Complex Earthquake-Cycle Behavior Revealed by Distributions of Paleoseismic Inter-Event Times

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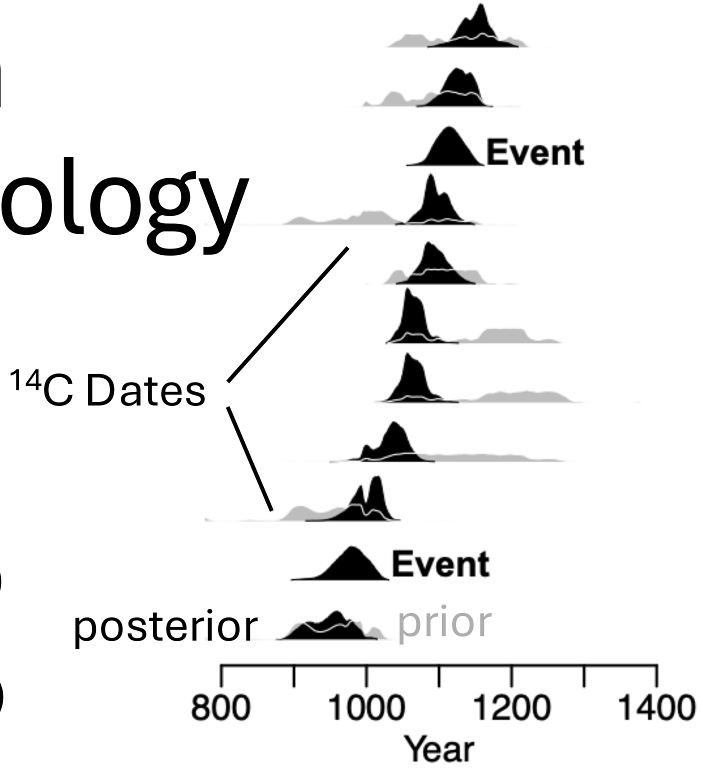
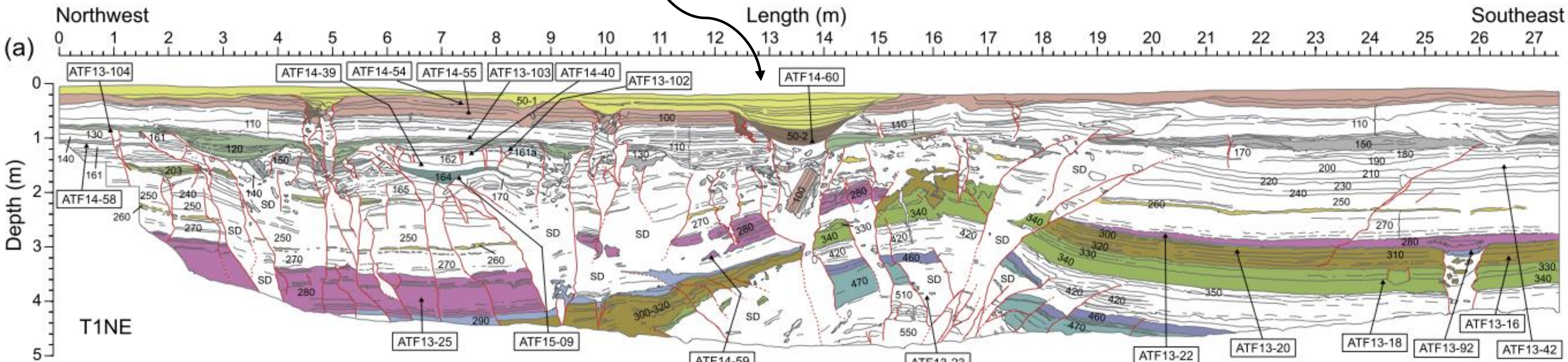
Trench Paleoseismology

Copper Mine Site, Altyn Tagh Fault

Pallett Creek Site
San Andreas Fault
(age model excerpt)

Scharer et al. (2025)

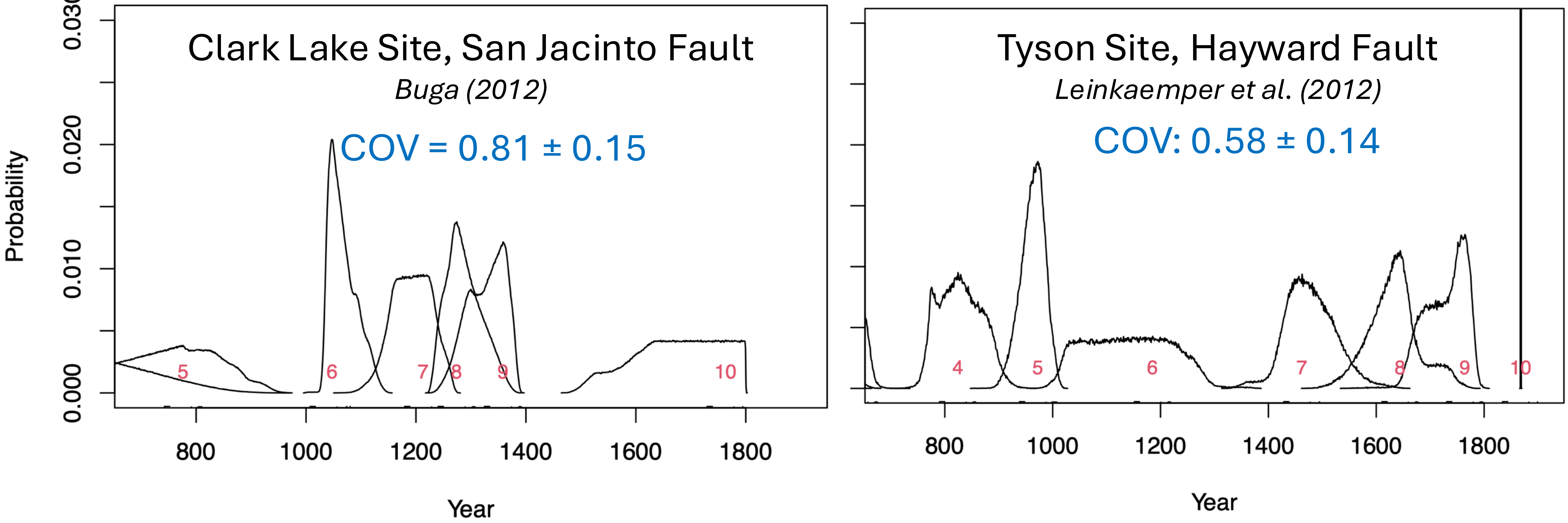




Yuan et al., (2018)

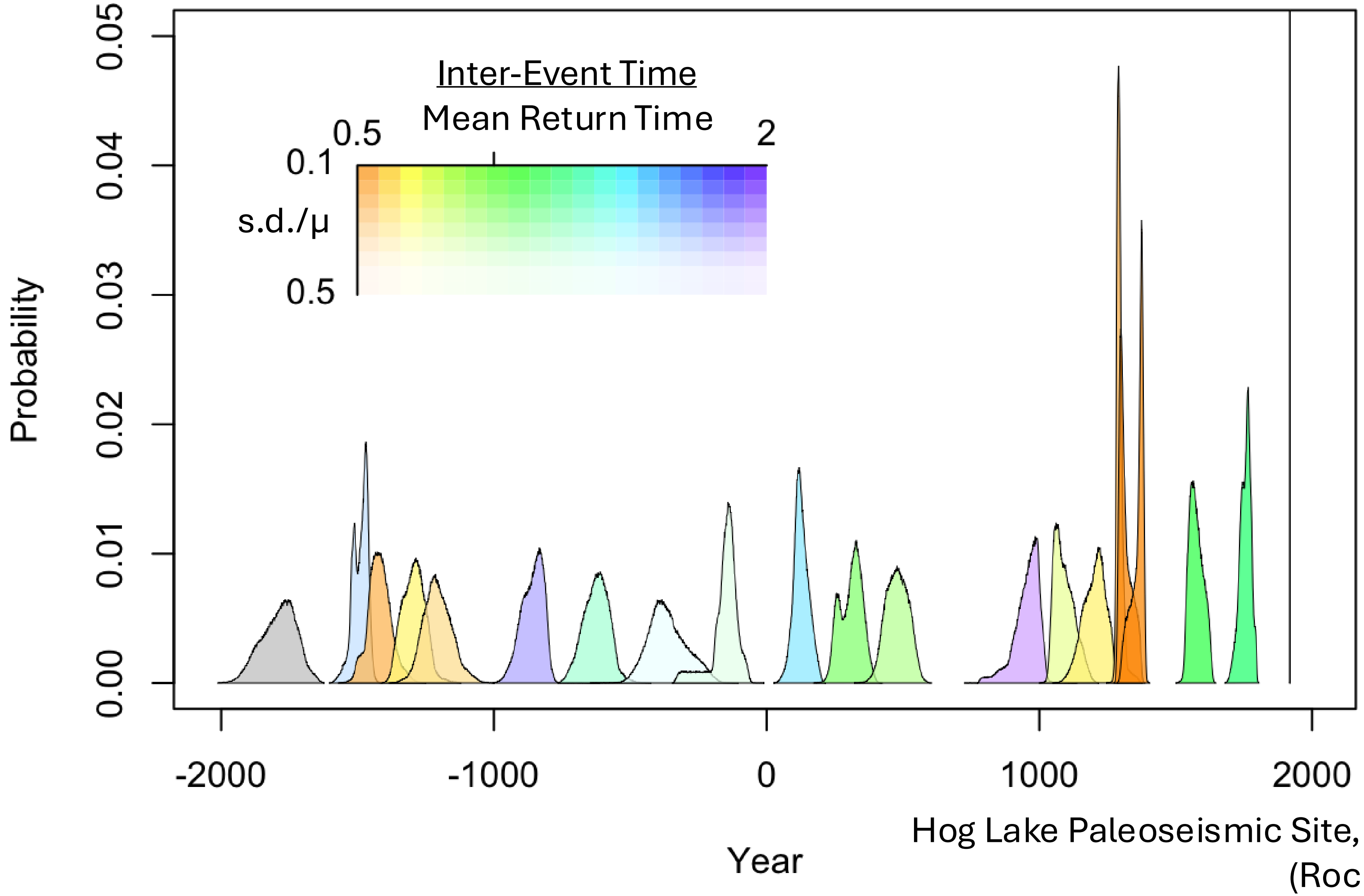
Paleoseismic Time Series are Underutilized in Time-Dependent Hazard

