



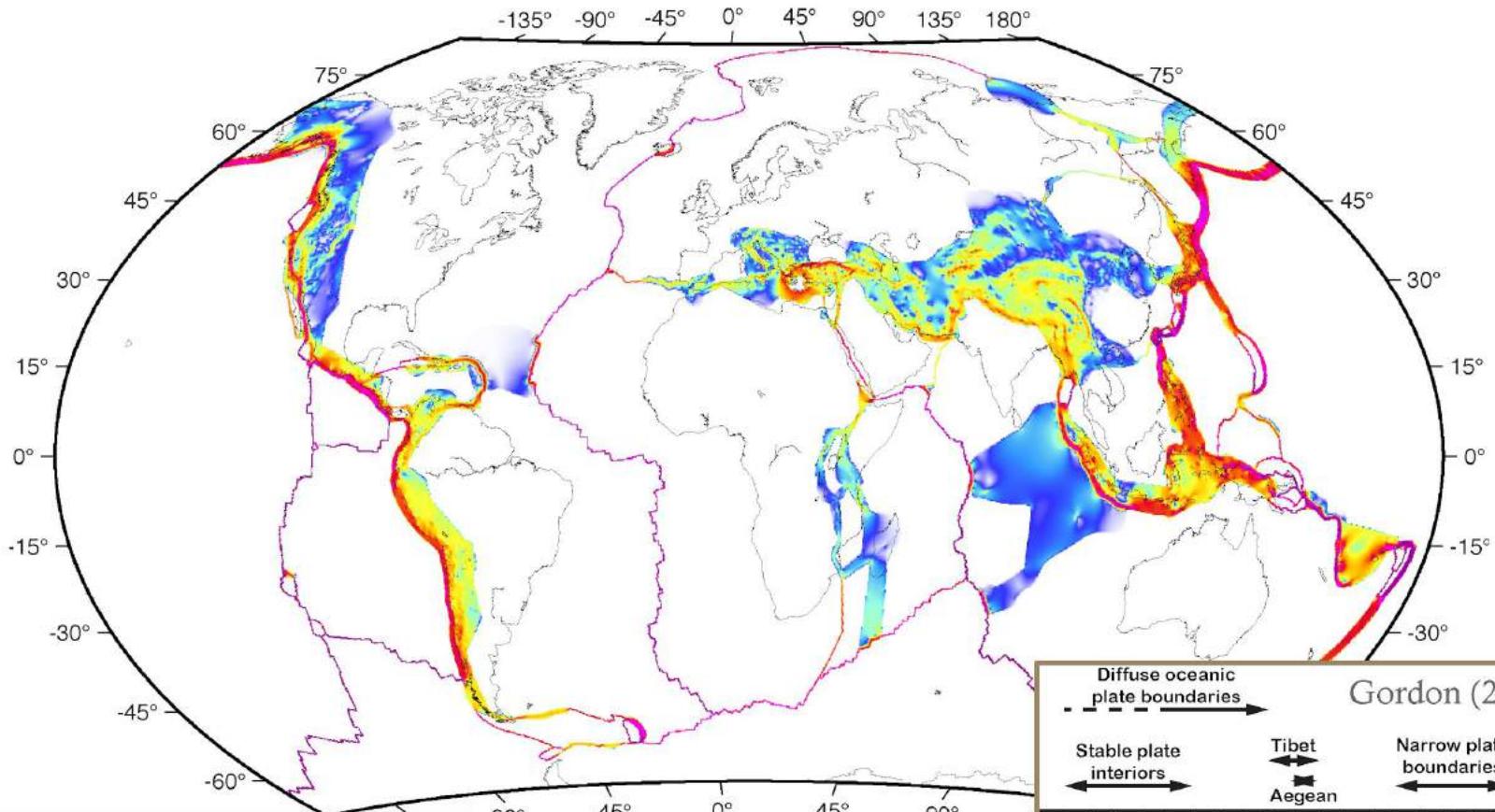
# Rheology of Southern California from Mineral to Regional Scale

Laurent G.J. Montési<sup>1</sup>

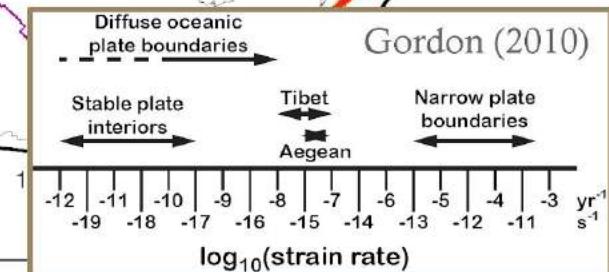
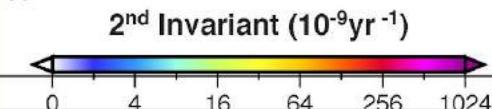
Kristel Izquierdo<sup>1</sup>, Kali L. Allison<sup>1</sup>, William E. Holt<sup>2</sup>, Alireza Bahadori<sup>2</sup>, Greg Hirth<sup>3</sup>, William Shinevar<sup>4</sup>, & Michael E. Oskin<sup>5</sup>

<sup>1</sup>University of Maryland <sup>2</sup>Stony Brook University <sup>3</sup>Brown University

<sup>4</sup>Massachusetts Institute of Technology <sup>5</sup>University of California Davis

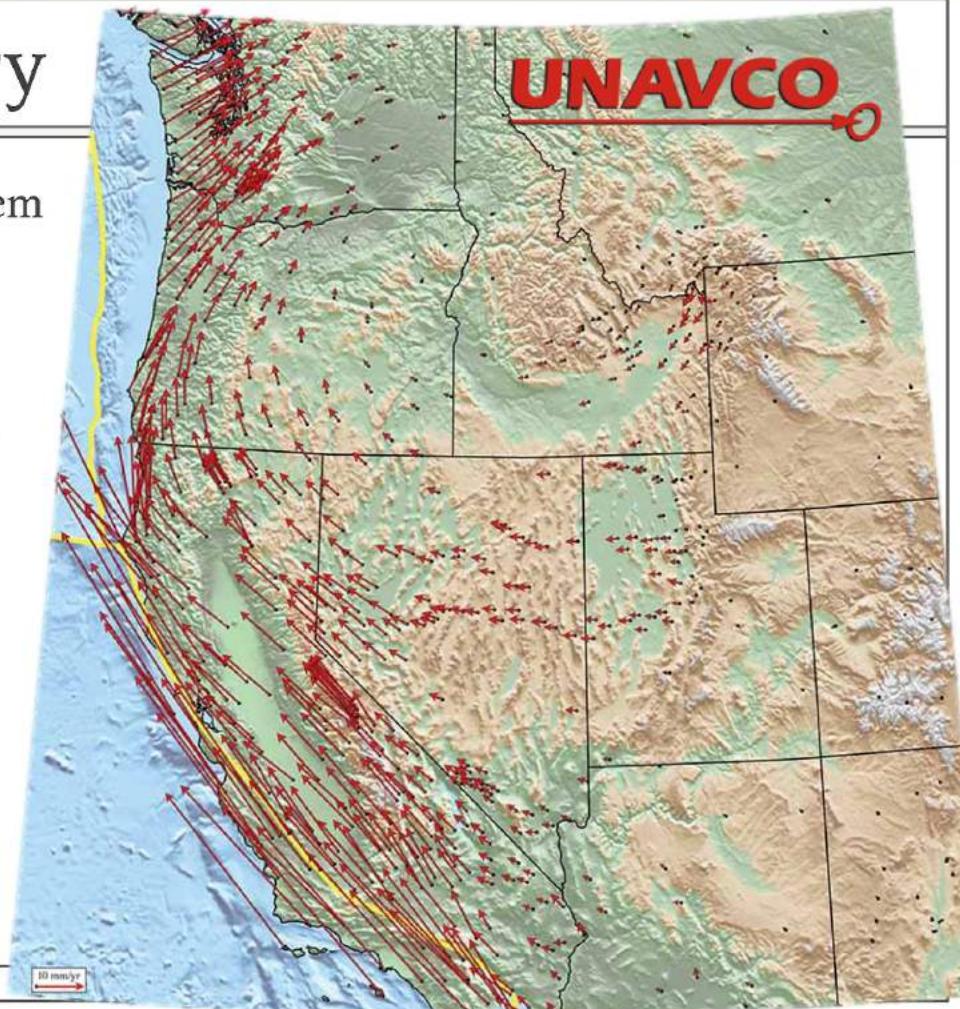
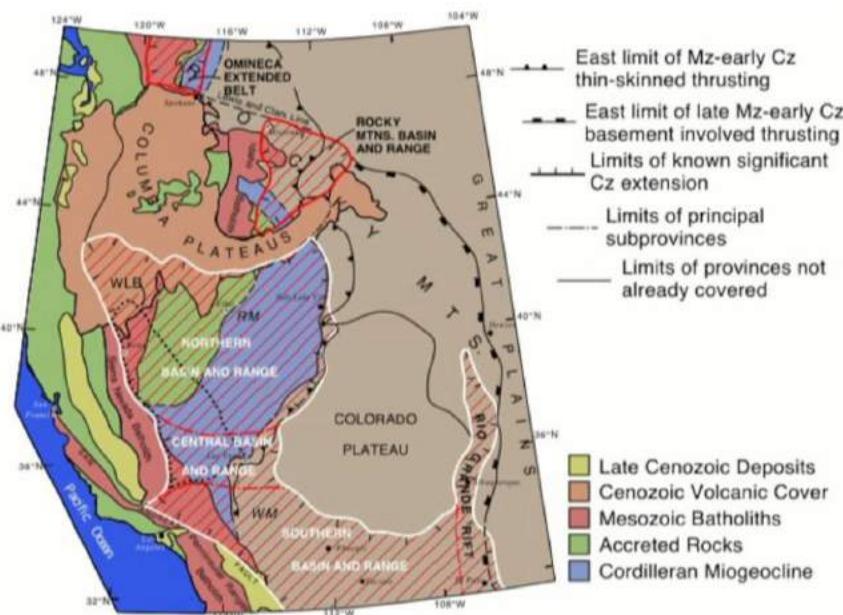


Global Strain Rate map  
Kreemer et al. (2014)

