Evolving shear traction and its spatial variability on the southern San Andreas fault system since 1000 CE

B #050

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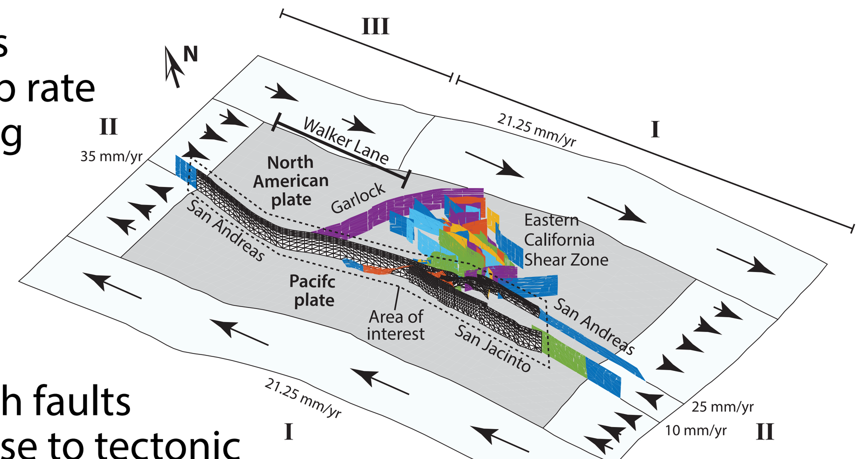
Motivation: Estimates of the stress state through time can help constrain conditions that precede ground-rupturing earthquakes and provide initial conditions for dynamic rupture models.
Goals: Estimate evolving and pre-quake strike shear traction on the San Andreas and San Jacinto faults since 1000 CE and investigate the impacts of uncertainty in earthquake timing, stress drop, and effective upper crustal viscosity on traction estimates.

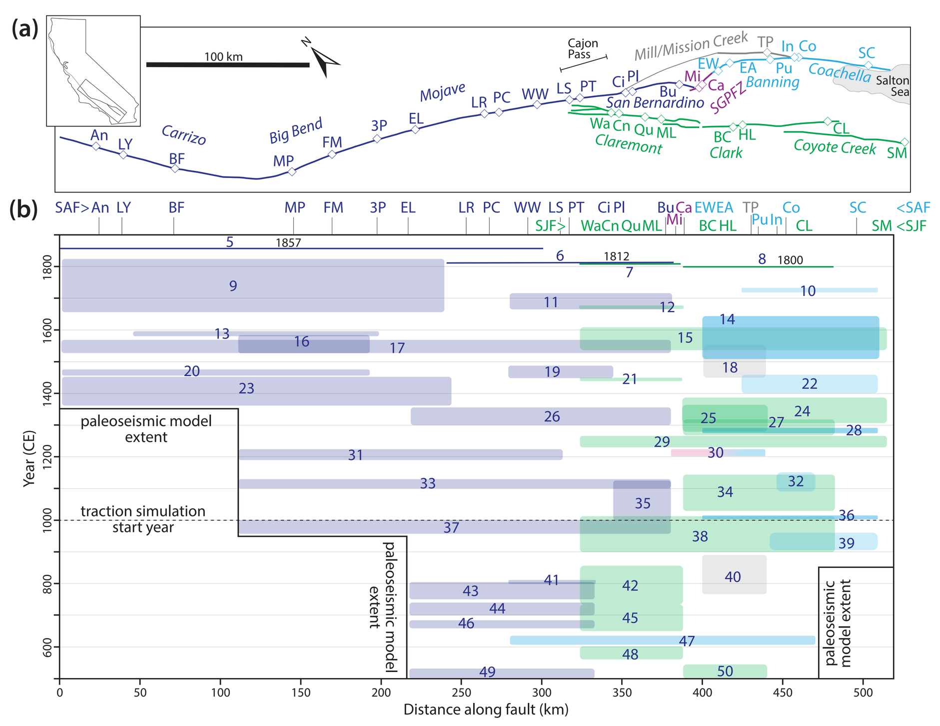
1. Methods

3D numerical BEM models estimate tractions on the San Andreas and San Jacinto faults by combining the effects of interseismic stressing and ground-rupturing earthquakes.

