Rheology and Localization
From the lab to the lithosphere

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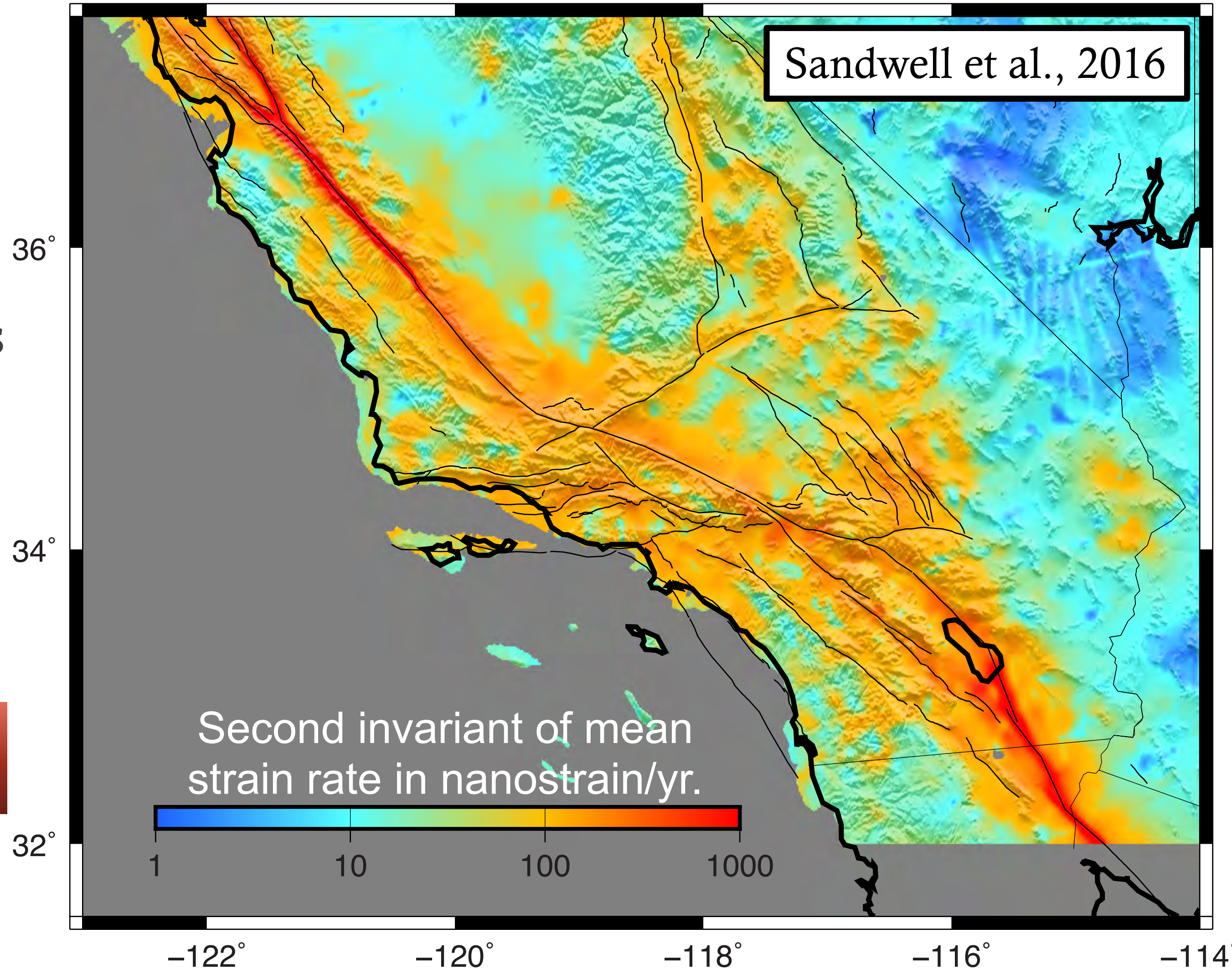
Community Geodetic Model

- Significant strain rate variations
  - Localized shear zones
  - Within blacks
- Stress or rock type?

Rheology



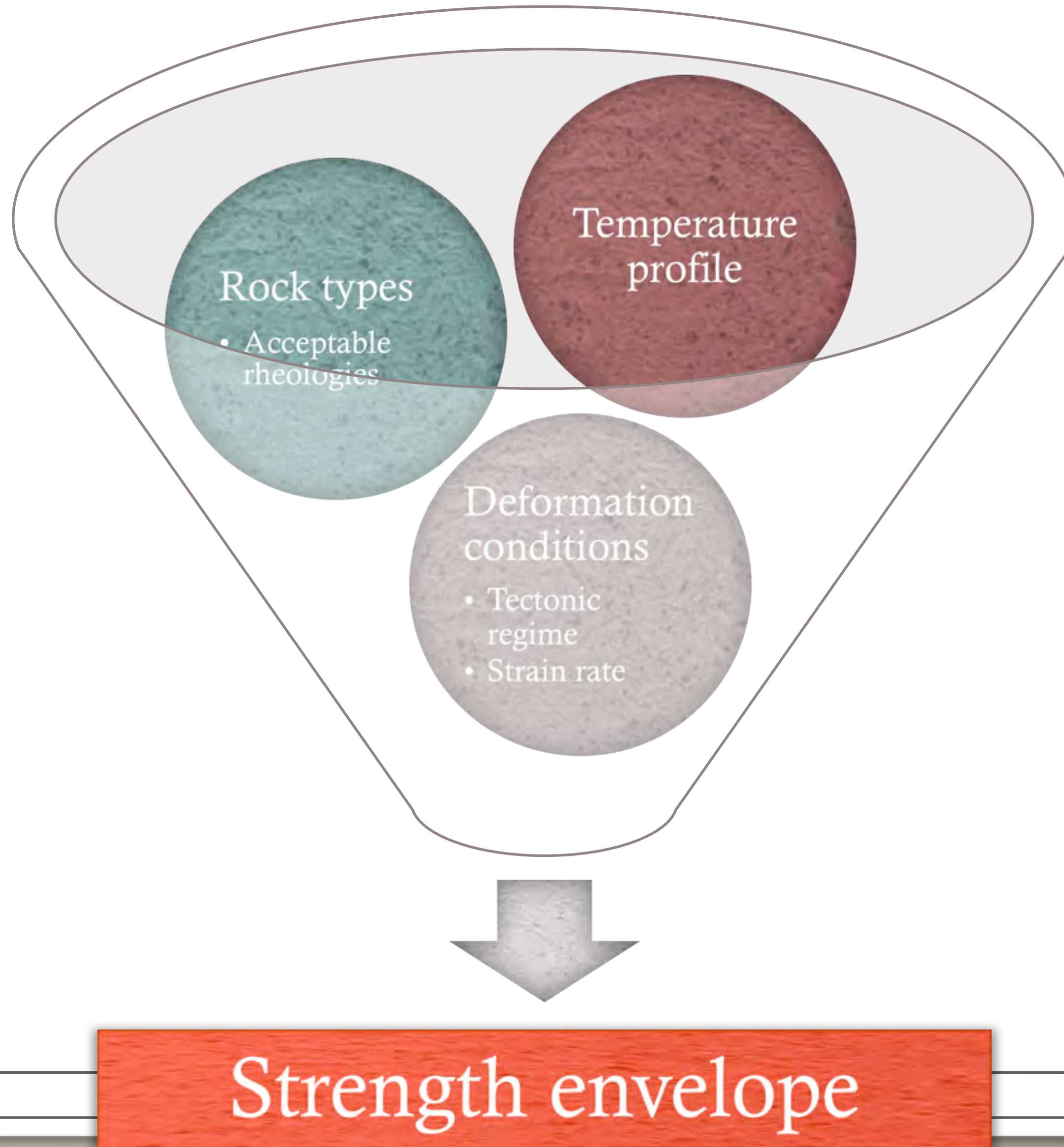
What is a rheology?

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

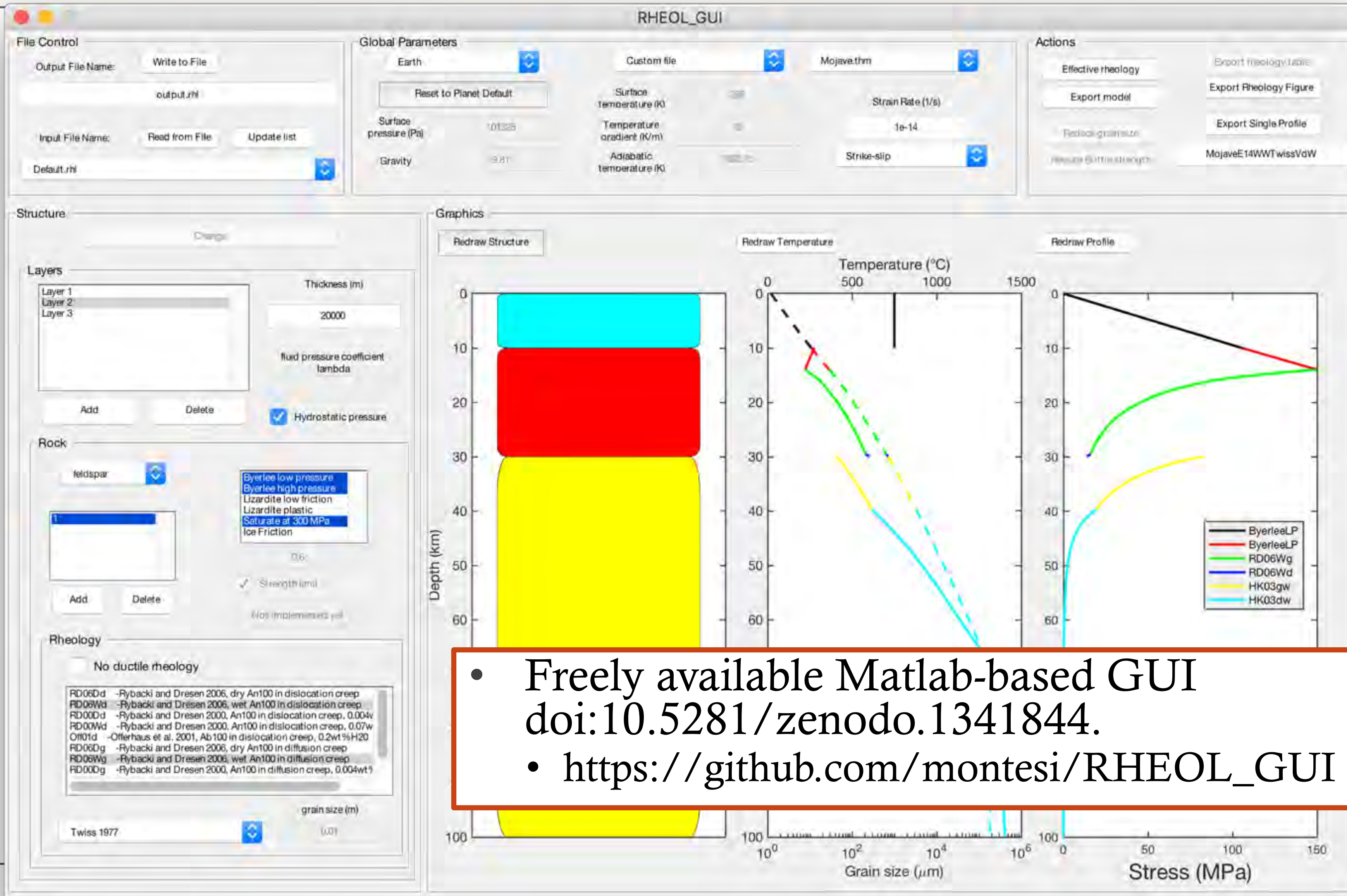
NOT A NUMBER!

