Seismic coupling at divergent plate boundaries from rate-and-state friction

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9 February 2017

Seismic coupling coefficient

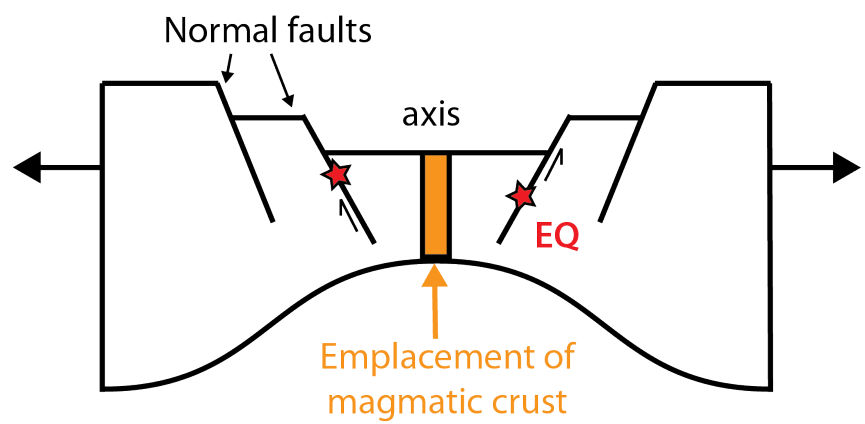
The seismic coupling coefficient χ is the fraction of slip on a fault that occurs seismically.

Total plate separation
= Tectonic + Magmatic

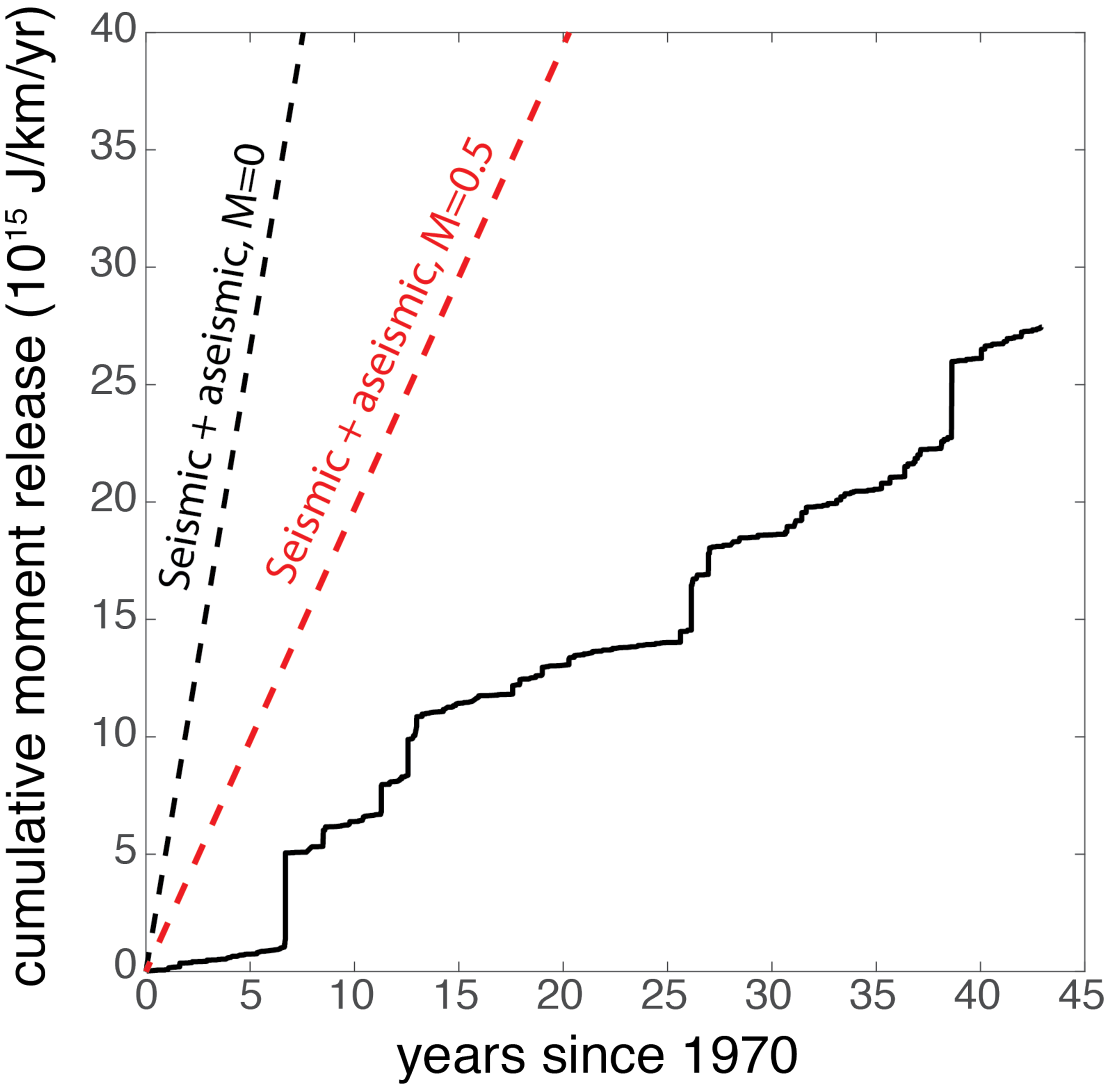
Seismic   Aseismic

χ = Seismic/Tectonic

M = Magmatic/Total



Seismic moment release



Estimate χ based on seismic moment release rate R. χ is related to R by:

