The Bridge from Earthquake Geology to Earthquake Seismology

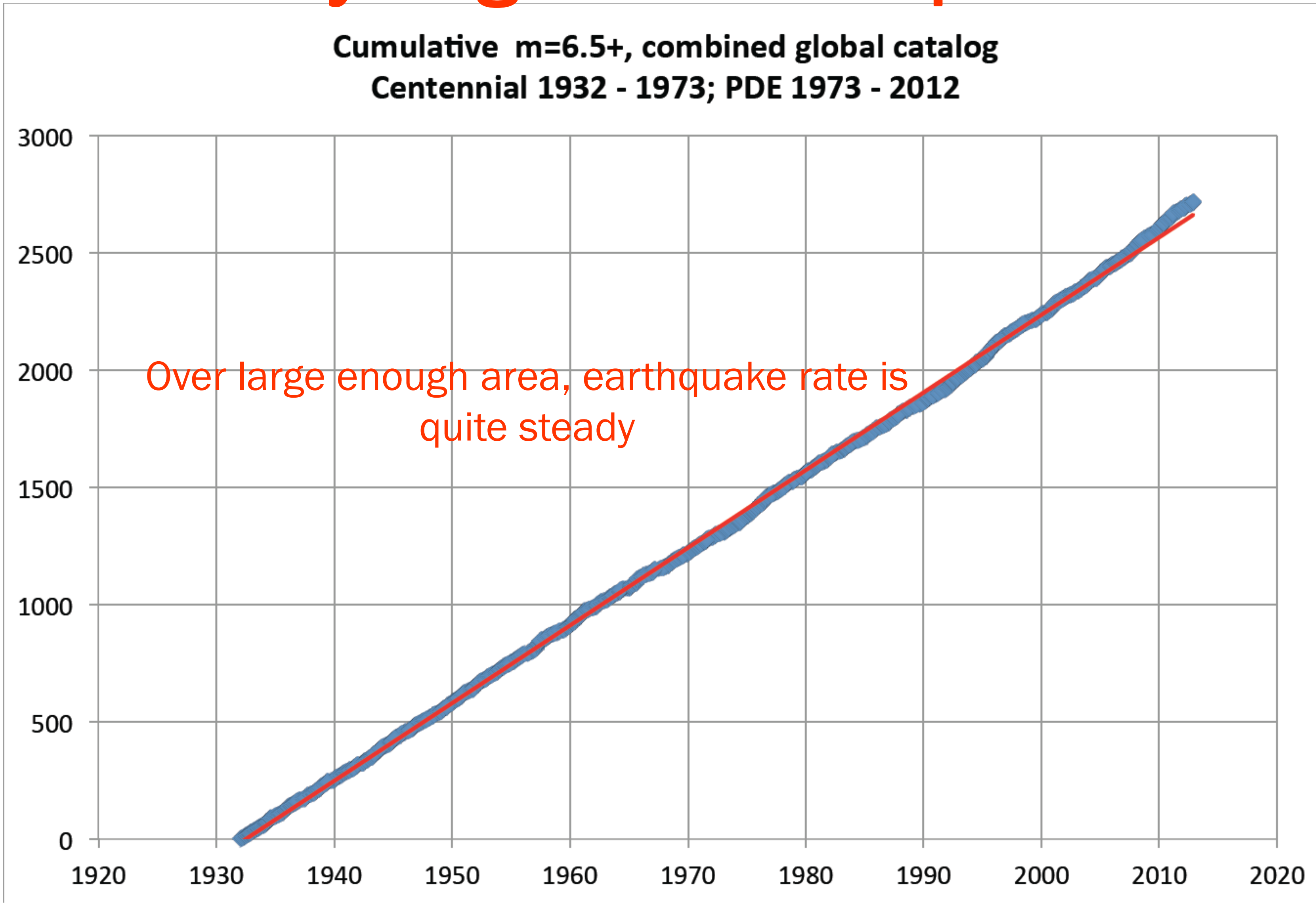
David D. Jackson djackson@g.ucla.edu

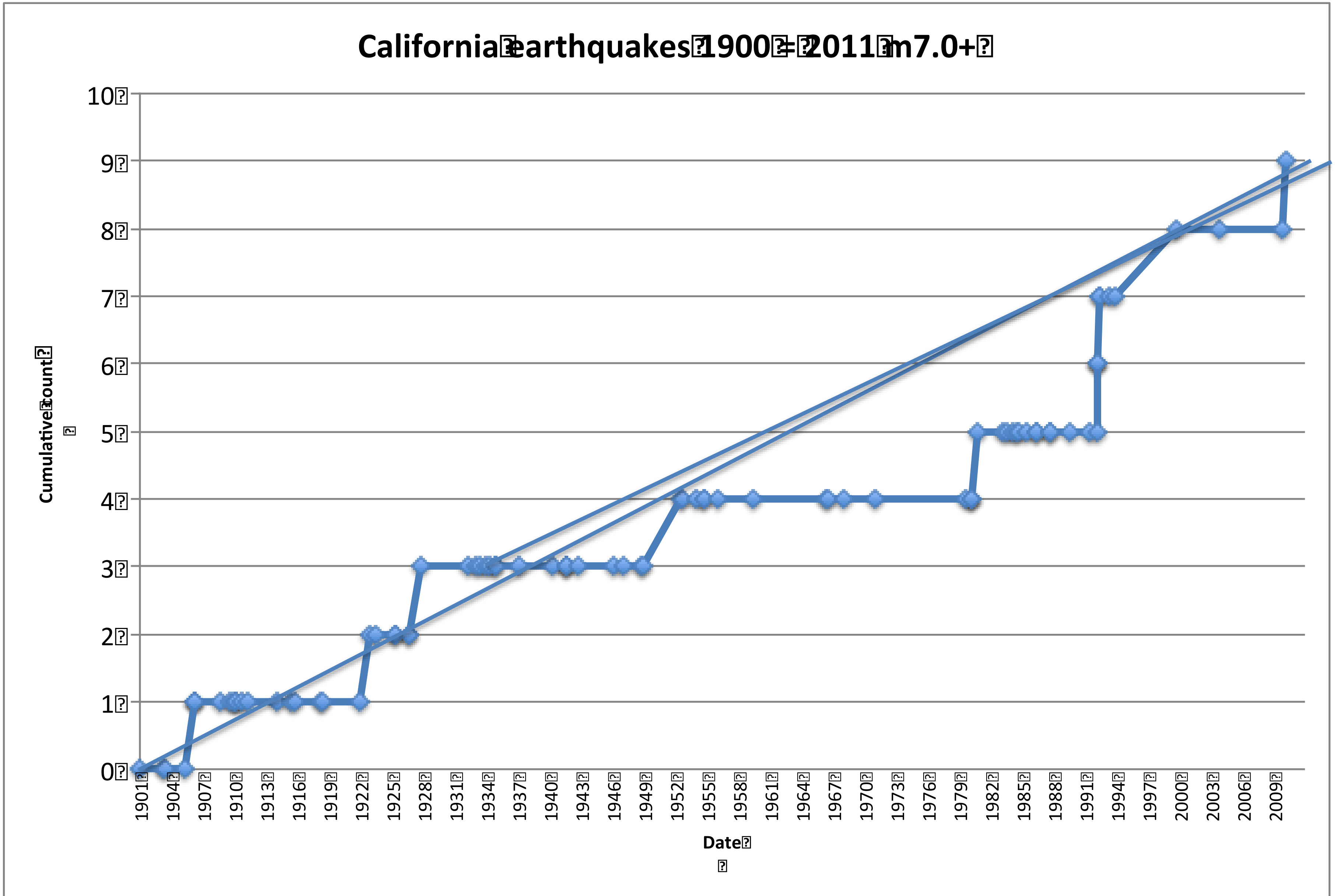
Thanks to Ned Field, Kevin Milner, Kieth Richards-Dinger, Jacqui Gilchrist, Jim Dieterich, Glenn Biasi, and Morgan Page

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

Stability of global earthquake rate





California earthquakes 1900 - 2011 m7.0+
Cumulative count
Date
0
1
2
3
4
5
6
7
8
9
10
1901
1904
1907
1910
1913
1916
1919
1922
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009

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.

The UCERF3 Paleo-seismic data

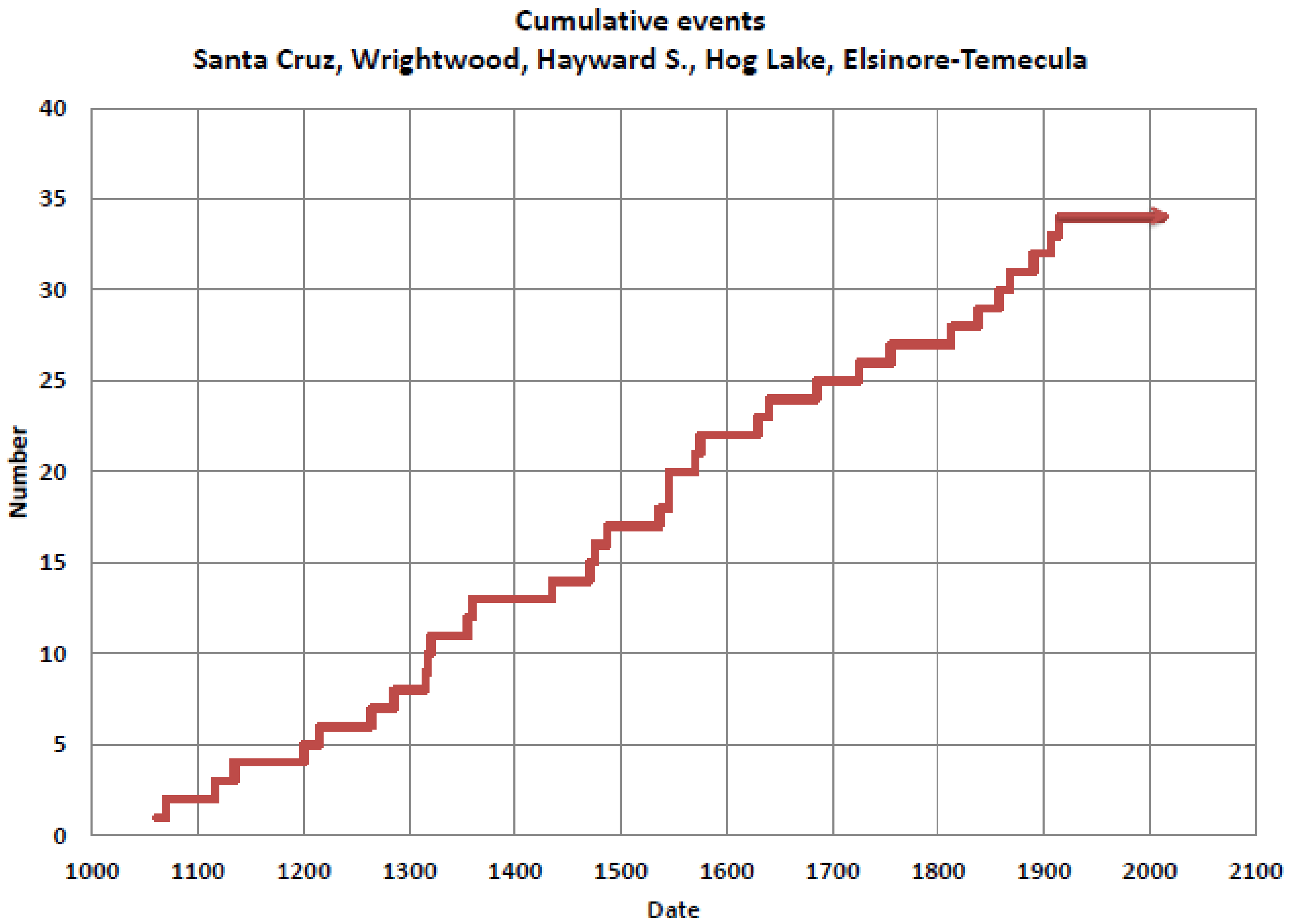
Site	Events	Open interval	Poiss rate	Lognormal Rate
Elsinore—Glen_Ivy	6	**102**	0.0051	0.0056
N._SAF—Santa_Cruz_Segment	10	106	0.0094	0.0091
N._SAF—Alder_Creek	2	106	0.0011	0.0011
N._SAF—Fort_Ross	4	106	0.0029	0.0033
N._SAF—North_Coast	12	106	0.0039	0.0038
N._SAF—Offshore_Noyo	15	106	0.0053	0.0053
Hayward_Fault—South	12	144	0.0057	0.0060
