GRC – ROCK DEFORMATION: REAL-TIME RHEOLOGY
Aug. 3 - Aug. 8, Tilton NH

Earthquakes and the Rheology of the Lithosphere
Discussion Leader: Terry Tullis
Keynotes: Susan Owen & Greg Beroza

Rheological Properties of Faults During Earthquakes
Discussion Leader: Tom Heaton
Keyotes: Judi Chester, Nick Beeler & Yehuda Ben-Zion

Deformation of Ice sheets and Glaciers
Discussion Leader: Erland Schulson
Keynotes: David Goldsby, Neal Iverson &Sridhar Anandakrishnan

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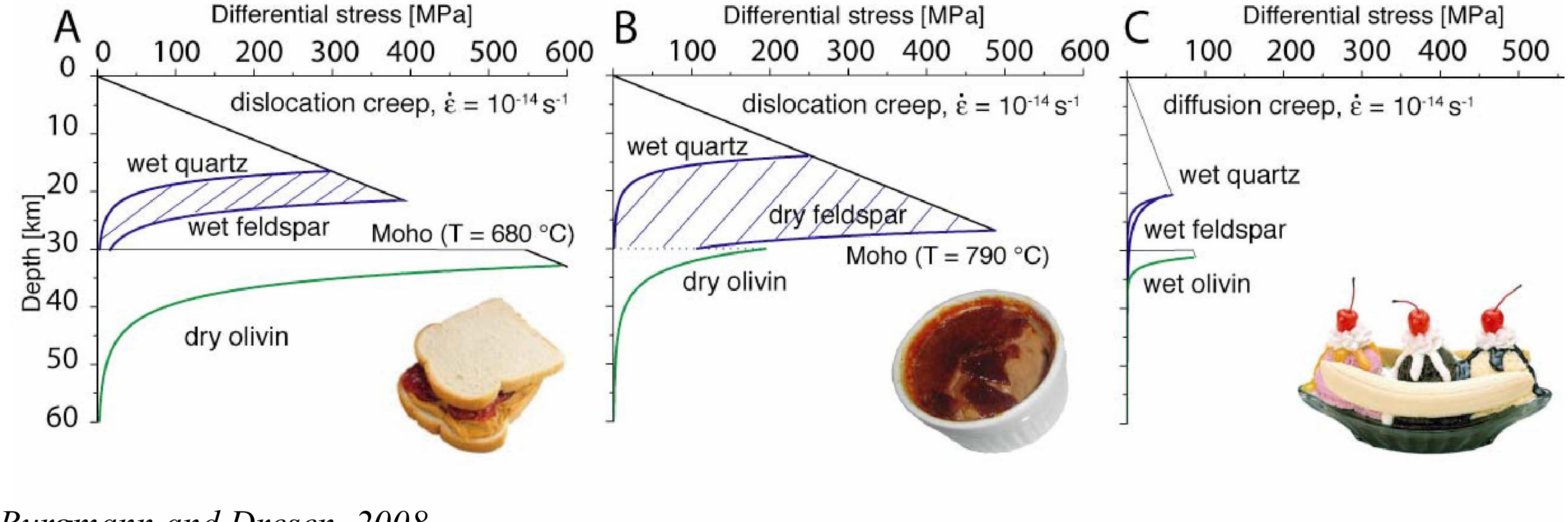
Seismic Attenuation and Rheology of the Upper Mantle
Discussion Leader: Doug Wiens
Keynotes: Marshall Sundberg & Colleen Dalton

Deformation and Rheology of the Lower Continental Crust
Discussion Leader: Steve Mackwell
Keynotes: Georg Dresen, Alex Copley & Roland Burgmannn

Linking Mantle Anisotropy and Rheology
Discussion Leader: Neil Ribe
Keynotes: Martyn Drury, Donna Blackman & Einat Lev

Future Directions in linking rheology and reactive porous flow
Discussion Leader: Wenlu Zhu
Keynotes: Steve Karner & Peter Kelemen

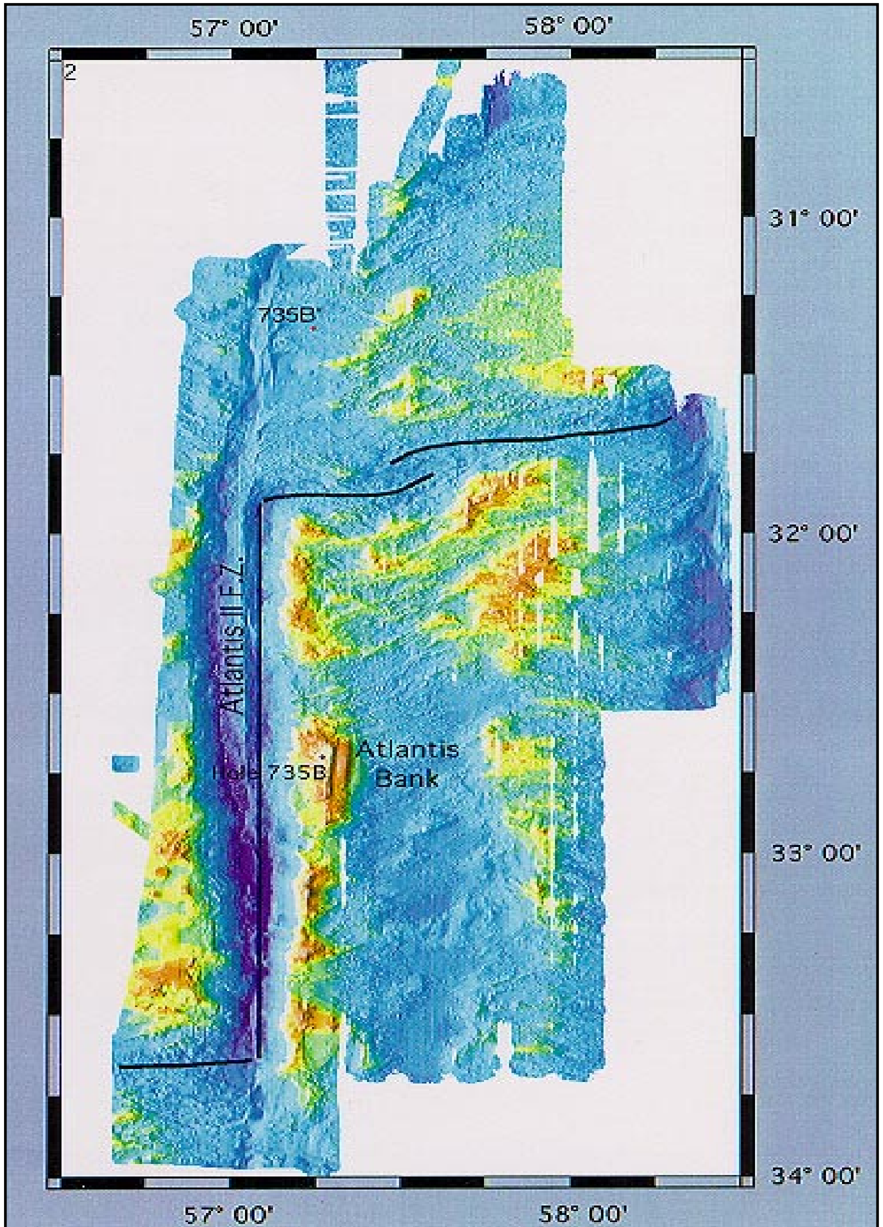
Lithosphere Rheology

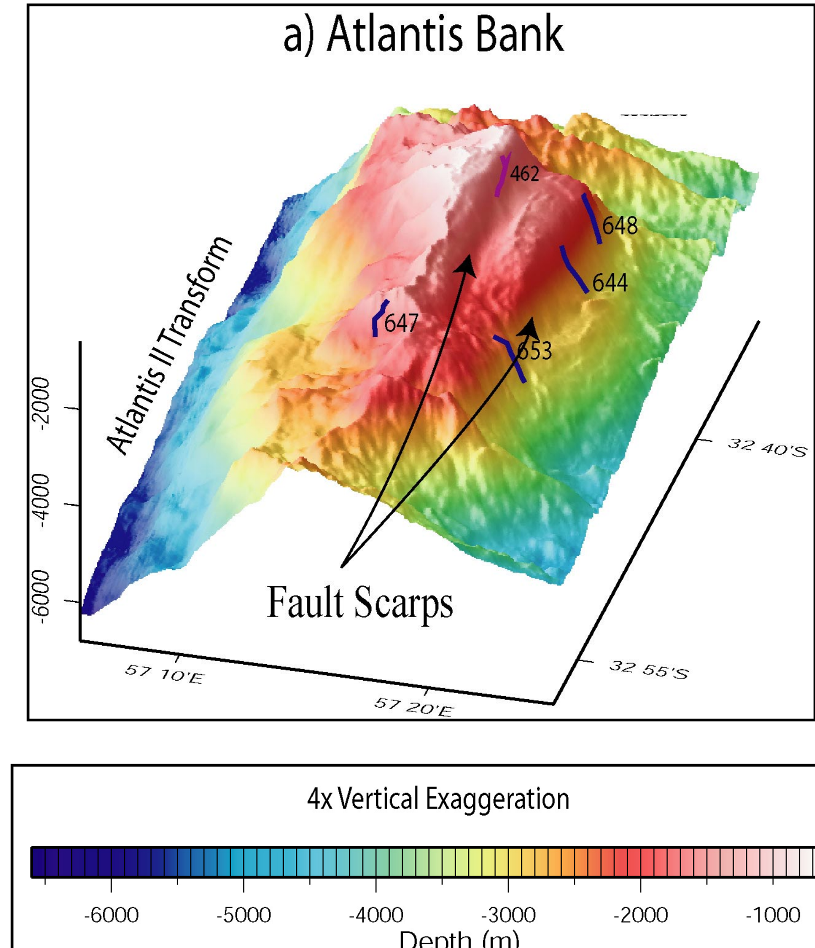


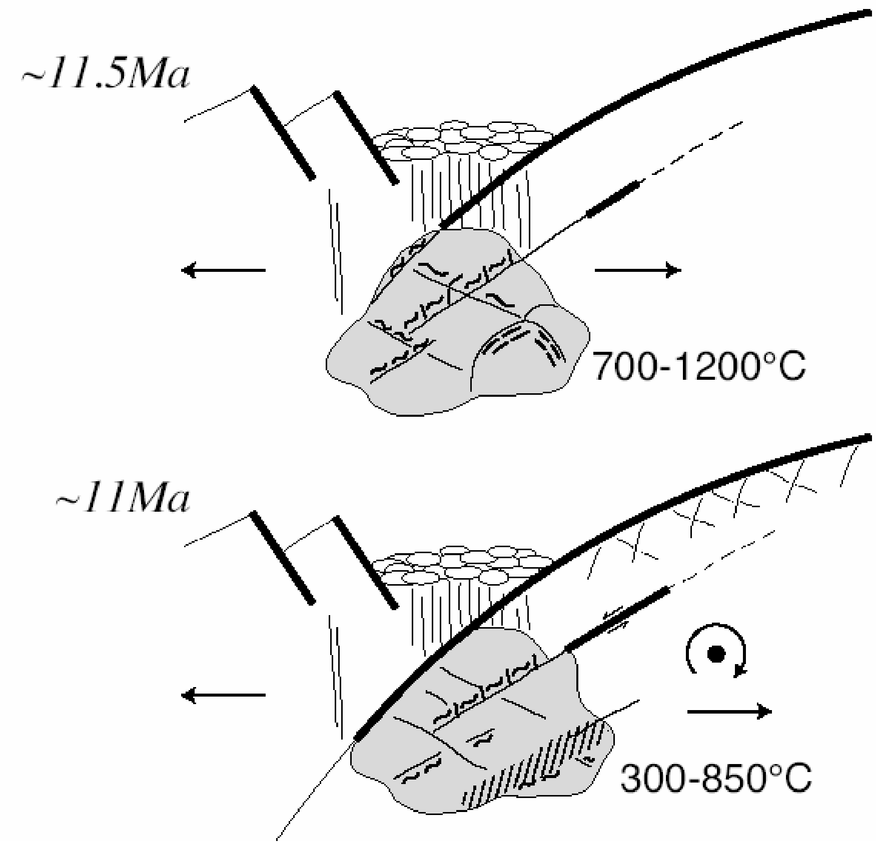
Burgmann and Dresen, 2008

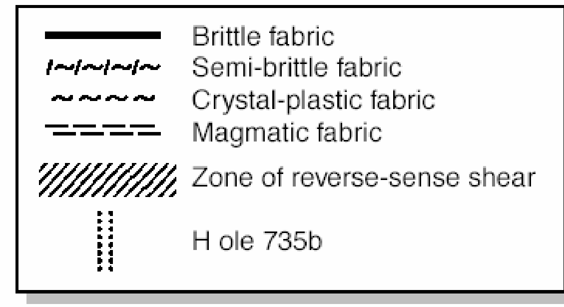
Dry Lower Crust: Luc Mehl
Wet Lower Crust & Mantle: Janelle Homburg & Peter Kelemen
Mantle Shear Zones: Jessica Warren
Mantle Seismicity: Margaret Boettcher & Brian Evans

