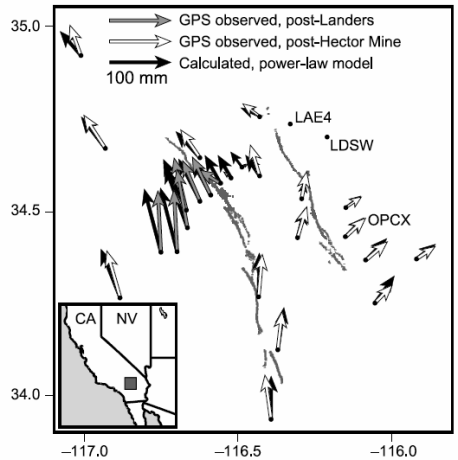
transient rheologies for postseismic & interseismic models

for timescales of days–kyrs (postseismic–seismic cycle), not rupture timescales…

potential transient rheologies to consider:

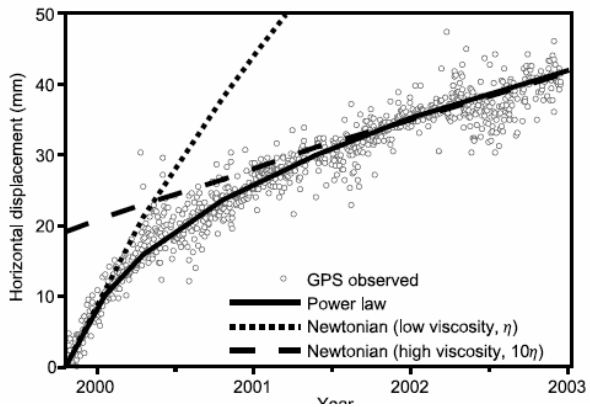
- transient viscoelastic rheologies (not σ dep)
- non-linear Maxwell viscosity (power-law flow)
- stress-dependent fault slip (e.g., friction)
- poroelasticity
- plasticity
- damage

postseismic deformation in the Mojave

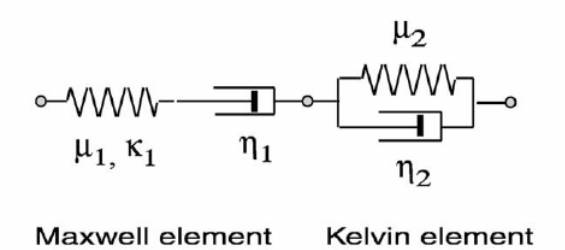


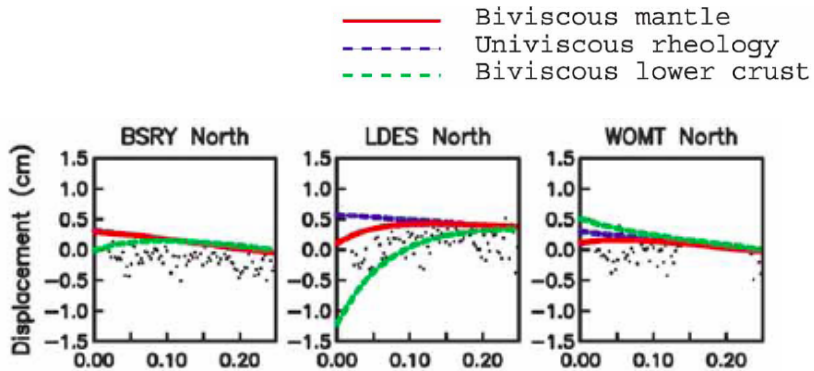
Freed and Bürgmann, 2004

post-Landers & Hector deformation can be described by **non-linear viscous** relaxation



post-Hector deformation may also be described by **linear transient viscoelastic** relaxation



