How Lab Experiments on the Physical Properties of Earth and Planetary Materials can aid Ocean World Exploration

Christine McCarthy

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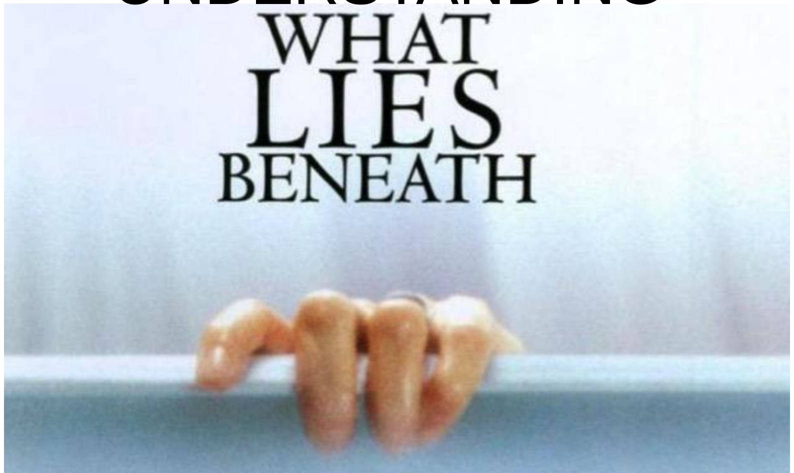
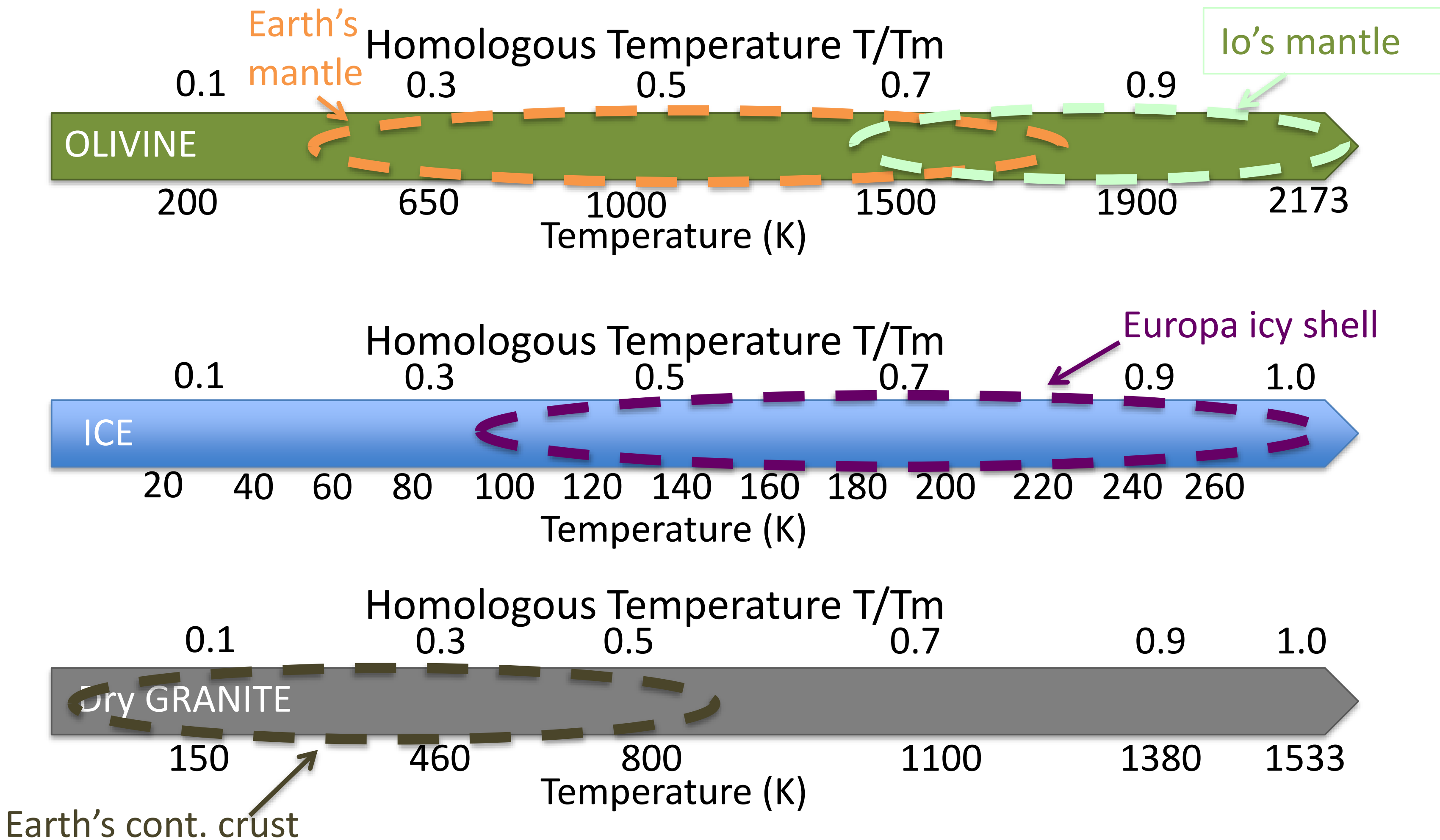
OR

