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Mid-Ocean Ridge Transform Faults

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Abstract

Drawing from recent work on specific aspects of fault slip in strike-slip oceanic settings, I've constructed a synoptic model that integrates findings from rock mechanics, seismology, and thermal modeling to predict the strength and seismic behavior of oceanic ridge transform faults (RTFs). Slip on RTFs is primarily aseismic, only 15% of the tectonic offset is accommodated by earthquakes. Despite extensive fault areas, few large earthquakes occur on RTFs, and few aftershocks follow the large events. Standard models of seismicity, in which all earthquakes result from the same seismic triggering process, do not describe RTF earthquakes. Instead, large earthquakes appear to be preceded by an extended fault preparation process marked by abundant foreshocks. I use data from experimental tests on olivine, the primary component of the oceanic lithosphere, and its alteration phases, serpentine and talc, to determine the deformation mechanisms likely to be active on RTFs. The experimental flow laws were then extrapolated from the laboratory to the Earth and crosschecked using microstructures preserved in dredged samples of the oceanic lithosphere. We found that the depth extent of oceanic faulting is thermally controlled and limited by the 600°C isotherm. Using thermal modeling I can apply these rheologic laws to individual faults and construct spatially varying cross sections of fault strength and frictional stability. I find that a scaling model, which we have developed from global RTF datasets, provides relatively successful predictions of seismicity distributions on individual RTF segments. Integrating the rheology, geology, and seismicity of RTFs allows us to better understand how slip is accommodated on RTFs.