S._SAF—Wrightwood______	15	156	0.0094	0.0094
S._SAF—Carrizo_Bidart	6	156	0.0084	0.0087
S._SAF—Frazier_Mountian	8	156	0.0071	0.0067
S._SAF—Pallett_Creek	10	156	0.0066	0.0067
S._SAF—Burro_Flats	7	200	0.0048	0.0049
S._SAF—Pitman_Canyon_____	7	200	0.0055	0.0058
S._SAF—Plunge_Creek__	3	200	0.0036	0.0049
Elsinore—Temecula	3	203	0.0010	0.0010
San_Jacinto—Hog_Lake	14	243	0.0037	0.0032
Puente_Hills	3	250	0.0003	0.0003
Hayward_Fault—North	8	300	0.0030	0.0031
Rodgers_Creek	3	304	0.0026	0.0031
S._SAF—Coachella	7	329	0.0055	0.0056
Garlock—Western_(all_events)	5	330	0.0008	0.0008
S._SAF_Mission_Creek,_1000_Palm	5	332	0.0034	0.0038
S._SAF—Indio__	4	333	0.0030	0.0036
Green_Valley—Mason_Road	4	407	0.0030	0.0034
San_Jacinto—Superstition	3	462	0.0021	0.0020
Garlock_Central_(all_events)	6	469	0.0007	0.0007
San_Gregorio—North	2	490	0.0010	0.0010
Calaveras_Fault—North	4	722	0.0014	0.0016
Compton	6	1209	0.0004	0.0004
Elsinore—Julian	2	1755	0.0003	0.0003
Elsinore—Whittier	2	1801	0.0003	0.0003
Little_Salmon—Strong's_Creek	3	10890	0.0001	0.0001
Total			**0.1117**	**0.1156**

