Statistical Analysis of Paleoseismically Determined Earthquake Recurrence

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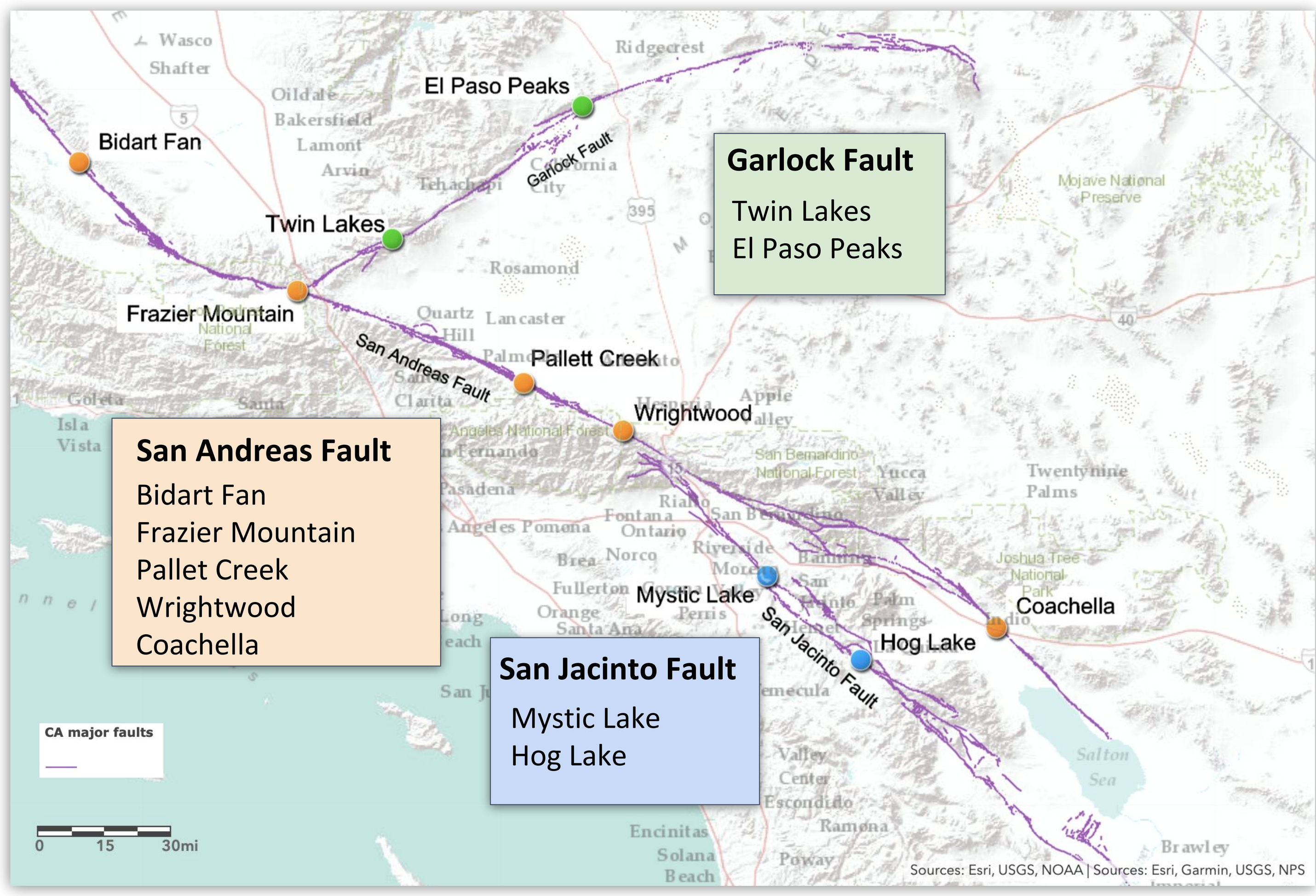
Introduction

We present cumulative distributions for earthquake recurrence intervals, sampled from the original paleoseismic age constraints. We modeled 11 available paleoearthquake datasets, most with sufficient length to constrain a probability model. In this poster, we present the results of the 9 sites in California. The sites are shown in the map below.