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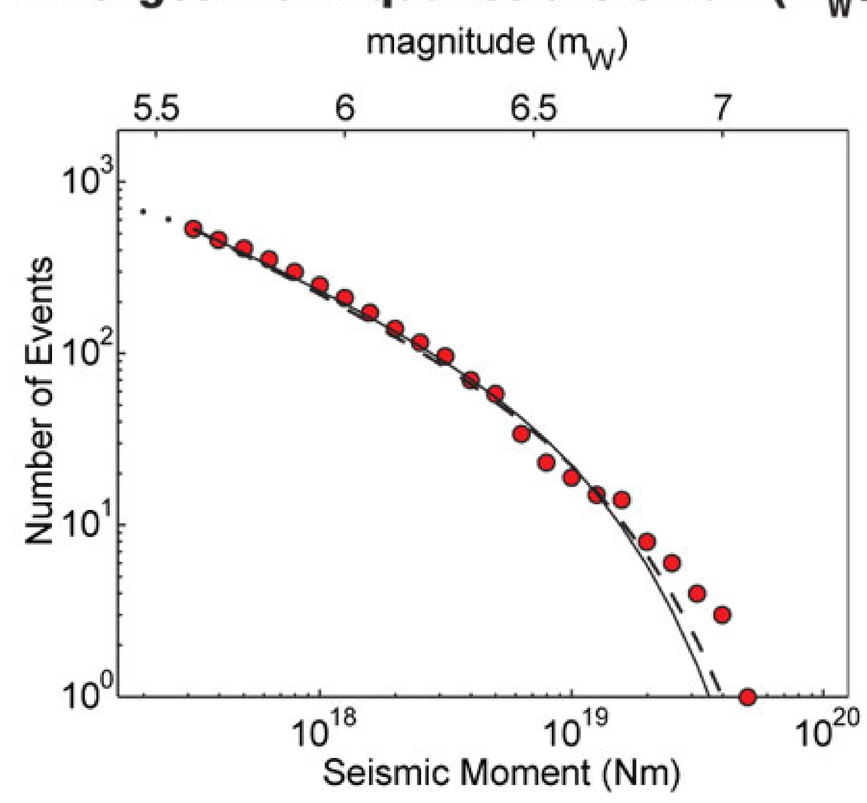
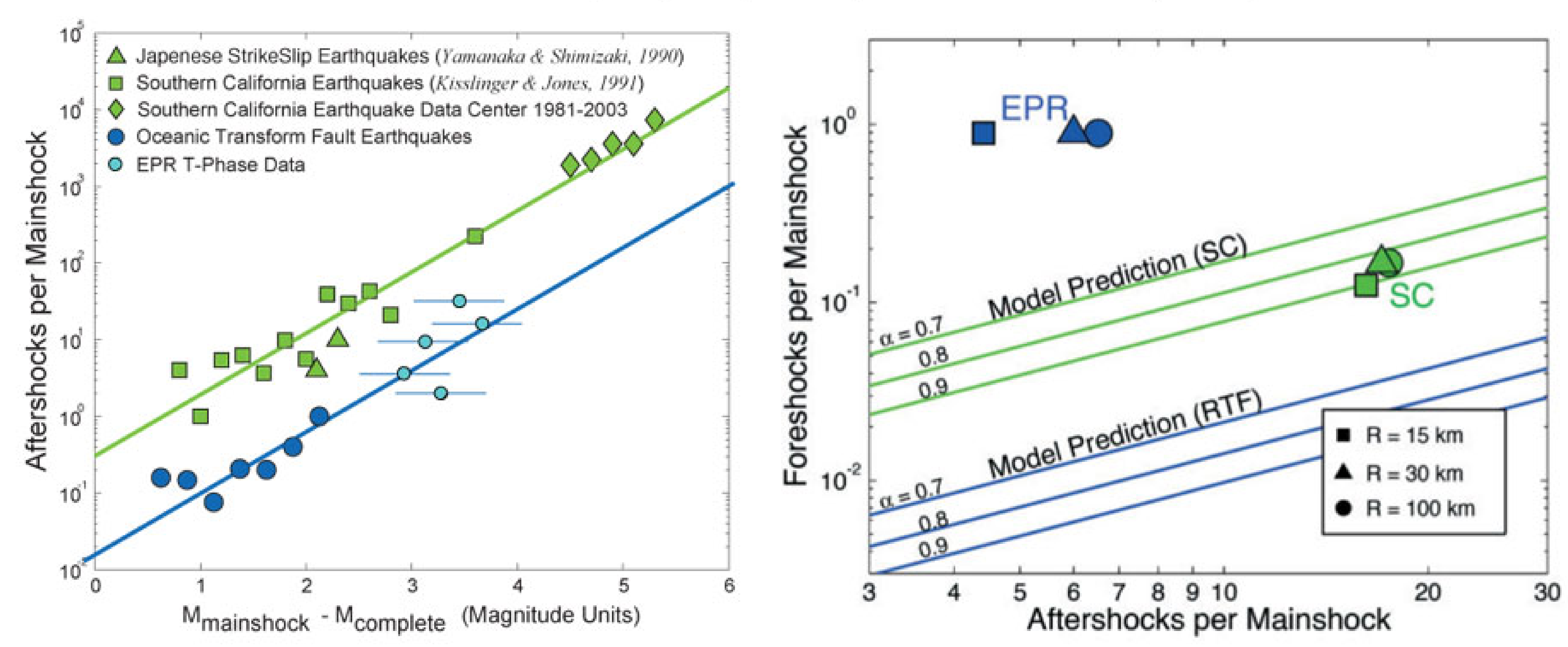
Seismic Characteristics of Ridge Transform Faults