Selected "independent" sites

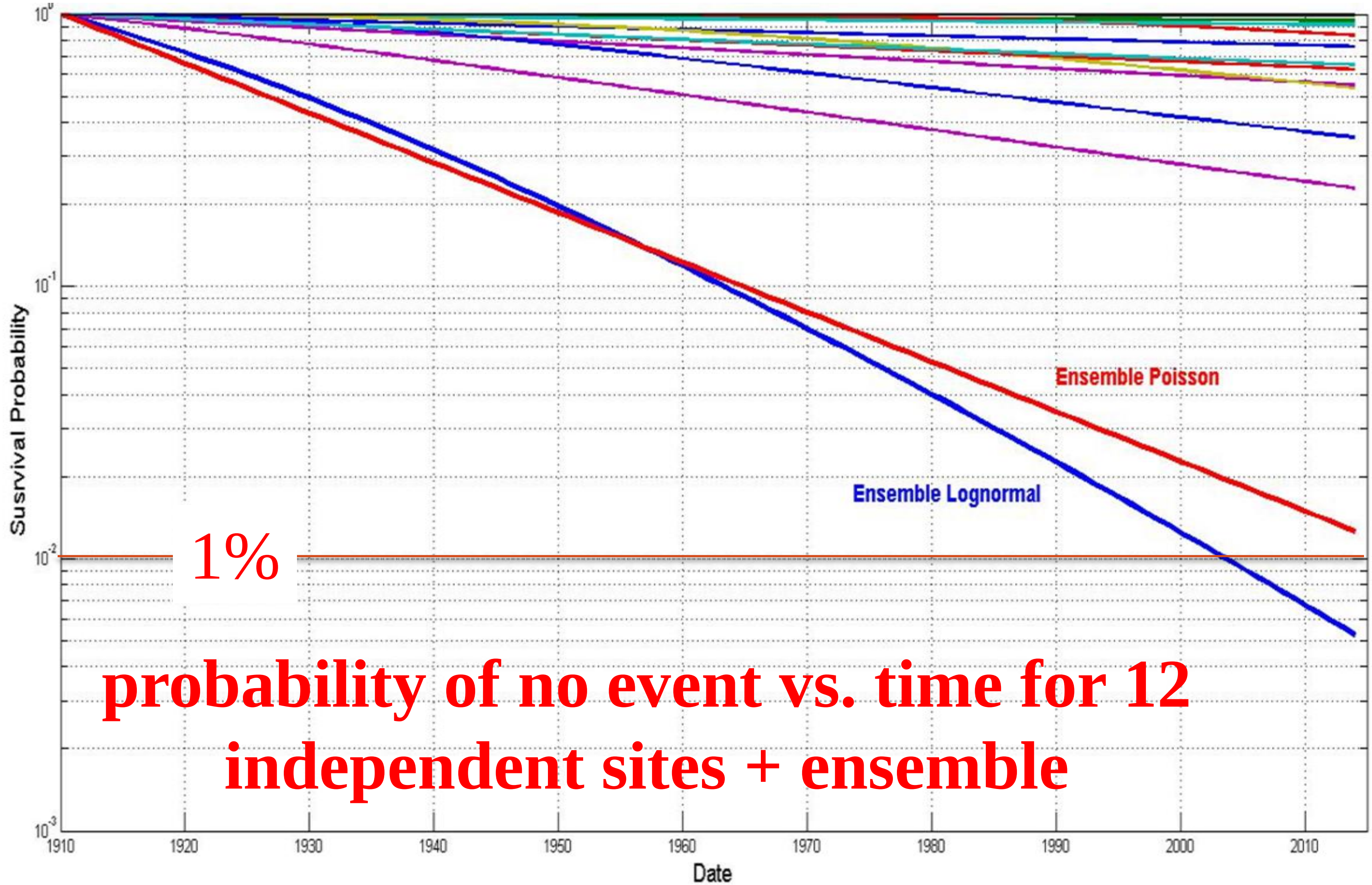
Amended to 1918

Index	Site	Most recent event	Poisson rate, lamda	mu	σ	Poisson Survival 1910 - 2014	Lognormal Survival 1910 -2014
14	**N._SAF—Santa_**	1906	0.00944	1.90	0.80	0.375	0.3521
32	**S._SAF—Wright**	1857	0.00940	1.93	0.65	0.376	0.2289
11	**Hayward_Fault**	1868	0.00572	2.18	0.45	0.551	0.5339
3	**Elsinore—Glen**	**1910**	0.00513	2.21	0.45	0.586	0.8363
21	**San_Jacinto—H**	1769	0.00374	2.25	1.07	0.678	0.6509
9	**Green_Valley—**	1605	0.00296	2.39	0.60	0.735	0.5494
20	**Rodgers_Creek**	1708	0.00264	2.40	0.70	0.760	0.6269
