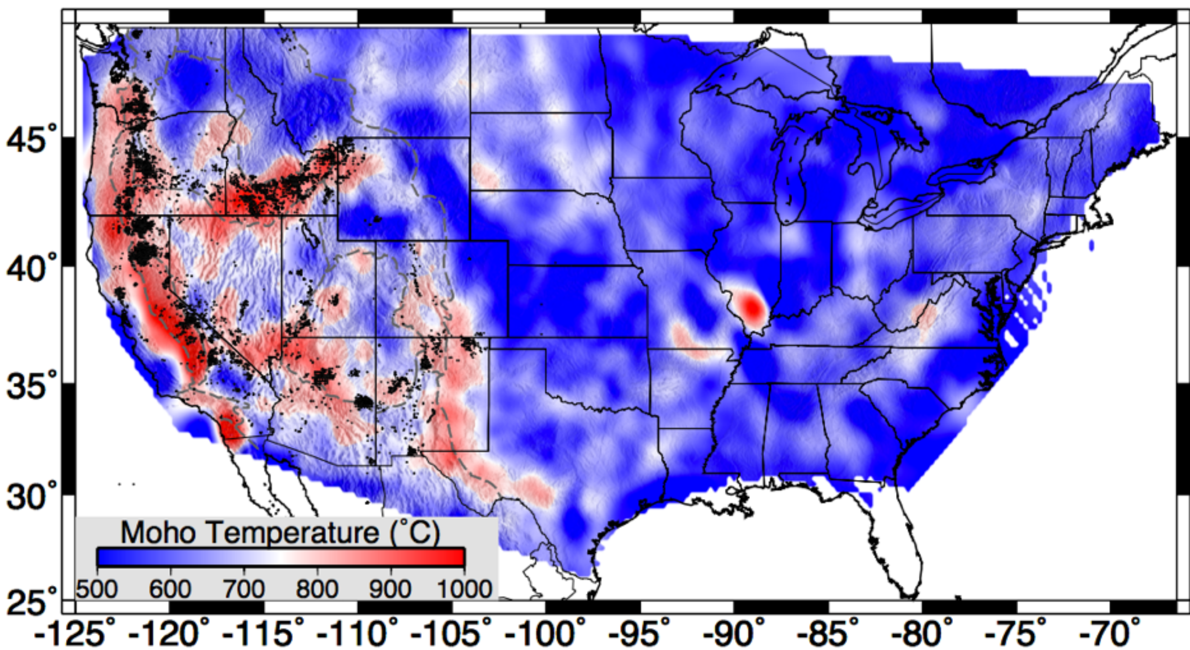
Schutt et al., *Geology* (revised, 2017)

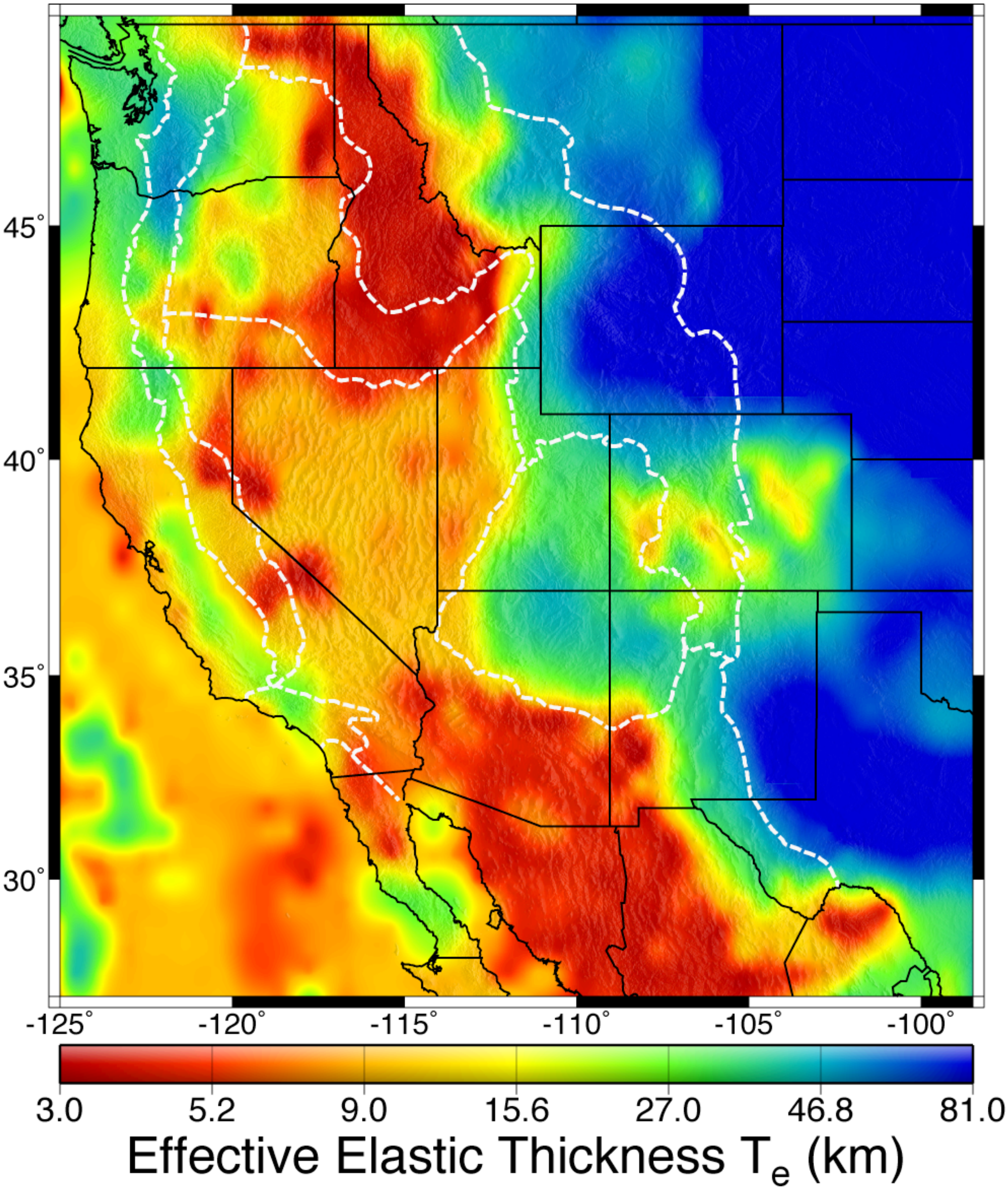
Flow Strength...

depends mostly on:

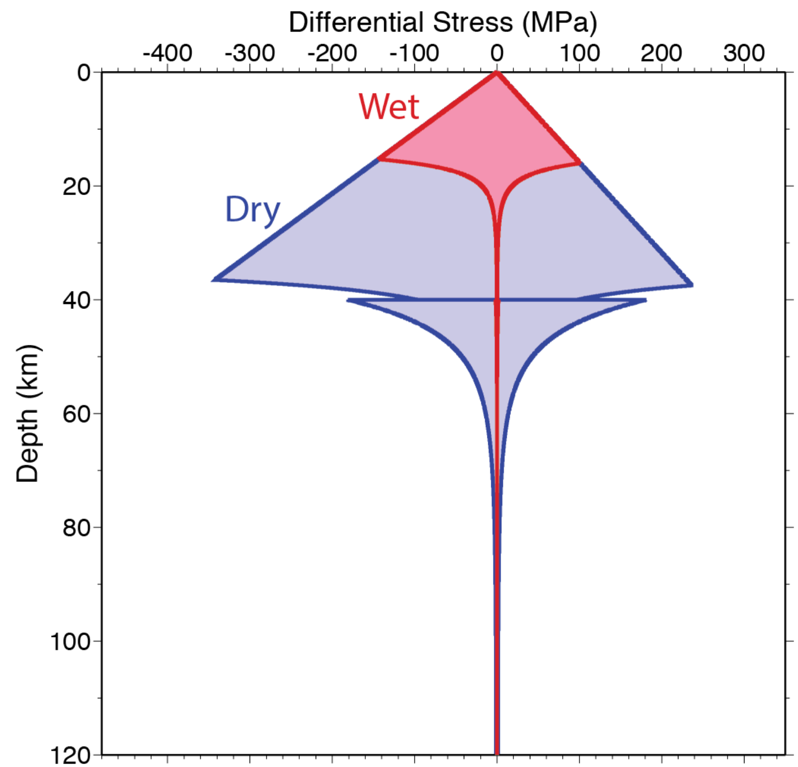
- **Mineralogy** ✓
- **Temperature** ✓
- **Hydration**





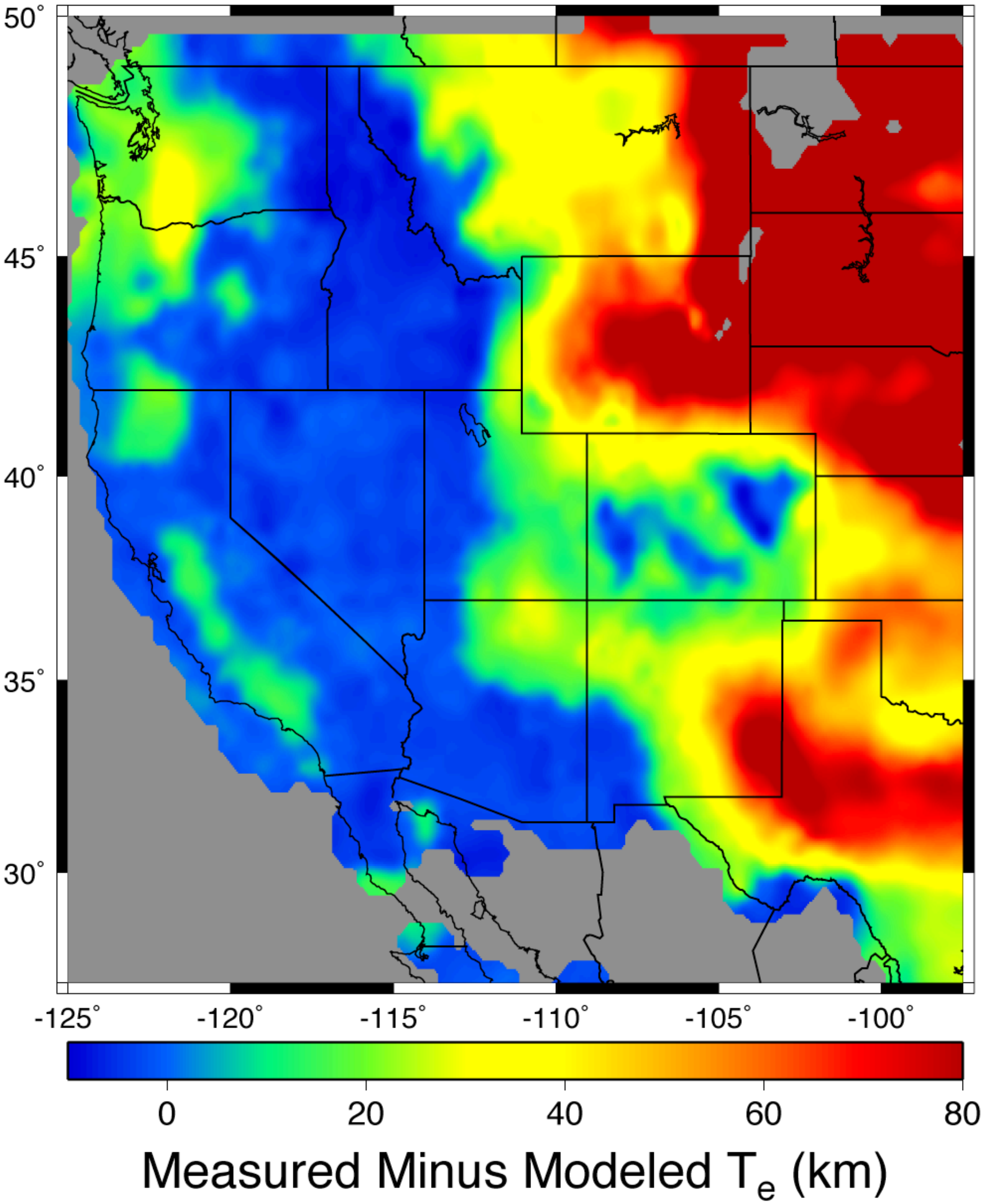


45°
40°
35°
30°
-125°
-120°
-115°
-110°
-105°
-100°
3.0
5.2
9.0
15.6
27.0
46.8
81.0
Effective Elastic Thickness T_e (km)