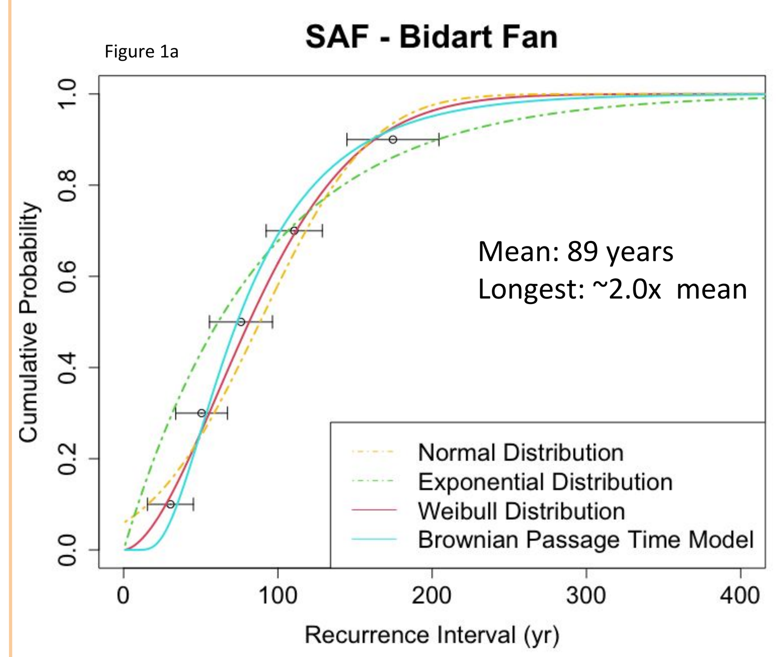
Data and Methodology

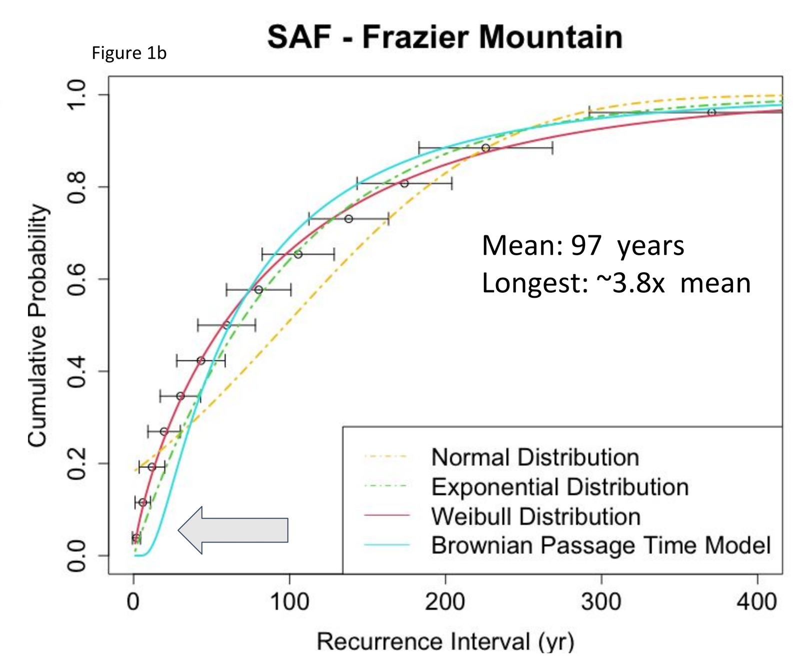
We modeled the earthquake recurrence distributions for 11 paleoseismic records, each of which has at least 5 events. The datasets are from continental strike-slip faults in California (San Andreas [5], San Jacinto [2], Garlock [2]), and China (Altyn Tagh [1], Haiyuan [1]). We obtained the raw OxCal files of 10 sites from published research papers (Akçiz et al., 2010, Philibosian et al., 2011, Scharer et al., 2011, Sieh et al., 1989, Scharer et al., 2007, Scharer et al., 2010, Rockwell et al., 2014, Onderdonk et al., 2013, Madugo et al., 2012, Liu-Zeng et al 2015, JGR, Yuan et al., 2018, EPSL) and reconstructed the OxCal file for El Paso Peaks site using the published geochronology data (Dawson et al., 2003). Using the OxCal files, we generated the distribution of event ages, as constrained from bounding layer ages and stratigraphic ordering. Using R, we use the distribution of event ages to sample the recurrence intervals distributions at each site. We then model these with 4 statistical distributions: Normal, Exponential, Weibull, and the Brownian passage-time model (Matthew et al., 2002).