1	**Calaveras_Faul**	1290	0.00142	2.71	0.62	0.863	0.7604
8	**Garlock—West**	1682	0.00079	2.91	0.90	0.921	0.9134
2	**Compton**	803	0.00041	3.21	1.00	0.959	0.9481
18	**Puente_Hills**	1762	0.00027	3.52	0.30	0.972	1.0000
12	**Little_Salmon–**	-8878	0.00015	3.51	1.71	0.985	0.9927
	Ensemble		**0.04207**			**0.013**	**0.0053**

Cumulative paleo events since 1060



Survival Function based on single site recurrence parameters



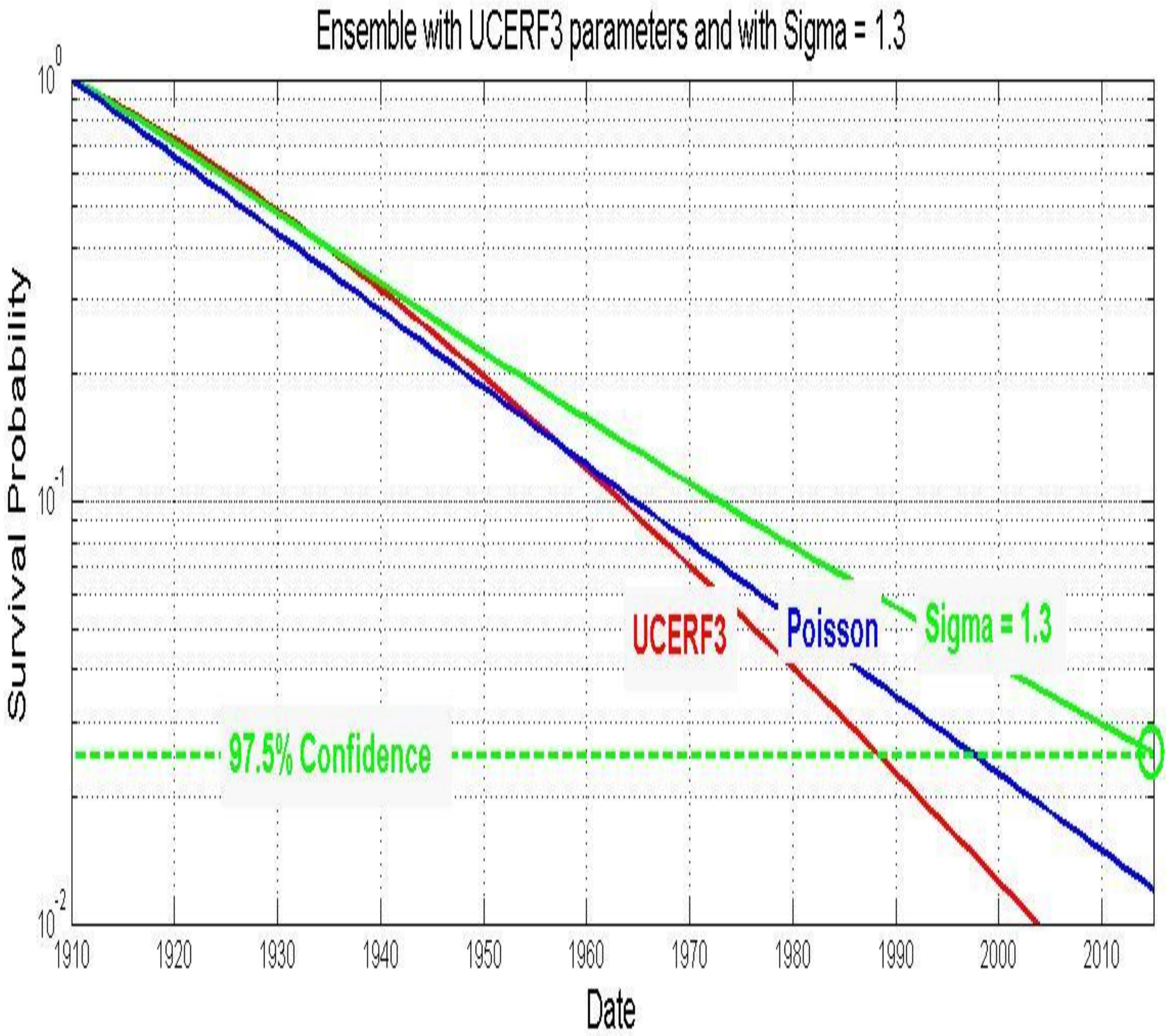
Possible explanations

- 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.