Interseismic models prescribe steady slip rate below 20 km locking depth.

Distribution of steady slip rates comes from long-term model in which faults slip freely in response to tectonic loading applied at the model edges.





Earthquakes release either 1) all accumulated shear traction (complete stress drop) or 2) a % of accumulated shear traction (incomplete stress drop).

Earthquake rupture lengths and timing are from Scharer & Yule (2020).

2. Combining interseismic loading and earthquakes

We test different assumptions about the rheology of the crust, earthquake timing, and completeness of the static stress drop.

Elastic vs. viscoelastic interseismic traction accumulation:

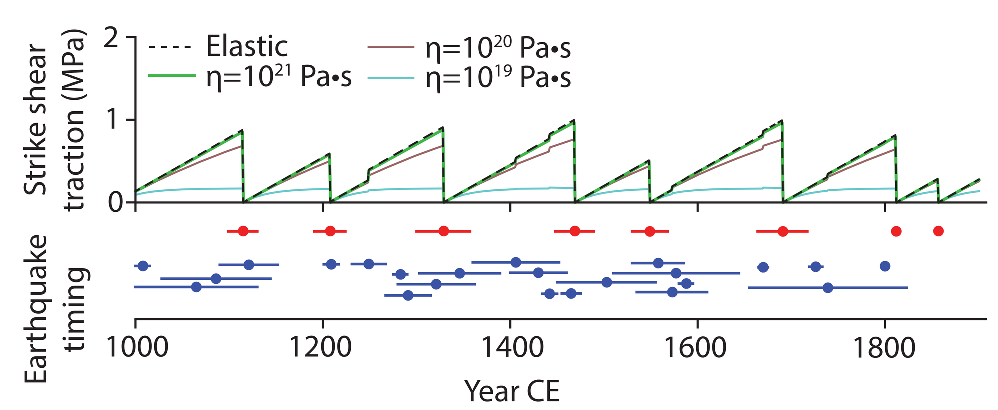
$$\sigma = \dot{\sigma} * t \quad \text{vs.} \quad \tau(t) = \left(\tau_0 - \eta\frac{\dot{\tau}}{\mu}\right) * e^{-\frac{\mu}{\eta}t} + \eta\frac{\dot{\tau}}{\mu}$$

Minimum viscosity that produces reasonable average slip per event: $\eta = 10^{20}$ Pa•s (Anderson-Merritt et al., 2026).

Earthquake timing uncertainty: uniform distribution using time ranges from Scharer & Yule (2020).

Residual shear traction (stress drop completeness): half normal distribution (peak 0%, std dev 25% of accumulated traction).