UNDERSTANDING



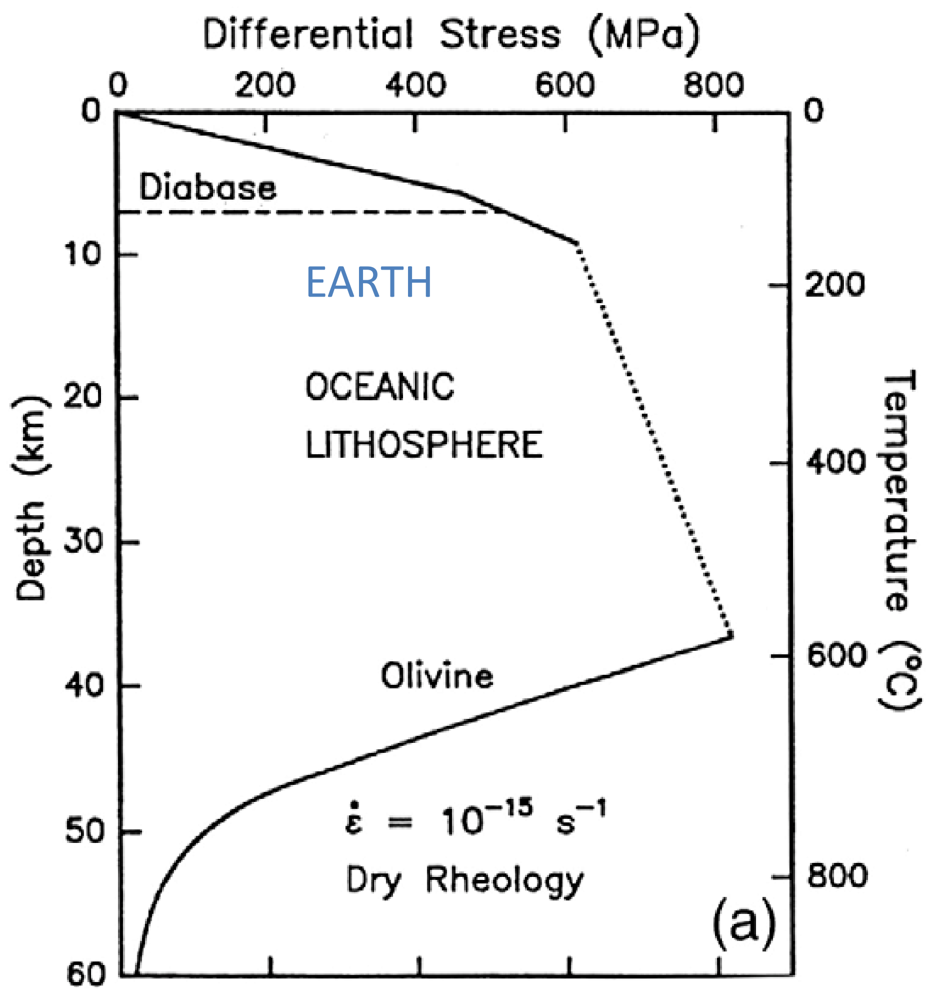
…the observable surface

Homologous temperature

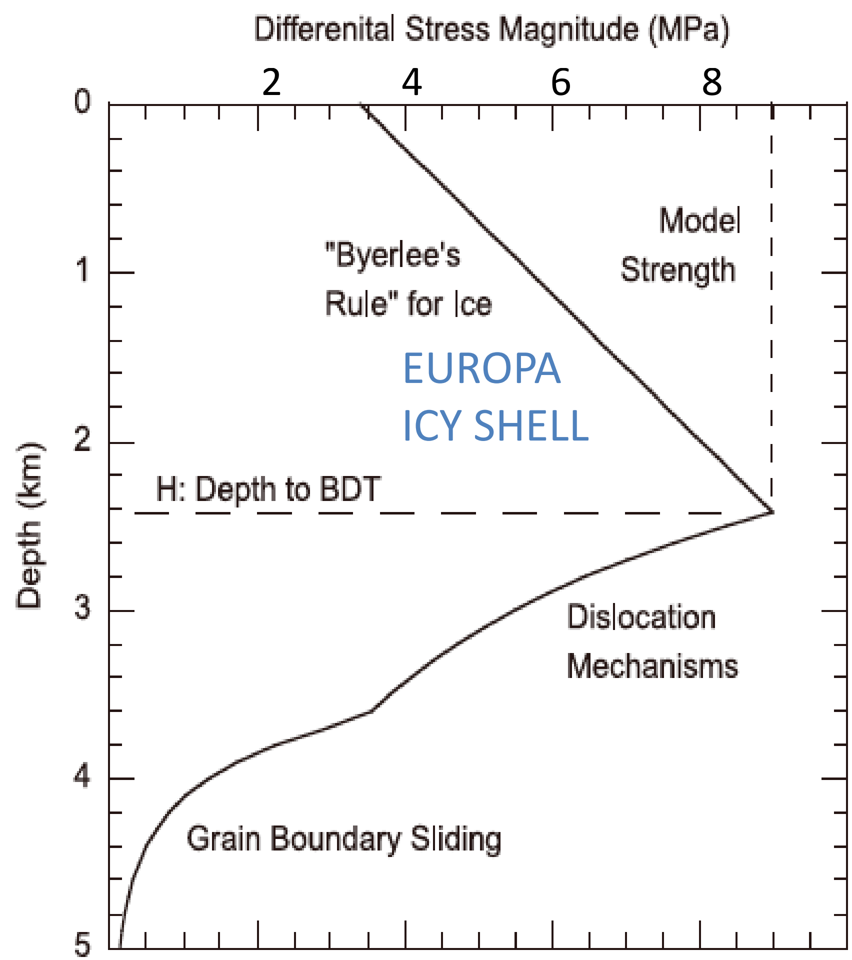


Strength envelopes:

From rheology of relevant minerals and T,P profiles



[Kohlstedt et al., 1995]

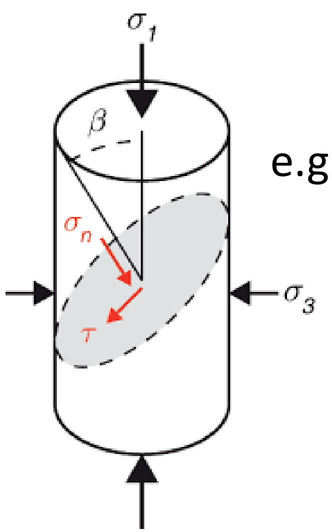


[Dombard and McKinnon, 2006]

Strength envelopes:

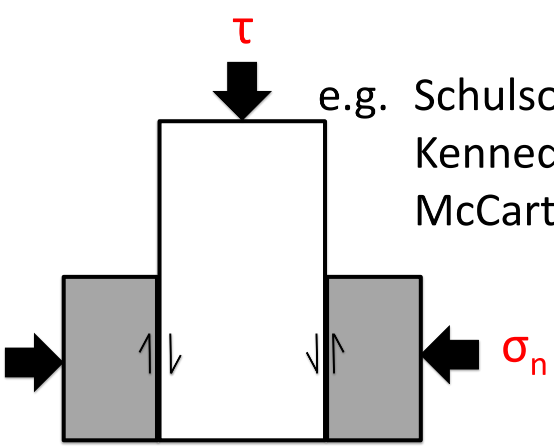
where do they come from?

