2002 SCEC Progress Report
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SCEC 2002 award: $8,000
Title: Coordinated High-Resolution Paleoseismic Characterization of the Southern San Andreas Fault: Building the Foundation of a Multiple Seismic Cycle Model.

My part of the omnibus 2002 paleoseismic proposal was to study the problem of event correlation between sites on the San Andreas fault. A deposit on this problem is included in the 2002 publication (BSSA, in press), Biasi, Weldon, Fumal, and Seitz, *Paleoseismic event dating and the conditional probability of large earthquakes on the southern San Andreas fault, California*. The work began with two general themes. First was an investigation of time correlation methods used or proposed for paleoseismic application. Second has been the investigation of slip measurements and physically reasonable strain arguments as a basis for event correlation between paleoseismic sites.

Figure 1 shows the southern San Andreas fault and key paleoseismic sites along it. Figure 2 shows four well studied event chronologies spanning from Pallett Creek to Thousand Palms. Correlations proposed in Fumal et al (BSSA, in press) are shaded. There is some suggestion of events seen at southerly sites versus northern sites, and some events that span the full length considered. While the events considered here are among the best studied in the world, there is still a remarkable lack of agreement even among sites as close as Wrightwood and Pallett Creek. It should be evident that correlations based on time alone will be subject to question.

Figure 3 taken from a poster presented at the 2002 SCEC Annual Meeting surveys several methods cited in paleoseismic correlation. The method implicit in Figure 2, that of overlapping distributions, is perhaps the most widely used. It has the unexpected property that narrowing date widths, usually associated with increased precision of event distributions, can decrease the probability of correlation unless the means of the two event estimates are very close. Other methods are noted in outline form in the figure.

The second investigatory thread has proven most fruitful, that of using point slip measurements, as from paleoseismic investigations, as a basis for estimating event magnitude and rupture length. By using the distribution of slip measurements summarized by Hemphill-Haley and Weldon (BSSA, 1999) and mean relationships between magnitude and displacement, a Bayesian inversion may be posed that yields the probability of an earthquake magnitude given a point estimate of displacement from trenching. Figure 4 outlines the approach. An analogous relationship is developed between surface rupture length and the point estimate of slip. Surface rupture length is closely related to the probability of that a rupture spans two sites, which is an essential objective of the correlation study. With slip estimates at a given site, relationships of the total length of slip to the amount of it that extends up or down should be straightforward. These relationships and their application to the actual data of the southern San Andreas fault will be key objectives of future investigation.

Though only intermediate results, the probability distributions relating earthquake magnitude to point estimates of slip could be very significant. It is common in seismic hazard calculations to have one estimate of slip and only a poor idea of fault length. Figure 4d shows, for the two meter offset case, that magnitudes of events and a their probabilities can still be estimated.

Future plans are detailed in the 2003 proposal, and include extension of the Bayesian relationships for point displacement and formalizing the discovery made with SCEC 2002 funding.