Atlantis Bank, SWIR

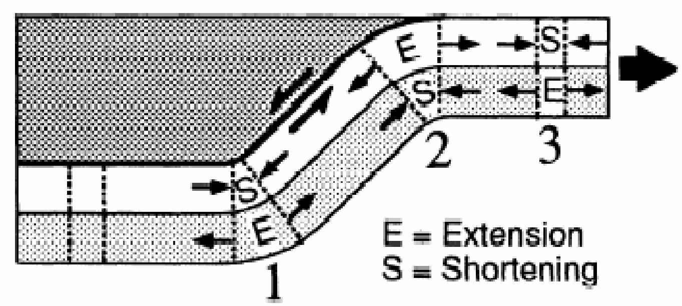


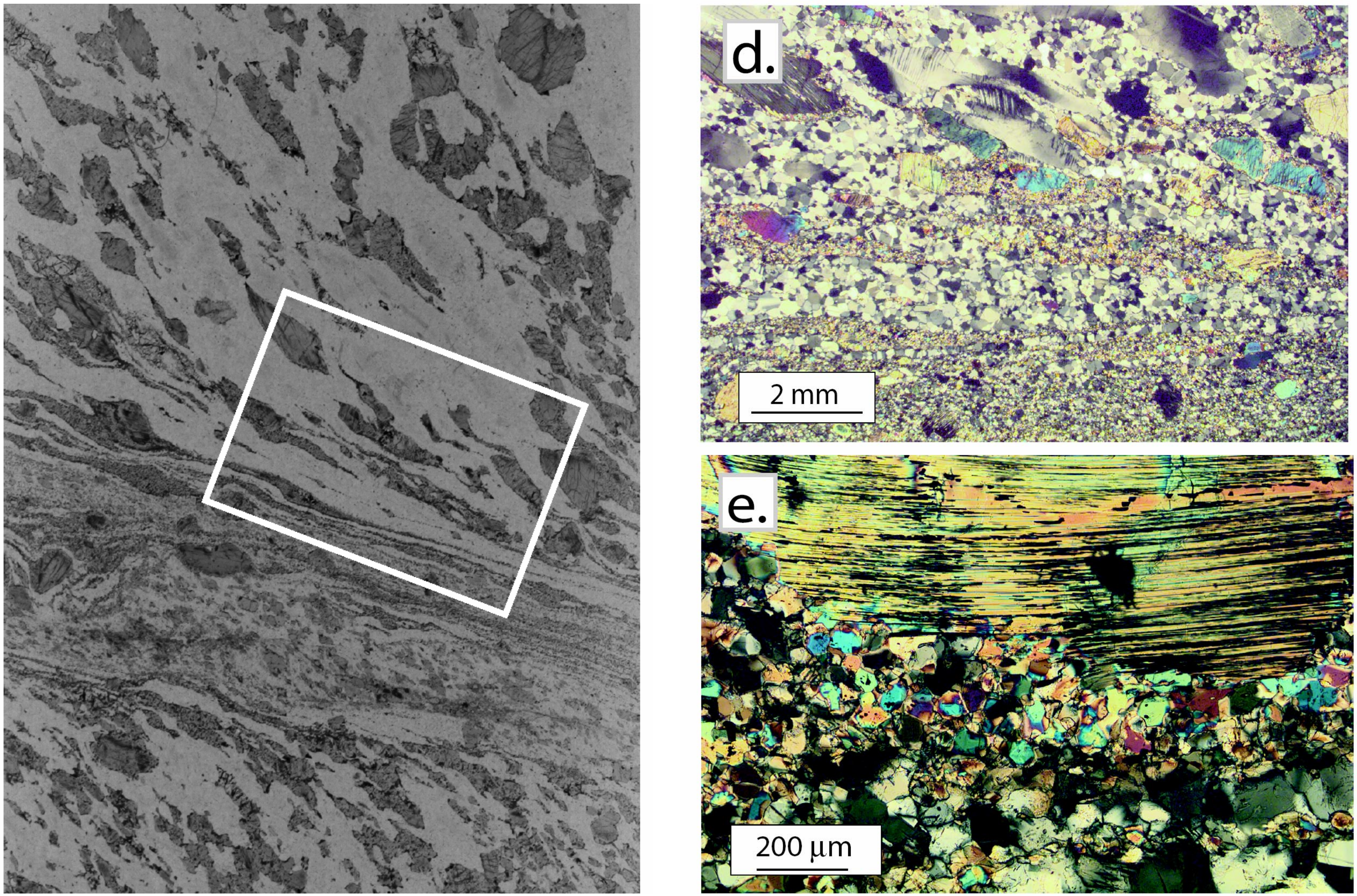


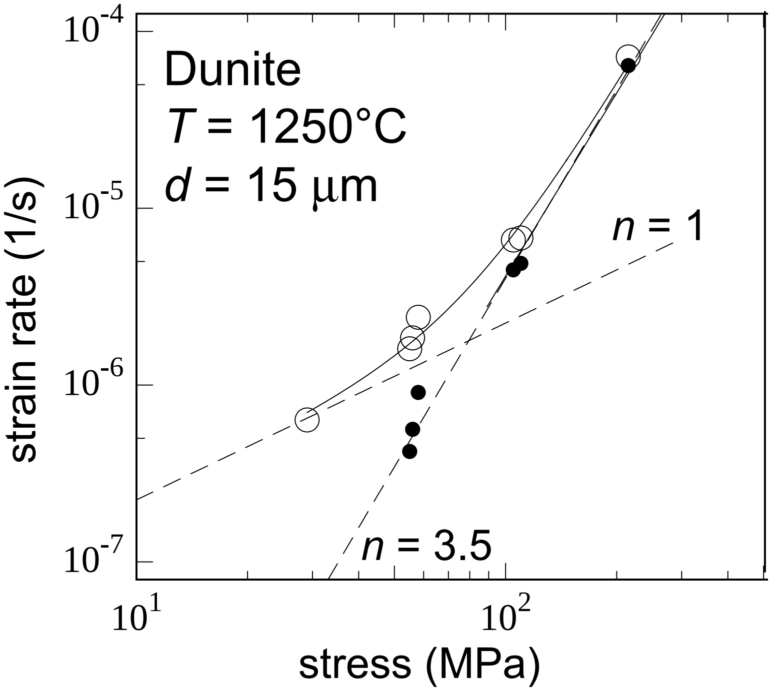


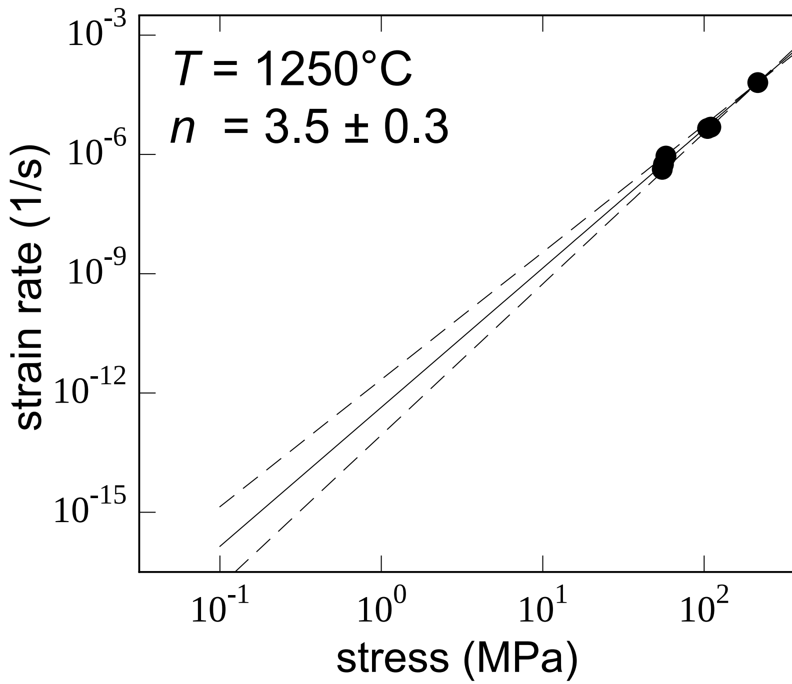


a. Flexural Failure




d.
2 mm
e.
200 µm

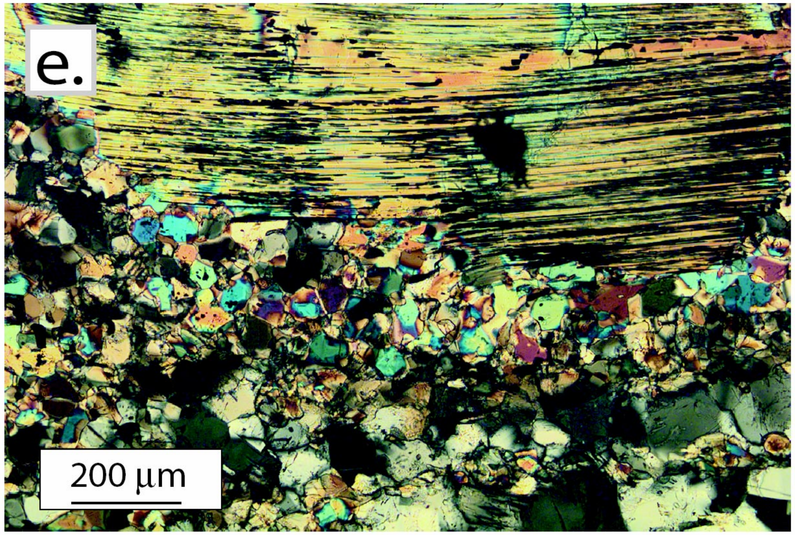




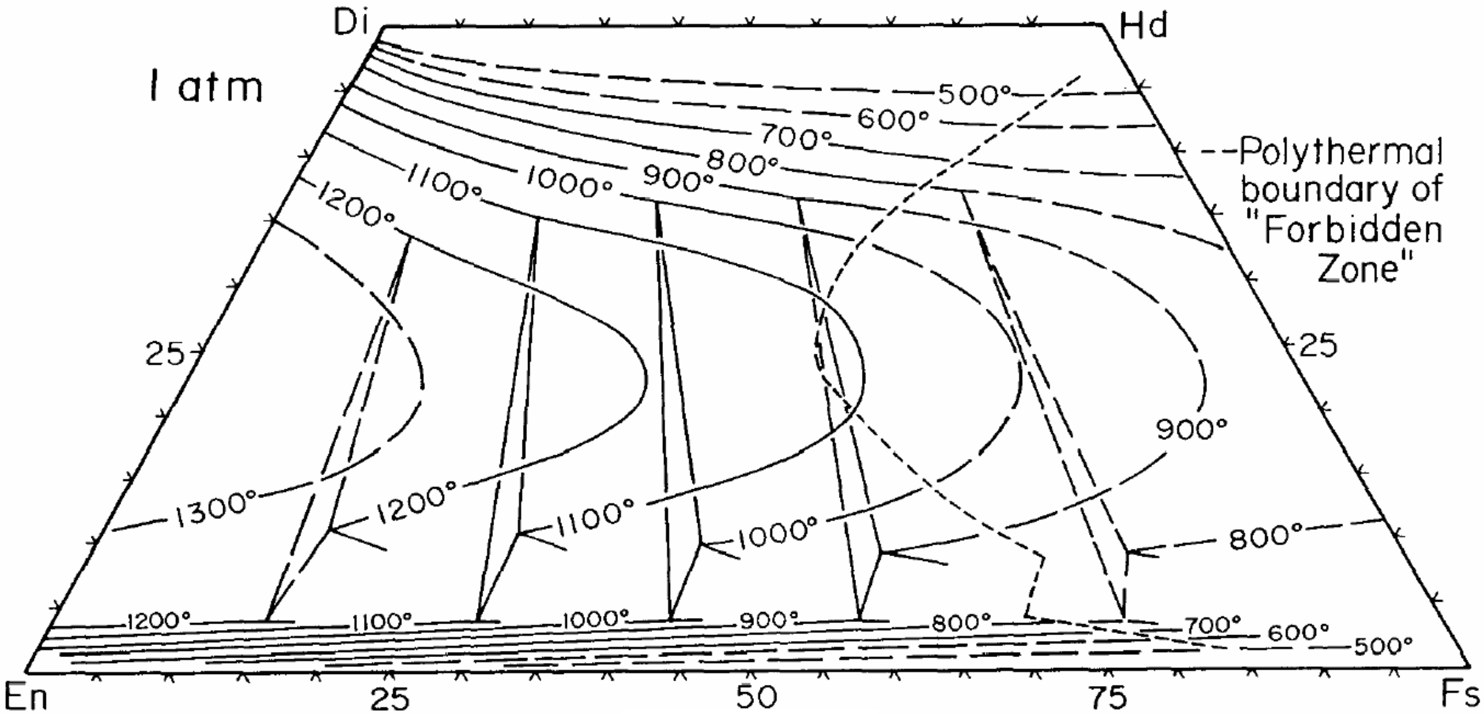
$$\dot{\varepsilon} = A\frac{\sigma^n}{d^m} f(\phi,\ C_{\mathrm{OH}}) \exp\left(-\frac{Q + PV^*}{RT}\right)$$

"Composite Rheology"

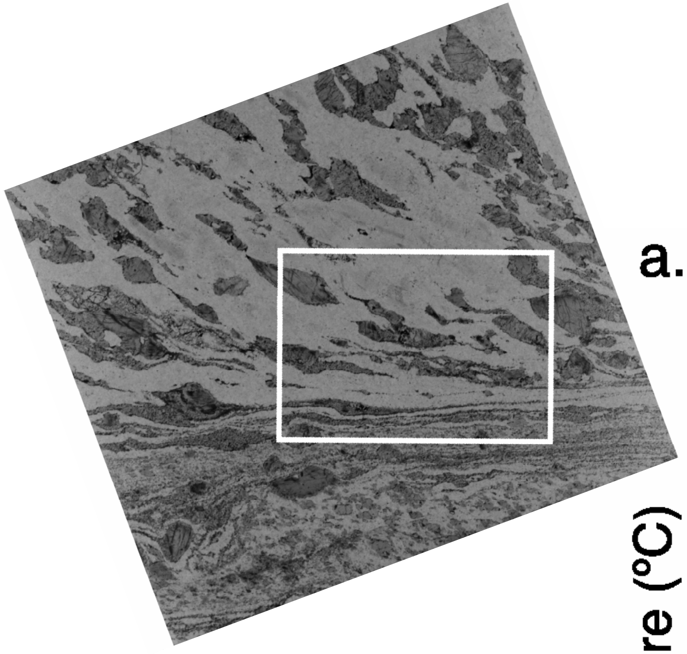
$$\dot{\varepsilon} = \dot{\varepsilon}_{disl} + \dot{\varepsilon}_{diff}$$