Friction experiments
define the brittle portion

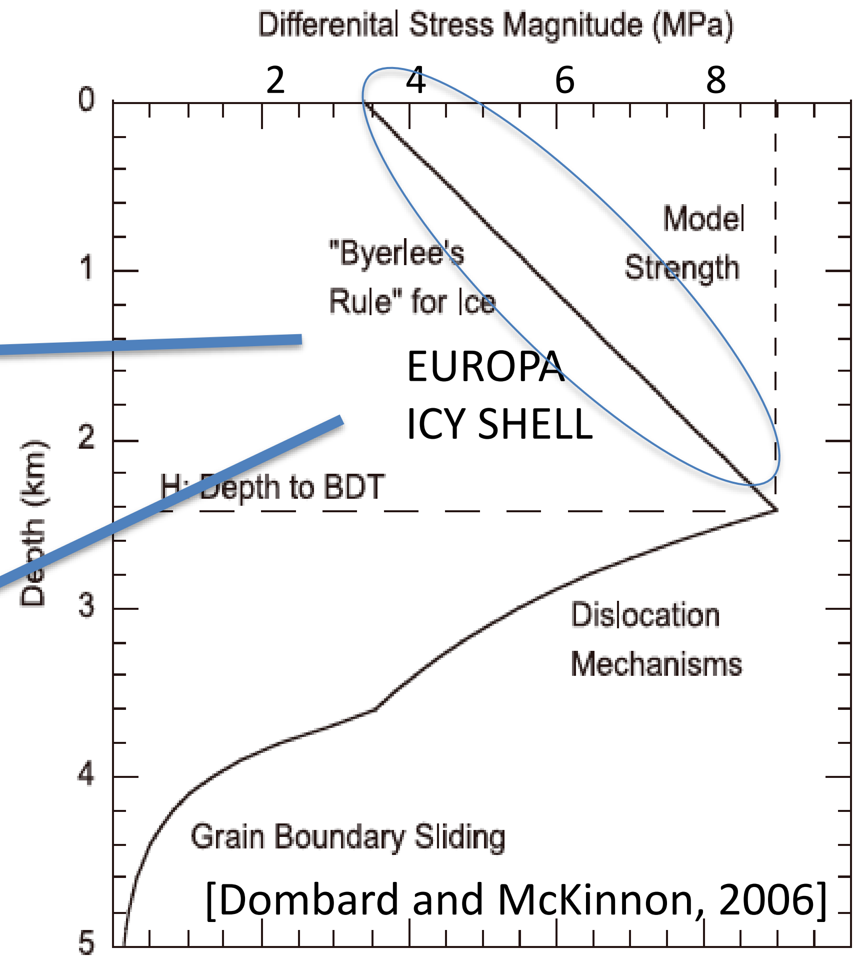


e.g. Beeman et al., 1988

friction $\mu = \tau/\sigma_n$



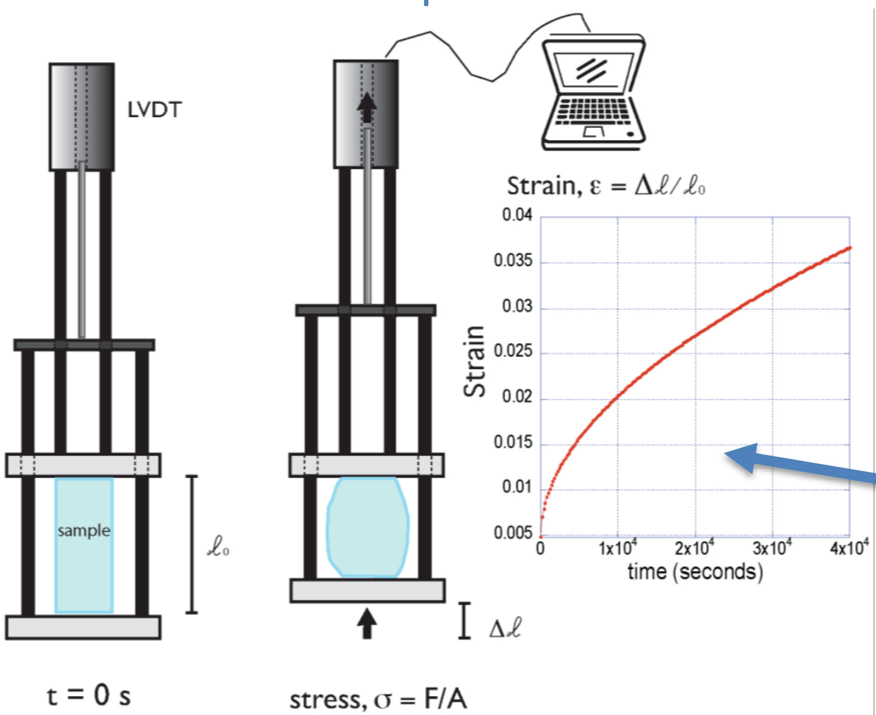
e.g. Schulson&Fortt, 2012
Kennedy et al, 2009
McCarthy et al., 2016,2017



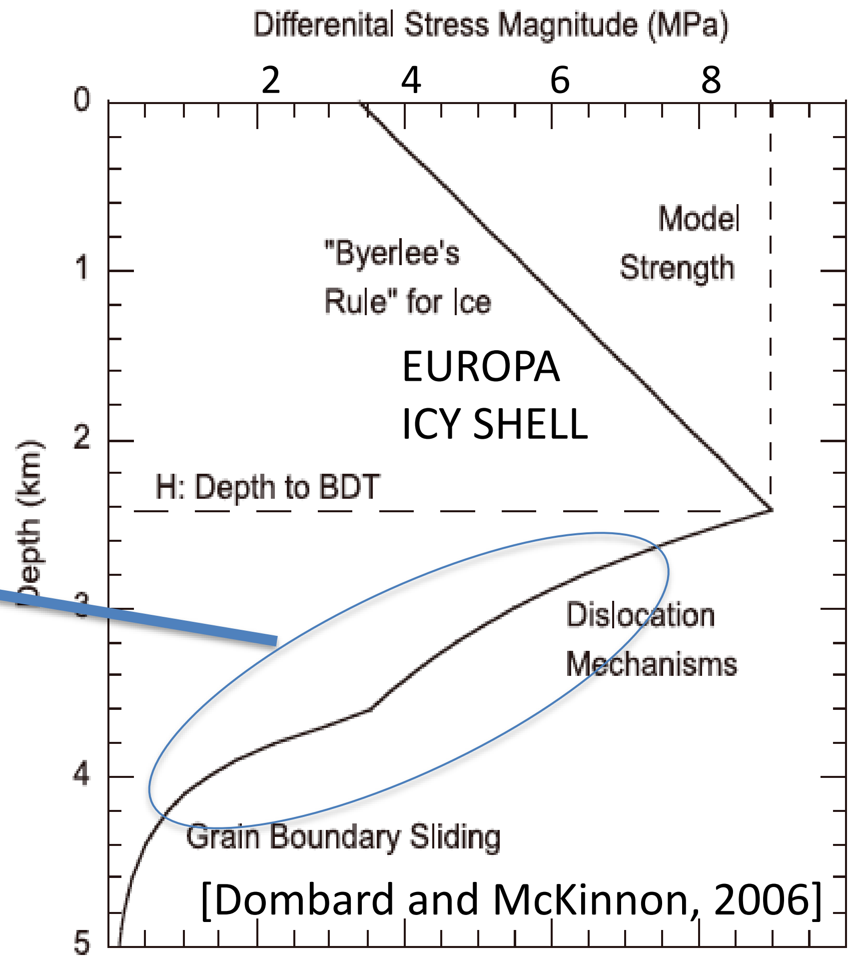
Strength envelopes:

where do they come from?

Creep experiments
define the ductile portion



e.g. Goldsby&Kohlstedt, 2001
Durham et al., 2001



[Dombard and McKinnon, 2006]

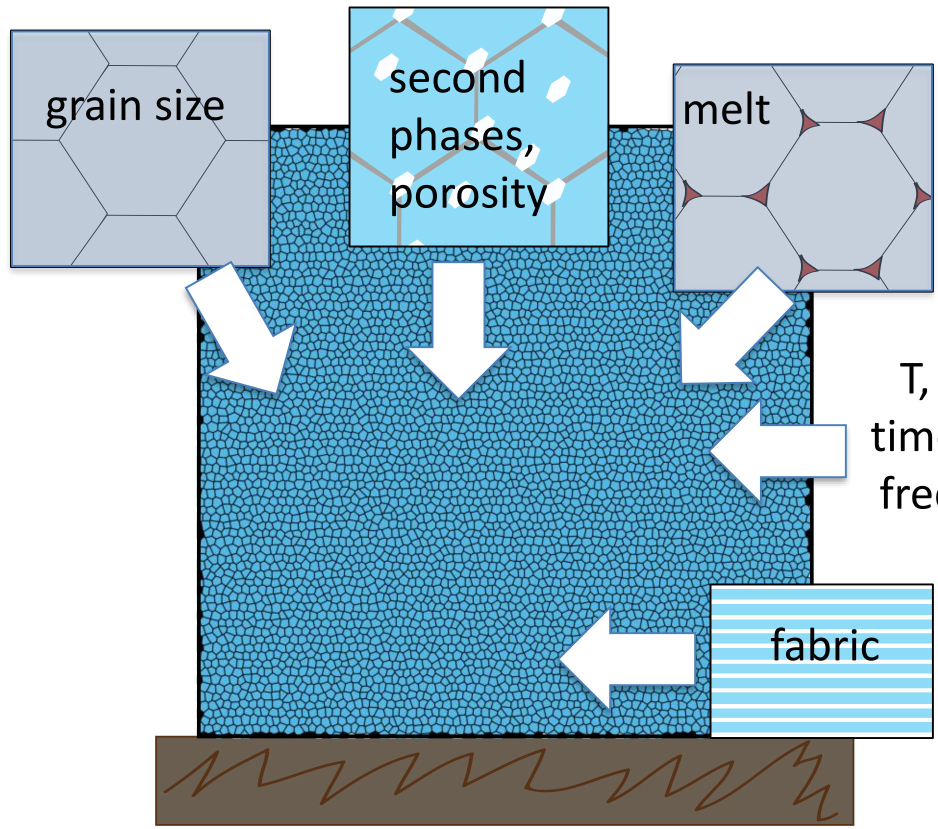
$$\dot{e} = A\frac{s^n}{d^p}\exp\left(\frac{-E_A + PV}{RT}\right)$$

$$\dot{\varepsilon} = \dot{\varepsilon}_{diff} + \left(\frac{1}{\dot{\varepsilon}_{basal}} + \frac{1}{\dot{\varepsilon}_{gbs}}\right)^{-1} + \dot{\varepsilon}_{disl}$$

Microstructure influences mechanical behavior

Physical properties that we can measure in the lab, that you will incorporate into your models, that are likely influenced by microstructural properties (and conditions):