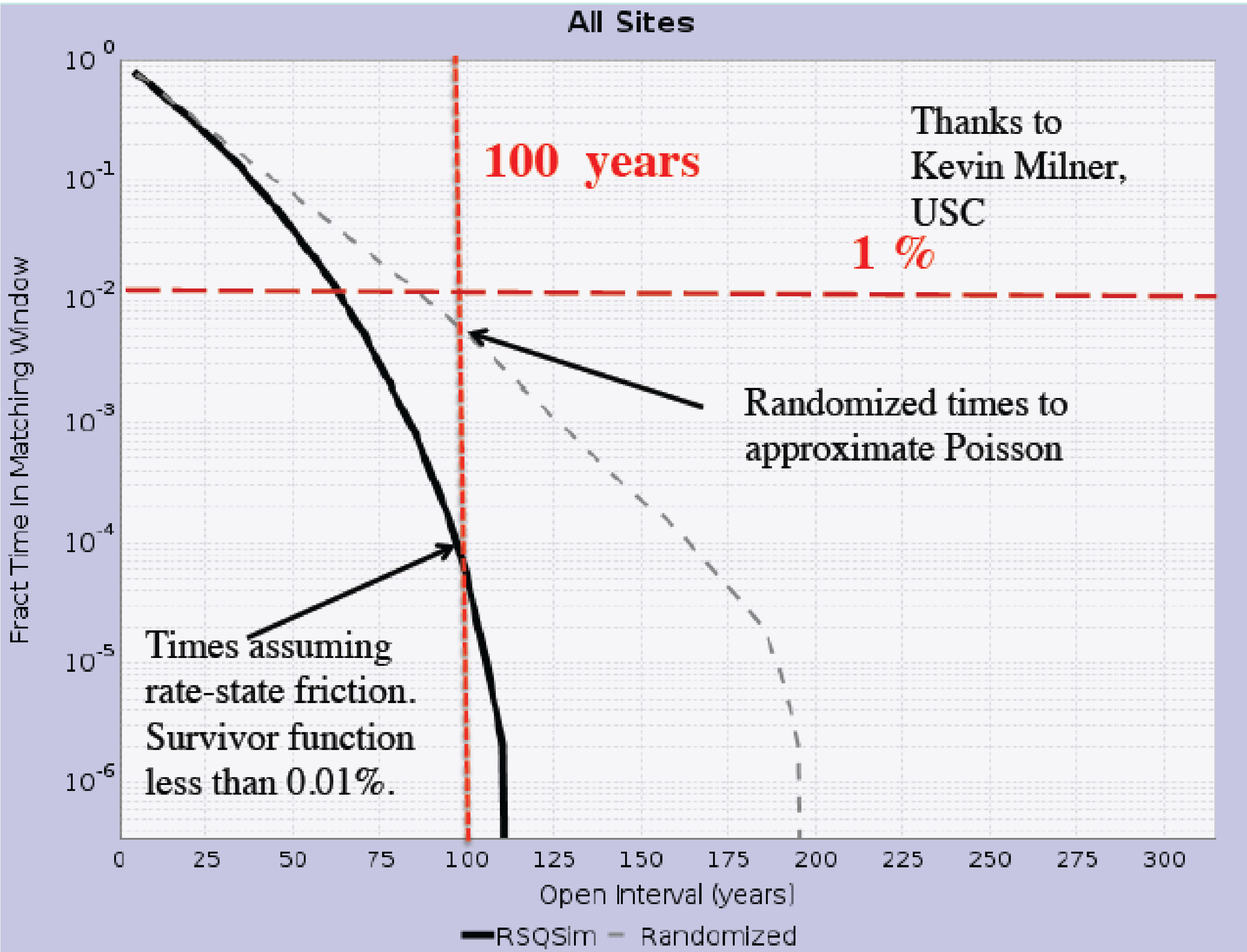
Luck

25 rounds of Russian Roulette. (5/6)^25=0.01

Survival for modified C.O.V.