1. Largest Earthquakes are Small ($M_W \leq 7.1$)

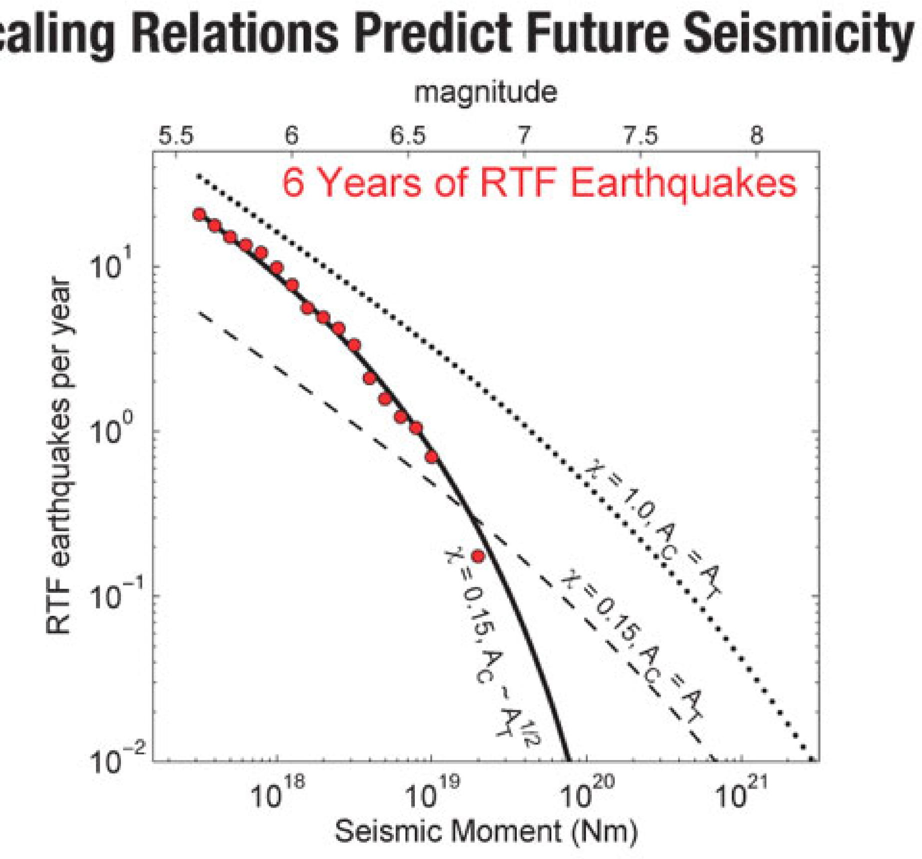


2. Few Aftershocks and Many Foreshocks, Greater Predictibility

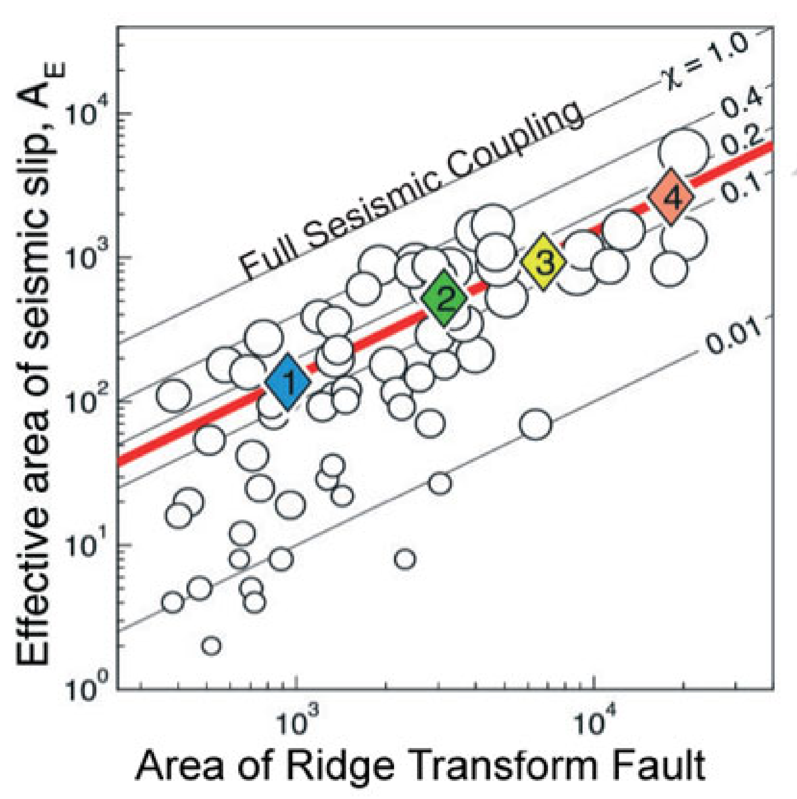
Boettcher and Jordan, JGR, 2004McGuire, Boettcher and Jordan, Nature, 2005