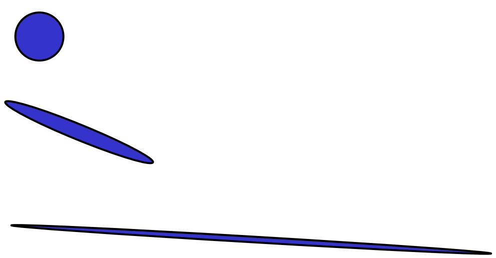


T = 800-950°C



Mole %

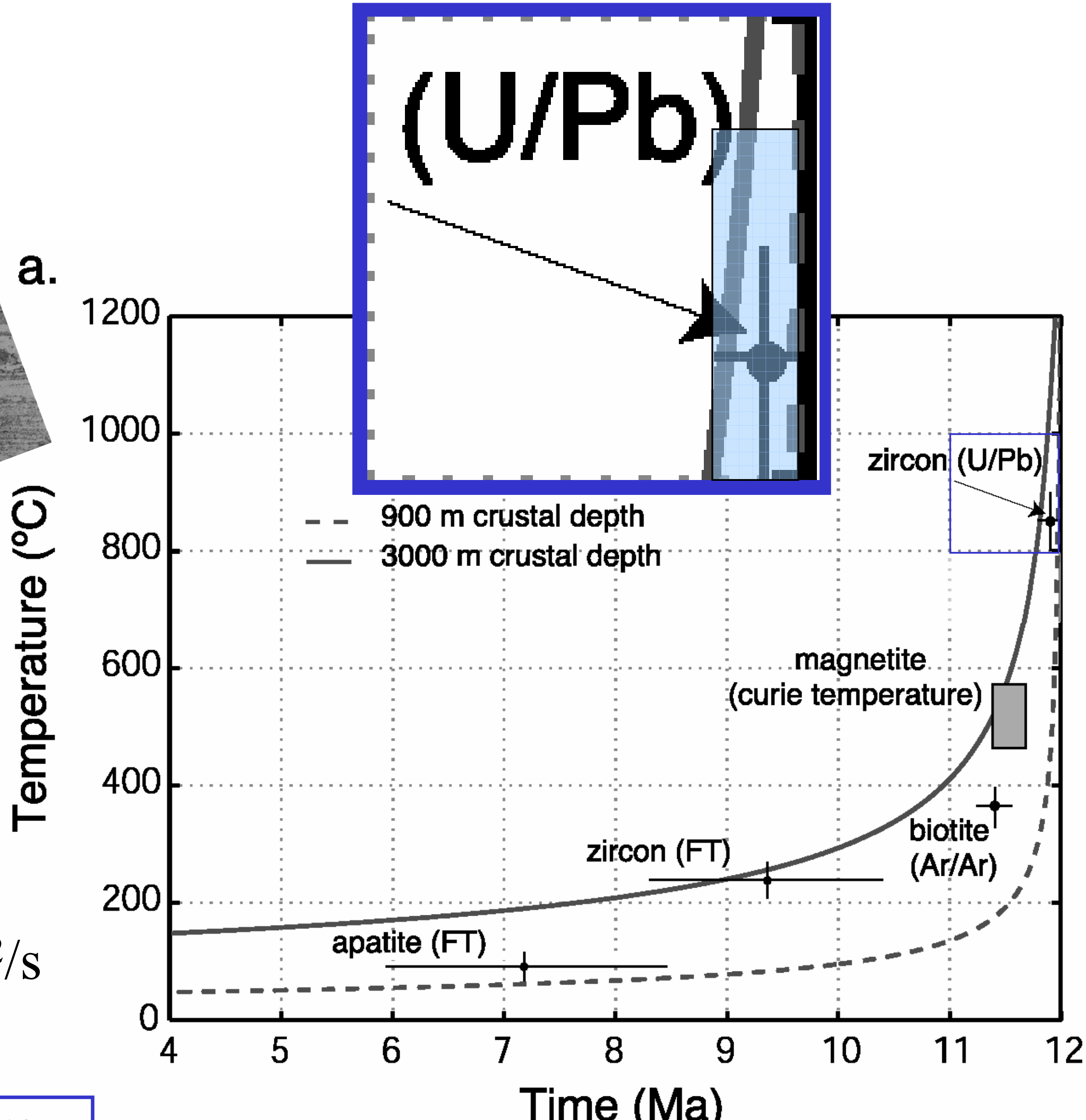




$10/200ky = 1.6\times10^{-12}/s$

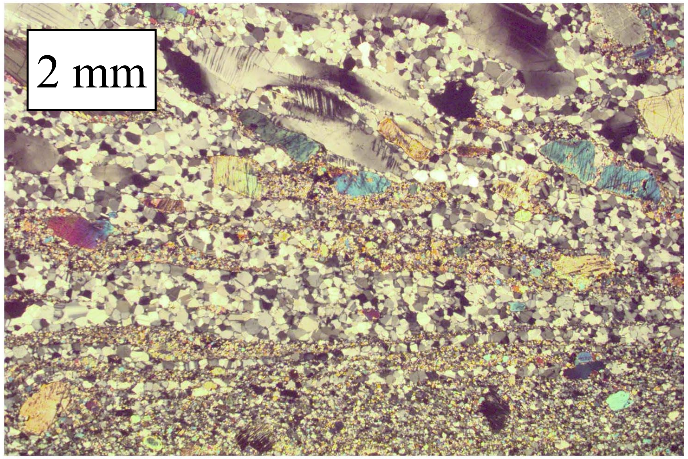
$3/1\ my = 10^{-13}/s$

Strain Rate 10^{-11} to $10^{-12}/s$

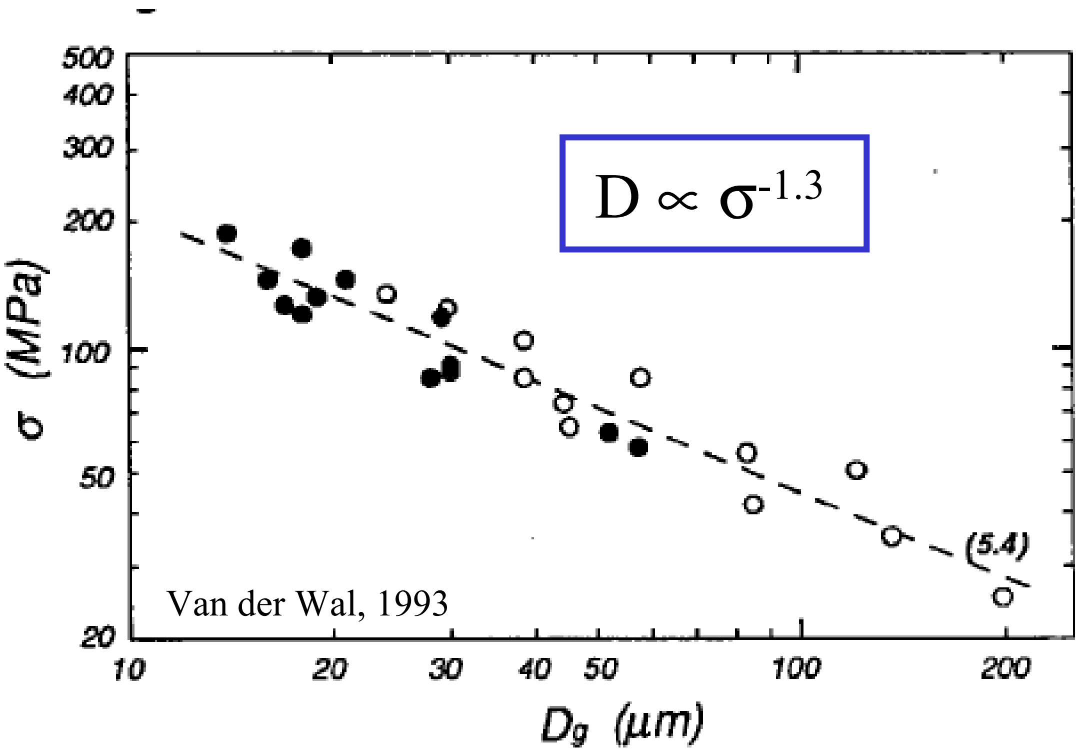


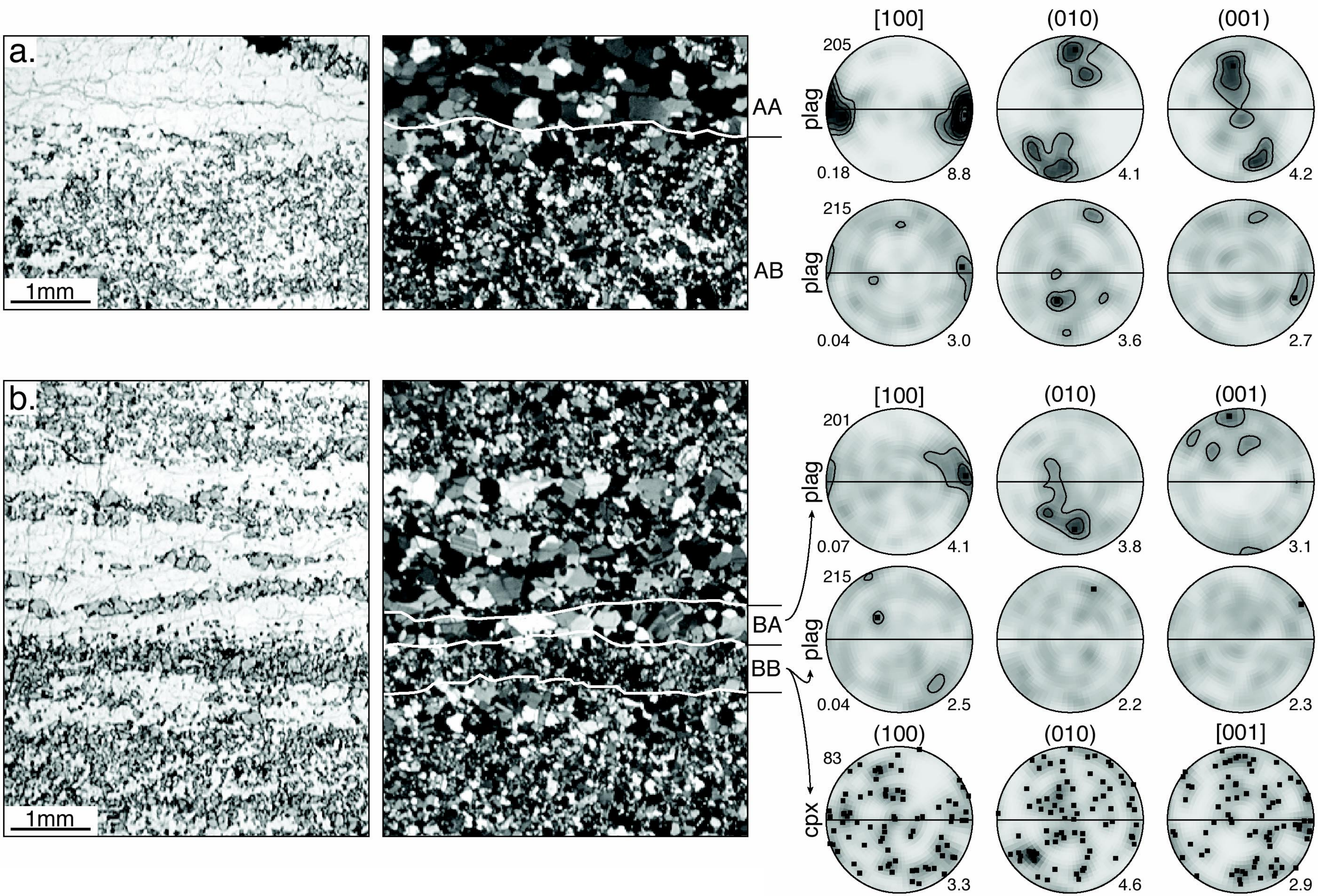
John et al., 2004

Dynamic Recrystallization

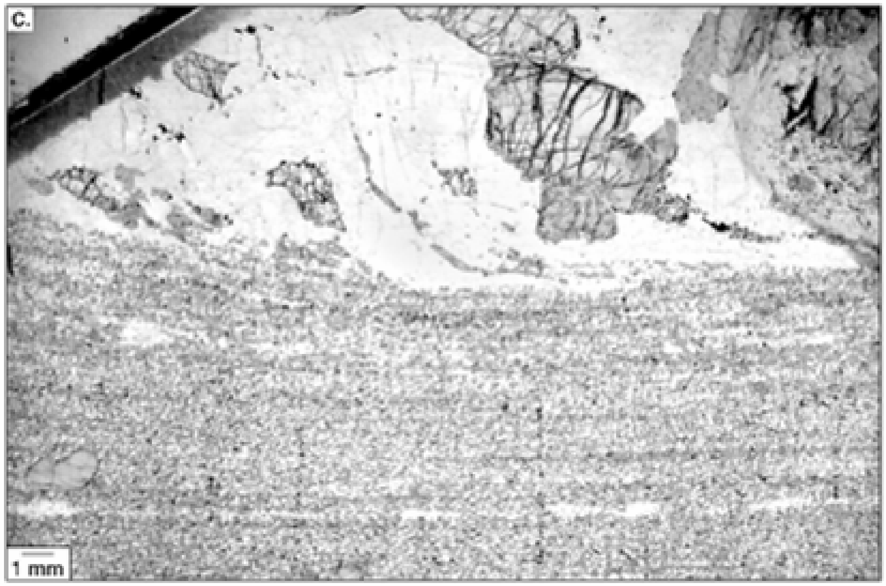


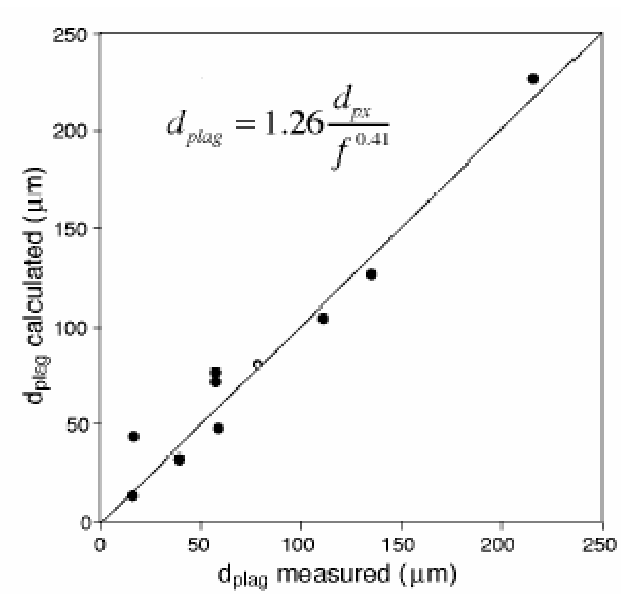
Larger grain size
indicates lower stress

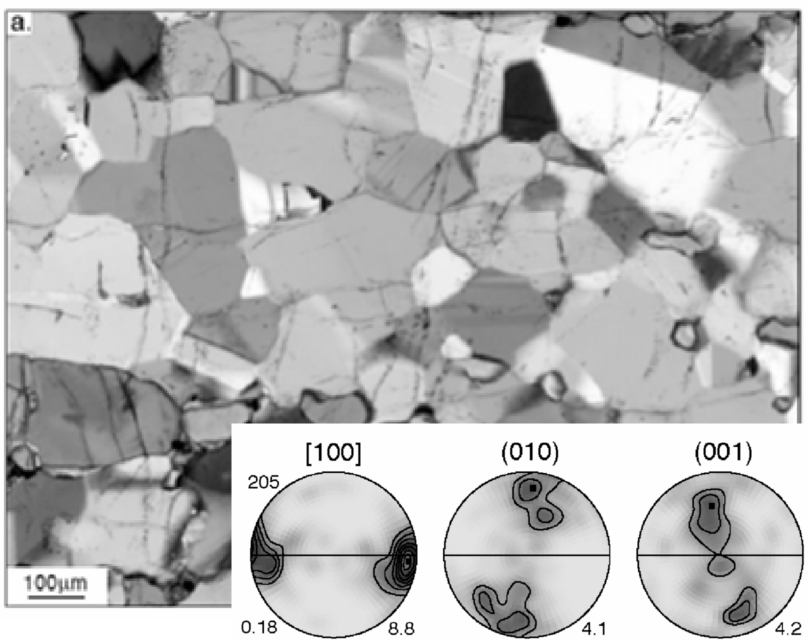


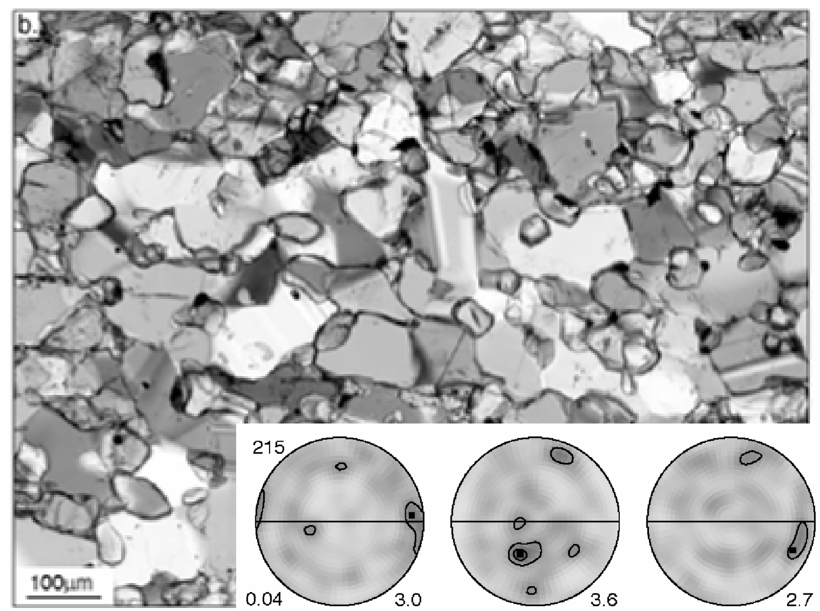


Mehl and Hirth, JGR 2008







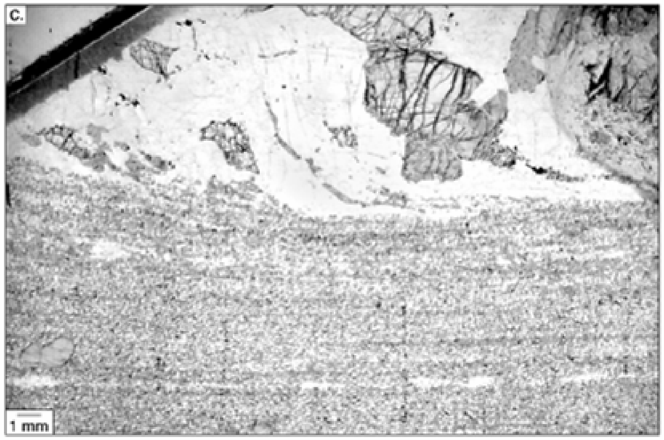


Mehl and Hirth, JGR 2008

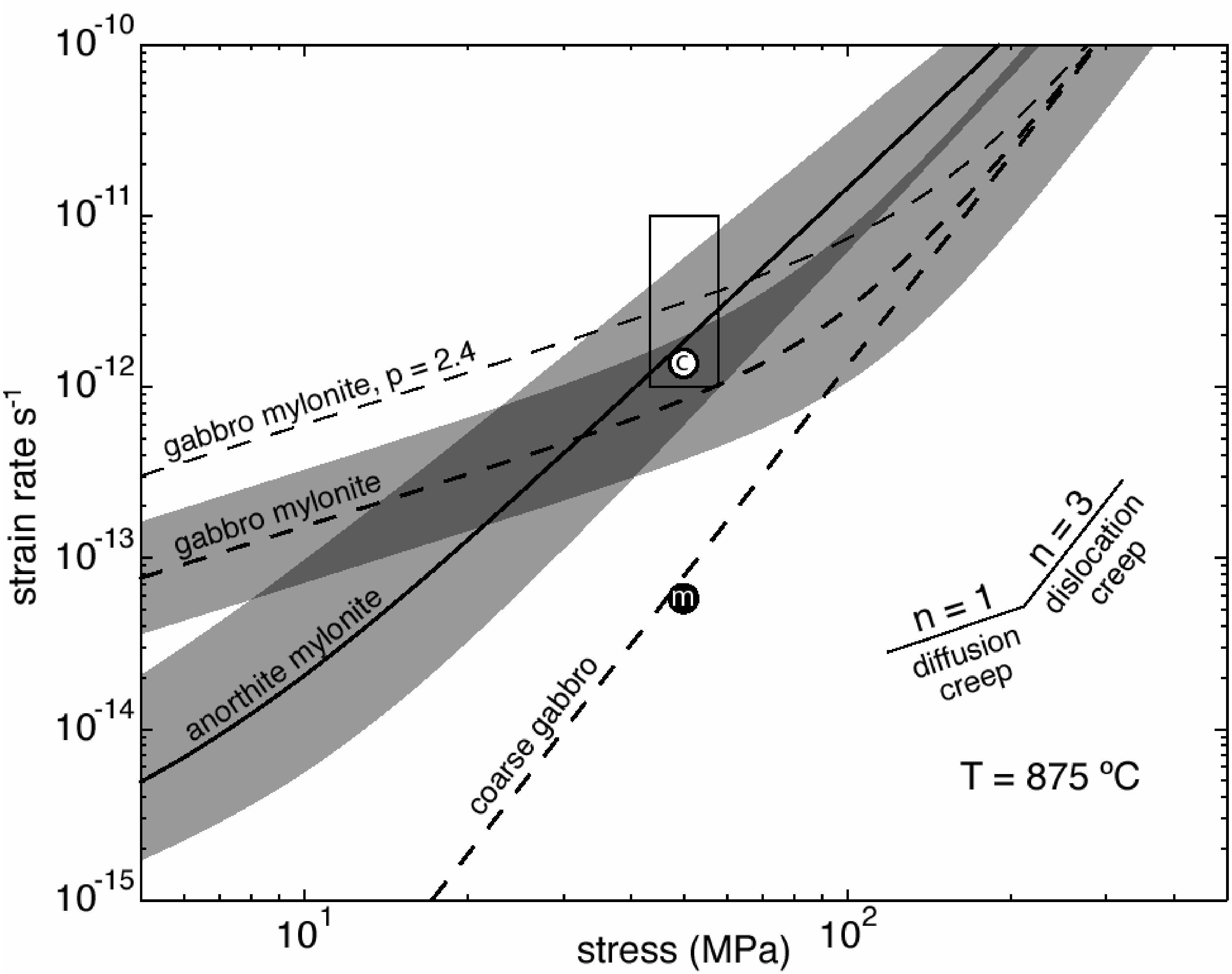
Fine-grained gabbro and anorthosite layers have similar viscosity, both are weaker than coarse-grained gabbro

Anorthosite deforms by dislocation creep while fine-grained gabbro deforms by diffusion creep

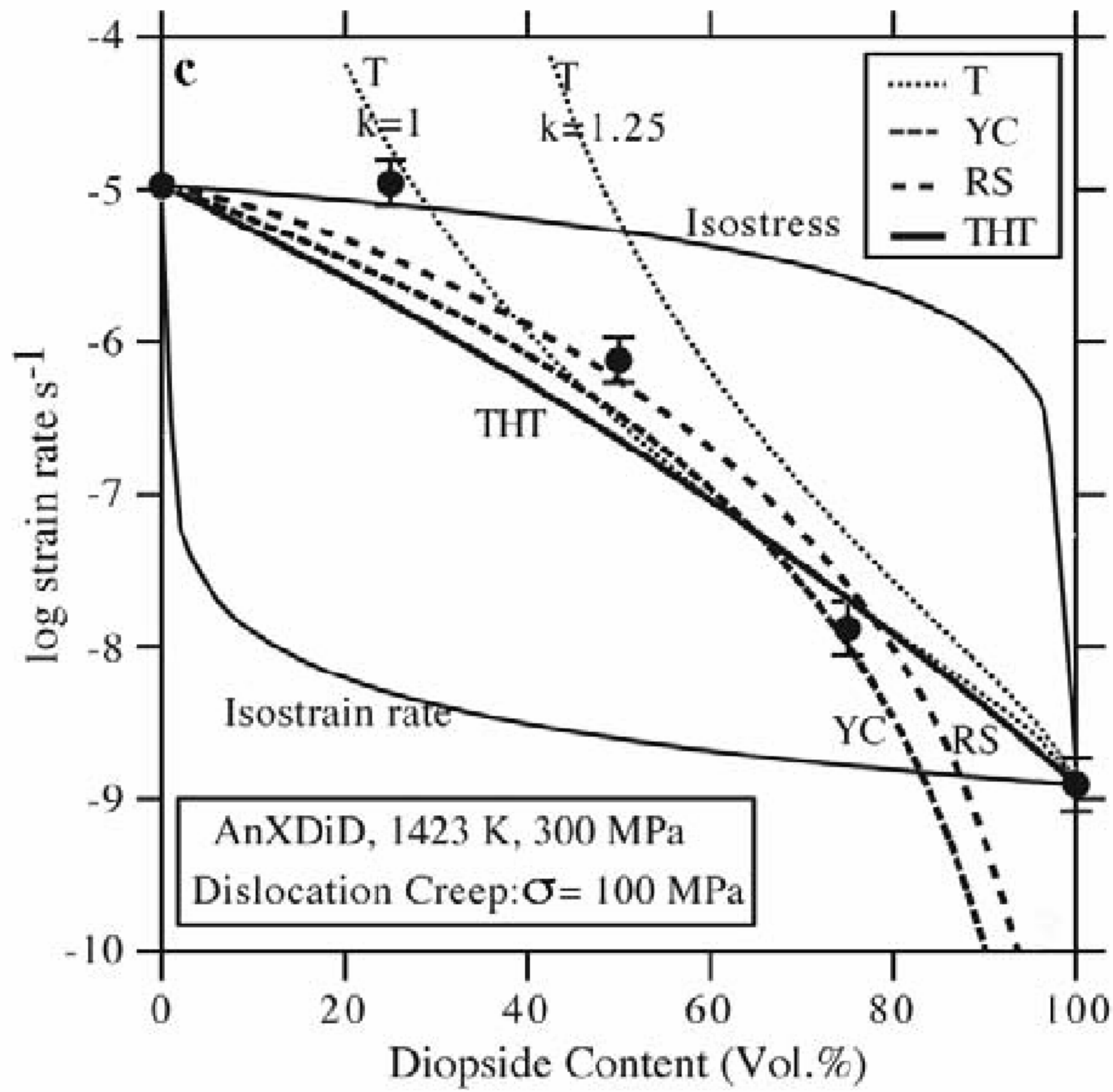
Strain rate of shear zone in the range 10^{-11}/s to 10^{-12}/s at a stress of 50 MPa and temperature of 875°C