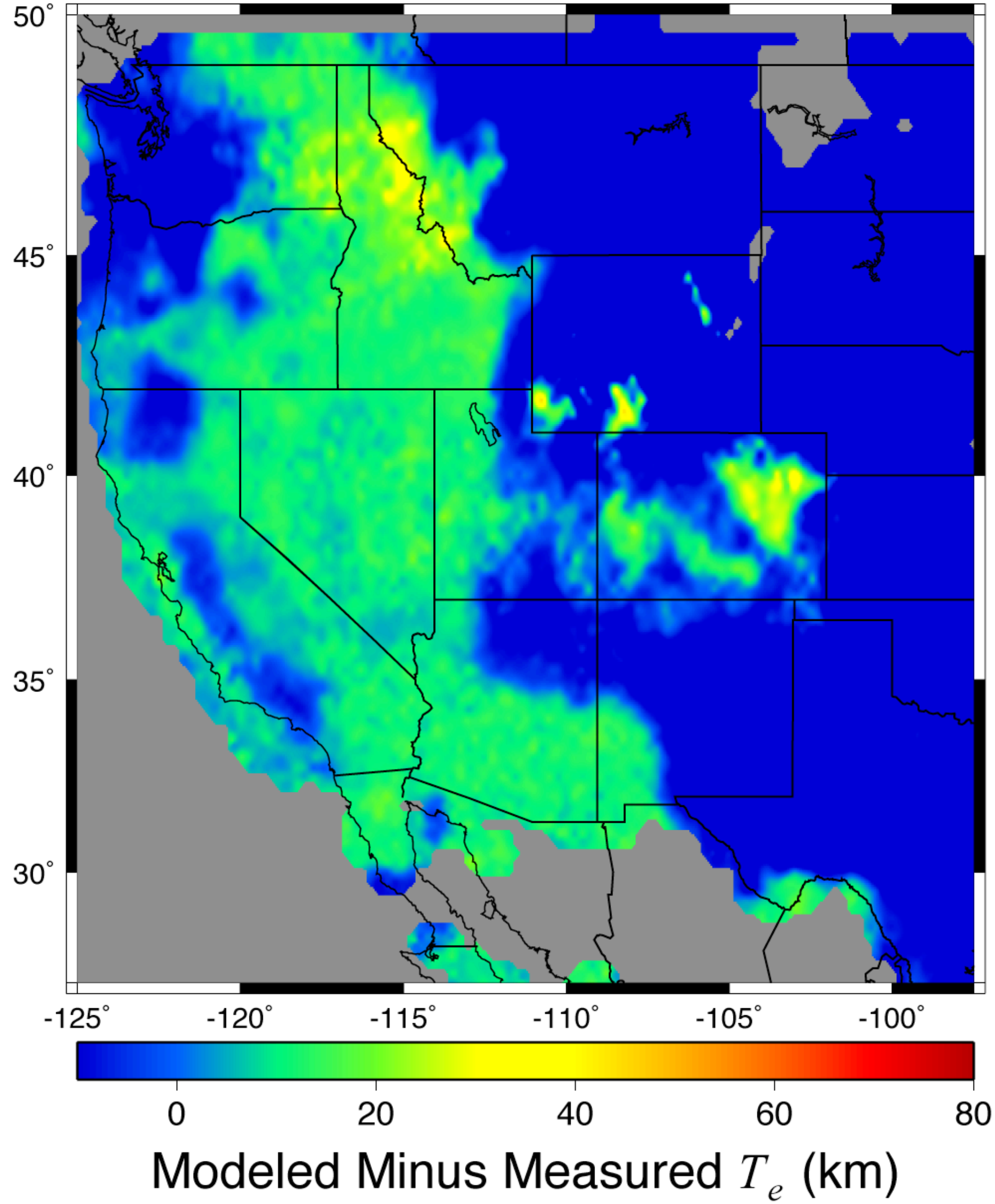


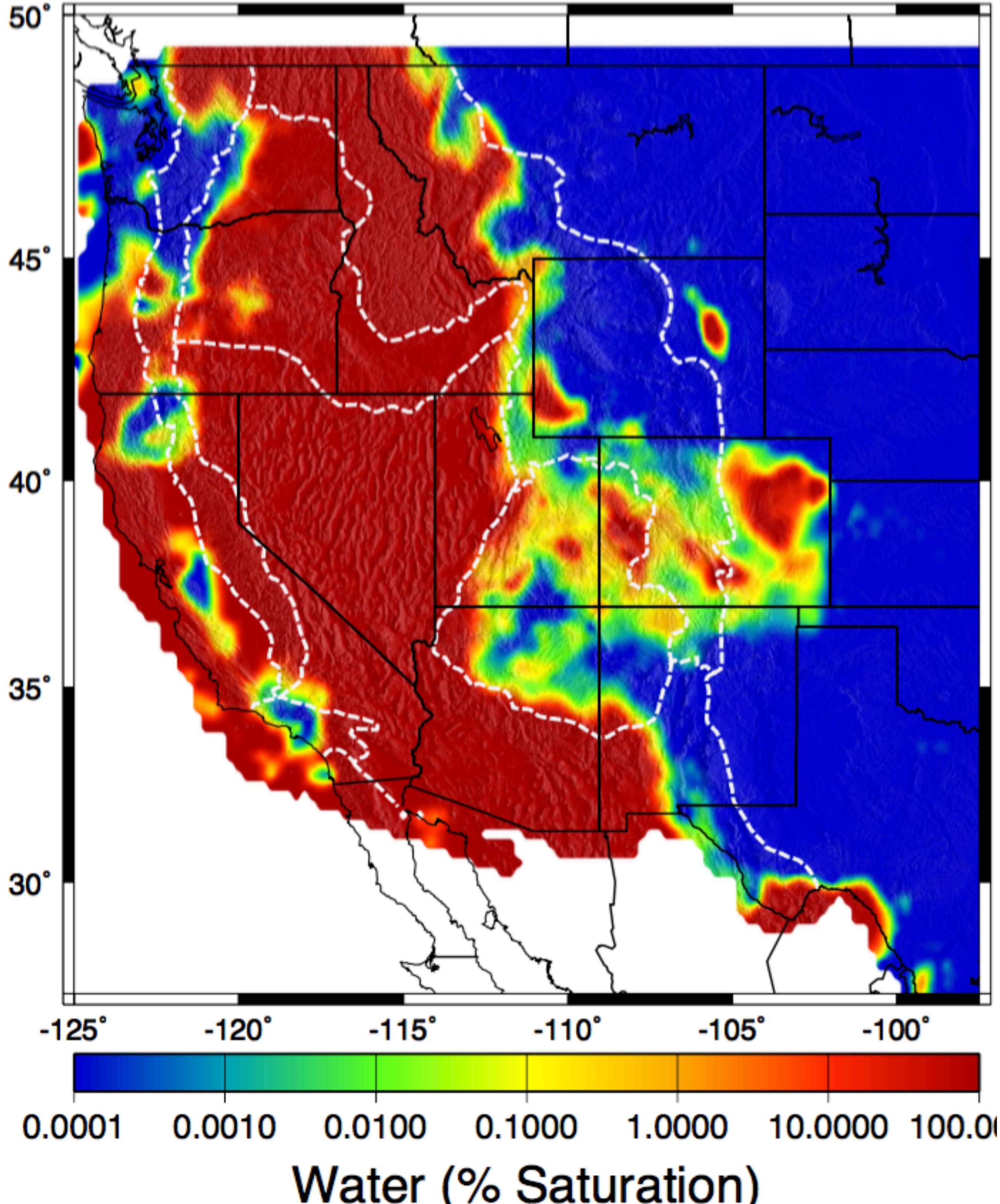
Differential Stress (MPa)
-400
-300
-200
-100
0
100
200
300
Depth (km)
0
20
40
60
80
100
120
Wet
Dry