3. Traction through time at Wrightwood

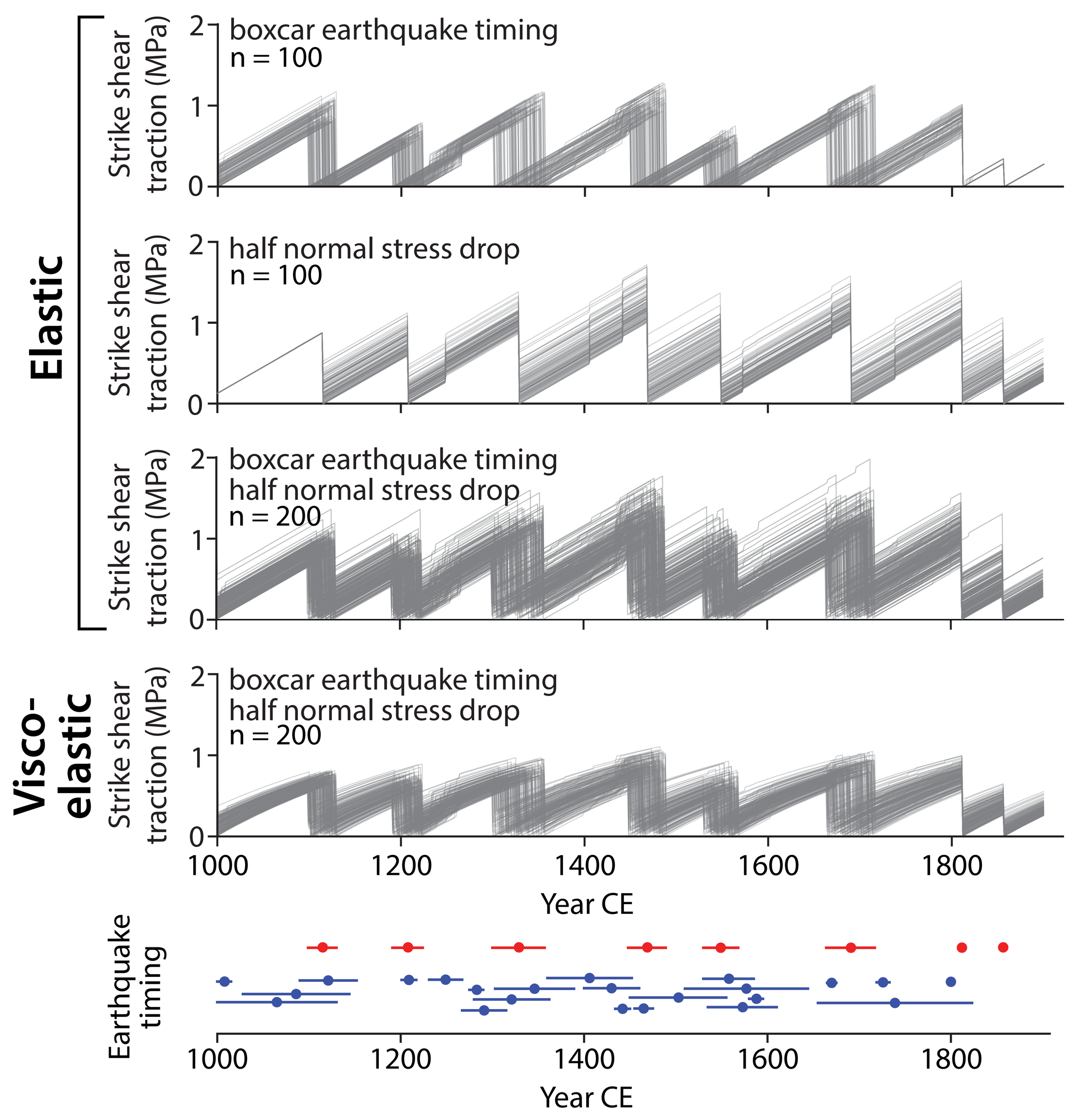


Red dots: earthquakes that go through Wrightwood. Blue dots: other earthquakes in S&Y (2020).

Choice of viscosity has the greatest effect on accumulated shear tractions.

Earthquakes elsewhere in the system have small effects at this site.