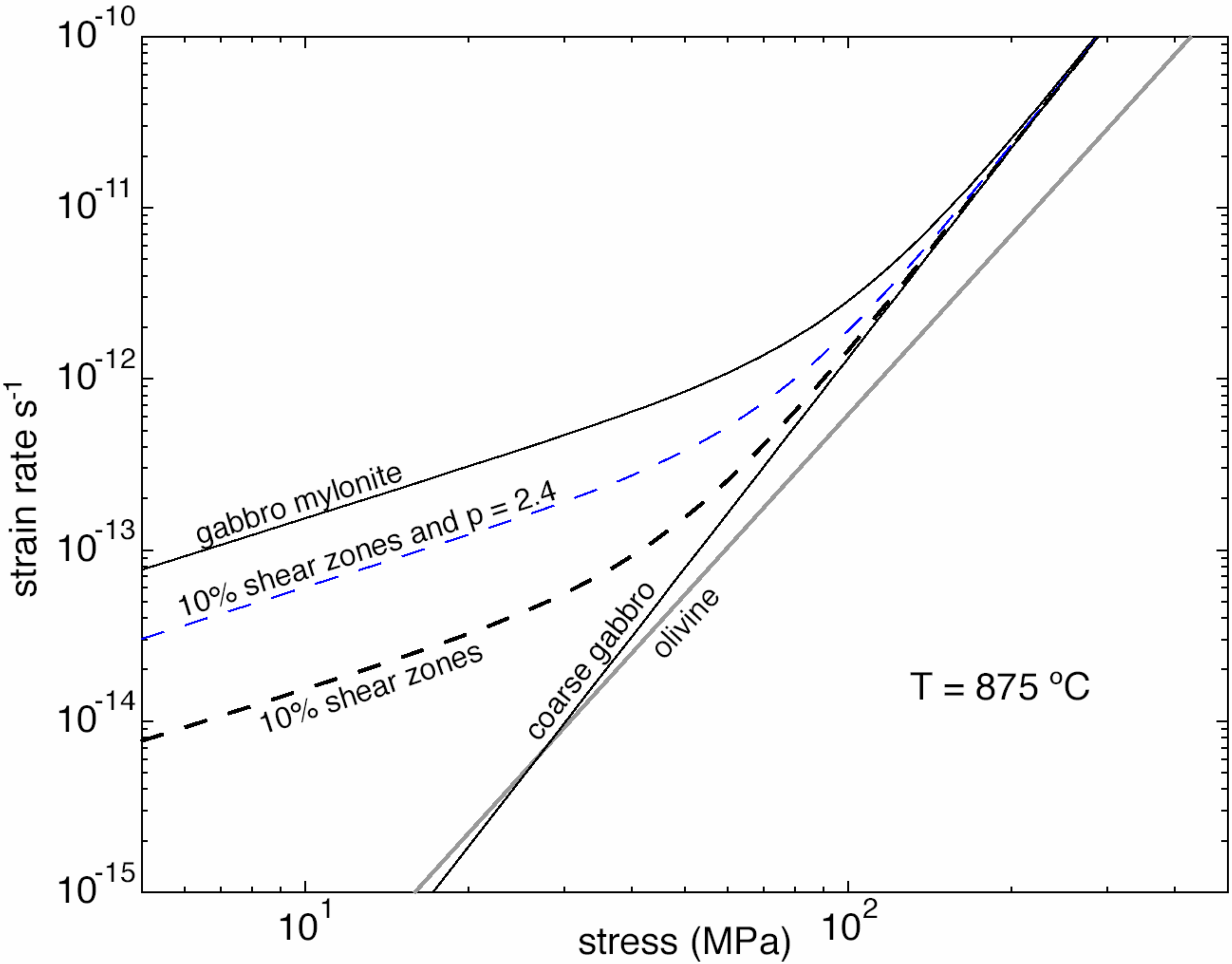
Compare to predictions from lab data



Mehl and Hirth, JGR 2008



Dimonov & Dresen, 2005



Mehl and Hirth, JGR 2008

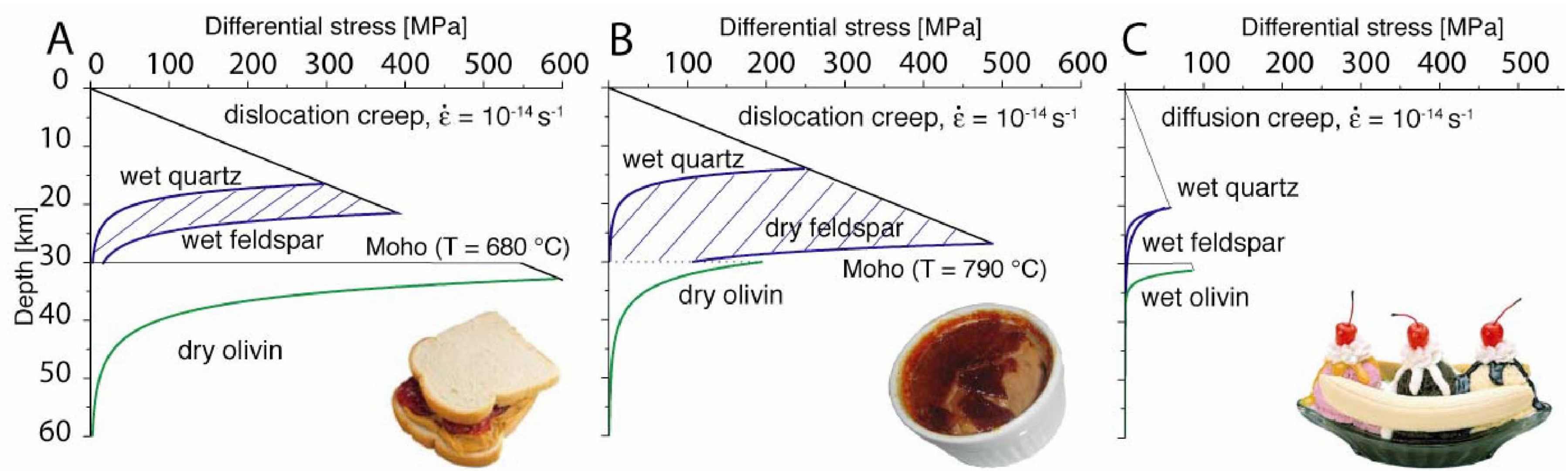
Fine-grained gabbro and anorthosite layers have similar viscosity, both are weaker than coarse-grained gabbro
(STRAIN LOCALIZATION)

Anorthosite deforms by dislocation creep while fine-grained gabbro deforms by diffusion creep
(EFFECT OF PYROXENE)

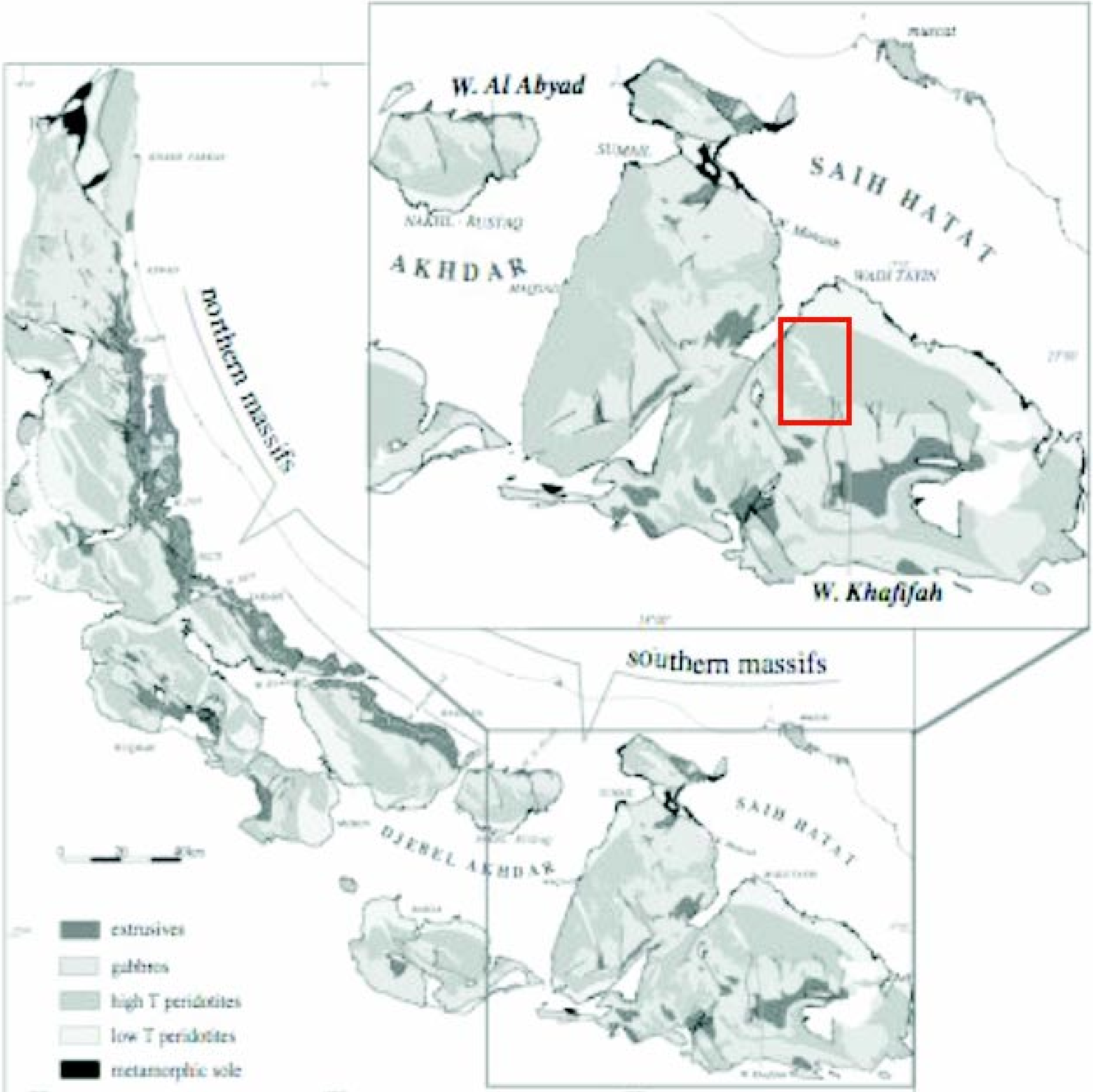
Strain rate of shear zone in the range 10^{-11}/s to 10^{-12}/s at a stress of 50 MPa and temperature of 875^{o}C
Viscosity around 10^{19} Pa s

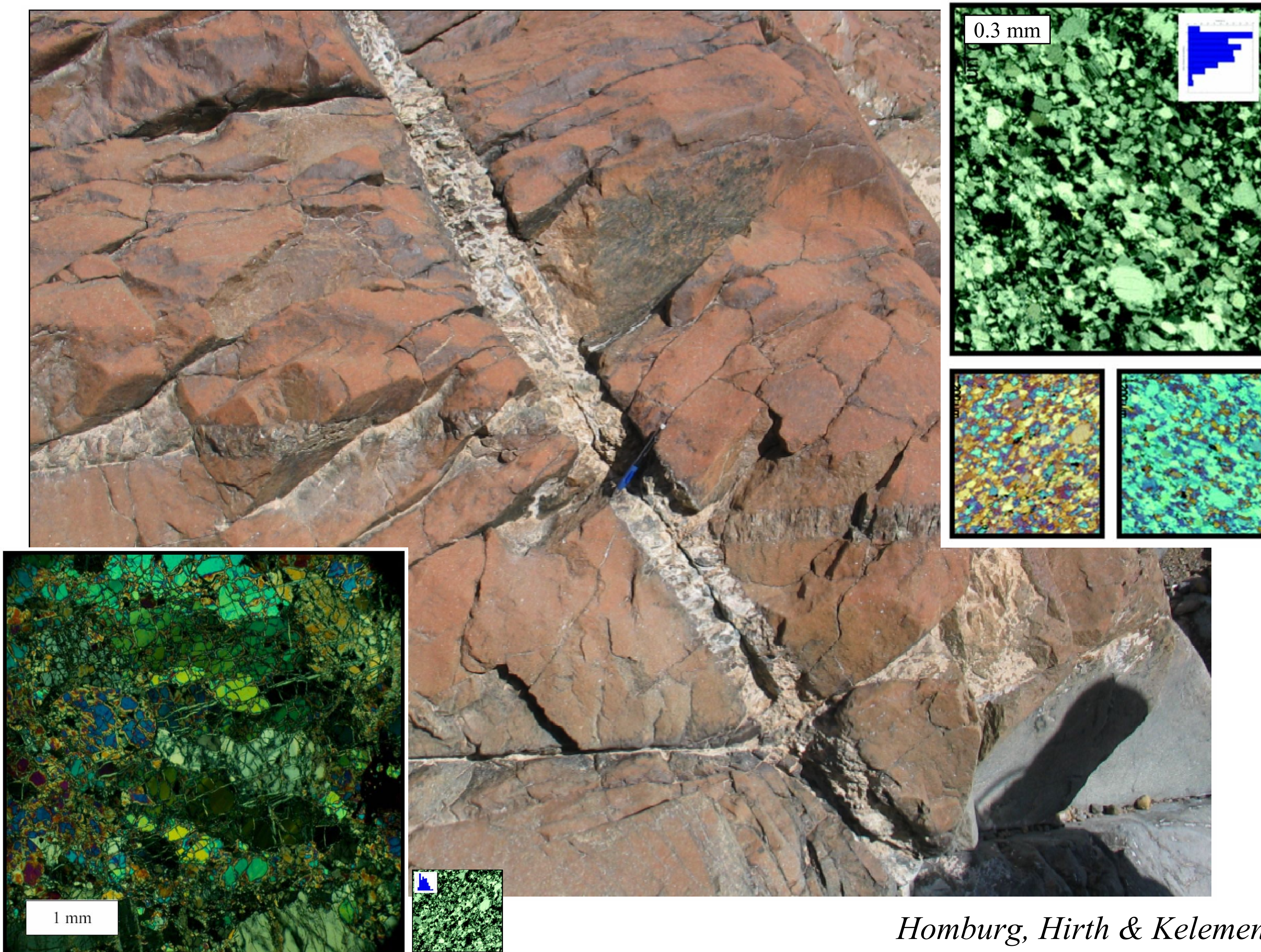
Comparison to predictions from lab data
PRETTY GOOD!

Lithosphere Rheology



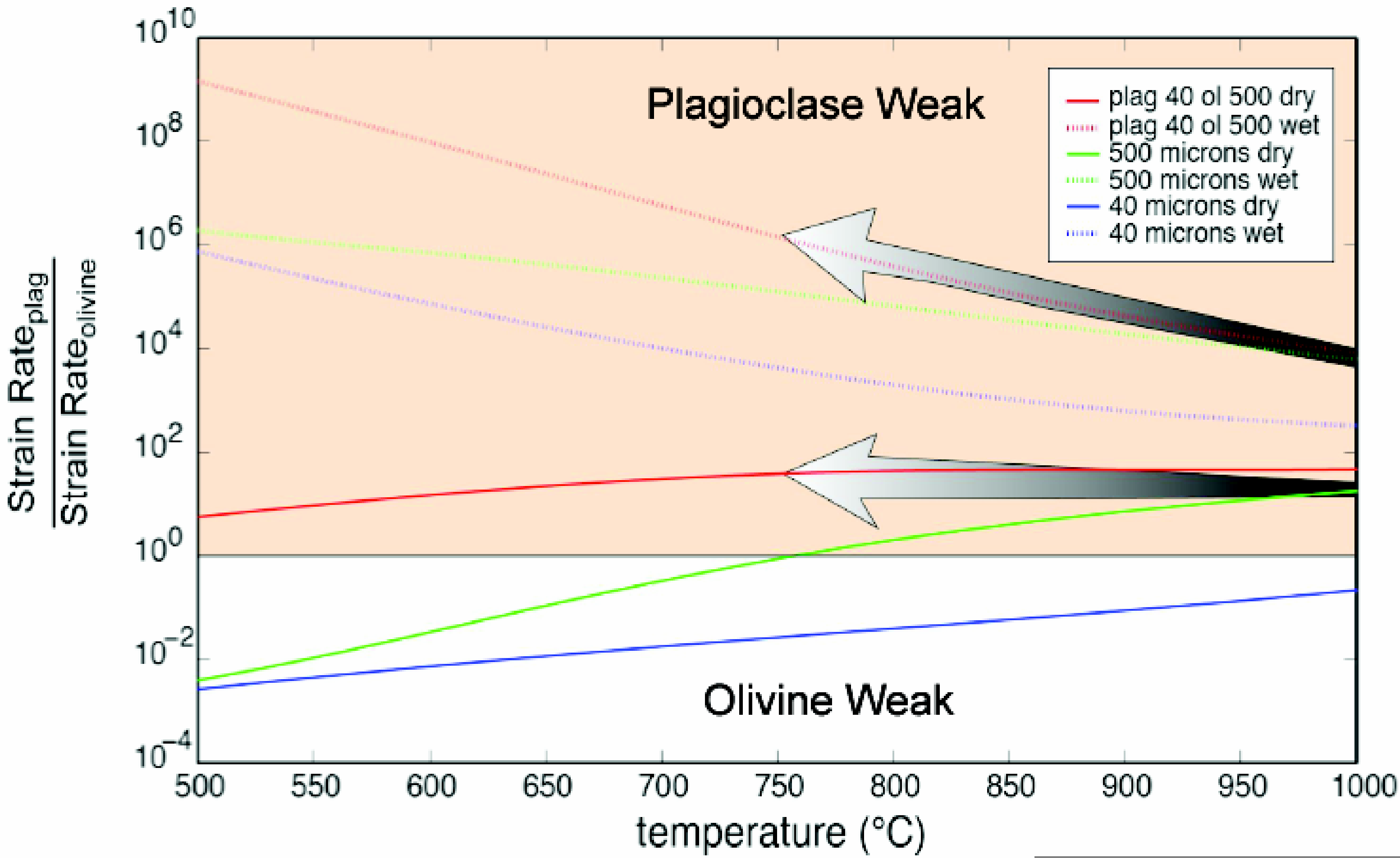
Burgmann and Dresen, 2008


W. Al Abyad
SUMAIL
NAKHL - RUSTAQ
SAIH HATAT
AKHDAR
WADI TAYIN
W. Khafifah
northern massifs
southern massifs
DJEBEL AKHDAR
SAIH HATAT
extrusives
gabbros
high T peridotites
low T peridotites
metamorphic sole



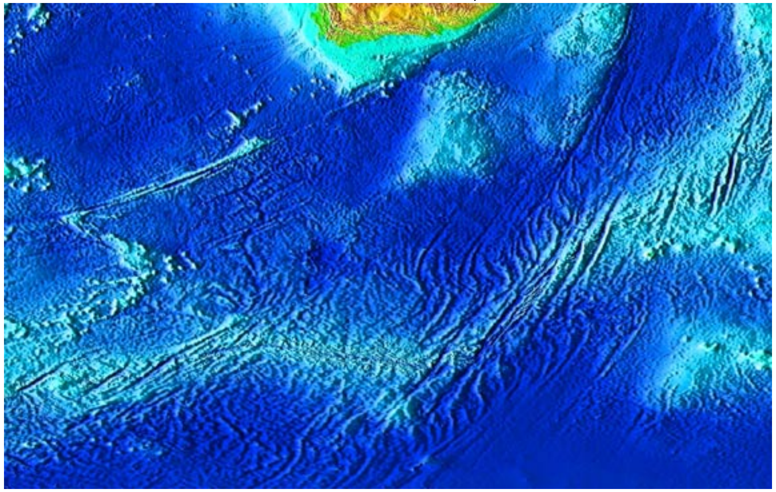
Homburg, Hirth & Kelemen

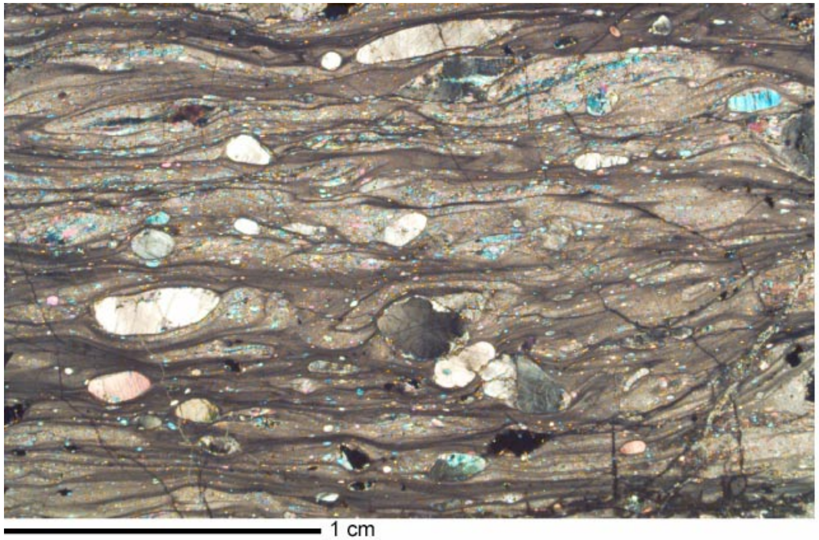
$$\dot{\varepsilon} = A\sigma^n d^{-m} \exp\left(-\frac{Q}{RT}\right)$$