Strength envelope approach

- Various deformation mechanisms provide estimates of stress required to deform at specified strain rate
  - Brittle regime: strength increases with depth
    - Depends on tectonic regime
    - Depends on pore fluid pressure
    - Minor dependence on rock type
  - Ductile regime: strength decreases with depth
    - Depends on rock type (composition, grain size, water content)
    - Rheology temperature activated
- Strength for the weakest process

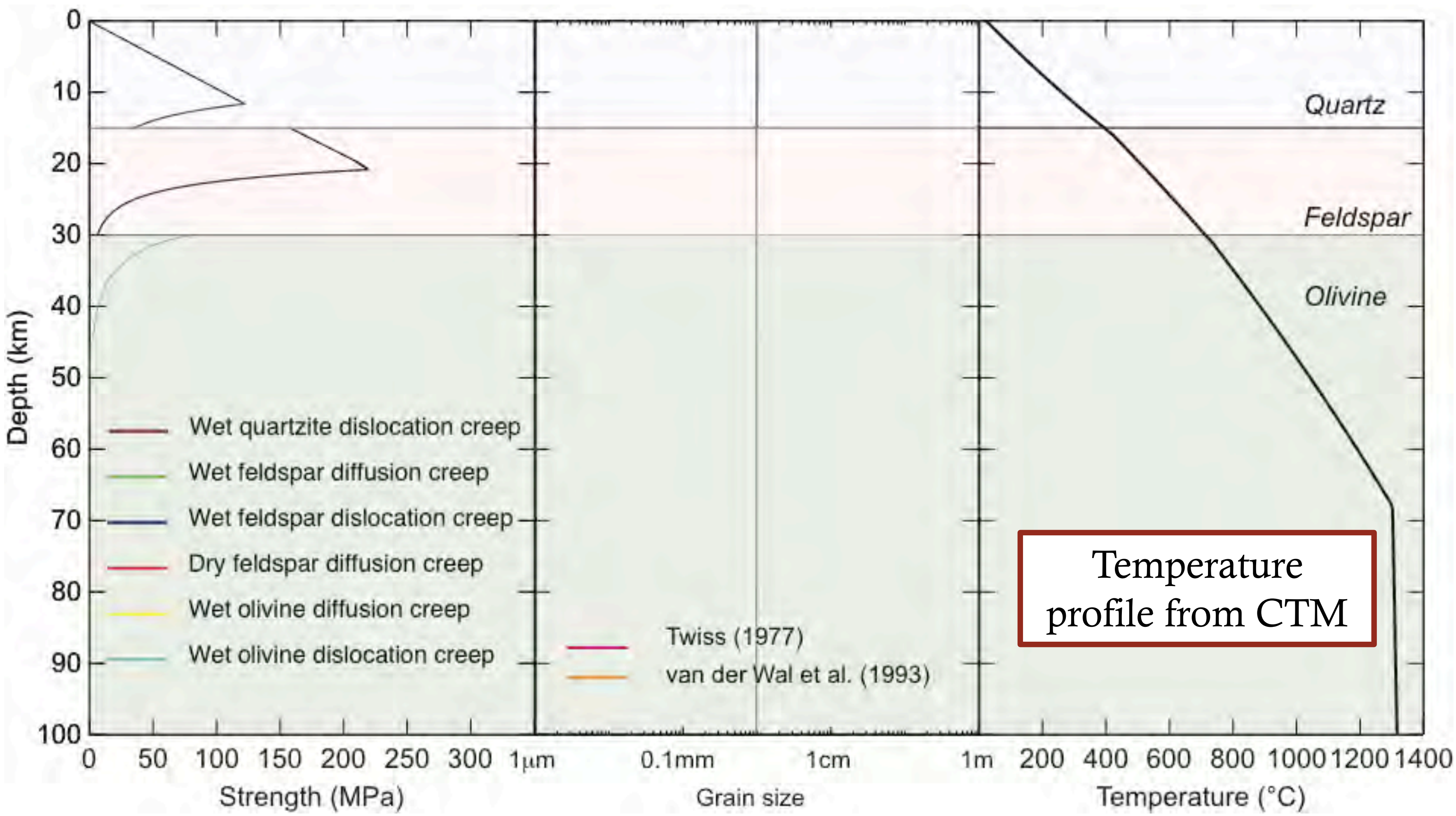


Example using RHEOL_GUI



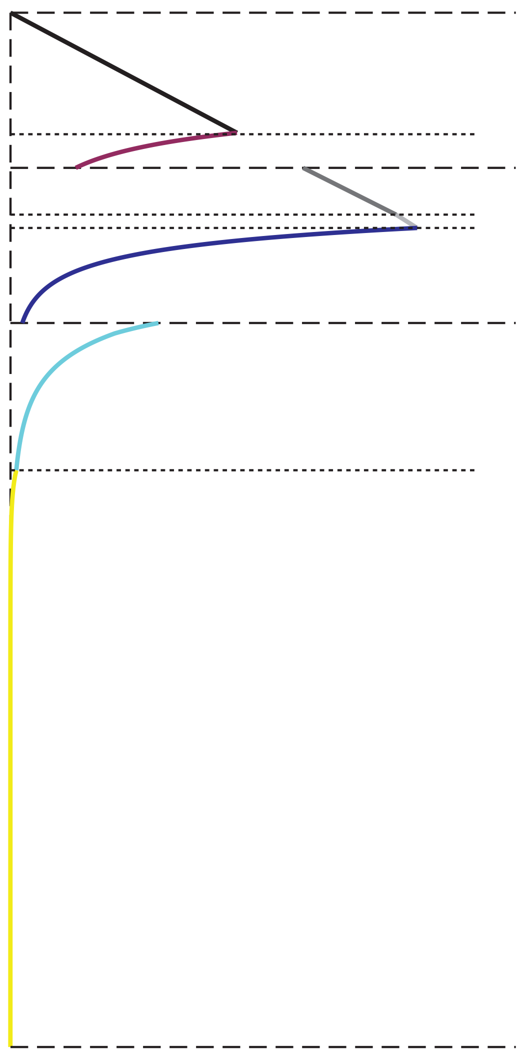
- Freely available Matlab-based GUI doi:10.5281/zenodo.1341844.
  - https://github.com/montesi/RHEOL_GUI

Demo model – 1mm grain size



What really happens?

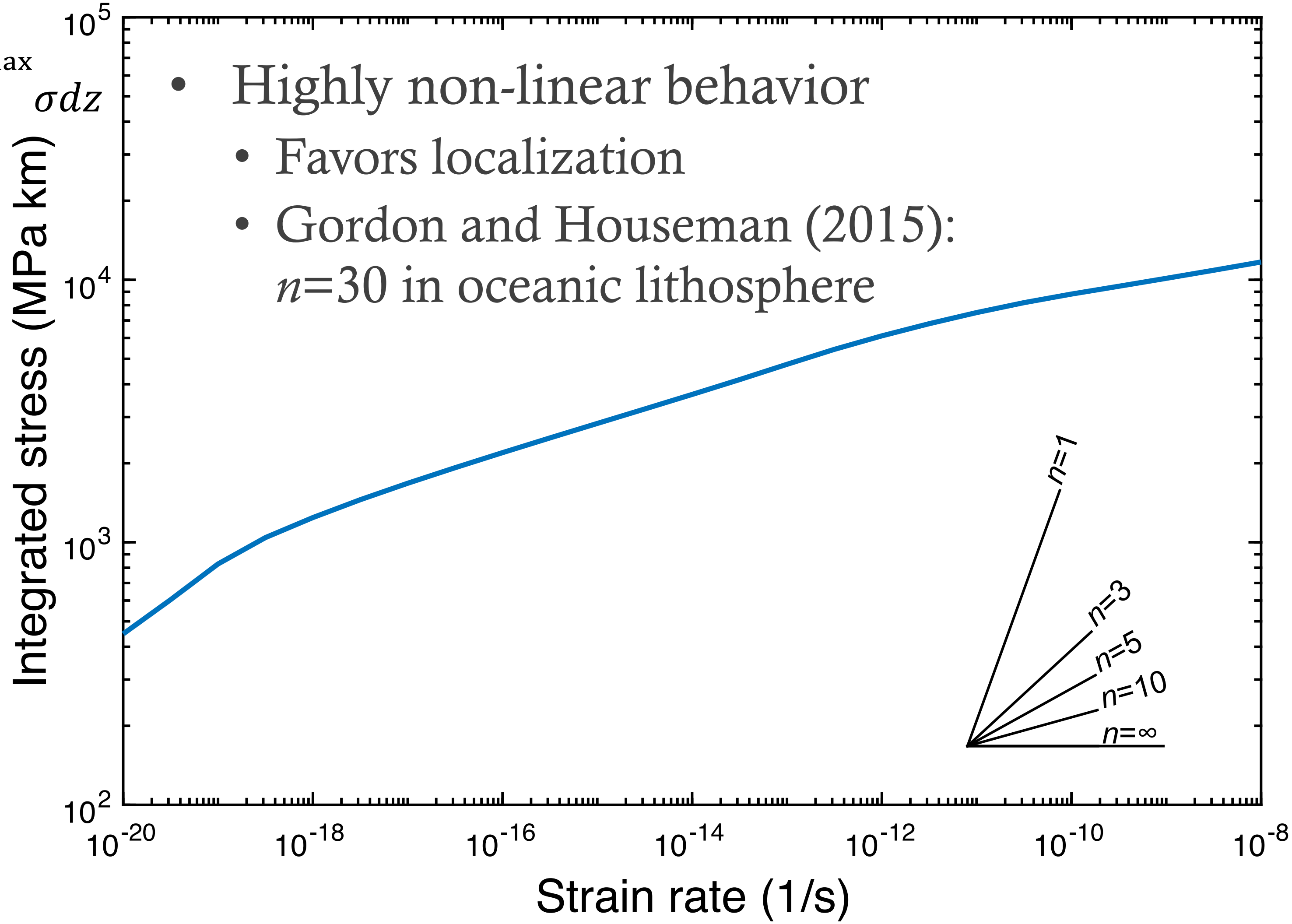
- In each stratigraphic layer from top to bottom
  - Determine the function T(z) and P(z)
  - Find the weakest rheology R_{top} on top (z_{top})
  - For every rheology that is weaker than R_{top} at the bottom of the layer:
    - Solve for the depth z_{trs} where that law has the same strength as R_{top}
    - Identify the rheology with the shallowest z_t
    - Define the rheology sublayer from z_{top} to z_{trs} and associate rheology R_{top}
  - Remove R_{top} from available list of rheologies
  - Define the new z_{top} as the old z_{trs}
  - If we're not at the bottom of the stratigraphic layer, iterate.
- *Note 1:* if grain size is set to a piezometer, we solve simultaneously for grain size and stress
- *Note 2:* If a rheology is labeled as "wet", we calculated water fugacity as function of Temperature and Pressure
- *Note 3:* Profile continuous within strata and discontinuous at strata boundary