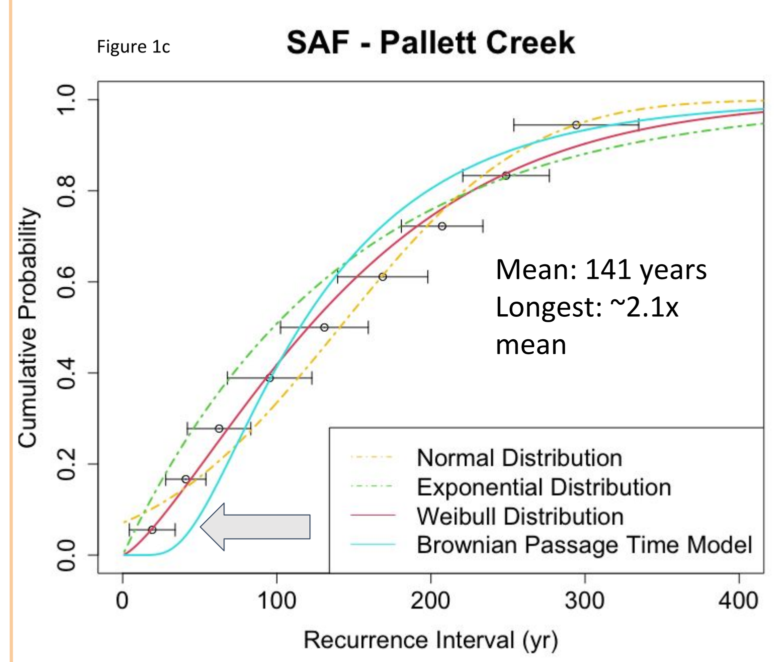
Results

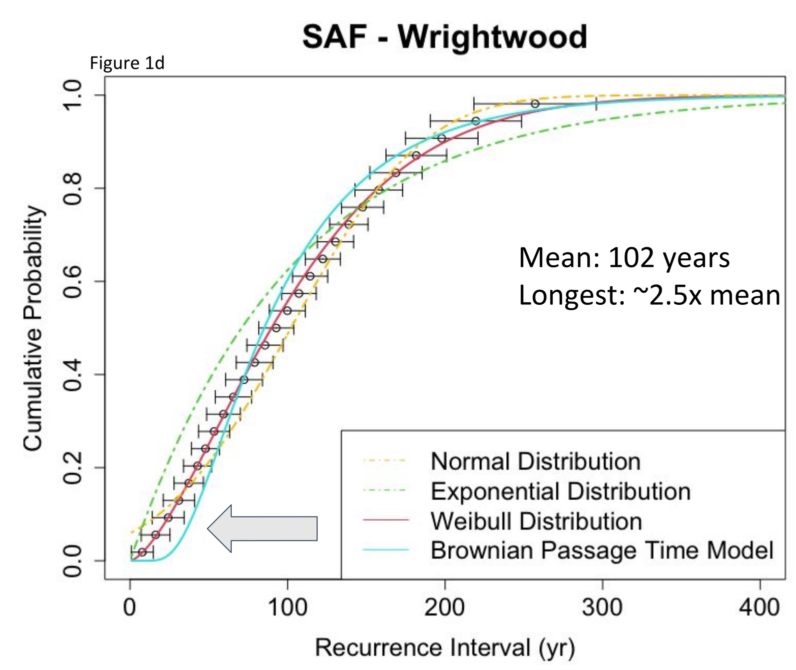
We find that recurrence intervals show no central tendency, contradicting the characteristic earthquake recurrence model. Instead, the recurrence interval distributions are long-tailed, with the average greater than the median, and the longest recurrence interval >5x the shortest interval. We find better fits to the majority of paleoseismic data sets using a Weibull distribution.