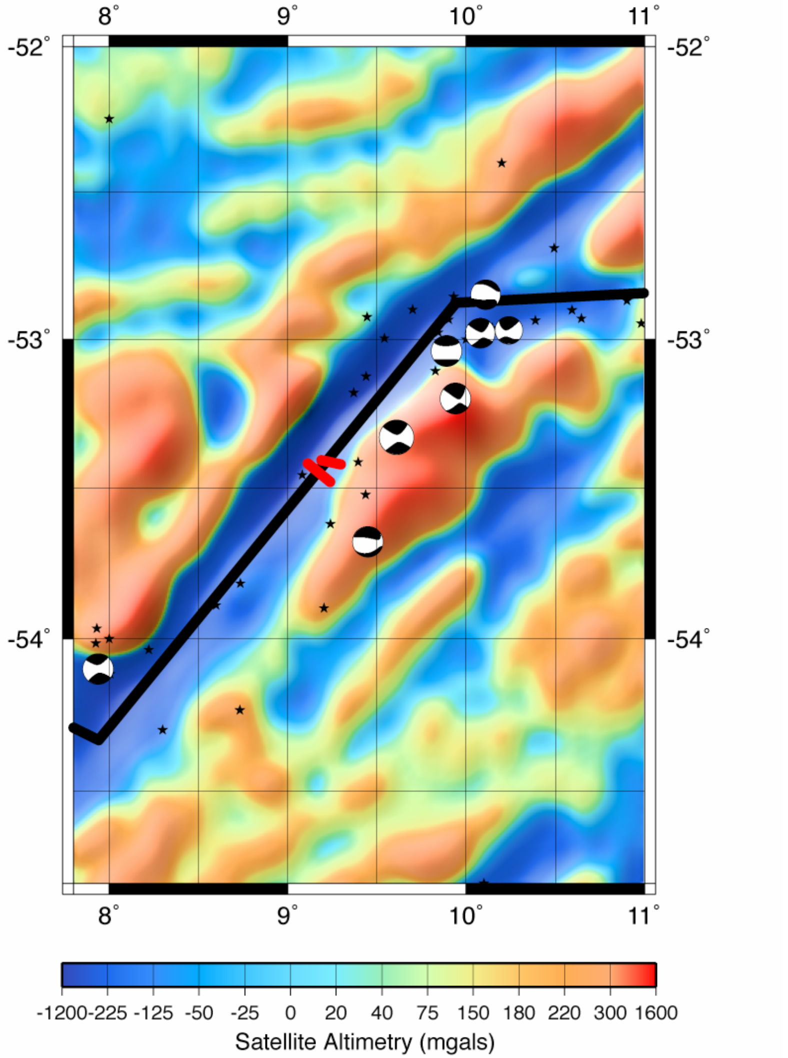
Homburg, Hirth & Kelemen

Fracture zones, SWIR

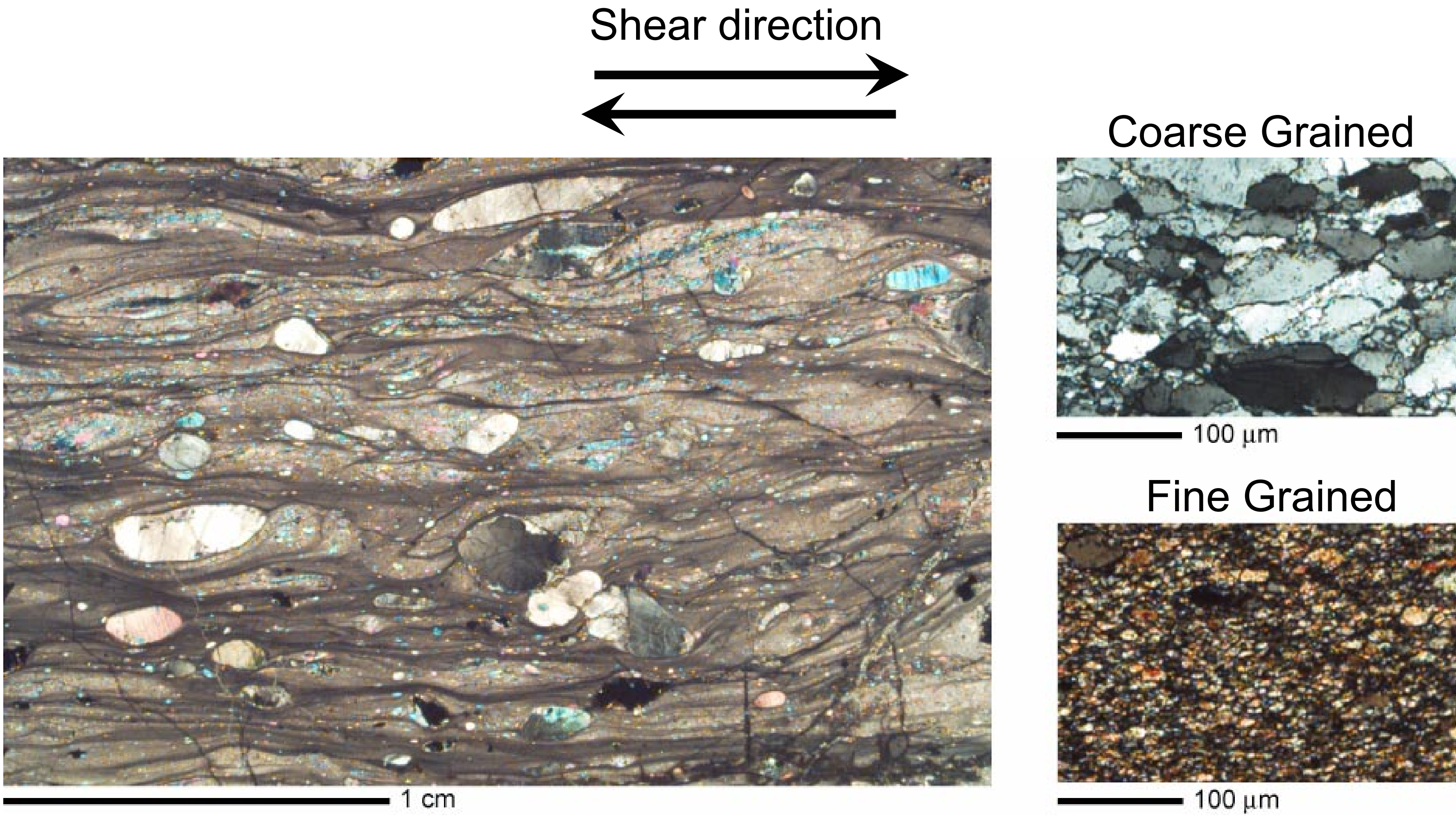




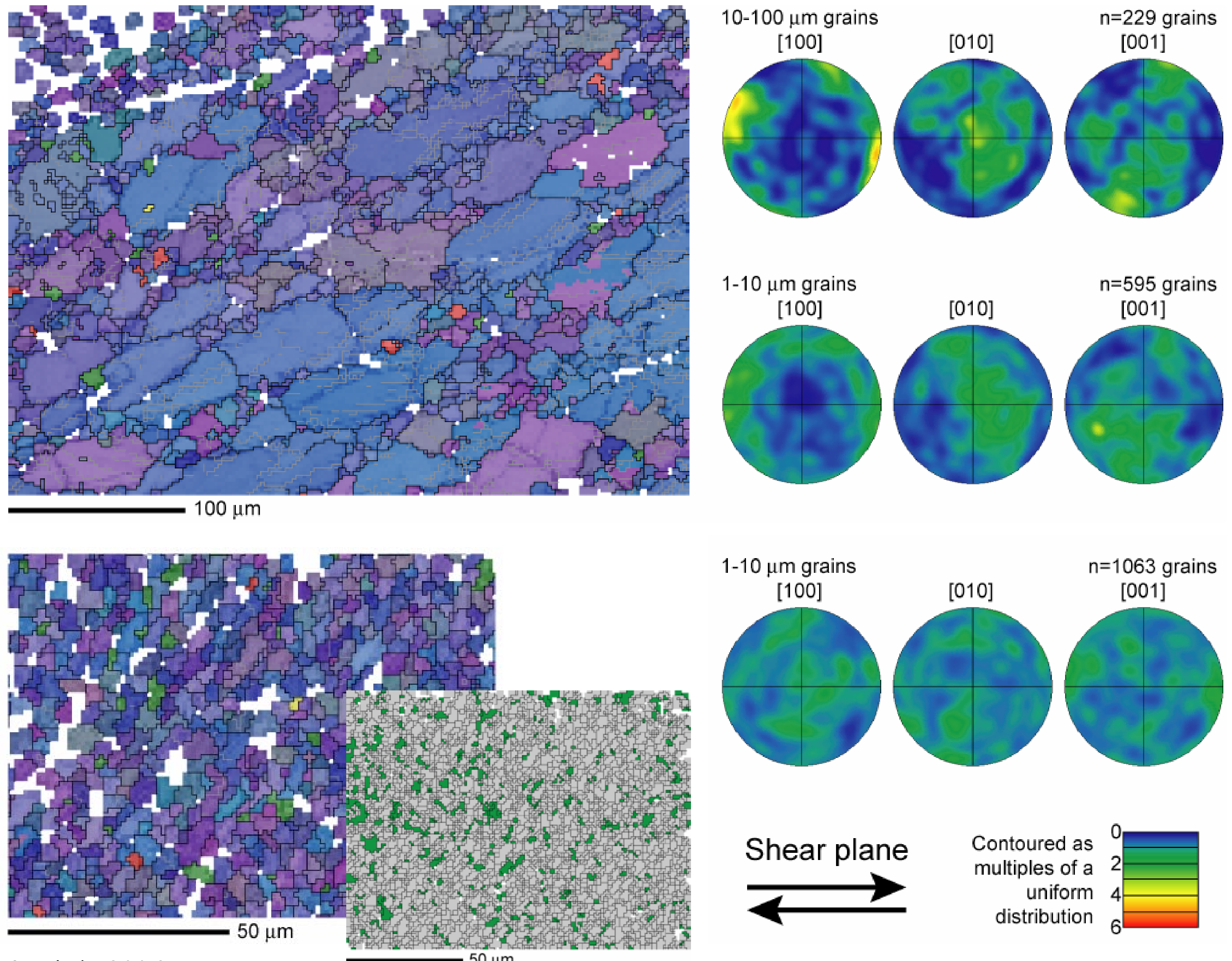
Shaka F.Z. (South West Indian Ridge)



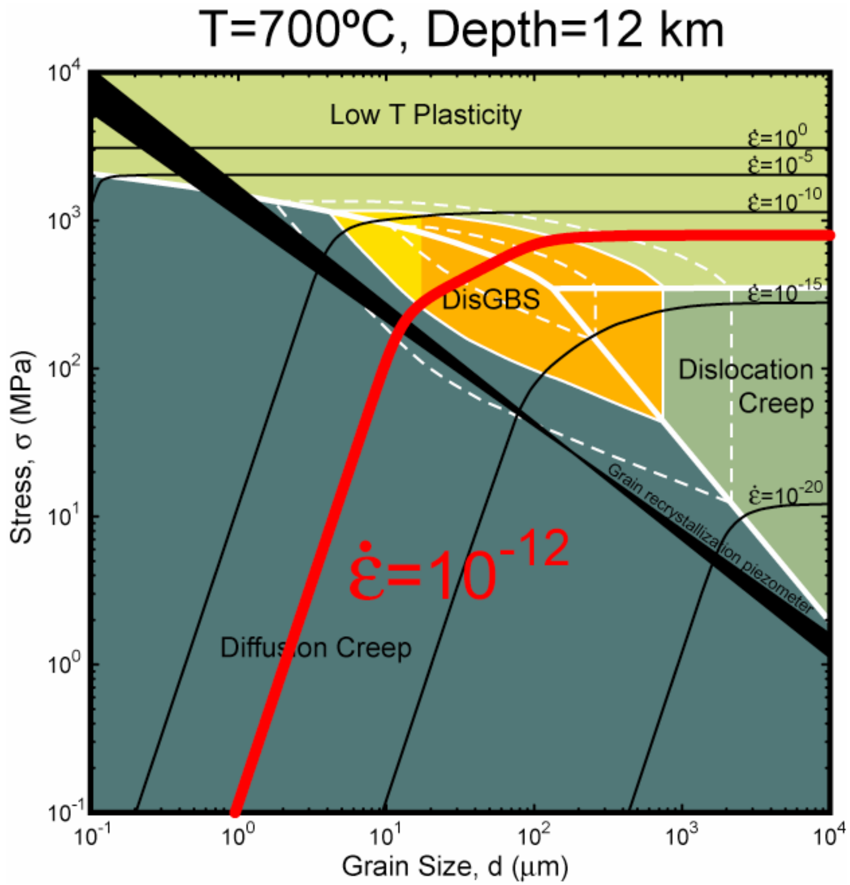
Peridotite Mylonite from Shaka Fracture Zone



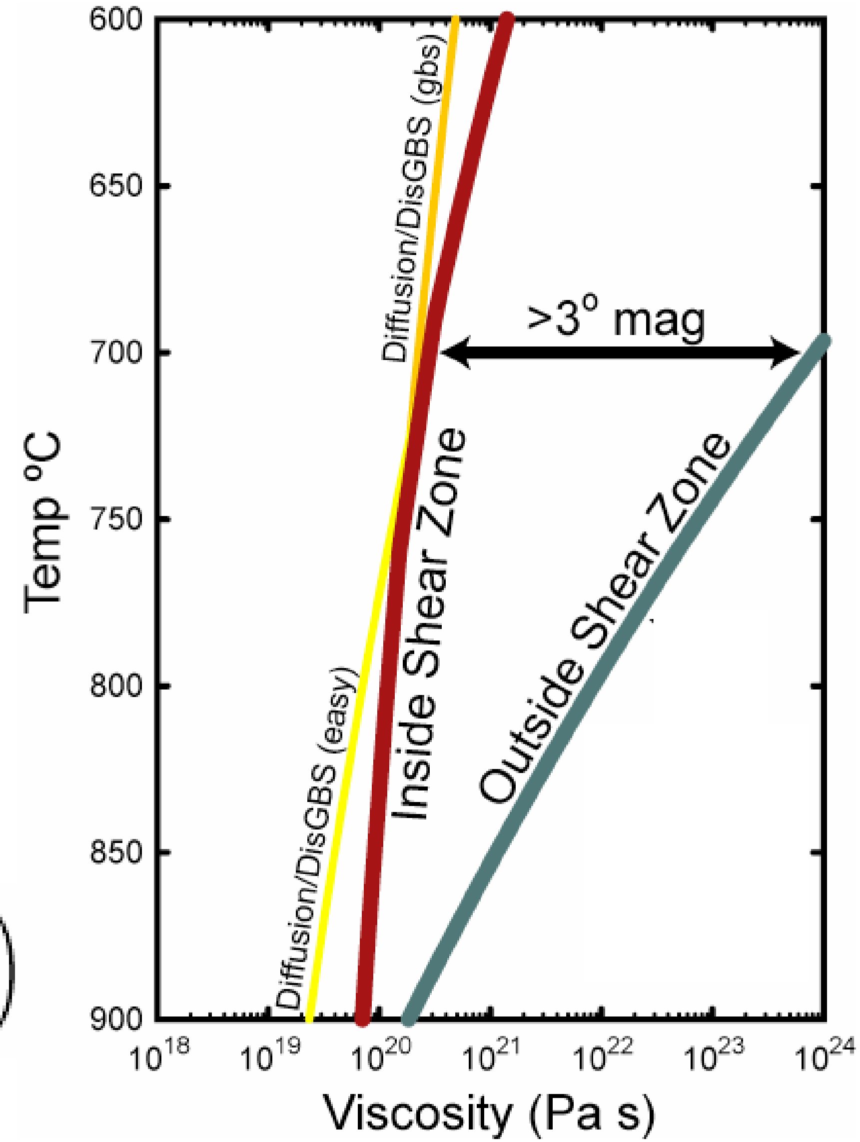
Warren & Hirth, 2006



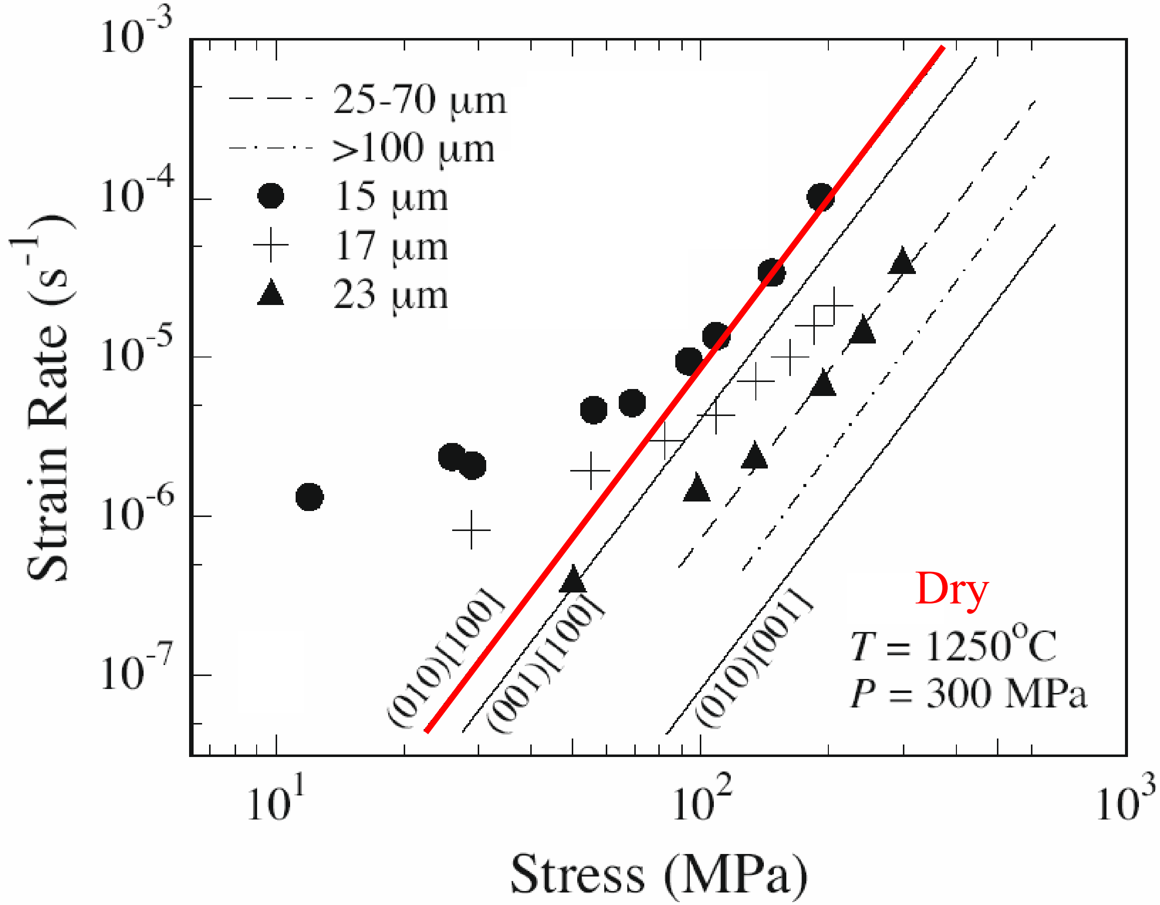
Warren & Hirth, 2006



$$\dot{\varepsilon} = A\frac{\sigma^n}{d^m} f(\phi,\ C_{\mathrm{OH}})\exp\left(-\frac{Q+PV^*}{RT}\right)$$