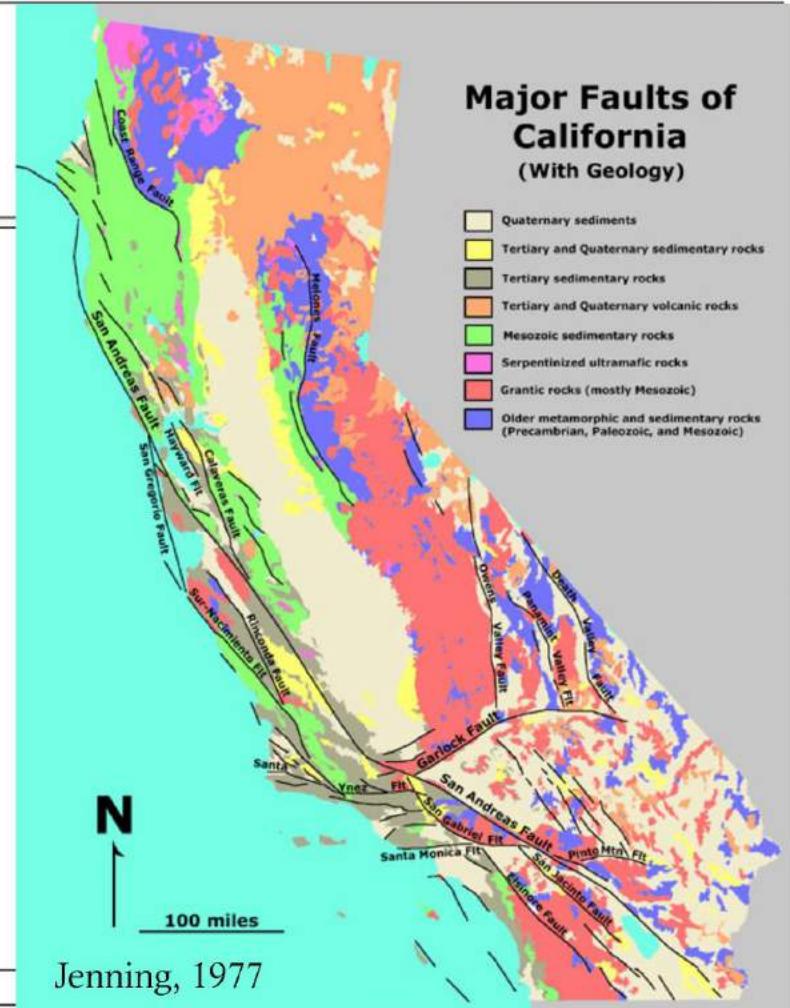
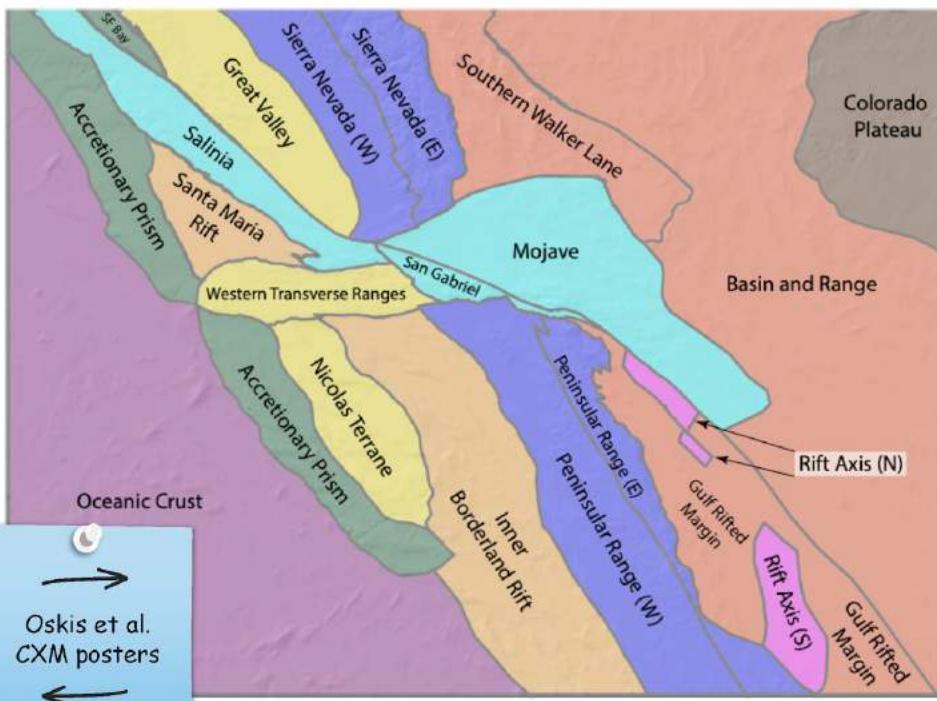


# Western US Boundary

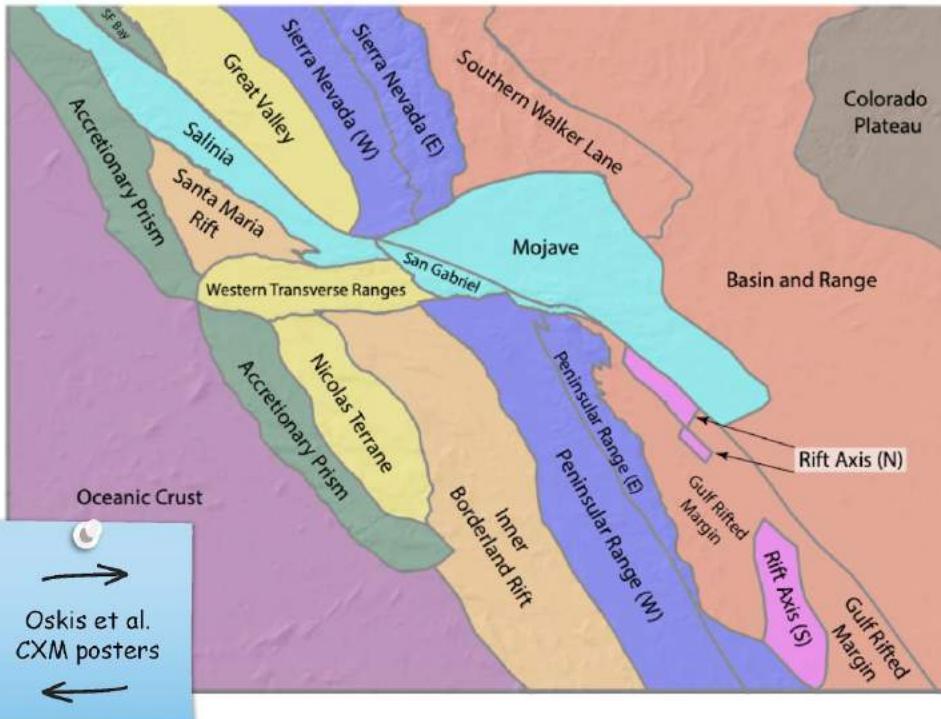
- Shear localized on San Andreas fault system
- Diverse litho-tectonic blocks



# Zooming in to Southern California



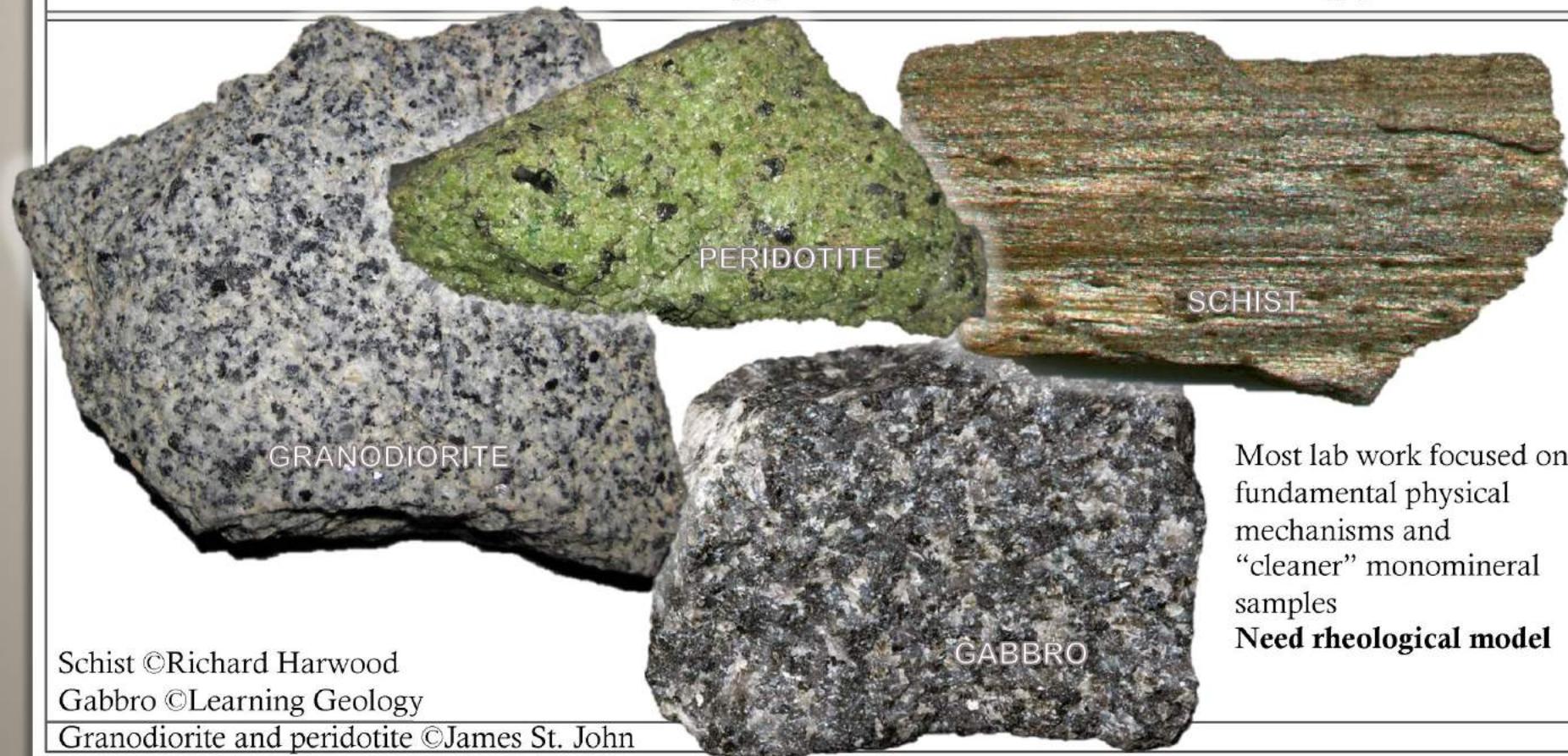
# Zooming in to Southern California



- Community Rheology Model (CRM)
  - Led by Liz Hearn
  - Community Thermal Model (Wayne Thatcher)
  - Geological Framework (Mike Oskin)
  - Rheology (Greg Hirth)

Jenning, 1977

# How does lithology influence rheology?



Most lab work focused on fundamental physical mechanisms and “cleaner” monomineral samples

**Need rheological model**

Schist ©Richard Harwood

Gabbro ©Learning Geology

Granodiorite and peridotite ©James St. John

# What is a rheology?

- Relation between stress and deformation
  - $\sigma = f(\varepsilon, \dot{\varepsilon}, T, P, C, F, g, C_{OH}, \Xi \dots)$
  - Strain  $\varepsilon$
  - Strain rate  $\dot{\varepsilon}$
  - Temperature  $T$
  - Pressure  $P$
  - Composition/mineralogy  $C$
  - Fabric  $F$
  - Grain size  $g$
  - Water content  $C_{OH}$
  - Stress regime
- Can also express apparent viscosity  $\eta = \sigma / 2\dot{\varepsilon}$

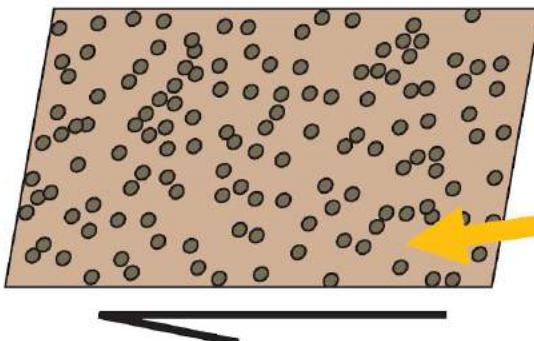


# Making up rheologies

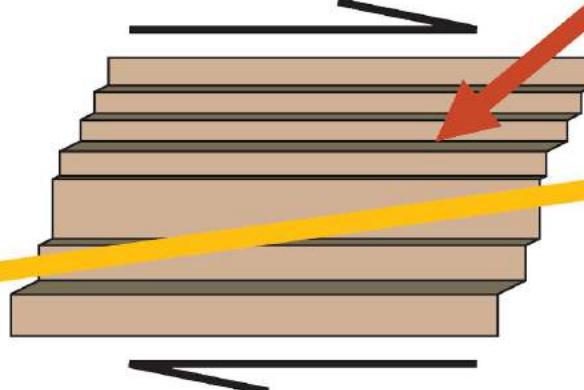
Protolith (uniform strain)



Shear zone (uniform stress)