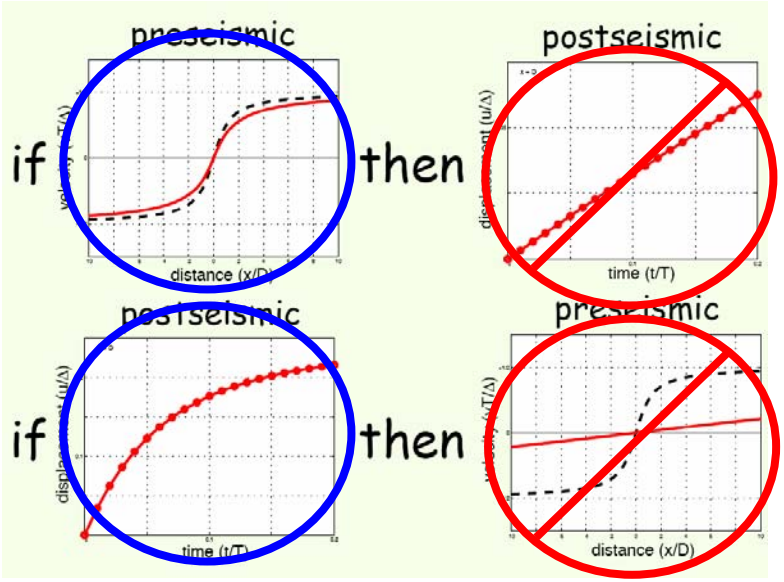


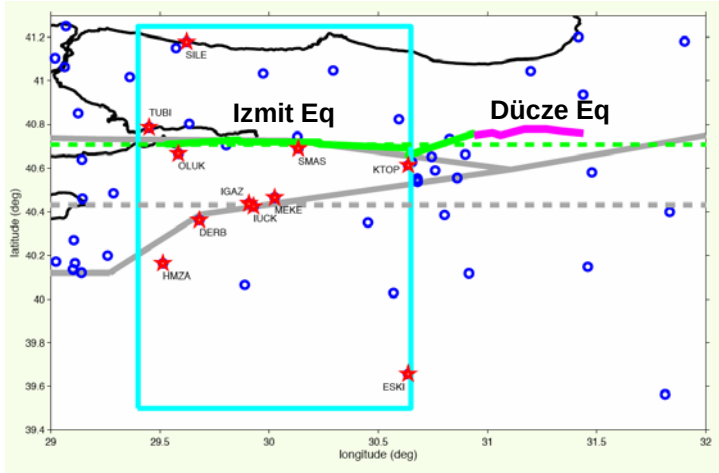
Pollitz, 2003

avoiding scientific debates, postseismic deformation seems to require some transient rheologies

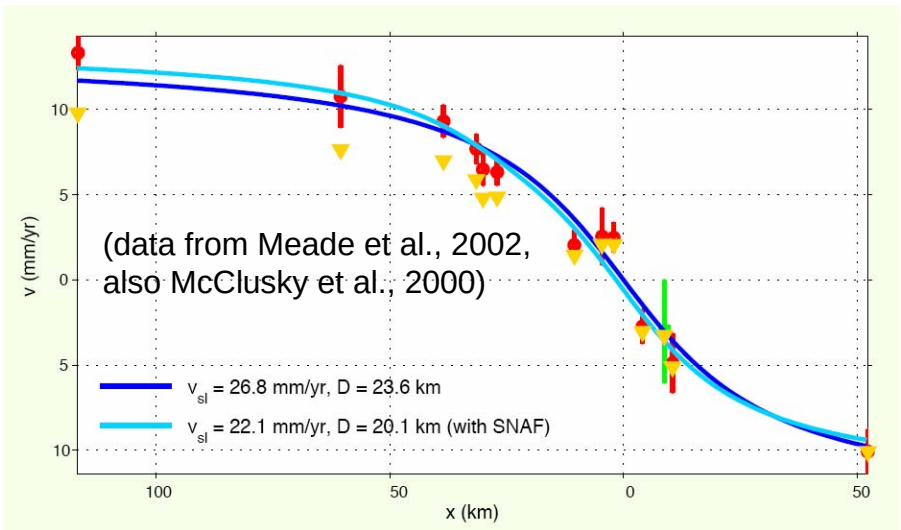
interseismic deformation may also require transient deformation

predictions of 2D interseismic models with only Maxwell viscoelasticity (Savage and colleagues, 1978, 1998, 2000)

