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

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Seismic coupling coefficient

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

Total plate separation = Tectonic + Magmatic

$\chi = \text{Seismic} / \text{Tectonic}$

$M = \text{Magmatic} / \text{Total}$
Seismic moment release

Estimate $\chi$ based on seismic moment release rate $R$. $\chi$ is related to $R$ by:

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

Figure from JA Olive
Variations in seismic coupling?

Seismic coupling coefficient $\chi$ varies across divergent boundaries.

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

Variations in seismic coupling with thermal structure for transform faults. Figure from Liu et al. [2012]
Rate-and-state friction

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

Friction parameter \((a-b)\):

\((a-b) > 0 \rightarrow \text{velocity-strengthening}\)
\((a-b) < 0 \rightarrow \text{velocity-weakening}\)
Rate-and-state friction model

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

Friction parameter \((a-b)\):

\[(a-b) > 0 \rightarrow \text{velocity-strengthening}\]

\[(a-b) < 0 \rightarrow \text{velocity-weakening}\]

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

Cooler (50°C/km)

Distance down dip [km]

Velocity-strengthening

W=7.37

Velocity-weakening

Hotter (65°C/km)

Along-strike distance [km]

Velocity-strengthening

W=5.68

Velocity-weakening

Scaled max velocity

1 mm/s

Time [yr]

Time [yr]
Model results

![Graph showing cumulative moment release and seismic coupling coefficient over time for different temperature scenarios.]

- **Total moment (seismic + aseismic)**
- **Seismic moment**

**Cooler (50°C/km)**

**Hotter (65°C/km)**

Seismic coupling coefficient

- \( \chi = 0.63 \)
- \( \chi = 0.11 \)
What controls seismic coupling?

$W \propto H / \sin \phi$

$h^* = \text{critical EQ nucleation size}$
What controls $W/h^*$ in natural systems?

$D_c$ 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 $\varphi$  
→ Calculate $\chi(U)$

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 $\chi$ 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?