We find that the normal distribution poorly fits earthquake recurrence, as expected from the lack of a central tendency. A minority of data sets are well fit by the exponential distribution, consistent with a Poisson process with uniform hazard over time and no memory of prior events. Most of the paleoseismic records, however, indicate an increase in hazard over time. We find that the Brownian passage-time model, formulated as perturbations added to steady tectonic loading, systematically underpredicts the young tail of earthquake recurrence at 4 out of 5 sites with >10 events (arrows on the plots).









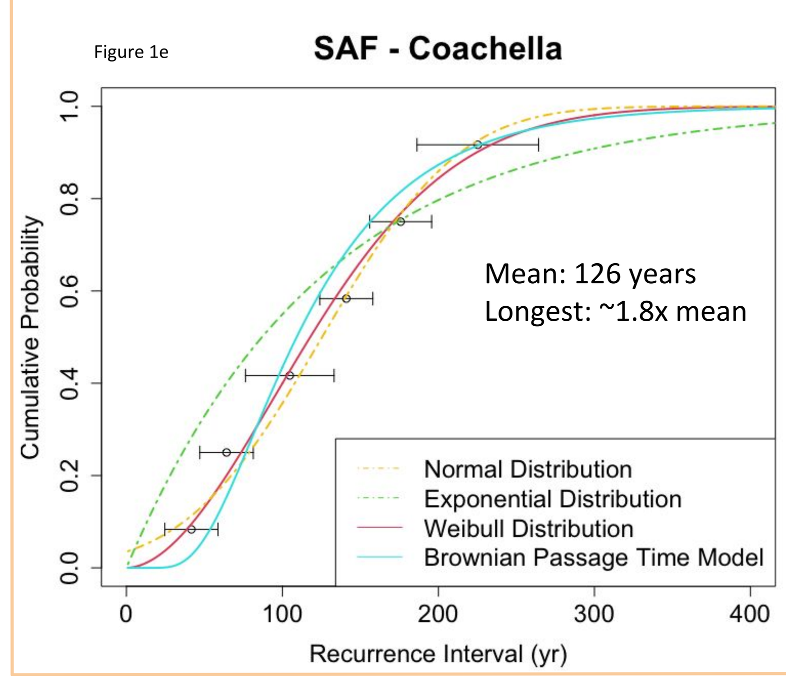
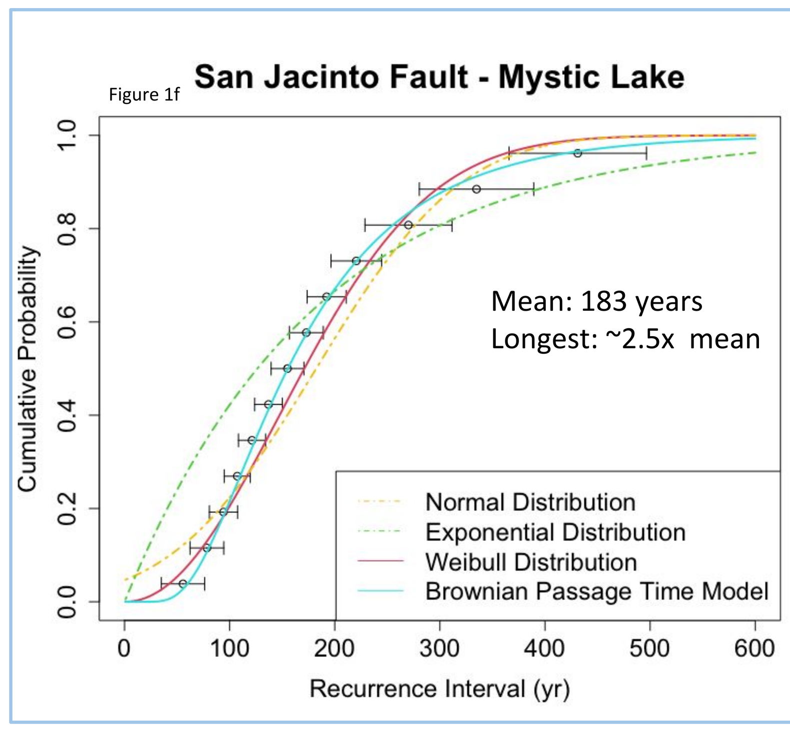
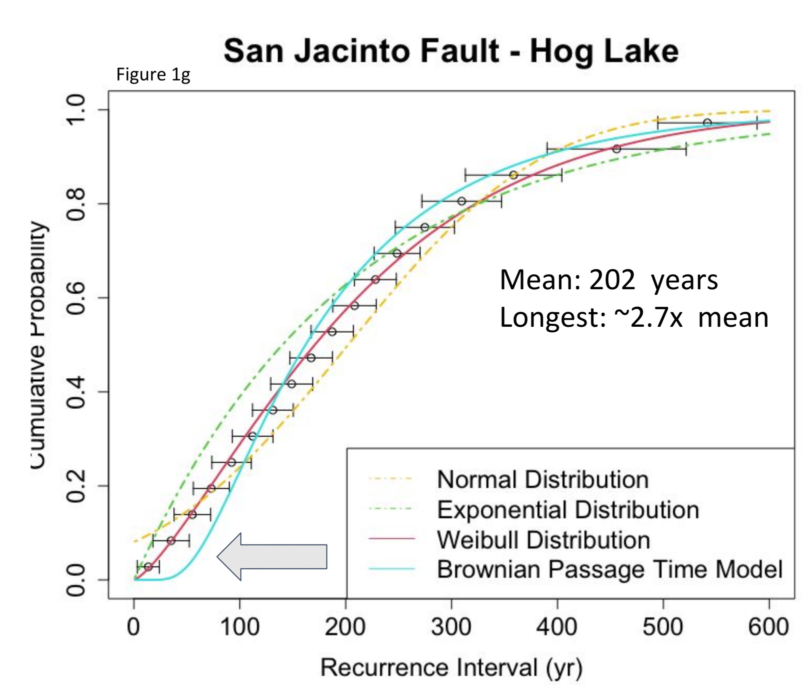
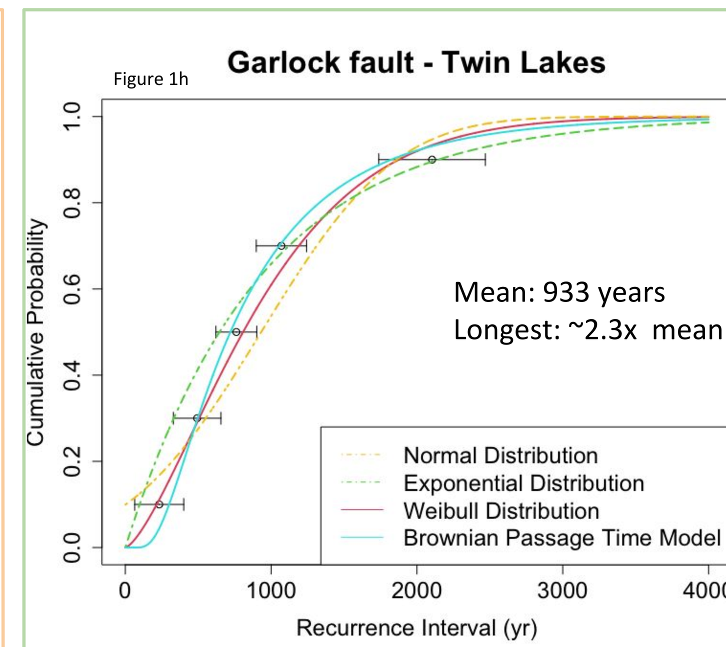
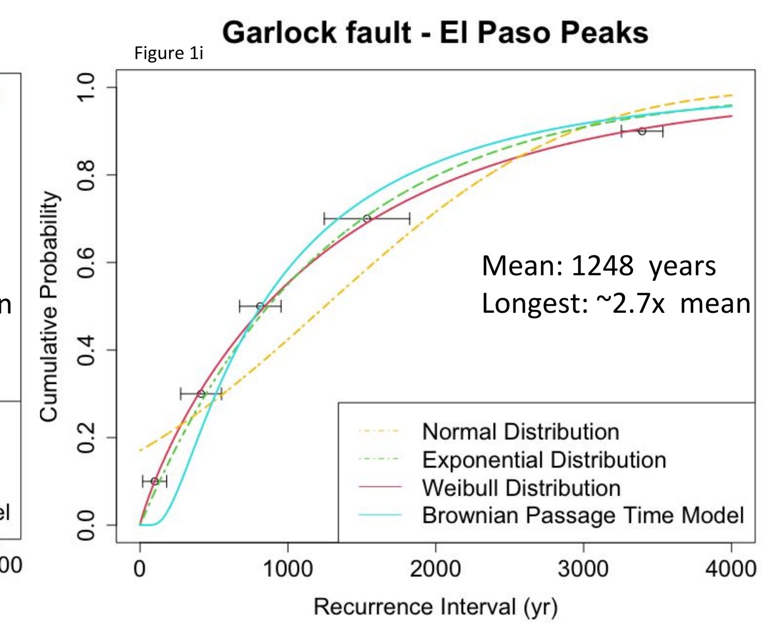