4. Monte Carlo simulations at Wrightwood

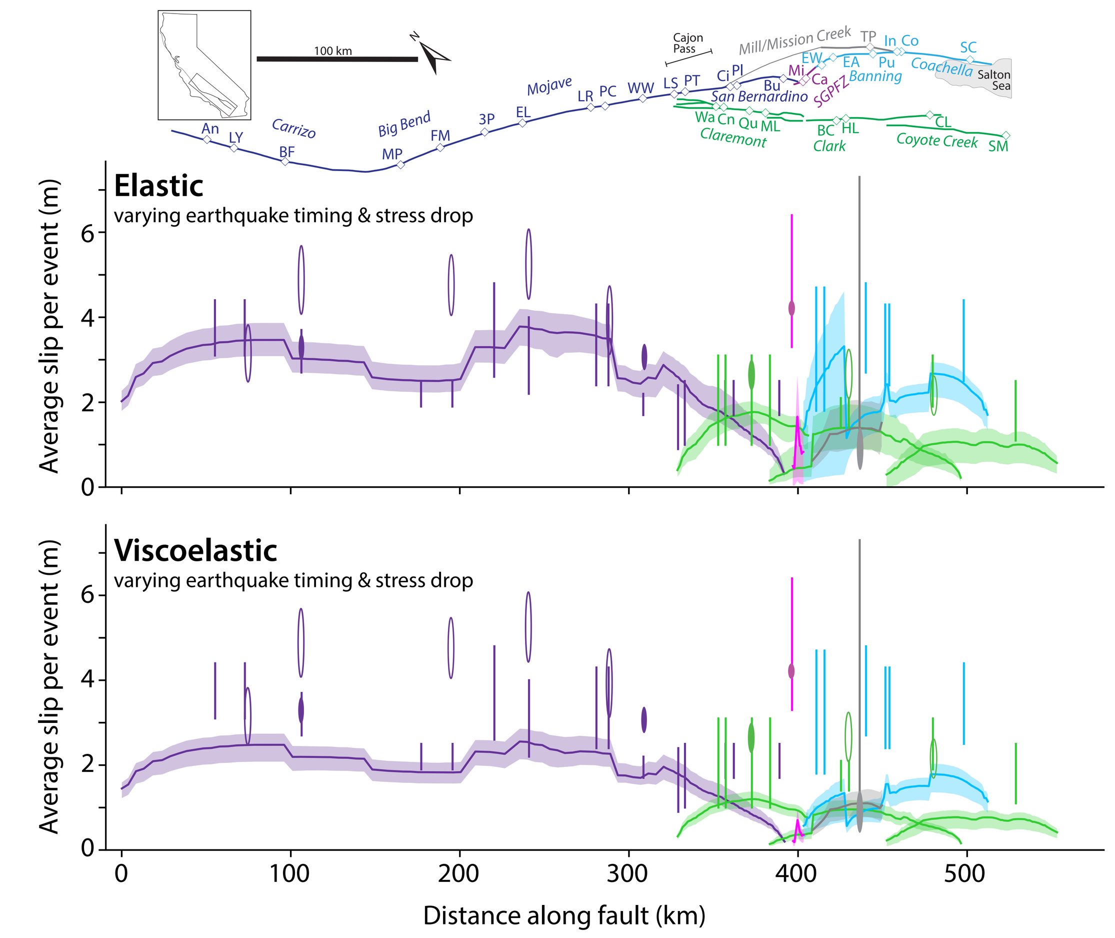


Following model spin-up time, varying stress drop produces greater traction uncertainty than varying earthquake timing (less well constrained parameter).

Including viscoelastic stress relaxation ($\eta = 10^{20}$ Pa•s) reduces maximum shear traction and traction uncertainty over the course of each interseismic interval.

Red dots: earthquakes that go through Wrightwood. Blue dots: other earthquakes in S&Y (2020).

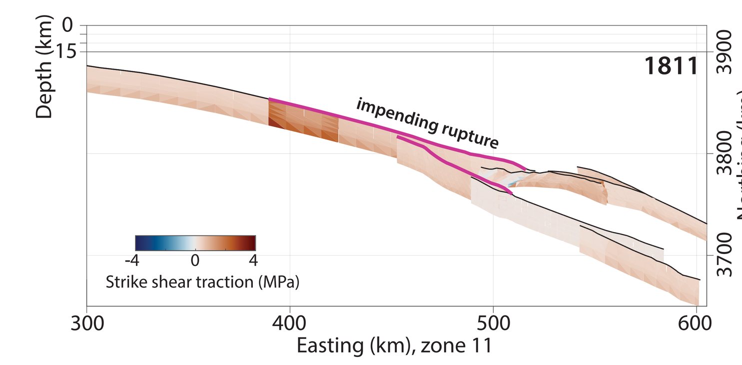
5. Validation: average slip per event



Average slip per event from elastic and viscoelastic simulations generally matches estimates calculated from recurrence interval and slip rate (vertical bars; Scharer & Yule, 2020) and from paleoseismic studies (ovals).

