The Bridge from Earthquake Geology
to Earthquake Seismology

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Thanks to Ned Field, Kevin Milner, Kieth Richards-Dinger, Jacqui Gilchrist, Jim Dieterich, Glenn Biasi, and Morgan Page

Tectonic

Moment rate

Seismic

Computer simulation

Fault slip rate

Earthquake rate

Fault geometry

Magnitude distribution

Strain rate

Paleo-seismology
Common Assumptions

• Sediment offsets in trenches caused by quakes
• Constant rate (earthquakes and strain) in time
• Moment balance (tectonic in = seismic out)
• Magnitudes limited by fault length
• Big quakes occur on big faults
• Important faults are known
• Elasticity
• Quakes caused by stress
• Quakes repeat, but not too soon
• Big and small quakes come from different populations
• Rupture length, width, and slip scale with Moment
Over large enough area, earthquake rate is quite steady.
California earthquakes 1900 = 2011 m7.0+
Implications of paleo-seismic studies in California

- Paleoseismic data provide the primary support for the assertion that large earthquake rates were higher before 1900 than after.
- Paleoseismic data provide the primary support for the assertion of quasi-periodic recurrence, that is fairly regular time intervals between slip events.
<table>
<thead>
<tr>
<th>Site</th>
<th>Events</th>
<th>Open Interval</th>
<th>Poiss Rate</th>
<th>Lognormal Rate</th>
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<td>Elsinore—Glen_Ivy</td>
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</table>

Total 0.1117 0.1156

The UCERF3 Paleoseismic data
Selected “independent” sites

<table>
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<tr>
<th>Index</th>
<th>Site</th>
<th>Most recent event</th>
<th>Poisson rate, lamda</th>
<th>mu</th>
<th>σ</th>
<th>Poisson Survival 1910 - 2014</th>
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</table>

Amended to 1918
Cumulative paleo events since 1060

Cumulative events
Santa Cruz, Wrightwood, Hayward S., Hog Lake, Elsinore-Temecula
Survival Function based on single site recurrence parameters

1% probability of no event vs. time for 12 independent sites + ensemble
Possible explanations

- Luck
- Physical process that synchronizes faults and produces occasional long intervals with no paleo-events.
- Mis-identification of paleo-events as earthquakes before the instrumental era, exaggerating the number and rate of earthquakes that displace sediments at trench sites.
Luck

25 rounds of Russian Roulette. \((5/6)^{25}=0.01\)
Survival for modified C.O.V.

Ensemble with UCERF3 parameters and with Sigma = 1.3

97.5% Confidence
Can physics-based simulations explain a 100 year paleo-hiatus at 12 sites?

This particular RSQSIM run does not, but it employs some rather arbitrary parameters, including a high rate of San Andreas events, and other reasonable choices might allow longer intervals?
RSQSim cumulative fraction of 100 year intervals with \( \leq N \) paleo-site hits.

Red: 64 intervals chosen to follow simulated events like 1857 and 1906.

Black: 1000 random 100 year intervals.

Results: Probability of 100 year survival is miniscule.

Thanks to Keith Richards-Dinger, UCR.

UCERF3 faults, 1 km cell size.
UCERF3 TD Quasi-periodic fraction of 100-year intervals with N hits

Thanks to Ned Field, USGS

UCERF3 employs instrumental seismic, geologic slip rate, and geodetic strain rate as well as paleo data.

The paleo test is not a test of UCERF3.
Supercycles?
Supercycles

- Another word for clustering?
- What is cyclic about them?
- Can they fit any actual data? e.g., paleo-events?

"I think you should be more explicit here in step two."
Trench wall cross-section,
San Andreas Fault in Carrizo Plane

From Grant and Sieh, J. Geophys. Res., 1994,
Approaches: Probability of survival 1918 – 2016

- Empirical: event history for 5 independent sites
  - 35 events in 956 years \( \Rightarrow \) rate \( > 0.036/a \) \( \Rightarrow \) \( S(98) < 0.027 \)

- UCERF3 tabulated single site recurrence (Appendices G and H)
  - Poisson 12 independent sites \( S(104) < 0.013 \)
  - Lognormal 12 independent sites \( S(104) < 0.0053 \)

- Physical models and UCERF3 Grand Inversion: a few examples
  - cases only: stay tuned. Note that these results don’t suggest that the models are wrong; they are based on many types of data.
    - Coulomb Rate State 12 sites \( S<0.0001 \)
    - Coulomb Rate State 12 sites Conditional on 1857, 1906: \( S < 0.01 \)
    - UCERF3 GI (32 Sites?): \( S<0.01 \)
Next steps

*Earthquake Geology*: Establish procedures for multiple independent “diagnoses”

*CISM*: Predict the past with computer simulations: set up initial conditions at 1932 (?), “predict” later events m6.5+.

*CSEP, WGCEP*: Devise retrospective and prospective tests for fault rupture: set up “wickets” along faults, and estimate probabilities for all combinations of ruptured wickets (like paleo sites, but wider, and don’t need historic rupture).

*All SCEC*: Simplify models that convert tectonic moment rate to earthquake rate; apply and test globally.
Conclusions

- One thing is certain: the single site recurrence parameters allow century-long hiatus only at 1% probability.
- Actual paleo-event dates themselves less certain, but they also suggest century hiatuses at a few percent at most.
- Paleo-puzzle has three possible solutions
  - **Extreme luck**: don’t trust it; individual recurrence parameters inconsistent with hiatus
  - **Statewide clustering or “supercycles”**
    - Contrasts with quasiperiodic behavior at individual sites
    - Lacks a physical explanation
  - **Over-estimation of paleo-rates** before instrumental century
    - Stopped by instrumental vetting