Figure 1a-1i
Cumulative probability distributions with Normal, Exponential, Weibull and Brownian Passage Time model fits at each site. Gray arrows point out underprediction of the young tail by Brownian passage-time model for sites with >10 events. Weibull model provides a superior fit for these sites, except for Mystic Lake on the SJF.









Conclusion

Our analysis of 11 long paleoseismic records (9 from California shown here) favors a Weibull distribution model. This model may be envisioned as arising from an ensemble of many possible failure points (earthquake nucleation sites) along a given length of the fault, at each of which the hazard is growing over time. Once initiated, a rupture grows and propagates through the point of observation at a paleoseismic trench. This multiple failure-point approach challenges traditional renewal models for earthquake recurrence. Earthquake distributions vary widely along the length of the 1857 Fort Tejon earthquake rupture and suggest that this event ruptured sections of the fault at distinctly different hazard levels. Variations in mean recurrence and distribution shape suggest that interactions with the Garlock Fault and the San Jacinto Fault may affect the time-to-failure on the San Andreas fault.

References

Akçiz, S. O., Ludwig, L. G., Arrowsmith, R., & Zielke, O. (2010). Century-long average time intervals between earthquake ruptures of the San Andreas fault in the Carrizo Plain, California. *Geology*, *38*(9), 787-790.https://doi.org/10.1130/G30995.1

Dawson, Timothy & Mcgill, Sally & Rockwell, Thomas. (2003). Irregular recurrence of paleoearthquakes along the central Garlock fault near El Paso Peaks, California. Journal of Geophysical Research. 108. 10.1029/2001JB001744.