COV: Coefficient of Variation = σ/μ



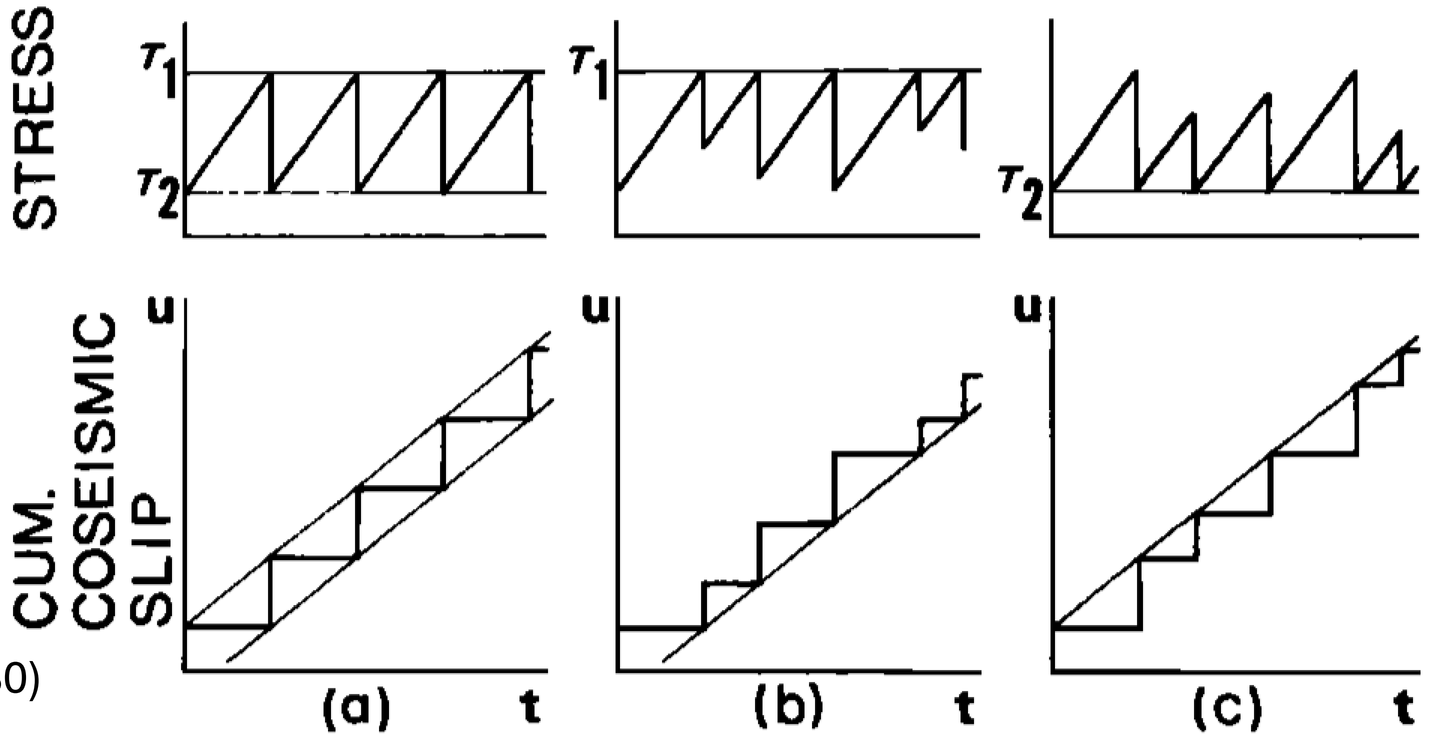
Example paleoseismic time series from faults in California.
Both slip at ~1 cm/yr, with ~170-200 yr average recurrence.
Means are similar, but time-dependent hazard is not!

Paleoseismic Time Series are Noisy, but also *Discrete* and *Ordered*

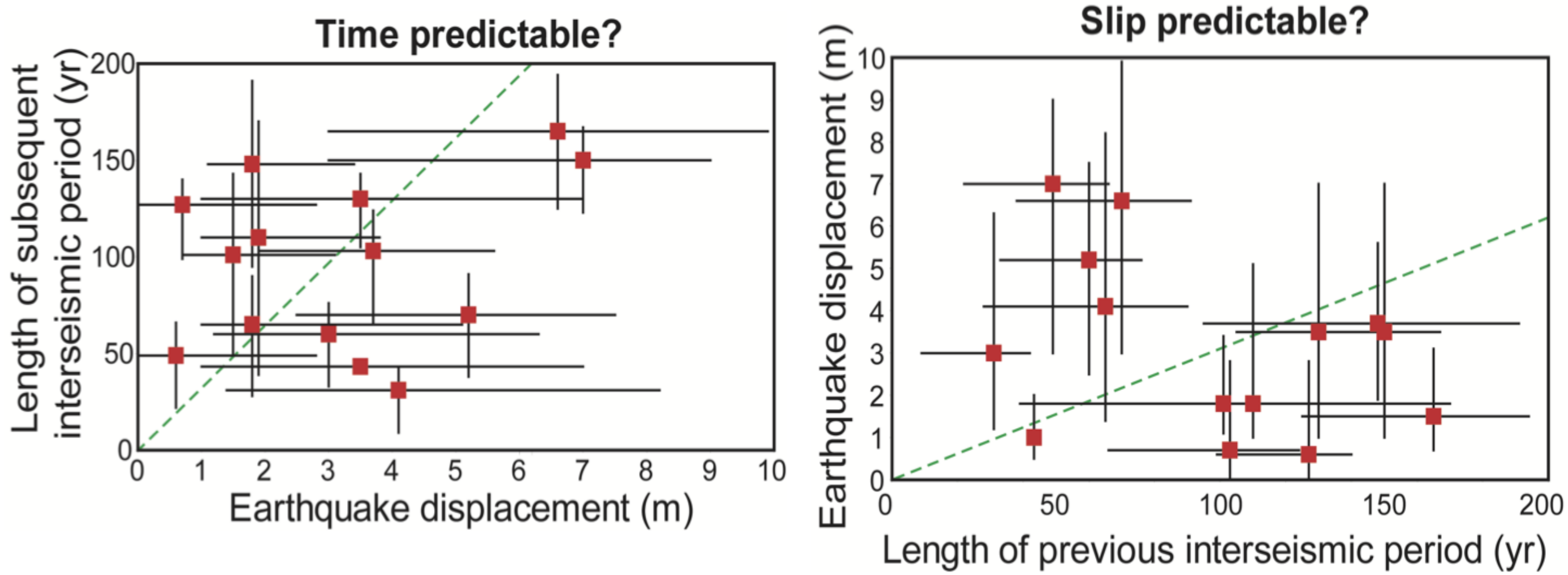


Hog Lake Paleoseismic Site, San Jacinto Fault
(Rockwell et al., 2015)

Mechanical Earthquake Recurrence Models



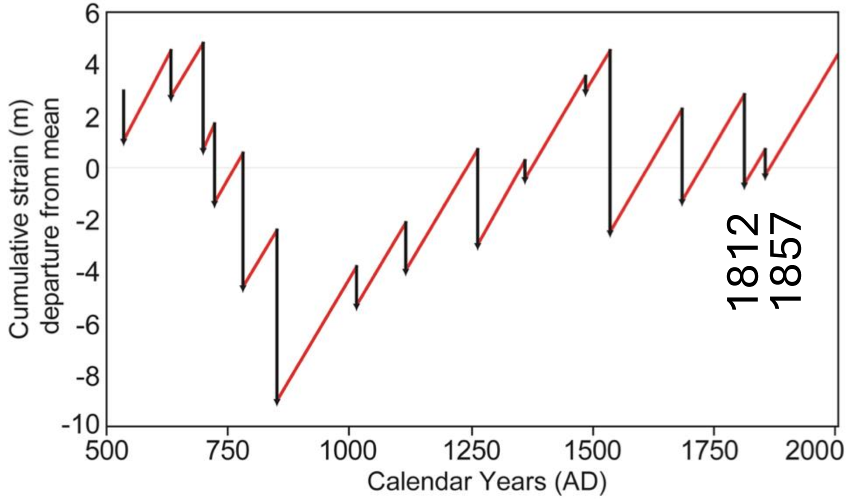
Shimezaki & Nakata (1980)