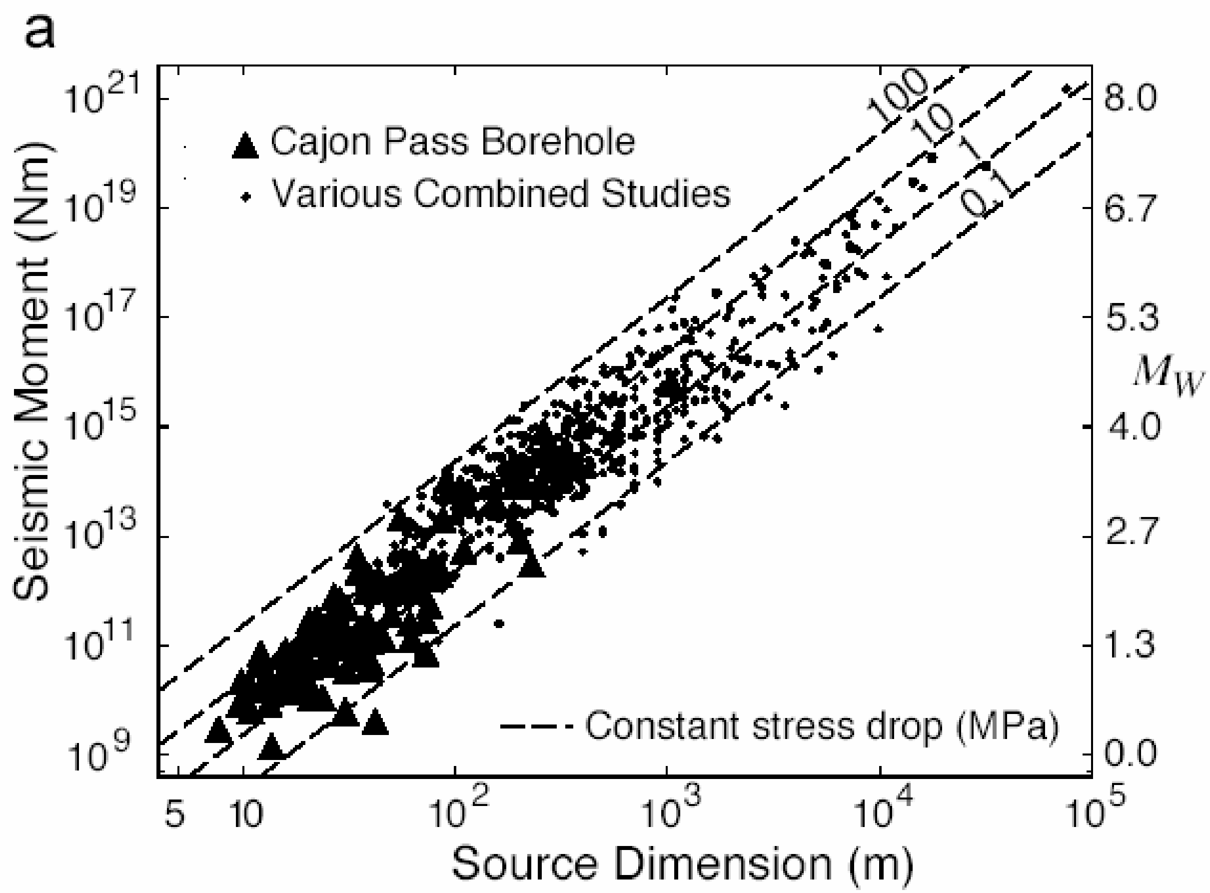


Warren & Hirth, 2006

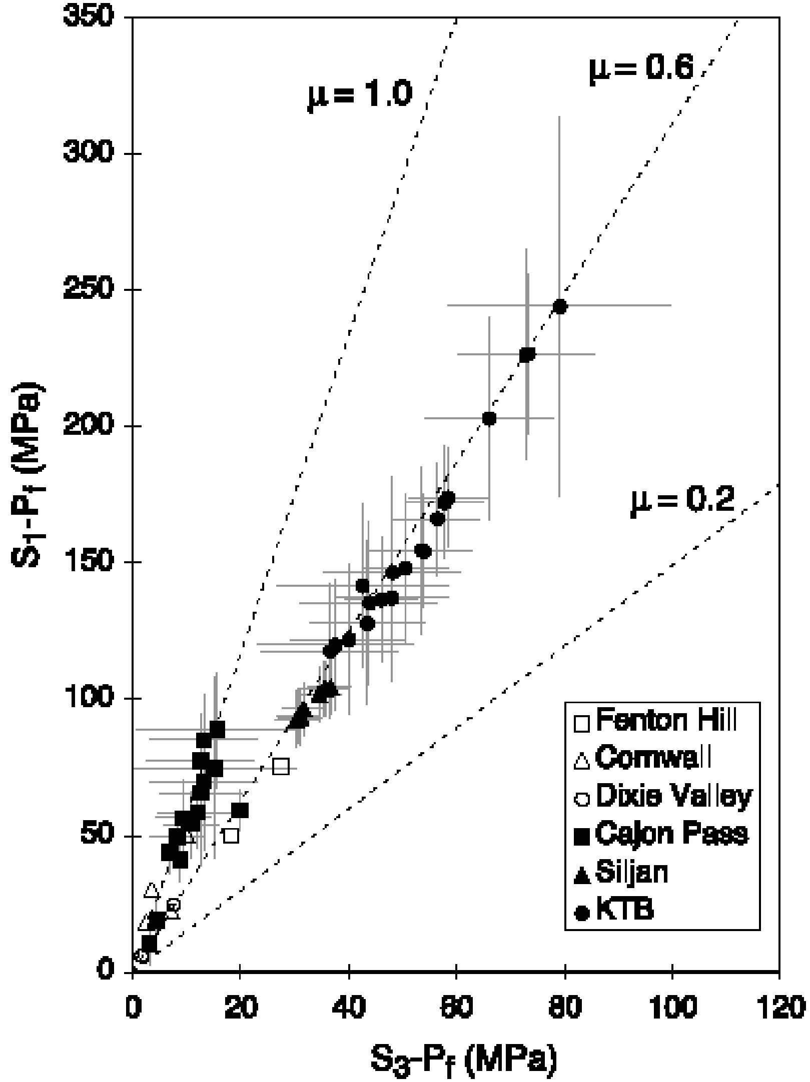


$$\dot{\varepsilon} = A\frac{\sigma^n}{d^m} f(\phi,\ C_{OH}) \exp\left(-\frac{Q + PV^*}{RT}\right)$$

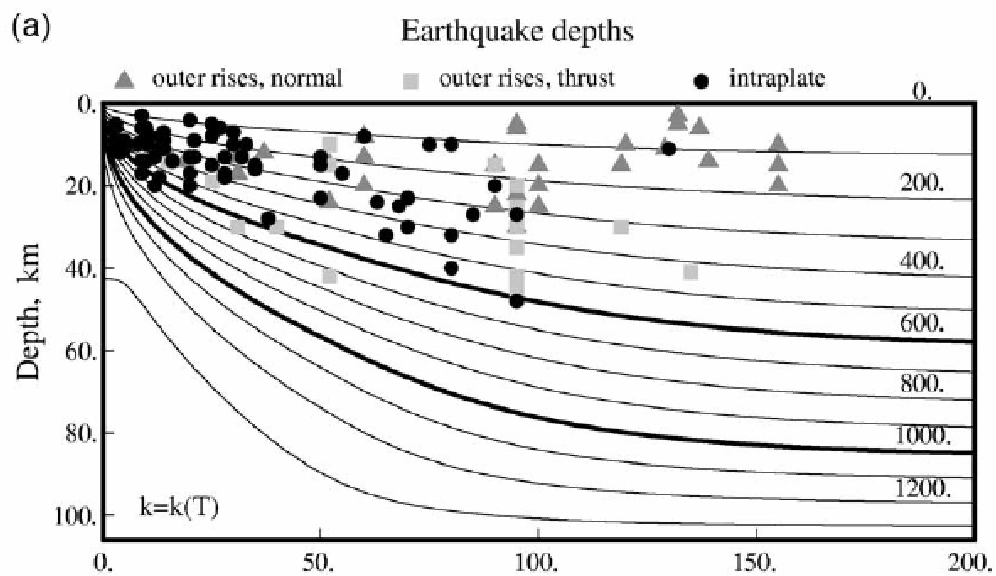
Hirth & Kohlstedt, 2003

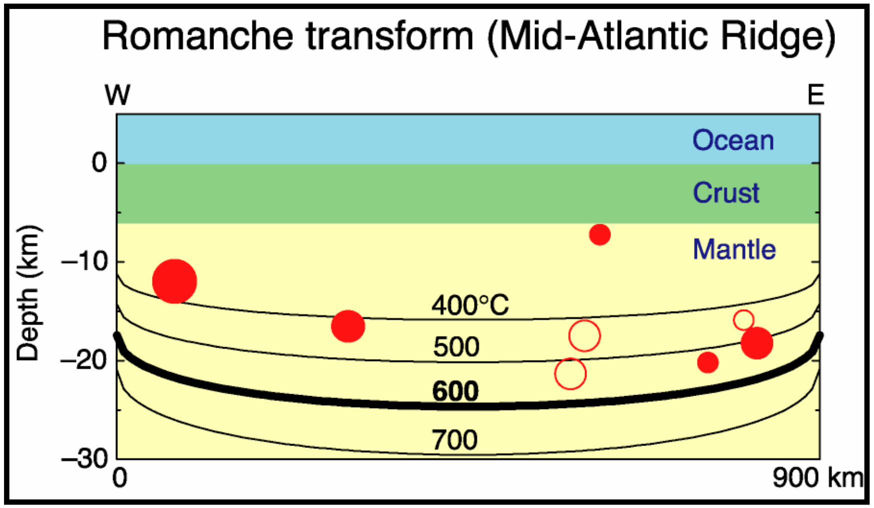


Abercrombie and Rice

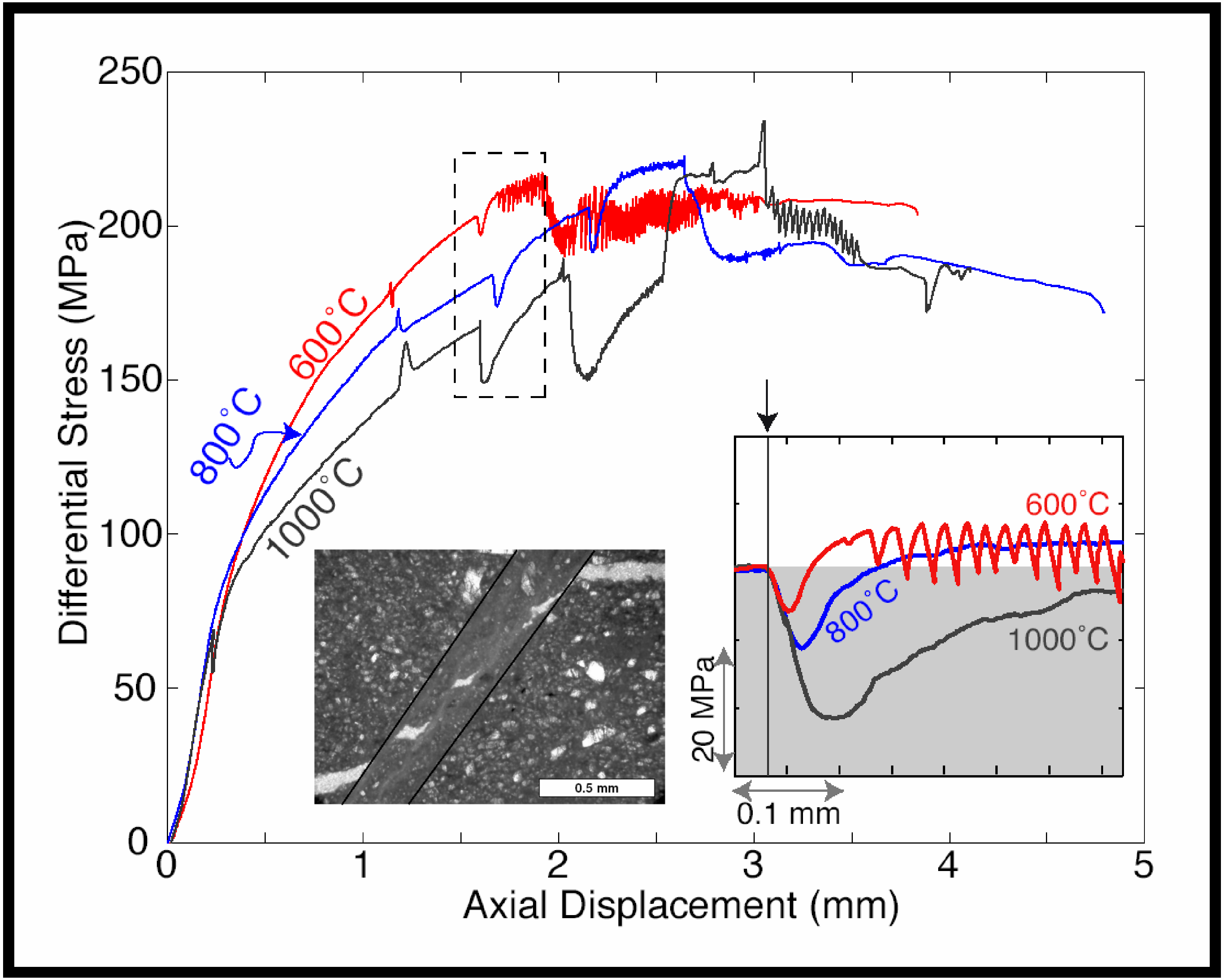


Zoback and Townend, 2001

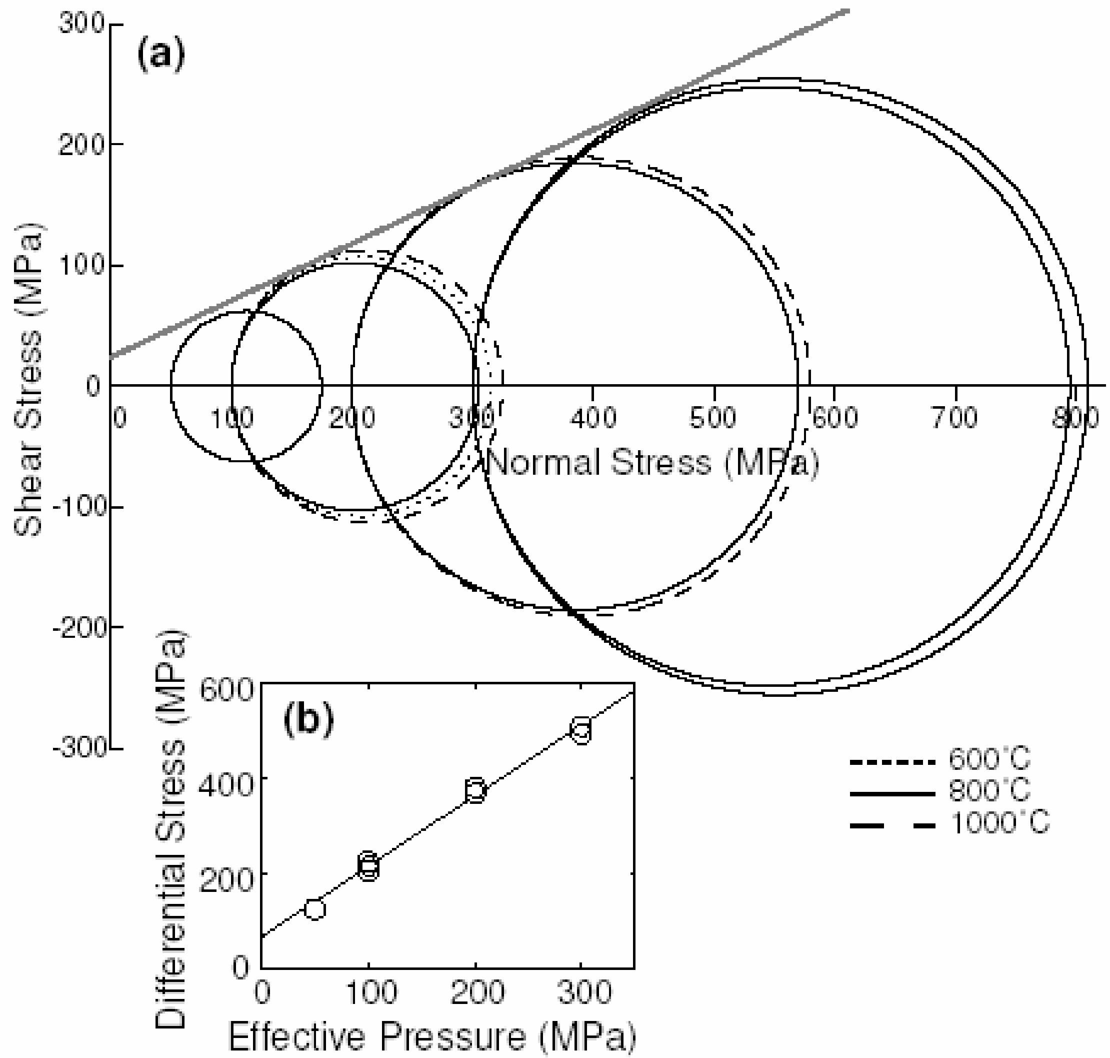




Abercrombie and Ekstrom (2001)