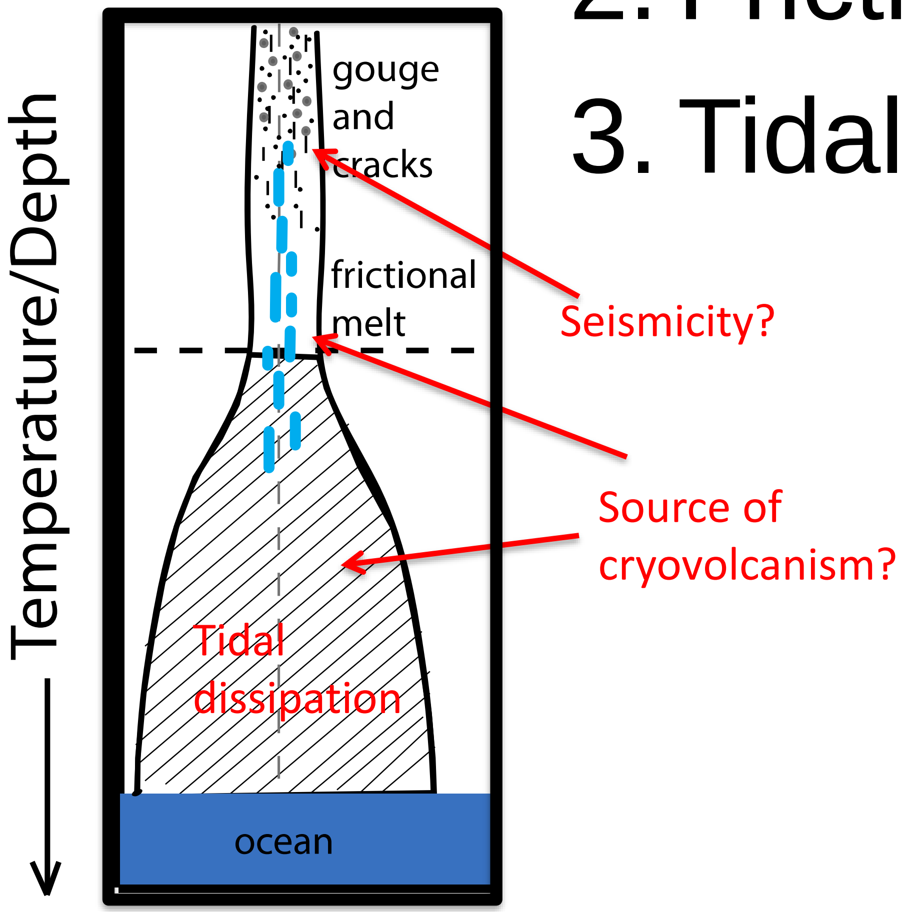
Elastic moduli (unrelaxed to relaxed)
Viscosity
Attenuation (i.e. tidal dissipation)
Friction (and frictional heating
Fracture toughness
hardness
thermal conductivity

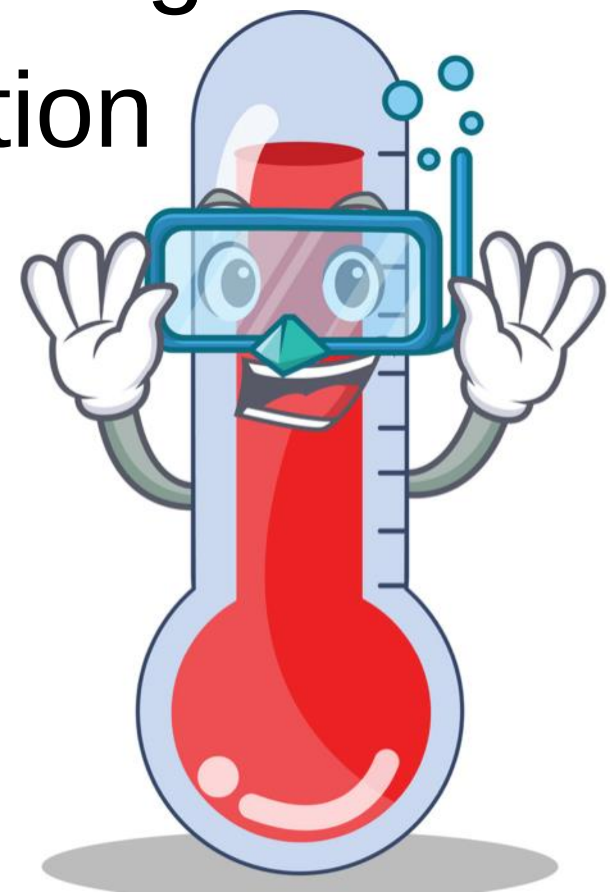


A polycrystalline viscoelastic solid, warts and all

Sources of heating on Ocean Worlds

1. Impacts
2. Frictional heating
3. Tidal dissipation

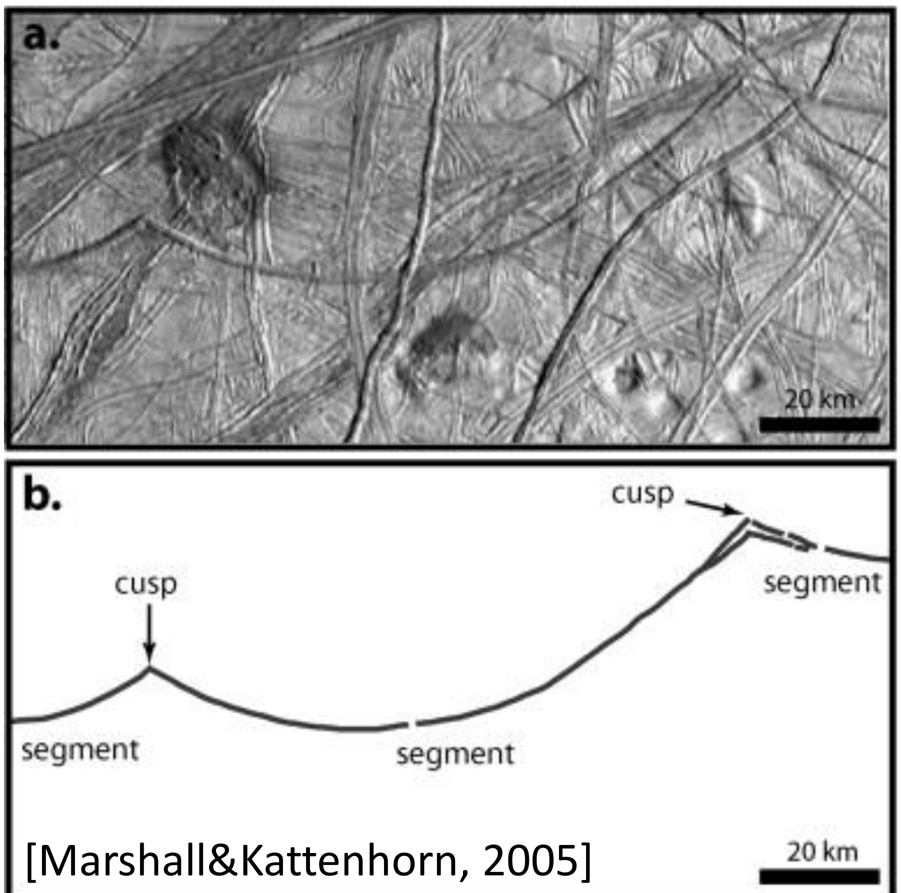




Frictional heating

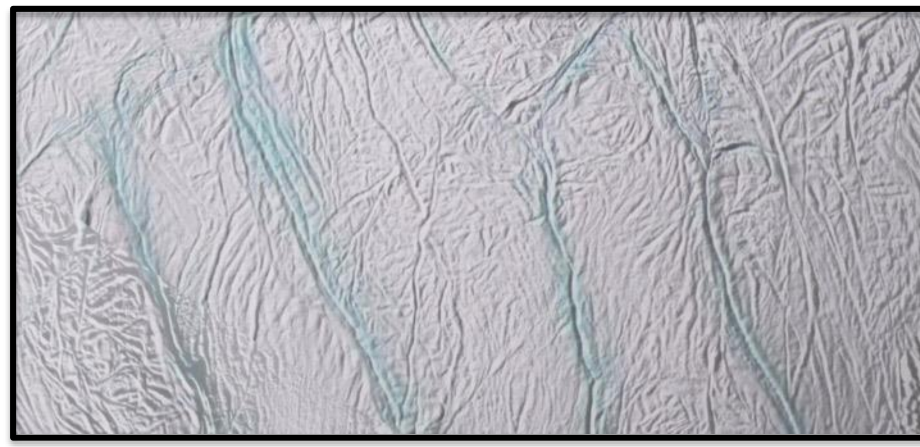
Knowing frictional properties can help explain dynamics of faults and estimate heating