$$\chi = \frac{R\sin(\phi)}{UGH(1-M)}$$

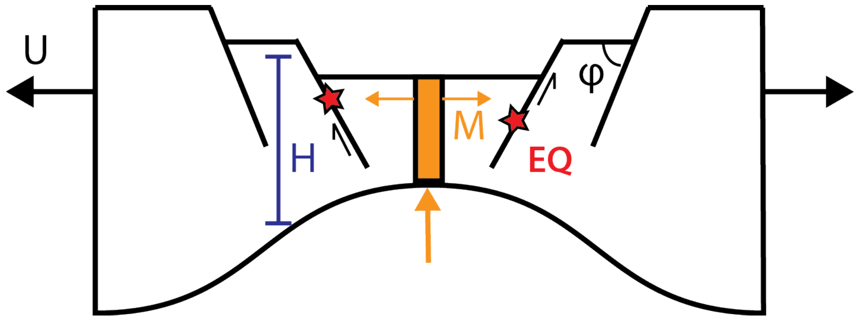
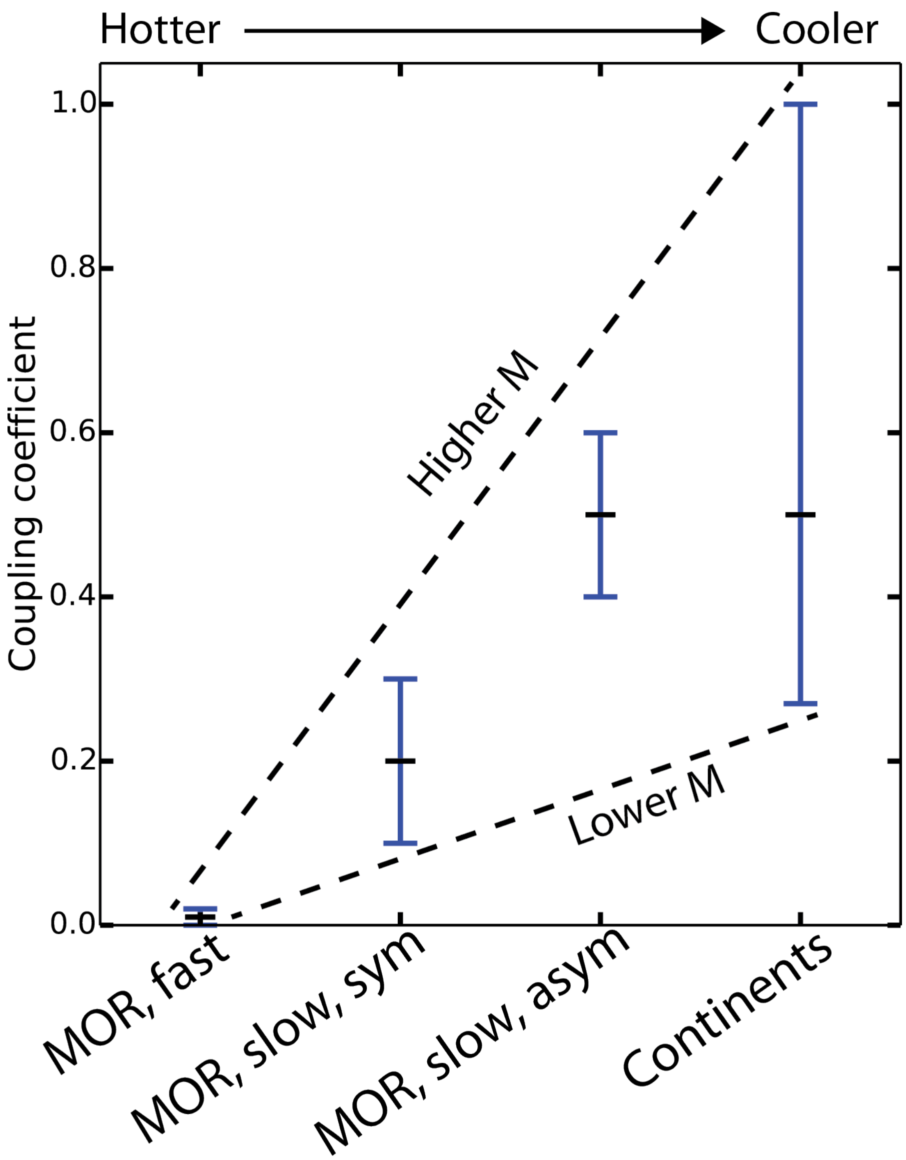
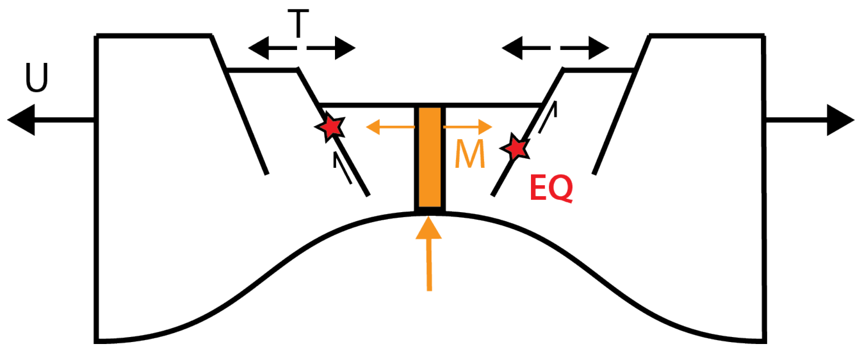


Figure from JA Olive

Variations in seismic coupling?