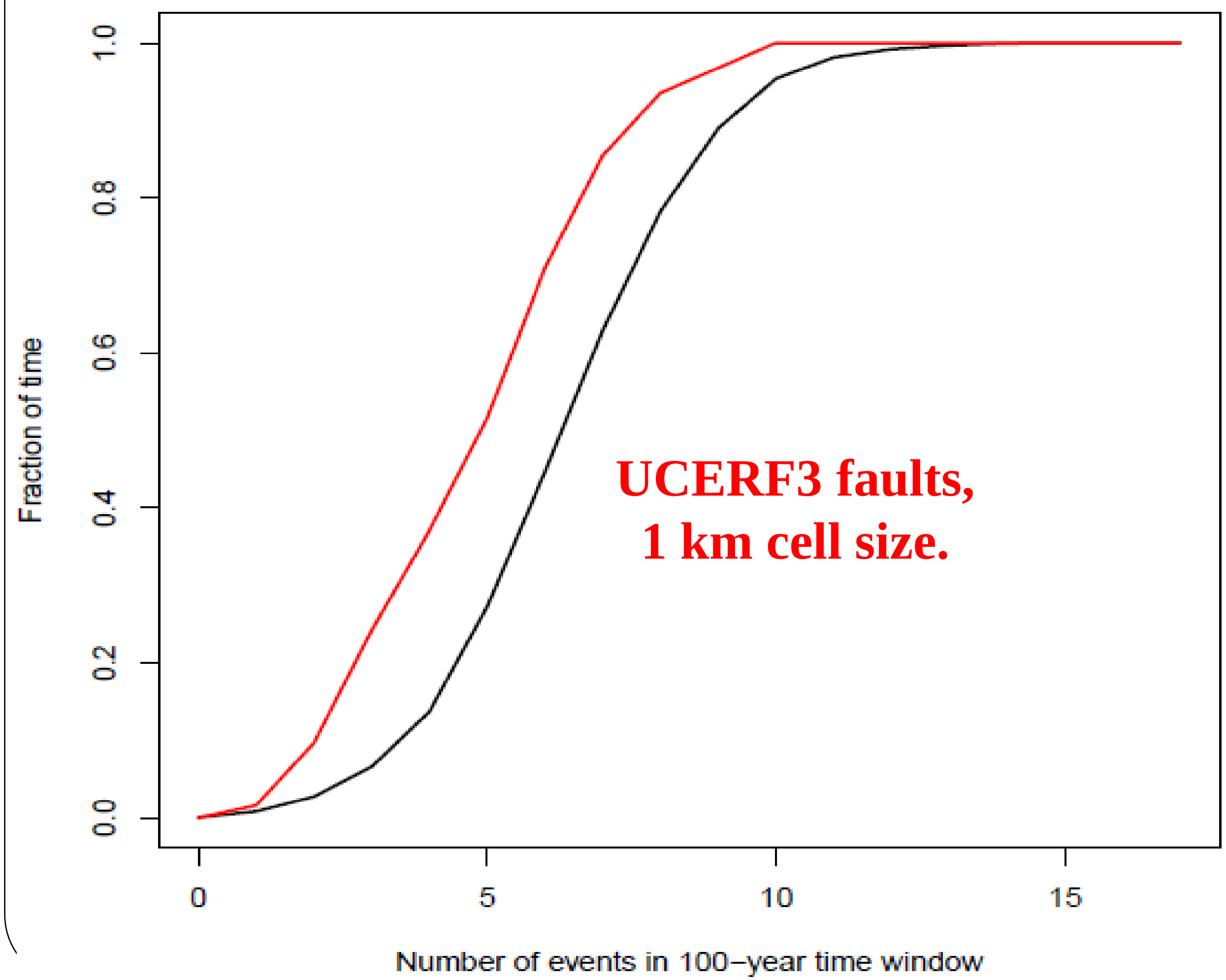


Can physics-based simulations explain a 100 year paleo-hiatus at 12 sites?



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 ≤N paleo-site hits.



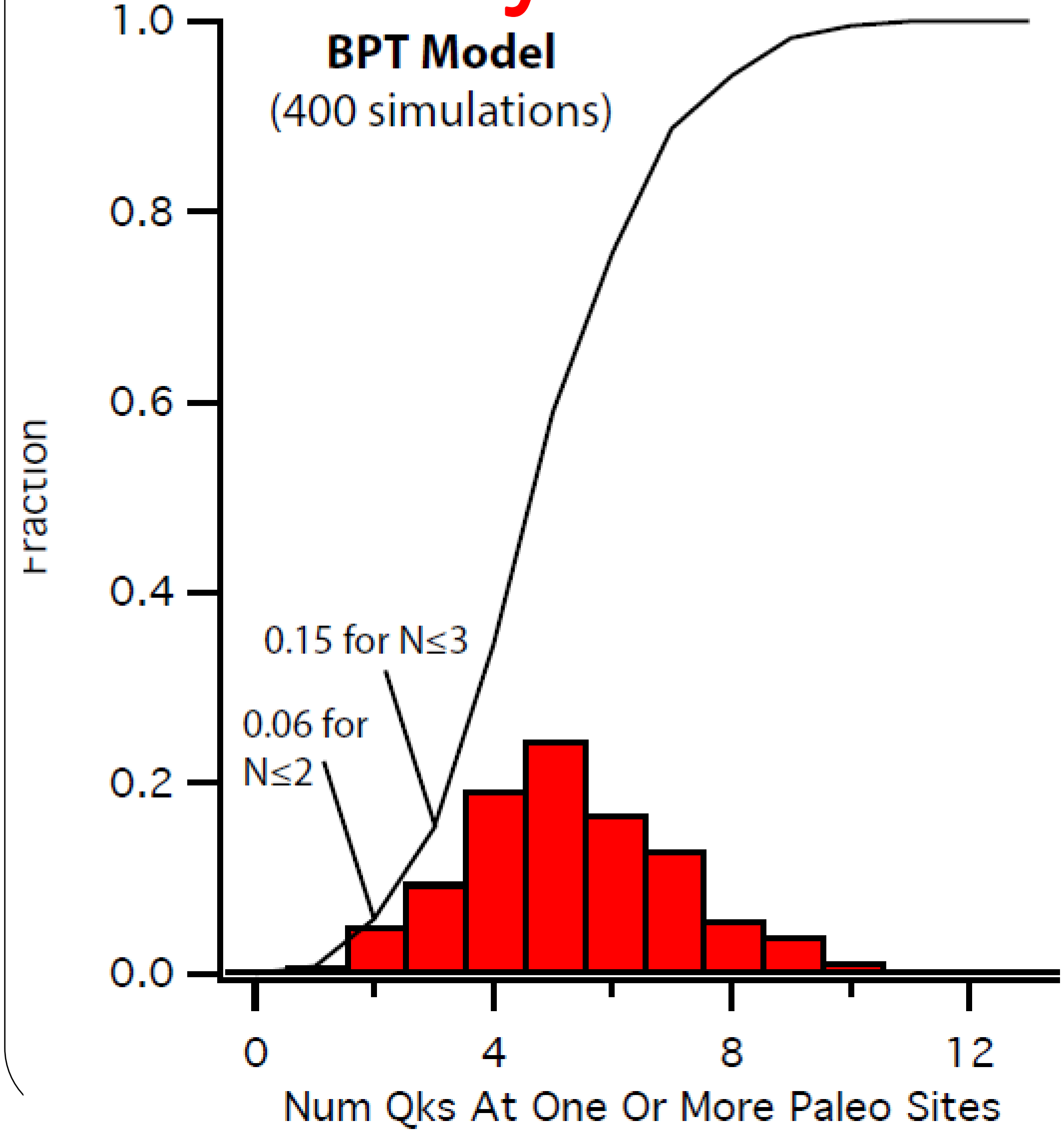
Red: 64 intervals chosen to follow simulated events like 1857 and 1906

Black: 1000 random 100 year intervals.