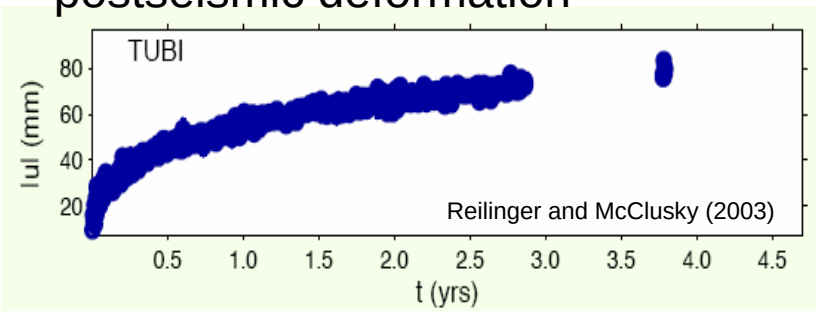




interseismic velocities



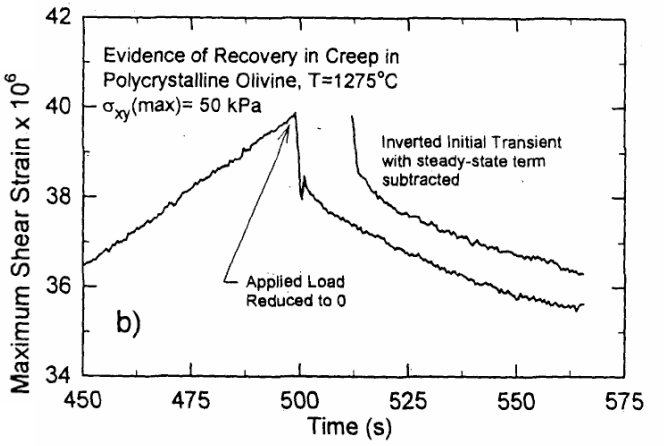
postseismic deformation



to be complete, interseismic deformation models also need transient rheologies

viscoelastic transient rheologies

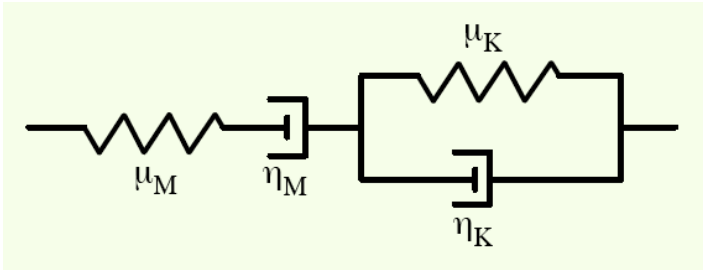
invoked for postglacial rebound (e.g., Yuen et al., 1986) and attenuation (e.g., Jackson et al., 2002)



Gribb and Cooper (1998)

also Carter and Ave'Lallement (1970) and Chopra (1997)