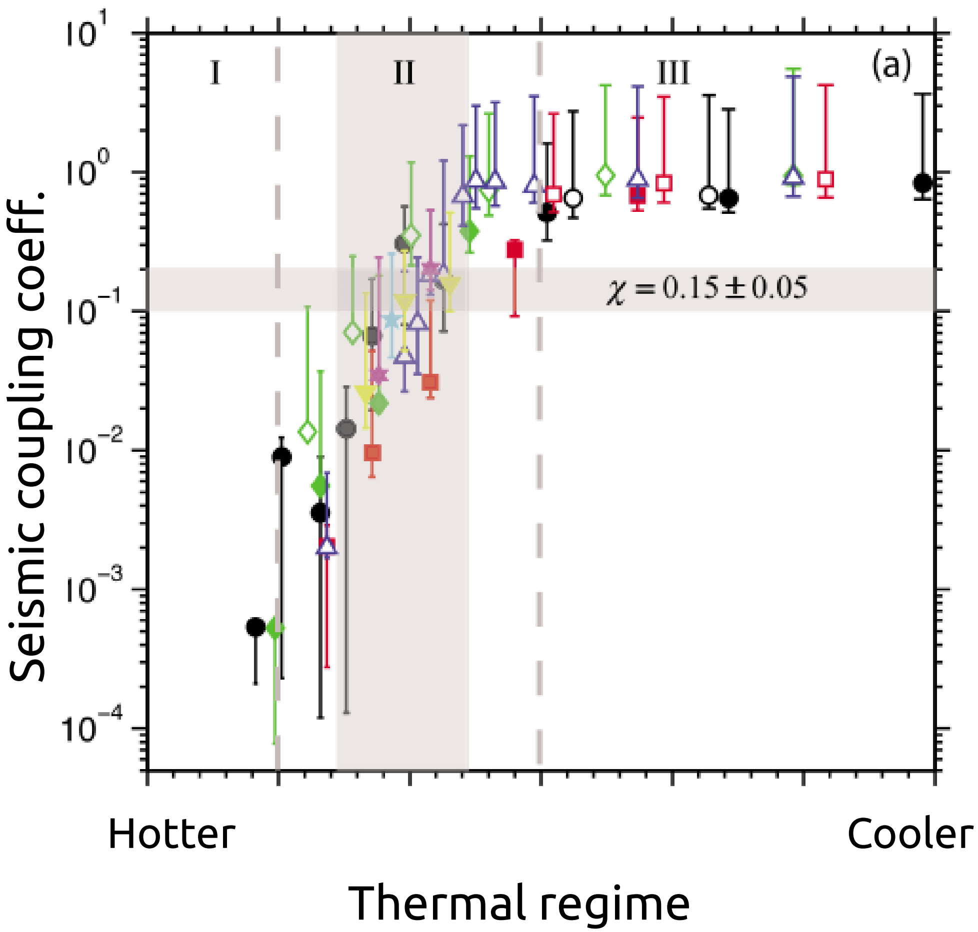


Seismic coupling coefficient χ varies across divergent boundaries.



Data from Bird and Kagan [2004], Cowie et al. [1993], and Olive and Escartin [2016].

Variations in seismic coupling?



Variations in seismic coupling with thermal structure for transform faults. Figure from Liu et al. [2012]

Question:

How much of the variation in seismic coupling can we explain with variations in thermal structure and fault geometry?

Test:

- Model seismic cycles on normal faults
- Vary thermal structure and fault geometry
- Compare the range of coupling behavior generated in models to the range of values observed in natural systems.

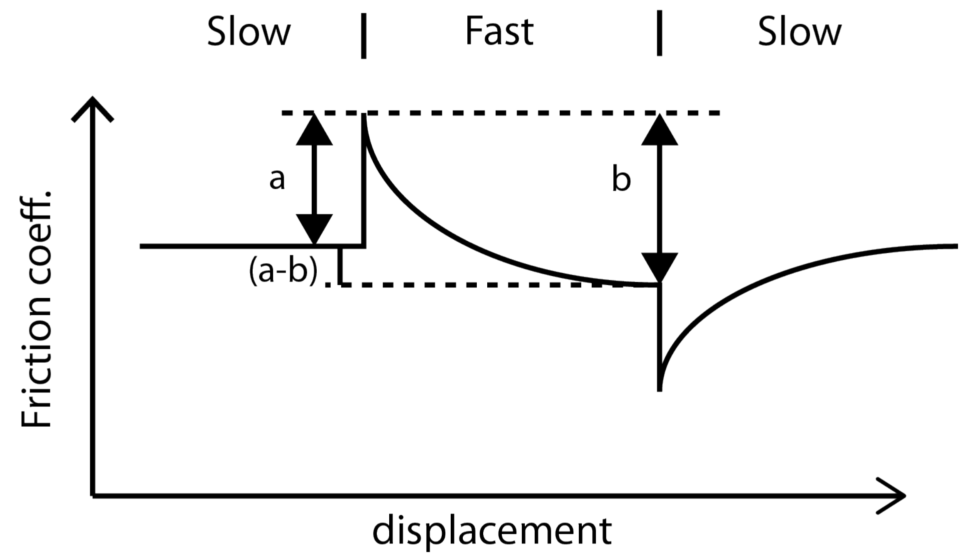
Rate-and-state friction

Empirical laws where friction properties depend on slip **rate** and slip **history**

Friction parameter (a-b):

(a-b) > 0 → velocity-strengthening

(a-b) < 0 → velocity-weakening



Rate-and-state friction model

Empirical laws where friction properties depend on slip **rate** and slip **history**

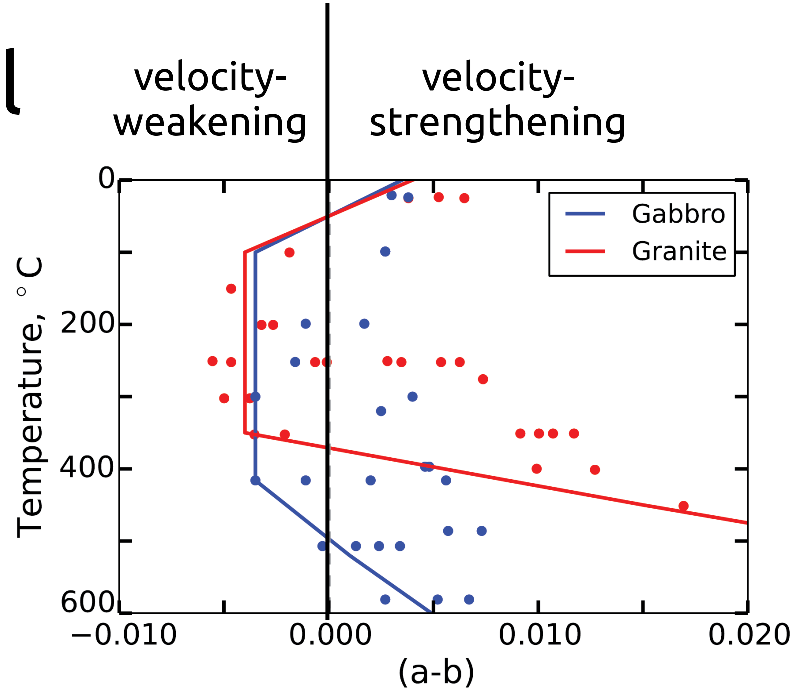
Friction parameter (a-b):

