SoSAFE Workshop: Project Successes and Future Challenges

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Conveners: Kate Scharer and Ramon Arrowsmith

The central goal of the Southern San Andreas Fault Evaluation (SoSAFE) project was to increase knowledge of the occurrence and size of earthquakes along the southern San Andreas Fault (SAF) and San Jacinto Fault (SJF) over the last 2000 years. When SoSAFE began in 2006, only two published paleoseismic records, Wrightwood and Pallett Creek, extended greater than 1000 years. Since then, funding from SCEC, USGS NEHRP and NSF, many paleoseismic investigations have been initiated and/or published by SoSAFE investigators, greatly increasing the number of sites with long records and estimates of paleoslip. There is now a high-resolution paleoseismic site at least every 150 km along the fault system and in many places the distance is <50 km. With more data we have the ability to test the original fault behavior models designed on limited data, and have the ability to refine results based on multiple, independent datasets to obtain a clearer understanding of the plate boundary behavior in Southern California.

The purpose of this workshop was to: (1) discuss the latest methods and data that have improved our knowledge and (2) investigate new approaches and enhance collaborations needed to advance paleoseismic investigations on the SAF/SJF system. The workshop was structured with a set of morning presentations focused on variations in the signature of slip on the plate boundary system. The afternoon covered two topics; the first explored how paleoenvironmental data can be used to leverage paleoseismic sequences, and the second aimed to improve coordination between paleoseismic data and modeling approaches such as the Collaboratory for Interseismic Simulation and Modeling (CISM). The meeting agenda allowed for ample discussion time. We distilled the following key points from conversations and discussions with participants during and after the meeting.

1. There is ample evidence that slip rates can vary over time at a point, and the magnitude of slip per event varies. For example, there is slip variation due to long term fault evolution, due to variations in per-event rupture behavior and earthquake magnitude, and due to creep (though to date, only observed on a few portions of the fault system). Variable slip at a point in successive earthquakes is suggested by detailed evidence from many sites, i.e., the variable slip model seems favored by the data for the SAF and SJF. It is likely there is also a mix of moderate and large (or large and great) earthquakes observed at these locations. This is a good picture of the earthquake phenomena but a greater challenge for interpretation (recurrence of what?). A synoptic analysis like “Stringing Pearls” (Biasi and Weldon, 2009) utilizes these data to develop qualitative estimates of the magnitude-frequency distributions along these well-studied sections of the faults. Other techniques provide more “expert-opinion” approach, such as the ”maximum possible” events modeled in more simple approaches (e.g., Scharer et al., 2014).

2. Datasets of slip per event, obtained either through measurement on high-resolution topographic or by 3D excavation and reconstruction of offset features provide testable data on earthquake behavior. Such tests have been accomplished by merging the topographic analyses with excavated paleoseismic event sites, and through dating to test the offset reconstructions. Via the combined efforts of the SoSAFE community, we have generated a good base of locations where we can combine approaches, using high-

quality anchor sites to pin the observations and extrapolate where they are not as easily tested. New anchor sites can be used to test these models going forward.

3. The session on earthquake simulators was instructive for the participants (mostly earthquake geologists), who were able to ask detailed questions about the model parameters in the earthquake simulators. The models have great potential to examine the system-level knowledge of the features that are most critical to fault behavior. However, in discussion there were aspects of the models such as the smoothness of the faults, the method used to tune the model to match paleoearthquake rates, and the backslip approach that were considered places where improvements could be made in the simulator models. We anticipate that better communication between modeling and earthquake geology will be an outcome of the SCEC5 projects. So far, the datasets used for tuning and testing the simulators have limited metadata and don't allow for clear exploration of alternatives. Thus, one of the outcomes of the workshop is an appreciation of the need for richer paleoseismic data products including event pdfs, quality weighting, etc. to be made available in uniform formats.