5. Scaling Relations Predict Future Seismicity

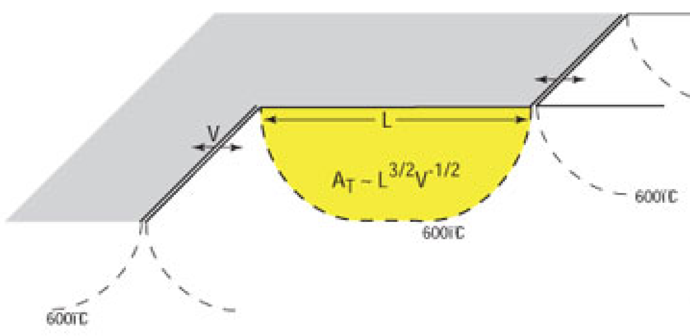


3. Most (~85%) plate motion is accommodated aseismically



4. Seismic parameters scale with tectonic parameters (e.g. L & V)

Boettcher and Jordan, JGR, 2004



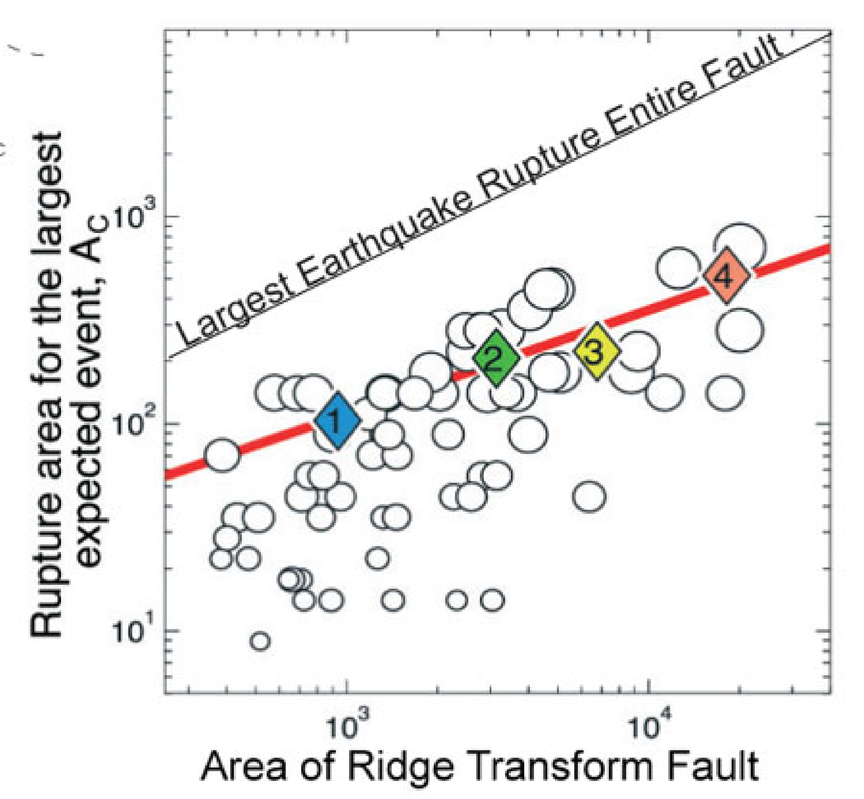
Effective Area of Seismic Slip

$A_E = \Sigma M/(tGV)$

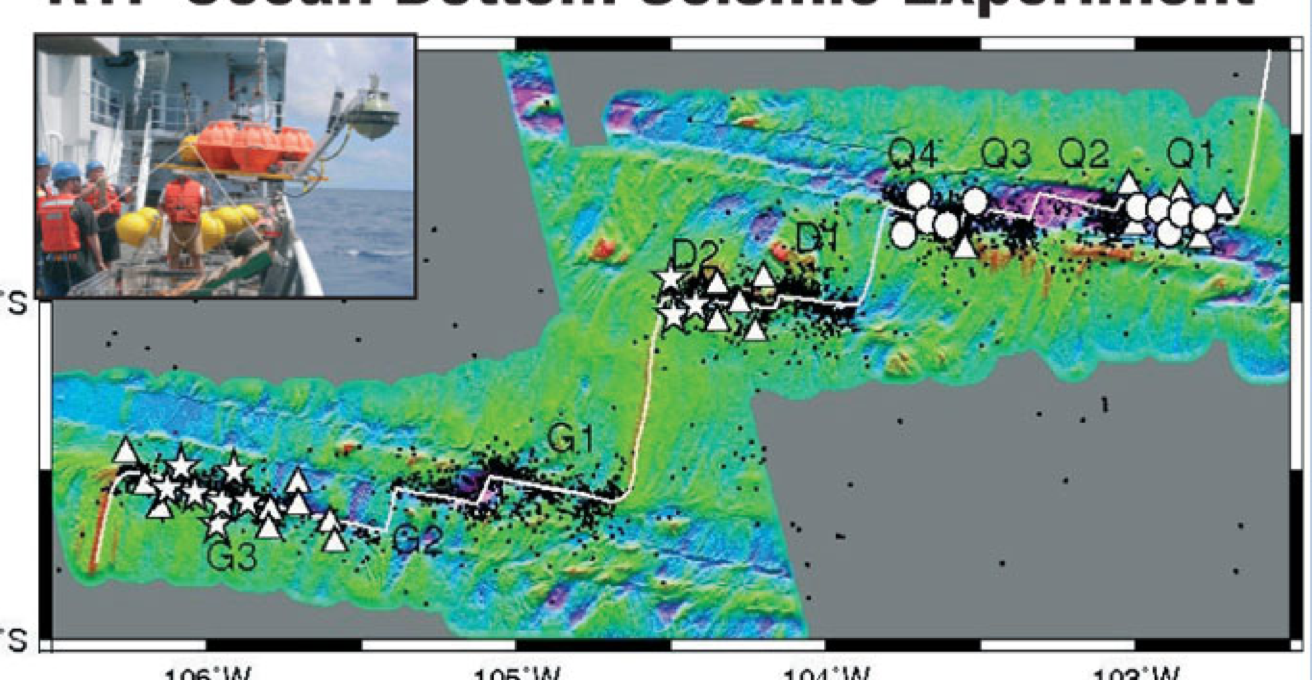
$A_E = \dfrac{\text{rate of seismic activity}}{\text{rate of plate motion}}$