(a-b) > 0 → velocity-strengthening

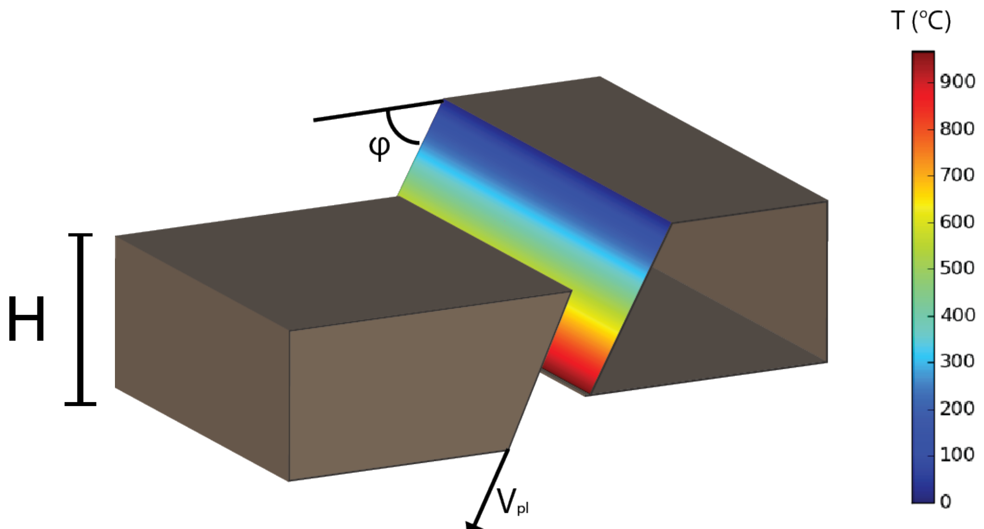
(a-b) < 0 → velocity-weakening

Use (a-b) vs. T and a uniform thermal gradient to prescribe frictional parameters

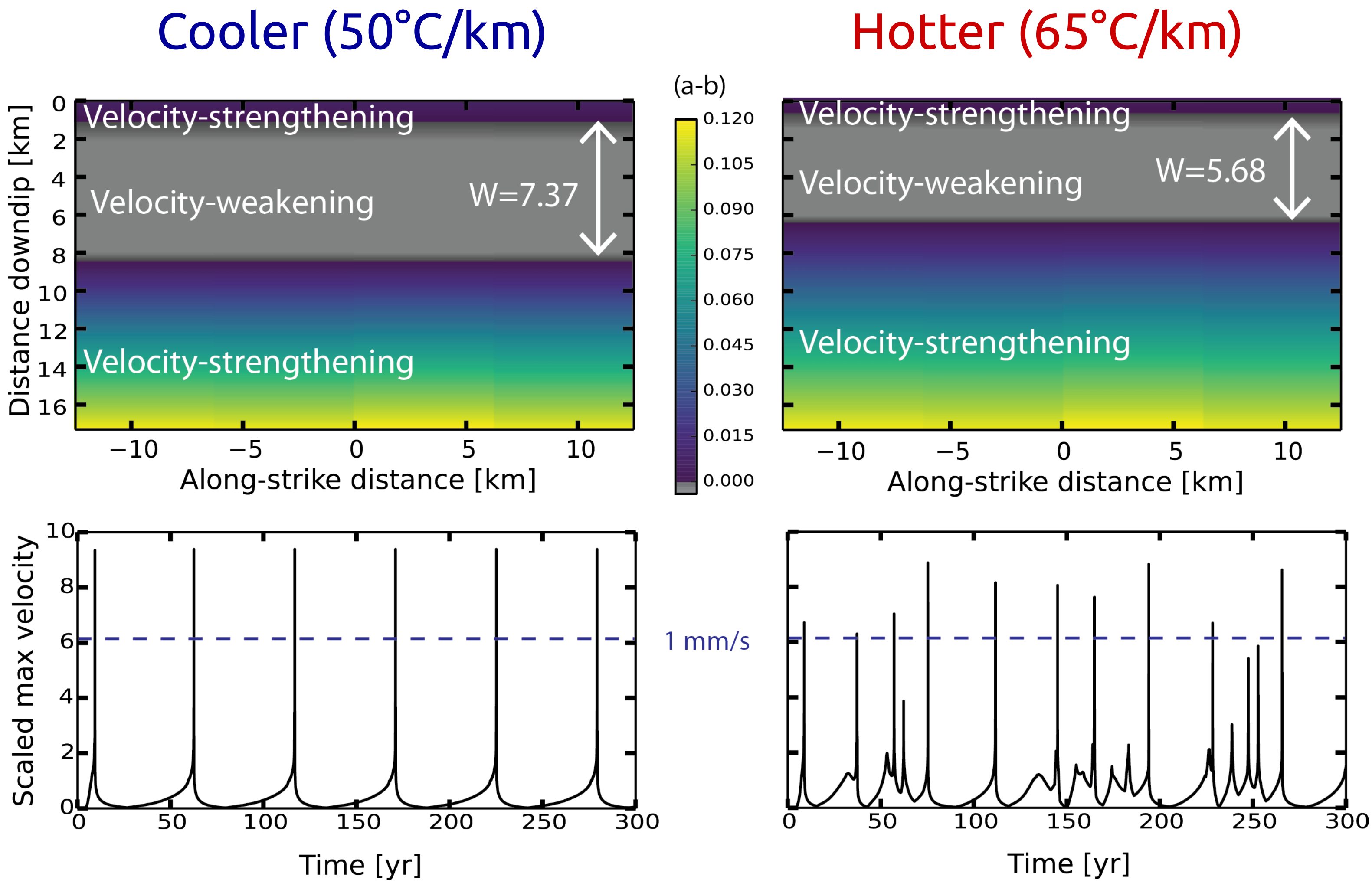
Vary: **thermal gradient, fault dip, lithology, long-term slip rate, along-strike dimension**