Solid lines: average of simulation results
Shaded regions: range of simulation results

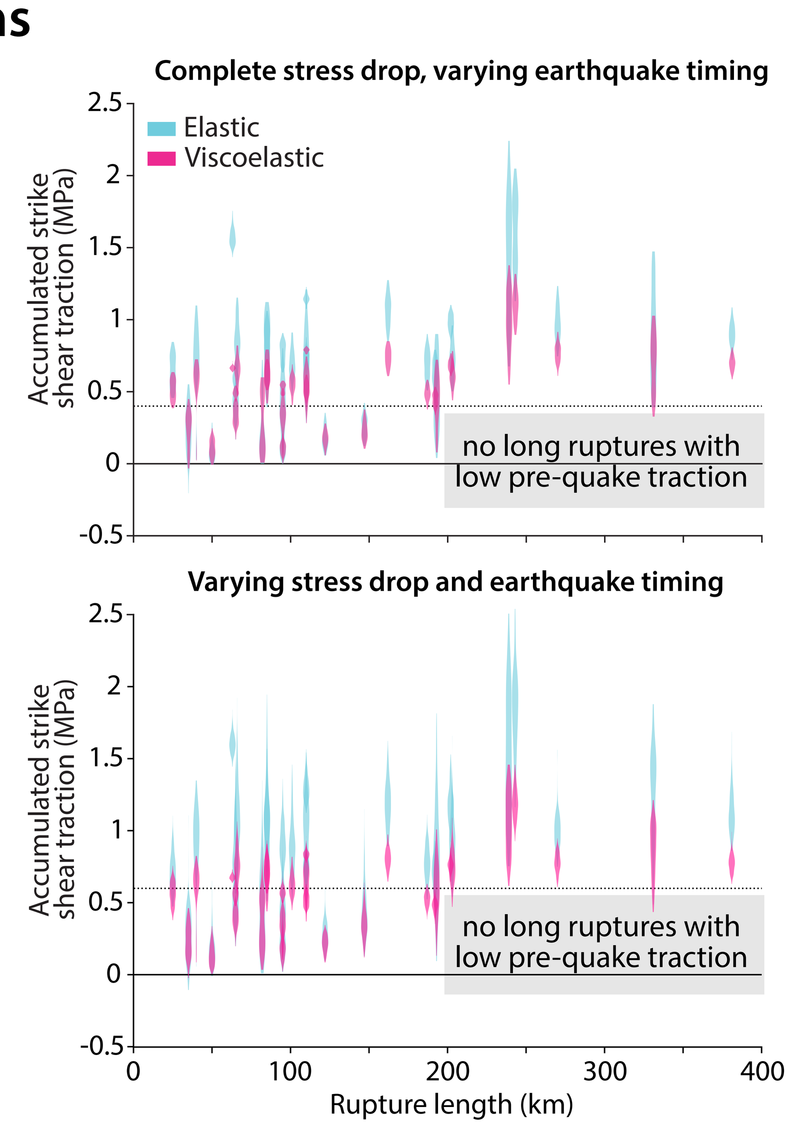
6. Pre-earthquake shear tractions



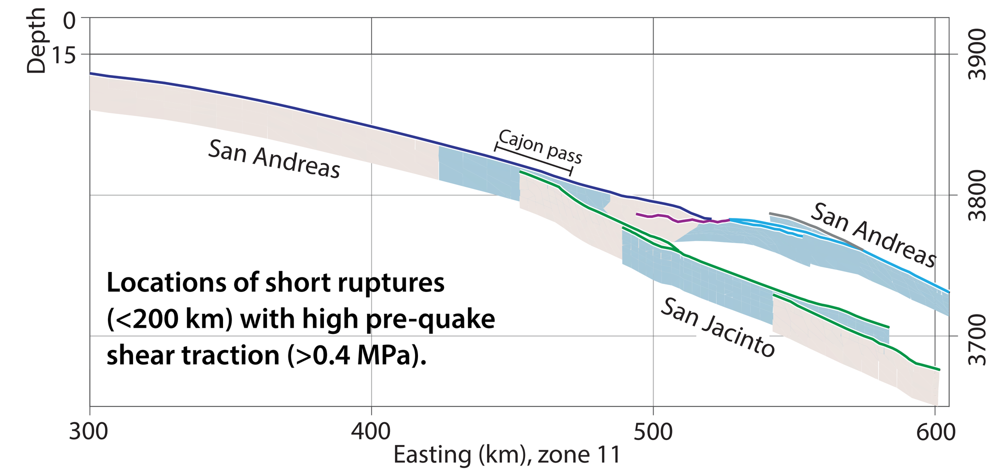
Violin plots show average strike shear traction on the rupture patch on the eve of each earthquake.