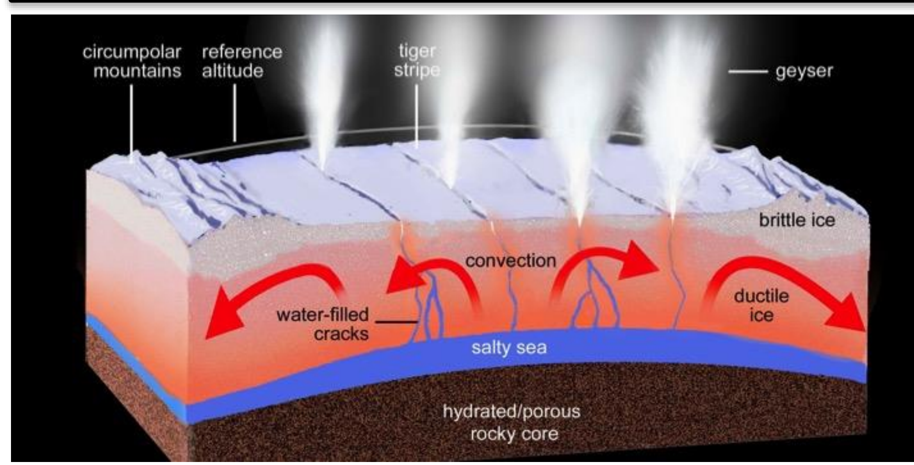
Cycloids on Europa



[Marshall&Kattenhorn, 2005]

"Tiger Stripes" on Enceladus

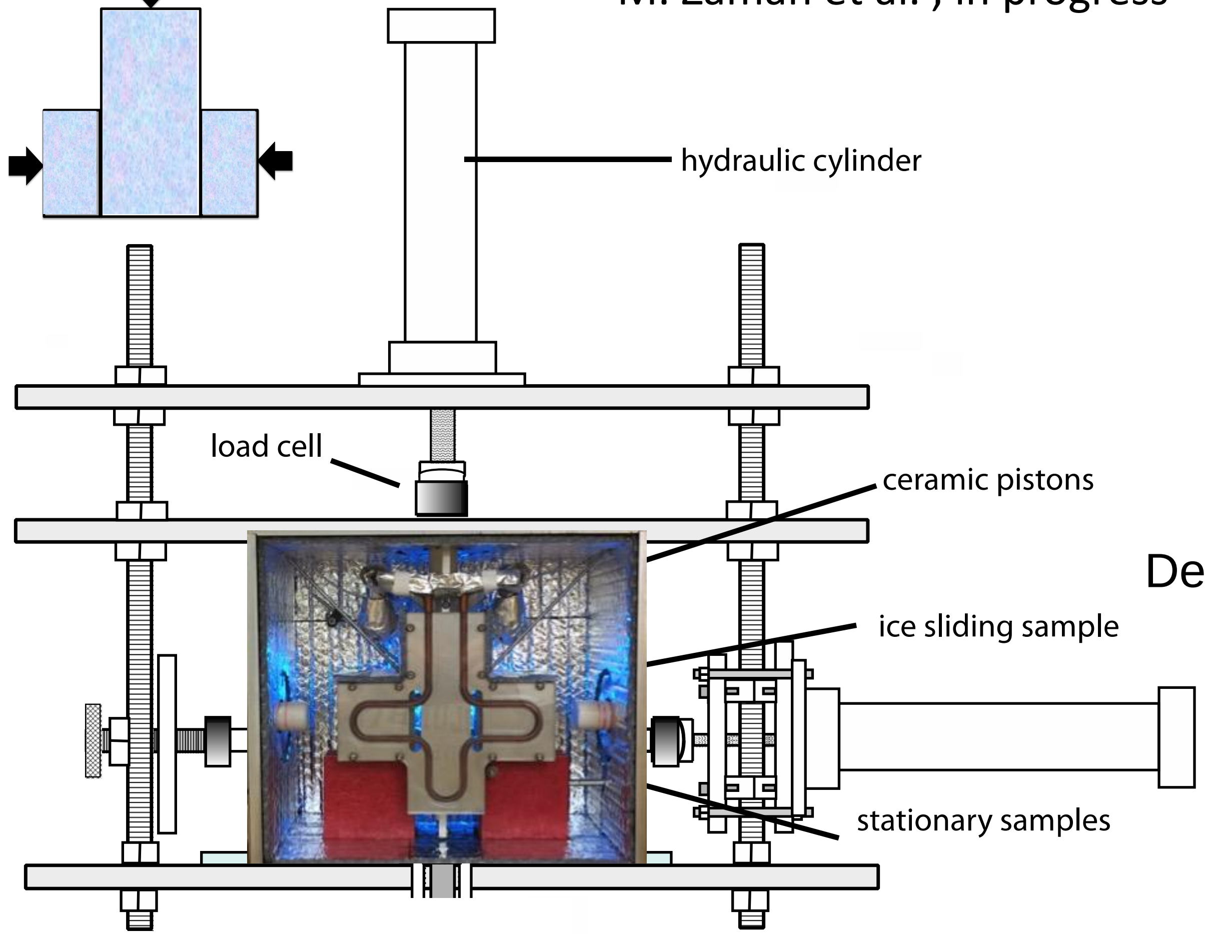




Friction Experiments

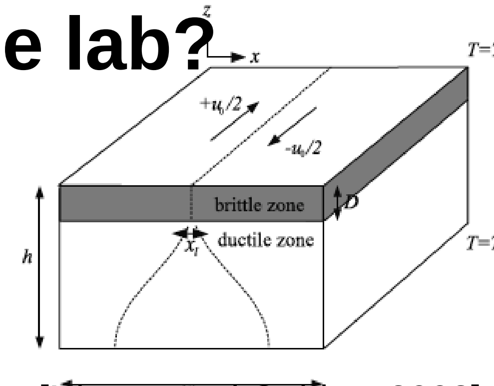
How do we measure friction in the lab?

M. Zaman et al. , in progress



friction $\mu = \tau/\sigma_n$

[Apparatus described in McCarthy et al., 2016]



[Nimmo and Gaidos, 2002]

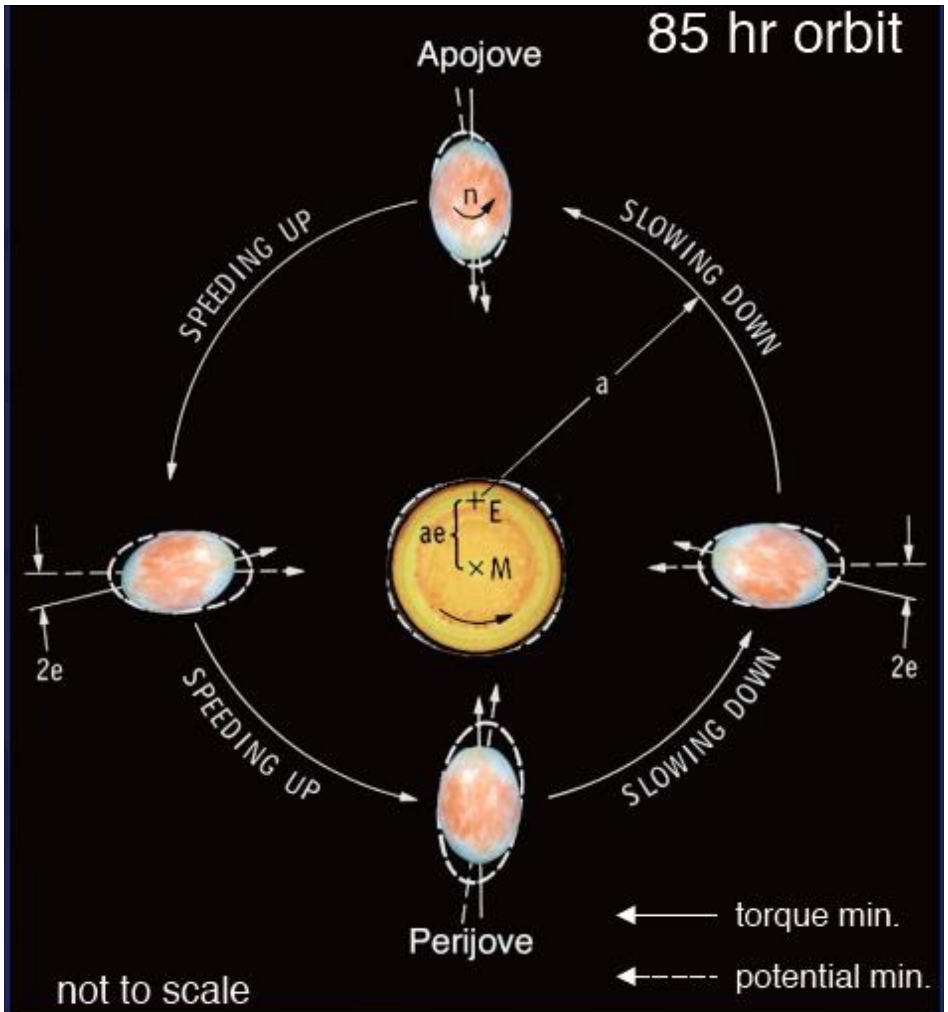
FRICTIONAL HEATING:

$$H_f = \mu\rho g z u$$

Depends on friction and velocity.

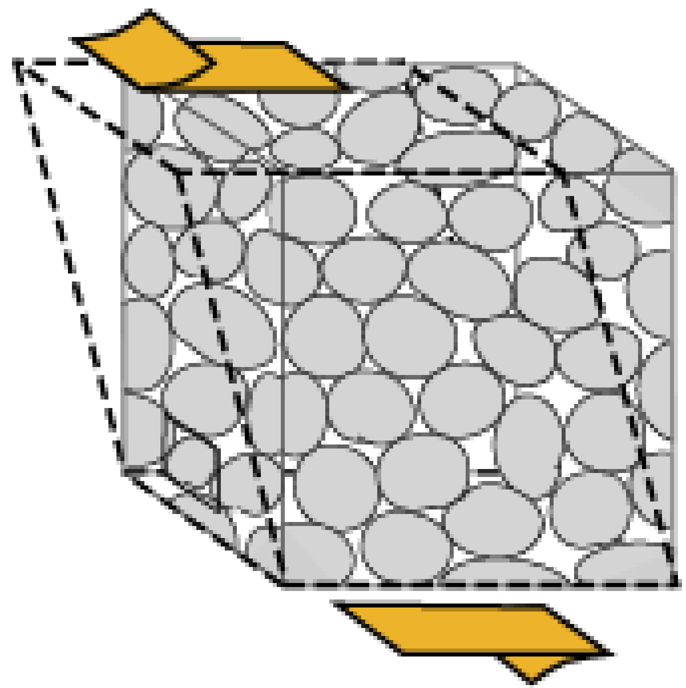
Using estimated tidally driven stress patterns and experimentally determined values for friction make improved models of frictional heating with depth and over time.

Tidal dissipation



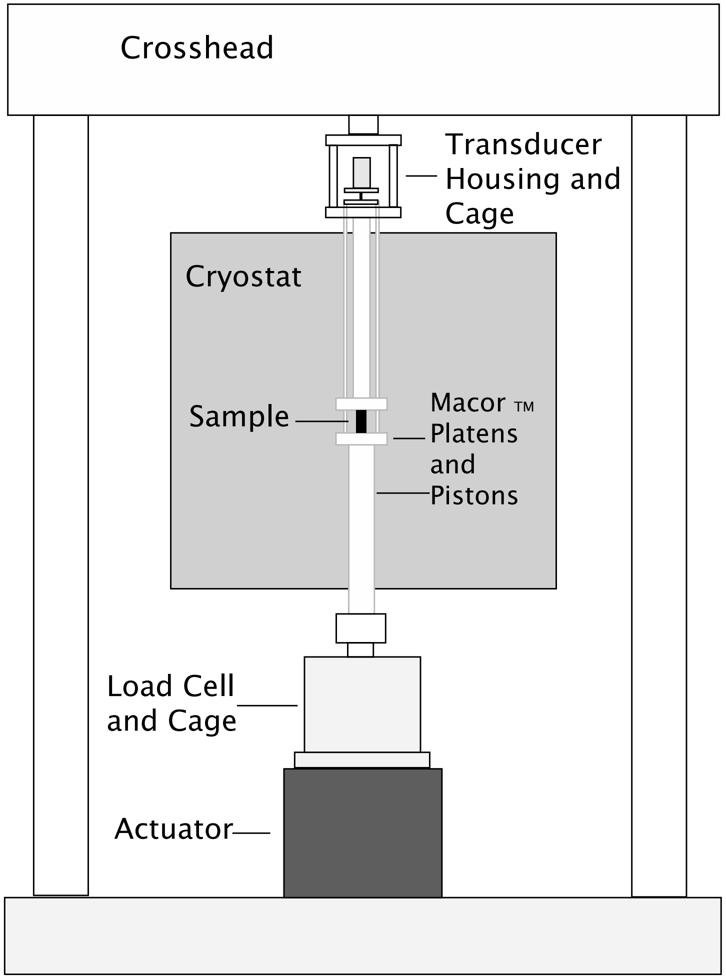
"friction" of defects inside the ice

Magnitude of heating depends on amplitude of bending and damping of material



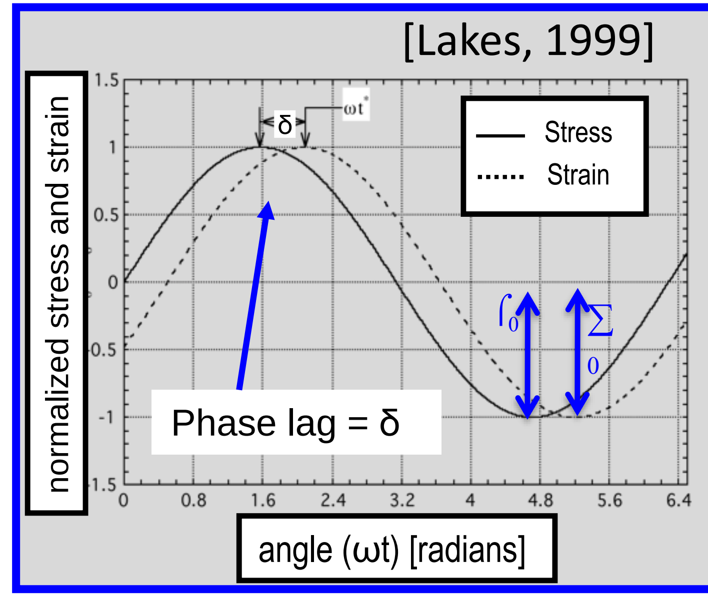
Tidal dissipation

How do we measure anelasticity in the lab?