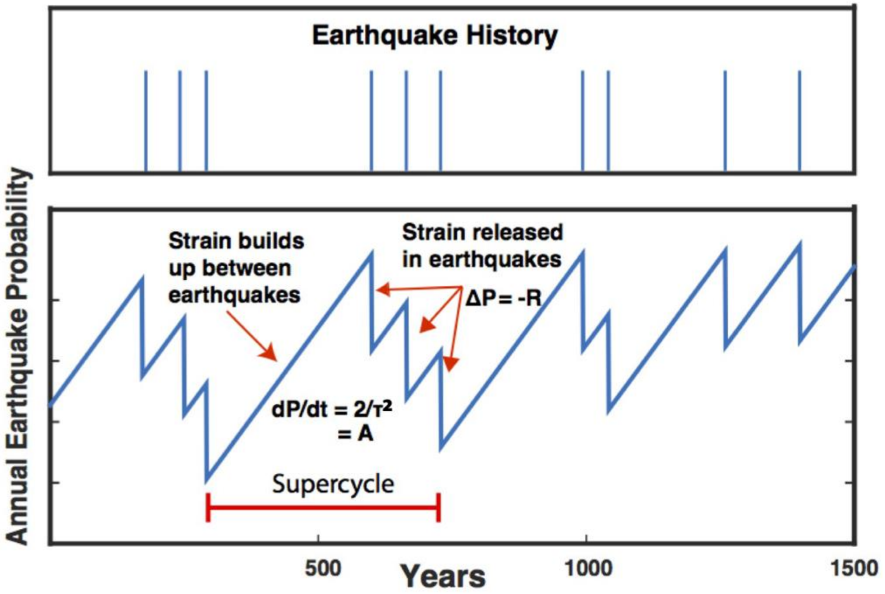
Wrightwood Site,
San Andreas Fault,
Weldon et al. (2004)

Earthquake Super-Cycles

San Andreas Fault (Weldon et al., 2004)



Long-Term Fault Memory Model (Salditch et al., 2022)



Sumatra Subduction Zone (Sieh et al., 2008)

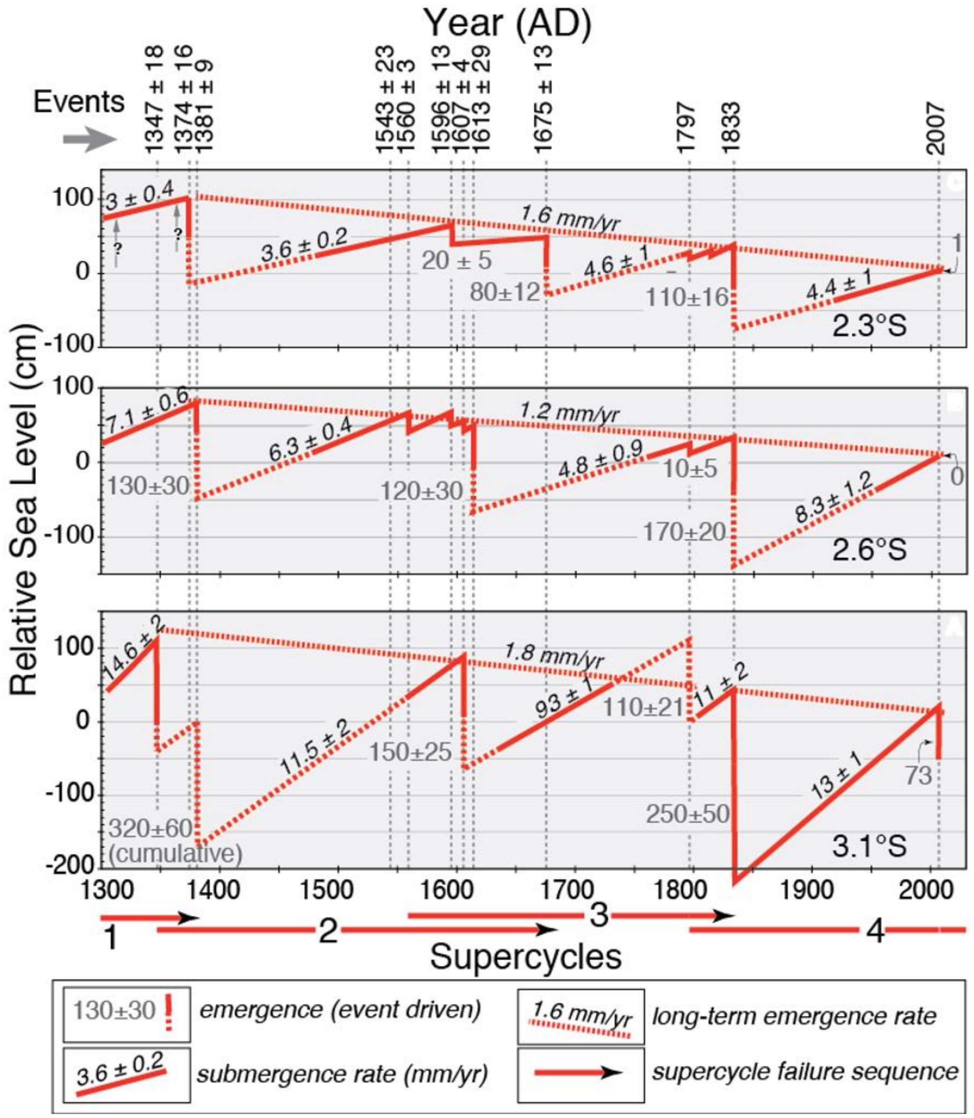
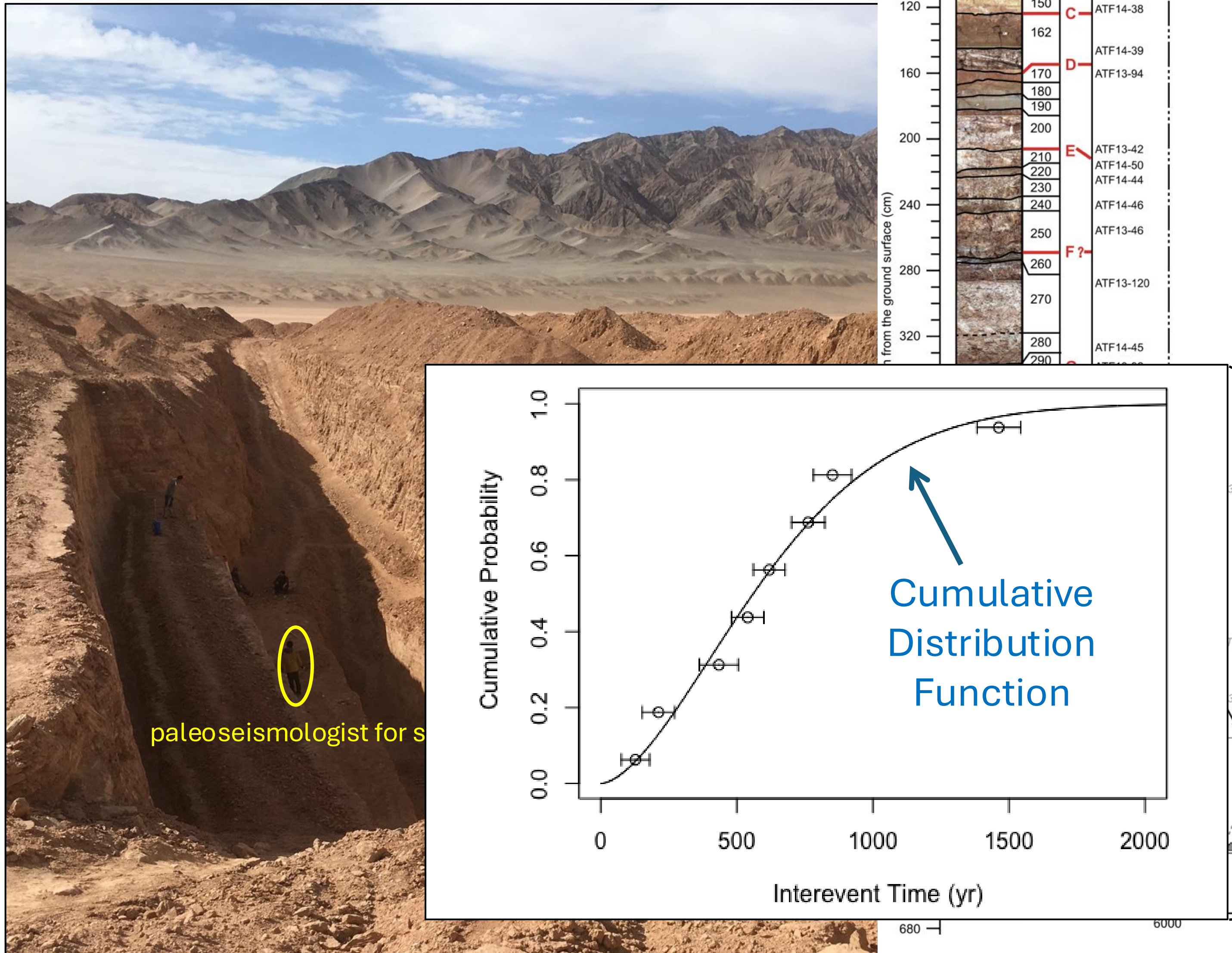
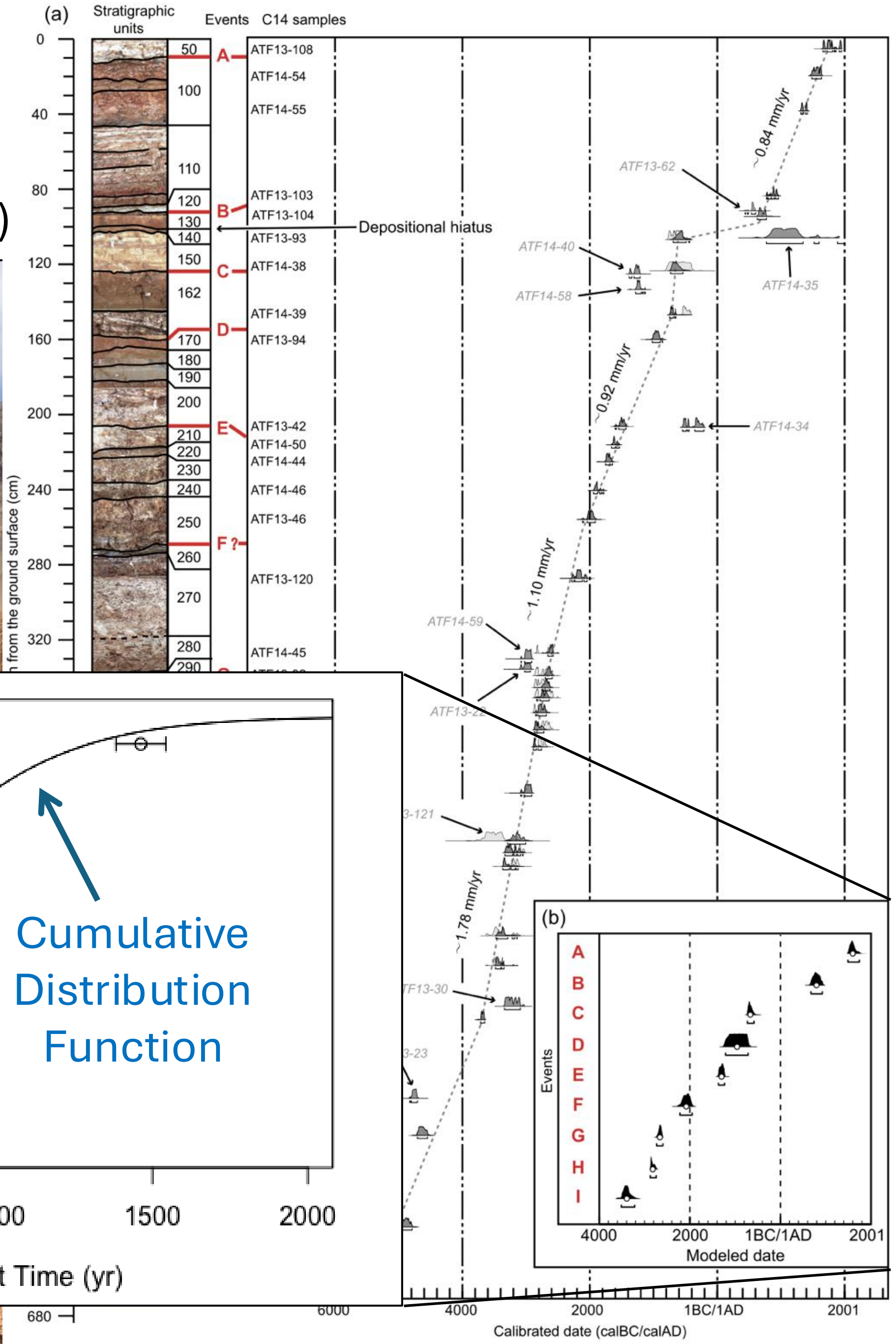