We divide earthquakes into four categories by rupture length and pre-quake traction:

	200 km	
0.4 MPa	Short rupture, high pre-quake traction	Long rupture, high pre-quake traction
	Short rupture, low pre-quake traction	None in this record

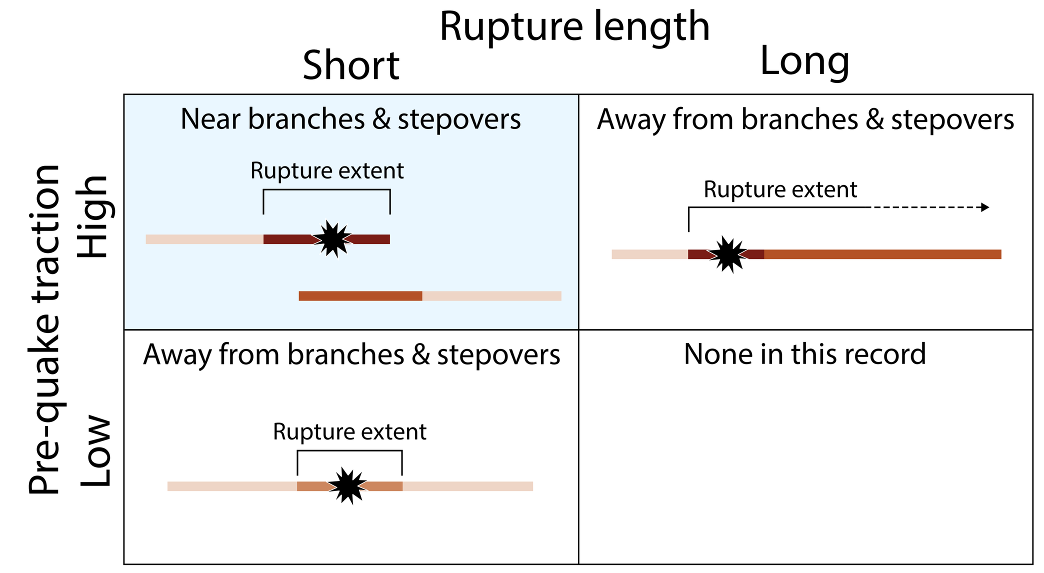


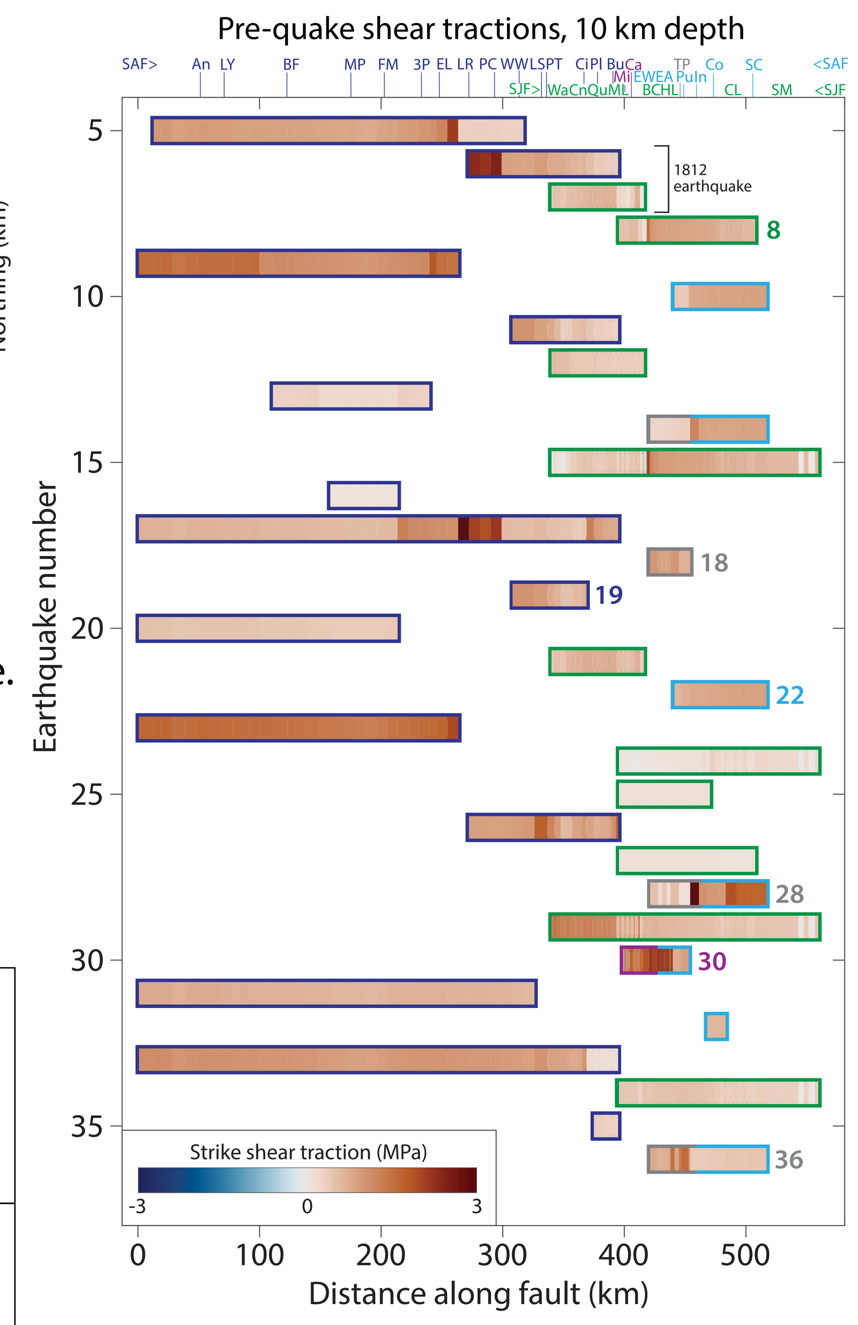
7. Role of geometric complexity



Single-stranded (simple) fault geometry & high accumulated tractions encourage ruptures to propagate.

