Linear rheologies versus lab-derived flow laws and heterogeneity of lithosphere deformation

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Linear Rheologies to Model Earthquake Cycle

Hooke solid
\[ \varepsilon = \sigma / \mu_1 \]

Maxwell fluid
\[ \dot{\varepsilon} = \dot{\sigma} / \mu_1 + \sigma / \eta_1 \]

Newton fluid
\[ \dot{\varepsilon} = \sigma / \eta_1 \]

Burgers body
\[ \eta_2 \dot{\varepsilon} + \mu_2 \varepsilon = \sigma \]

Kelvin solid
Lab-derived Non-linear Rock Rheology

\[ \varepsilon = A \sigma^n d^{-m} f_{H_2O}^r \left( \frac{Q+pV}{RT} \right) \]

where \( A \) is a material constant, \( \sigma \) is differential stress, \( n \) is the (power-law) stress exponent, \( Q \) is activation energy, \( p \) is pressure, \( V \) is activation volume, \( T \) is absolute temperature, \( R \) is the molar gas constant, \( d \) is grain size, \( m \) is the grain size exponent, \( f_{H_2O} \) is the water fugacity, and \( r \) is the fugacity exponent.

For Steady State Dislocation Creep: Need to know Temperature, Strain Rate, Grain Size, Water, ...

CRM: “We propose developing a repository of bulk rock and shear zone rheologies based on composition, temperature and (for power-law flow) assumed strain rate.”
Need to Get Located on Deformation Mechanism Map

![Deformation Mechanism Map](image)

- **GB - Diffusional Flow (linear)**
- **Dry**: An$_{100}$ (0.004 wt% H$_2$O)
- **Wet**: An$_{100}$ (0.07 wt% H$_2$O)
- **Power-Law Creep**

Rybacki & Dresen, 2004
Power-law Rheology of Mojave Lower Crust and Mantle

- **Mineralogy**: Wet Olivine
- **Creep Mechanism**: Dislocation Creep
- **Grain Size**: 10-20 mm
- **Strain Rate**: 0.1 µstrain/yr

- Mantle below ~40 km depth is hot, wet and weak asthenosphere
- Mantle viscosity is stress and time dependent due to power-law rheology

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Need to Get Located on Deformation Mechanism Map (spatially and temporally variable)

Rybacki & Dresen, 2004
Need 4D Geology

Bürgmann & Dresen, 2008

Hirth, 2013

Behr and Hirth, 2014
Mojave: Rock rheology from postseismic deformation

- Strong lower crust over wet and weak mantle asthenosphere

Cholame: Deep fault strength from tidally triggered tremor

- Extremely weak and localized lower-crustal fault zone
Localization and Weakening Of Fault Zones in the Lower Crust

\[ \tau = \sigma \left[ \mu + a \ln \left( \frac{V}{V_o} \right) + b \ln \left( \frac{V_o \theta}{d_c} \right) \right] \]

Johnson and Shelly, 2012

Bruhat et al., 2011

% excess of LFE events at positive tidal shear stress

Thomas et al., 2012
Mojave, Basin and Range etc.

Strong lower crust

Parkfield SAF
Ultra-weak, frictional, tremor-producing, lower-crustal shear zone

Rybacki & Dresen, 2004
Mature SAF at Cholame

- Extremely weak, and localized lower-crustal fault zone

Mojave Desert

- Strong lower crust over weak mantle asthenosphere

Linear rheologies versus lab-derived flow laws and heterogeneity of lower-crustal deformation

Thomas et al., 2012
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Mojave Desert
• Strong lower crust over weak mantle asthenosphere

Mature SAF at Cholame
• Extremely weak, and localized lower-crustal fault zone

Quartzofeldspathic granulites (S. Madagascar)

Mylonitic metasediments (Cap de Creus shear belt Spain)

Bürgmann & Dresen, 2008