Rupture Area of Largest Expected Event:

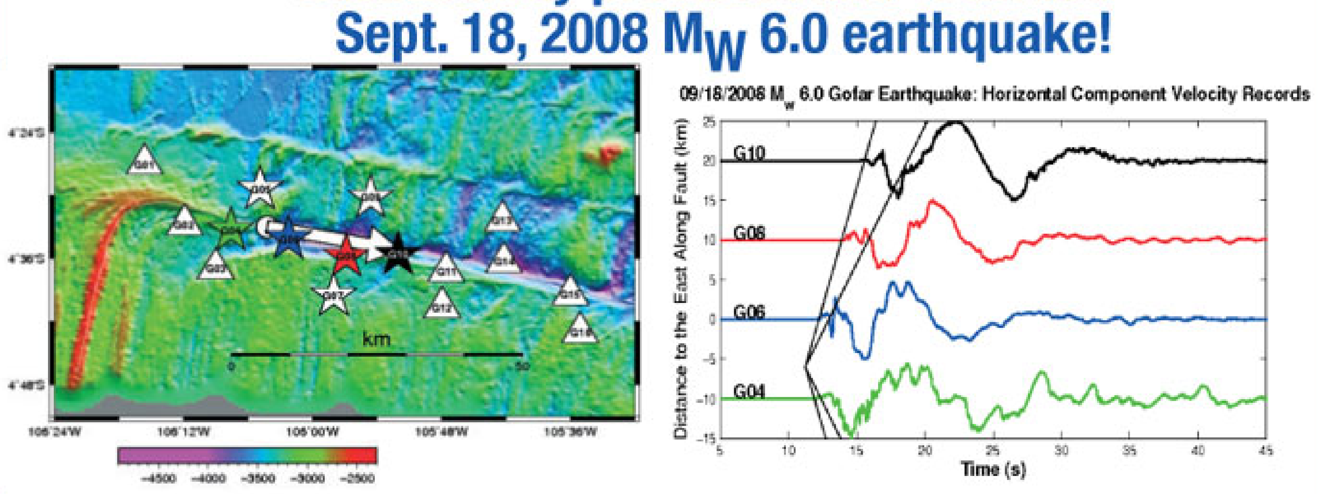
$A_C = M_C/GD_C$



McGuire's 2008 Gofar/Discovery/Quebrada RTF Ocean Bottom Seismic Experiment



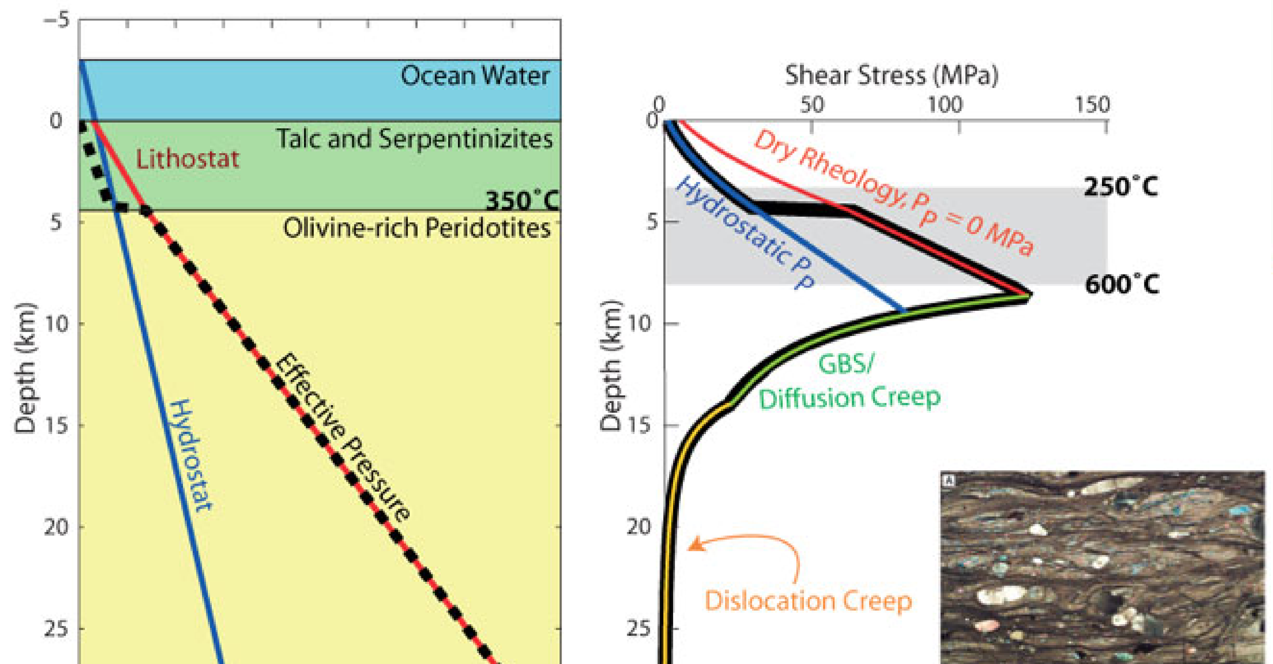
Successfully predicted and recorded Sept. 18, 2008 M_W 6.0 earthquake!



Rheological Constraints on RTF Deformation

1. Compositional and Rheological Model based on

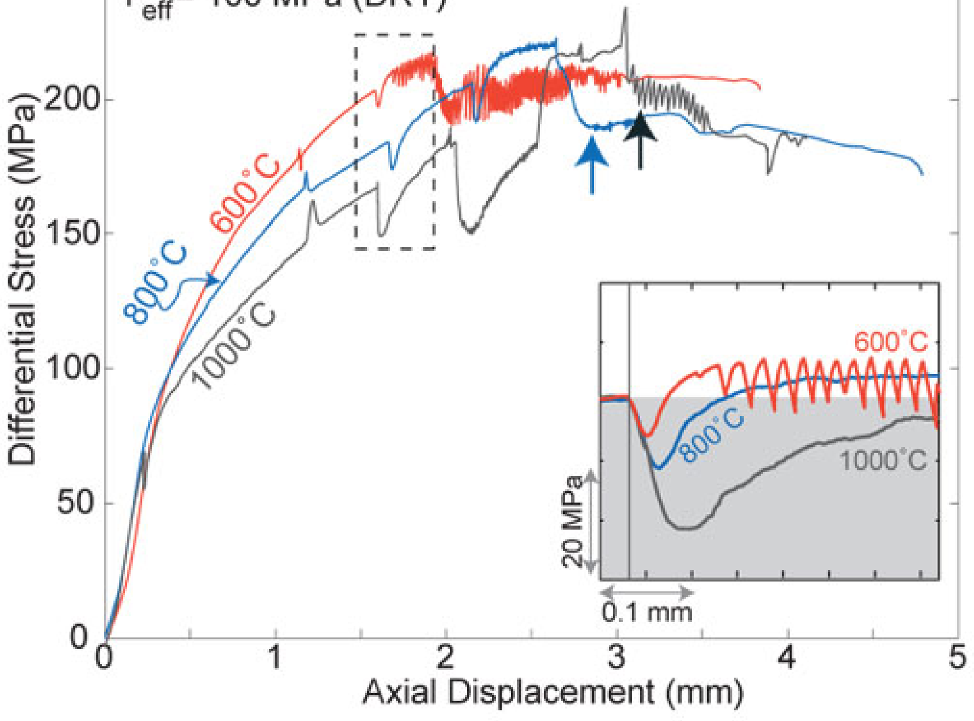
- Observations of abundant peridotite, serpentine, and talc on RTFs
- Hydrothermal fluids likely reach ~350°C (from analysis of serpentine veins- Andreani et al, Gcubed, 2007 and seismic velocities- Canales et al, JGR, 2000)
- Frictional strength of olivine and serpentine (e.g. Boettcher et al. JGR, 2007, Moore et al, Int. Geol. Rev. , 2004)
- Olivine flow laws (e.g. Goetze, Phil. Trans. Royal. Soc., 1978)
- Transform fault thermal structure