Demo model – Effective rheology

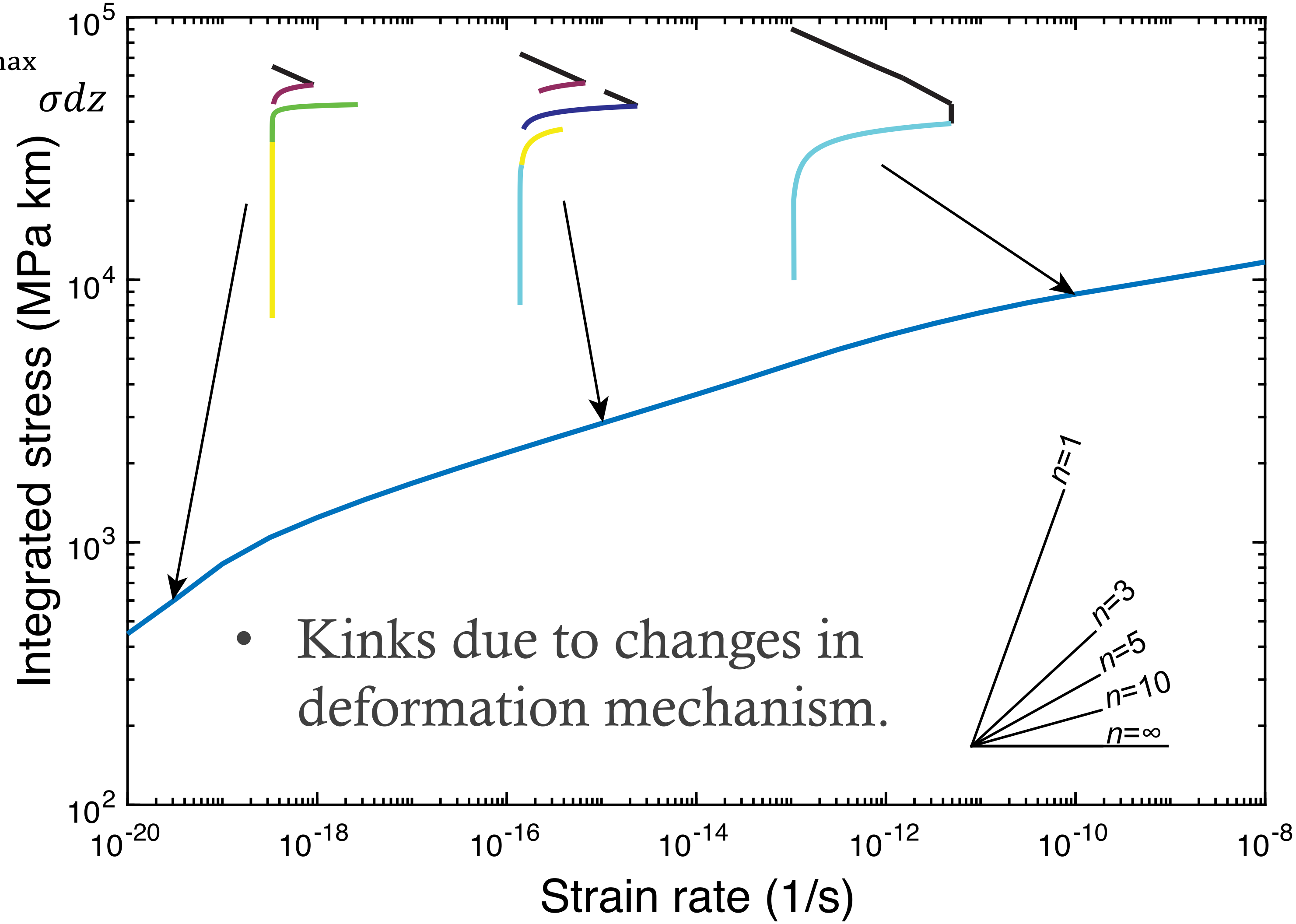
$$S = \int_0^{z_{\max}} \sigma dz$$

- Highly non-linear behavior
  - Favors localization
  - Gordon and Houseman (2015): n=30 in oceanic lithosphere