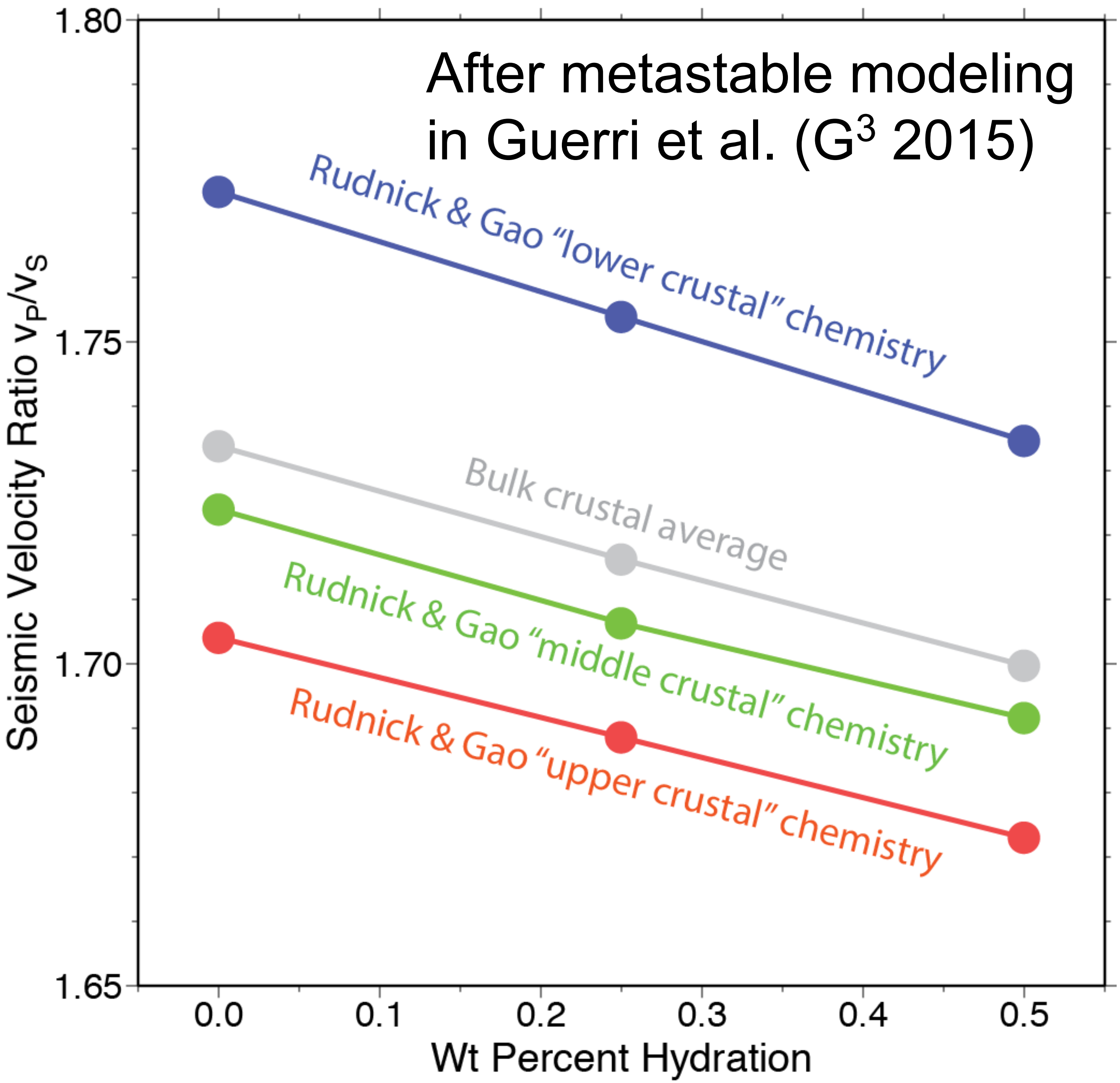
Wet (saturated) end-member



Dry end-member

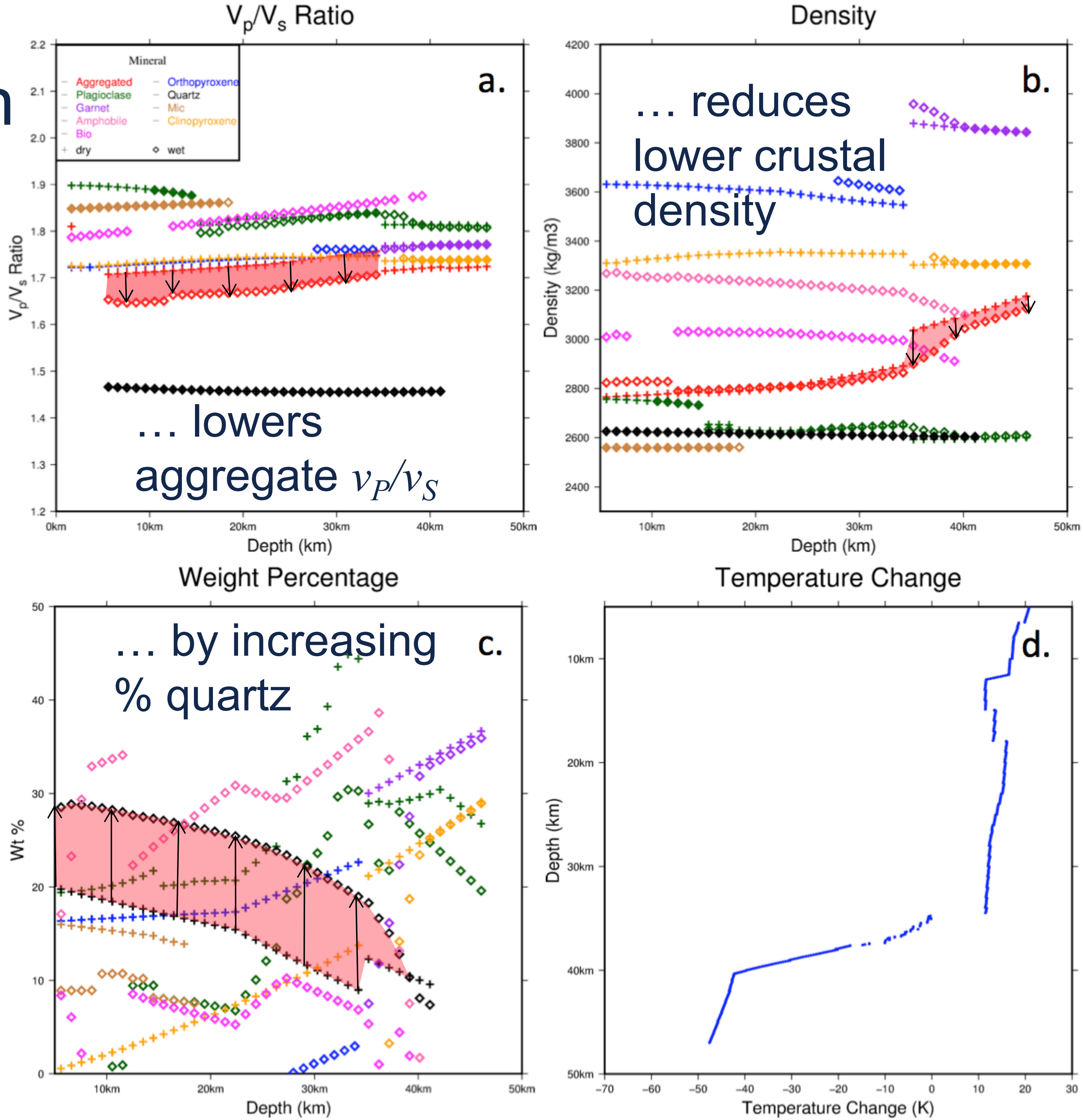



50°
45°
40°
35°
30°
-125°
-120°
-115°
-110°
-105°
-100°
0.0001
0.0010
0.0100
0.1000