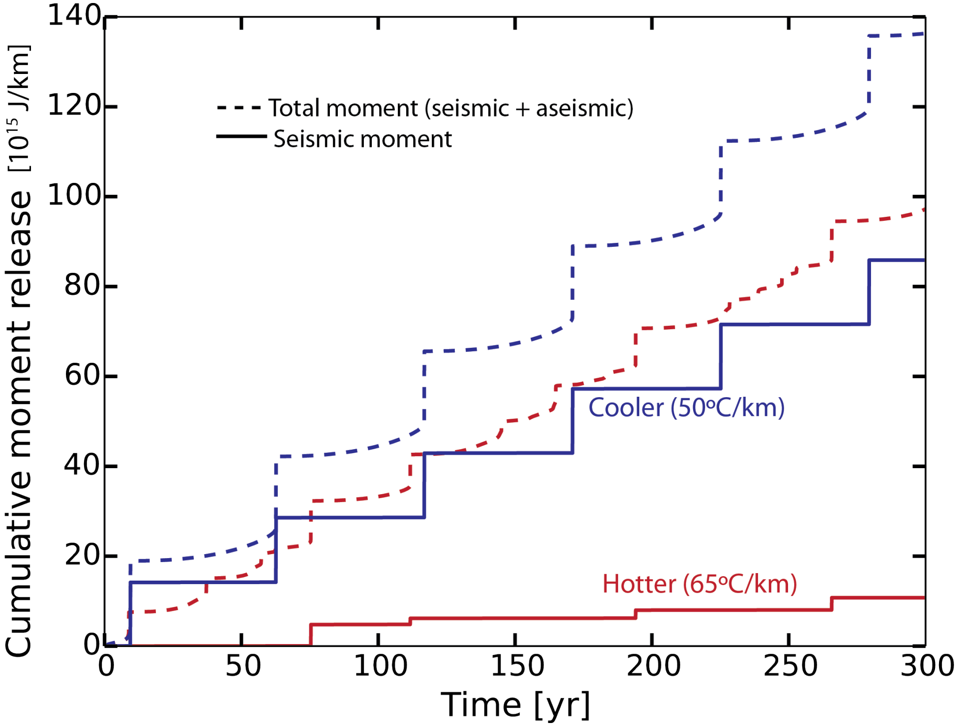
Data from Blanpied et al. [1995] and He et al. [2007]