Results: Probability of 100 year survival is miniscule.

Thanks to Keith Richards-Dinger, UCR.

UCERF3 TD Quasi-periodic fraction of 100-year intervals with N hits

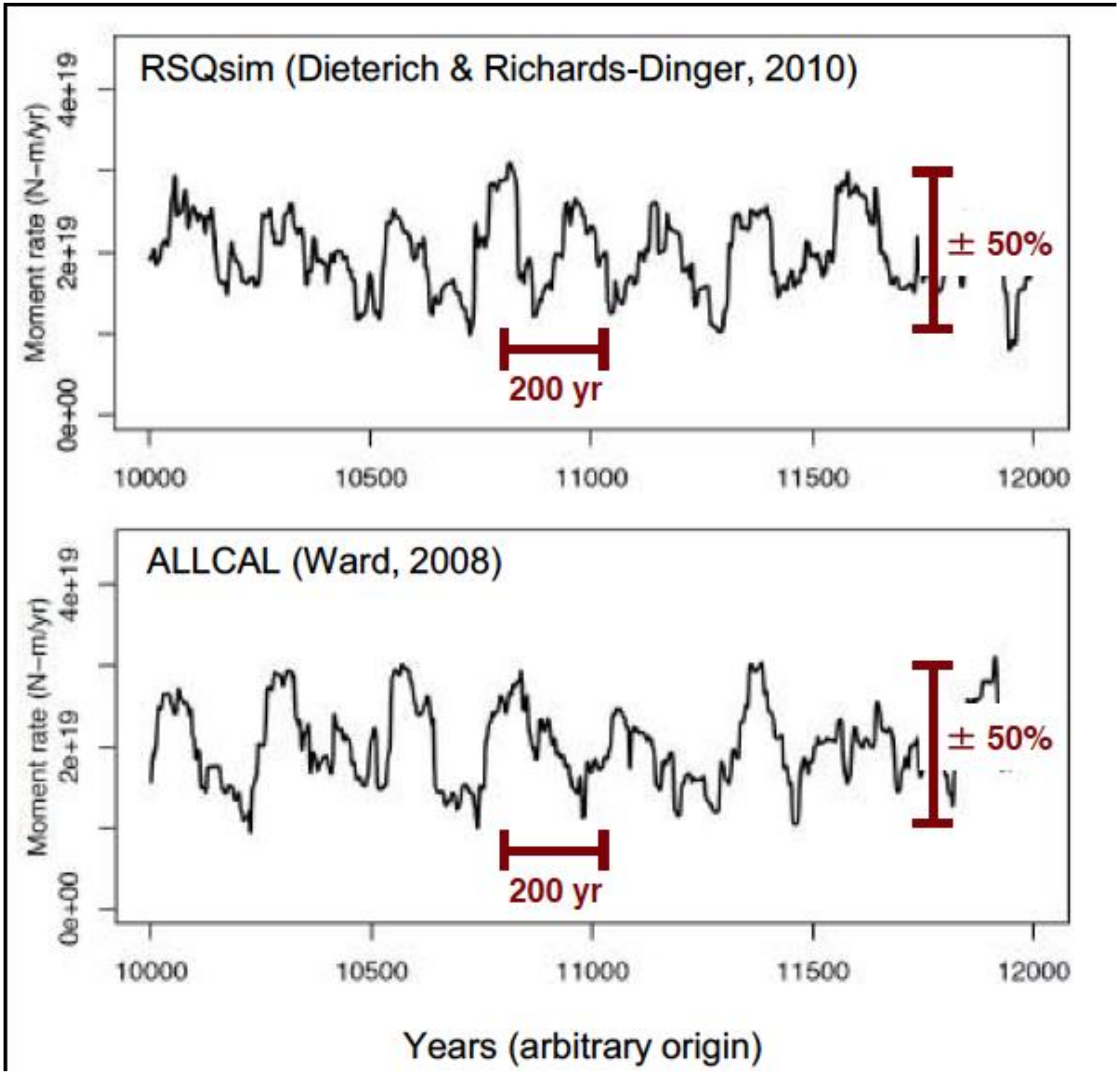


Thanks to Ned Field, USGS

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

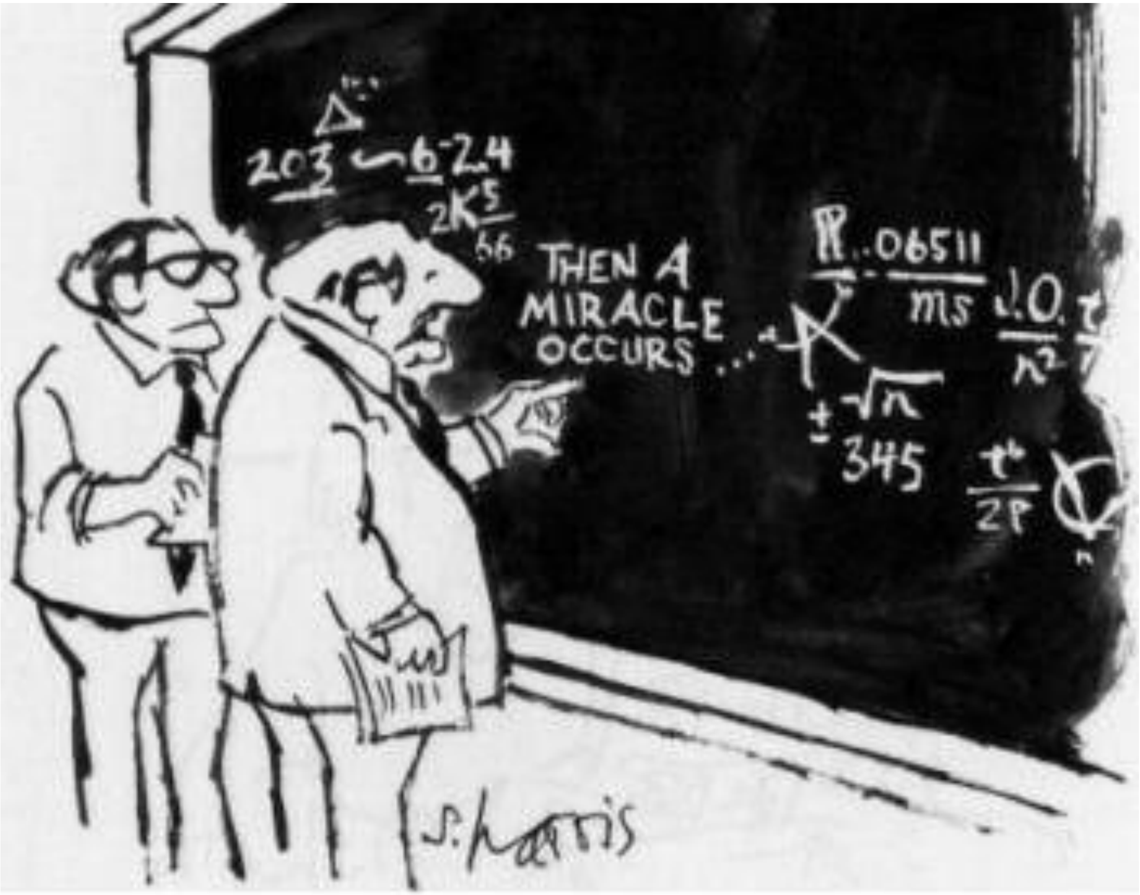
The paleo test is not a test of UCERF3.