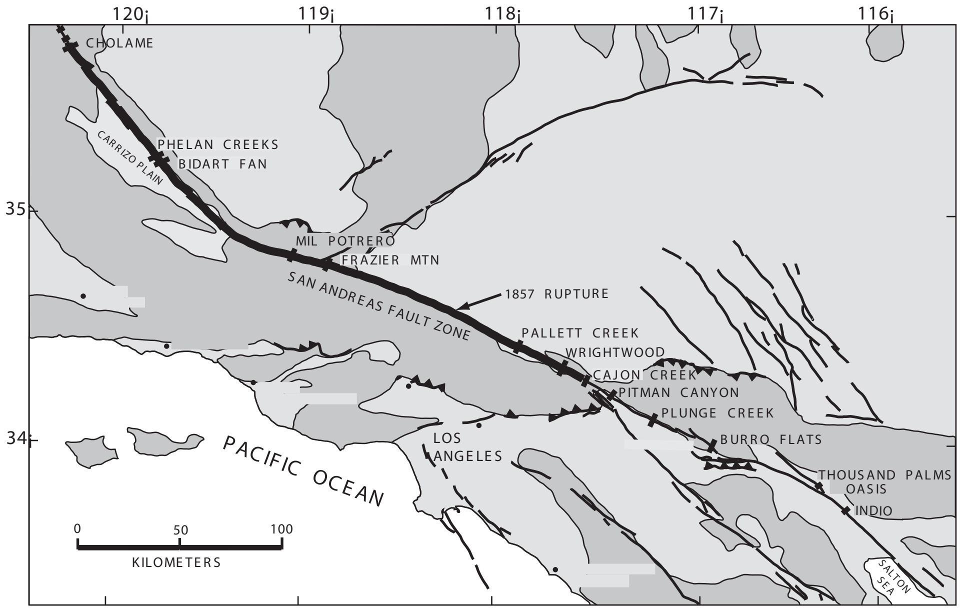
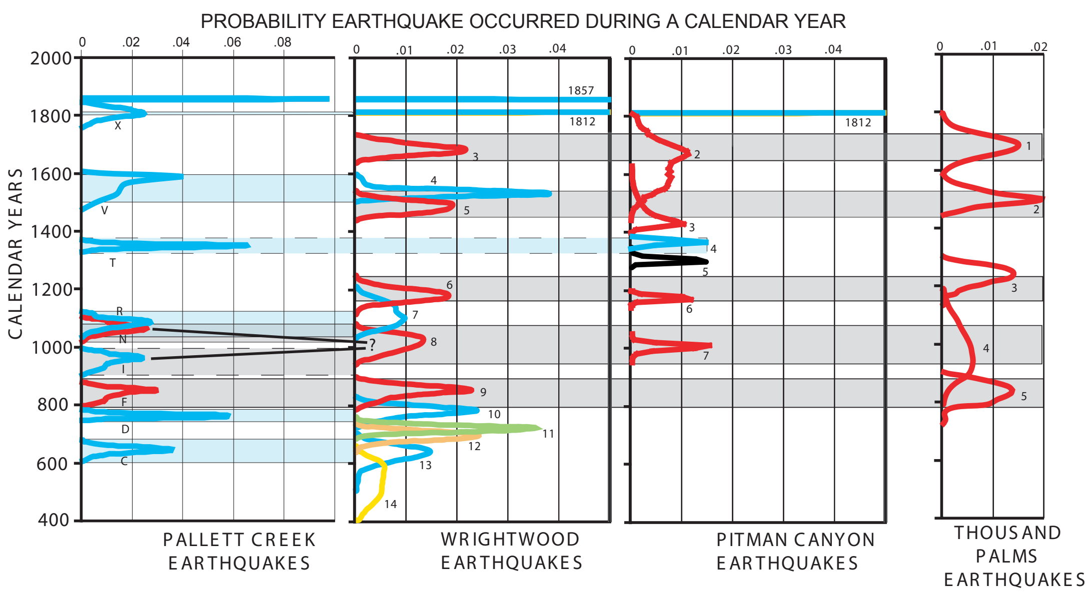


Figure 1. Location of paleoseismic sites important for the characterization of the most recent several events on the southern San Andreas fault. The 1857 rupture extent shows the need to consider asymmetric correlation probabilities, where some fraction F extends southeast along the fault, and 1-F extends to the northwest.

Figure 2. Multiple-event chronologies from Pallett Creek, Wrightwood, Pitman Canyon, and Thousand Palms. Events are shown in the form of probability distribution functions, and include radiocarbon uncertainties and improvements from stratigraphic ordering relationships (e.g., Biasi and Weldon, 1994; Biasi et al., 2002). Light shaded bars indicate suggested correlations if time overlap is the main criteria. Rupture length, and thus understanding the ground-motion history on the southern San Andreas fault depend on being able to confidently identify correlations among events.



The Event Correlation Problem

Key points:

Temporal overlap is weak evidence by itself.
Improved dating precision is of limited help.

Need to include other information.
Slip-per-event is the most important accessable measurement.

Overlapping Gaussian - I

"Z" statistic (e.g., McCalpin, 1996)
$Z = (T_1 - T_2) / \mathrm{sqrt}(\sigma^2 + \sigma^2)^2$, Small Z, large overlap

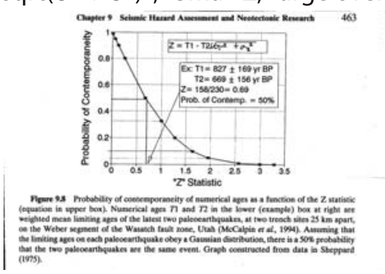


Figure 9.8 Probability of contemporaneity of numerical ages as a function of the Z statistic (equation in upper box). Numerical ages *T1* and *T2* in the lower (example) box at right are weighted mean limiting ages of the latest two paleoearthquakes, at two trench sites 25 km apart, on the Weber segment of the Wasatch fault zone, Utah (McCalpin *et al.*, 1994). Assuming that the limiting ages on each paleoearthquake obey a Gaussian distribution, there is a 50% probability that the two paleoearthquakes are the same event. Graph constructed from data in Sheppard (1975).