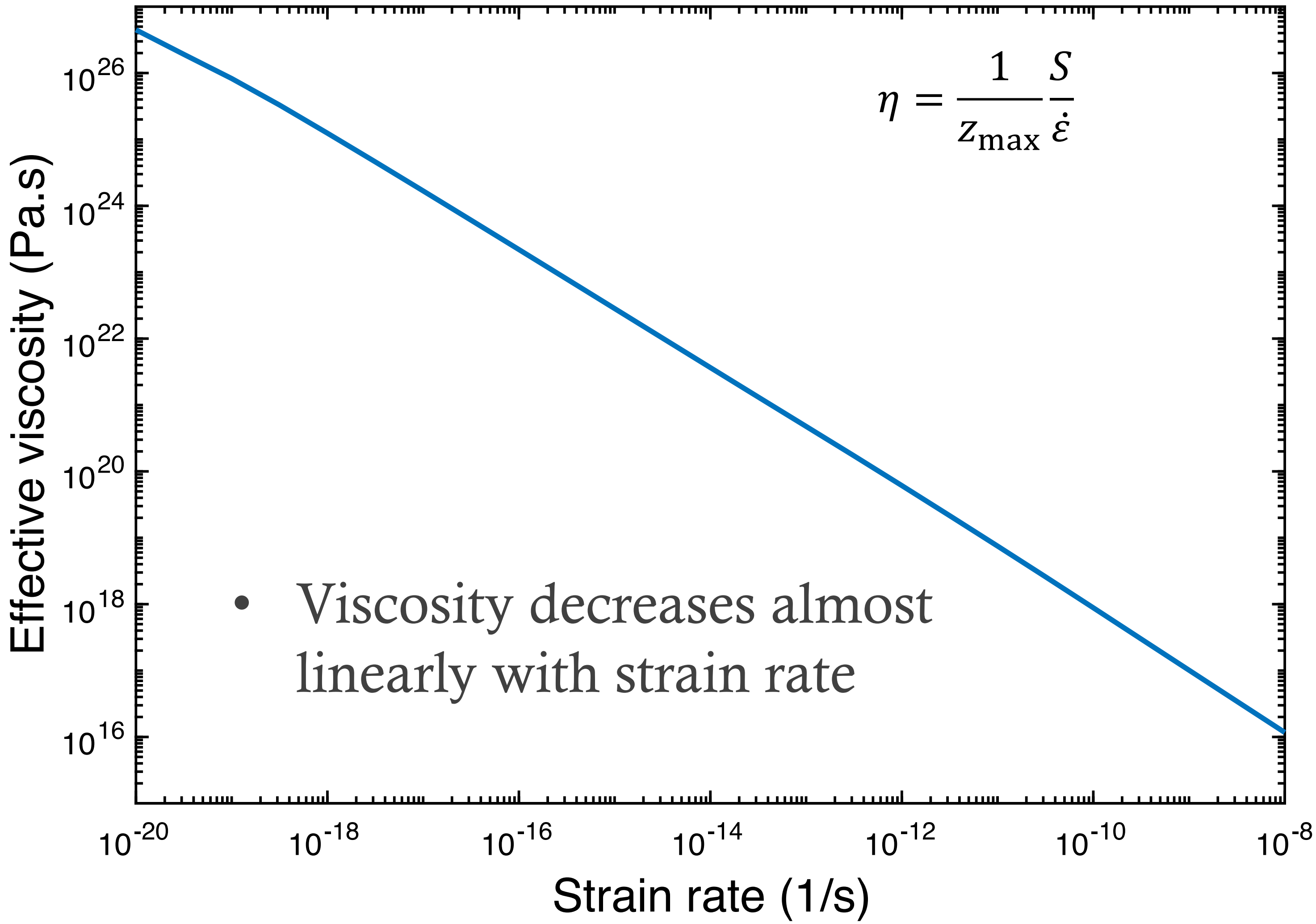
Demo model – Effective rheology

$$S = \int_0^{z_{\max}} \sigma dz$$



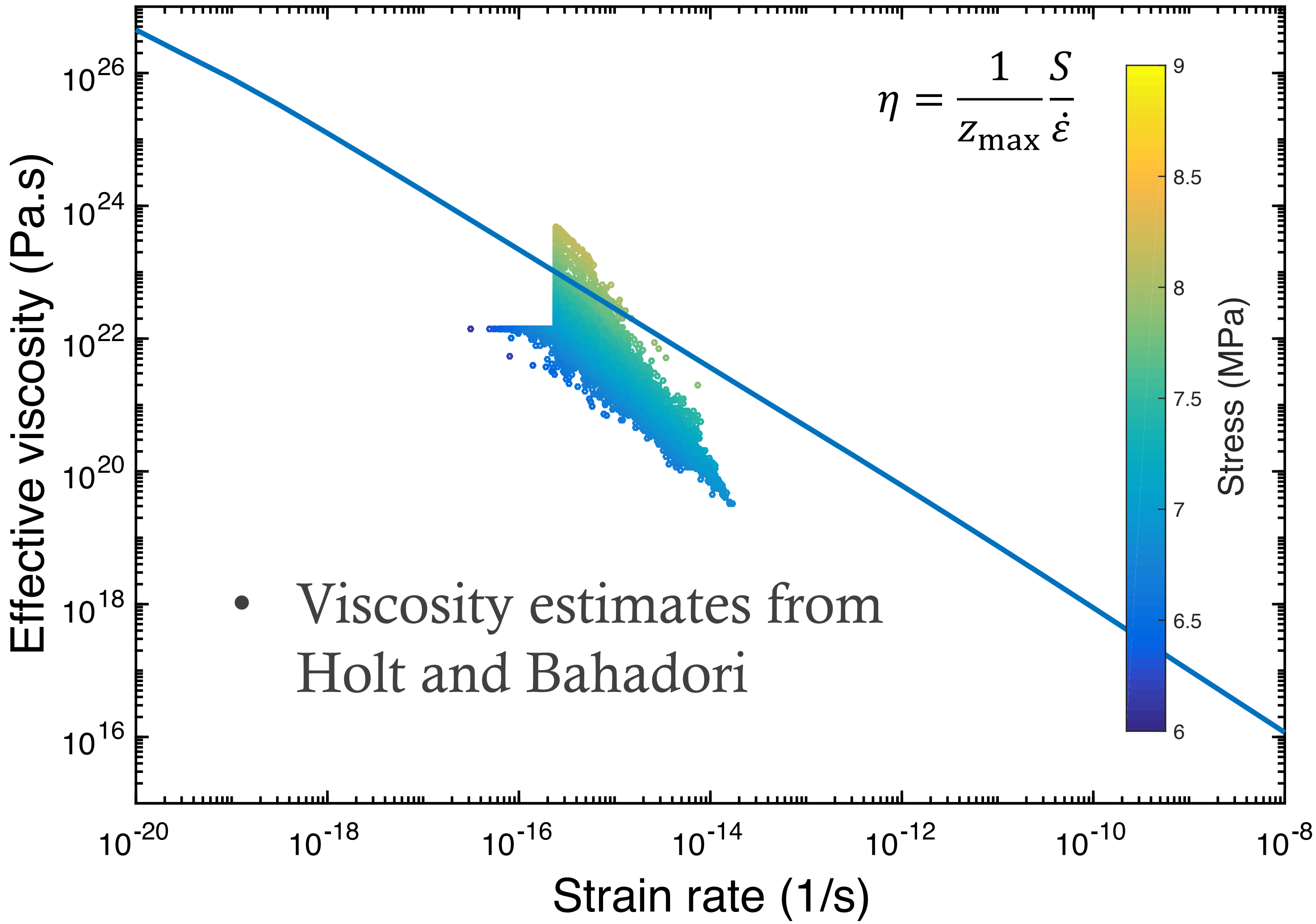
- Kinks due to changes in deformation mechanism.

Demo model – Effective viscosity



- Viscosity decreases almost linearly with strain rate

Demo model – Effective viscosity



- Viscosity estimates from Holt and Bahadori

Community Geodetic Model

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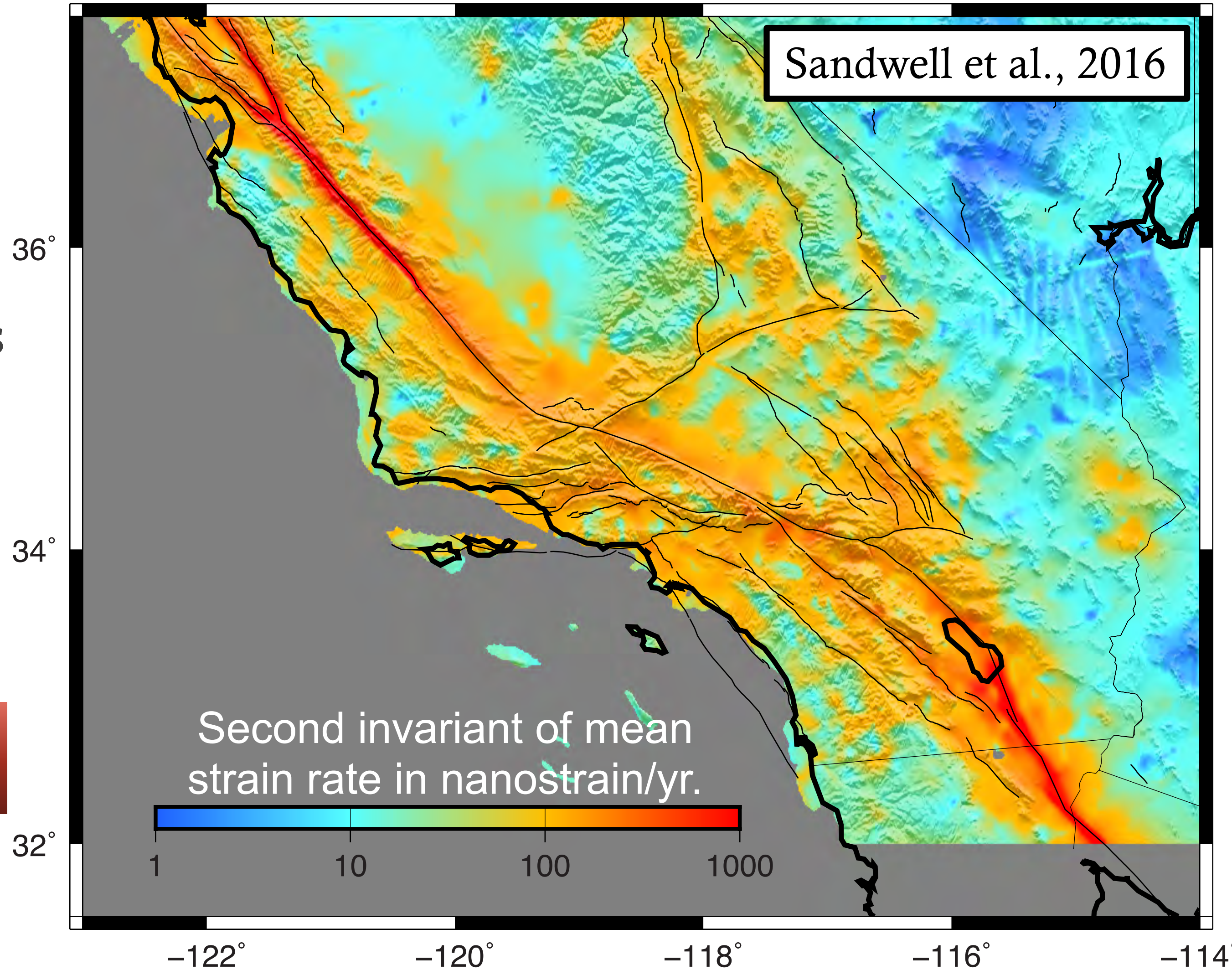
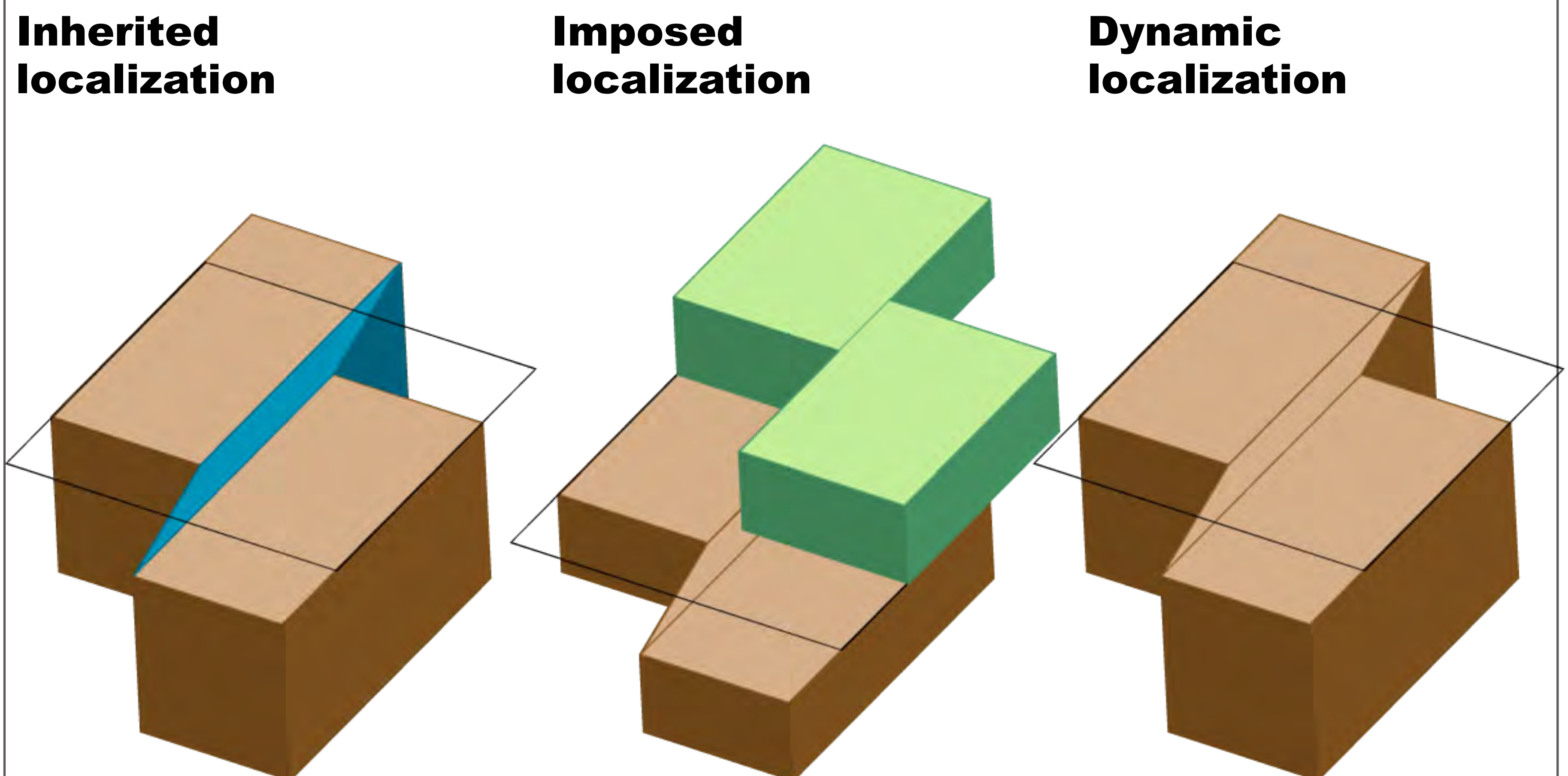
Rheology

