Workshop Summary: Ductile Rheology of the Southern California Lithosphere: Constraints from Deformation Modeling, Rock Mechanics and Field Observations

The question

plate 1

plate 2

fault | brittle upper crust

mantle asthenosphere

?
Some Possible Geometries for Ductile Lithosphere

Case 1
Ductile Flow Mostly in Lithospheric Mantle & Asthenosphere

Seismogenic Upper Crust
Aseismic Lower Crust
Lithospheric Mantle

MOHO
LAB

Brittle/Ductile Transition
Tremor Events
WEAK

STRONG
WEAKEST

Case 2
Ductile Flow Mostly in Weak Shear Zone

Brittle/Ductile Transition
WEAK DUCTILE SHEAR ZONE

MOHO
LAB

Case 3
Ductile Flow Mostly in Weak Lower Crust

MOHO
LAB

WEAK
STRONG

W Thatcher
Workshop Summary: Ductile Rheology of the Southern California Lithosphere: Constraints from Deformation Modeling, Rock Mechanics and Field Observations

- deformation modelers
- mineral physicists
- field geologists
Current areas of focus for participants’ deformation modelers

1. rheology

Explore power law, transient, and power law + transient rheology combinations for models of postseismic and interseismic deformation.

2. shear zones

Tremor may argue that a deep SAF SZ is present and provide constraints on its rheology (e.g. D. Shelly). Physics plus flow laws also seem to require the development of shear zones (Takeuchi and Fialko, 2012; Montesi 2004). Earthquake cycle models with shear zones... (T and F 2012; Johnson et al. 2007; Hetland 2012; Hearn 2012).

3. material heterogeneity

Geophysical studies suggest heterogeneous lithosphere thickness, asymmetric structure and/or dipping fault geometry. Including these may improve model fit to data and makes models more realistic (e.g. Pollitz et al. 2012; Ryder et al., 2011).
Rheology of the Crust and Mantle

(steady-state rheology)

A

Differential stress [MPa]

0 100 200 300 400 500 600

dislocation creep, \( \dot{\varepsilon} = 10^{-14} \text{s}^{-1} \)

Depth [km]

wet quartz

wet feldspar

Moho (T = 680 °C)

dry olivin

B

Differential stress [MPa]

100 200 300 400 500 600

dislocation creep, \( \dot{\varepsilon} = 10^{-14} \text{s}^{-1} \)

Moho (T = 790 °C)

dry feldspar

dry olivin

C

Differential stress [MPa]

100 200 300 400 500

diffusion creep, \( \dot{\varepsilon} = 10^{-14} \text{s}^{-1} \)

wet quartz

wet feldspar

wet olivin

G Hirth
Shear Zones

Brittle Mechanisms
- Brittle fault with cohesive cataclasite
- Brittle fault with pseudotachylytes

Plastic Mechanisms
- Narrow ductile shear zone with mylonite
- Wide ductile shear zone with striped rocks

Strength

Increasing P & T

Sibson 1977, 1983
Scholz 1988, 1990

Diagram from Passchier and Trouw

L Montesi
Transient viscoelastic rheology

Jackson et al., 2002

response: elastic + transient + viscous
Lab based steady-state ductile flow laws are supported by field based observations at same P, T, state.

We should use these laws in modeling seismic cycle, along with candidate transient flow laws.

Relatively narrow ductile shear zones exist beneath seismogenic faults with large displacements.

“Ghost transients” from past, large earthquakes could be important contaminants of presumed steady-state surface deformation field.

SCEC4 goal: Map 3D structure of S. California ductile lithosphere via seismic imaging, infer P-T-state, rock type, define range of possible ductile rheologies.

Need to explain postseismic, interseismic and long-term (e.g. lake unloading) deformation in the same region with the same Earth. More sophisticated models and inversions, transient rheology?
Relevance to CDM (modelers’ perspective)

- Constrain rheology with postseismic deformation models: spatially and temporally dense postseismic velocities. Dense, high-precision 3D pre-earthquake velocity field and coseismic displacements.

- Bracket rheology with interseismic deformation: spatially dense 3D surface deformation field. Will we ever see curvature (Japan)?

- Be able to remove seasonal signal and apparent signals due to non-tectonic activity.

- Slow slip events: identify and characterize

- (CSM): use aforementioned rheologies into deformation models calibrated to surface velocity field (and other constraints)