4. Radiocarbon dating typically results in 50-100 year uncertainties on paleoearthquake event ages due to variable ^{14}C production through time and (appropriately) conservative date modeling that constrains the event age based on the ^{14}C dates in surrounding layers. Due to the frequency of earthquakes along the SAF/SJF system of 100-200 years, we are searching for new levers to identify if temporally correlative events seen at two or more sites are in fact the same rupture. In addition to the use of paleoslip (Biasi and Weldon, 2009), new approaches such as environmental proxy data are now seen as a possible way forward (Rockwell 2016, Scharer et al., 2014. Participants were enthusiastic about the utilization of high-resolution proxy data from southern California, climatic/weather events that may be useful to the 1000-year records of paleoearthquakes, and the value of the paleoseismic records for the paleoclimate community. Moving forward, paleoearthquake studies will need to be undertaken with such approaches in mind, and by revisiting existing sites to augment the original data.

References cited

Biasi, G. P., & Weldon, R. J. (2009). San Andreas fault rupture scenarios from multiple paleoseismic records: Stringing pearls. *Bulletin of the Seismological Society of America*, *99*(2 A), 471–498. https://doi.org/10.1785/0120080287

Rockwell, T. K. (2016). Open Intervals, Clusters and Supercycles: 1100 years of Moment Release in the Southern San Andreas Fault System: Are we Ready for the Century of Earthquakes?. Oral Presentation at 2016 SCEC Annual Meeting.

Scharer, K., Weldon, R., Streig, A., & Fumal, T. (2014). Paleoearthquakes at Frazier Mountain, California delimit extent and frequency of past San Andreas Fault ruptures along 1857 trace. *Geophysical Research Letters*, *41*(13), 4527–4534. https://doi.org/10.1002/2014GL060318

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AGENDA

9:00 Introductions

9:15-11:45 EARTHQUAKE RECURRENCE AND SLIP OVER SHORT AND LONG TERM: HOW DOES IT ALL ADD UP

8 talks, 15 min each

Creep and other EQ cycle challenges from recent observations (9:15-10:15)

Toke: The Dry Lake Valley site: Observations of structures formed by modern and prehistoric creep on the central San Andreas Fault

Dawson: South Napa 2013 trenches: creep, afterslip, missed events!

Lindsey: Creep on the Imperial Fault and new faults in the Salton Trough

Milliner: Near field and off fault deformation revealed using optical image correlation

15 min break

Adding up slip: Segment boundaries and slip rate variations (10:30-11:45)

Cooke: Slip rates and distributed deformation in and around San Gorgonio Pass

Onderdonk: Earthquake displacements and timing of events at Quincy and Mystic Lake, SJF

Salisbury: Reconciling topographic and subsurface measures of offset

Discussion: What does slip rate variability mean for fault and crustal rheologies? Why aren't paleoseismic/geologic data used as constraints on this? Proposal and project ideas. (30 min)

1-3 INTEGRATING EARTHQUAKE AND PALEOCLIMATE/PALEOENVIRONMENTAL CHRONOLOGIES ON THE SoSAFE SYSTEM

Rockwell: A lake-based event chronology for the Southern San Andreas and San Jacinto Faults (15 min)

Scharer: Sediment accumulation curves discriminate between proximal event records on the southern San Andreas Fault (15 min)

Kirby: Holocene droughts, fires, floods and pluvials in southwestern California (30 min)

McKay: PAGES 2k and other approaches to integrating paleoclimate proxy data (30 min)

Discussion: Where does SoSAFE go to advance this research (30 min, Arrowsmith lead)

15 min break

3:15-4:45 OUTSIDE LOOKING IN: BROAD APPLICATIONS OF BEHAVIOR OF HIGH SLIP RATE FAULTS

Biasi: So many earthquakes, so little time: An examination of SAF-system earthquake recurrence

Gilchrist: RSQSim for paleoseismologists; what's under the hood and SoCal results

Milner: Data integration and visualization tools for bringing paleoseismic data and simulator results together

Discussion and Wrap up (30 min)

Earthquake geology data and metadata needs

Paleoseismology in CISM

Simulator opportunities

Adieu to SoSAFE!