Liu-Zeng, J., Shao, Y., Klinger, Y., Xie, K., Yuan, D., and Lei, Z. (2015), Variability in magnitude of paleoearthquakes revealed by trenching and historical records, along the Haiyuan Fault, China, J. Geophys. Res. Solid Earth, 120, 8304– 8333, doi:10.1002/2015JB012163.

Madugo, Christopher & Dolan, James & Hartleb, Ross. (2012). New Paleoearthquake Ages from the Western Garlock Fault: Implications for Regional Earthquake Occurrence in Southern California. The Bulletin of the Seismological Society of America. 102. 2282-2299. 10.1785/0120110310.

Matthews, M.. (2002). A Brownian Model for Recurrent Earthquakes. Bulletin of The Seismological Society of America - BULL SEISMOL SOC AMER. 92. 2233-2250. 10.1785/0120010267.

Onderdonk, Nate & Rockwell, Thomas & Mcgill, Sally & Marliyani, Gayatri. (2013). Evidence for Seven Surface Ruptures in the Past 1600 Years on the Claremont Fault at Mystic Lake, Northern San Jacinto Fault Zone, California. The Bulletin of the Seismological Society of America. 103. 519-541. 10.1785/0120120060.

Philibosian, B.E., Fumal, T.E., & Weldon, R.J. (2011). San Andreas Fault Earthquake Chronology and Lake Cahuilla History at Coachella, California. *Bulletin of the Seismological Society of America, 101*, 13-38.Long-term Earthquake Production on a Major Plate Boundary Fault. Pure Appl. Geophys. 172, 1143-1165.

Rockwell, T.K., Dawson, T.E., Young Ben-Horin, J., Seitz, G., (2014). A 21-Event, 4,000-Year History of Surface Ruptures in the Anza Seismic Gap, San Jacinto Fault, and Implications for Long-term Earthquake Production on a Major Plate Boundary Fault. Pure Appl. Geophys. 172, 1143-1165.

Scharer, K. M., Weldon, R. J., Fumal, T. E., & Biasi, G. P. (2007). Paleoearthquakes on the southern San Andreas fault, Wrightwood, California, 3000 to 1500 BC: A new method for evaluating paleoseismic evidence and earthquake horizons. Bulletin of the Seismological Society of America, 97(4), 1054-1093.

Scharer, K. M., Biasi, G. P., Weldon, R. J., & Fumal, T. E. (2010). Quasi-periodic recurrence of large earthquakes on the southern San Andreas fault. Geology, 38(6), 555-558.

Scharer, K. M., Biasi, G. P., & Weldon, R. J. (2011). A reevaluation of the Pallett Creek earthquake chronology based on new AMS radiocarbon dates, San Andreas fault, California. Journal of Geophysical Research: Solid Earth, 116(B12).

Scharer, K., Weldon, R., Biasi, G., Streig, A., & Fumal, T. (2017). Ground-rupturing earthquakes on the northern Big Bend of the San Andreas fault, California, 800 AD to present. Journal of Geophysical Research: Solid Earth, 122(3), 2193-2218.

Sieh, K., Stuiver, M., & Brillinger, D. (1989). A more precise chronology of earthquakes produced by the San Andreas fault in southern California. Journal of Geophysical Research: Solid Earth, 94(B1), 603-623.

Yuan, Zhaode, Liu-Zeng, Jing, et al. (2017) A 6000-year-long paleoseismologic record of earthquakes along the Xorkoli section of the Altyn Tagh fault, China. Earth and Planetary Science Letters. Volume 497. 1 Sep 2018. Page 193-203. https://doi.org/10.1016/j.epsl.2018.06.008.

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