Strength controlled by strong phase

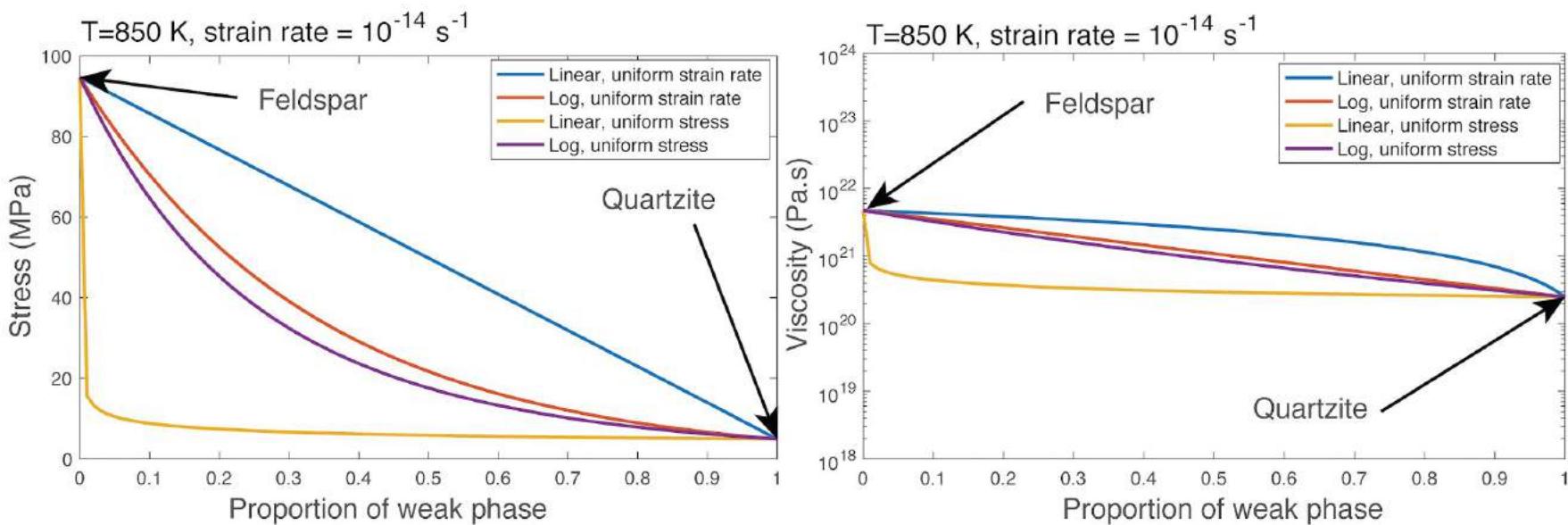


Strength controlled by weak phase

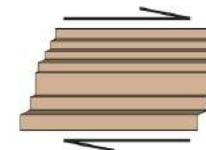
- Linear mixing (Voight/Reuss)
  - $\bar{A} = \sum_i C_i A_i$
  - Uniform strain rate
  - Uniform stress
- Logarithmic mixing (Ji et al., 2001)
  - $\bar{A} = \prod_i A_i^{C_i}$
  - Uniform strain rate
  - Uniform stress
- Minimize power
  - Huet et al., 2014

Montesi, 2013

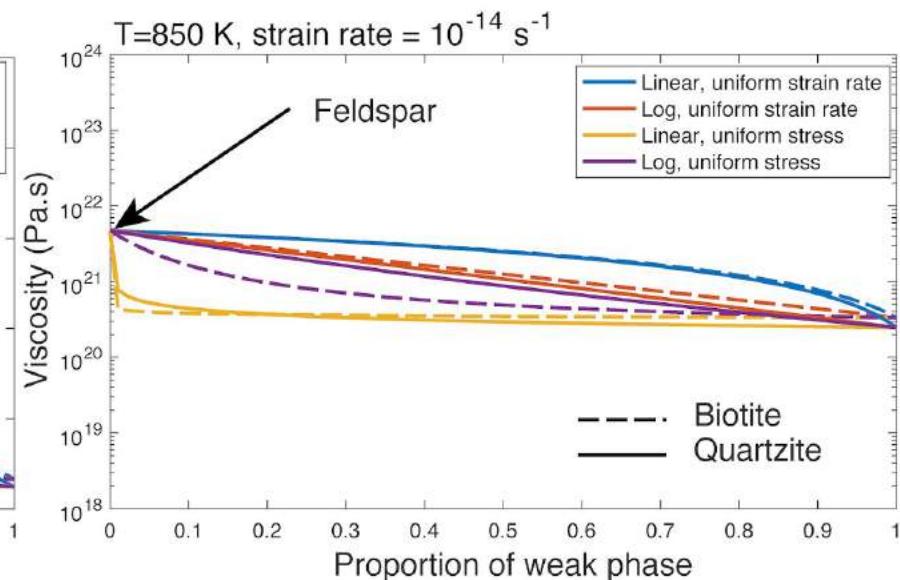
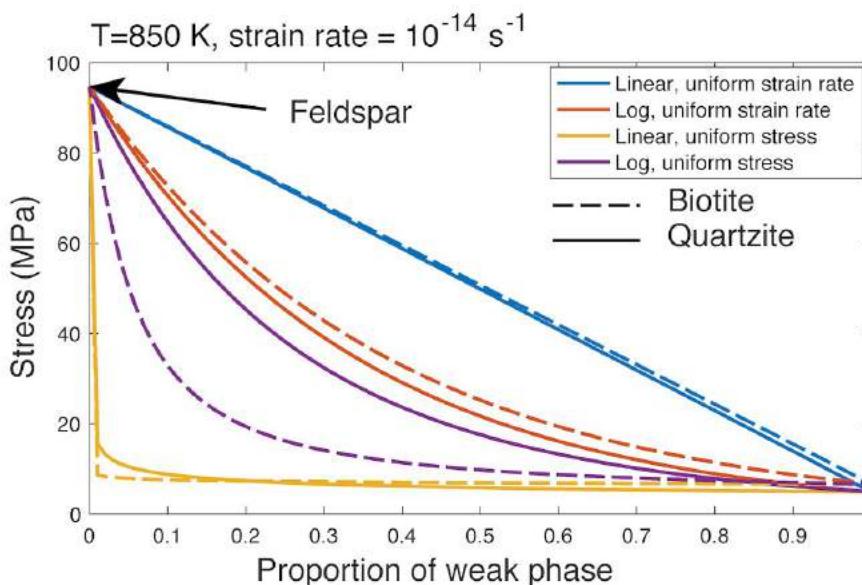
# Mixing feldspar and quartz



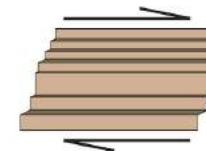
- Weak phase reduces aggregate viscosity
- Major effect if uniform stress and linear mixing



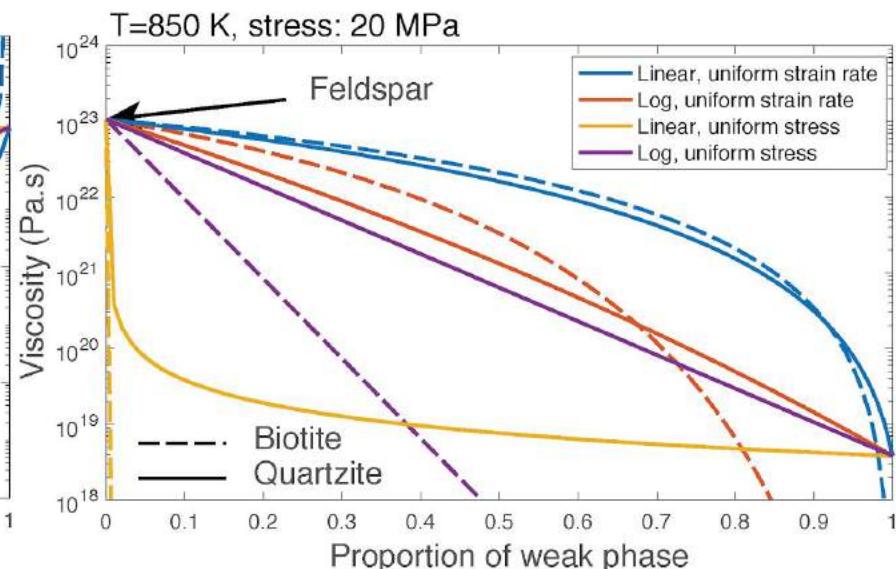
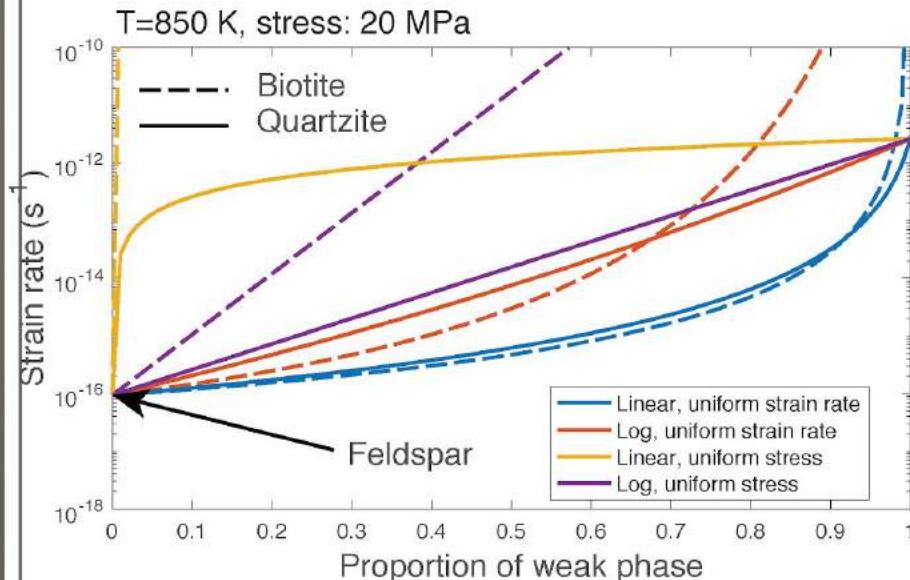
# Effect of mica vs. quartz



- Weak phase reduces aggregate viscosity
- Major effect if uniform stress and any mixing



# A matter of perspective: fix stress, not strain rate

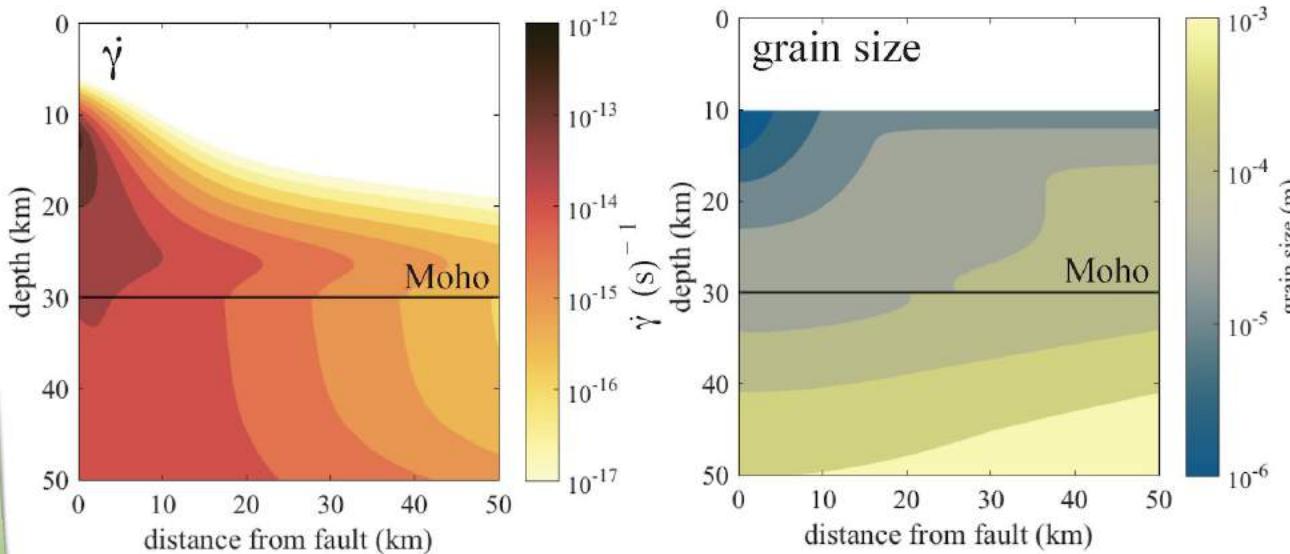


- Effect of NONLINEAR phase much more instance if fixed strength
- Likely best scenario for shear zones and maybe regionally (Platt and Behr, 2011; Montesi 2013)

