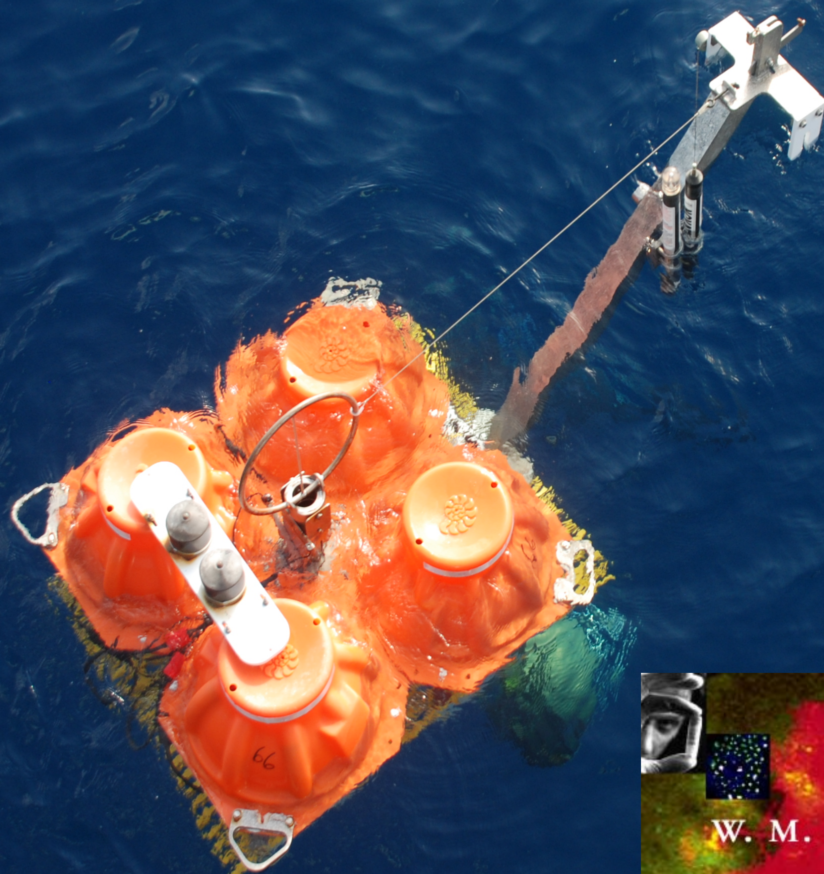
Scale Dependence of Rupture Barriers

Jeff McGuire, John Collins, Emily Roland, Pierre Gouédard, Dan Lizarralde,
Rob van der Hilst, Margaret Boettcher and Yajing Liu



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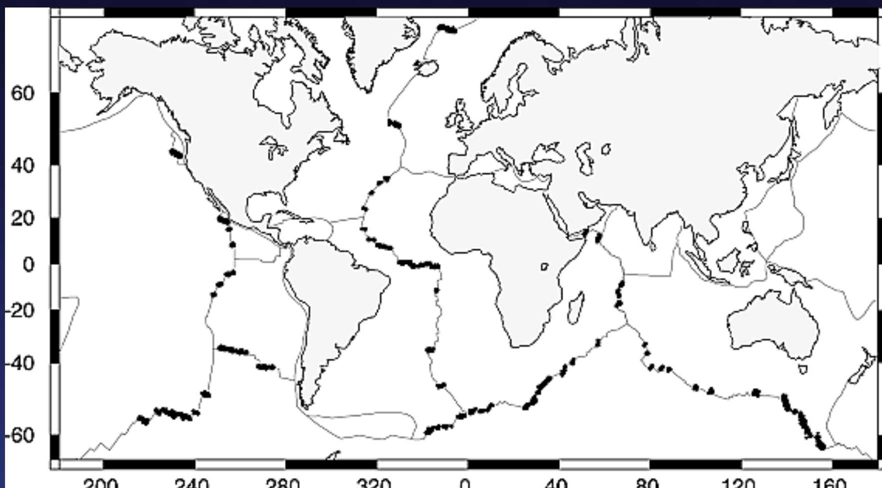
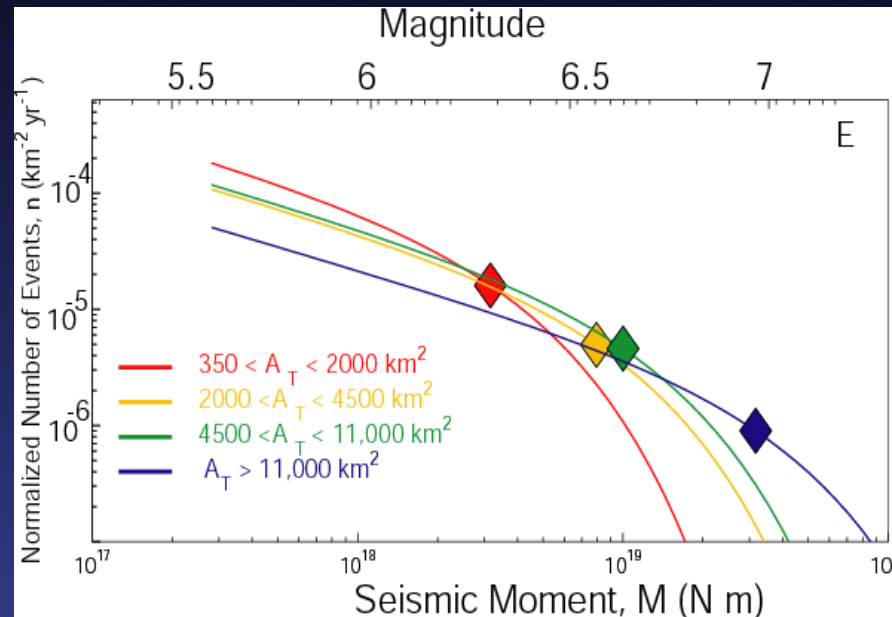
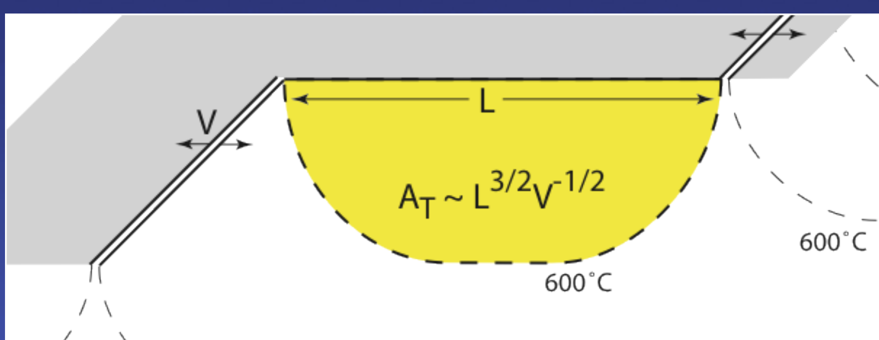
Systematics of Large Transform Fault Earthquakes

-The G-R distribution is well predicted by simple thermal models





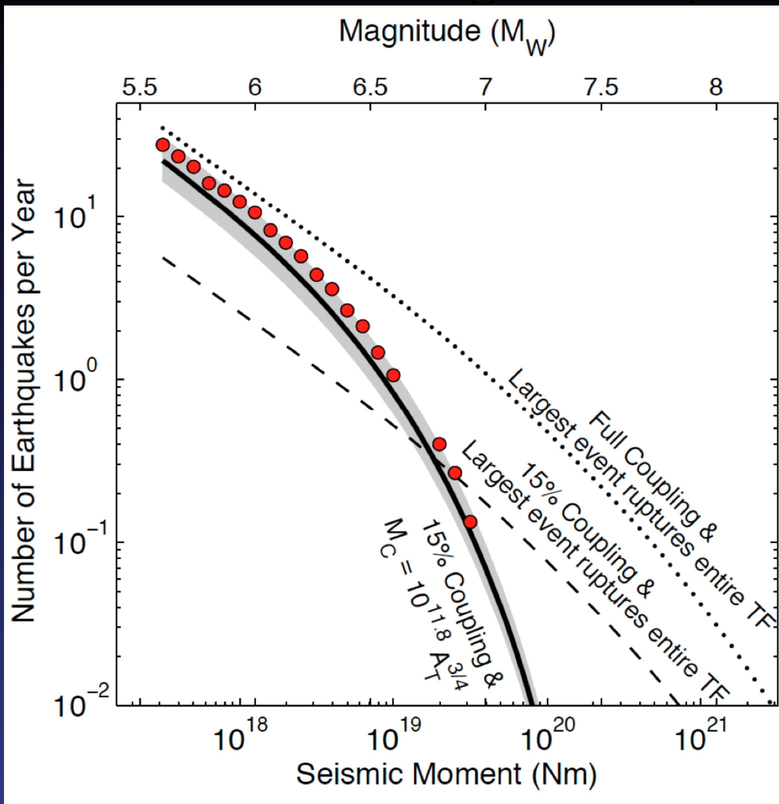


$$N(M) = N_0 \left(\frac{M_0}{M} \right)^{\beta} \exp\left(\frac{M_0 - M}{M_c} \right)$$

$$M_c = C A_T^{3/4} ; A_T = C_T L^{3/2} V^{-1/2}$$

Boettcher and Jordan, 2004
Bird et al., 2002

Systematics of Large Transform Fault Earthquakes

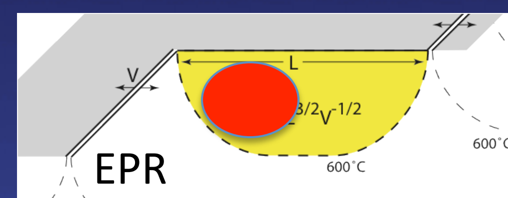


$$N(M) = N_0\left(\frac{M_0}{M}\right)^{\beta} \exp\left(\frac{M_0 - M}{M_c}\right)$$

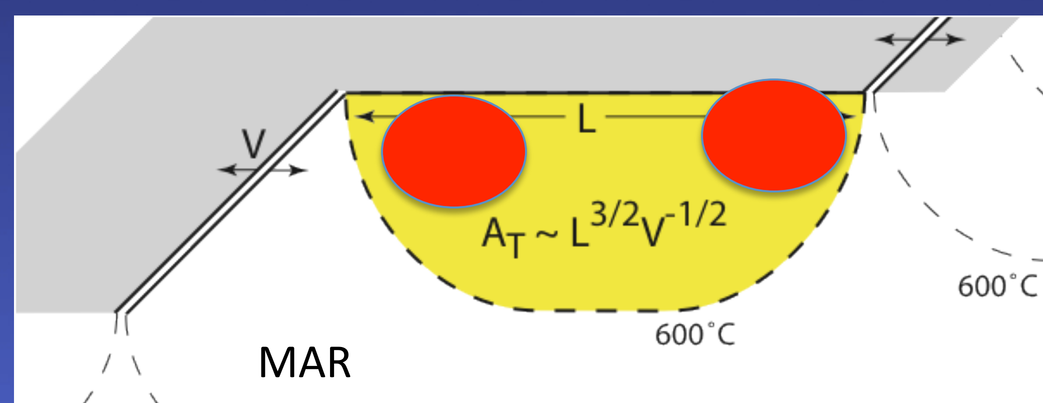
$$M_c = CA_T^{3/4}; A_T = C_T L^{3/2} V^{-1/2}$$

Estimate of C from 1964-2001 predicts 2002-2009 data extremely well; Boettcher and McGuire, 2009;

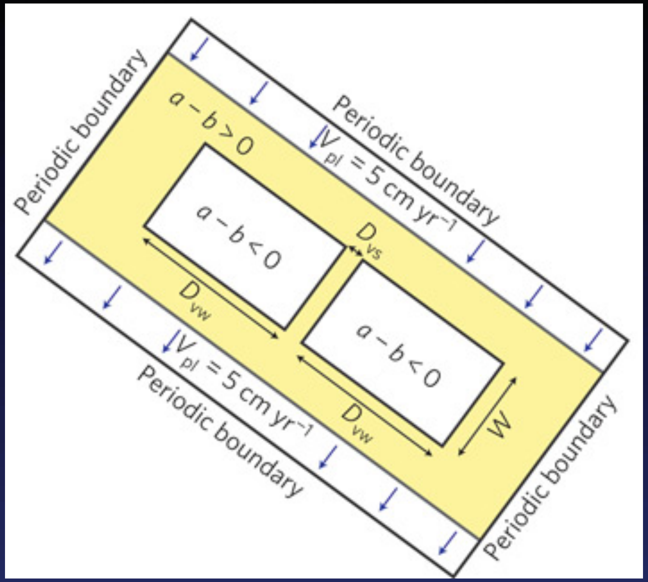
Large (Mc) earthquakes do not rupture the entire fault.