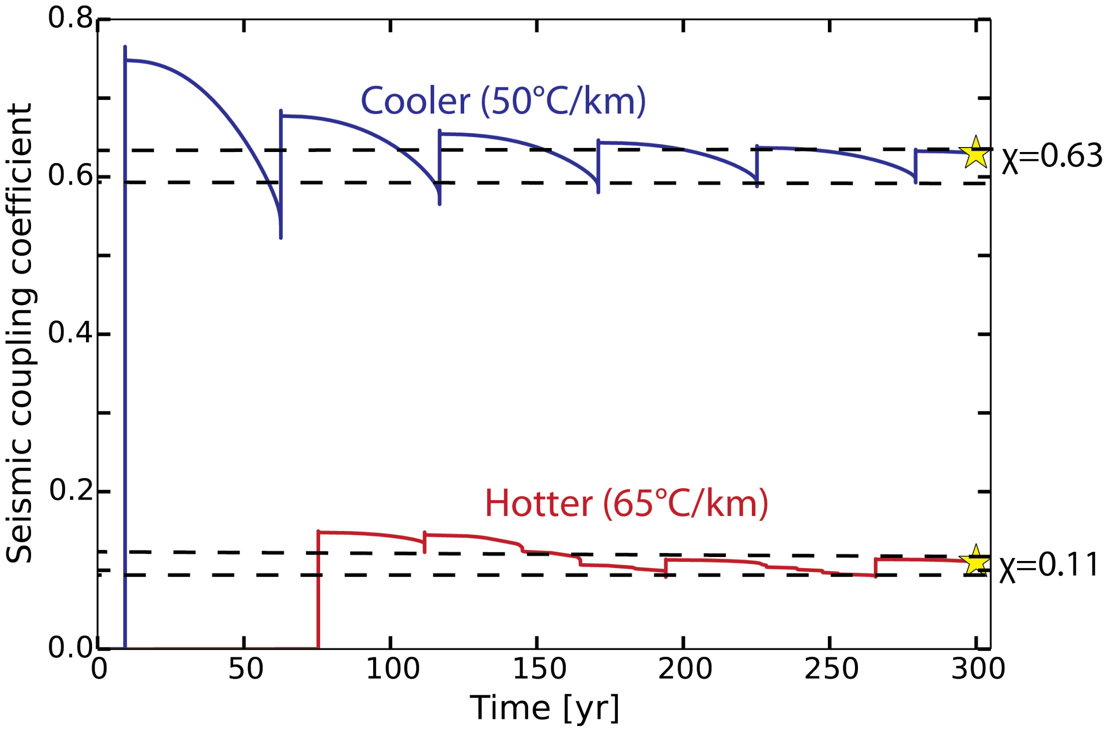


Model results

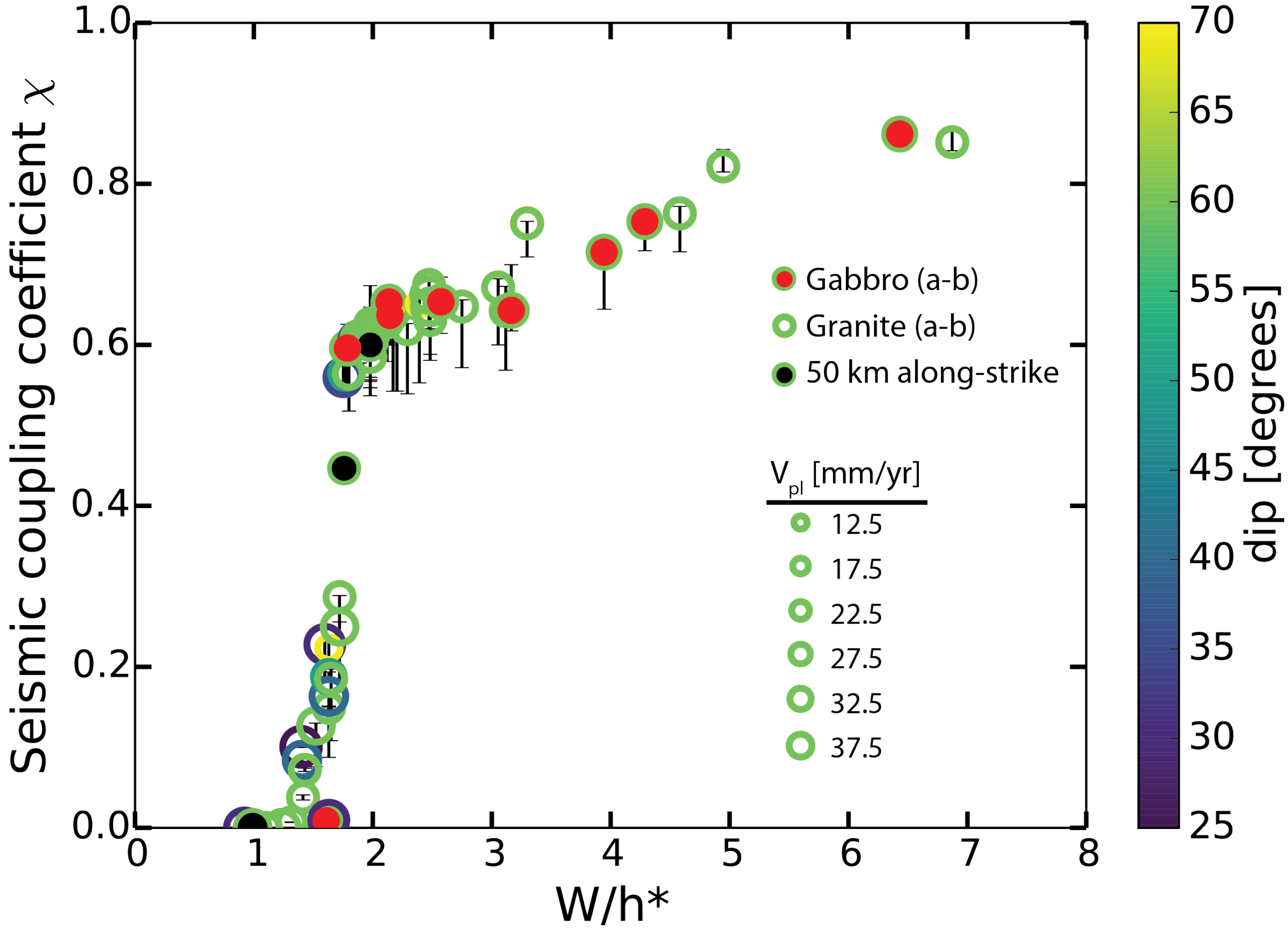


Model results





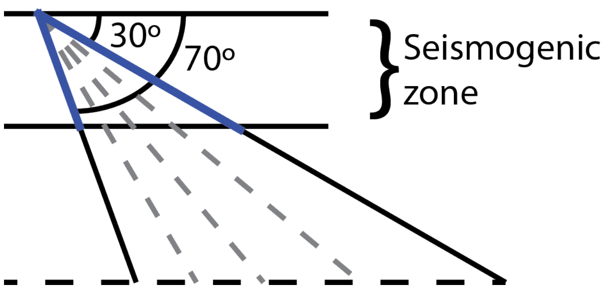
What controls seismic coupling?



Hotter

Cooler

$$W \propto H / \sin\phi$$



h* = critical EQ nucleation size

What controls W/h* in natural systems?

Effective shear modulus

Critical slip distance

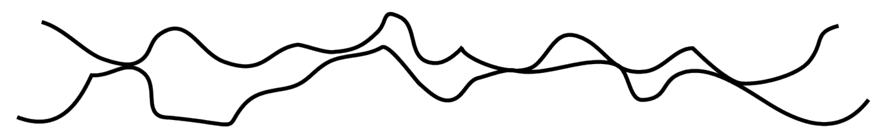
Rubin and Ampuero [2005]

$$h^* = \frac{2 G b D_c}{\pi (b-a)^2 \bar{\sigma}}$$

Friction parameters

Effective normal stress

Asperity contacts



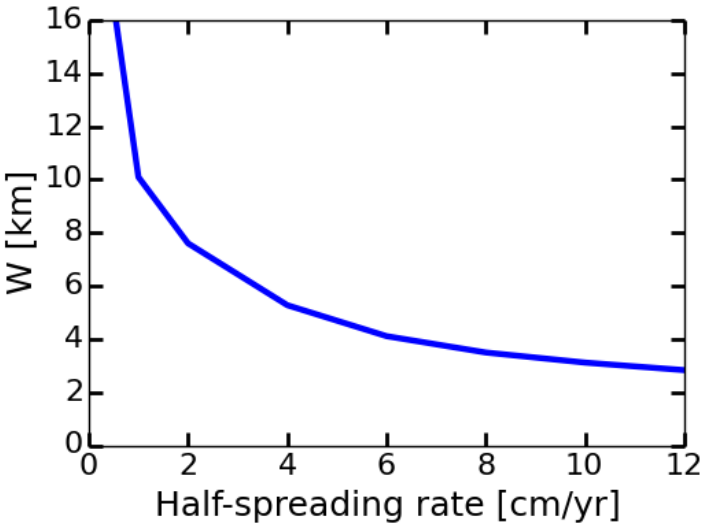
D_c related to the size of asperity contacts