Mylonite deformed by GBS/Diffusion Creep at T>600°C and τ≈100 MPa (Warren and Hirth, EPSL, 2006)

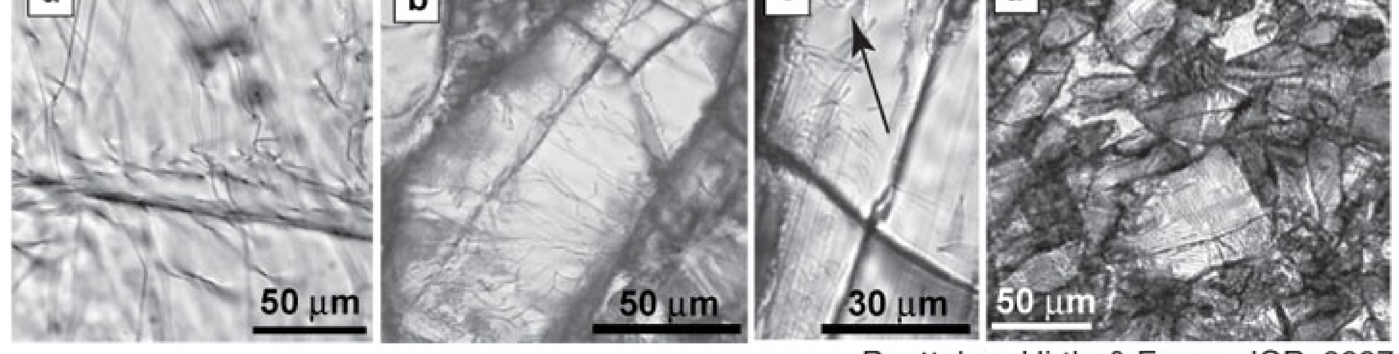
2. Olivine Friction Experiments- I. Strength Data

A transition from seismogenic (velocity-weakening) to aseismic (velocity-strengthening) conditions is found in our samples at ~1000°C. Using observations of the microstructures and olivine flow laws, we scale our experimental results to conditions appropriate for RTFs and find that the base of the seismogenic zone coincides with ~600°C isotherm.



2-II. Photomicrographs of decorated dislocation

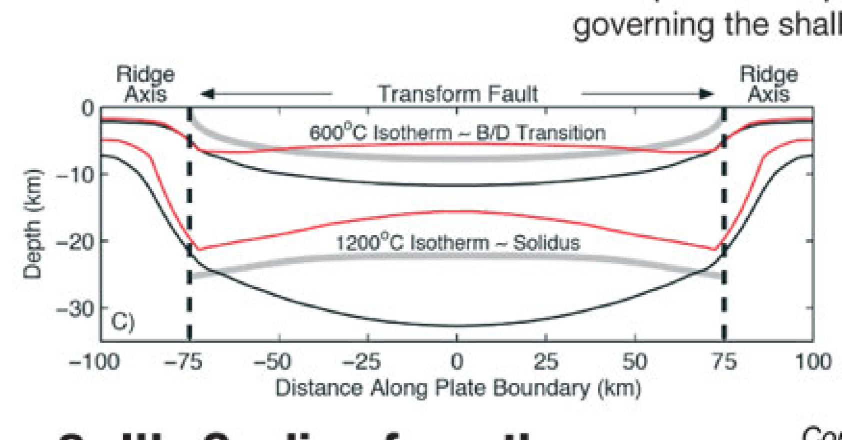
Evidence for crystal-plastic deformation resulting from stress concentrations at grain-to-grain contacts. Dislocations are observed in (a) a single-crystal of San Carlos olivine and (b)-(d) grains in a dry sample deformed at 800°C and Peff = 100 MPa. Shortening direction is oriented vertically. Note that the density of dislocations in the deformed grains increases towards the grain boundaries with many tangles of dislocations.