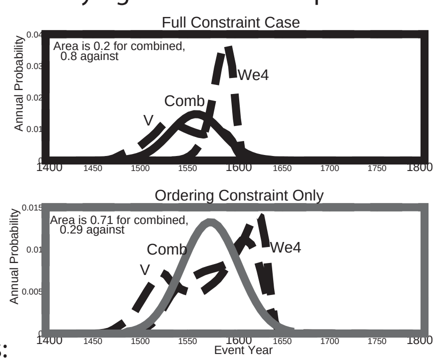
Issues:

(1) Test is backward: Z measures "can we say these are different", under the assumption that they are the same.

(2) Z statistic rewards dating imprecision.

Overlapping Gaussian - II

Likelihood approach: Treat each site earthquake estimate as an uncertain estimate of the underlying common earthquake date.



Issues:

(1) Assumes correlation;

(2) Poor and well-constrained events weighted equally;

(3) Pooled width can be much larger than any contributing event pdf.

Event Window Method

Events plotted as 95% ranges (bars)

Overlap = event range

Extensible to multiple events.

Issues:

(1) Assumes correlation - not a test

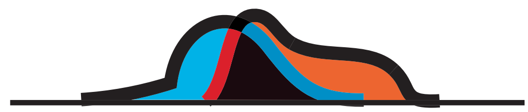
(2) Does not use probabilites in event pdfs.

(3) Quality of event evidence not considered.

Weakly documented event overlaps with equal weight as solid one => can skew dates.

Weighted Range Overlap

Formed from the overlapping area of event pdf's:
Min(E1(t), E2(t))



Better central tendency of resulting distribution.
Of present choices weighted range overlap seems most appropriate.

Issues:

(1) Assumes correlation.

(2) Quality of event evidence not included.

(3) No obvious theoretical foundation.

Unconditional Correlation

Correlation only accepted if in the same date bin;
e.g., P(E1) = 1650-1660 and P(E2) = 1650-1660.

Form by taking the probability product, a bin at a time.

Perfect overlap still gives low probabilities
- Two dice, identical pdf's, have 6 of 36 "same-bin" matches.
- Smaller bins => smaller correlation.
- Tight date constraints help little.

Method does down-weight poorly constrained event pdf's.

Does not assume correlation.

Issues:

(1) Never yields high probabilities.

(2) Cannot resolve "close in time" events.