1.0000
10.0000
100.0
Water (% Saturation)

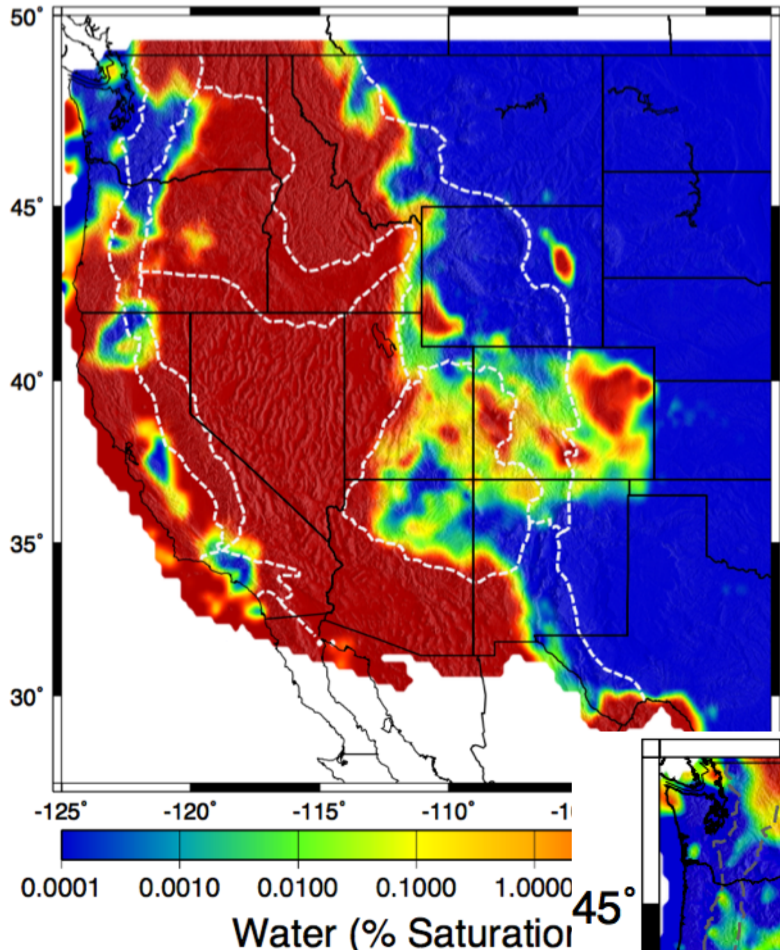


Thermodynamical modeling of P-T-H_2O dependent mineralogy…

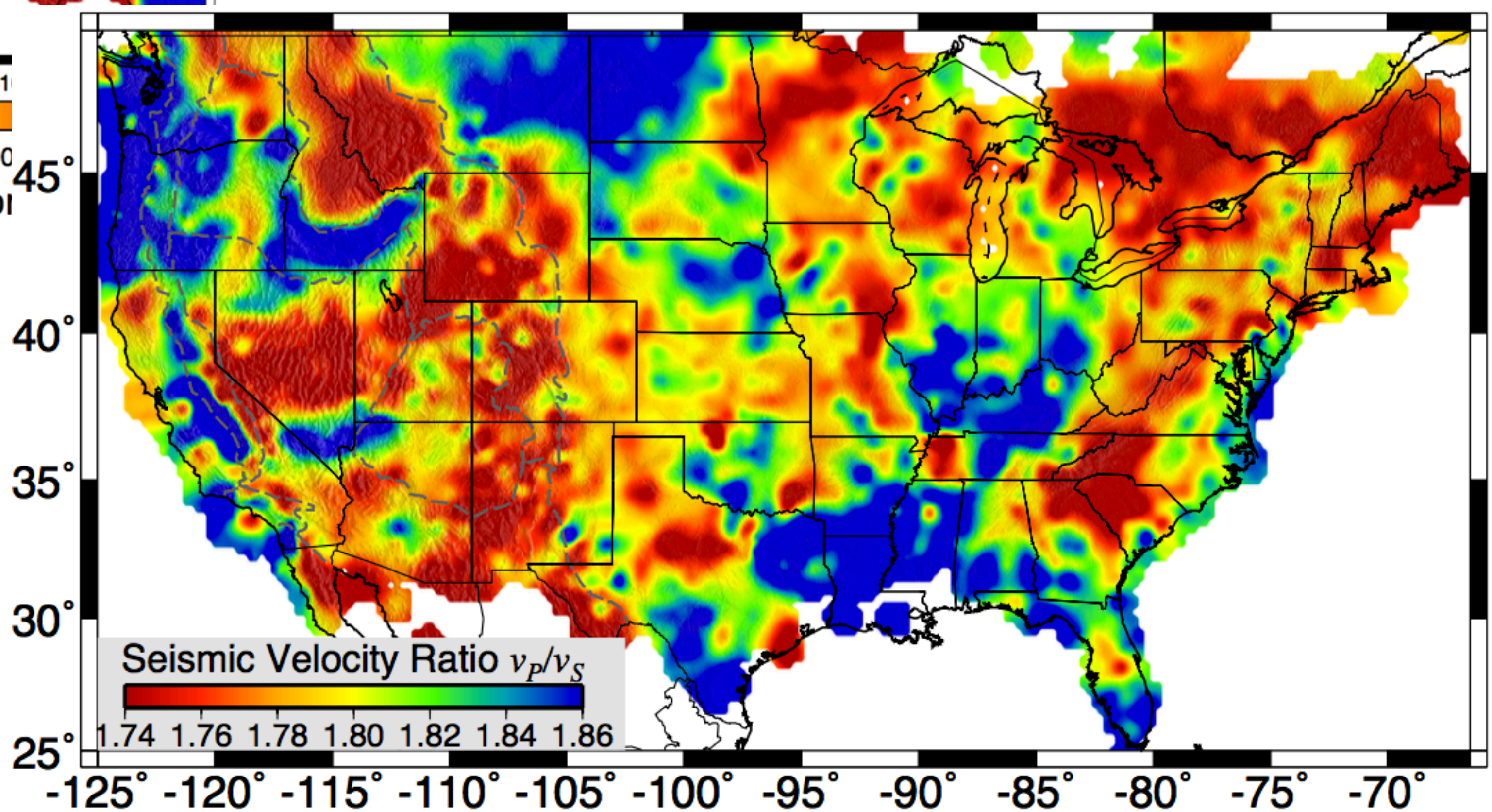
Hydration (1 wt-%)