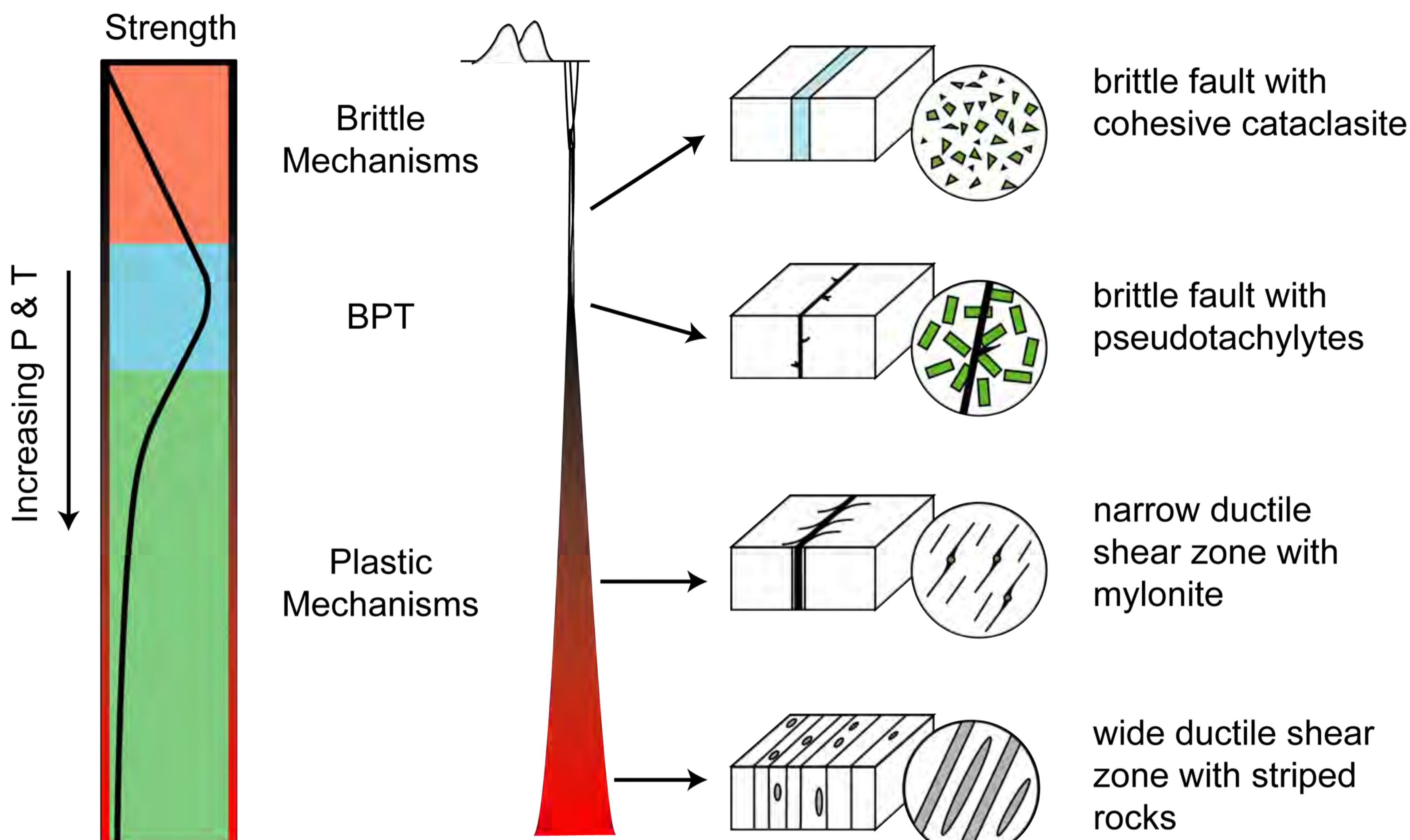


Three localization scenarios



Montési and Zuber, 2002

Faults and shear zones



Sibson 1977, 1983
Scholz 1988,1990

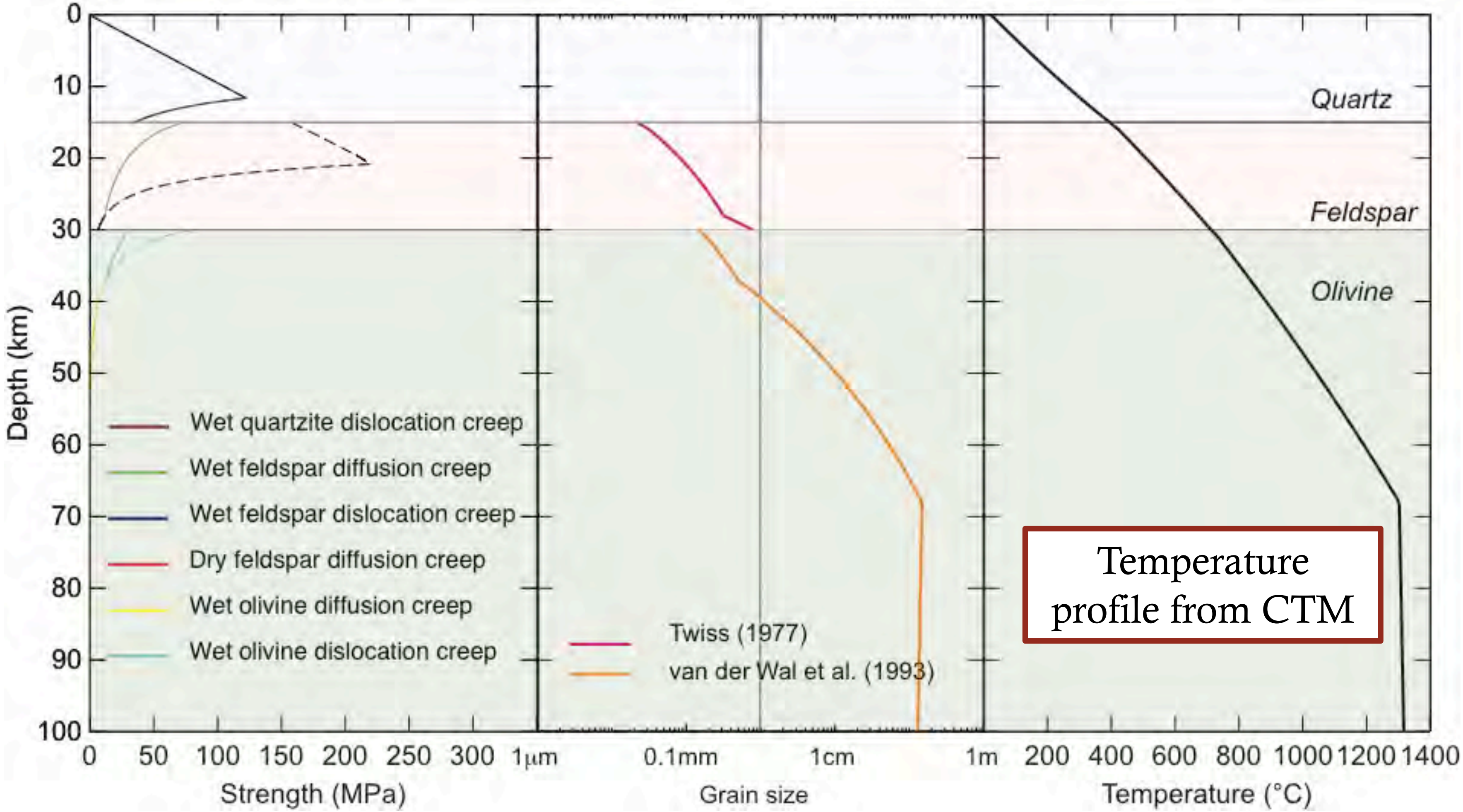
Diagram from Passchier and Trouw

Shear zone structure

- Requires change in state or environment
  - Temperature
  - Grain size
  - Interconnection of weak phase
  - Abundance of weak phase
  - Composition (metamorphism, melt)

L-S tectonites, South Armorican Shear Zone
F. Gueydan, personal communication, 2006