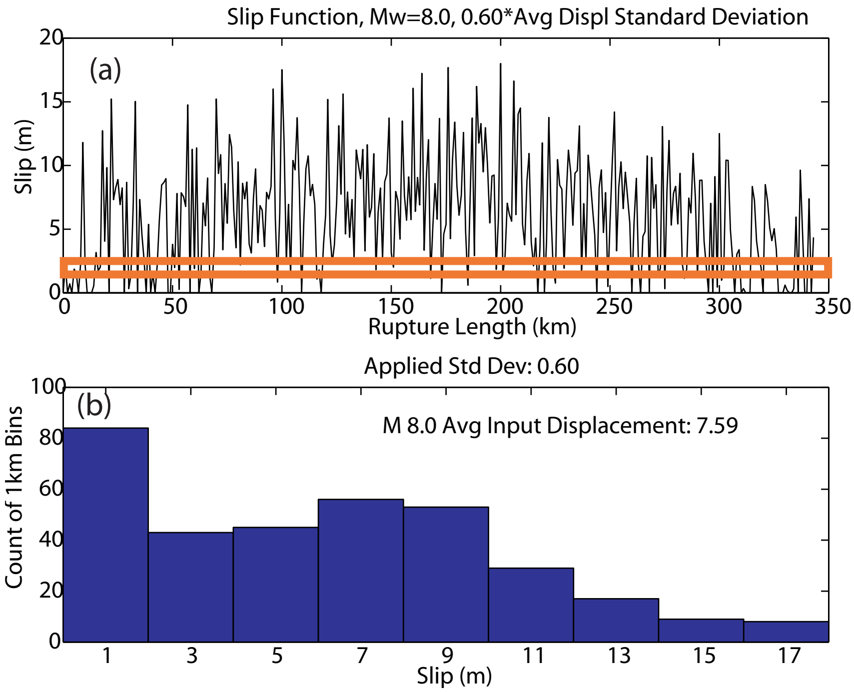
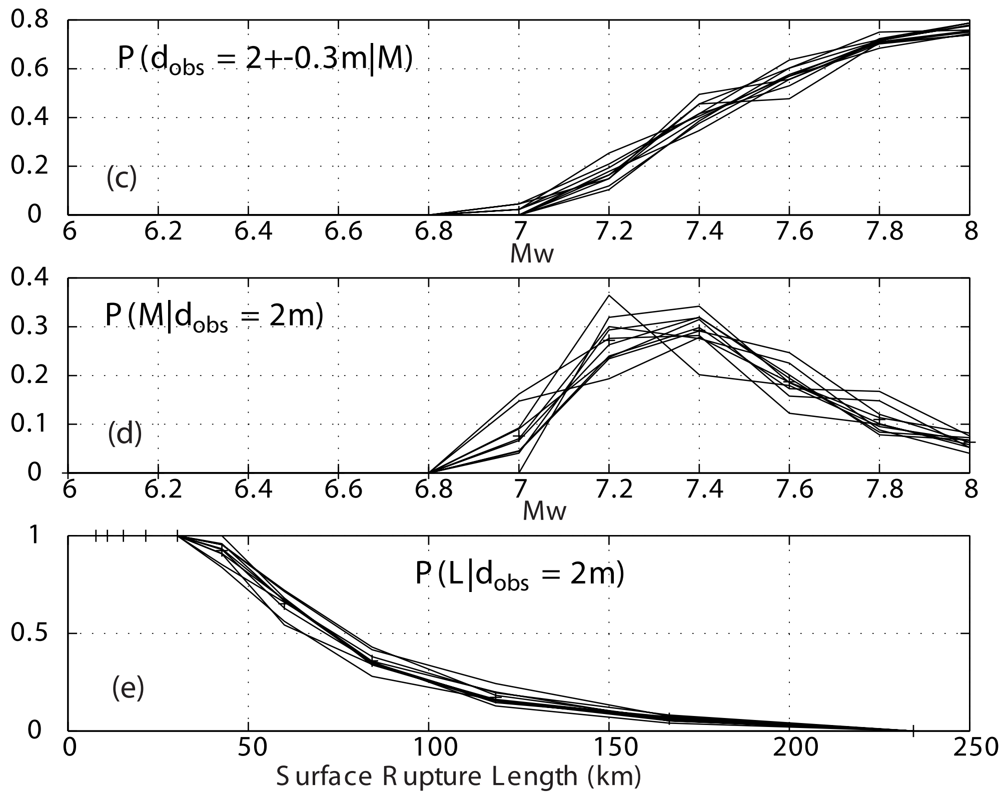


Figure 4. a,b. Synthetic slip distribution assuming a Gaussian variability around a smooth tapered slip function. Variability is too extreme for an actual slip distribution, but when slip is binned, the resulting histogram of slip matches the 14 event average of Hemphill-Haley and Weldon fairly well. Thus the variability in Fig 4a is correct on average. The red bar marks slip = 2.0+/- 0.3 m. For an M 8 event, most displacements are larger. If one trenches at random and finds a 2 meter displacement, it would be an unusual but not impossible circumstance. Smaller events have smaller total lengths and smaller maximum displacements.

Fig 4c, d, e (below) The cumulative probability of observing a displacement d_obs=2 meters is compiled for each magnitude event as the fraction of its total length falling near 2.0 m. Different lines reflect random trials in generating slip functions such as Fig 3a. Fig 4d (below, middle) is the Bayesian inverse of P(d_obs|M). Results conform to expectations. A 2 m rupture is a likely find if the true magnitude was 7.2 or 7.4. If the event magnitude was really M 7.0, d_obs would have come from an unusually high point in the slip distribution. Conversely, if the true magnitude is 7.6 or larger, d_obs = 2 m is lower than expected for a random sample of the rupture. Fig 4e (bottom) shows rupture length is almost certain to be at least 35 km, typically 70 km, and occasionally much longer.



Event correlation follows by extension from Fig 4e, where the total length is partitioned and its probability must be split between northwest and southeast sides.