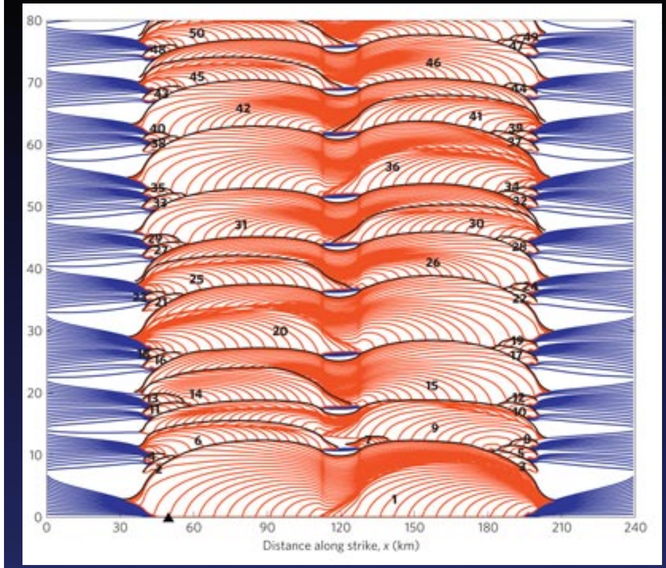


The creeping area on the large OTFs put together is the equivalent of having 10 completely aseismic San Andreas Faults. Or roughly 100 'creeping sections'

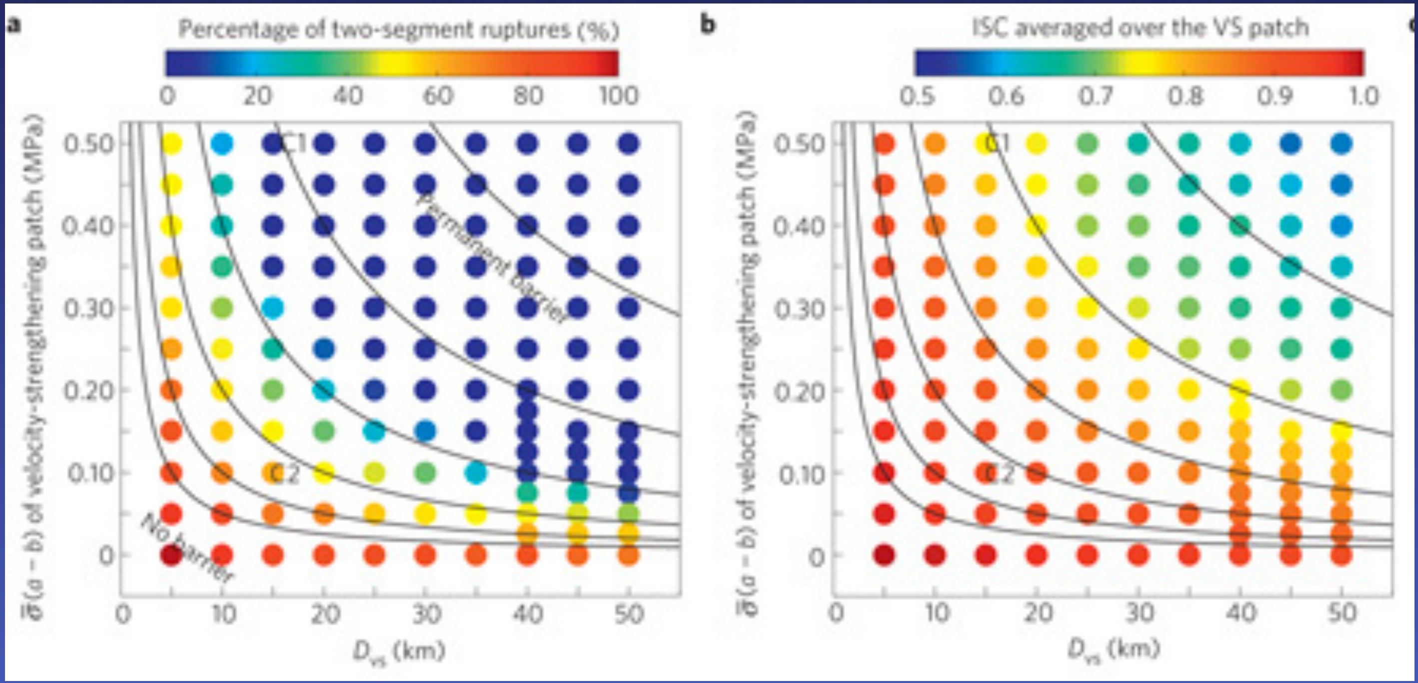


Rupture Barriers and Seismic Coupling



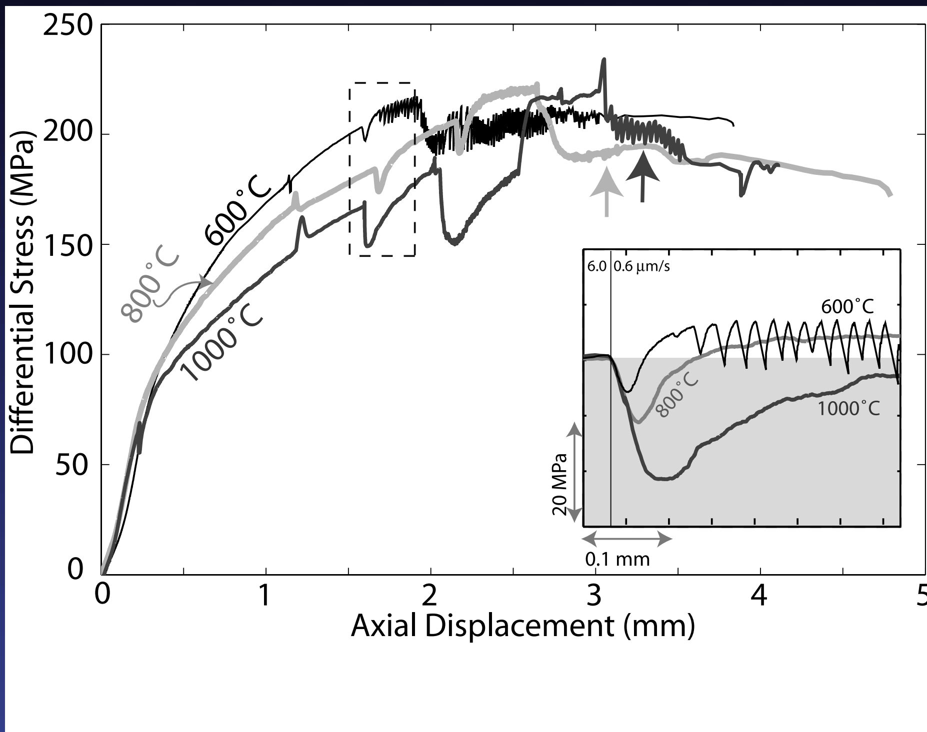


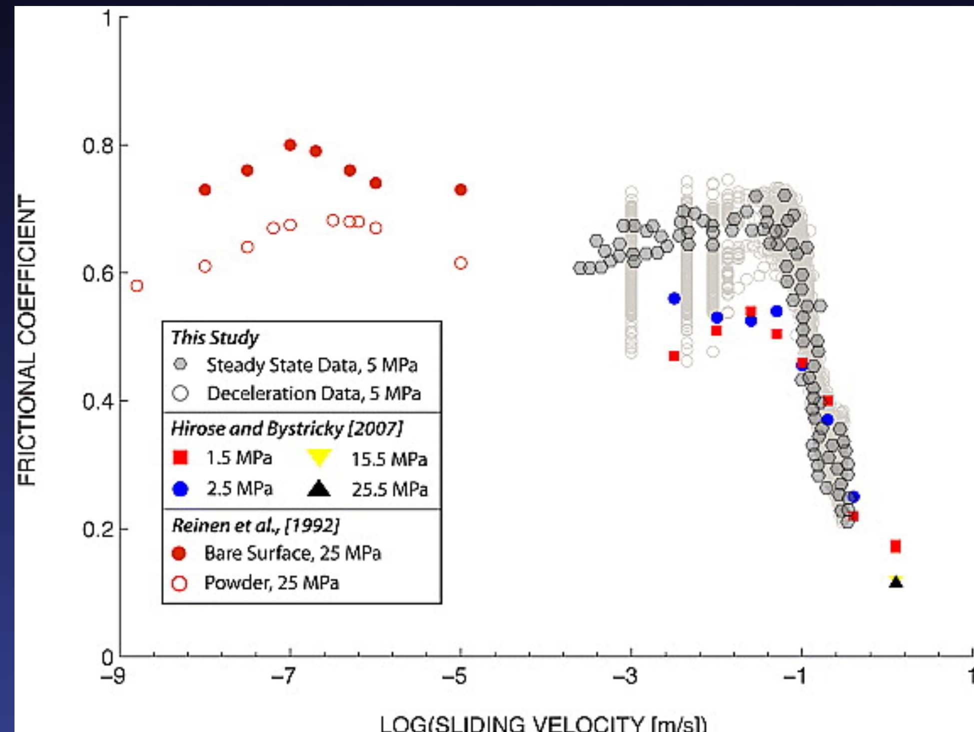
Stress is always high in the rupture barrier and earth-quakes are always followed by post-seismic creep in the barrier region



Kaneko et al, 2010

Oceanic Transform Fault Friction





Boettcher et al., 2007

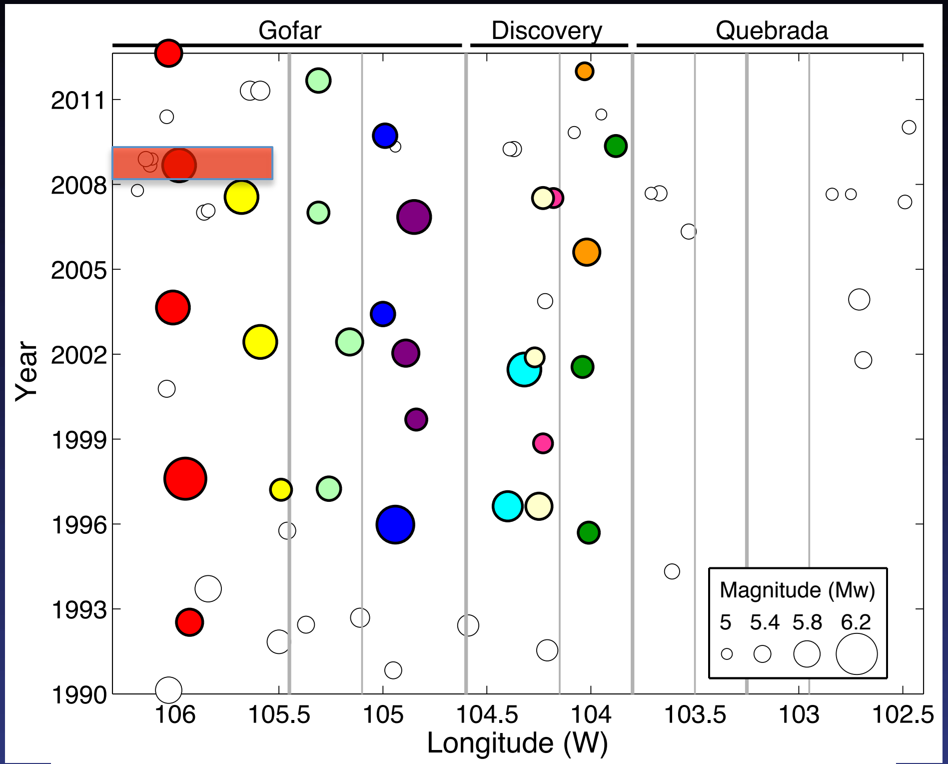
Kohli et al., 2011

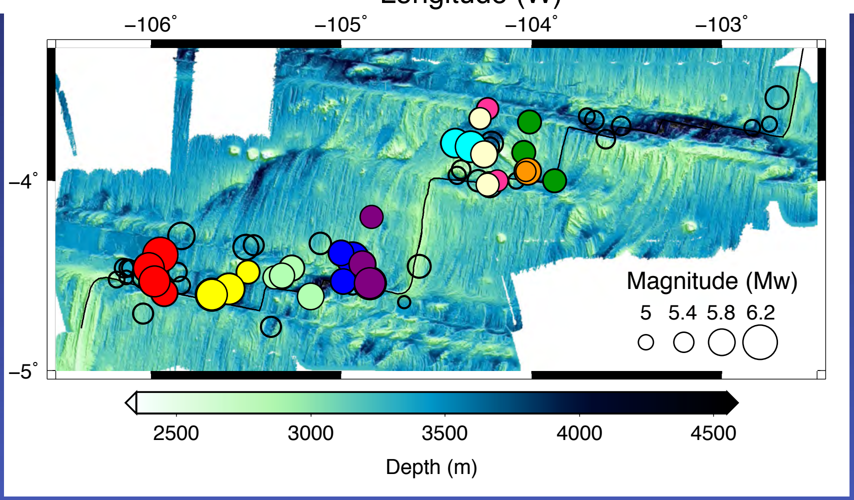
Gabbro and Peridotite expected to be velocity weakening up to 500-600 °C ->matches depth extent for both inter- and intraplate earthquakes

Serpentine expected to be velocity strengthening at low slip-rates but possibly undergo large amounts of dynamic weakening

Discovery and Gofar Transform Seismic Cycles

Mw 6 Ruptures repeat every ~5-6 years
Indistinquishable centroids but seismic moments can vary by a factor of 2-3 between cycles. Overall, they are suggestive of fully coupled patches separated by creeping segments.