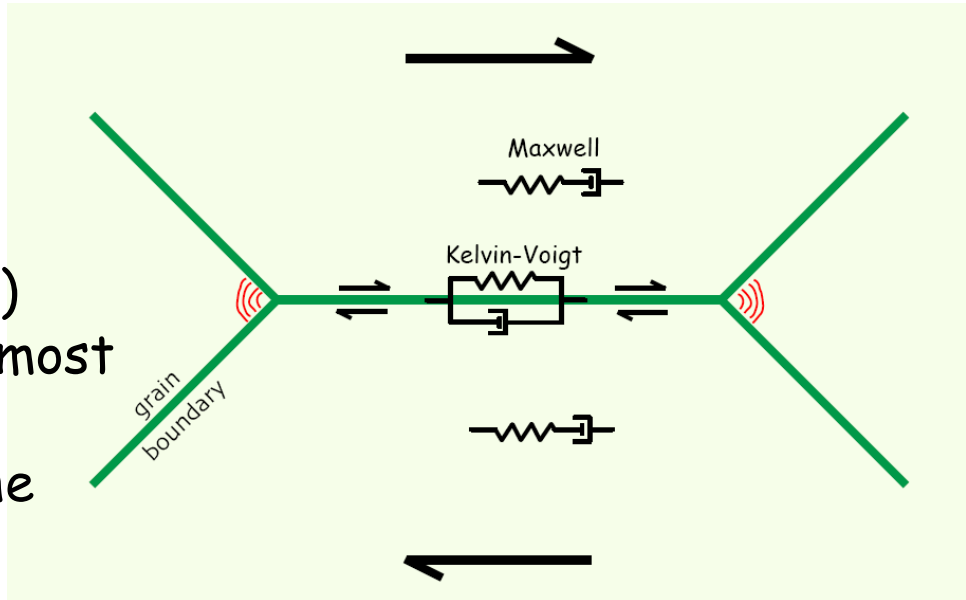
simplest VE rheology with a recoverable transient phase:



J.M. Burgers, "Mechanical considerations – model systems – phenomenological theories of relaxation and of viscosity" (1939)

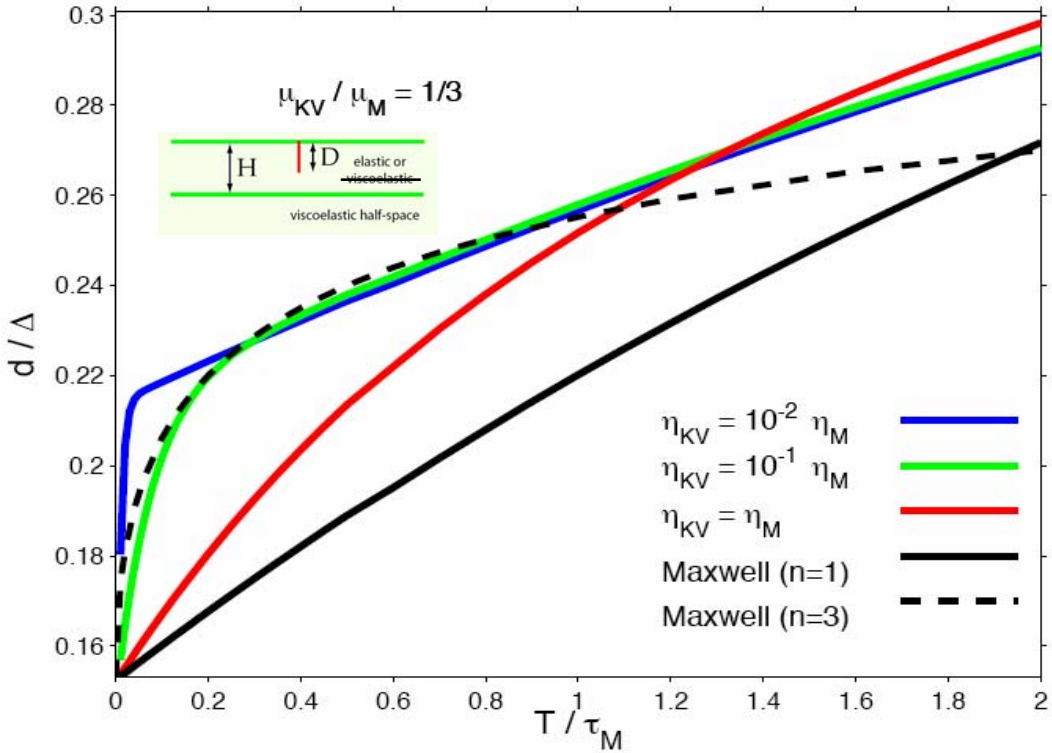
Jan Burgers (1895-1981) Dutch fluid dynamicist, most known for the "Burgers Equation", brother of the crystallographer W.G. Burgers.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.