# One more wrinkle: grain size

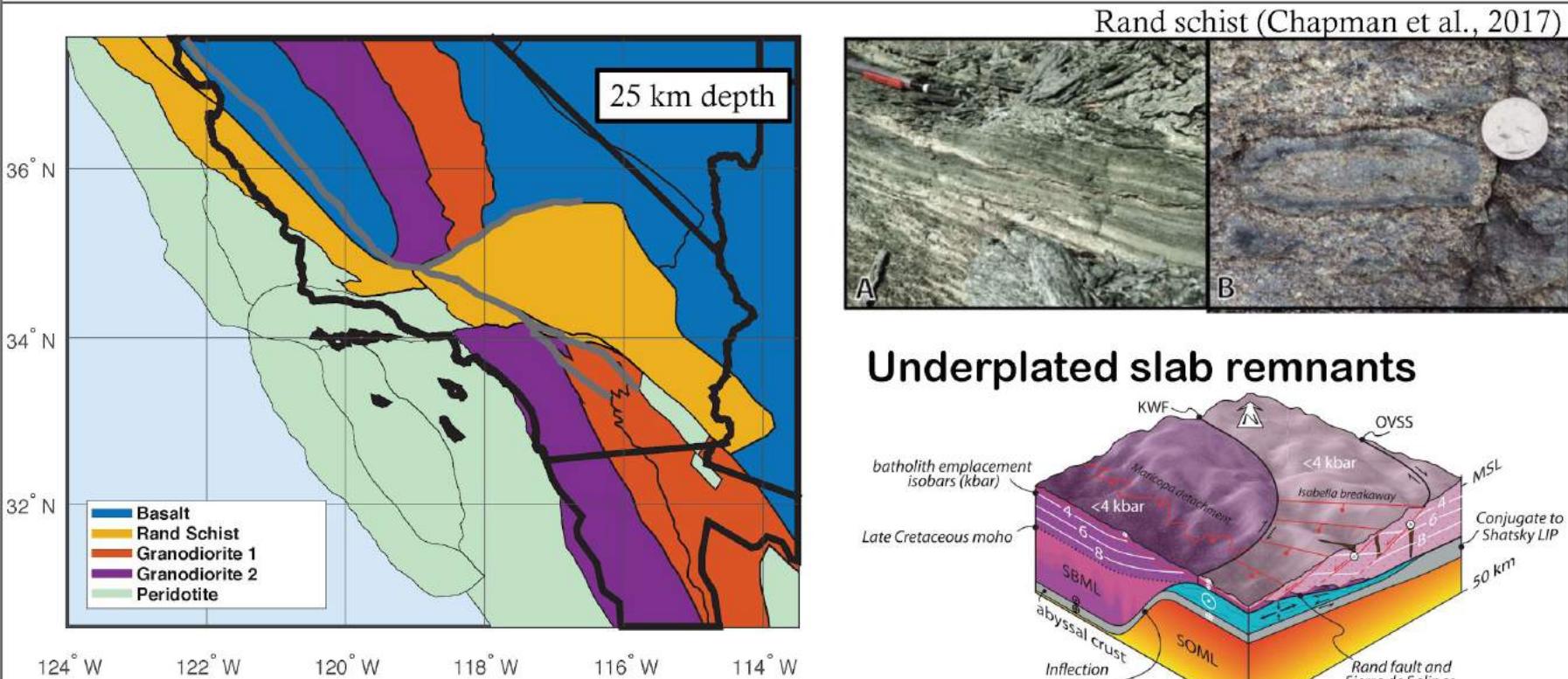


- Stress enhancement beneath fault zones leads to grain size reduction and dominance of diffusion creep



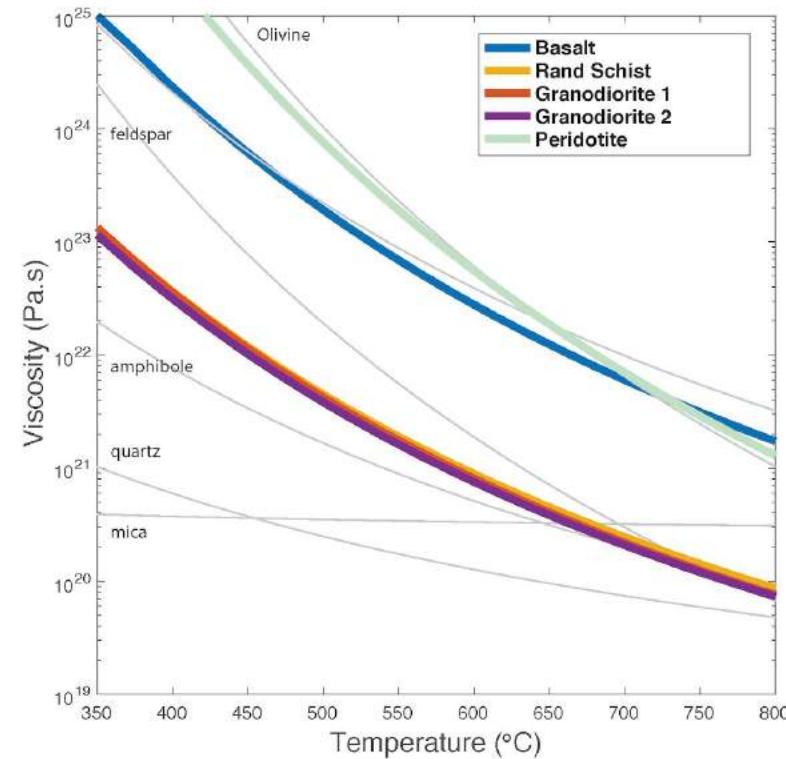
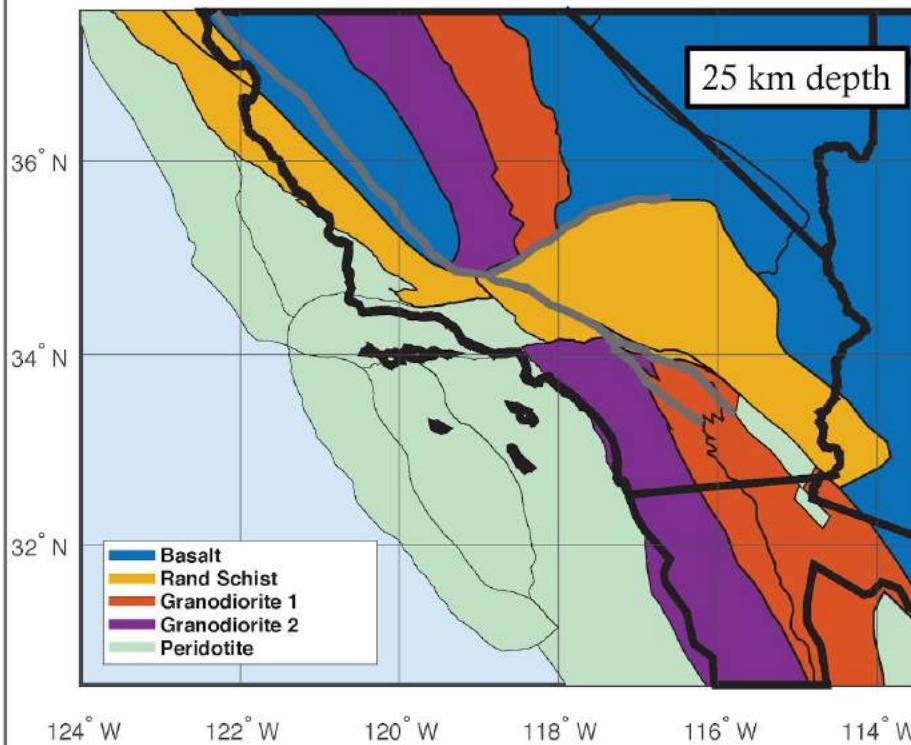
Allison and  
Montesi  
Poster 282