Fault branches and stepovers can hinder rupture propagation even if high tractions have accumulated.

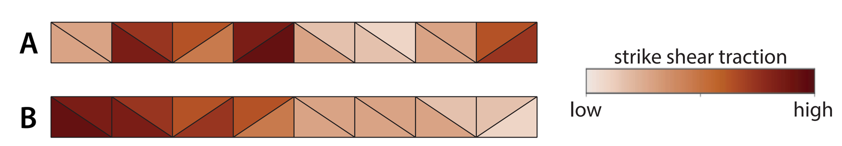




Pre-quake tractions at 10 km depth. Colored outlines correspond with fault surface trace colors on map above. Short ruptures with high pre-quake traction (bold quake #s) occur near fault stepovers and branches.

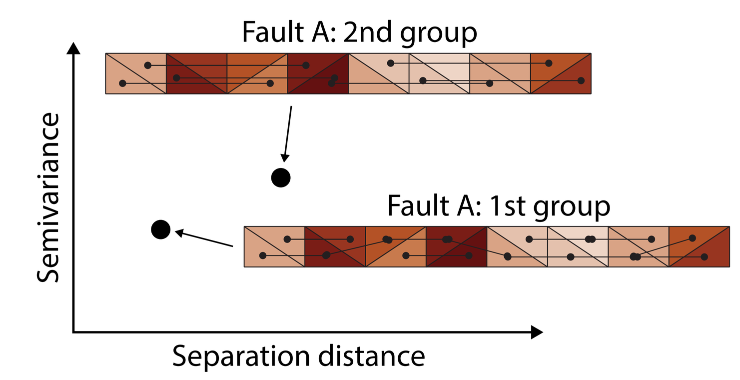
8. Spatial variability of shear traction