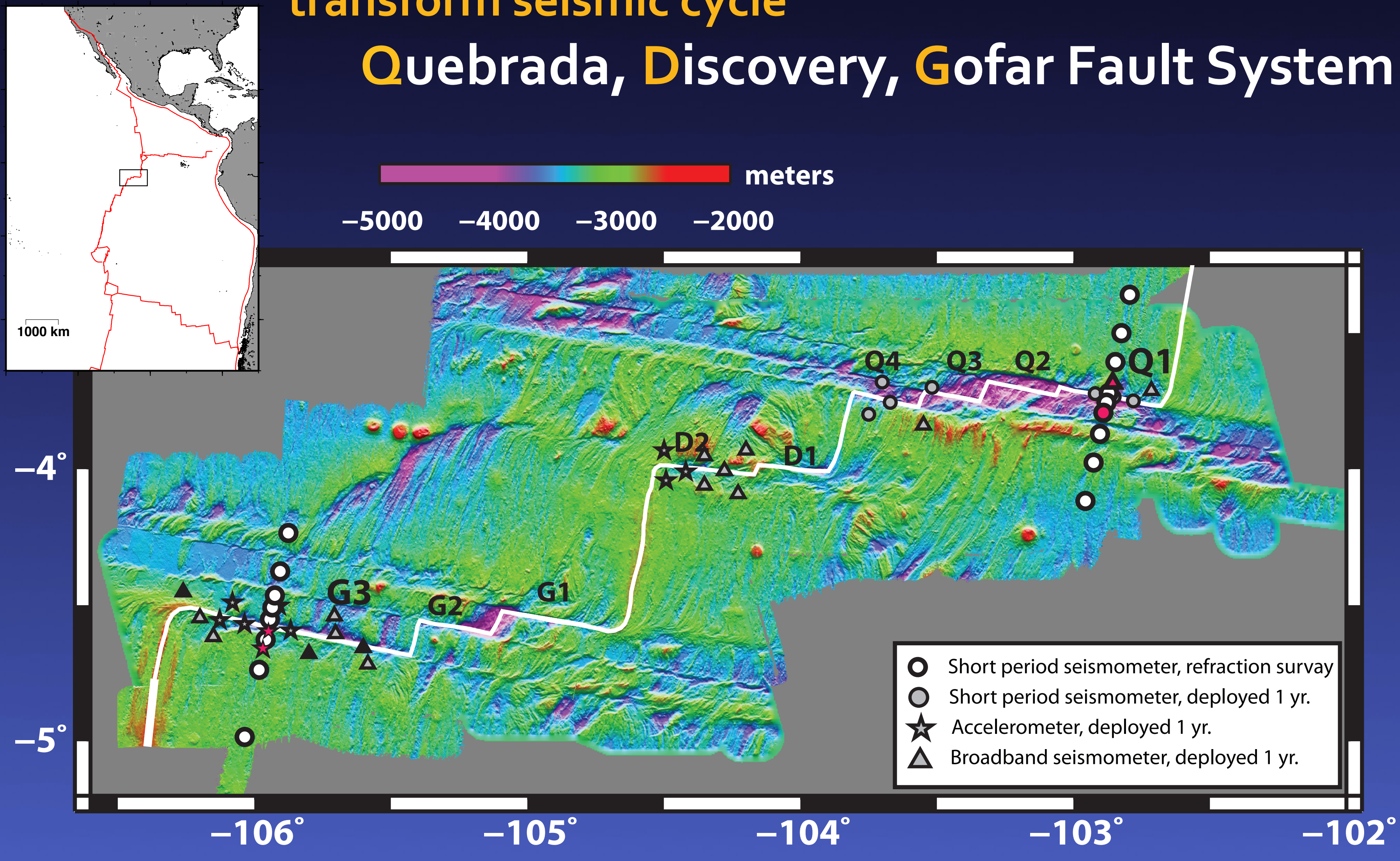


Clipperton	Mw ~6.5	~19±3 years
Blanco	Mw ~6.3	~14±2 years
Gofar	Mw ~6.1	~6±1 years
Discovery	Mw ~6.0	~5.5±1 years
Siqueiros	Mw ~5.8	~5.5±1 years

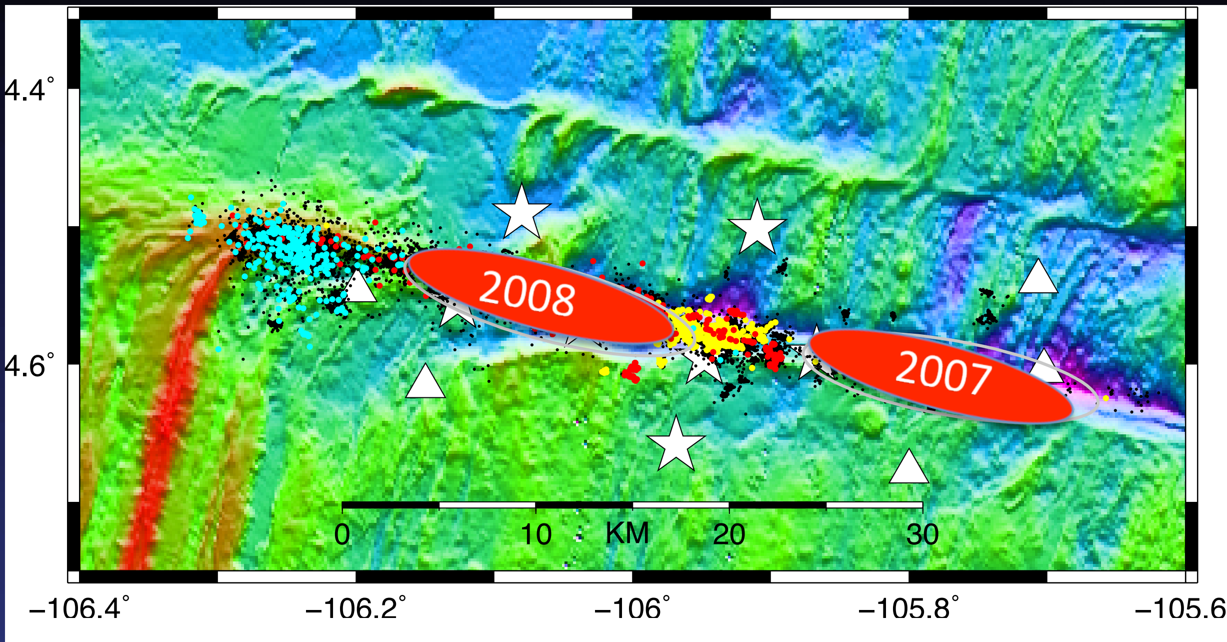
The QDG Experiment

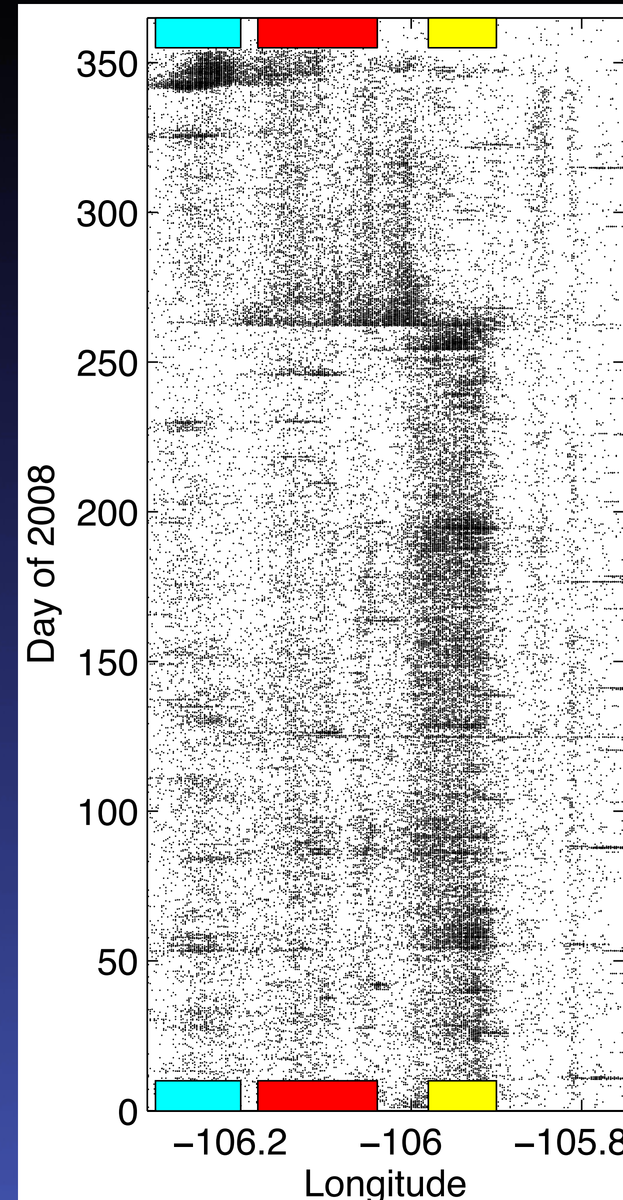
The first local observations of the end of a oceanic transform seismic cycle

Quebrada, Discovery, Gofar Fault System



The Gofar Fault



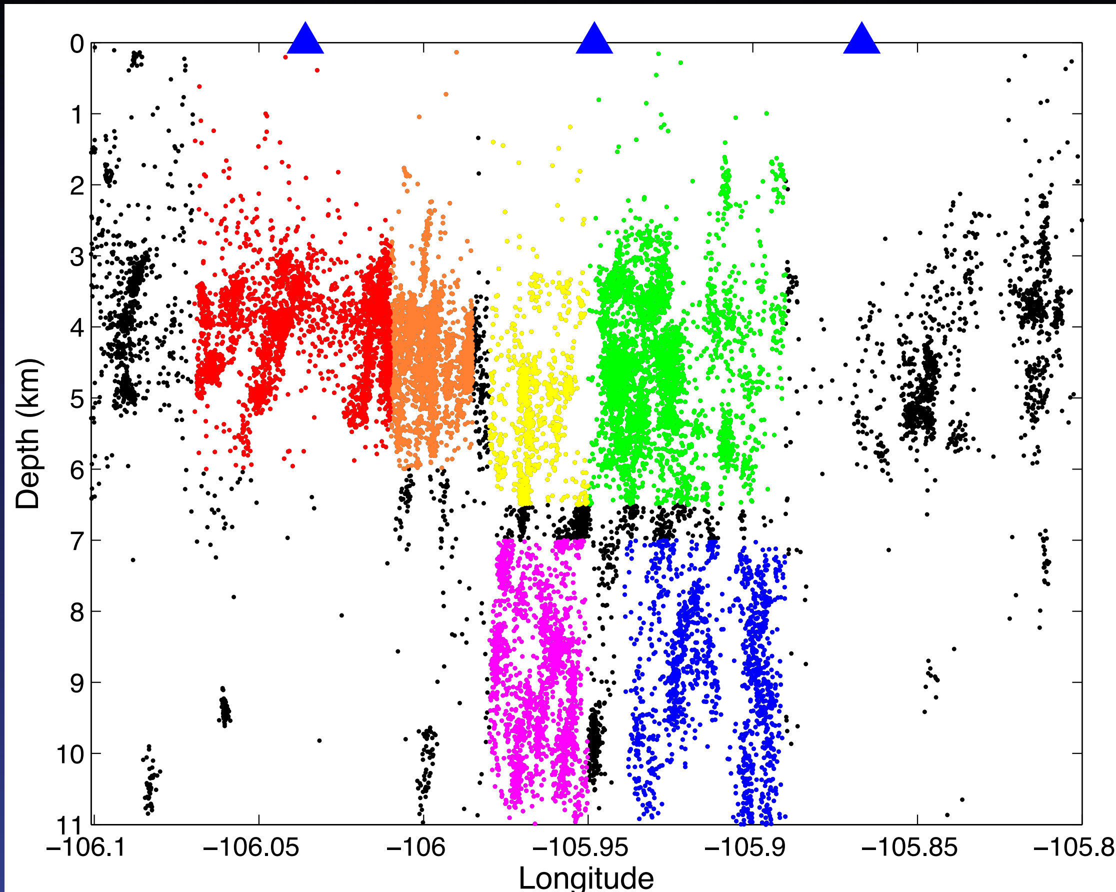


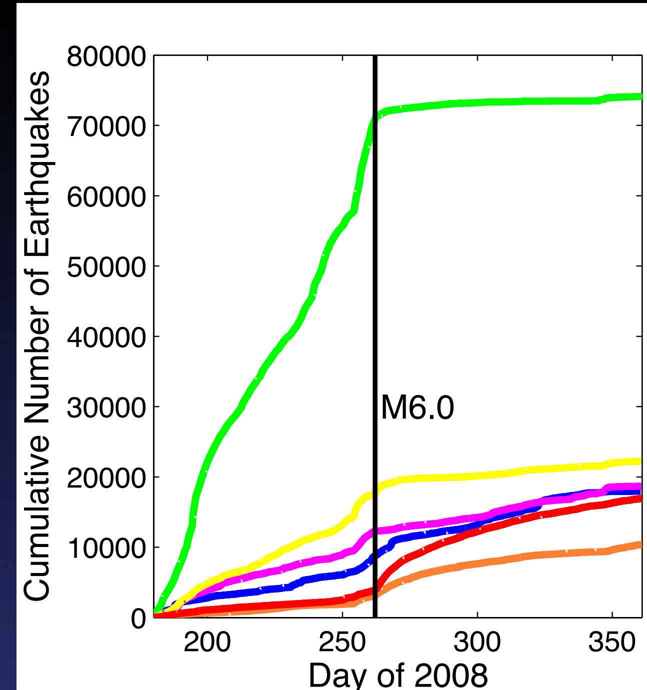
The western asperity had M ~6.0 earthquakes in 1992, 1997, 2003, and 2008 and 2012.
The eastern asperity had M ~6.0 earthquakes in 1997, 2002, and 2007 and maybe 2011.