# Application to Southern California lower crust



After Oskin, 2018, 2019

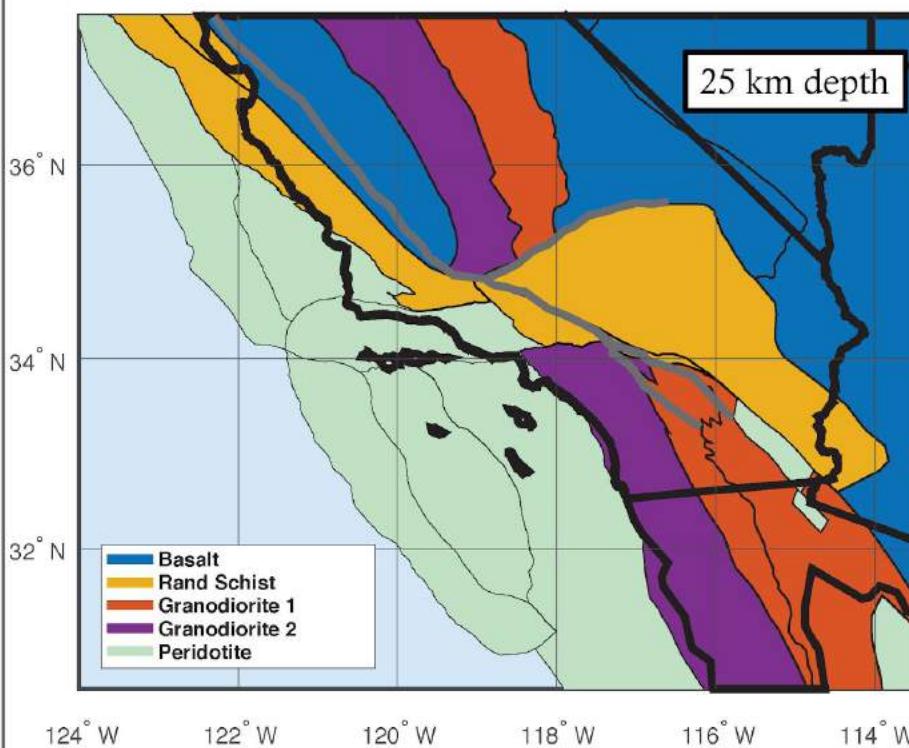
# Strength from end-members – no fabric



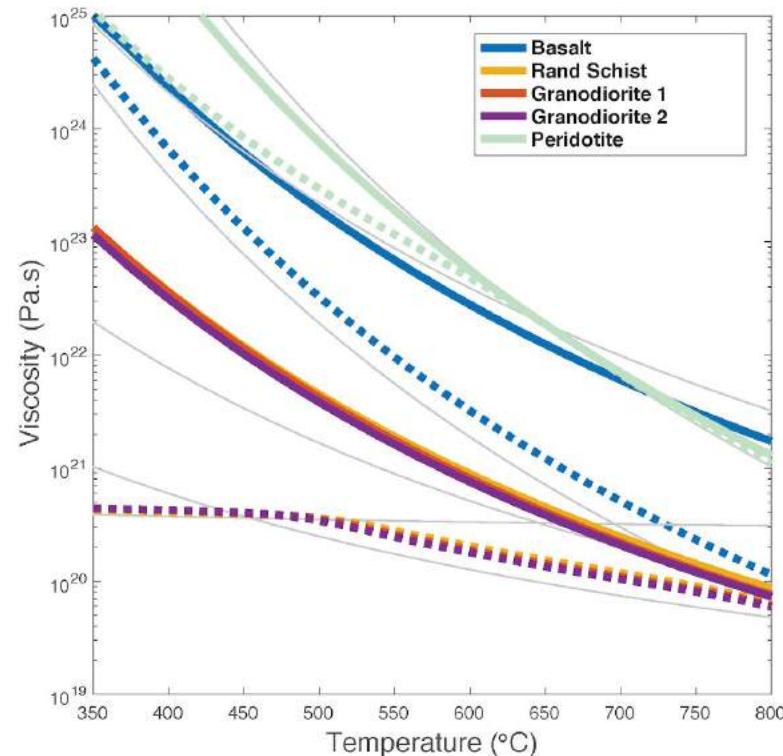
After Oskin, 2018, 2019

Montesi and Oskin

# Strength from end-members – shear zones

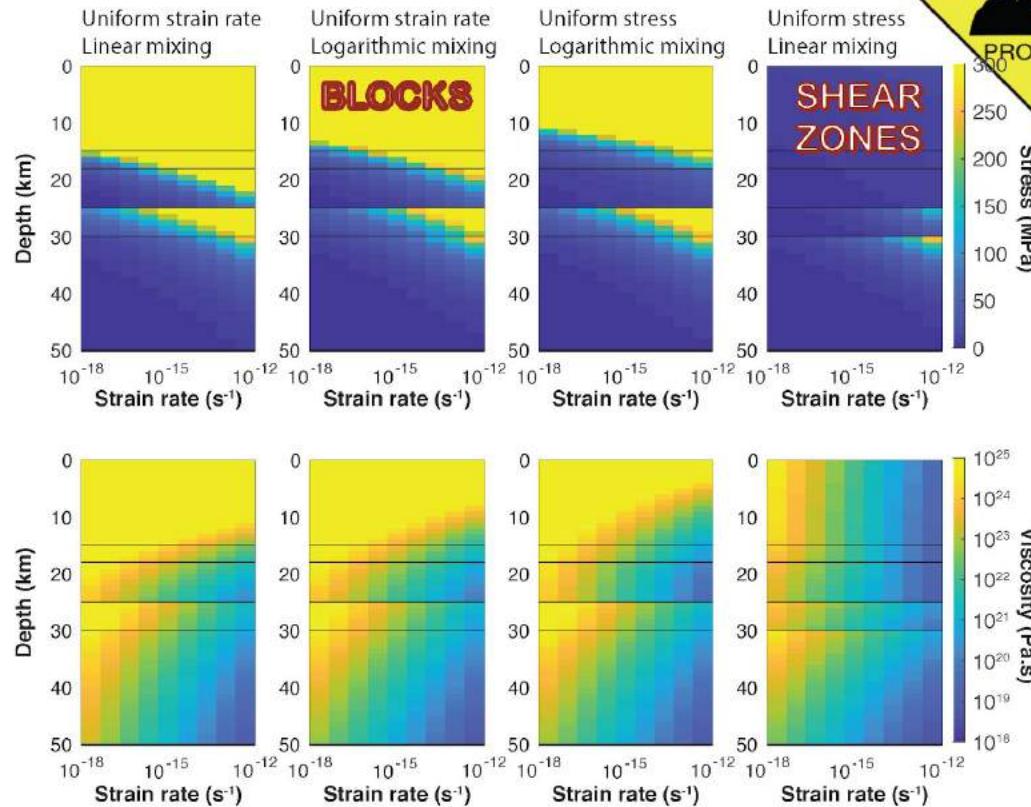
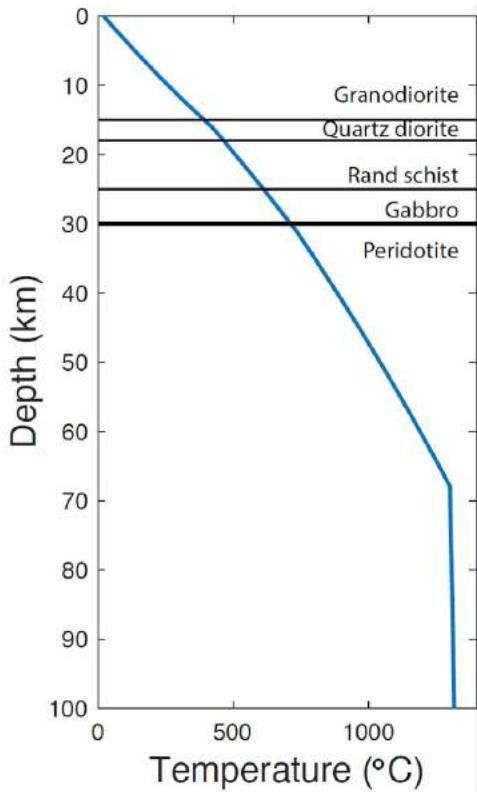


After Oskin, 2018, 2019

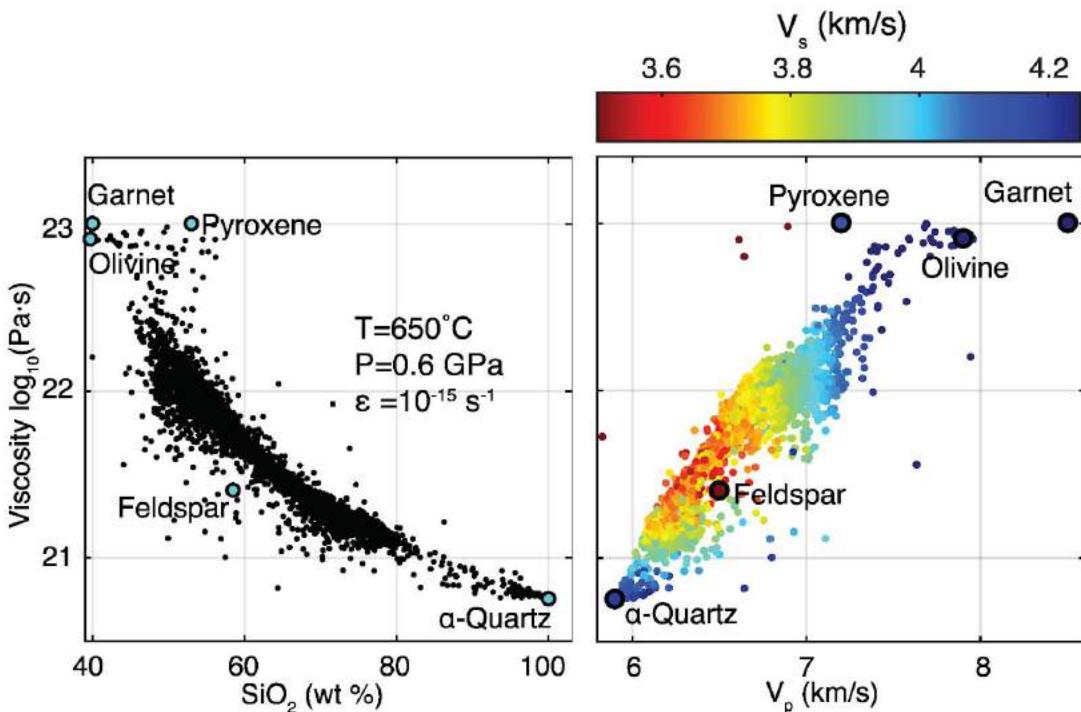


Montesi and Oskin

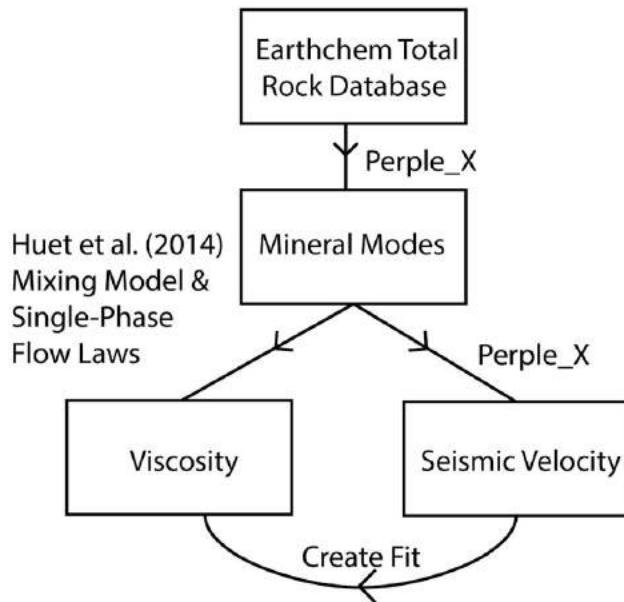
# Rheological moho?



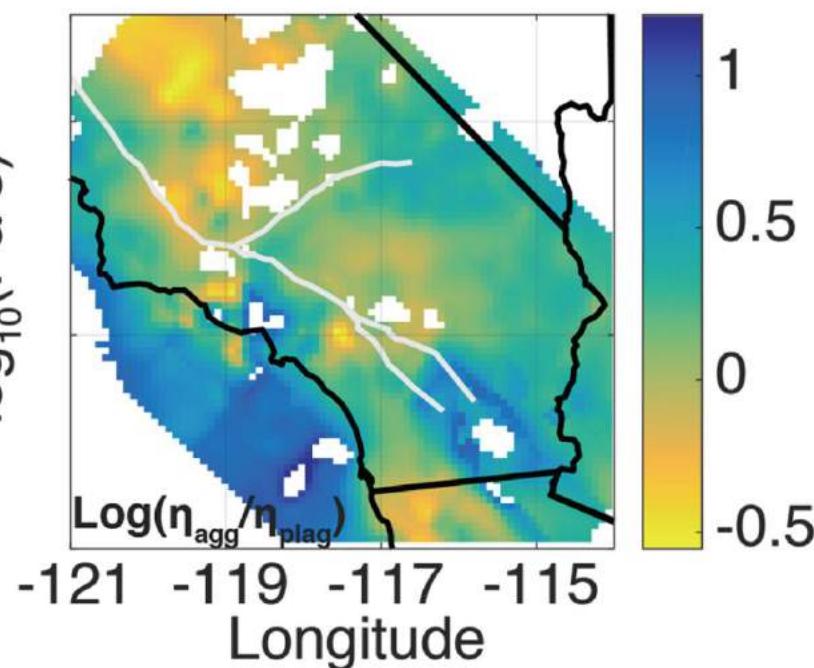
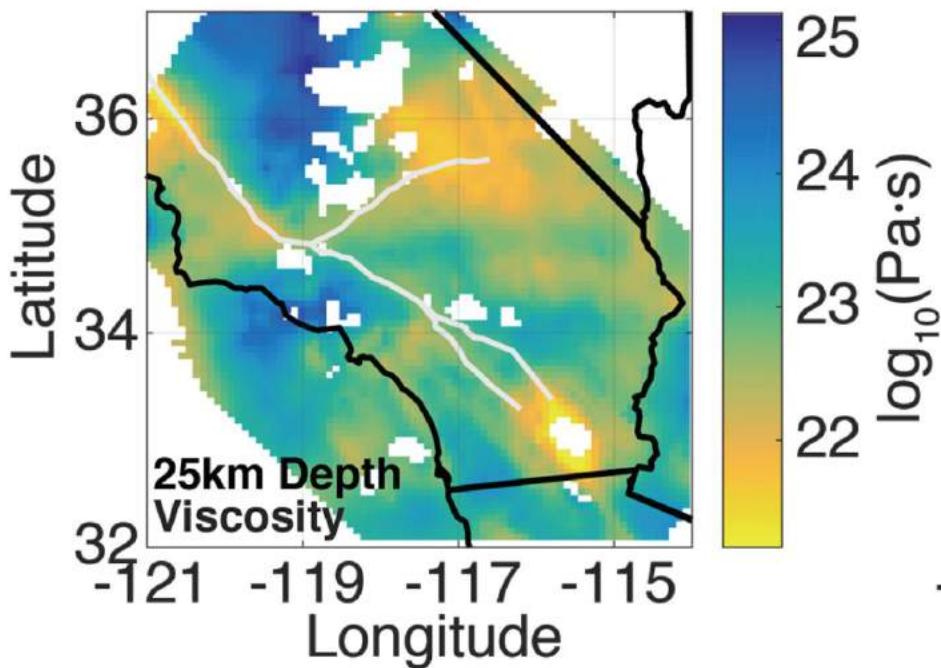
# Estimate viscosity from seismic velocity