Figure redrafted by Burbank & Anderson (2010)

Most Paleoseismic Sites Record Timing, Not Slip

Shown Here: Paleoseismic Trench on Xorkul Section of Altyn Tagh Fault, China (Yuan et al., 2018)





Brownian Passage Time (BPT) Model

Brownian Passage Time:

$$p(t) = \left(\frac{\mu}{2\pi\alpha^2 t^3}\right)^{1/2} \exp\left[-\frac{(t-\mu)^2}{2\mu\alpha^2 t}\right]$$

Mean Return Time: μ

Aperiodicity: $\alpha \sim COV = \sigma/\mu$

Alternate BPT Formulation:

$$p(t) = \left(\frac{\mu}{t}\right)^{3/2} \left(\frac{1}{2\pi\sigma^2}\right)^{1/2} \exp\left[-\frac{(t-\mu)^2}{2\sigma^2}\frac{\mu}{t}\right]$$

Compare with Normal Distribution:

$$p(t) = \left(\frac{1}{2\pi\sigma^2}\right) \exp\left[-\frac{(t-\mu)^2}{2\sigma^2}\right]$$

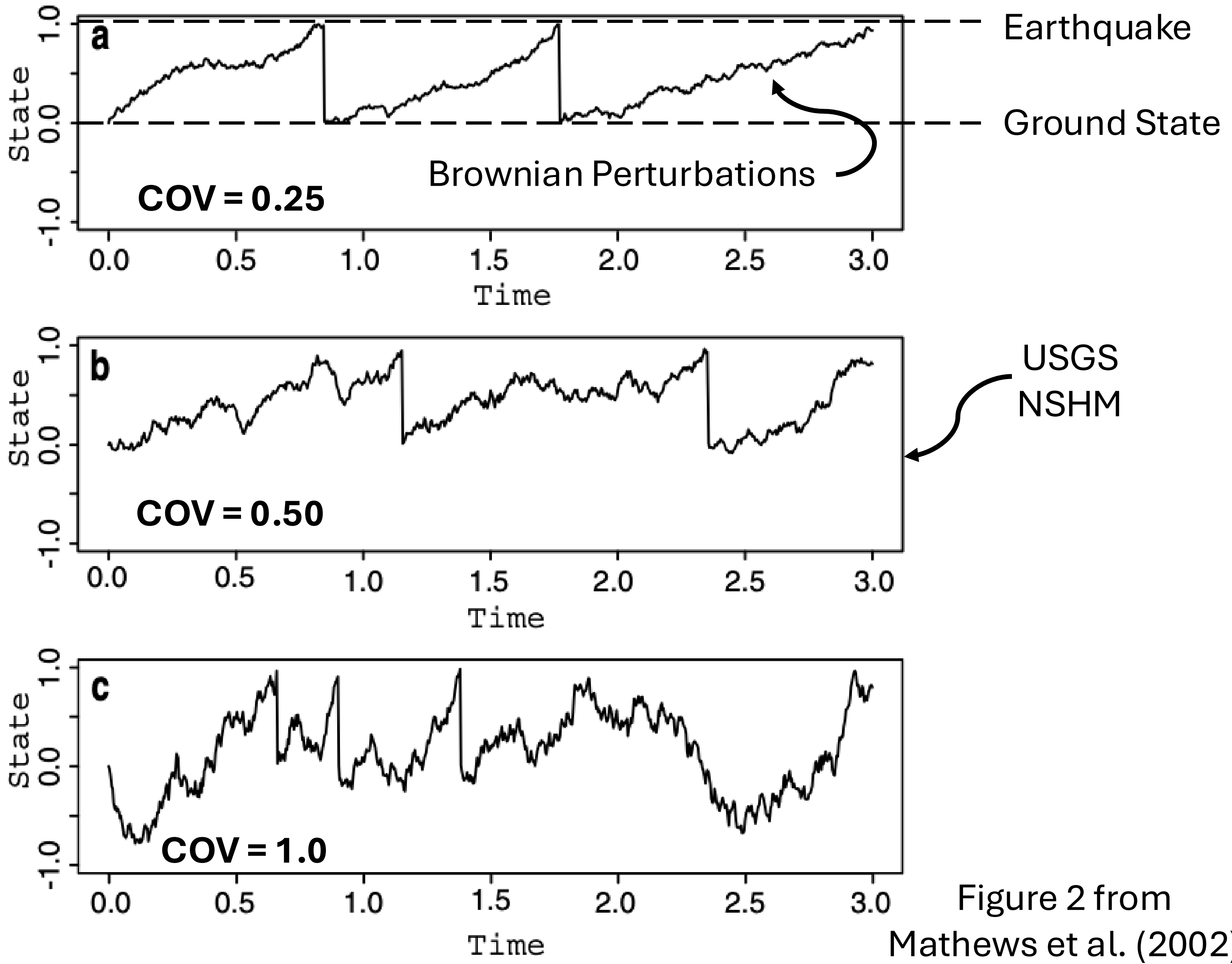


Figure 2 from Mathews et al. (2002)