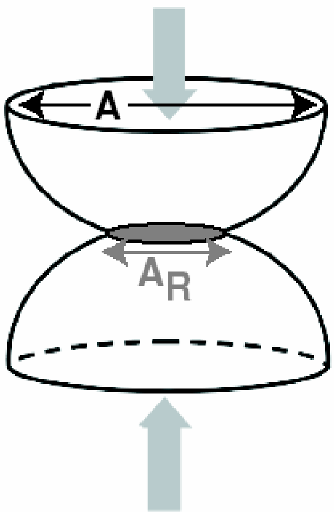


Boettcher, Hirth & Evans, 2006



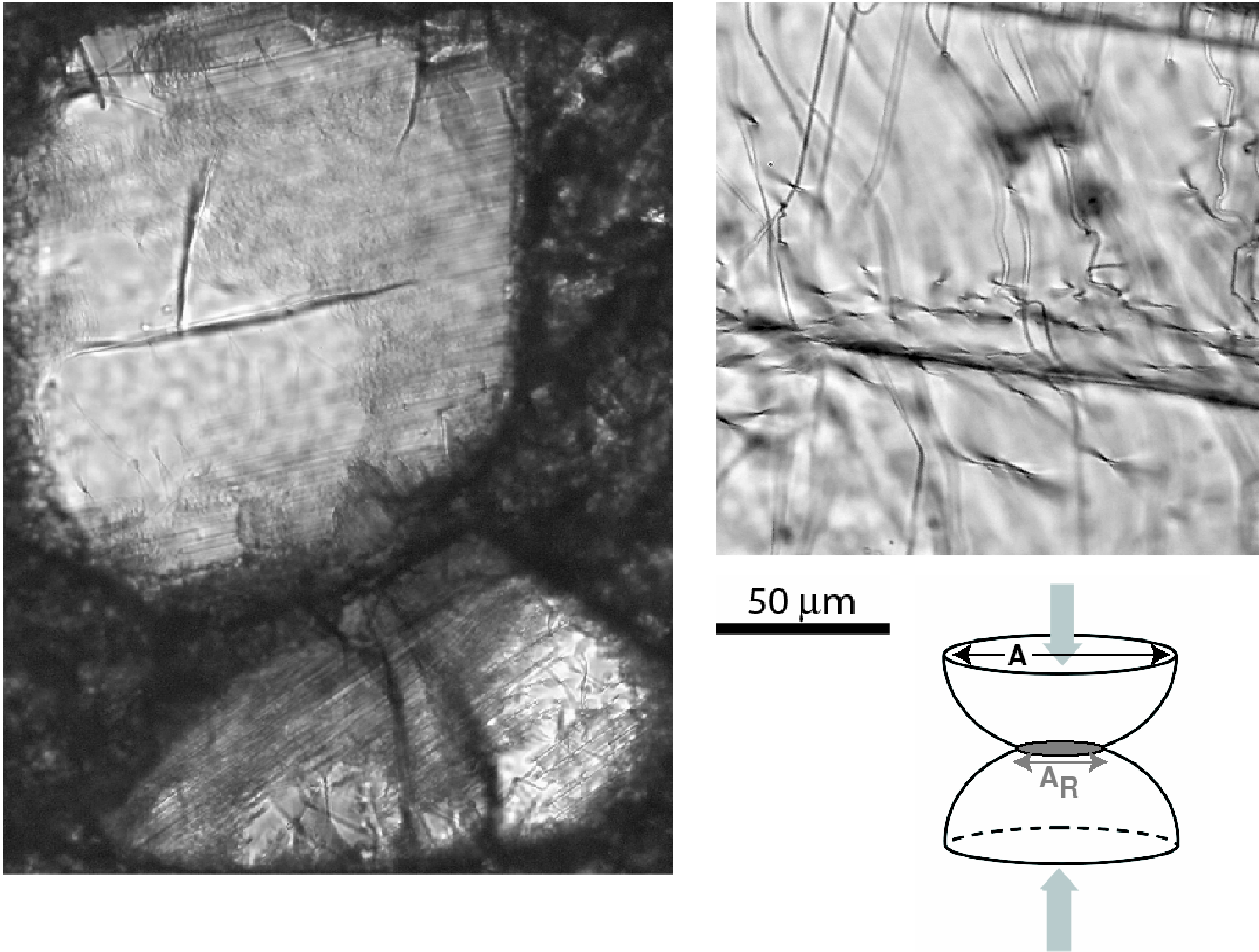
Boettcher, Hirth & Evans, 2006

Creep at asperities

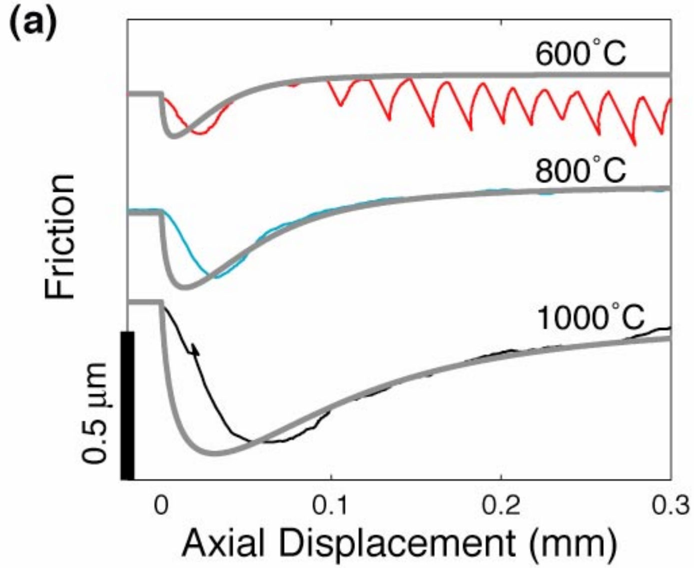


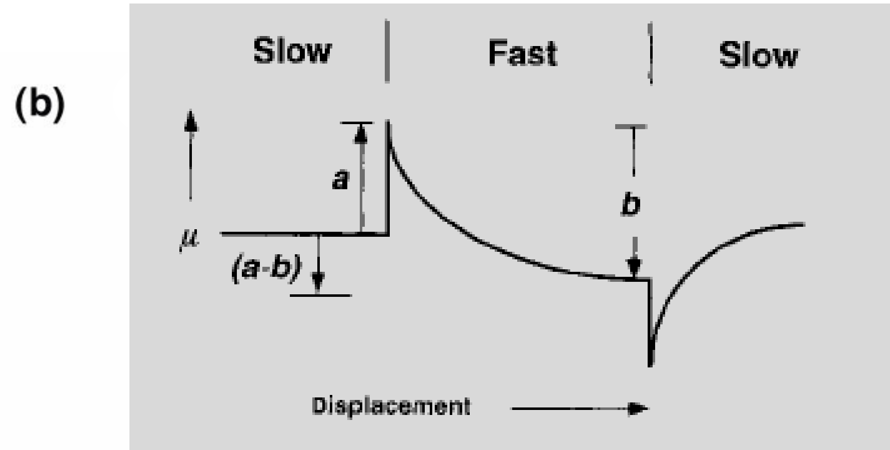
$$\frac{A_\mathrm{R}}{A} = \frac{\sigma_1 - \sigma_3}{\sigma_\mathrm{A}}$$

$$\sigma_\mathrm{A} = \sigma_\mathrm{P}\left[1 - \left(\frac{-RT}{H}\ln\frac{\dot{\epsilon}}{B}\right)^{1/q}\right]$$

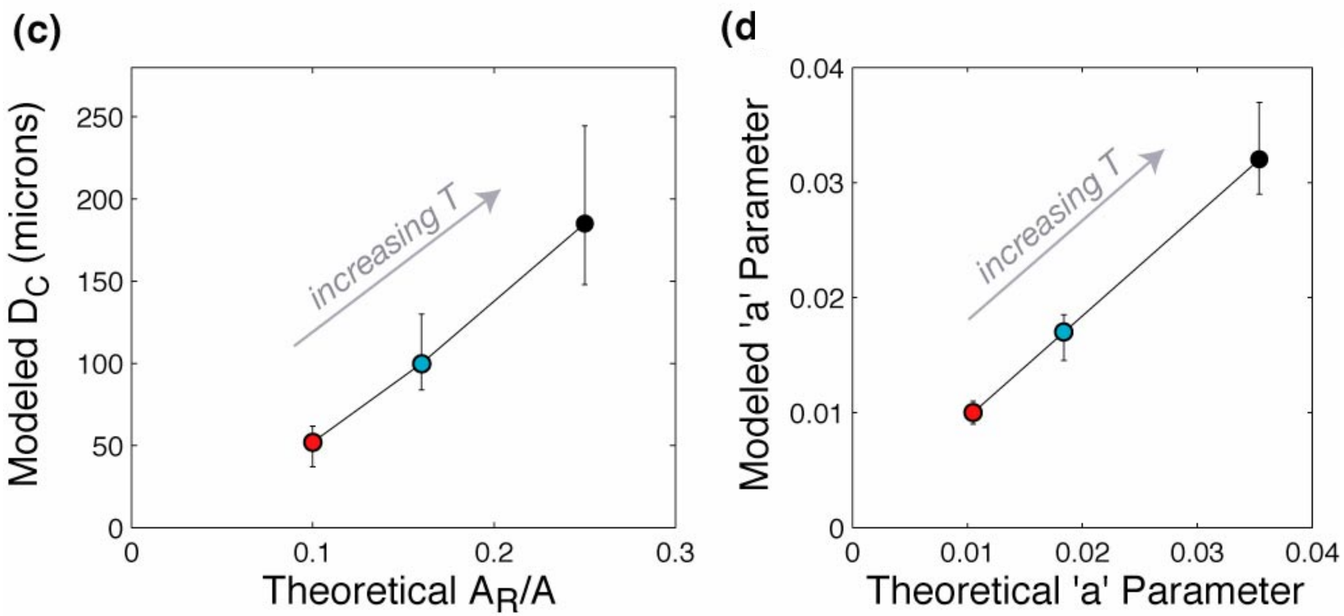


Boettcher, Hirth & Evans, 2006

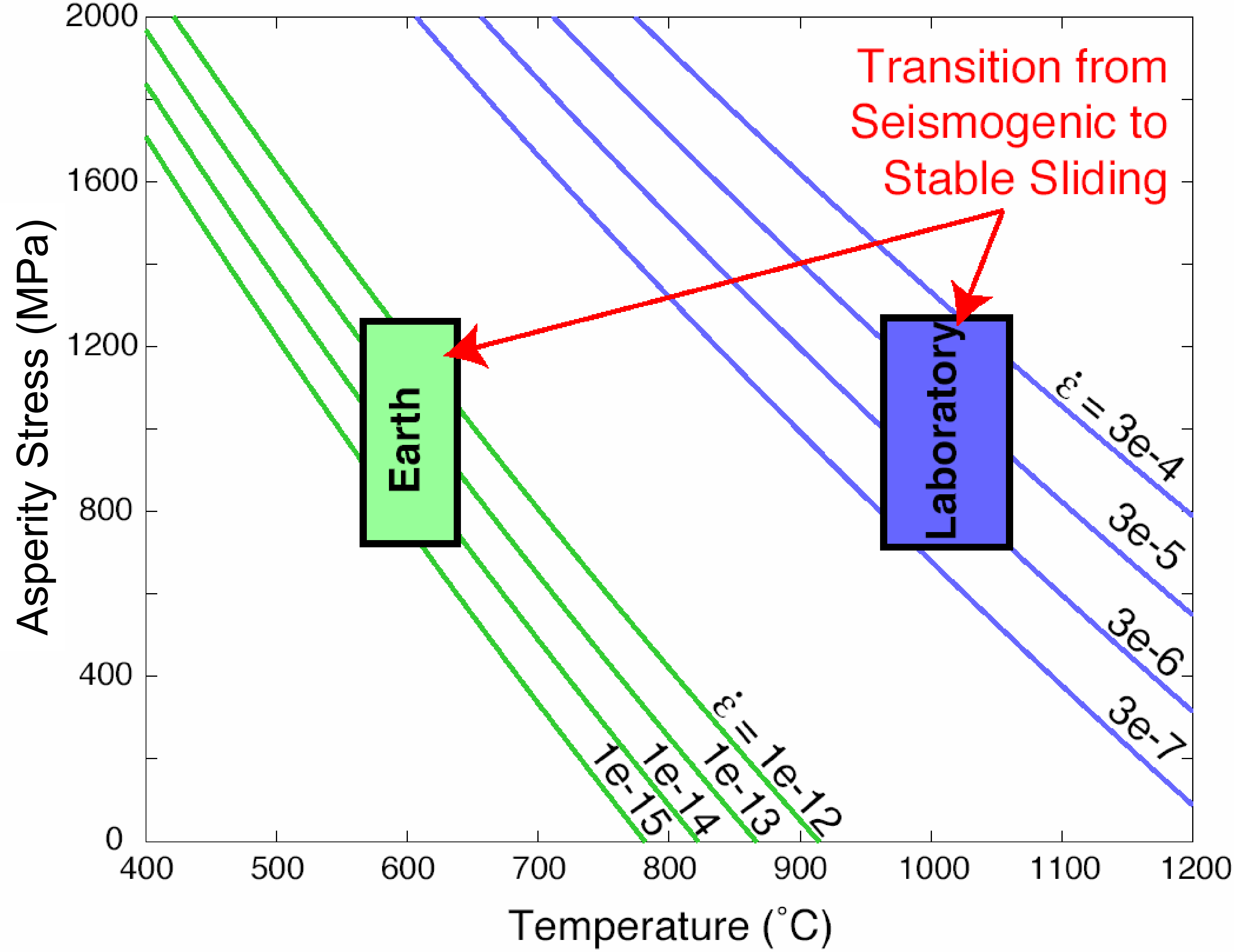




$$\mu = \mu_0 + a \ln\left(\frac{V}{V_0}\right) + b \ln\left(\frac{V_0 \theta}{D_c}\right)$$

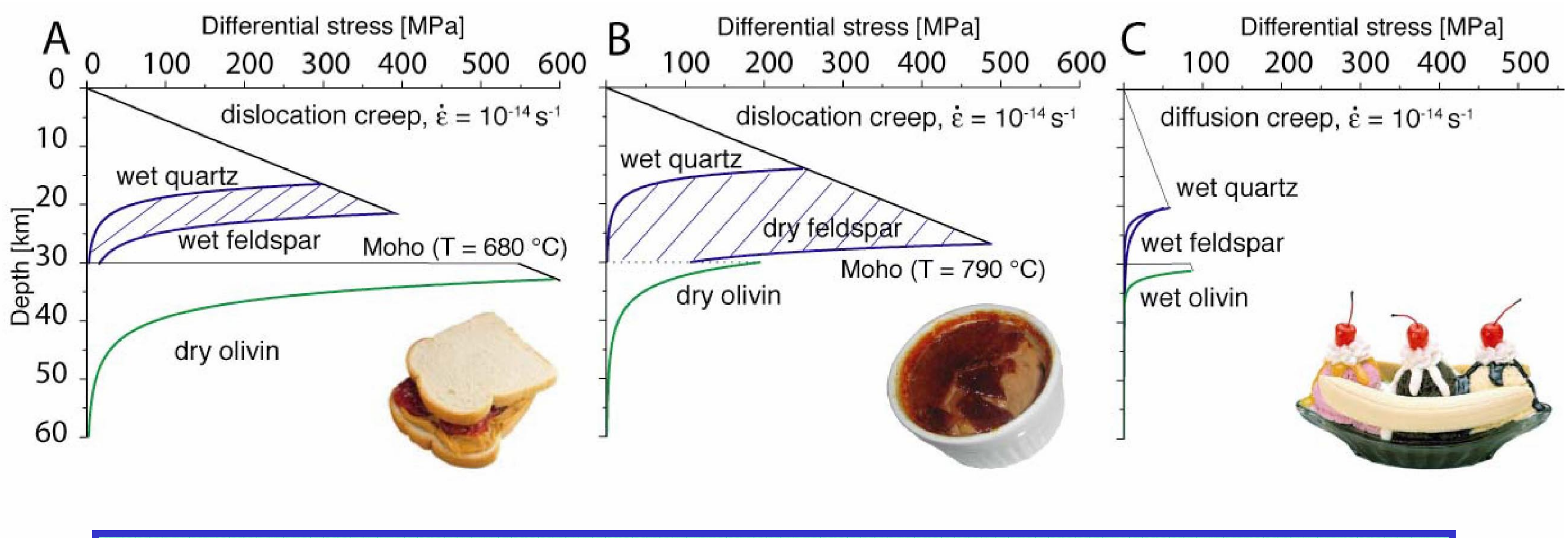


Boettcher, Hirth & Evans, 2006



Boettcher, Hirth & Evans, 2006

Lithosphere Rheology

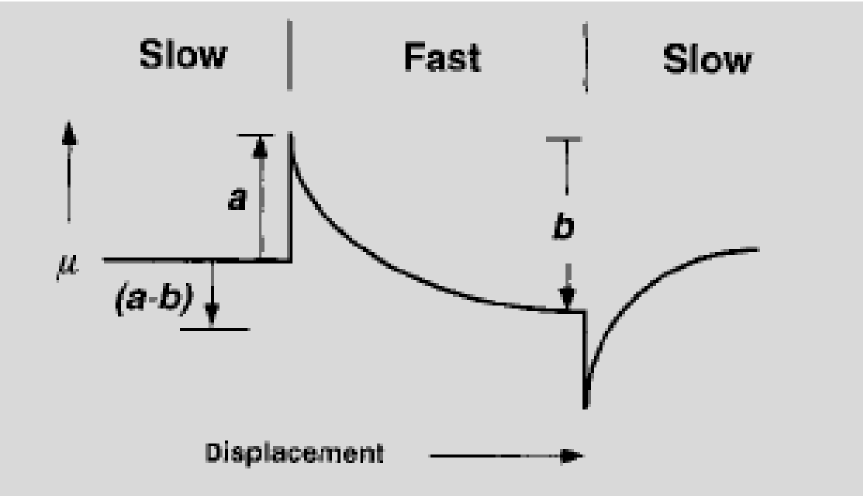


Viscosity contrast between crust & mantle (composition)

Role of shear zones in interpretation of geodetic data

Mylonites support “high” stresses but have much lower viscosity than surrounding rock

Temperature at base of seismogenic zone well predicted by extrapolation of lab data



$$\mu = \mu_0 + a \ln\left(\frac{V}{V_0}\right) + b \ln\left(\frac{V_0 \theta}{D_c}\right)$$

"State" evolution law: $$\frac{d\theta}{dt} = 1 - \frac{V\theta}{D_c}$$

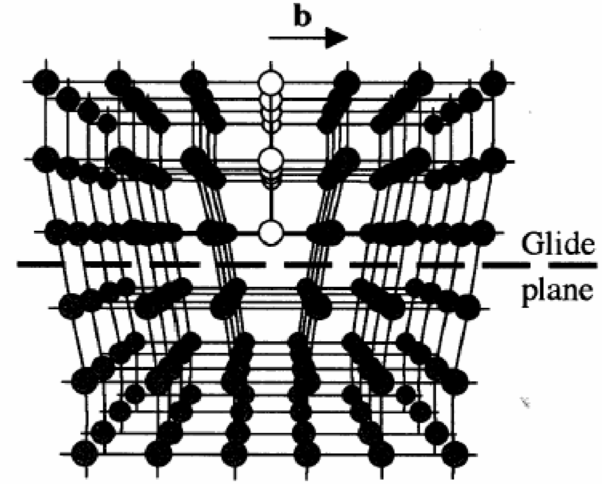
At steady state: $\theta = D_c / V$

"contact time"