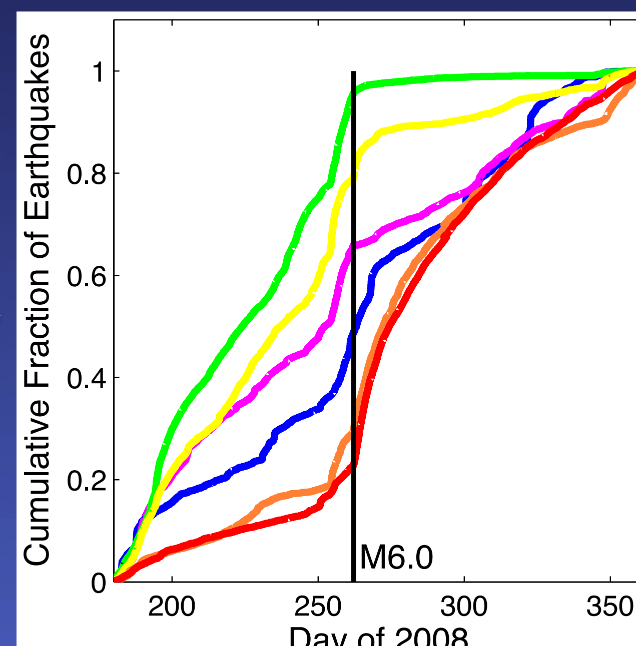
→ The Foreshock zone is a long-lived rupture barrier.

The failure of the rupture barrier may modulate the end of the seismic cycles.

The Gofar M6 Rupture Barrier



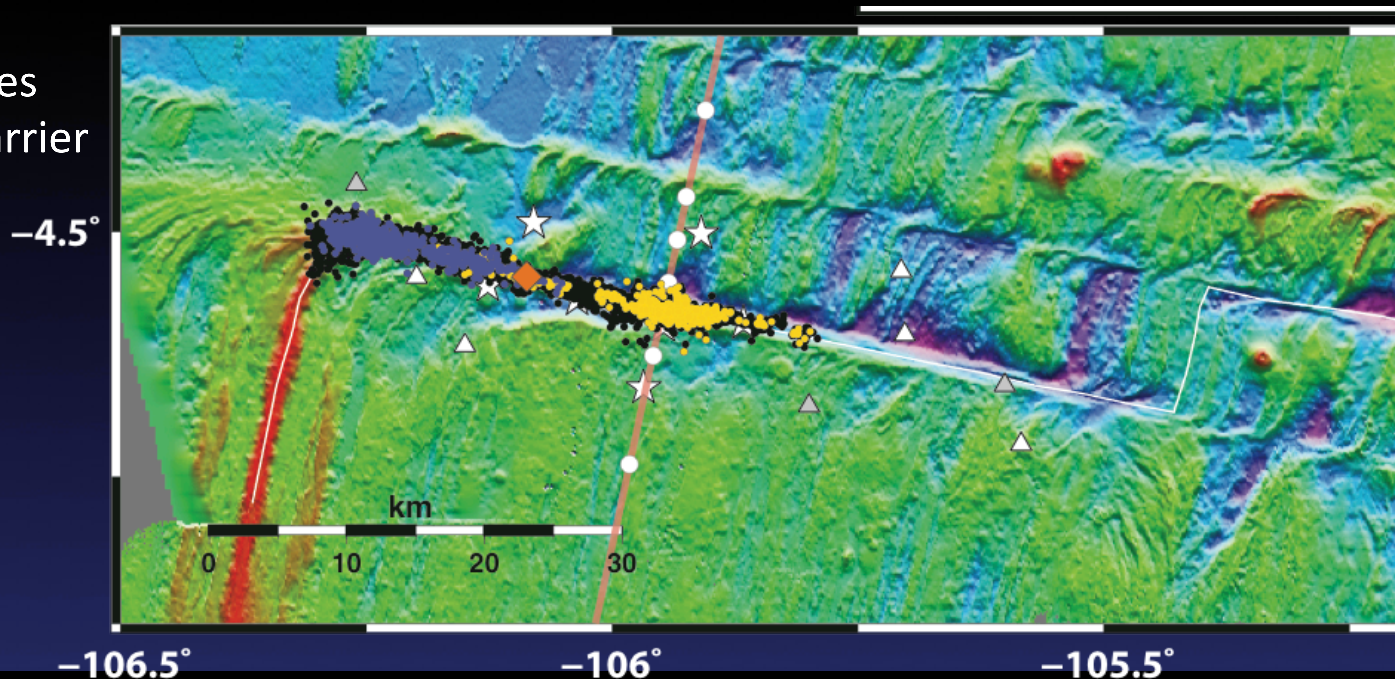




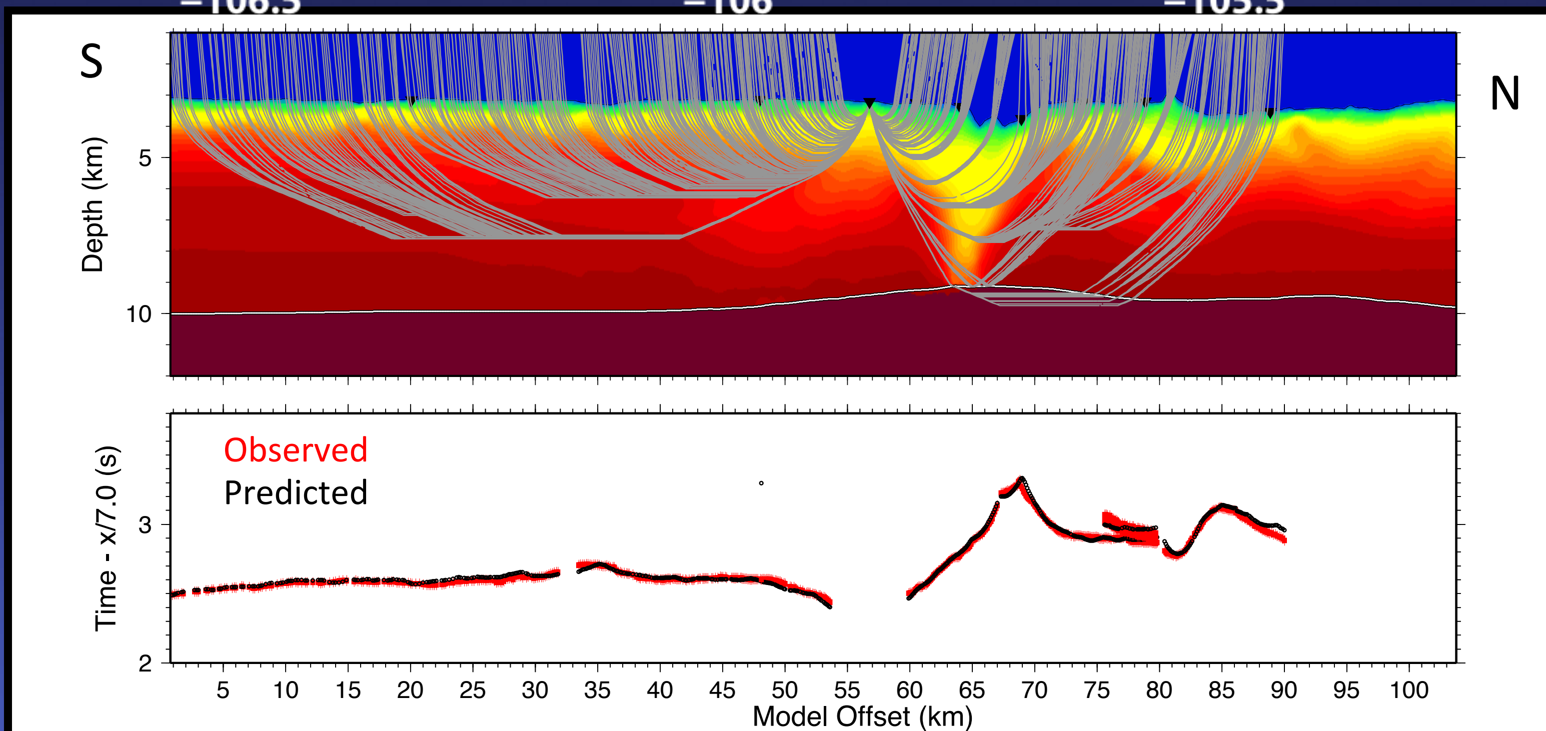
2008 M6 | Rupture Barrier | 2007 M6

The barriers to large earthquake propagation have the most microseismicity.