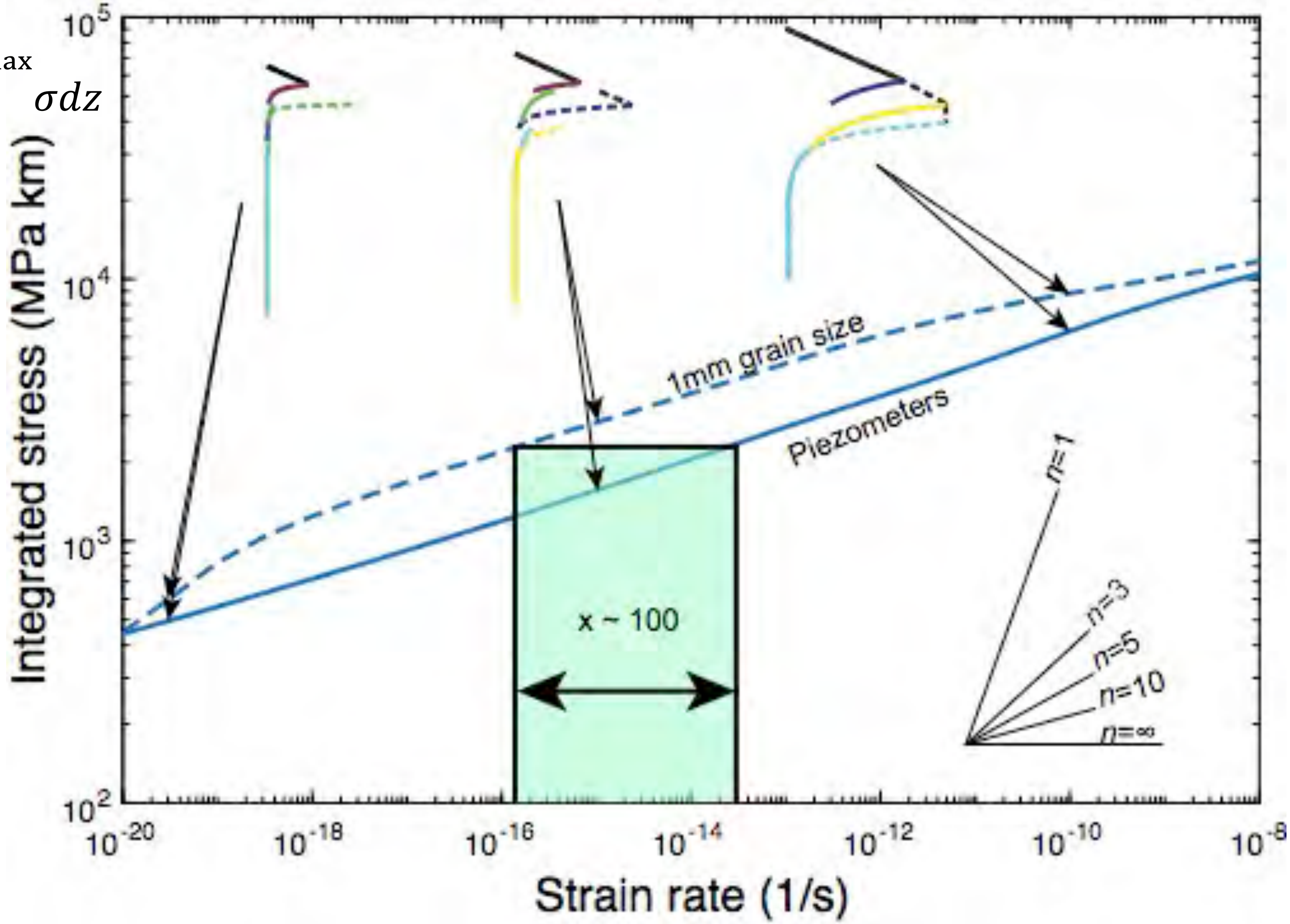
Reduced grain size



Temperature profile from CTM

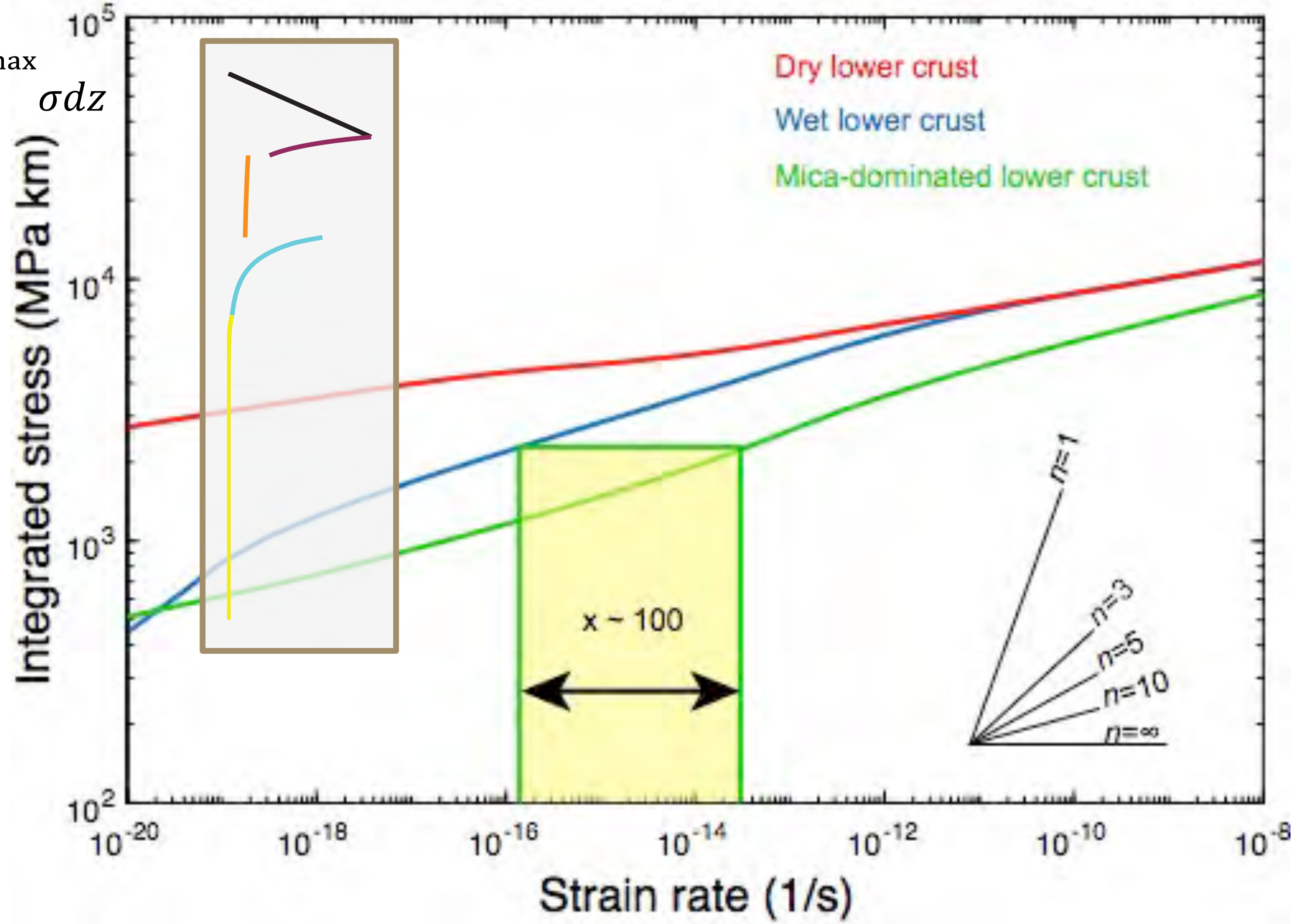
Effective rheology – grain size

$$S = \int_0^{z_{\max}} \sigma dz$$

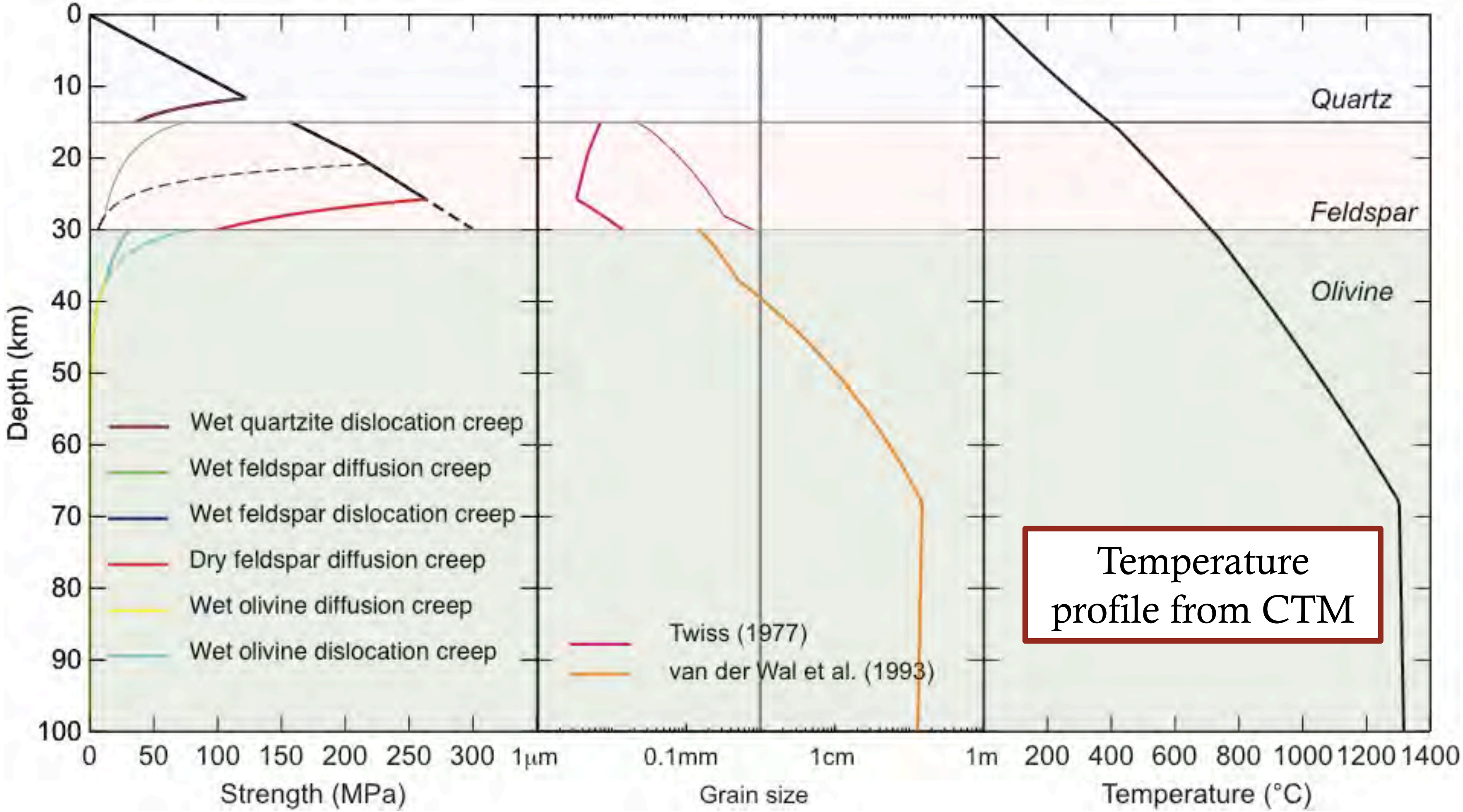


Effective rheology – Micas

$$S = \int_0^{z_{\max}} \sigma dz$$

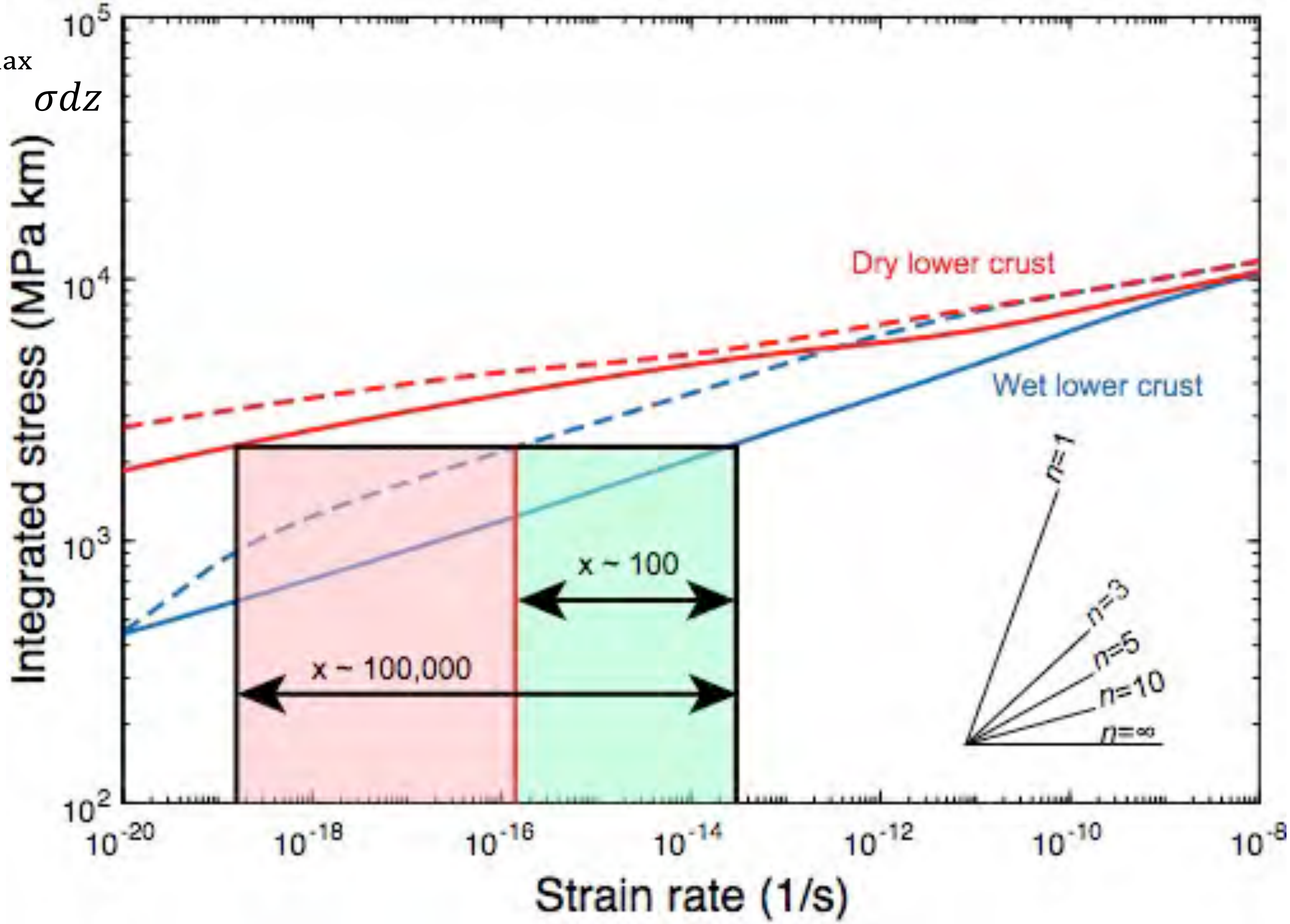


Dry lower crust



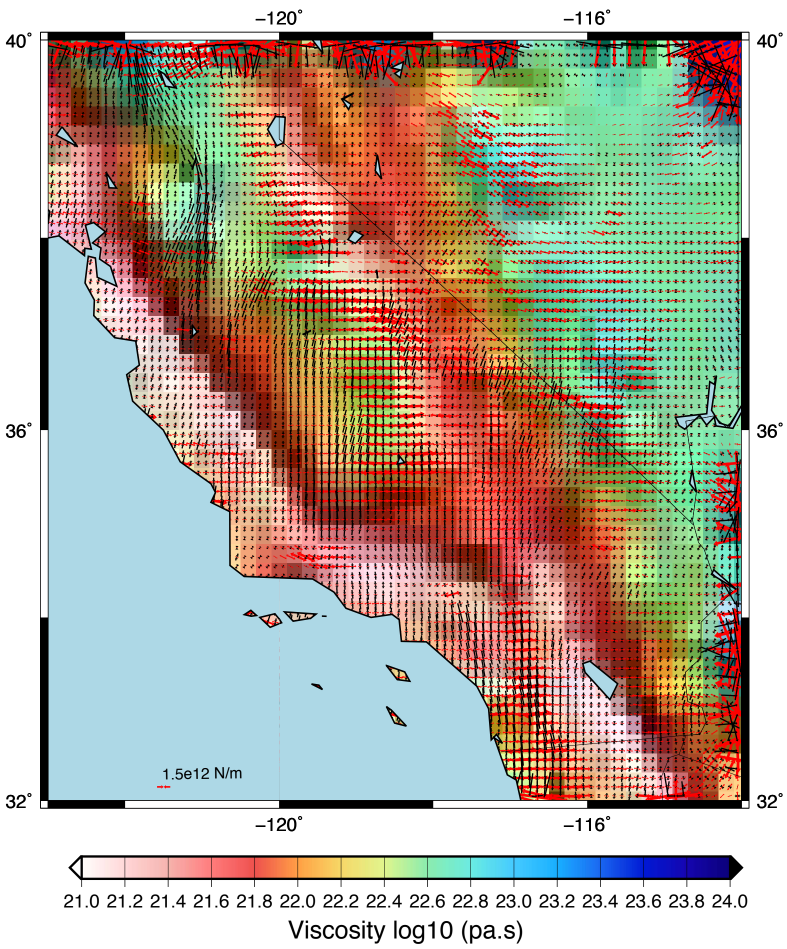
Effective rheology – wet vs. dry

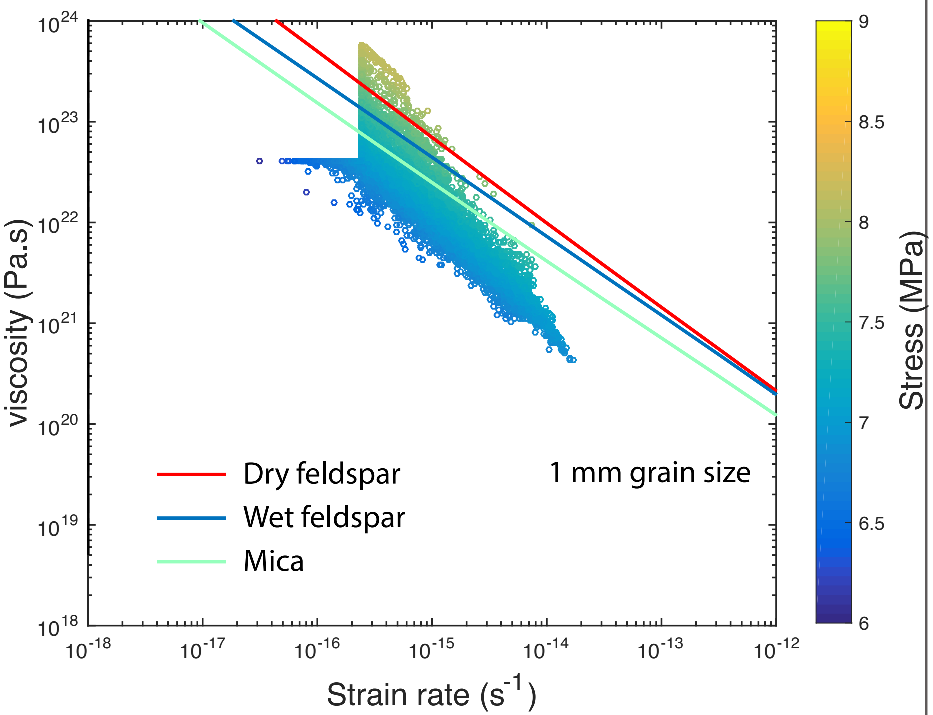
$$S = \int_0^{z_{\max}} \sigma dz$$



Comparison with geodetic models