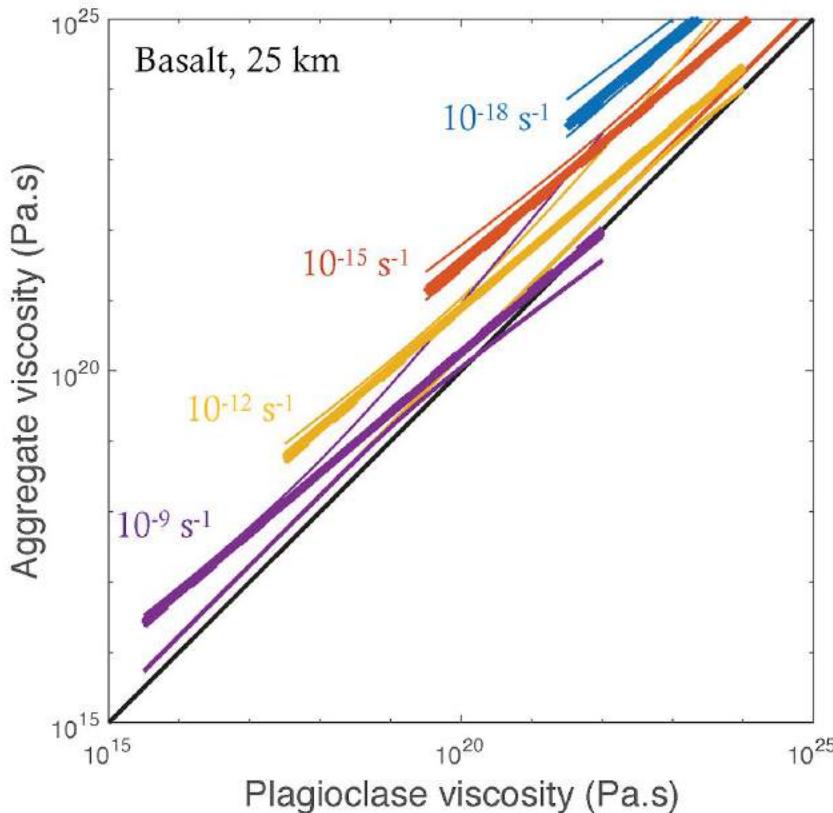
Shinevar et al., 2018



# Viscosity close to plagioclase



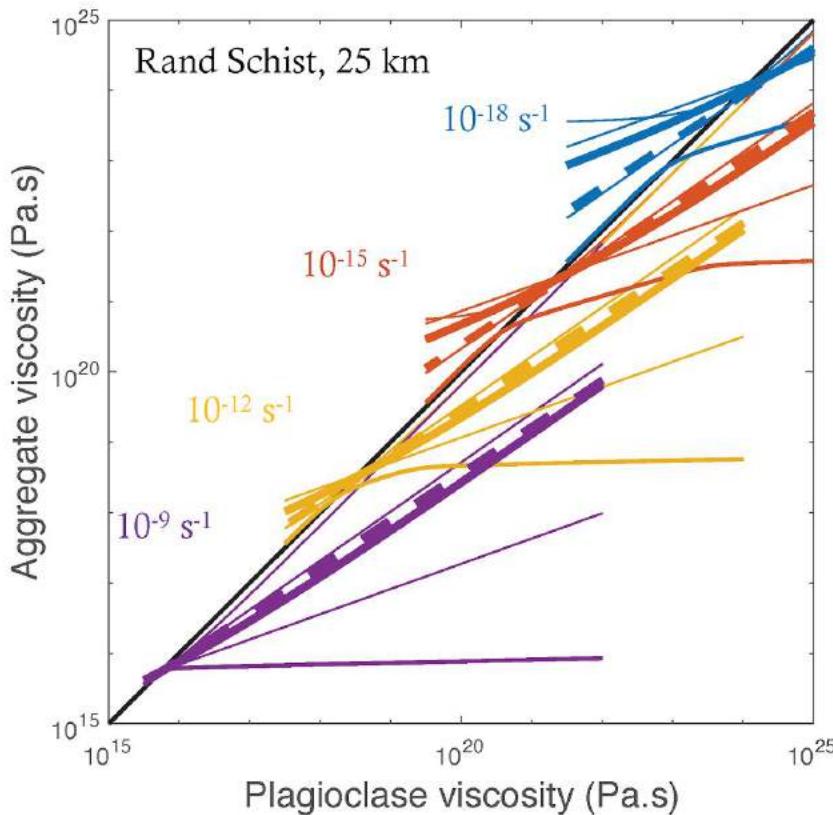
# Should we bother after all?



- Colors: strain rate
  - Temperature varies along line
- Thicker lines: non-textured rocks
- Medium thickness: layered rock
- If basalt:

**Plagioclase is quite good**

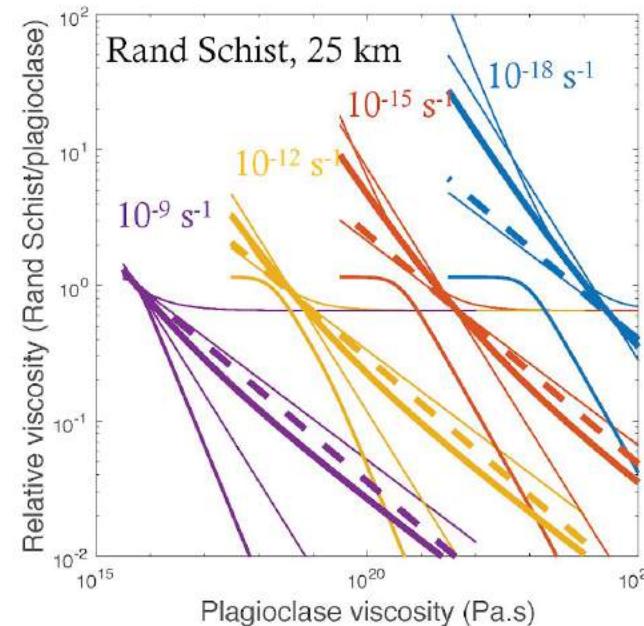
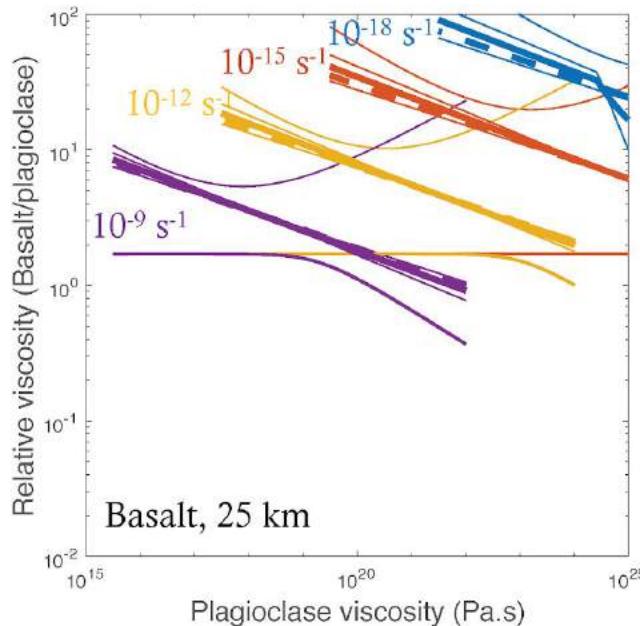
# Yes we should bother!



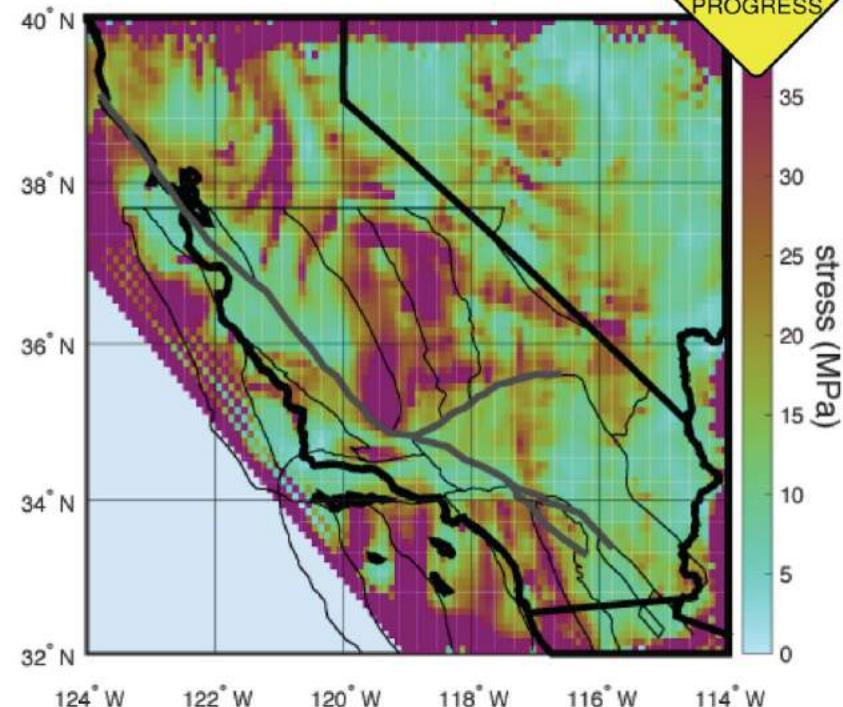
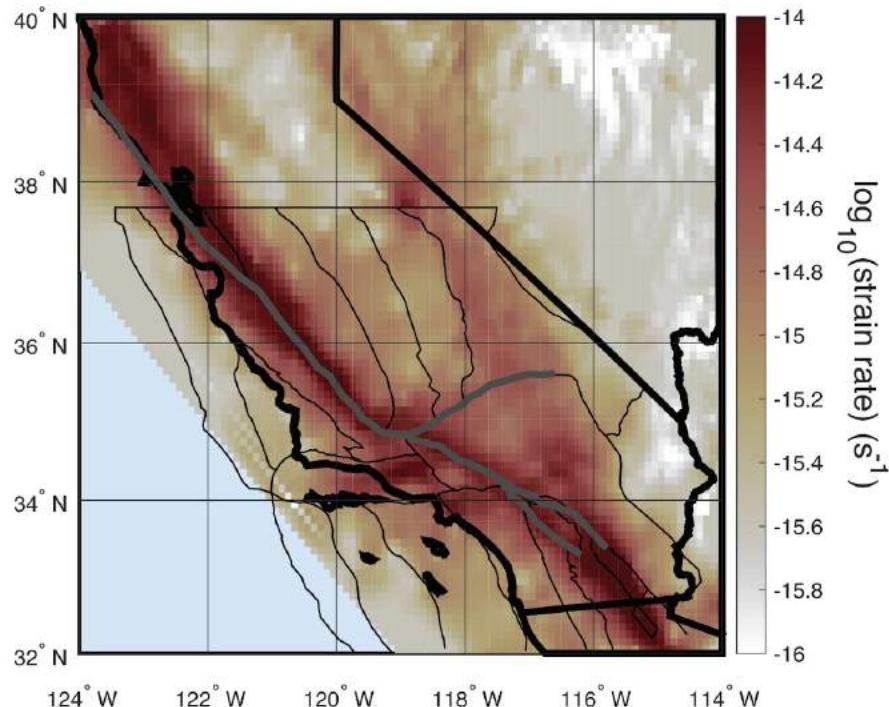
- Colors: strain rate
  - Temperature varies along line
- Thicker lines: non-textured rocks
- Medium thickness: layered rock
- If basalt (no biotite):  
**Plagioclase is quite good**
- If schist (includes biotite) :  
**Plagioclase is not as good  
foliation matters**

# Viscosity relative to plagioclase

- Within a factor of 10 expect for mantle and shear zones but there are systematic trends.