Weibull Model

The **hazard function** is the probability of an event at time ***t***, *conditioned on survival until time **t**:*

$$h(t) = p(t)/S(t)$$

Let's propose that earthquake rupture hazard increases with time raised to a power *k*:

$$h(t) \propto t^k$$

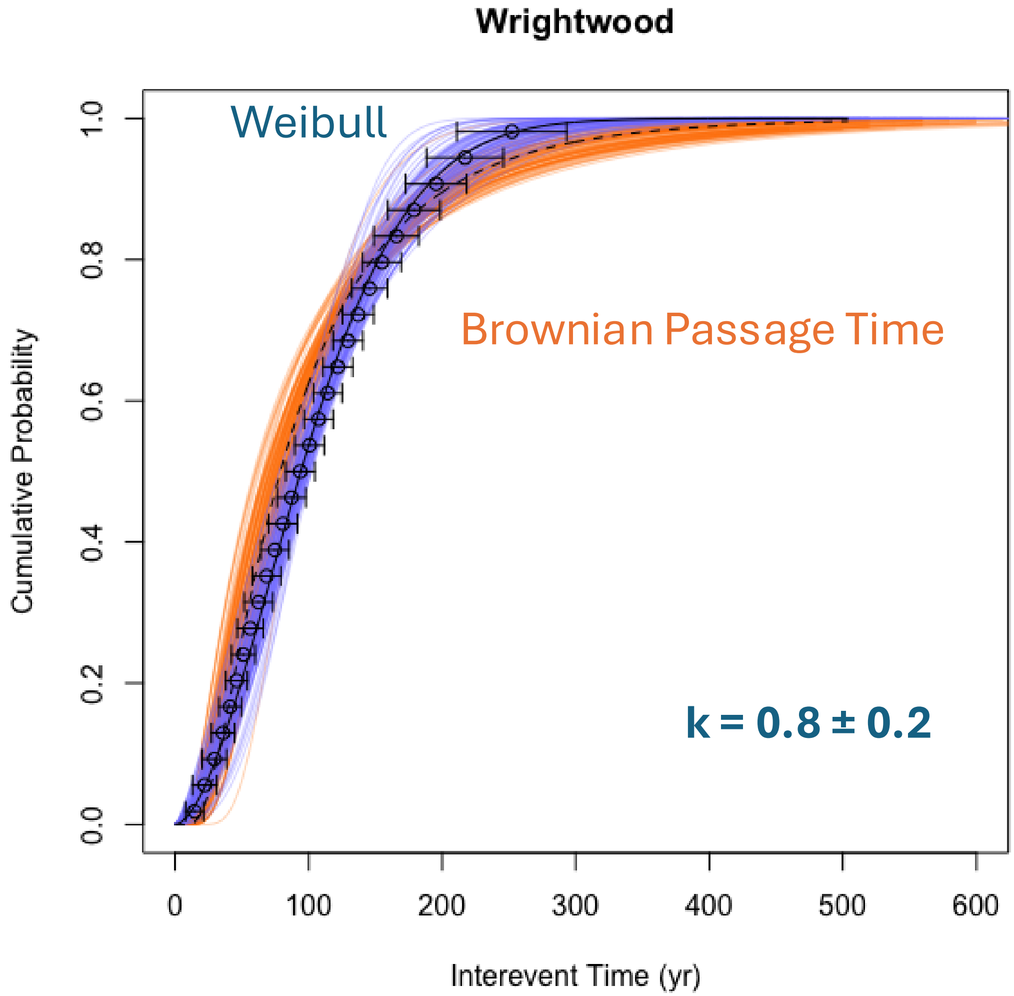
k = 0 : time independent

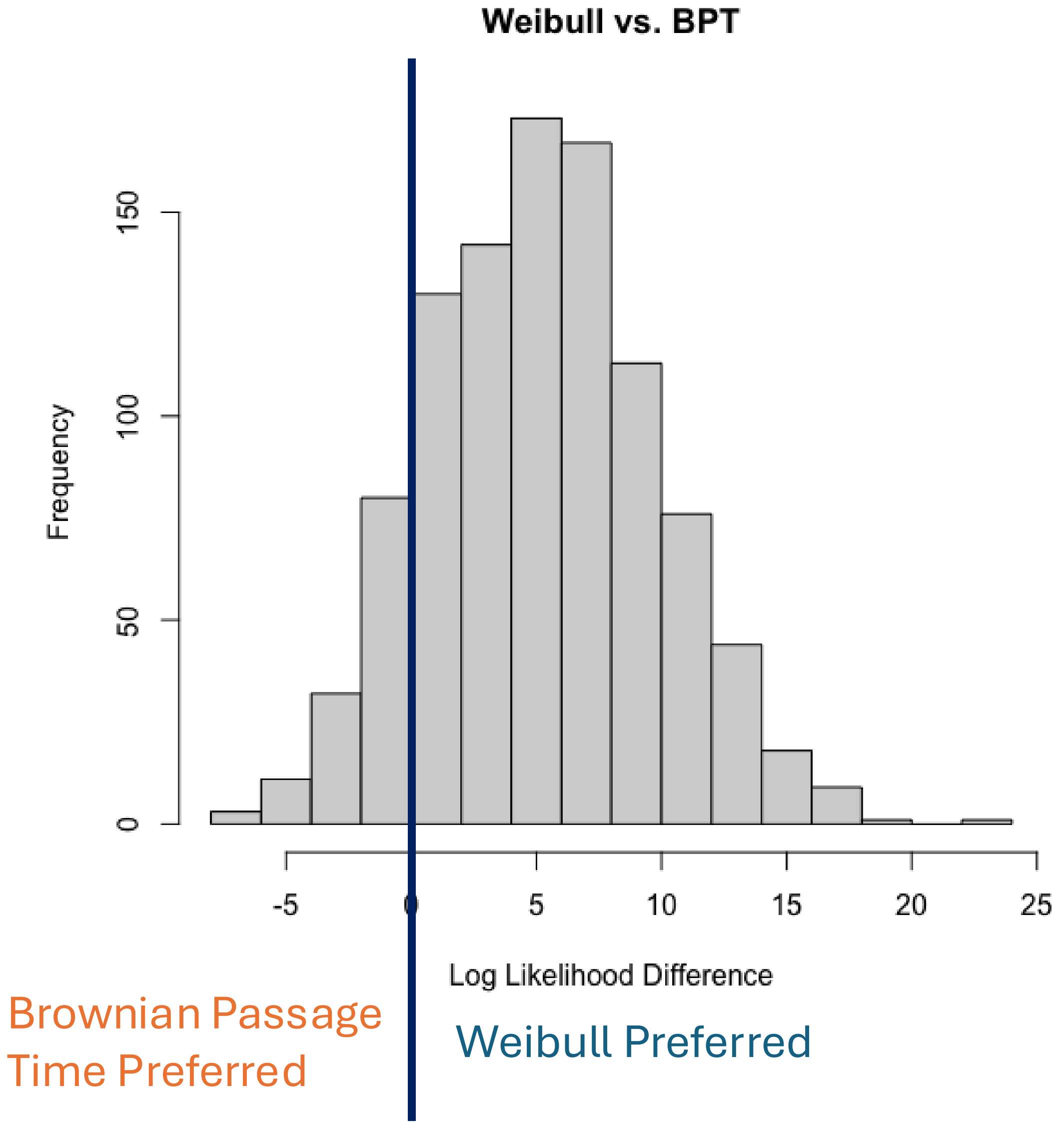
k = 1 : steady loading

k >> 1 : periodic

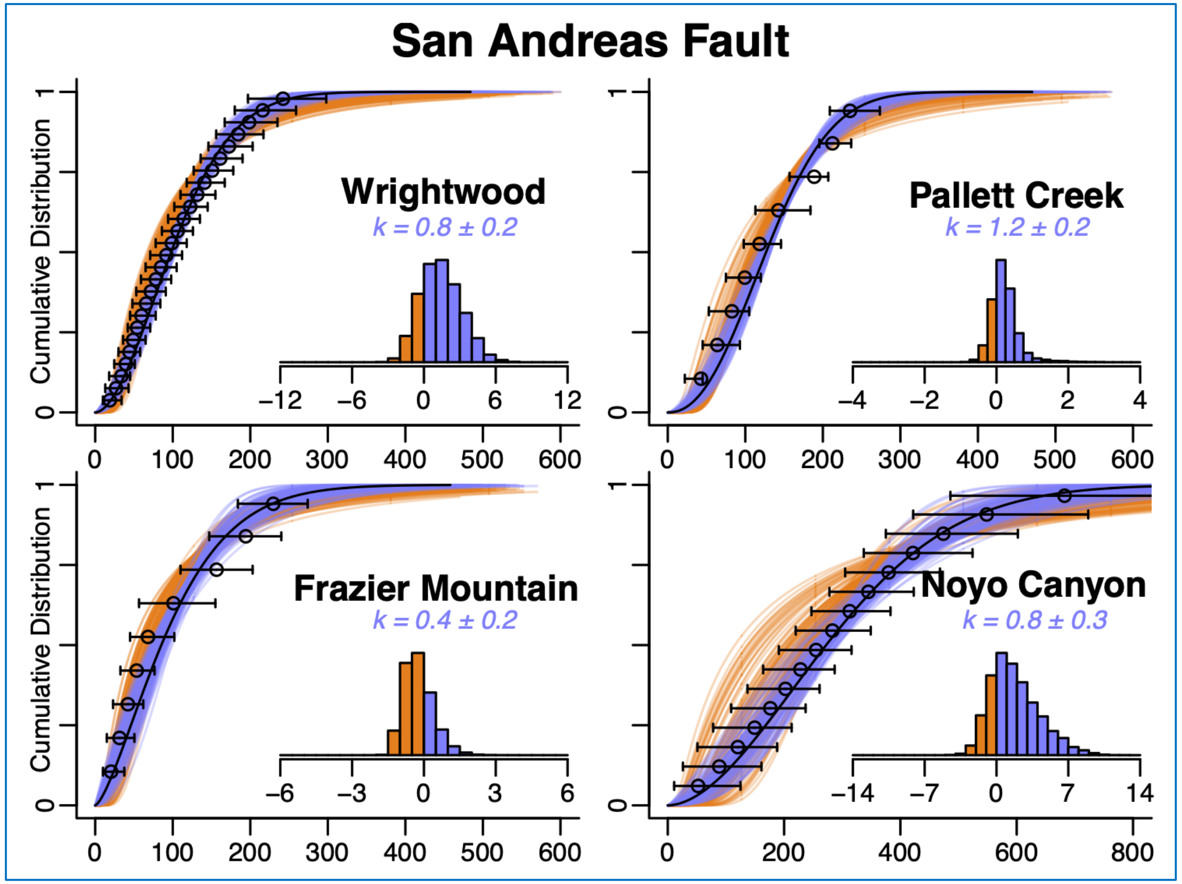
Paleoseismic Time Series

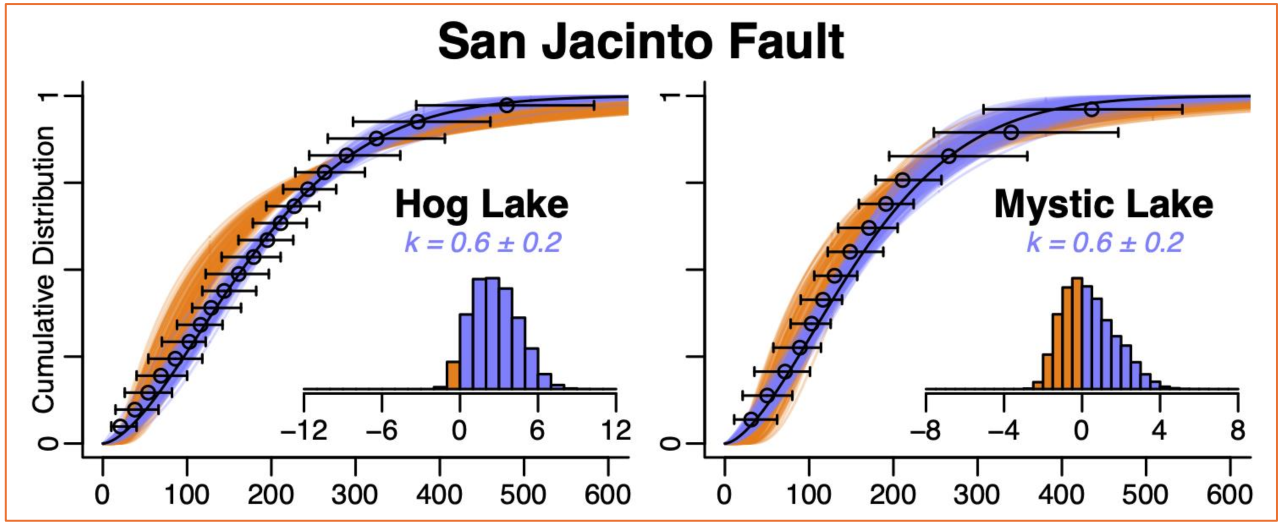
San Andreas Fault: Wrightwood Site



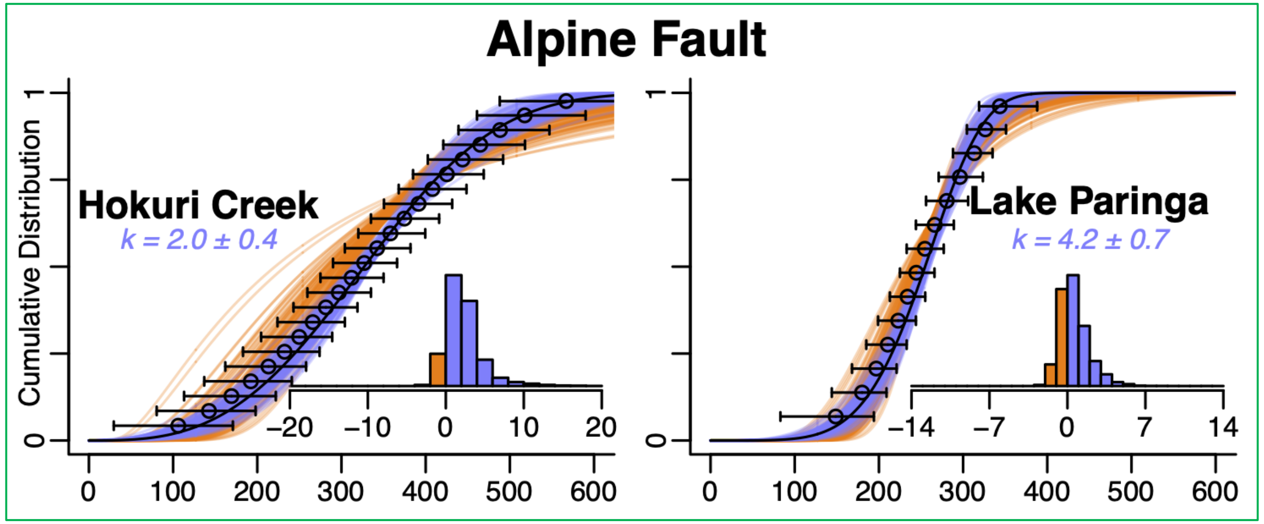