Hetland, Hager, O'Connell (2002 - AGU)

postseismic deformation with VE transient rheologies



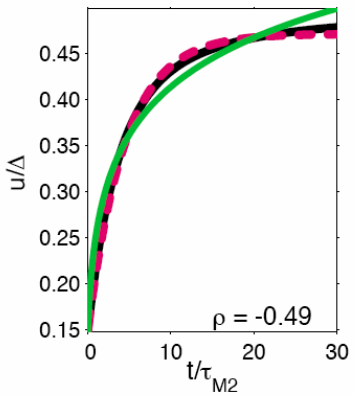
1D view of postseismic deformation:

$\ln(1+t/\tau)$ ⇨ after-slip
(e.g. Marone et al., 1991)

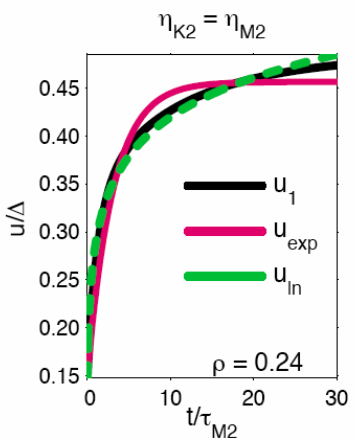
$1-e^{-t/\tau}$ ⇨ viscoelasticity

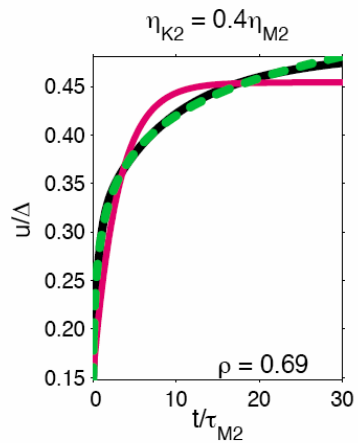
2D models

Maxwell model



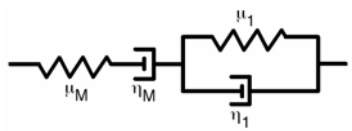
Burgers models (see Hetland and Hager, 2006)



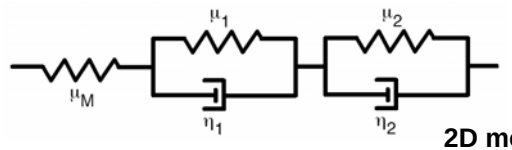


ignoring geometry, all of these can be equivalent:

$A \cdot \ln(1+t/\tau)$ **1D model**



2D model



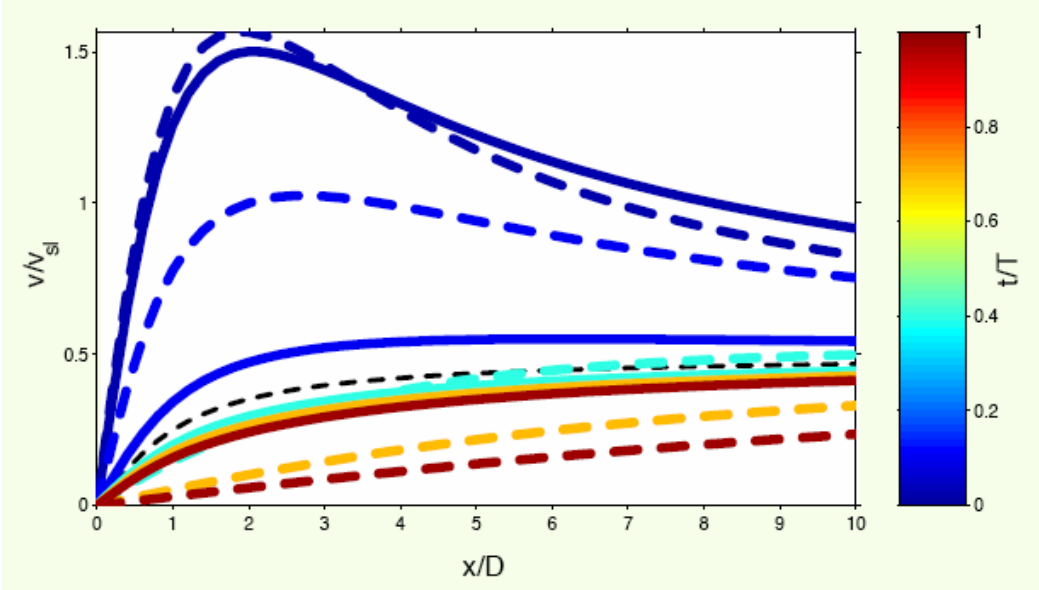
2D model

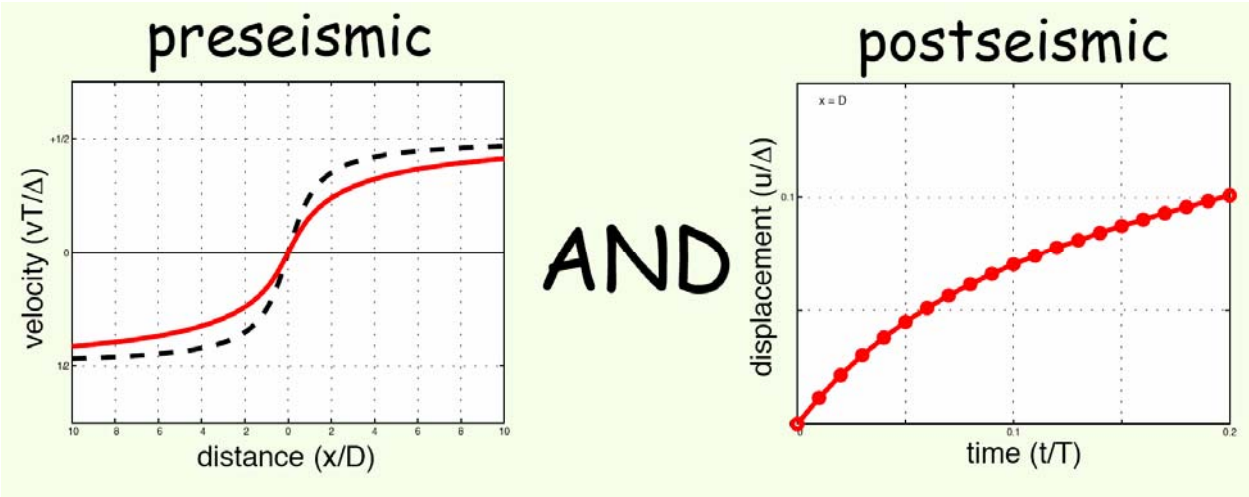
interseismic deformation with VE transient rheologies

interseismic velocities decay rapidly early, slowly in late cycle

univiscous model

biviscous model





NAF:

- $\tau_M \geq$ 500 yrs
- $\tau_K \approx$ 2–5 yrs

μ_M = 60GPa and $\mu_M = 3\mu_K$

→ $\eta_M \geq 10^{21}$ Pa·sec,

→ $\eta_K \approx 10^{19}$ Pa·sec

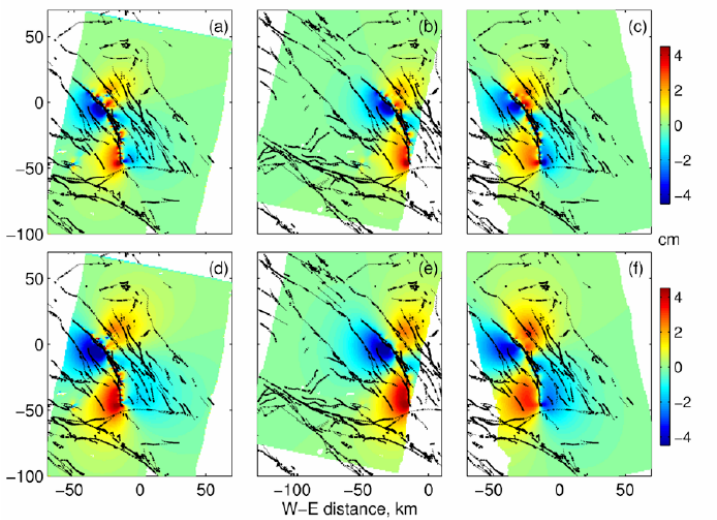
(Hetland et al, in prep.)

see also Hetland and Hager, 2005

story is not quite complete in the Mojave…

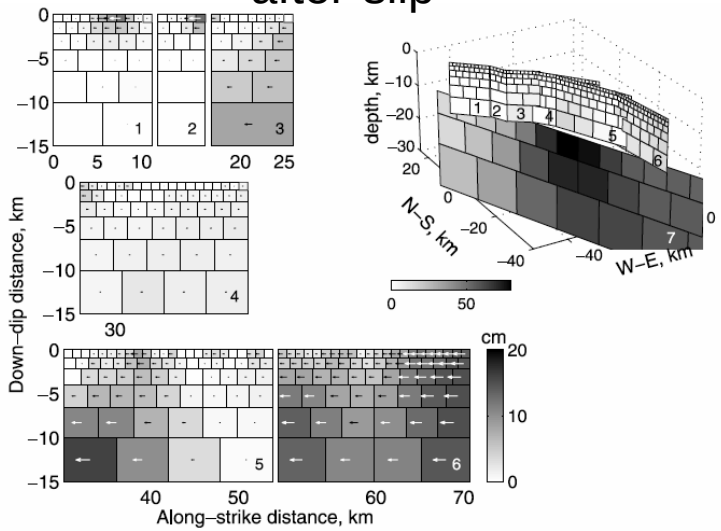
post-Hector deformation can also be described by **poroelasticity** and **after-slip** – both kinematic (Fialko, 2004)

poroelasticity 0-2.5 km depth



poroelasticity up to 15 km depth

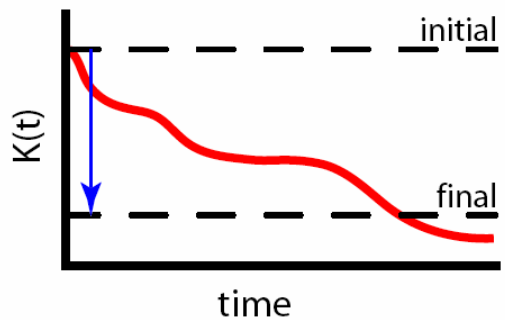
after-slip



to describe time dependent deformation, available FEM rheologies should *also* include:

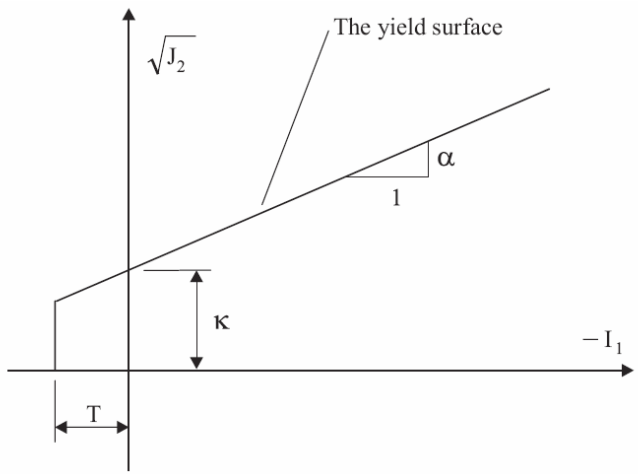
stress-dependent fault slip (e.g., rate-state friction, Marone et al., 1991 – more from Brad A.)