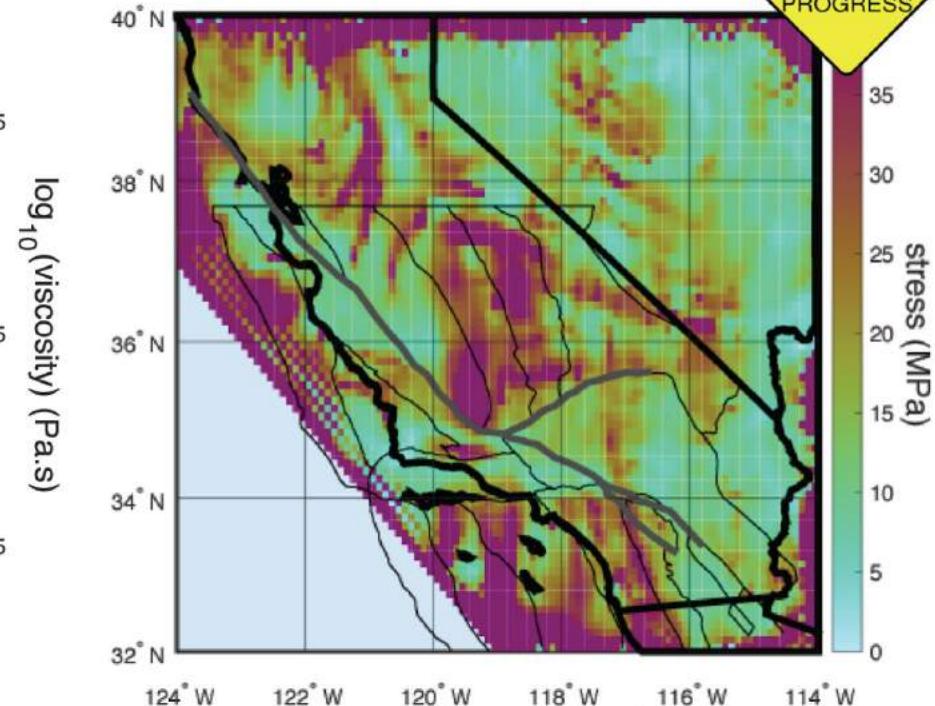
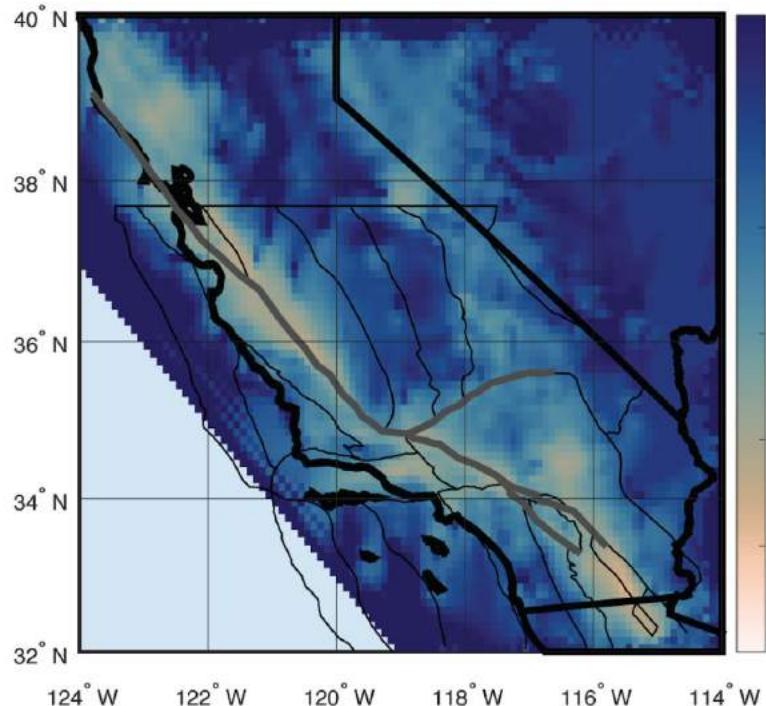


# Southern California geodynamics



Bahadori and Holt

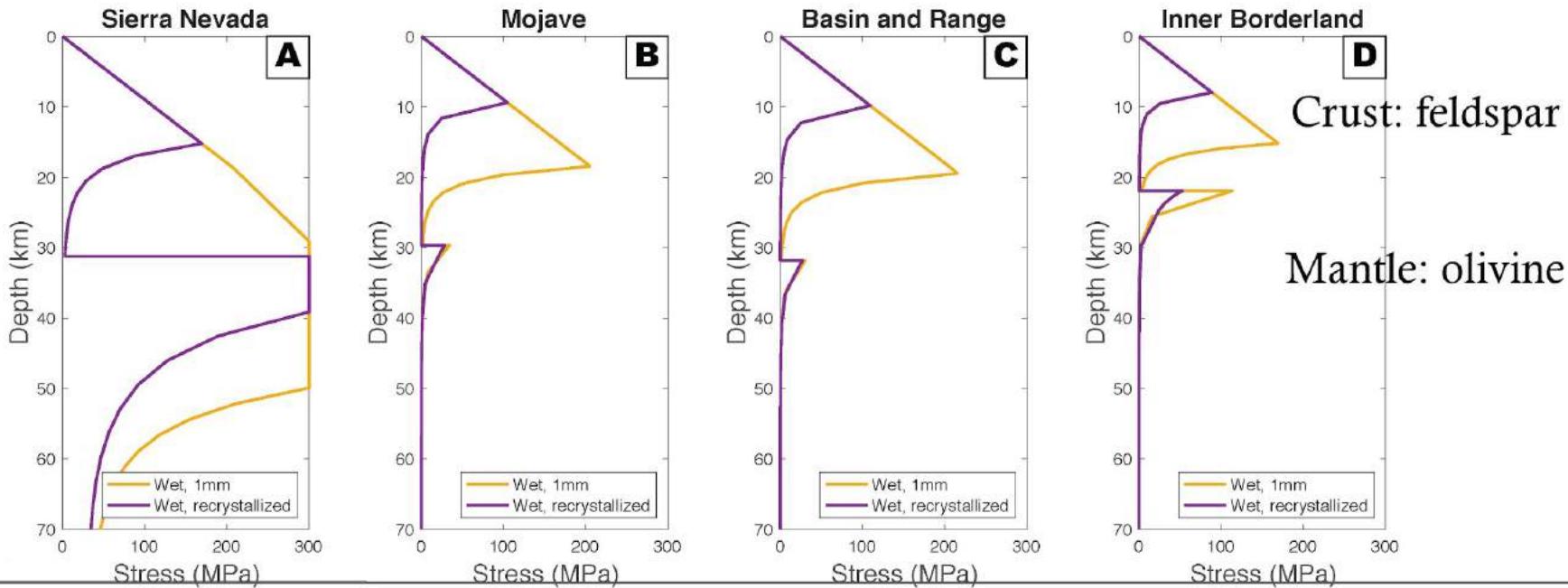
# Southern California geodynamics



Bahadori and Holt

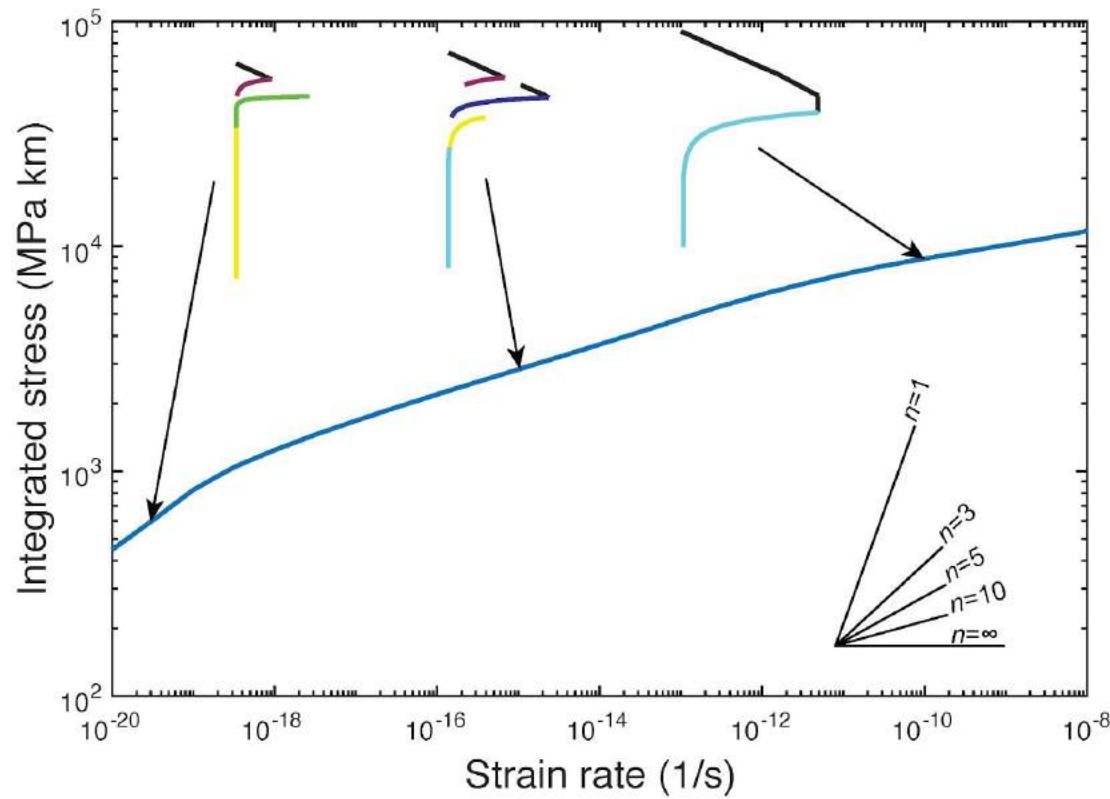
# Systematic strength envelopes

- Temperature model: Shinevar et al. (2018)
- Crustal thickness: Shen and Ritzwoller, 2016



# Integrated strength and effective rheology

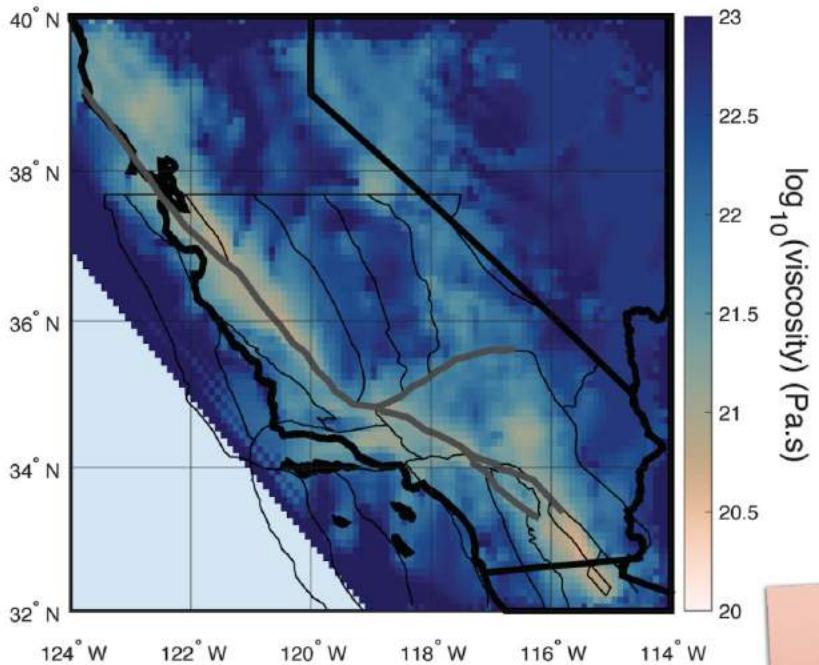
- Integrates strength envelope with depth
  - $S = \int_0^{z_{\max}} \sigma dz$
- **Effective rheology:** Report  $S$  for various strain rates
  - Kinks due to changes in deformation mechanism.
- If impose stress, deduce strain rate and effective viscosity
  - $\eta = \frac{1}{z_{\max}} \frac{S}{\dot{\varepsilon}}$