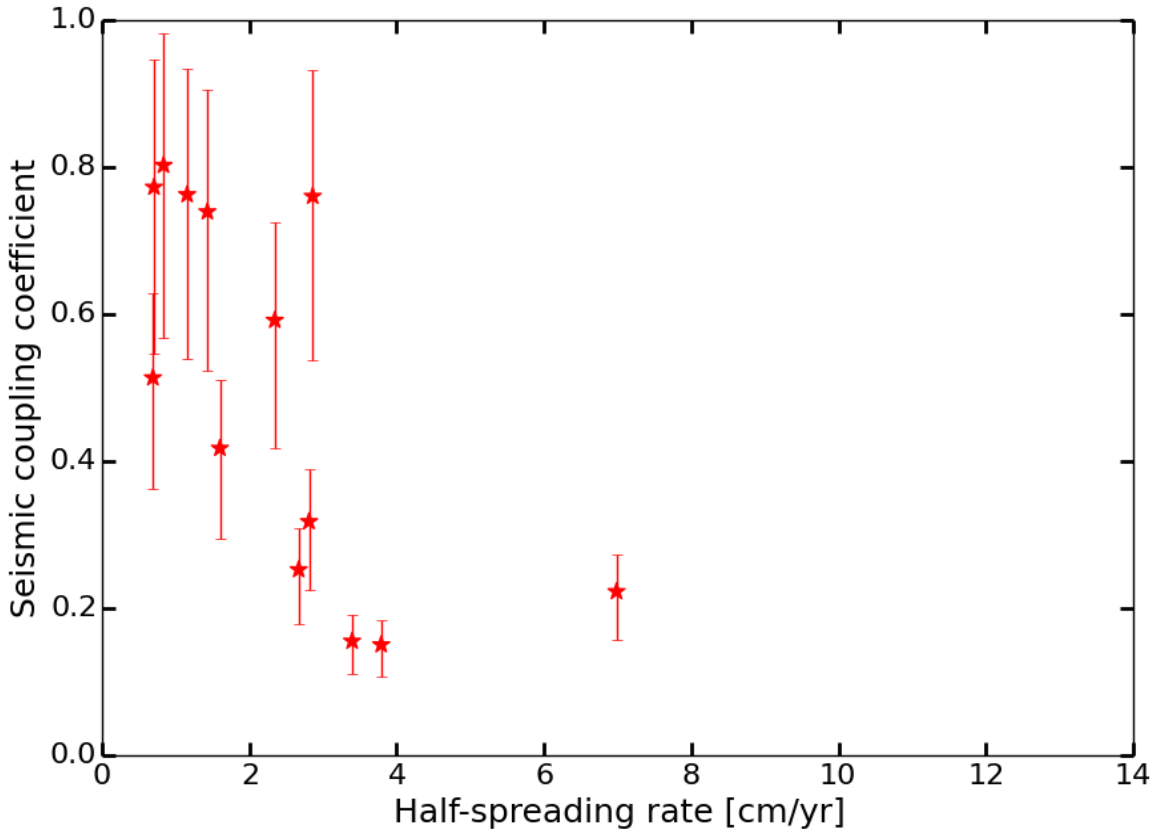
$D_c \approx .1$ mm from olivine friction experiments [Boettcher et al., 2007]

To match observations, we use D_c on the order of 5+ mm

Can we use model results to estimate h* or D_c in natural settings?

What controls W/h* in natural systems?