Paleoseismic Inter-Event Time Distributions



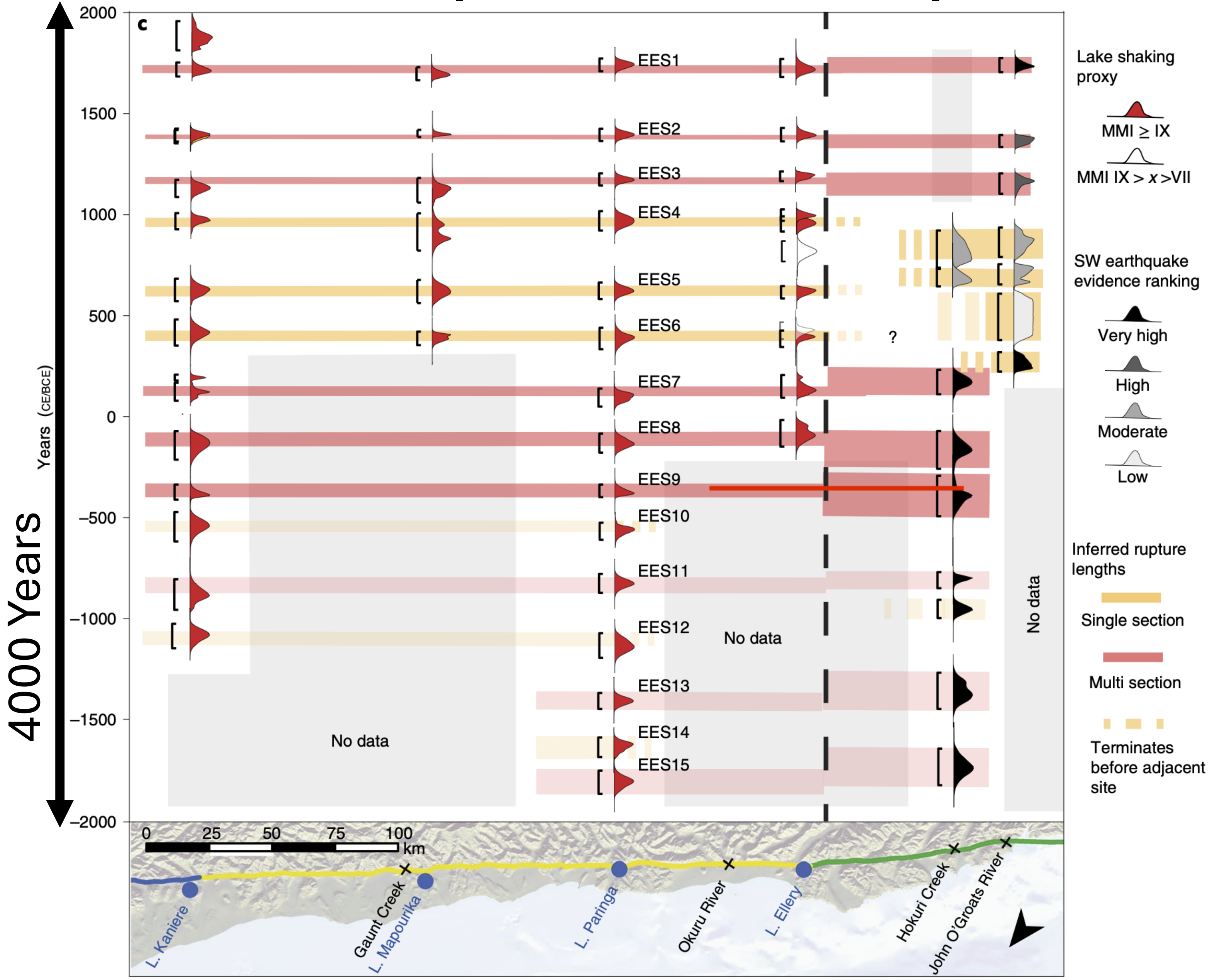


San Andreas & San Jacinto faults (California): $k \leq 1$

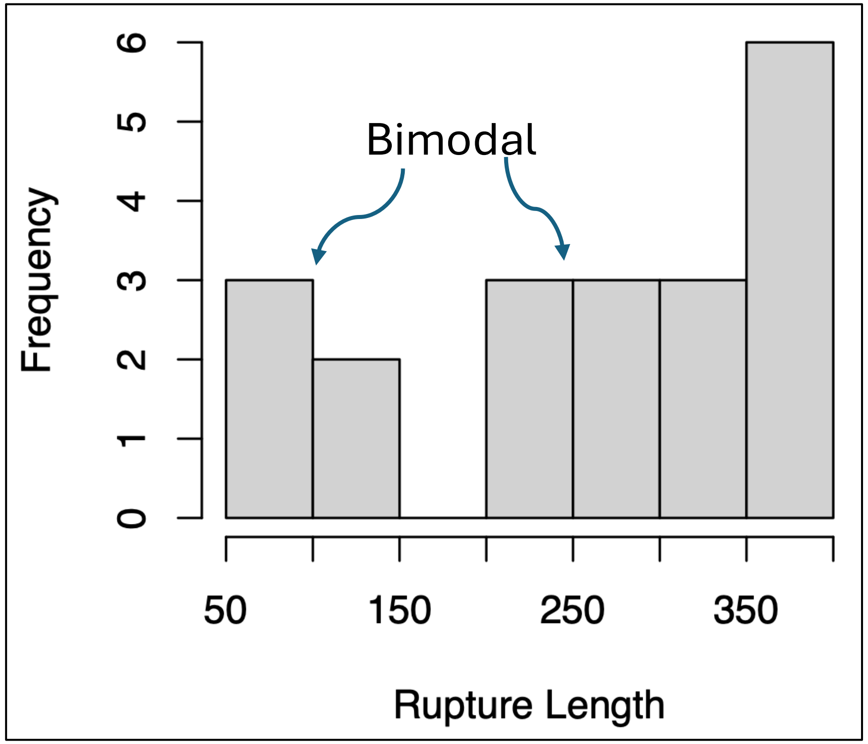


Alpine Fault (New Zealand): $k \geq 2$

Alpine Fault Rupture Lengths

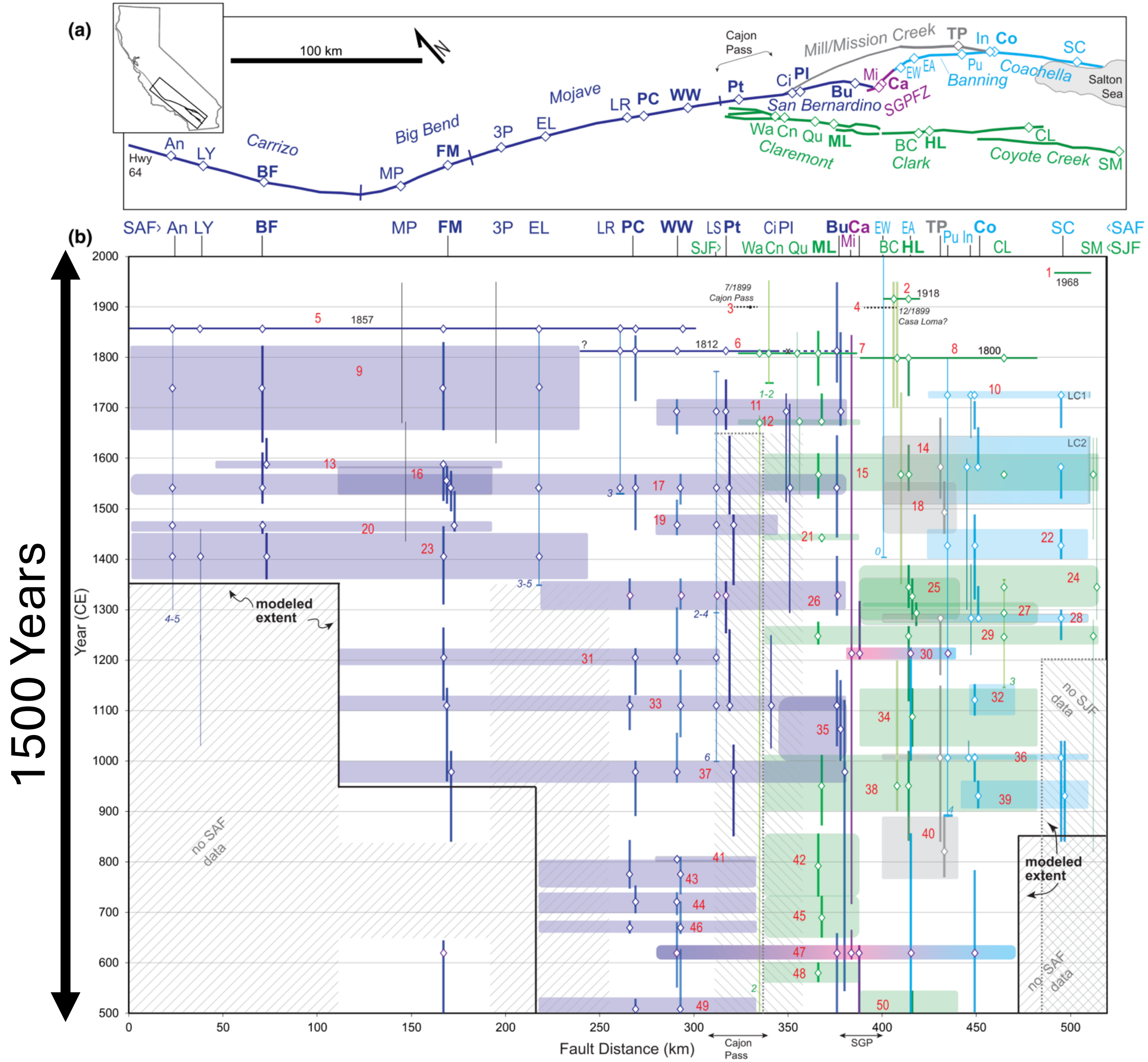


n = 20 events in 4000 yrs
System Recurrence ≃ 200 yrs
9/20 events exceed 300 km



Howarth et al. 2021

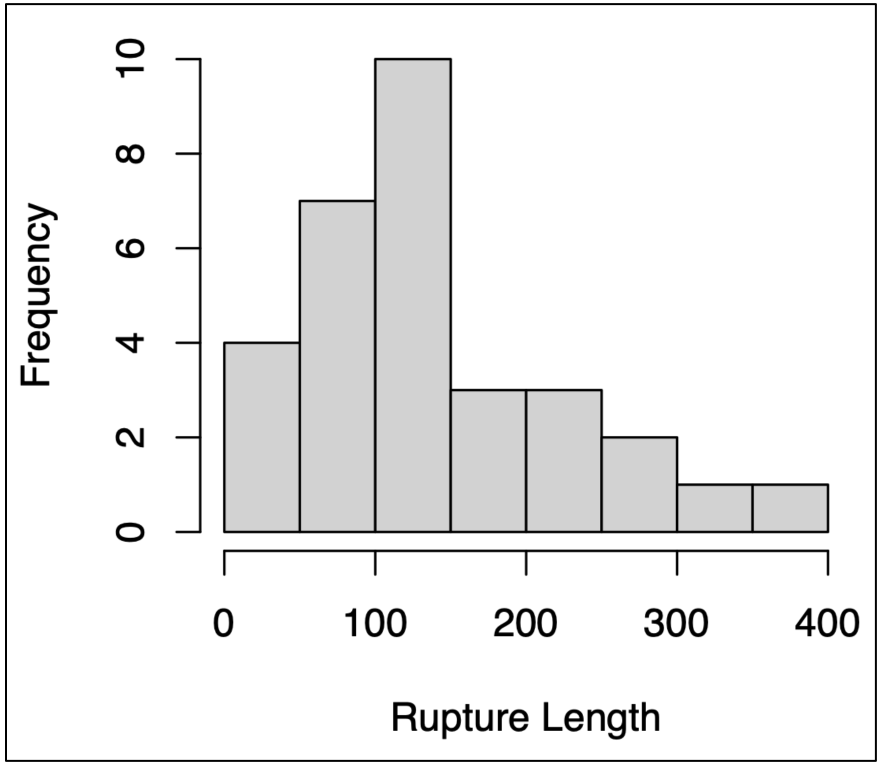
San Andreas Fault Rupture Lengths



n = 36 in 1500 years

System Recurrence ≃ 40 yrs

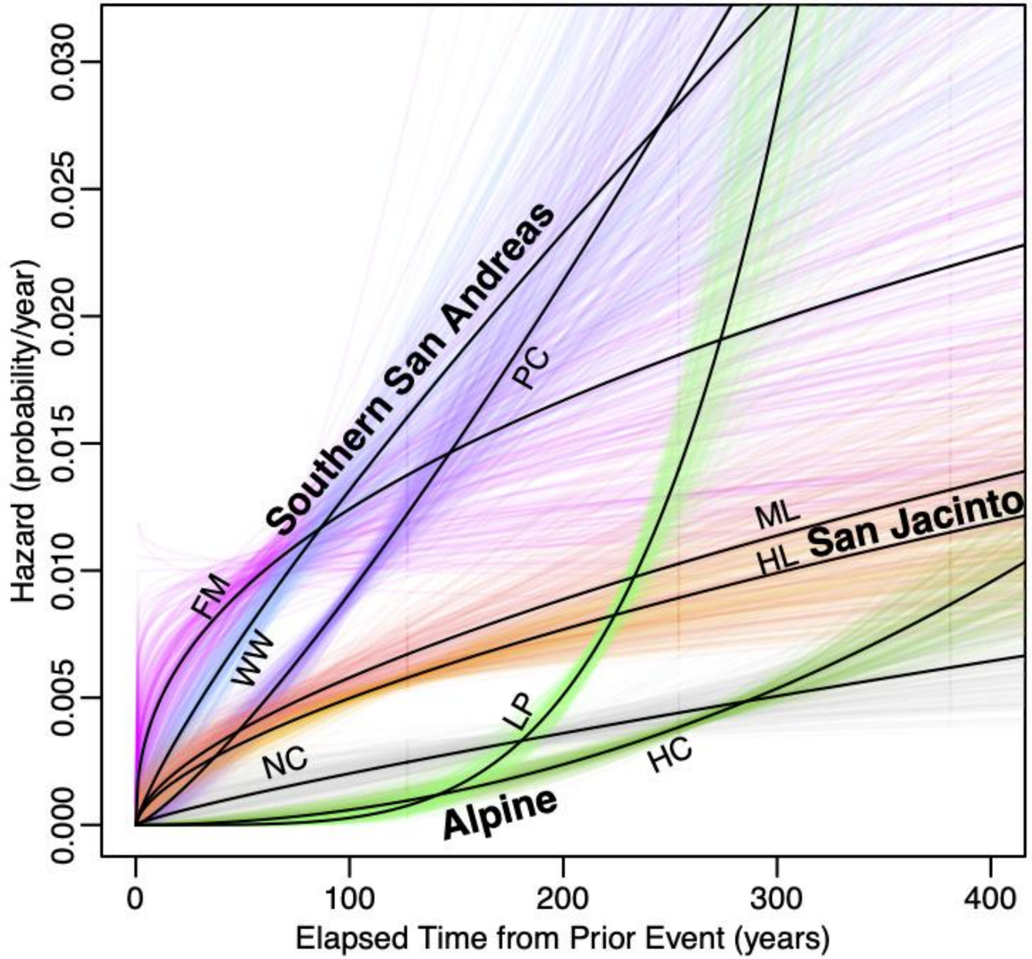