$$Q^{-1} = \tan d = \frac{J_2}{J_1};$$

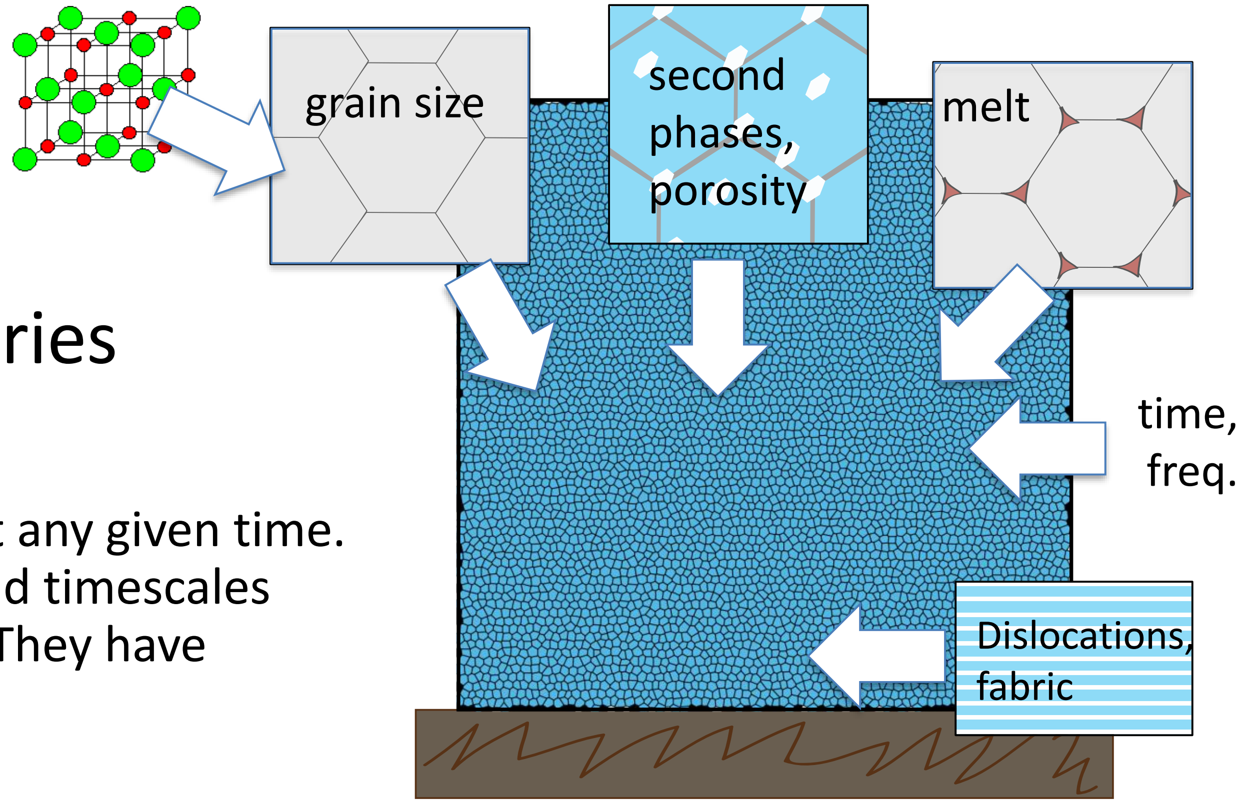
$$E = \left(\frac{s_0}{e_0}\right)$$



[McCarthy & Cooper, 2016]

Dissipation in polycrystalline materials occurs by motion of:

- 1D: point defects
- 2D: dislocations
- 3D: grain boundaries



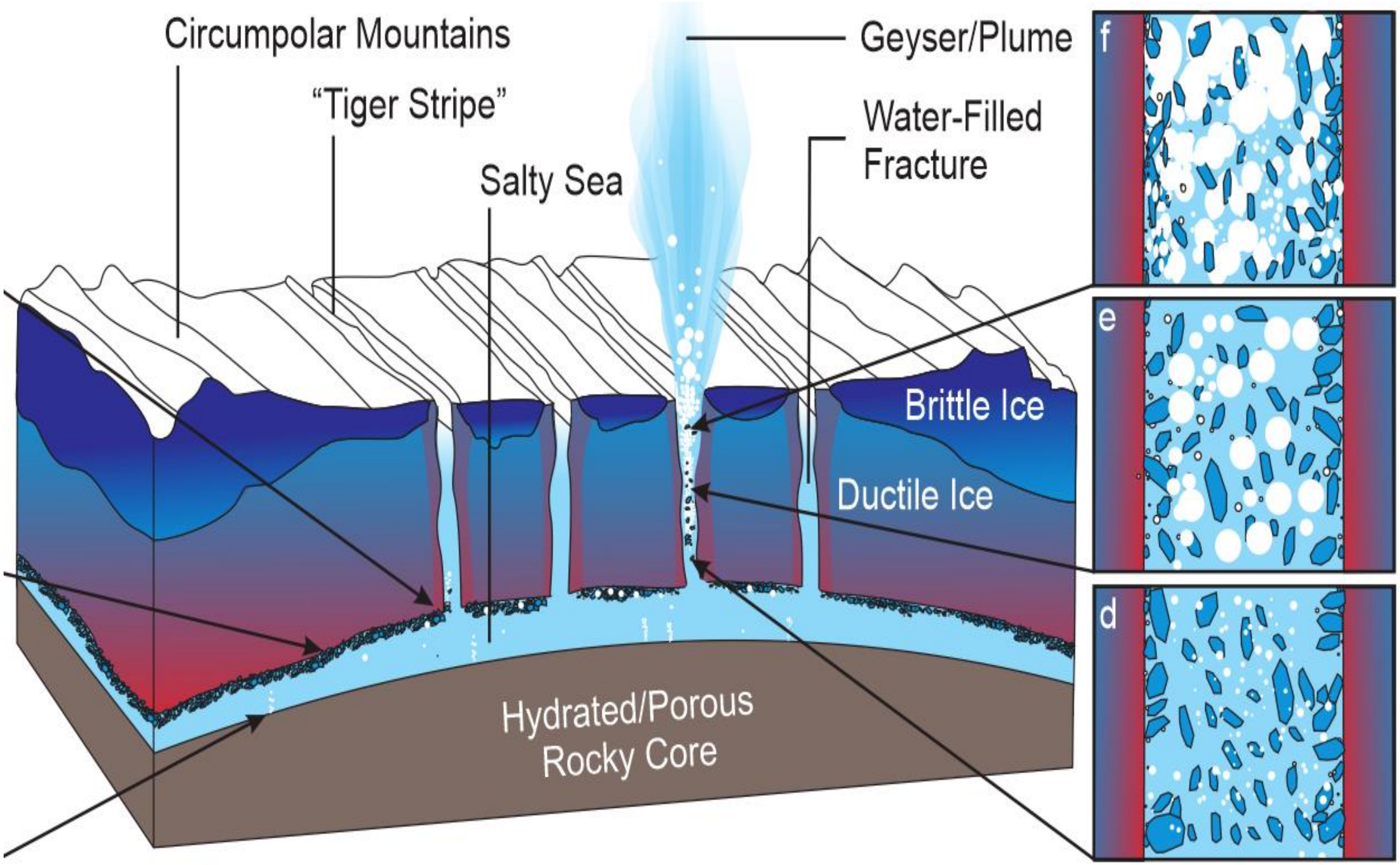
(more than one happening at any given time. under different conditions and timescales one or more may dominate. They have different “signatures”.)

ALSO influenced by:

melt and second phases

A polycrystalline viscoelastic solid, warts and all

Cryovolcanism: melt pathways through the ice?