Physical Properties of the rupture barrier



Roland et al., 2012

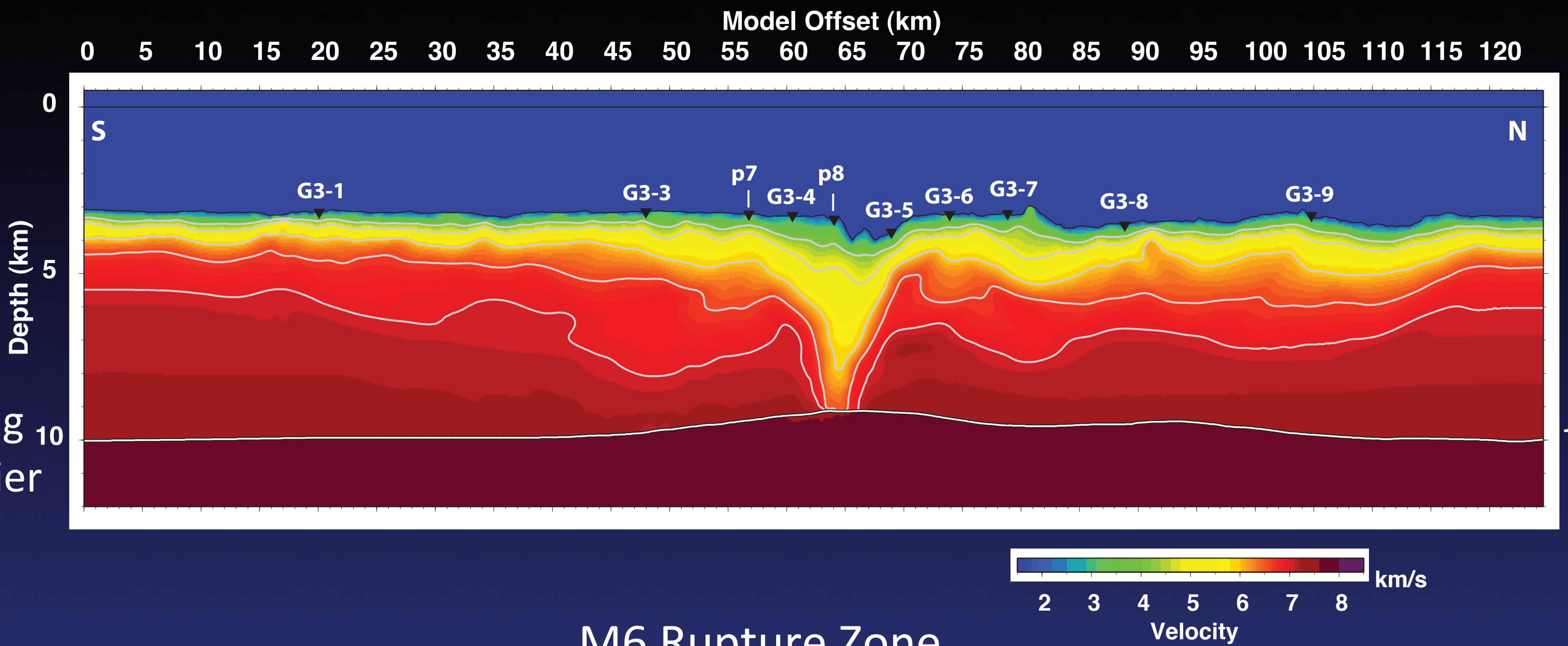


M6 Rupture Barrier

Gofar Transform

Roland Et al, 2012

~50% coupling
Rupture barrier

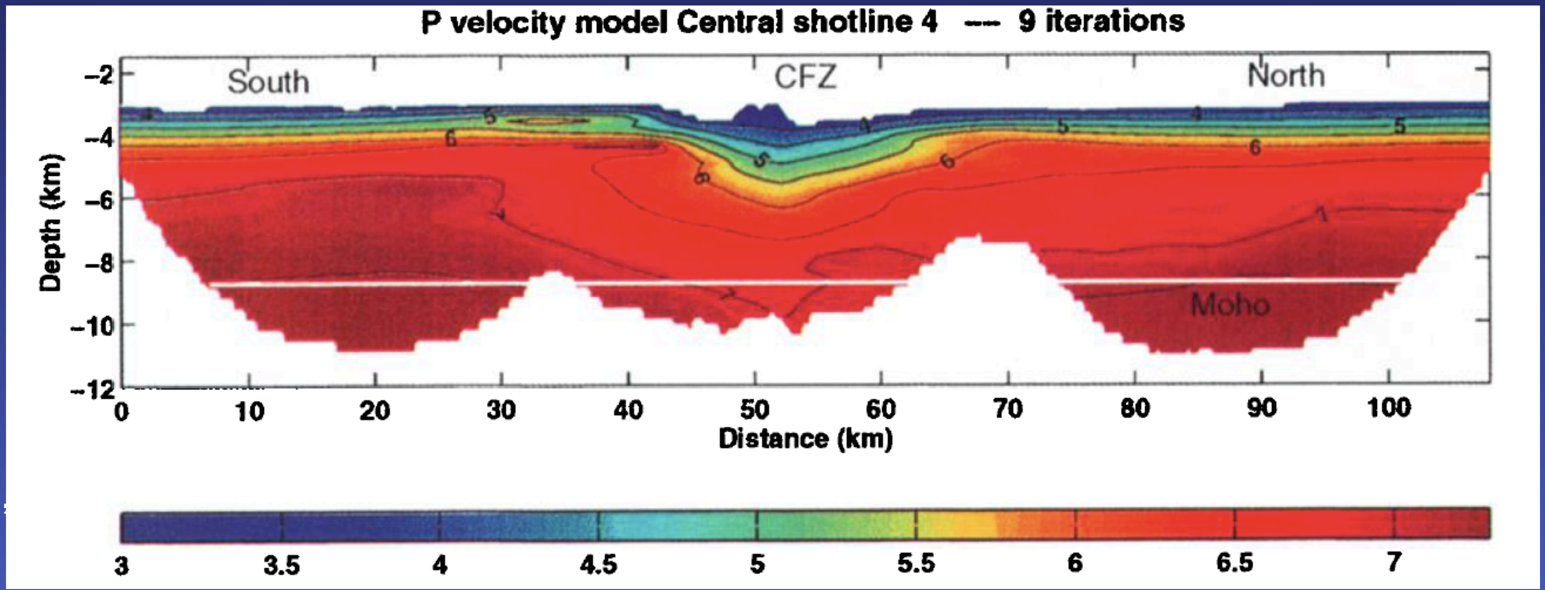


M6 Rupture Zone

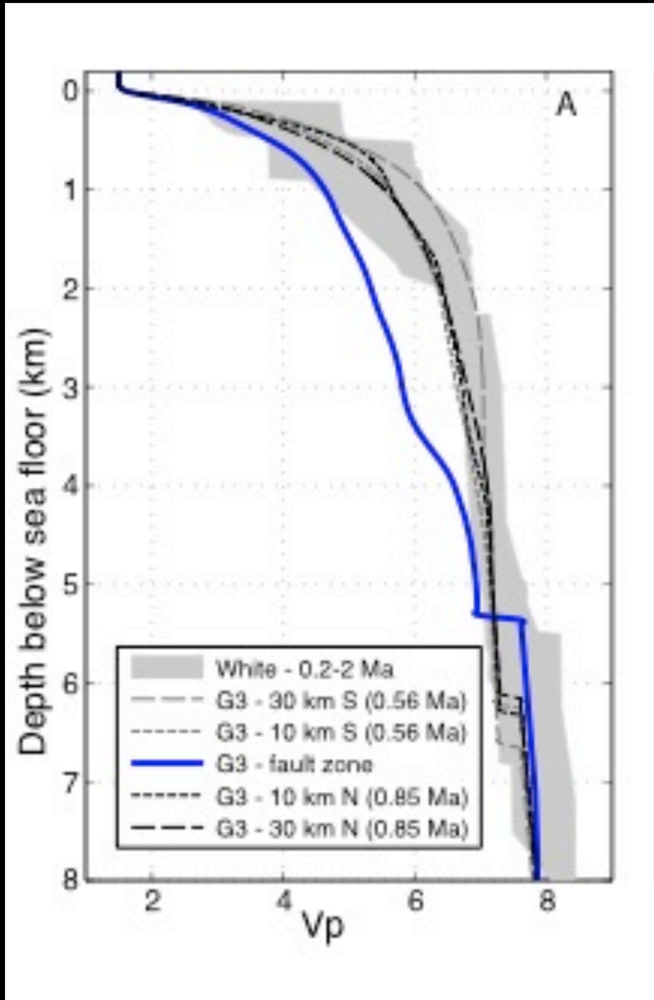
Clipperton Transform Fault,

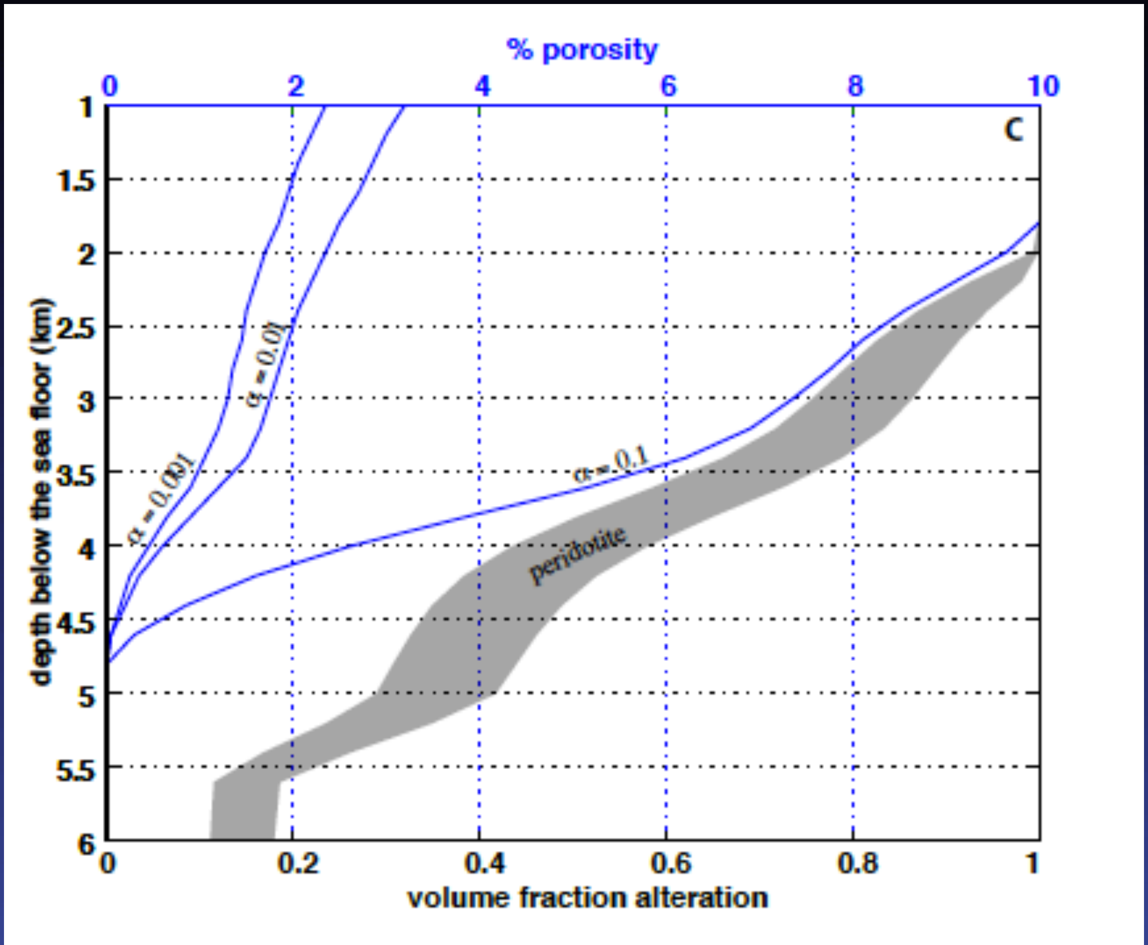
Van Avendonk
et al. 1998

Full Couplingv
M 6.6 to 6.8
earthquakes in
1911, 1936, 1957,
1978, and 1995



Cause of the Gofar Fault-Zone P-wave Velocity Reduction

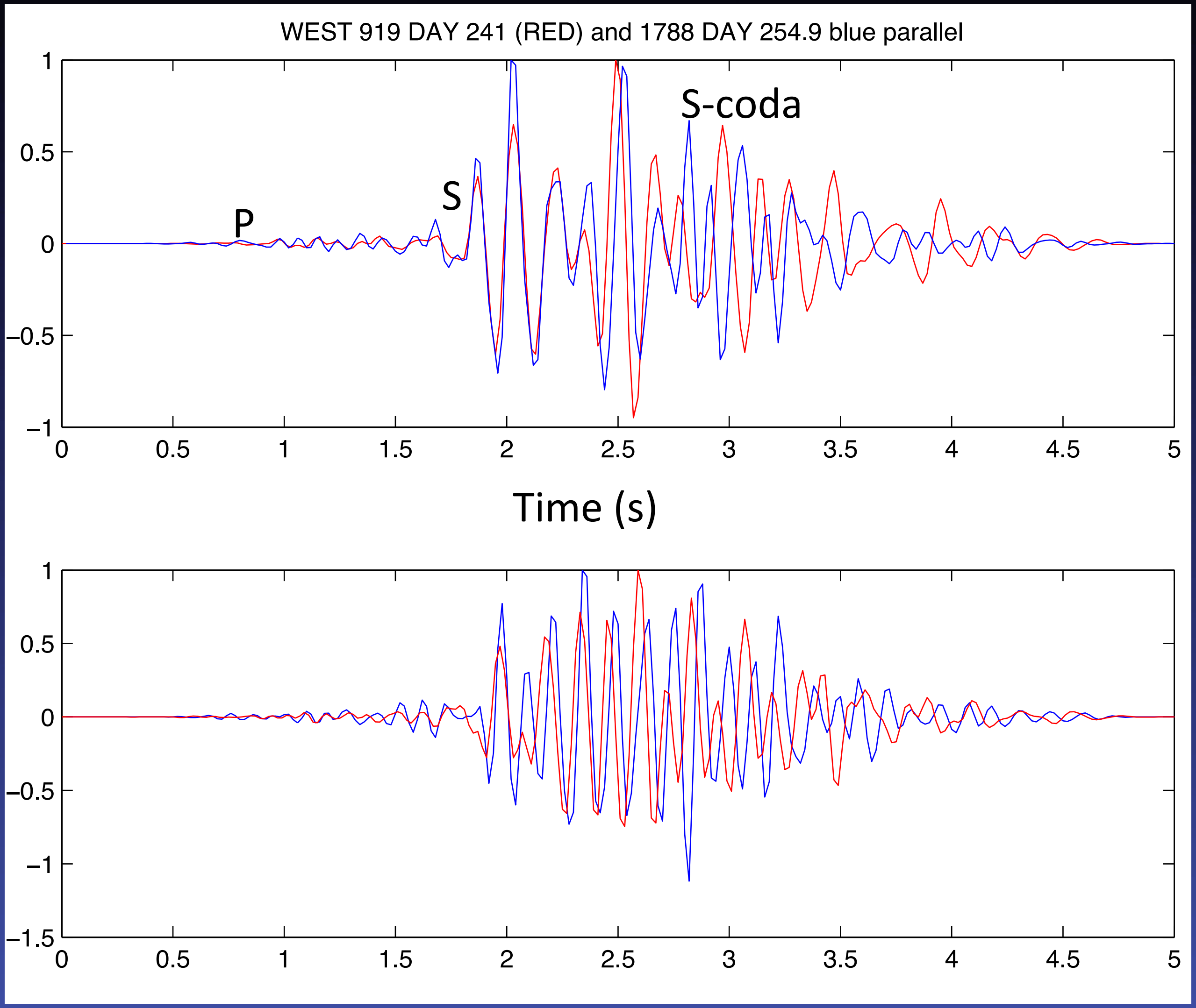




Serpentine could explain the anomaly, but is not supported by the gravity field and Is unlikely to change on weekly time scales.