2/36 exceed 300 km



Scharer & Yule 2020

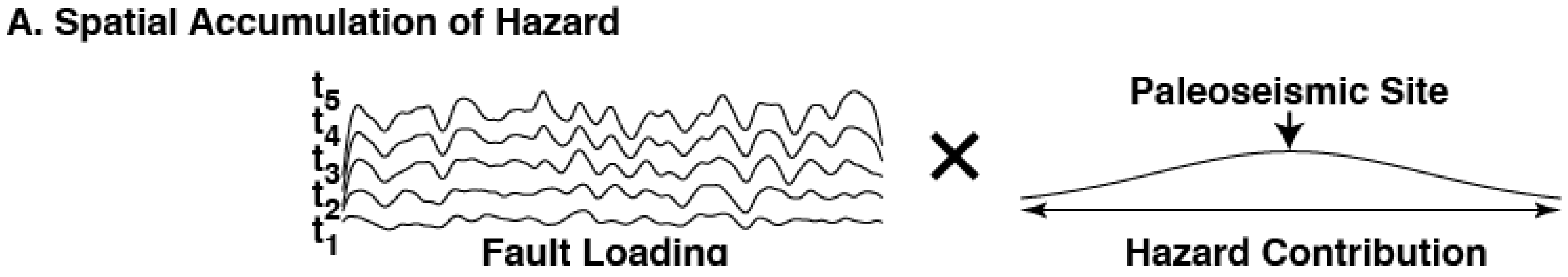
Contrasting Fault Recurrence Behaviors

Hazard Functions



California (San Andreas & San Jacinto):
Sub-linear to linear hazard increase
New Zealand (Alpine):
Non-linear hazard increase

Physical Basis for Weibull Model: Non-Local Hazard

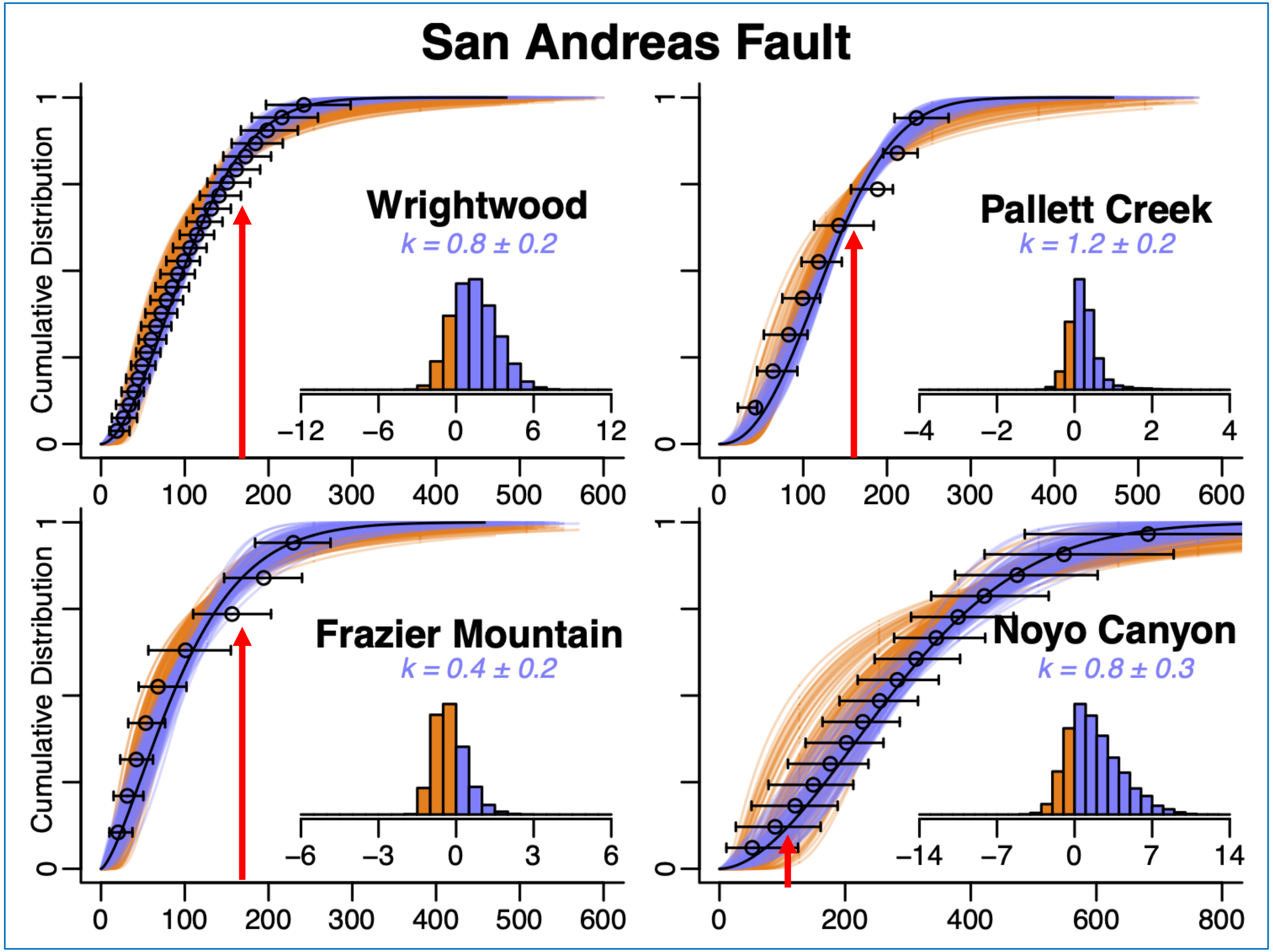


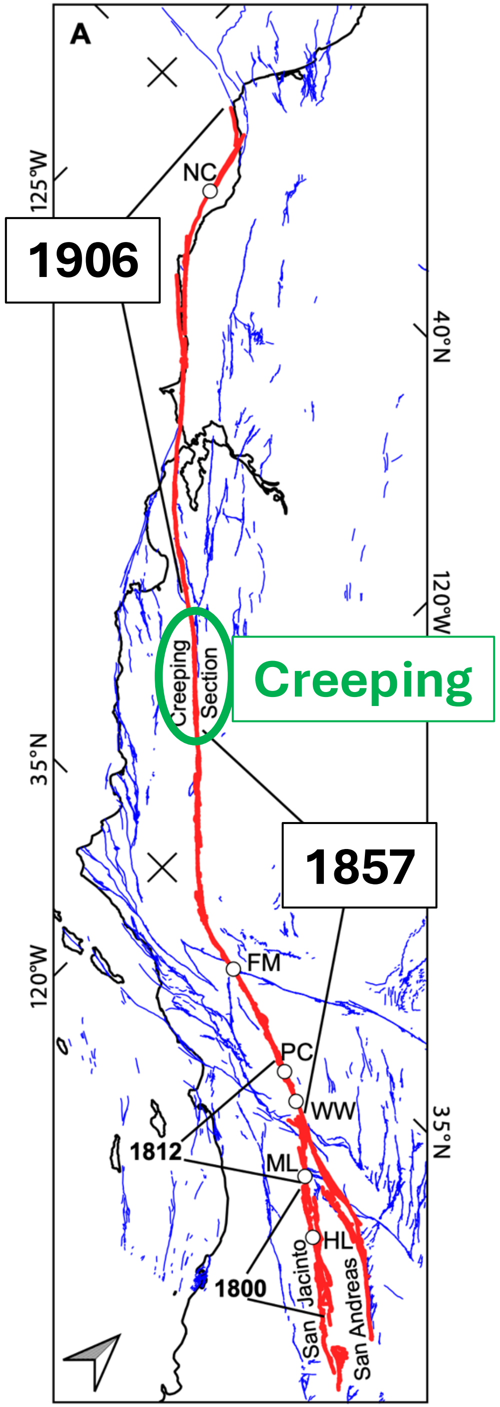
Conclusions

- Long Paleoseismic Records exhibit are well fit by the **Weibull Distribution**, with hazard ~ t^k
- Alpine Fault (New Zealand) and San Andreas fault system (California) exhibit **contrasting time-dependent recurrence behavior**:
  - Alpine fault exhibits a ***system-spanning rupture mode***, with repeated large events. Hazard increases non-linearly, consistent with cyclic renewal of fault loading.
  - San Andreas and San Jacinto faults exhibit a ***partial-rupture mode***, with variably-sized and more frequent events. Hazard rises early after an event and may exhibit a *survivor effect*.

This work is in review at Geophysical Research Letters

Earthquake Drought or Super Cycle?





Hazard Exponent Reproducibility from Split Records