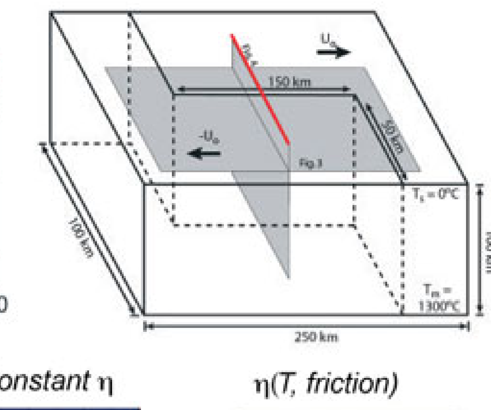


Boettcher, Hirth, & Evans, JGR, 2007

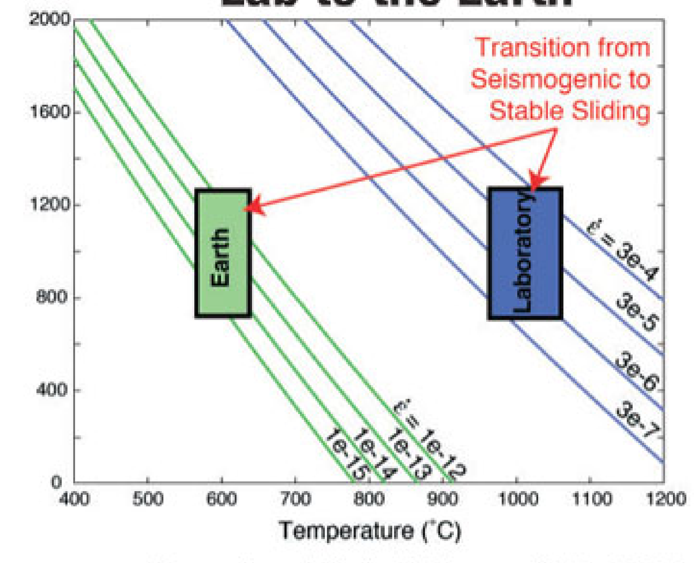
3. Thermal Modeling -

Thermal area obtained with the half-space cooling model is not very different than that determined with a temperature-dependent viscosity and a friction law governing the shallow lithosphere.

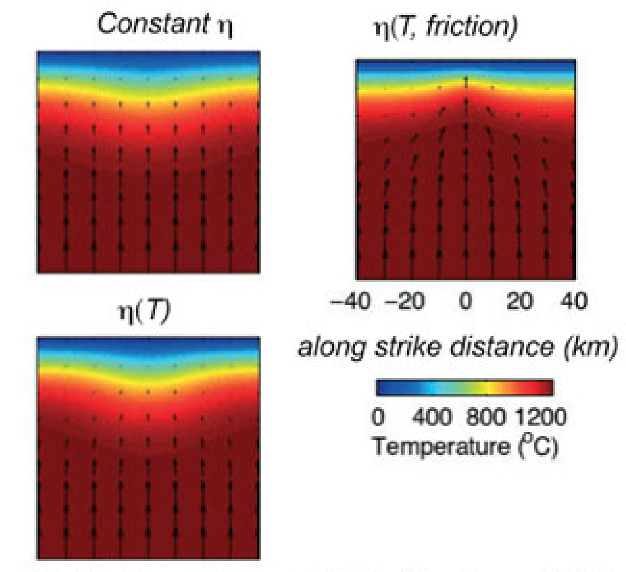




2- III . Scaling from the Lab to the Earth



Boettcher, Hirth, & Evans, JGR, 2007



Behn, Boettcher, & Hirth, Geology, 2007