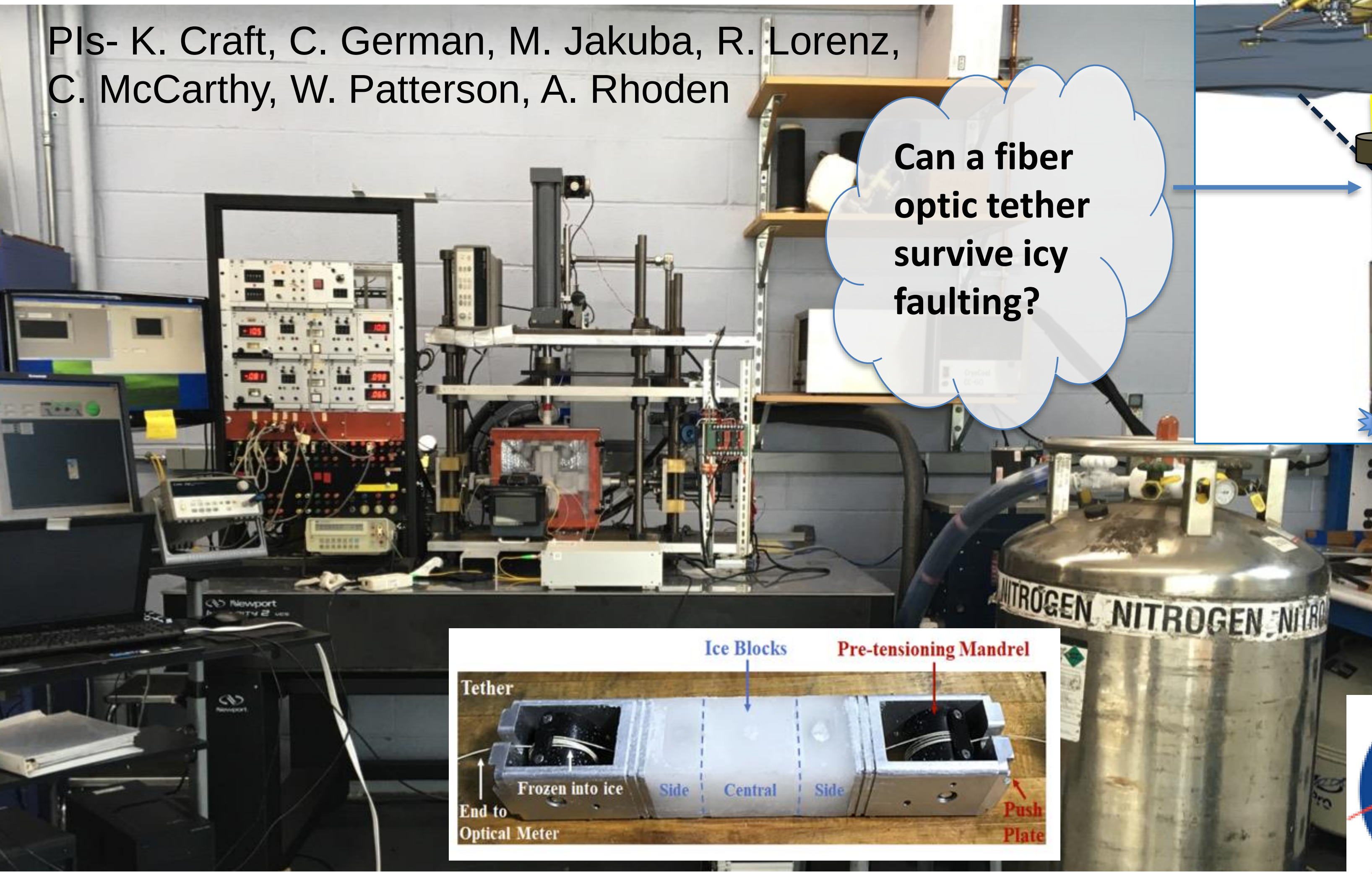


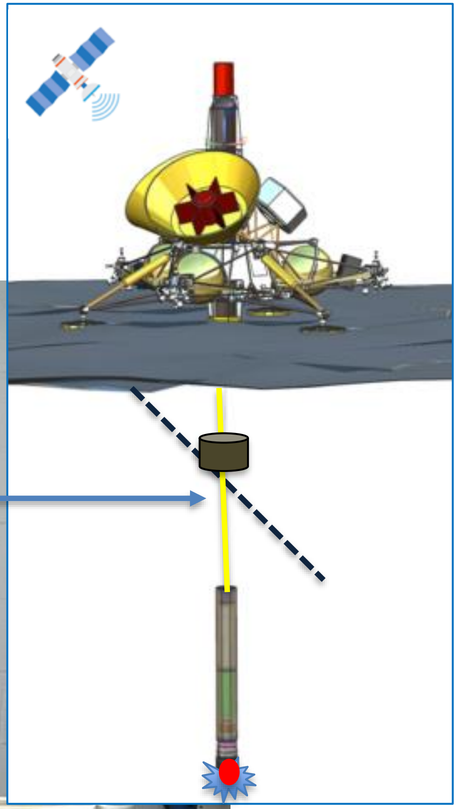
[schematic by Christopher Hamilton]

Europa (STI) – Exploring Communication Techniques and Strategies for Sending Signals Through the Ice (STI) for an Ice-Ocean Probe

PIs- K. Craft, C. German, M. Jakuba, R. Lorenz, C. McCarthy, W. Patterson, A. Rhoden

Can a fiber optic tether survive icy faulting?





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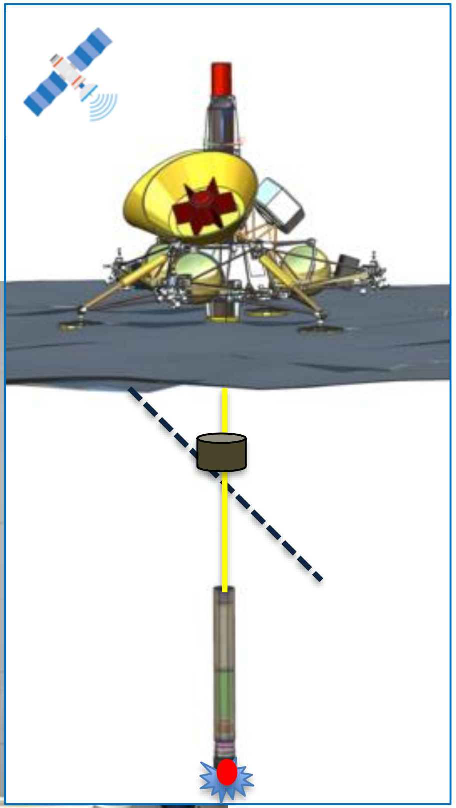
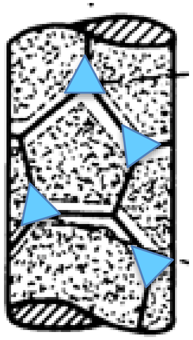
See Vishaal Singh's LPSC poster next week!
Abstract #2403



What next? Future directions

- Continue to understand effects of second (and third) phases on ice rheology (including melt)
- Cryovolcanism (eruptibility, transport)
- Continue to test technology at icy moon conditions
- Expand to even lower temperatures



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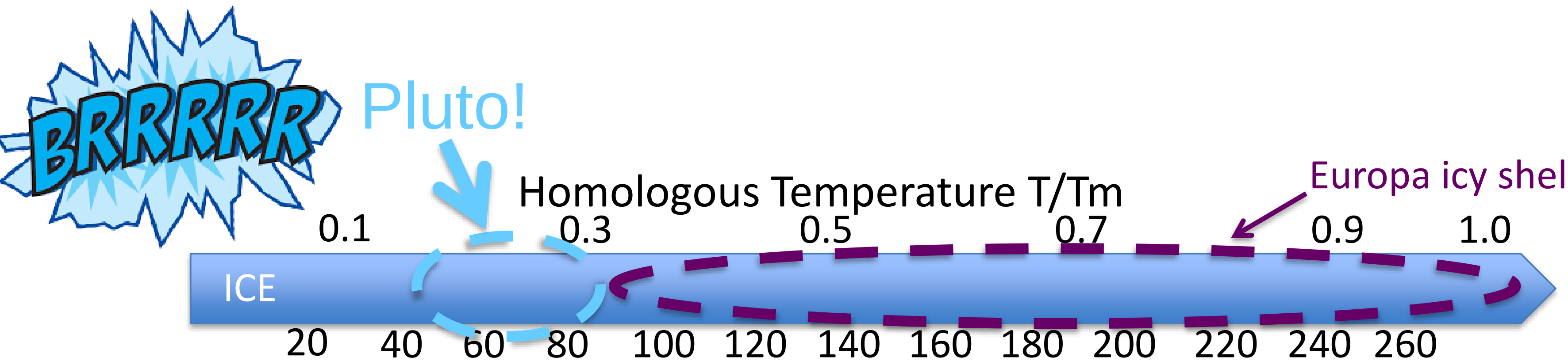
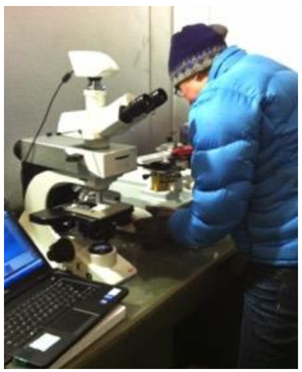


Thank you!



The Rock and Ice Mechanics Lab

Lamont-Doherty Earth Observatory

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