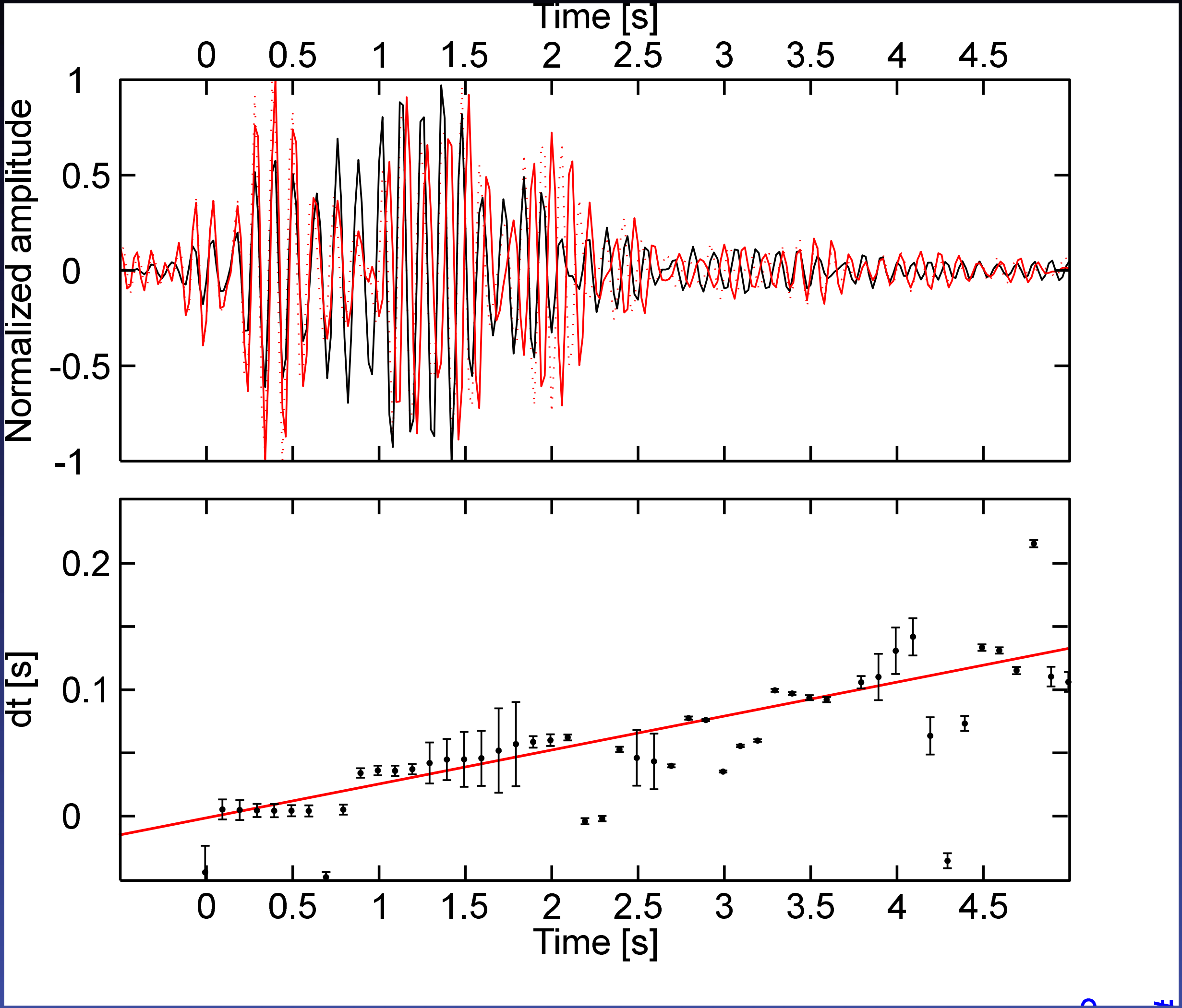
Roland et al., 2011

Fault-Zone Velocity Changes During the Foreshock Sequence



The coda following S-waves that propagate vertically in the fault-zone (~4-12 Hz) shows clear stretching during the week long foreshock sequence.

Fault-Zone Velocity Changes During the Foreshock Sequence

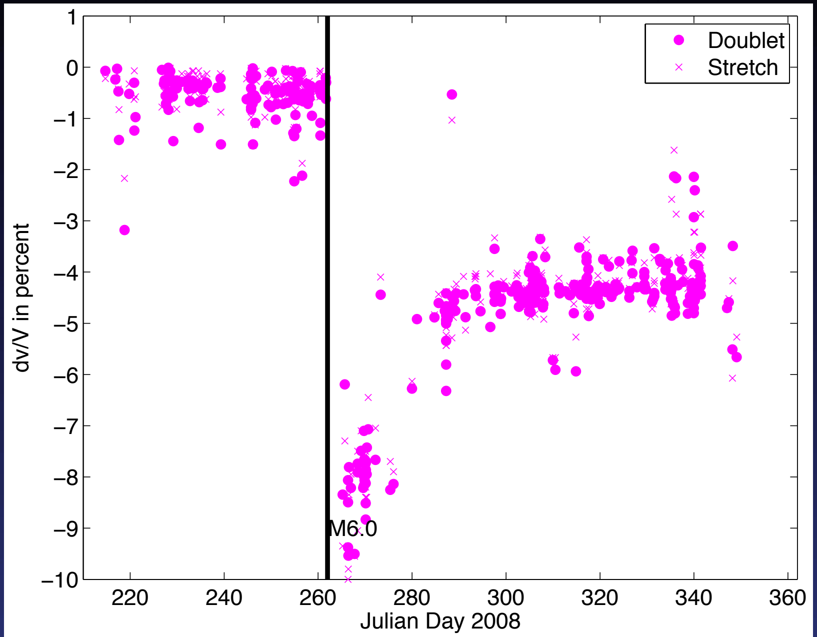


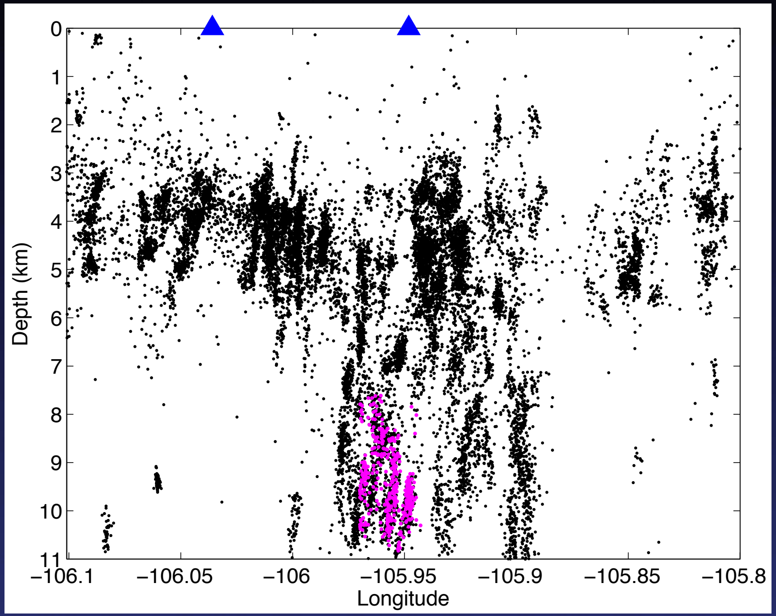
$$\frac{dt}{t} = -\frac{dv}{v}$$

From Pierre Gouédard

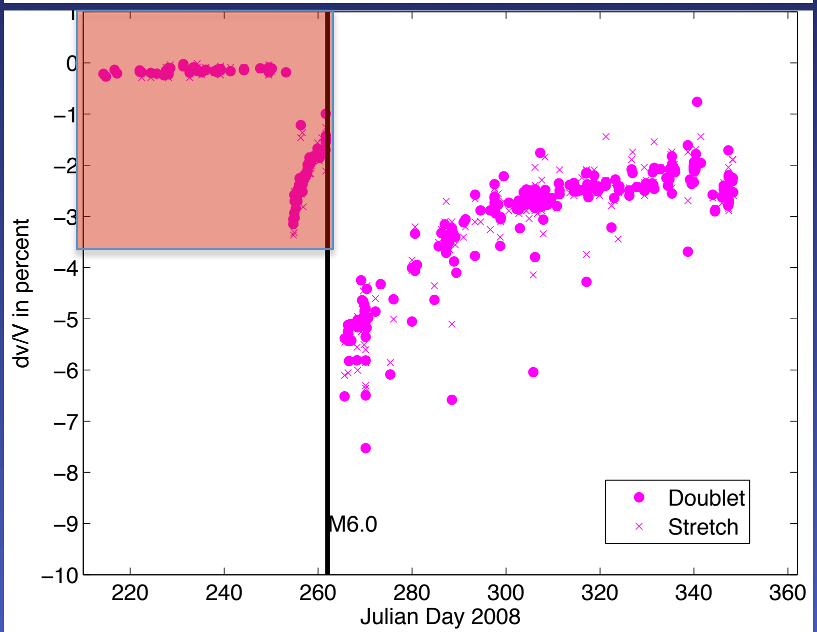
Space-time history of S-wave velocity changes

Mainshock zone





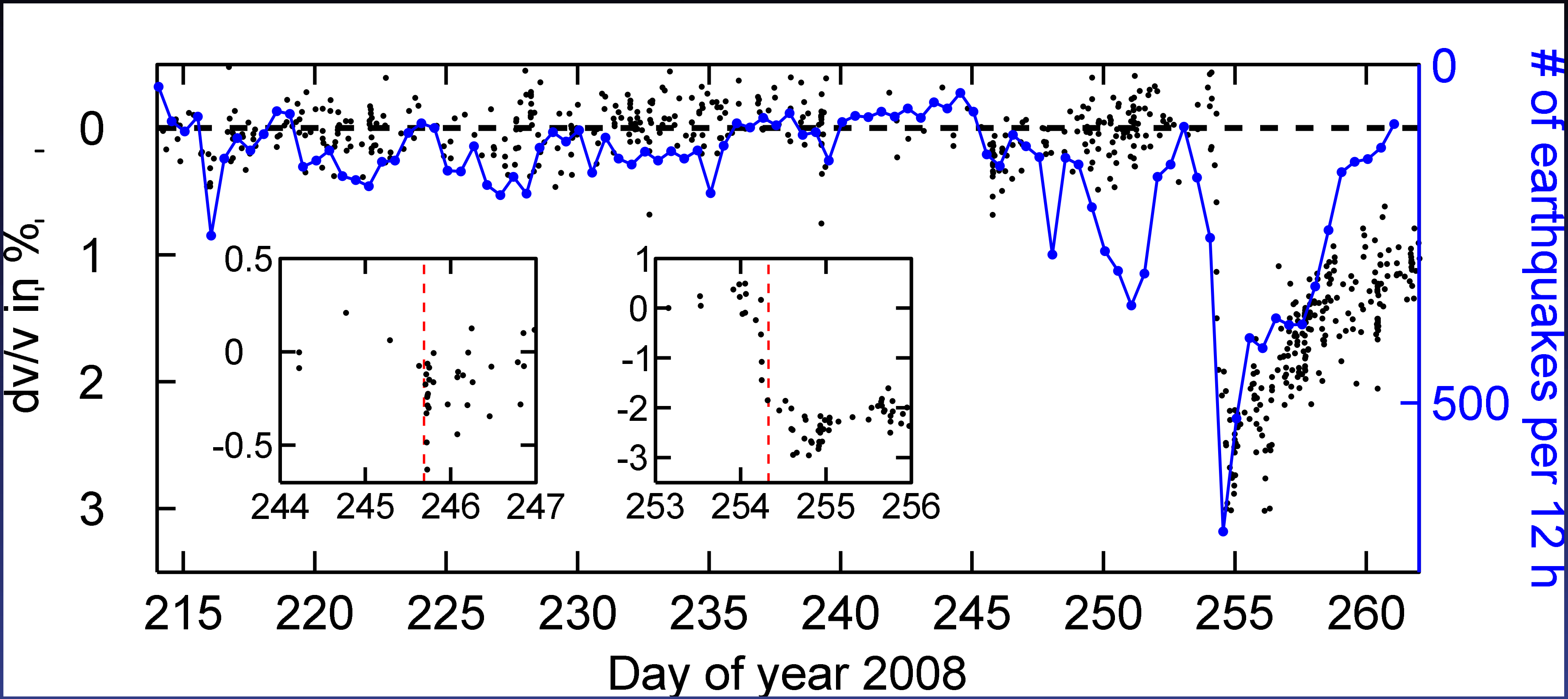
Rupture Barrier region



Larger coseismic velocity drop in the mainshock zone than the rupture barrier.