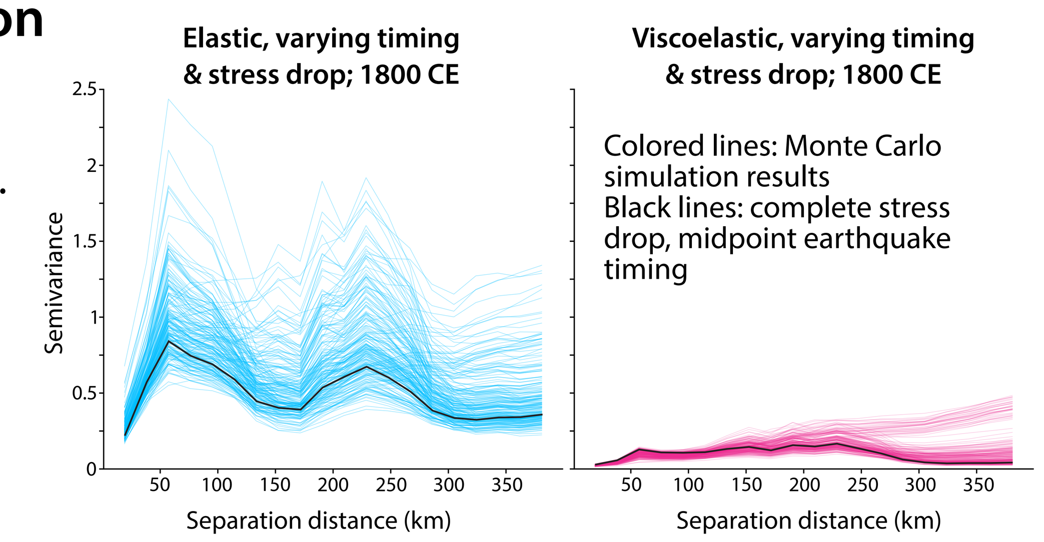
Variograms assess traction variability across spatial scales, accounting for both the spread of traction values and their spatial distribution.

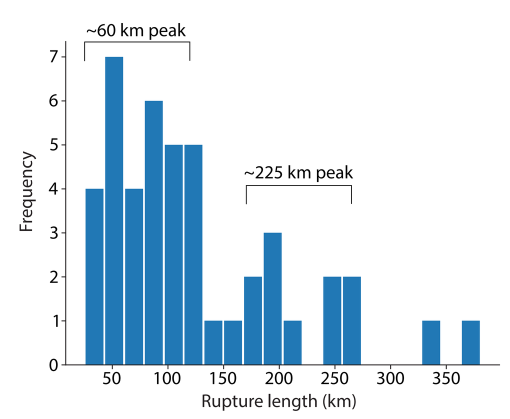


Schematic faults A and B have the same standard deviation of tractions but different variograms.

Variograms plot semivariance (avg square difference in traction for pairs of elements) for groups of element pairs at a variety of separation distances (physical distance between elements).







Histogram of earthquake rupture lengths in Sharer & Yule (2020) rupture model.

Peaks in semivariance frequently appear at ~60 and ~225 km separation distance, corresponding with common rupture lengths in the system.

Including viscoelastic stress relaxation helps equalize shear traction throughout the system, decreasing its spatial variability.

9. More! More! More!

See videos of evolving strike shear traction here:

Complete stress drop

Incomplete stress drop

Check out our BSSA paper exploring simulations with complete stress drop:

Anderson-Merritt, E. O., M. L. Cooke, and K. Scharer (2026). Stress States on the Eve of Past Earthquakes Inform Earthquake Rupture Through Fault Complexity Along the San Andreas and San Jacinto Faults, Bull. Seismol. Soc. Am. 116, 1125–1144, doi: 10.1785/0120250173