Supercycles?



Supercycles

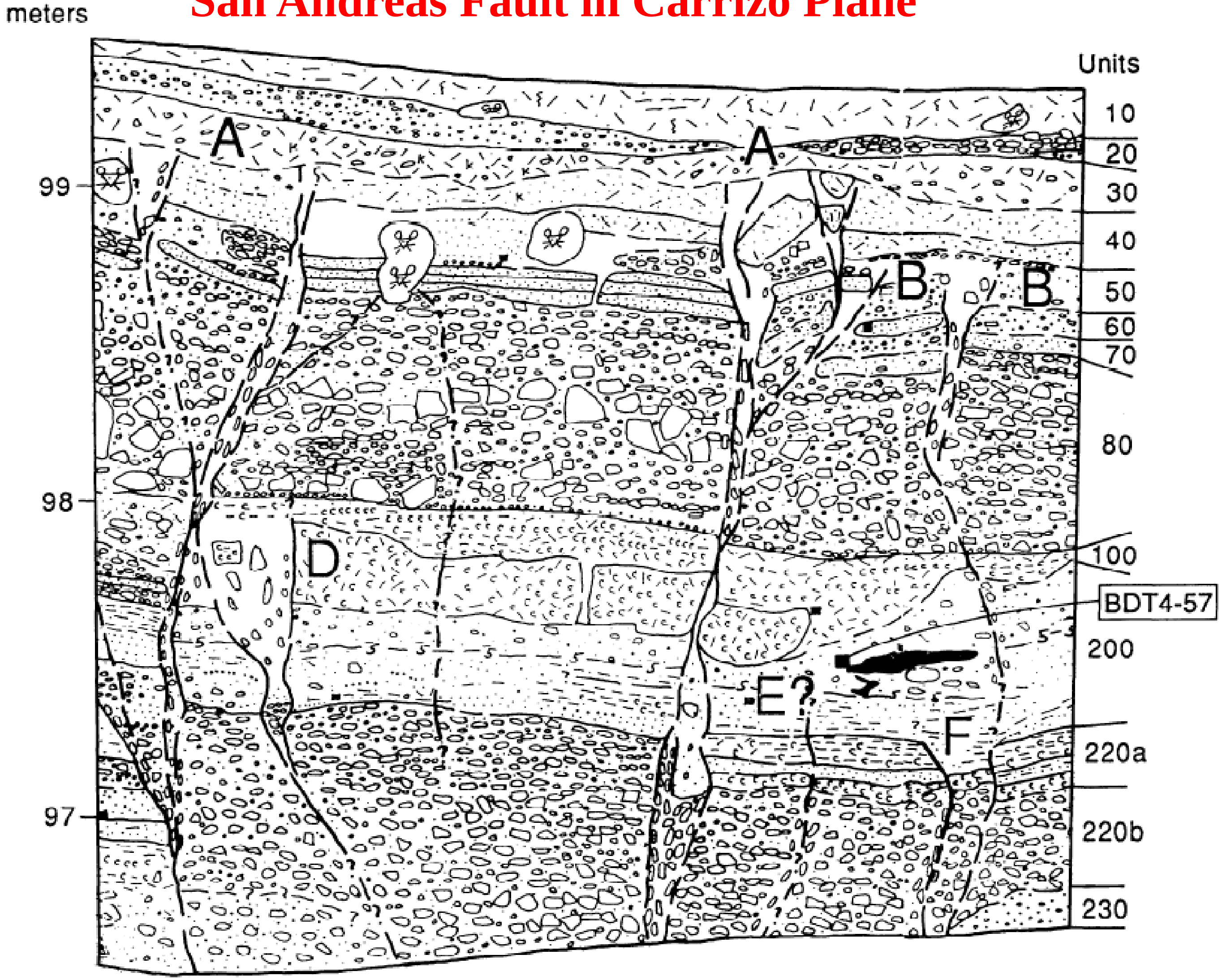
- Another word for clustering?
- What is cyclic about them?
- Can they fit any actual data? e.g, paleo-events?



"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 → rate > 0.036/a → 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 dats 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