Rapid temporal variations in the barrier during the foreshock sequence.

Fault-Zone Velocity Changes During the Foreshock Sequence



The seismicity-rate jumps by about an order of magnitude during the foreshock sequence.

This would correspond to at least an order of magnitude jump in stressing-rate in the Dieterich 1994 rate state seismicity model.

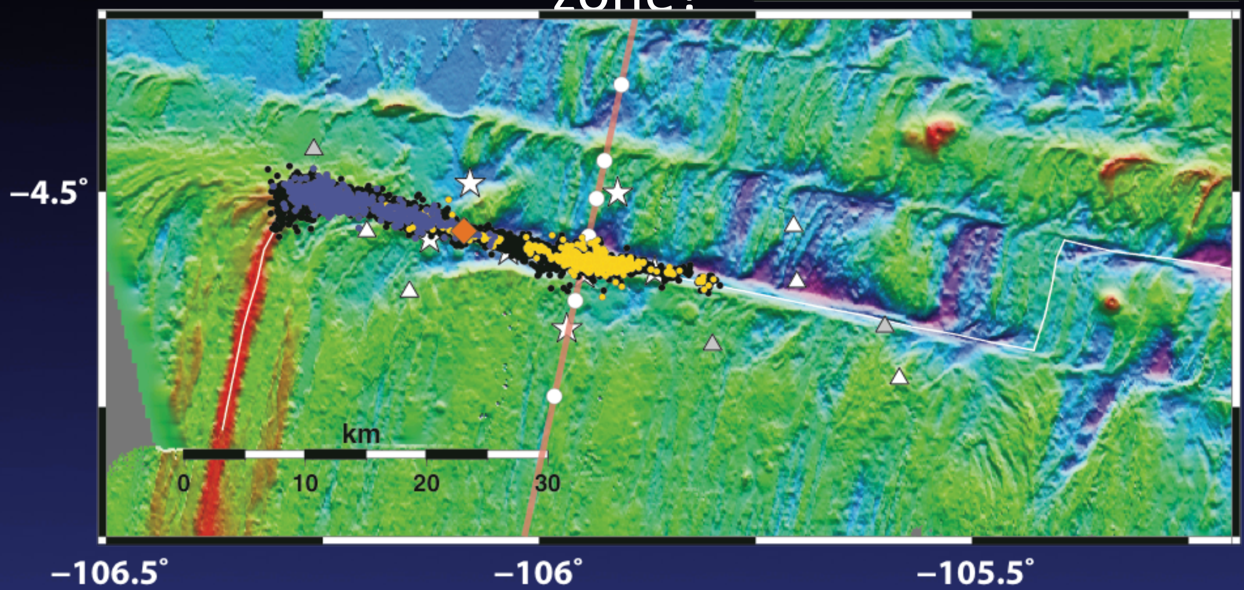
Summary

Rupture barriers to large earthquakes predominate on OTFs but are more complicated than a simple velocity strengthening zone

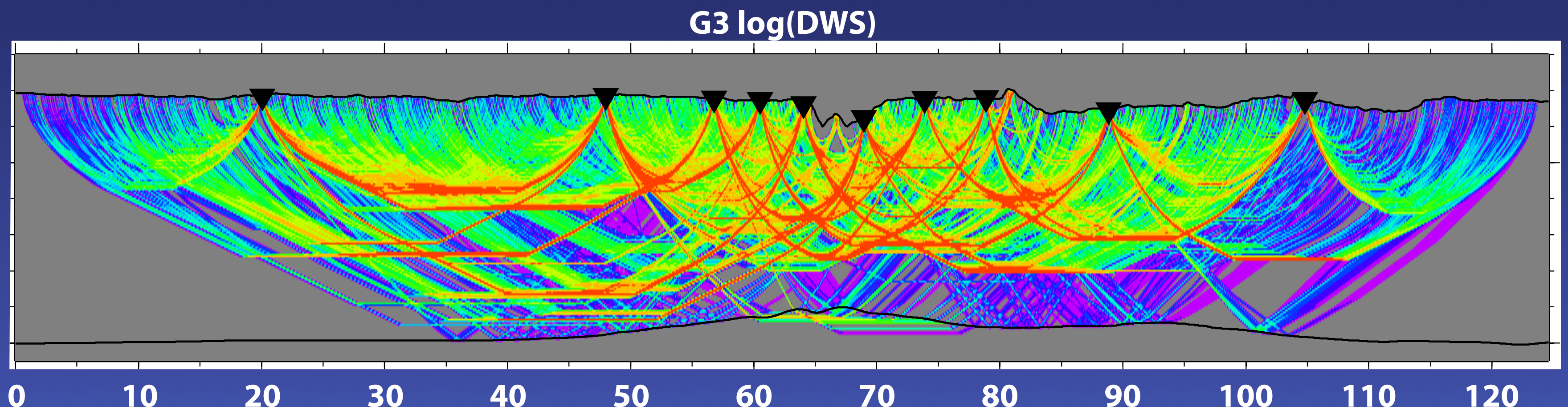
•Are long-lived through multiple seismic cycles
•Are able to nucleate intense micro-seismicity
    => velocity weakening at least at many small asperities
•Show significantly more damage in the seismogenic zone than regions that host large earthquakes
    => porosity of a few percent in the seismogenic zone
•Appear to have experienced a net drop in stress during the large rupture not the increase expected from simple models
    =>possible dynamic weakening?
•Show large time-dependence to their shear-wave velocities
    => high porosity /stress-dependence of velocity
    => coseismic damage may indicate damage

May also show lower apparent stress than mainshock zones (see Pamela Moyer's poster)

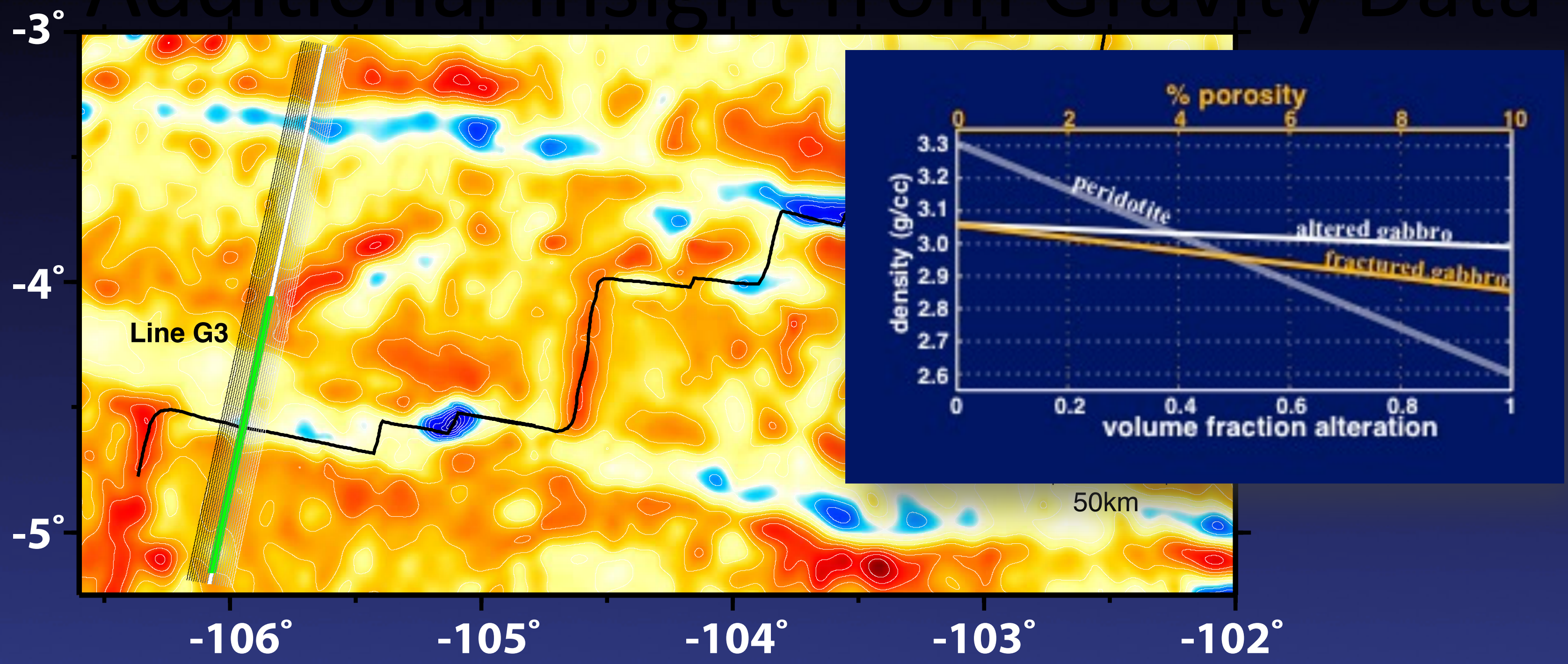
What are the material properties of the rupture barrier/foreshock zone?



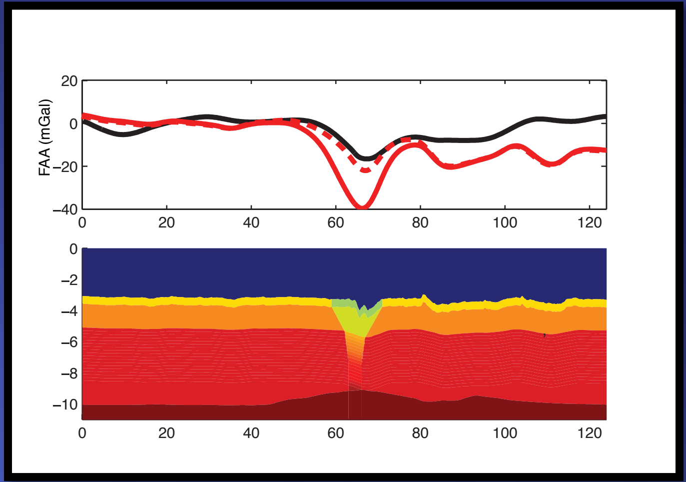
South North



Additional Insight from Gravity Data



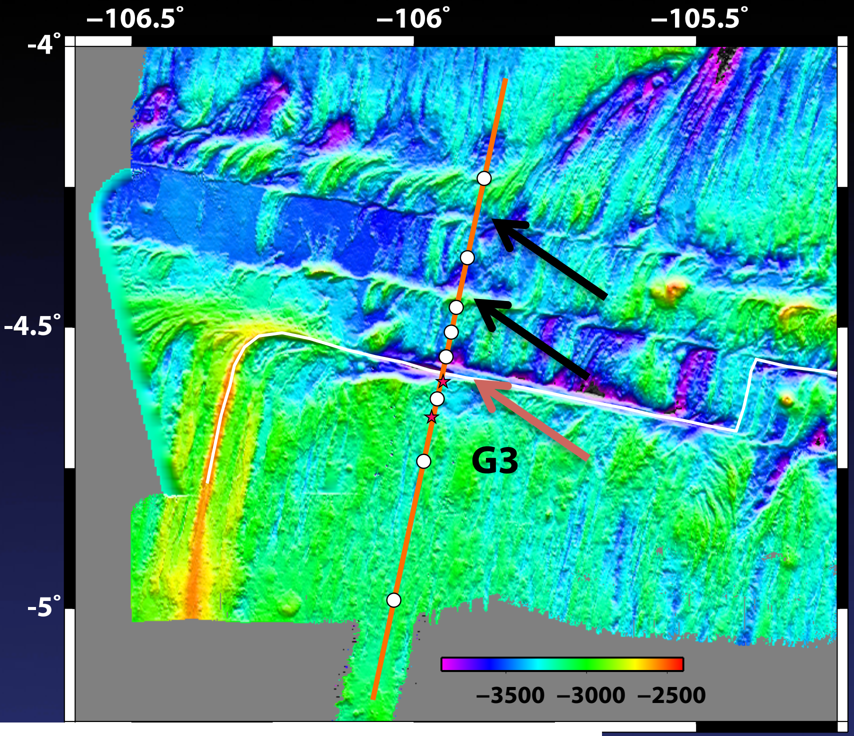
Simple model of gravity signature over fault zone containing partially serpentinized peridotite