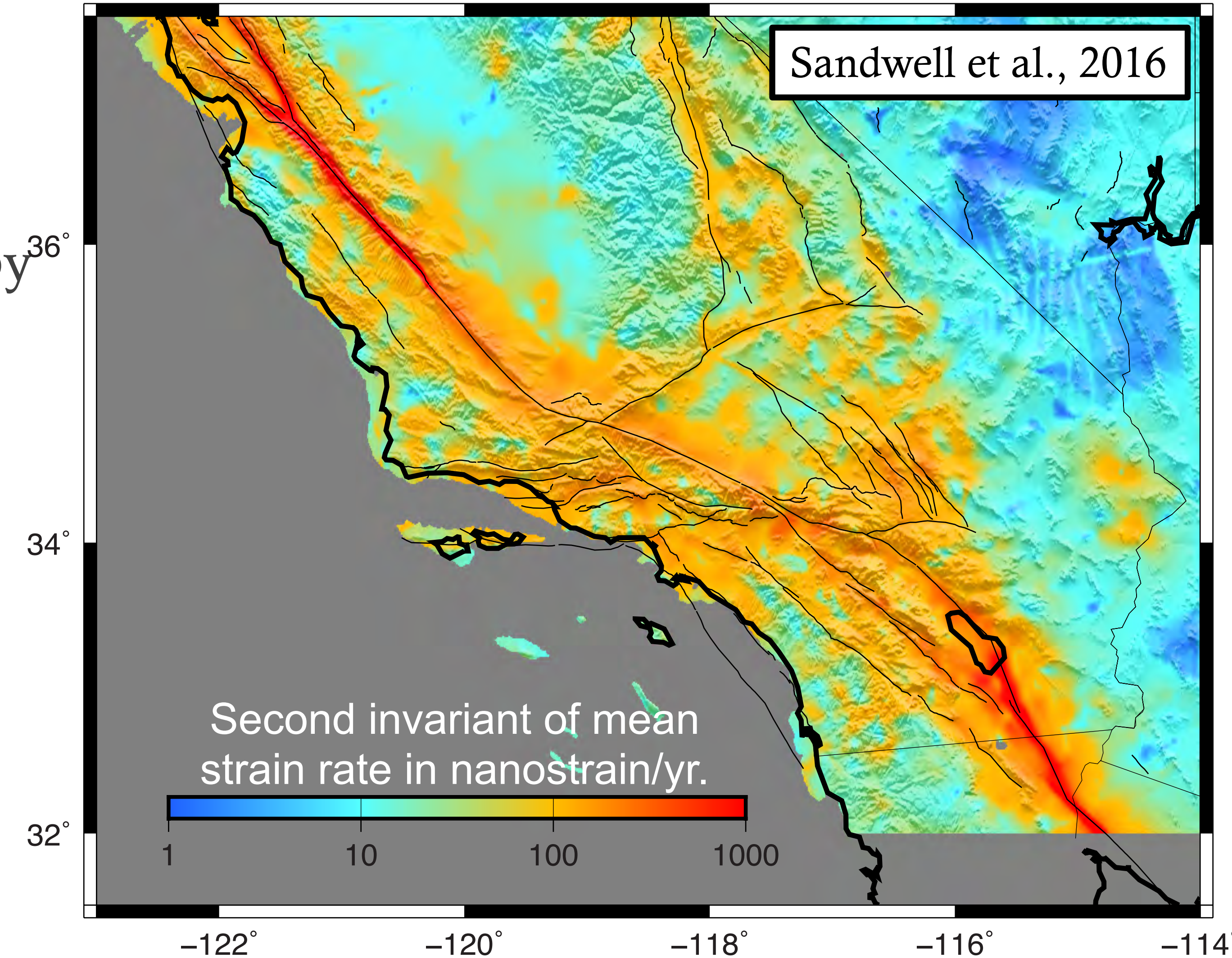
- Viscosity estimate from geodynamics and geodesy (Holt and Bahadori)
- Caveat: no variation in structure or temperature profile in rheological model





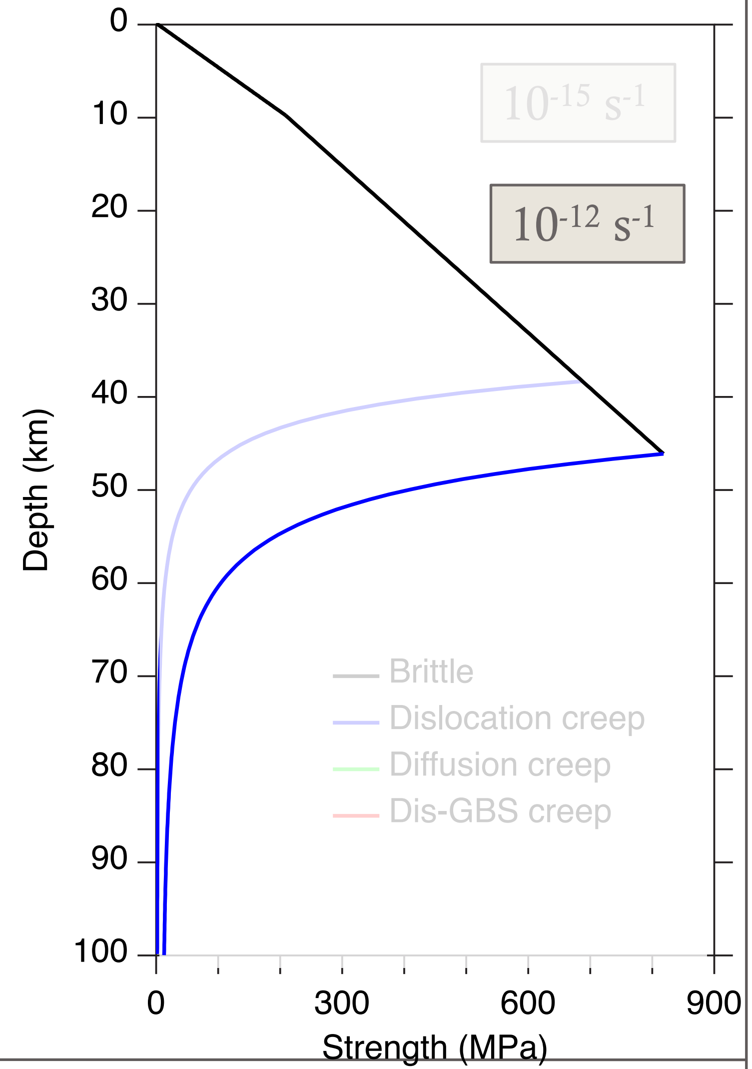
Summary

- Grain size reduction increases strain rate by ~100
  - Localized shear zones?
- Lithology matters
  - Different blocks?



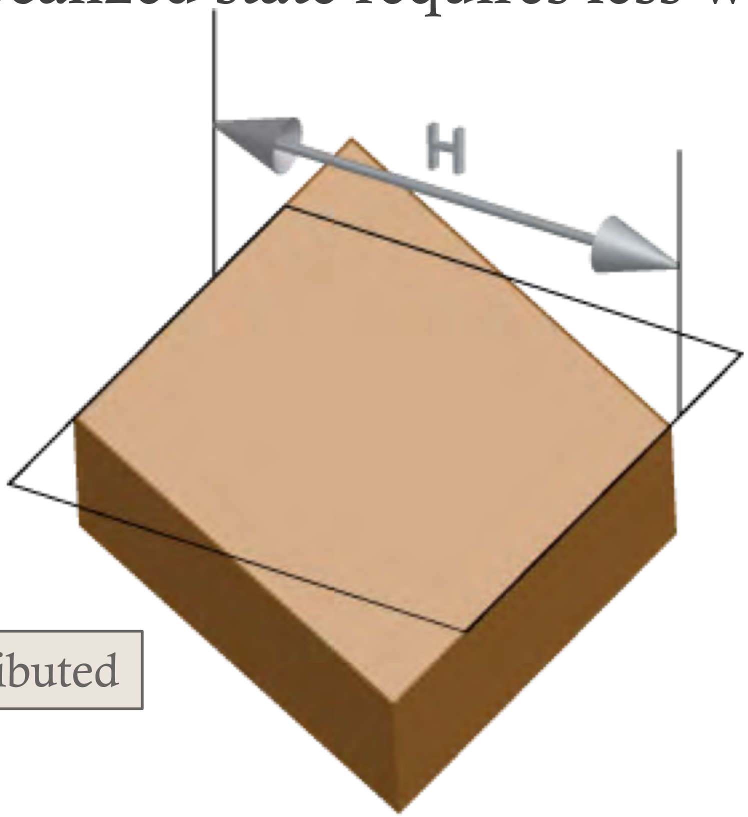
Lithospheric rheology models

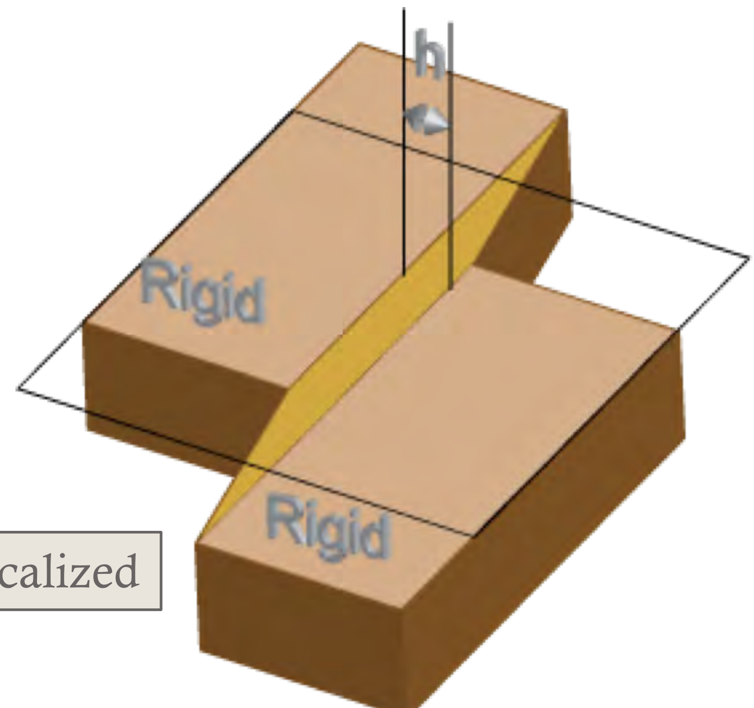
- Strength envelope approach (Brace and Kohlstedt, 1980)
  - Brittle strength from Byerlee (1978) with hydrostatic conditions in the crust
  - Dry olivine mantle (Hirth and Kohlstedt, 2006) with dislocation creep, diffusion creep, and dis-GBS creep
  - Wet anorthosite crust (Rybacki and Dresen, 2006) with dislocation creep and diffusion creep
- Conductive temperature profile (15°C to 1350°C) with surface geotherm of 20 or 50 K/km



Localization Potential

- Compare work in localized and distributed states
- Localization potential: Maximum $L=H/h$ for which localized state requires less work for same overall velocity





Montesi, 2013