W(U) from thermal models

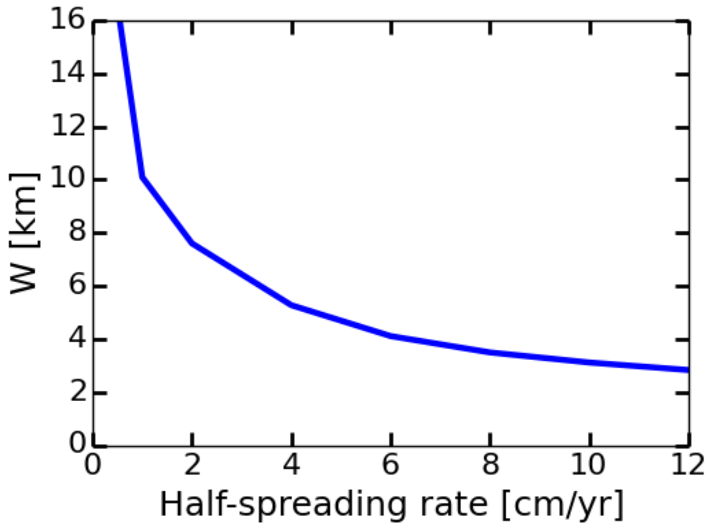
R(U) from observations

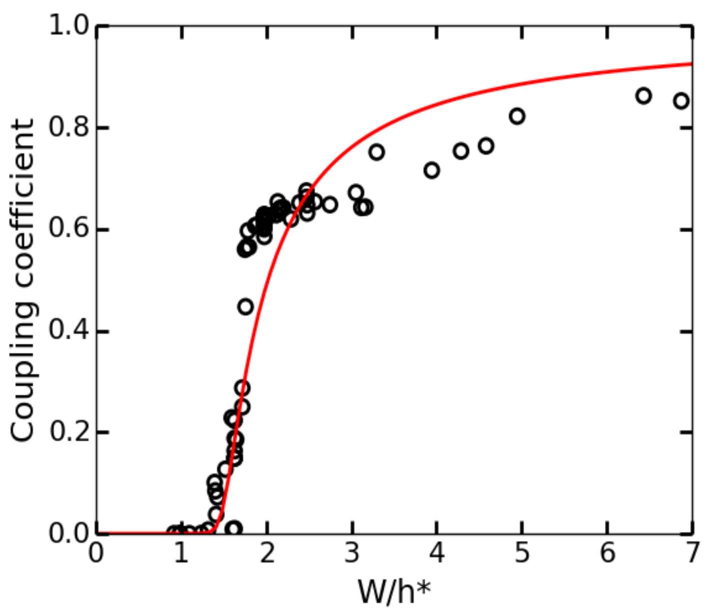
Choose values for M and φ

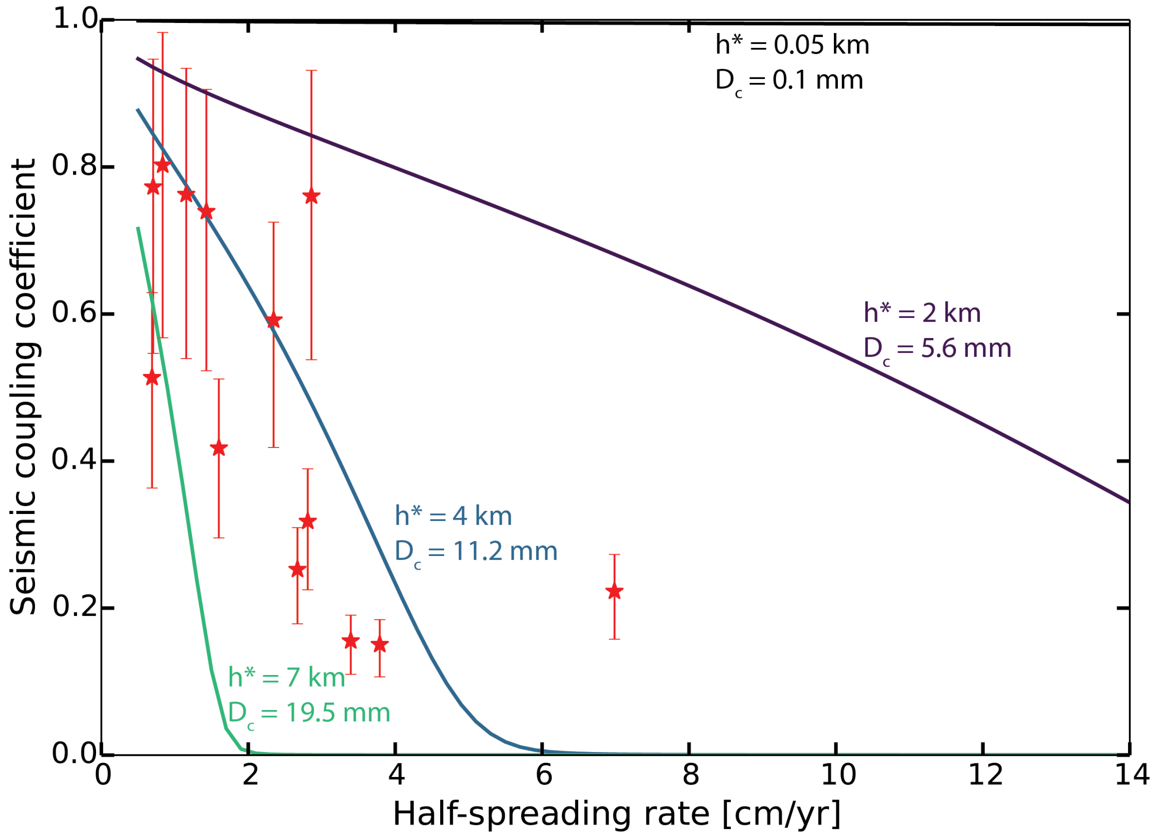
→ Calculate χ(U)

Red stars calculated with data
from Frolich and Wetzel [2007]

What controls W/h* in natural systems?



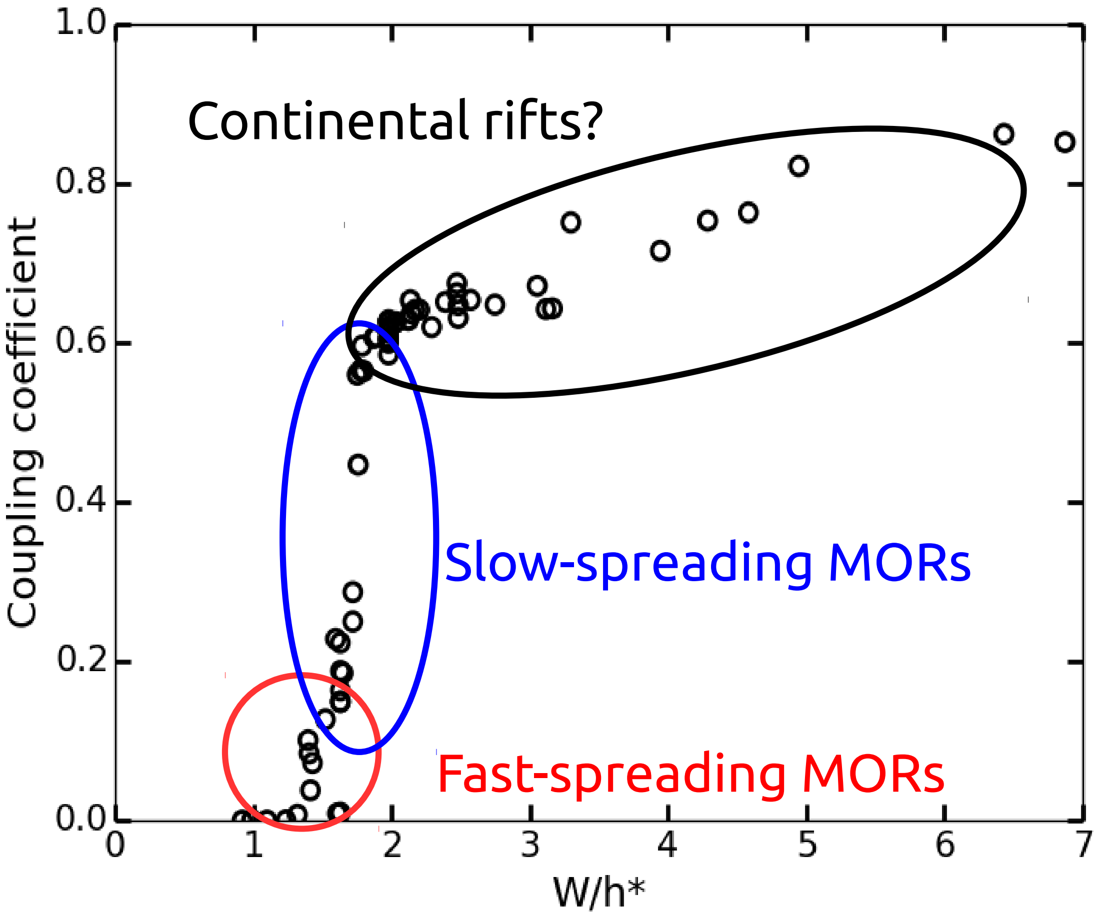




Red stars calculated with data
from Frolich and Wetzel [2007]

Conclusions

- Seismic coupling coefficient for normal faults scales with thermal regime (W/h*)
- Observations are best matched with h* approx. 10-50 times laboratory values
- Calculating χ from moment release rates involves a trade-off between h* and M



Continental observations

- Rifting environment with local array data over several years: Walker Lane?