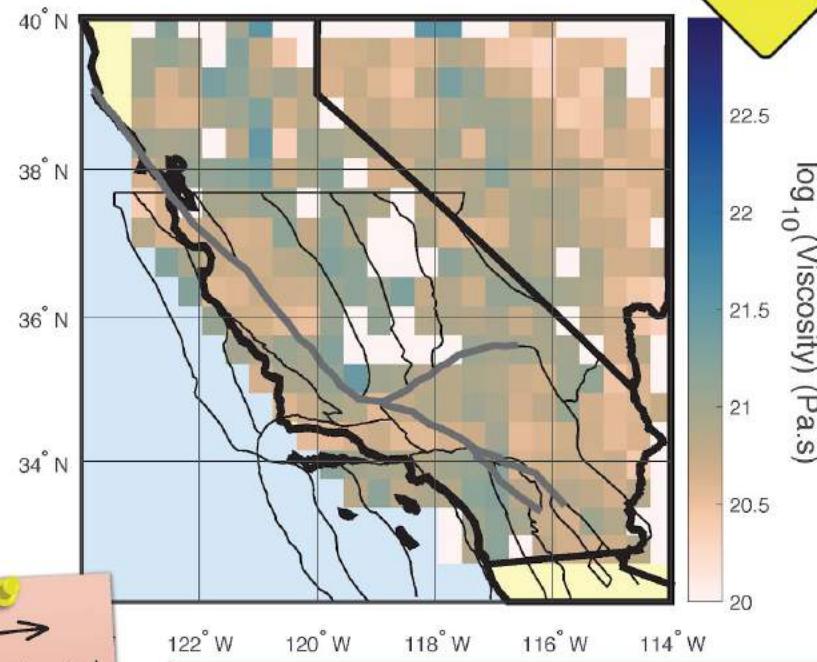
# Comparing rheology and geodynamics



**Geodynamics (Bahadori and Holt)**



**Rheology (Izquierdo and M...)**



Combines stress and strain rate

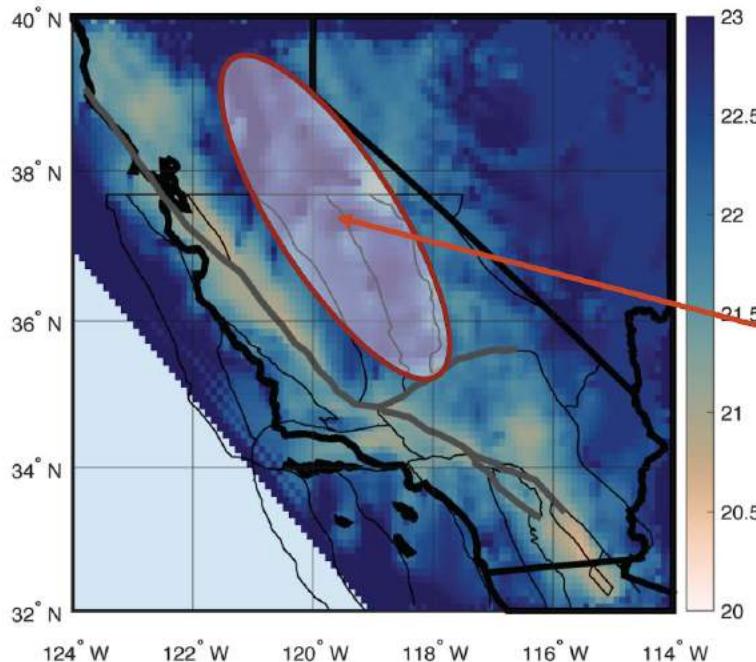
Izquierdo et al.  
Poster 316

Combines stress,  
temperature and rheology

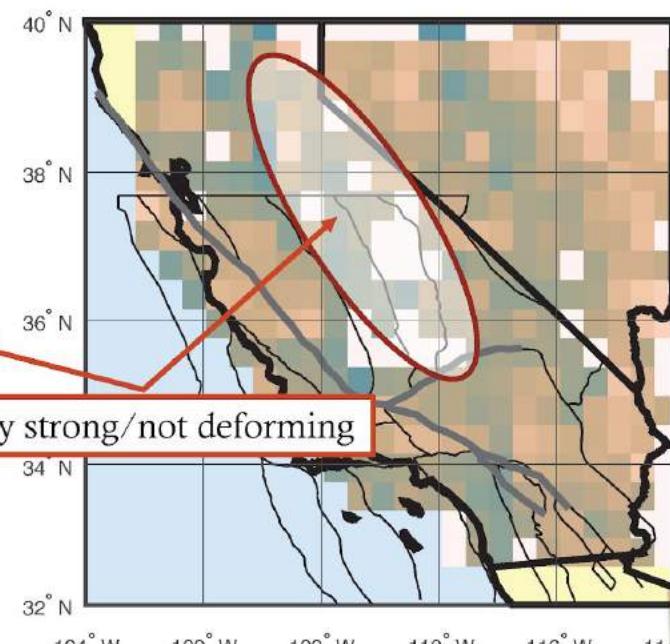
# Comparing rheology and geodynamics



**Geodynamics (Bahadori and Holt)**



**Rheology (Izquierdo and M...)**



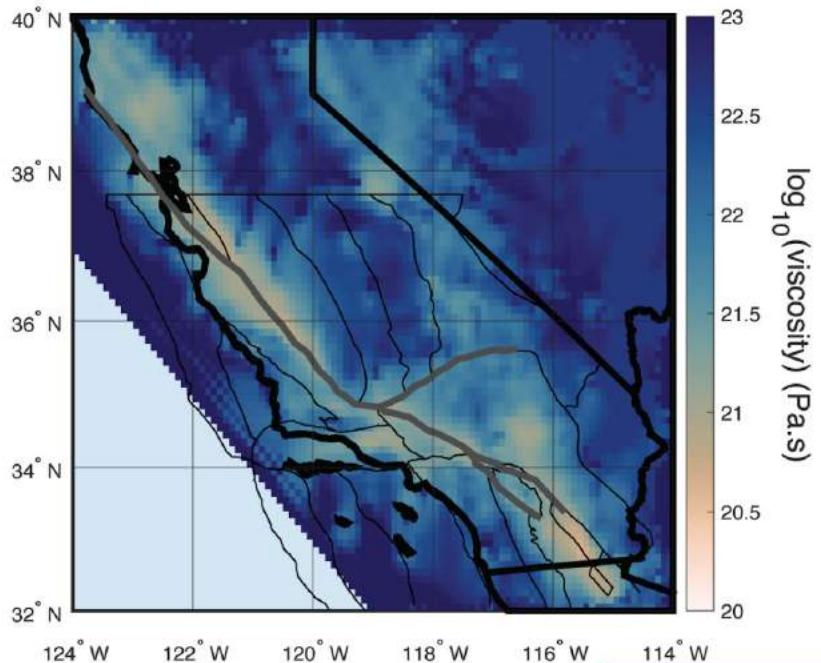
Very strong/not deforming

Izquierdo et al.  
Poster 316

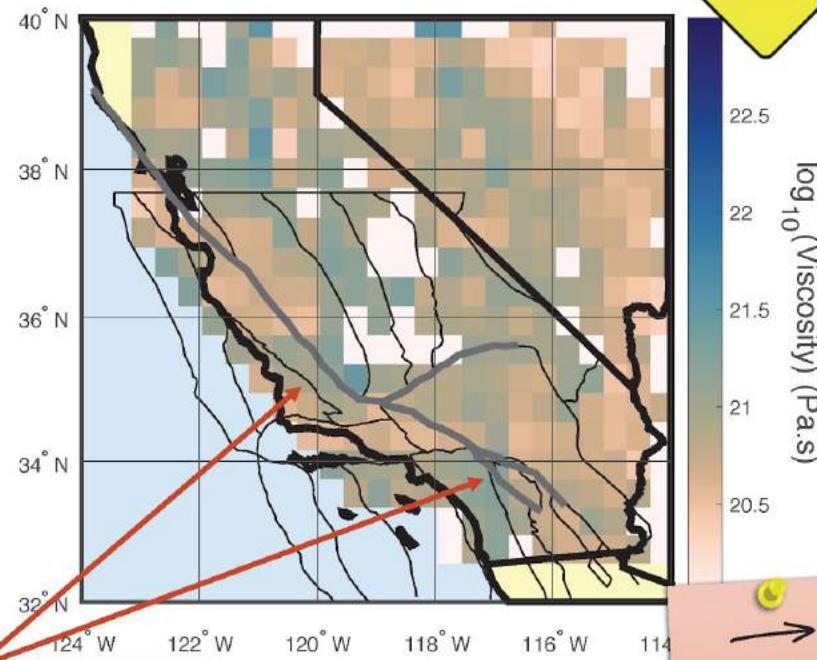
# Comparing rheology and geodynamics



Geodynamics (*Bahadori and Holt*)



Rheology (*Izquierdo and M*)



Consistent relative variations

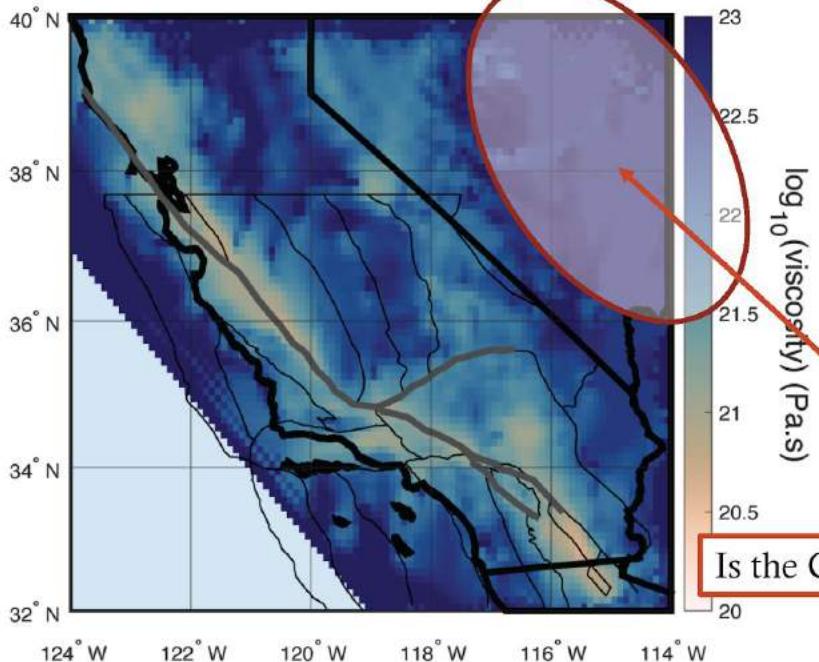
Izquierdo et al.  
Poster 316



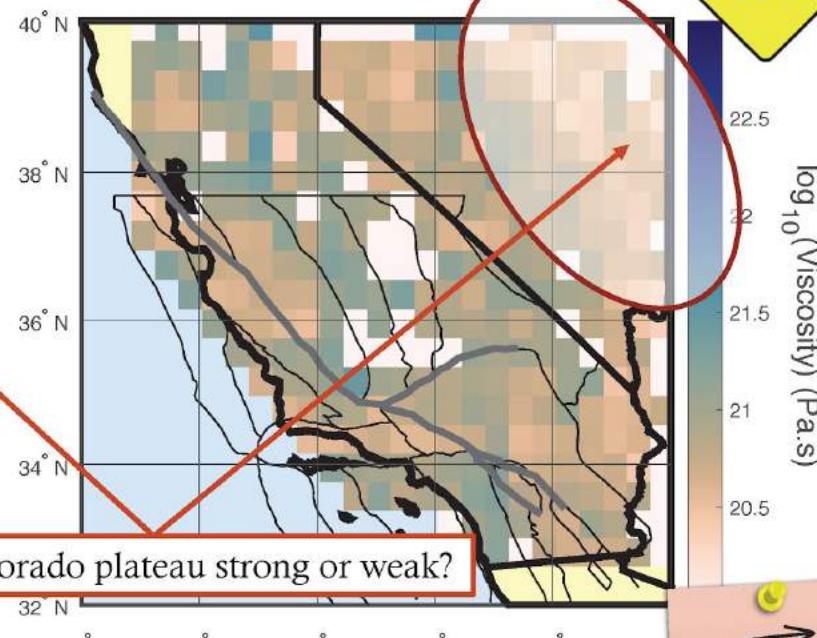
# Comparing rheology and geodynamics



**Geodynamics (Bahadori and Holt)**



**Rheology (Izquierdo and M...)**



Is the Colorado plateau strong or weak?

Izquierdo et al.  
Poster 316

Remember: no lithological variations (yet)

# Rheology of Southern California from Mineral to Regional Scale

- Lithology brings rheological complexity
  - Are there micas? Is there foliation?
  - What is the grain size?
- Testing regional rheological models
  - Some variability linked to thermal and crustal thickness
  - Lithology matters