$D_c = \theta \times V = time \times velocity$

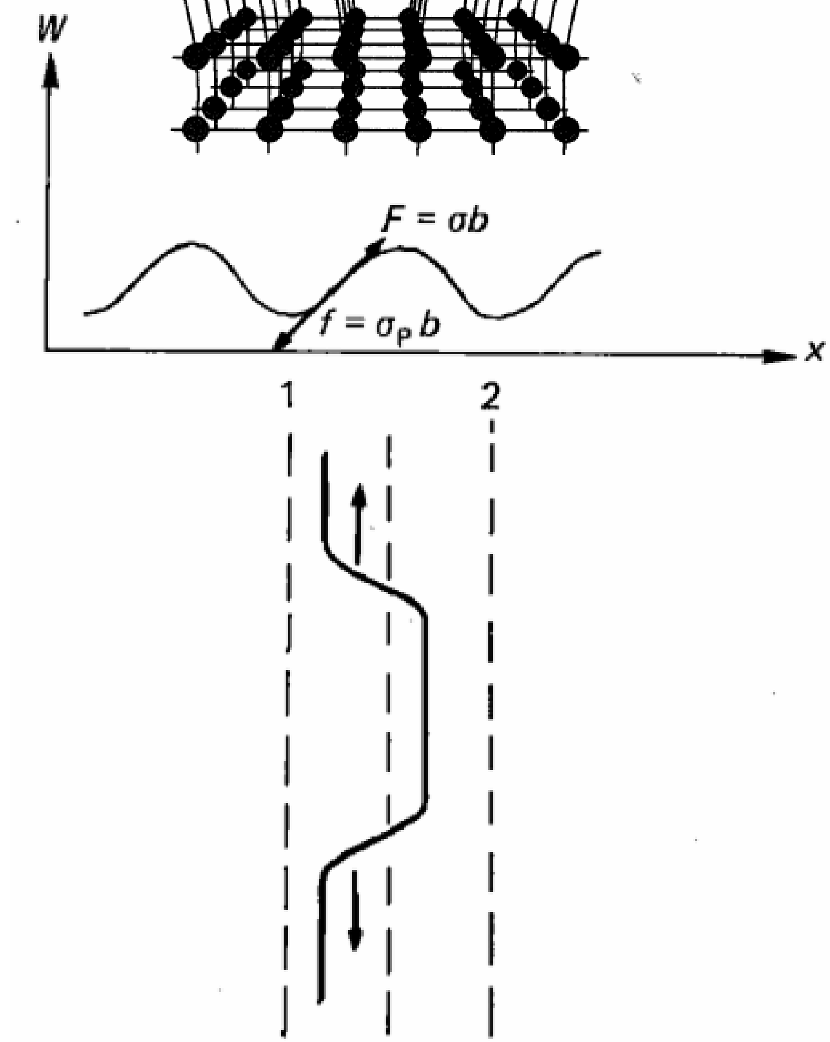
related to mean asperity size

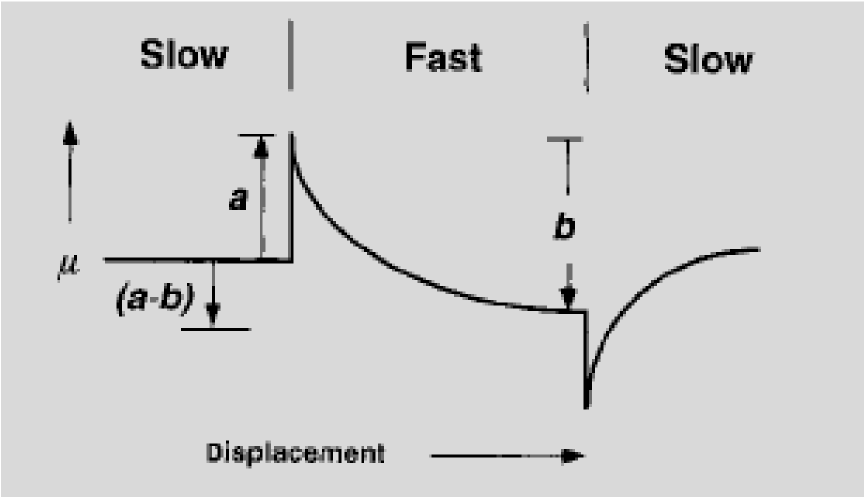
Kinetic basis for the direct effect



$$V = V_0 \exp\left(\frac{-E}{k_\mathrm{B}T}\right)$$

$$E = E' - \tau\,\Omega$$





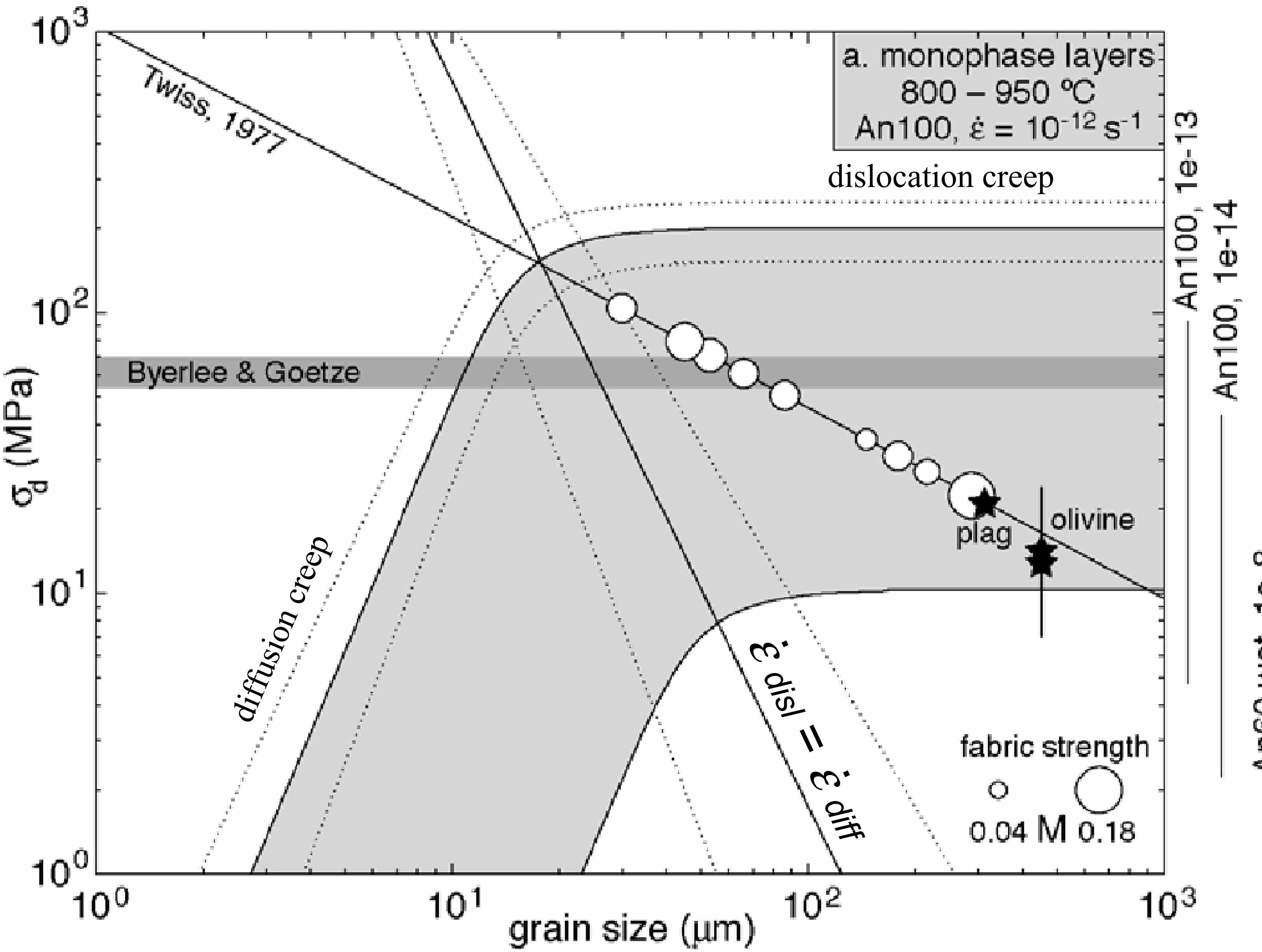
$$\mu = \mu_0 + a \ln\left(\frac{V}{V_0}\right) + b \ln\left(\frac{V_0 \theta}{D_c}\right)$$

$$V = V_0 \exp\left(\frac{-E}{k_B T}\right)$$

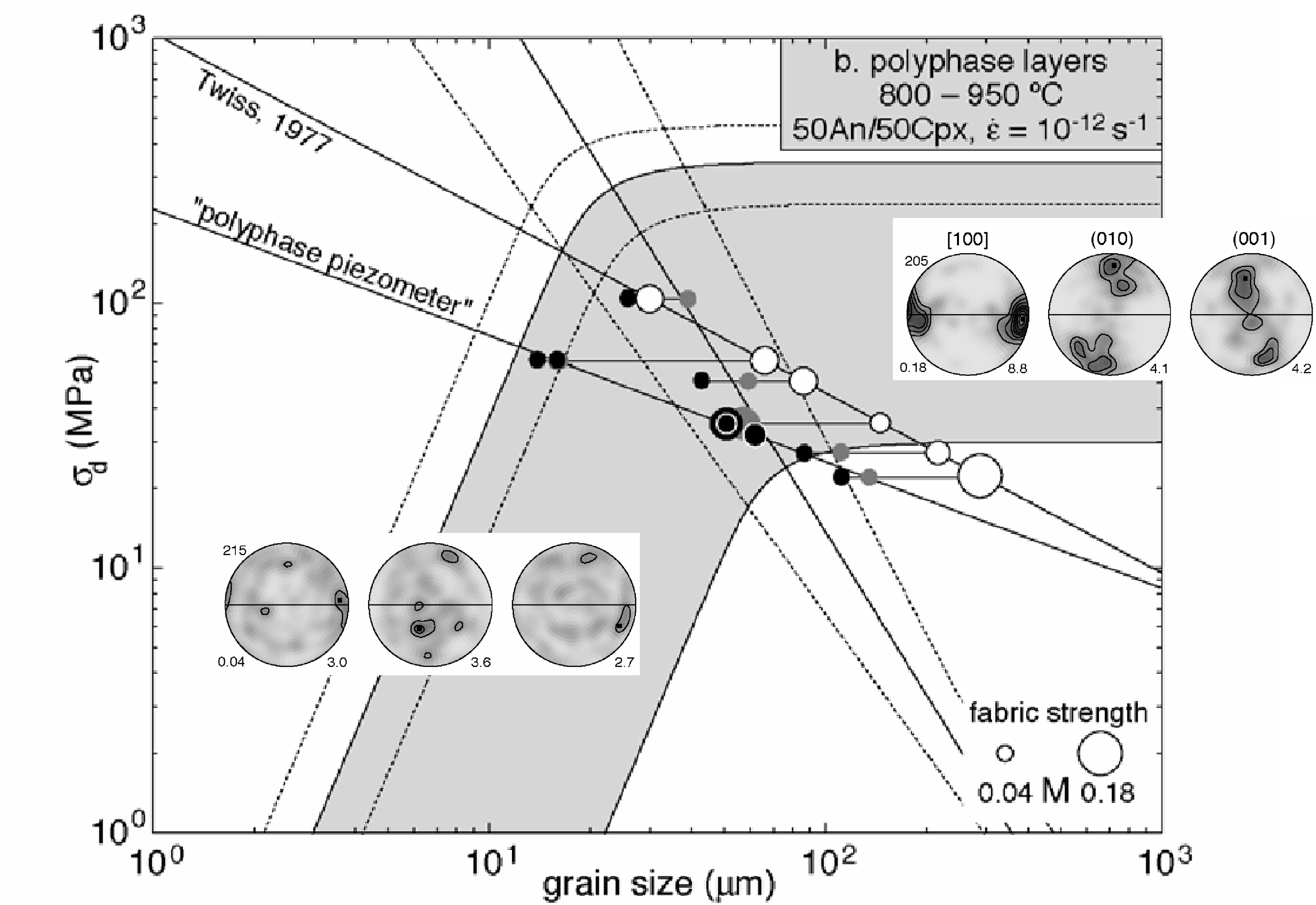
$$\Rightarrow \quad a = \frac{k_B T}{\sigma_A \Omega}$$

substitute $E = E' - \tau \Omega$

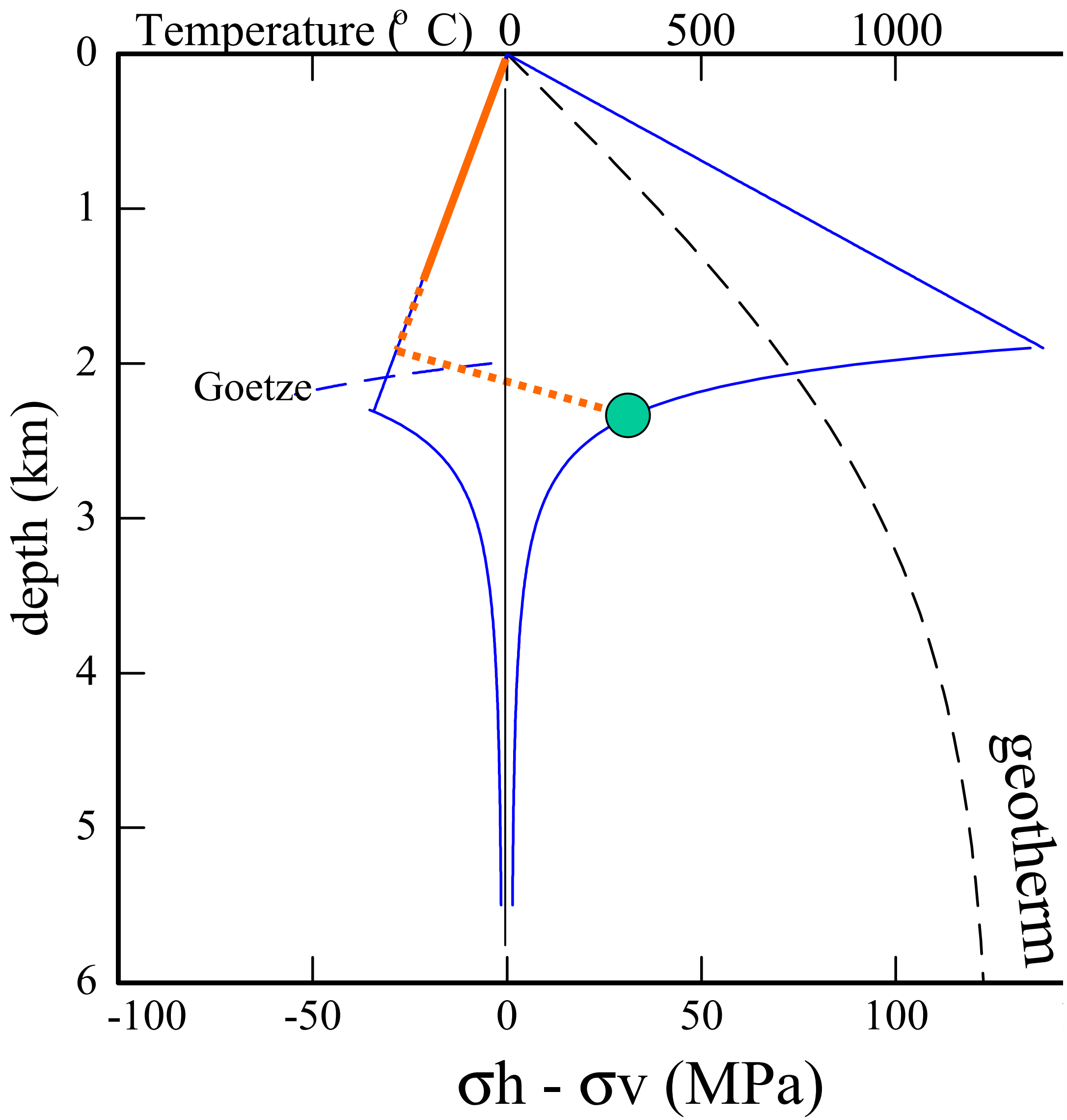
solve for τ



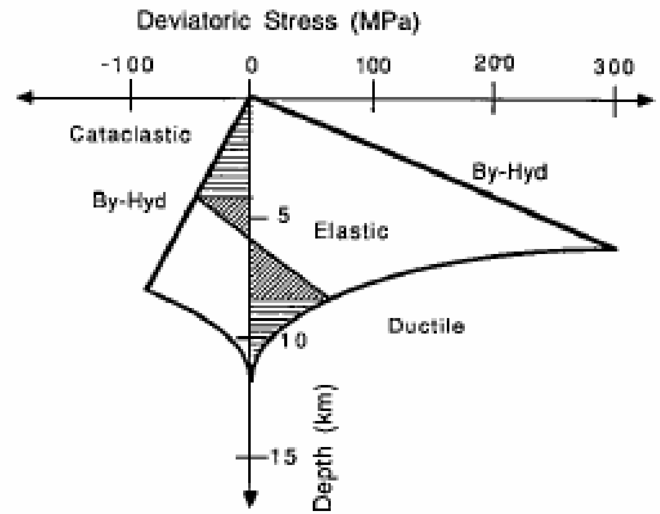
Mehl and Hirth, accepted, JGR



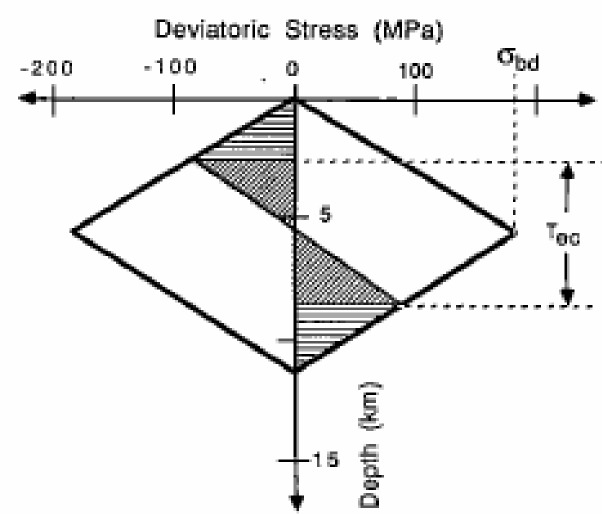
Mehl and Hirth, accepted, JGR



Temperature (°C) 0 500 1000
0
1
2
3
4
5
6
depth (km)
Goetze
geotherm
-100 -50 0 50 100
σh - σv (MPa)



Deviatoric Stress (MPa)
-100 0 100 200 300
Cataclastic
By-Hyd
By-Hyd
5
Elastic
Ductile
10
15
Depth (km)



Deviatoric Stress (MPa)
-200 -100 0 100
σbd
5
15
Depth (km)