Ma & Lowry, *Tectonics* (submitted 2017)



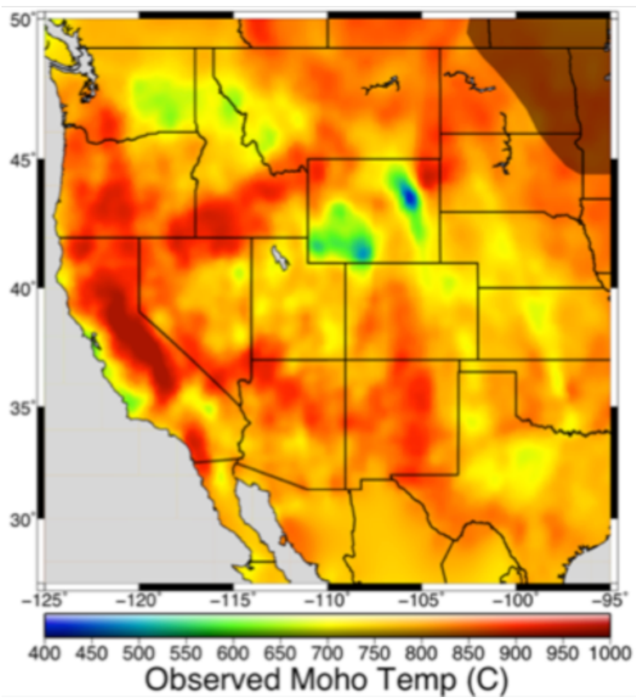
50°
45°
40°
35°
30°
-125°
-120°
-115°
-110°
0.0001
0.0010
0.0100
0.1000
1.0000
Water (% Saturatio



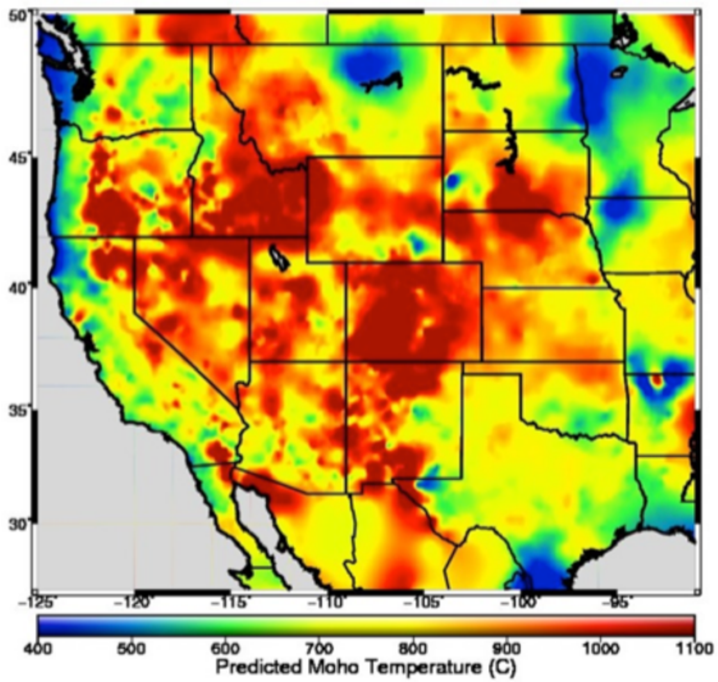
Seismic Velocity Ratio v_P/v_S
1.74 1.76 1.78 1.80 1.82 1.84 1.86
45°
40°
35°
30°
25°
-125° -120° -115° -110° -105° -100° -95° -90° -85° -80° -75° -70°

Moho Temperature

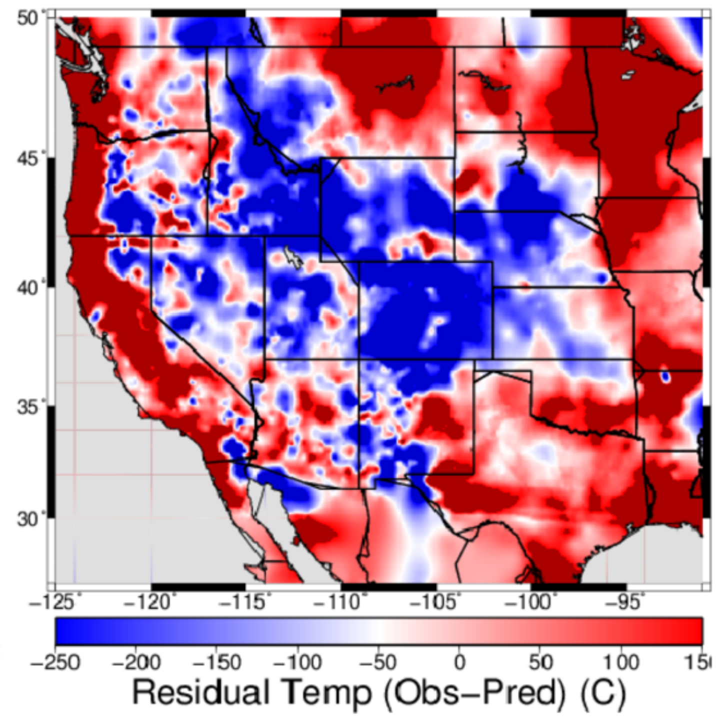
Measured (Pn)



Modeled (Qs)

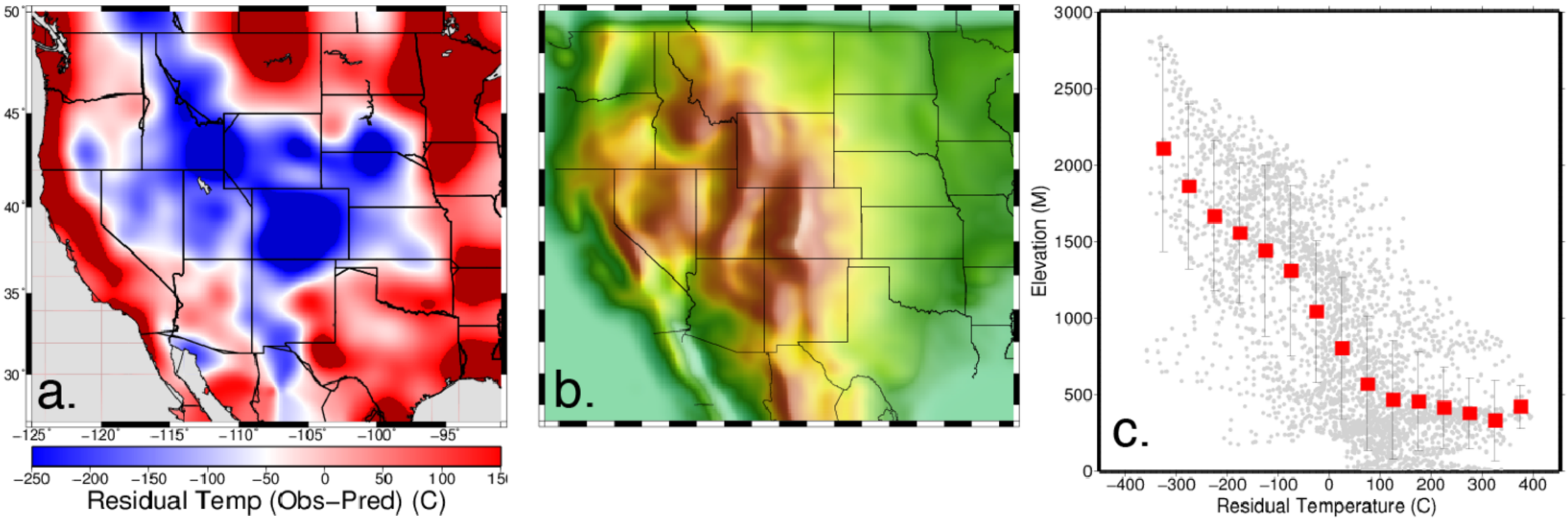


Obs Minus Mod



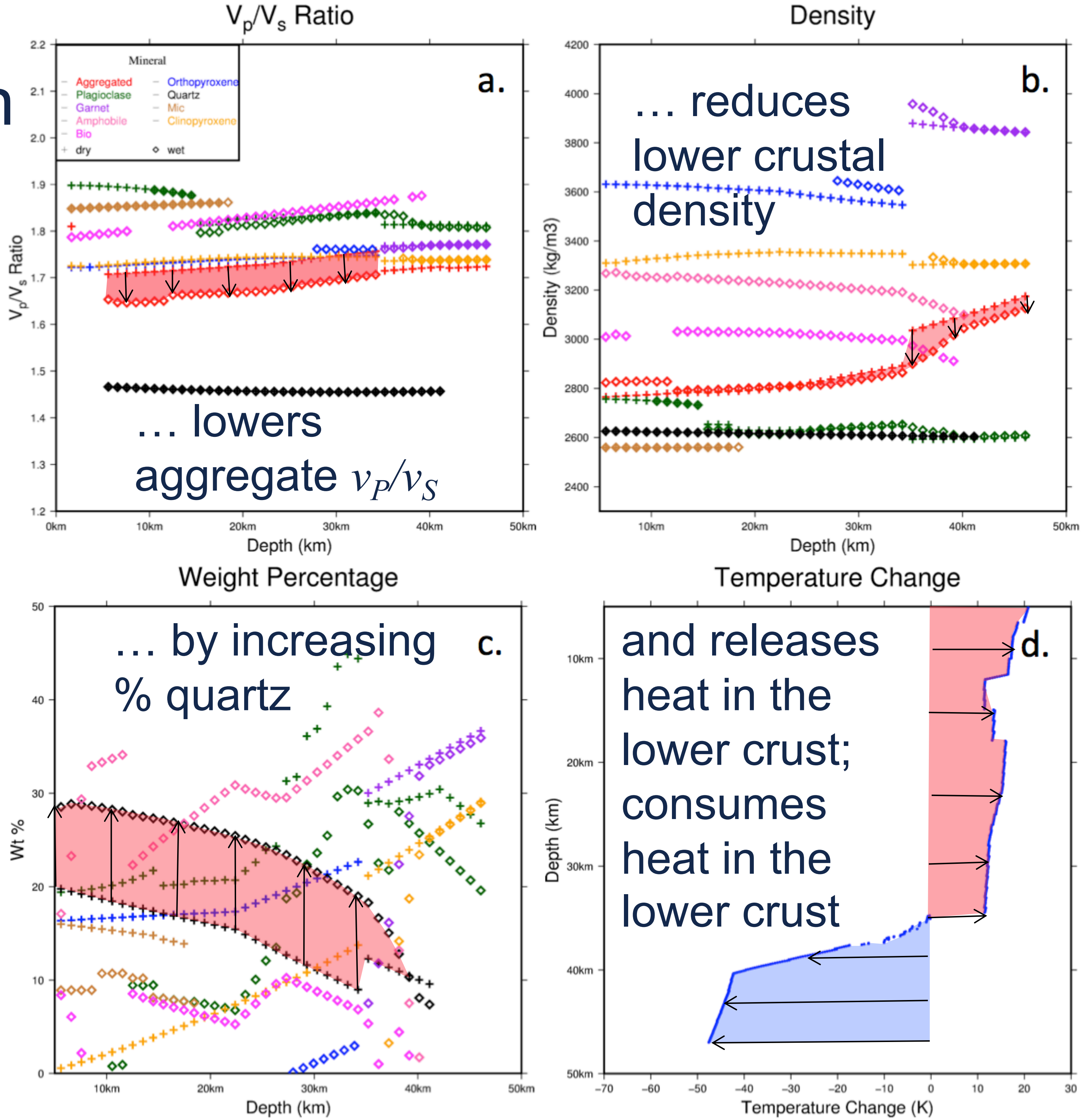
Berry et al. AGU Fall Mtg 2015

“Cold Moho” anomaly = high elevation? R = –0.71…



Berry et al. AGU Fall Mtg 2015

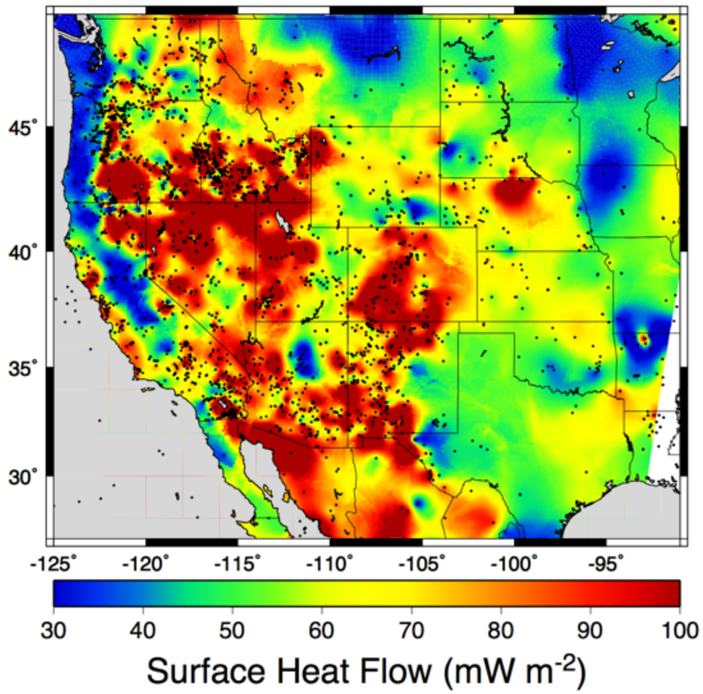
Hydration (1 wt-%)



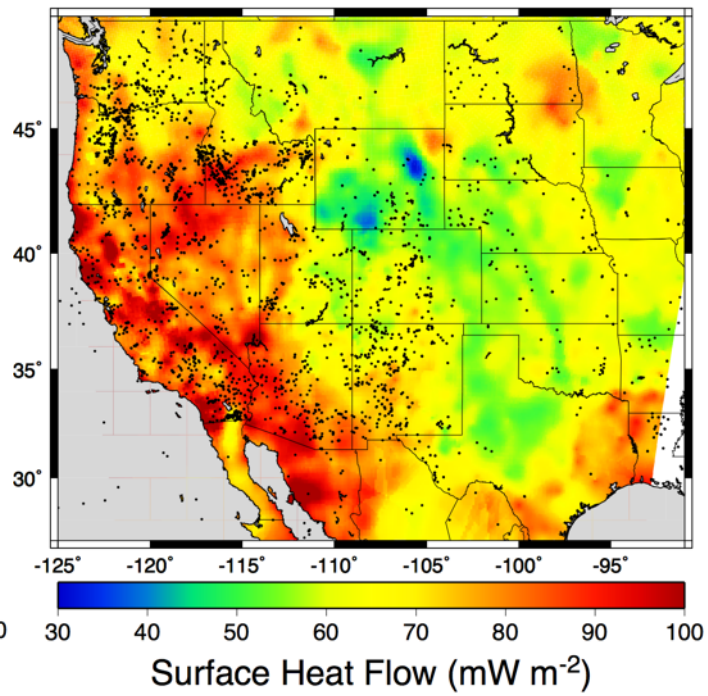
Ma & Lowry, *Tectonics* (submitted 2017)

Surface heat flow

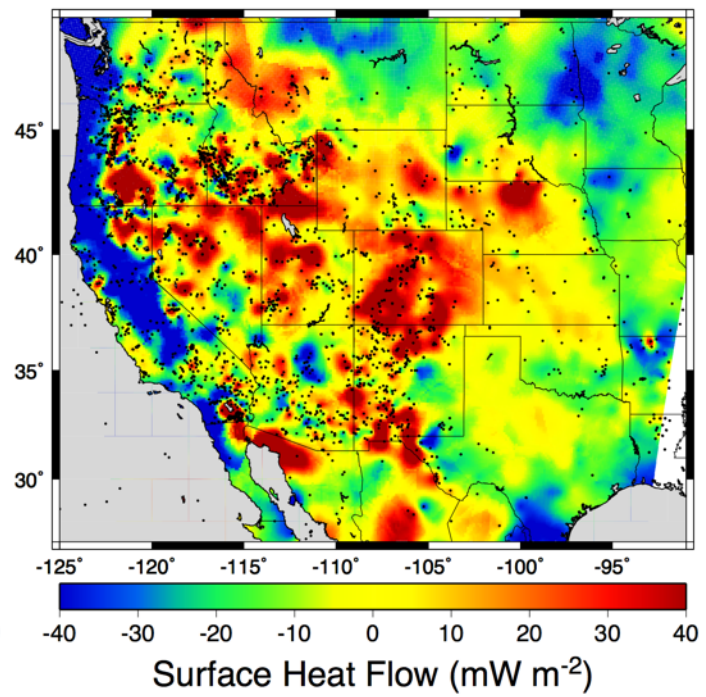
Measured (borehole temps)

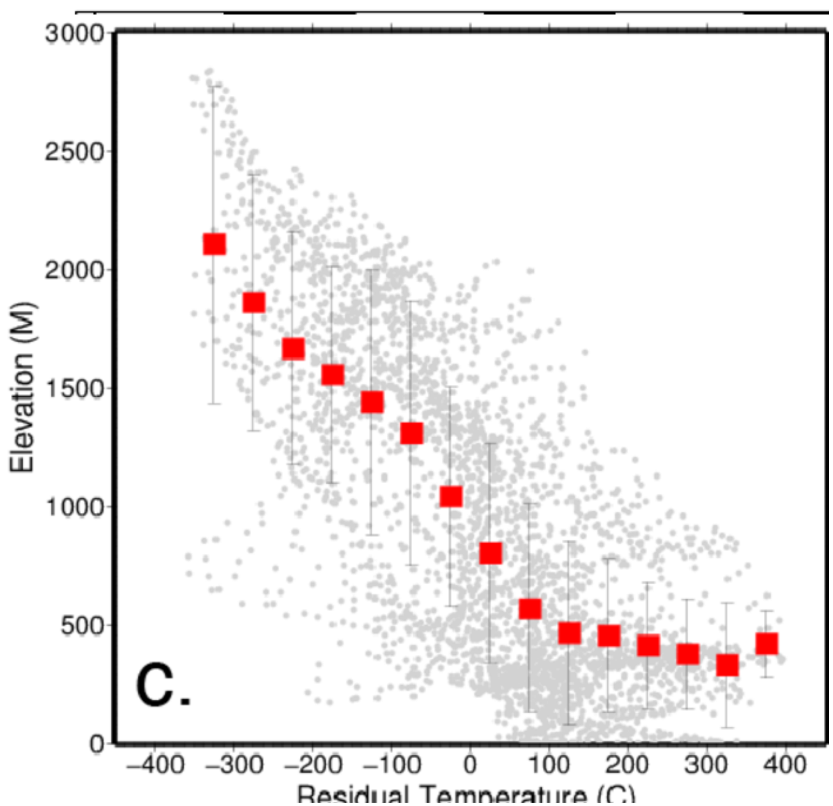


Modeled from Pn Moho temperature



Measured minus modeled





Conclusions:

- Hydration of the upper mantle dominates rheological strength
- Hydration of the crust is recorded in bulk v_P/v_S
- Differences in geotherms predicted from heat flow and Moho temperature suggest volatile flux dynamics
- Hydration may contribute to buoyancy of the lithosphere