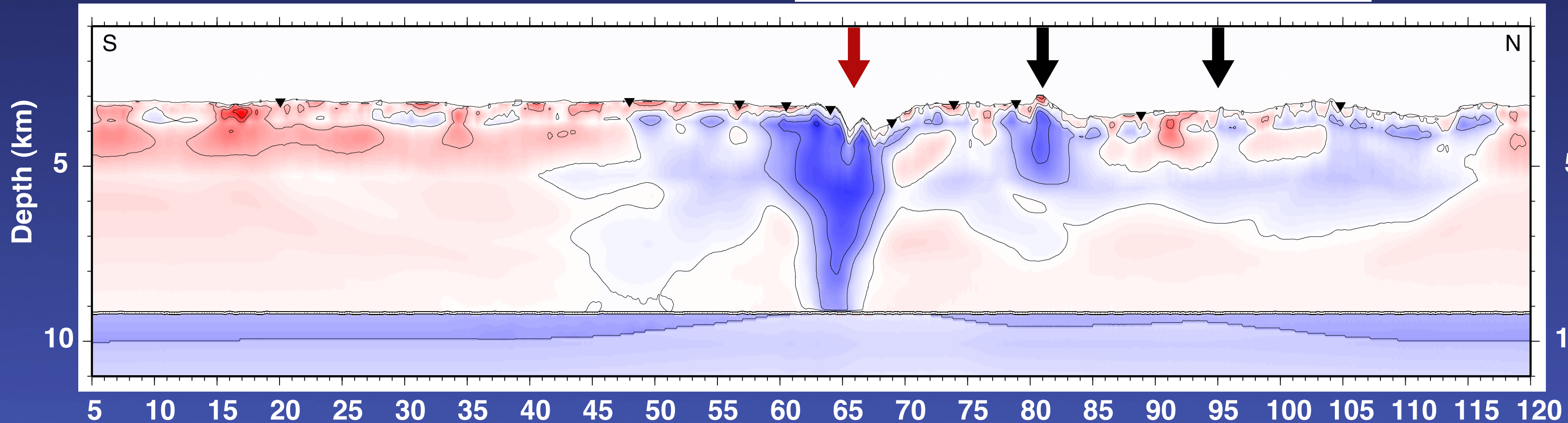
Free-air Anomaly does not show evidence for reduced density associated with altered mantle rocks

A 0.5-5% porosity increase comprised of high aspect ratio cracks extending ~5-6 km bsf could explain the Vp anomaly.

What do the “mainshock” parts of the fault look like?



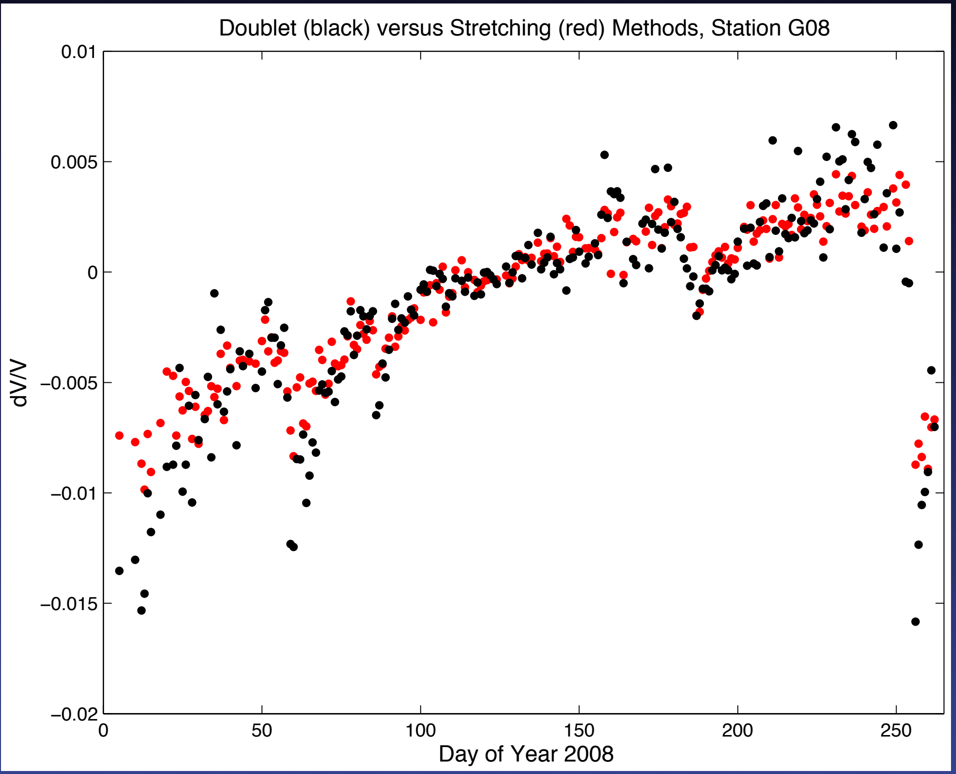
Active 0.85 Ma 1.3Ma



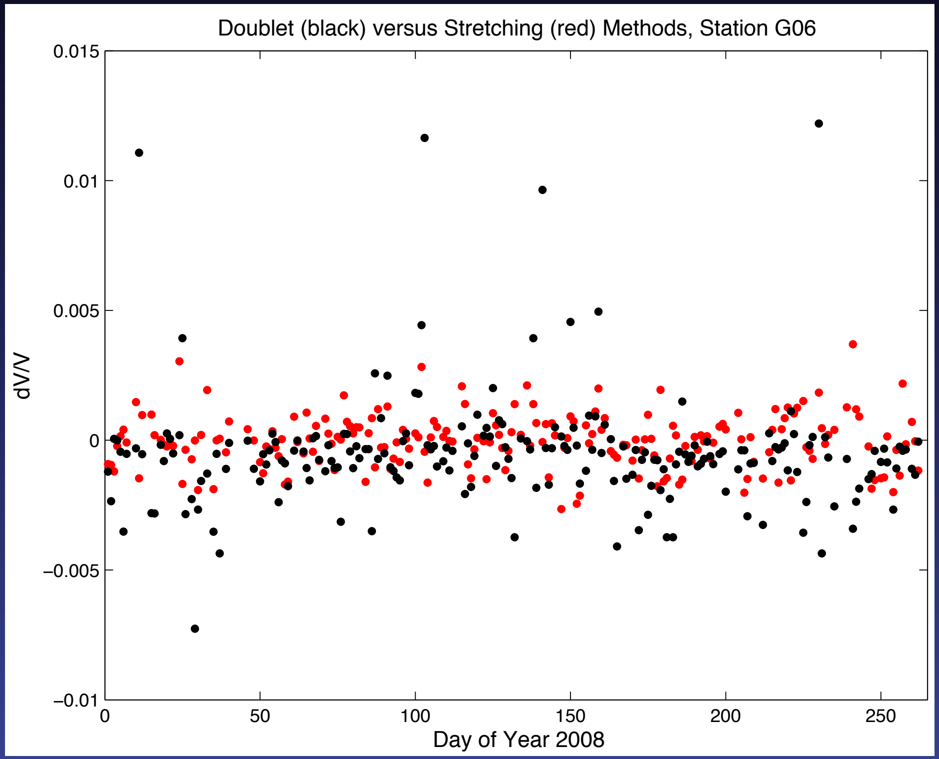
Roland et al., 2011

Velocity Changes

Foreshock Zone



Mainshock Zone

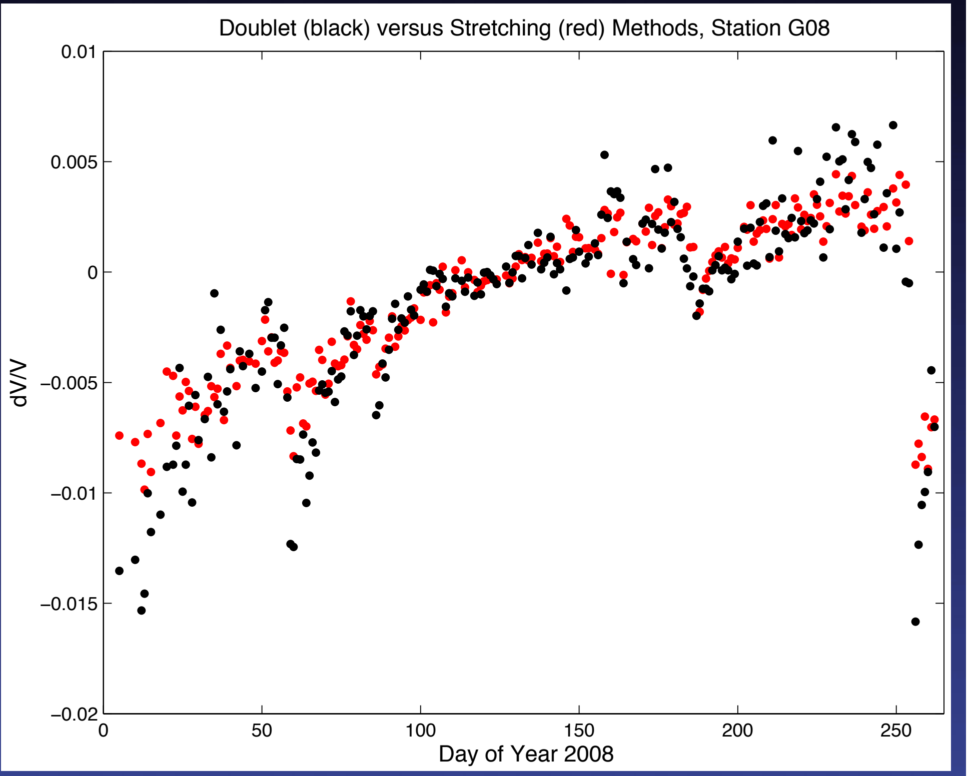


From Pierre Gouédard

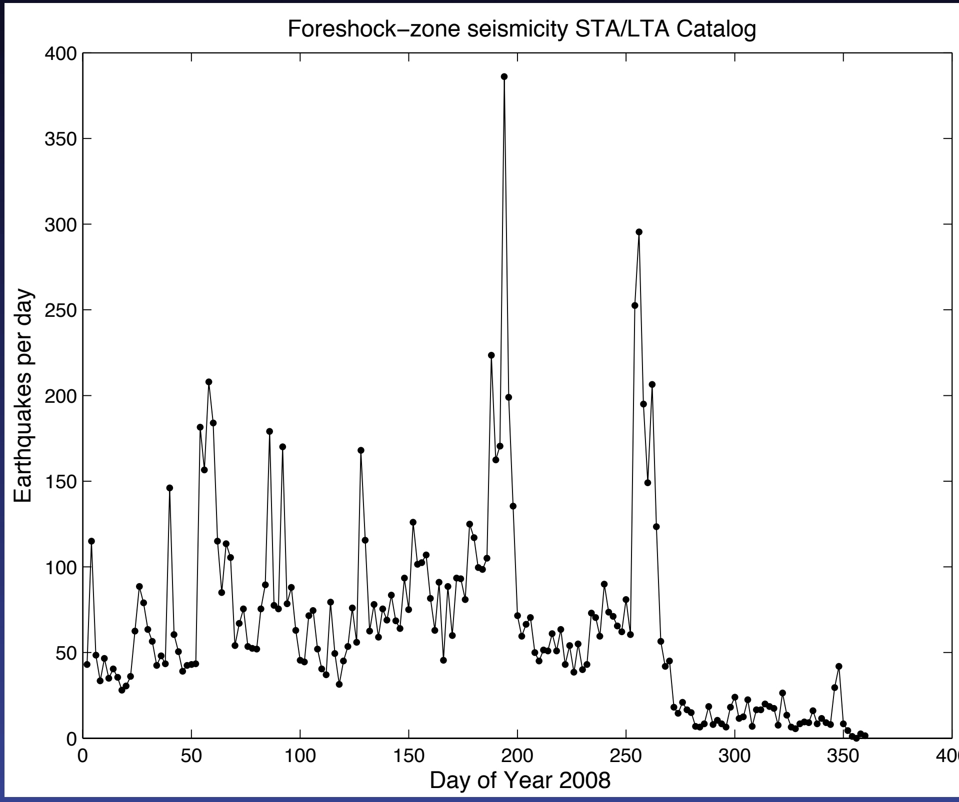
The key question is why does the foreshock zone show both an interseismic (positive) trend in velocity and multiple (negative) velocity decreases while the mainshock zone shows nothing?

Velocity Changes

Foreshock Zone



Foreshock Zone



From Pierre Gouédard

Velocity drops are correlated with earthquake swarms in multiple cases.