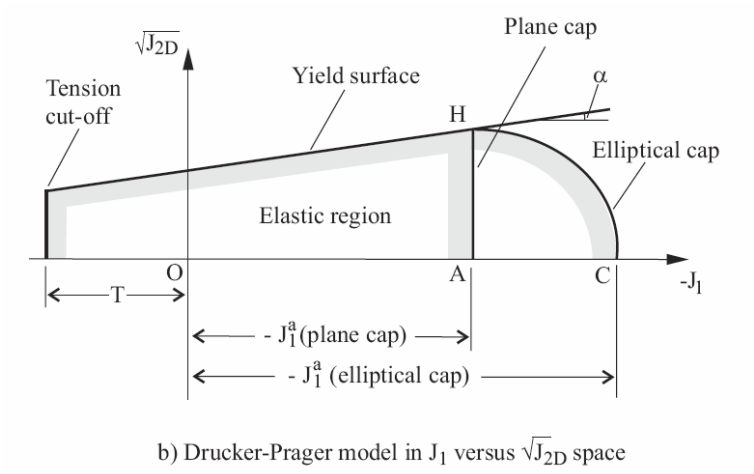
poroelasticity, or rheologies approximating effects of bulk (modulus) relaxation, i.e., something better than final minus initial elastic calculations



plastic rheologies, for instance:

Mohr-Coulomb





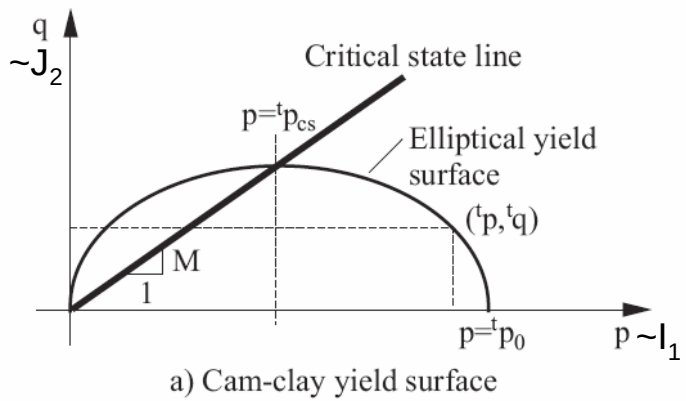
b) Drucker-Prager model in J_1 versus $\sqrt{J_{2D}}$ space

Druker-Prager

(in tecton, soon in pylith?)

Cam-Clay

(clayey consolidation behavior, hardening/softening, volumetric elastic strain non-linear with hydrostatic pressure, associated flow)

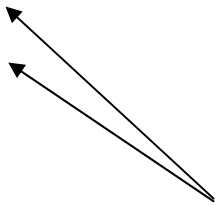


a) Cam-clay yield surface

diagrams from Adina reference manual

damage rheologies

evolution of rock elastic moduli and strength due to rock damage (eg. increase in crack density) at increasing loads before failure – see papers by Ben-Zion, Hamiel, and Lyakhovsky



brittle failure

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Hamiel et al., 2004

transient rheologies:

potential transient rheologies to consider:

- transient viscoelastic rheologies
- non-linear Maxwell viscosity
- stress-dependent fault slip
- poroelasticity
- plasticity
- damage

transient rheologies:

Easy:

Hard: