The Role of Climate in the Formation of Geomorphic Features Used for Fault Offset Measurement

Report for SCEC Award # 15139

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I. Project Overview

A. Abstract

In the box below, describe the project objectives, methodology, and results obtained and their significance. If this work is a continuation of a multi-year SCEC-funded project, please include major research findings for all previous years in the abstract. (Maximum 250 words.)

We targeted the Van Matre Ranch (VMR) reach of the San Andreas fault (SAF) in the southern Carrizo Plain to investigate the age of short-lived offset geomorphic features. Here, several closely-spaced channels from similar-sized drainages are offset along the relatively simple, well-expressed SAF. We excavated four subtle topographic depressions previously interpreted as beheaded channels (as confirmed in the B4 lidar data) less than 10 m from feeder channels. Three of the four beheaded gullies have associated sub-surface channel deposits from which we refined existing (and debated) surface slip measurements and sampled for radiocarbon and optically stimulated luminescence (OSL) estimates of initial channel incision/fill ages. At one site, we found no associated sub-surface channel deposits from the “beheaded gully” and conclude that the swale is actually a fosse (depression) between two small (~10 m radius) offset alluvial fans. In the same trench, we found three buried channel deposits with >10 m of displacement. In total, we have four distinct fault-offset geomorphic features (the ~10 m radius alluvial fan and three sub-surface channel fills) potentially sourced from the same channel feeder offset 3.8 m, 13.8 m, 16.4 m, and 26.3 m, respectively (with slip increments of 3.8 m, 10 m, 2.6 m, and 9.9 m). Based on reconstruction of the alluvial fan apex, these data suggest that slip in the Mw 7.9 1857 event was ~4 m at the VMR site and the additional 10 m of offset for the buried channel fill occurred in at least one and possibly more earthquakes.

B. SCEC Annual Science Highlights

Each year, the Science Planning Committee reviews and summarizes SCEC research accomplishments, and presents the results to the SCEC community and funding agencies. Rank (in order of preference) the sections in which you would like your project results to appear. Choose up to 3 working groups from below and re-order them according to your preference ranking.

Southern San Andreas Fault Evaluation (SoSAFE)
Earthquake Geology
Working Group on California Earthquake Probabilities (WGCEP)

C. Exemplary Figure

Select one figure from your project report that best exemplifies the significance of the results. The figure may be used in the SCEC Annual Science Highlights and chosen for the cover of the Annual Meeting Proceedings Volume. In the box below, enter the figure number from the project report, figure caption and figure credits.

Figure 3, Annotated air photo showing T1 with additional hand trenches. Approximate fan outlines are shown with white dashed lines and buried channel thalwegs are shown as dashed blue lines. All offset measurements are made using T1-T10 projections into the fault trace (pinpointed in T9 and T5-6-7). Salisbury, Arrowsmith, Rockwell, Akciz, Grant Ludwig.

D. SCEC Science Priorities

In the box below, please list (in rank order) the SCEC priorities this project has achieved. See *https://www.scec.org/research/priorities* for list of SCEC research priorities. *For example: 6a, 6b, 6c*

2a, 1a, 1d

E. Intellectual Merit

How does the project contribute to the overall intellectual merit of SCEC? *For example: How does the research contribute to advancing knowledge and understanding in the field and, more specifically, SCEC research objectives? To what extent has the activity developed creative and original concepts?*

Fault-offset fluvial features are commonly cited in paleoseismic and slip-per-event studies as indicators of slip magnitude for particular earthquake events (both historic and prehistoric), but the individual small scale offsets (up to 10's of m) are rarely dated, challenging attribution of slip to dated earthquakes. This project attempts to link fault-offset geomorphic features to causative storm events or multi-year climate episodes for a better understanding of under what conditions fluvial cut/fill sequences are created and preserved in the southern Carrizo Plain. Coupling this understanding with knowledge of recent earthquake timing along the southern San Andreas will help us improve earthquake chronologies and may be a key to refining slip-per-event along the SAF system.

F. Broader Impacts

How does the project contribute to the broader impacts of SCEC as a whole? *For example: How well has the activity promoted or supported teaching, training, and learning at your institution or across SCEC? If your project included a SCEC intern, what was his/her contribution? How has your project broadened the participation of underrepresented groups? To what extent has the project enhanced the infrastructure for research and education (e.g., facilities, instrumentation, networks, and partnerships)? What are some possible benefits of the activity to society?*

This collaborative, largely field-based investigation required help from a range of participants. We employed 5 undergraduate student researchers (2 from ASU, Sutton (F) and Fischman (F); 1 from SDSU, Marquez (F); and 2 from UCI, Matt Martin (M) and Juliet Olsen (F)), a USGS undergraduate intern (Midttun (M)), 2 graduate students from ASU (Salisbury (M) and Williams (F)), and four professional investigators. The undergraduates learned basics of 3-D trench excavation and logging, balloon aerial photography, and structure from motion (SfM) generation of high-resolution models of trench exposures and surface topography. Students helped with post-field data assimilation and attended the 2015 SCEC annual meeting.

G. Project Publications

All publications and presentations of the work funded must be entered in the SCEC Publications database. Log in at *http://www.scec.org/user/login* and select the Publications button to enter the SCEC Pubications System. Please either (a) update a publication record you previously submitted or (b) add new publication record(s) as needed. If you have any problems, please email *web@scec.org* for assistance.

II. Technical Report

The technical report should describe the project objectives, methodology, and results obtained and their significance. If this work is a continuation of a multi-year SCEC-funded project, please include major research findings for all previous years in the report. (Maximum 5 pages, 1-3 figures with captions, references and publications do not count against limit.)

A. Introduction and Background

In the past few decades, paleoseismic investigations in southern California have generated and refined an earthquake catalog, detailing the timing of and to a lesser degree the amount of offset in historic and prehistoric earthquakes (e.g., Weldon et al. 2004; Akciz et al. 2010; Madden et al. 2013; Dawson, 2013; Rockwell et al. 2014; Scharer et al. 2014; Field et al. 2014). This work has driven a change not only in our observations of earthquake recurrence, but also in the models used to explain the observed patterns: recurrence timing and moment distribution are significantly more variable than originally thought (Weldon et al. 2004; Akciz et al. 2010; Scharer et al. 2014; Rockwell et al. 2014).

Completing a comprehensive description of the spatio-temporal distribution of earthquakes in southern California is urgent. However, the geochronological techniques (^{14}C and Optically Stimulated Luminescence--OSL) we use to address earthquake timing in paleoseismic trenches are themselves a limit to achieving this goal. For example, radiocarbon ages may have ±25 years of measurement uncertainties which map into even narrower constraints in steep parts of the calibration curve (e.g., 500 years BP; Figure 1a). On the other hand, a 300 year BP age maps into a much broader multimodal calibrated age (Figure 1b). OSL can be as precise as ±10 years and it along with a sequence of stratigraphically constrained ^{14}C ages can be used to build very good age models (Lienkaemper and Ramsay, 2009). But, we always will run up against an approximately decadal scale uncertainty on earthquake timing using numerical dating alone.

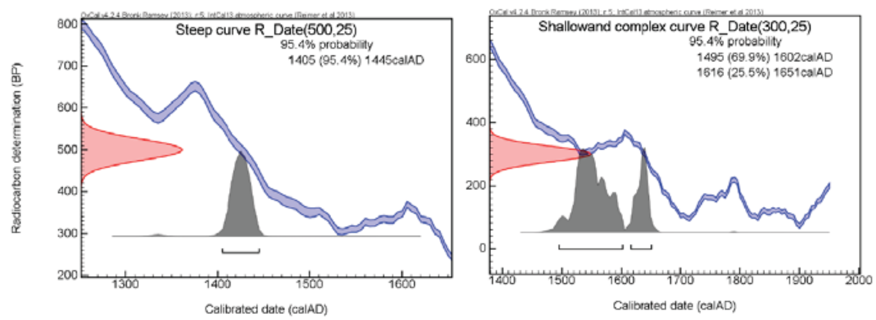

Figure 1. Simple illustration of effect of radiocarbon calibration on age control. (Left) Calibration through a steep portion of the curve at 500 years BP produces a narrow single mode date of similar uncertainty. (Right) Calibration over the last several hundred years—when we most need information about past earthquakes—generates broad multimodal dates. https://c14.arch.ox.ac.uk/oxcal/OxCal.html

In light of the geochronological limitations, a promising approach to refine the earthquake database is to use, where possible, evidence of geomorphic events that are driven by climatic episodes occurring over annual to decadal timescales. This project represents an effort to integrate paleoseismic and geologic data into rupture histories across southern California and to assess records of geomorphic events preserved in trench stratigraphy (e.g., Scharer et al. 2014). We combine geomorphic and climatologic approaches (e.g., Grant Ludwig et al. 2010) with chronometric techniques to explore the linkage of geomorphic offsets to dated paleoearthquakes.

For a test of these ideas in a place that we know well, we focused on the VMR reach of the Carrizo Plain where the SAF is well-expressed and preserves several closely-spaced offset channels and beheaded gullies (Figure 2) (Noriega et al. 2006). There, groups of displaced offset features, noted by Wallace (1968) and investigated by Sieh (1978), have been attributed to several thousand years of cumulative displacement in successive earthquakes (Noriega et al. 2006). These earthquakes are radiocarbon-dated at the nearby Bidart Fan, ~10 km to the northwest. Prior to the 1857 Fort Tejon (M_w 7.9) earthquake, the most recent ground-rupturing events occurred A.D 1631-1823, A.D. 1580-1640, A.D. 1510-1612, A.D. 1450-1475, and A.D. 1360-1452 (Akciz et al. 2010).

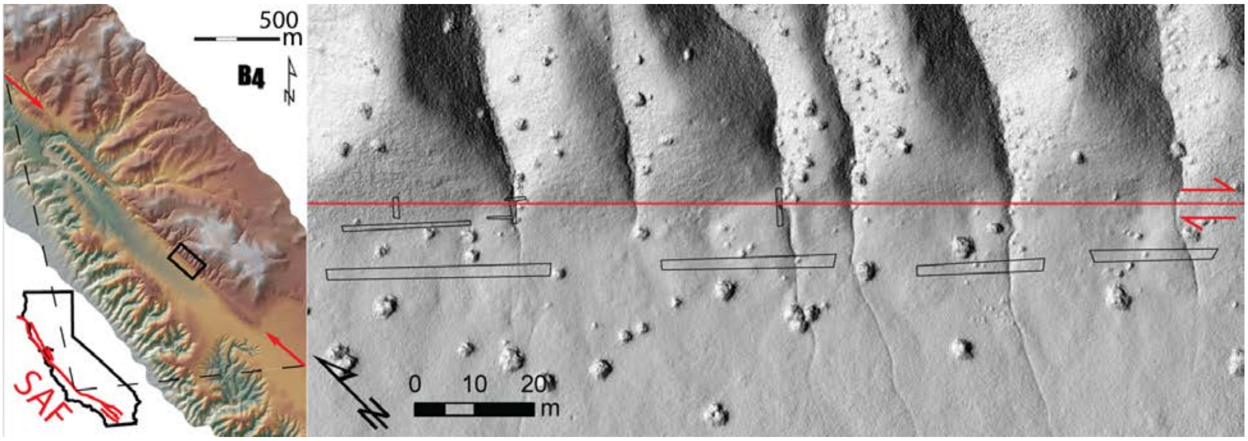

Figure 2. (Left) B4 lidar imagery of the Van Matre Ranch reach of the San Andreas fault in the Carrizo Plain (35.152798˚, -119.697454˚) with overview map showing location within CA. Black box shows location of right figure. (Right) Hillshade of 0.03 m digital elevation model (DEM) generated using low-altitude balloon aerial photographs in Agisoft Photoscan Pro structure from motion (SfM) software. Trench outlines shown.

Sieh (1978) originally identified and measured several channels along the VMR reach of the Carrizo, many of which were re-measured by Zielke et al. (2010) in an effort to refine slip estimates for the 1857 Fort Tejon earthquake. Groups of offset channels and beheaded gullies, ranging from 5 to 30 m of displacement, are in different stages of geomorphic evolution and may be indirectly associated with causative earthquakes based on event chronology at nearby Bidart Fan (Akciz et al. 2010). Work by Liu-Zheng et al. (2006) revealed that as many as four of the last six events ruptured with 7 to 8 m of slip, implying a somewhat regular but not strictly uniform rupture behavior, whereas Grant Ludwig et al. (2010) reported variable slip (0.5 to 5.9 m) for the last five ruptures at Bidart Fan. Additionally, Noriega et al. (2006) excavated a 28 m offset and dated timing of initial incision at A.D. 1160, producing a 29.3 to 35.6 mm/yr slip rate for the site. Considering the foundation of work here (in addition to other ongoing work at Phelan Creeks), this as an optimal natural laboratory to directly test whether or not we can use chronometric approaches to date these short-lived ephemeral fluvial features. One fundamental question addressed is whether or not we can determine if channels that formed between dated earthquake events were initiated in a punctuated event or over the course of seasons to decades, ultimately shedding light on slip-marker production rate for this region of the southern San Andreas fault.

B. Methods

Prior to excavation, we use low-altitude balloon aerial photographs to construct 3 cm digital elevation models (DEMs) of the VMR site in Agisoft PhotoScan Pro. We used the high-resolution topography to document the surficial geomorphology in greater detail than the B4 lidar data and refine proposed fault-parallel trench locations for backhoe excavation. We targeted four feeder channels and had the backhoe dig four fault-parallel trenches on the southwest side of the SAF across downstream elements of displaced or beheaded channels. Trenches were extra wide to avoid the need for shoring. Where necessary, we dug hand trenches to completely reveal channel bottoms, precisely locate the fault trace, evaluate fault zone width, reveal 3-D sedimentary geometries, and extend piercing lines (defined by channel thalwegs/margins) into the fault trace. We targeted four subtle topographic depressions previously interpreted as beheaded channels (as confirmed in the B4 lidar data) less than 10 m from feeder channels. We photographed trench exposures and generated high-resolution orthophotos in Agisoft Photoscan Pro. We logged trench stratigraphy at 1:20 scale on printed orthophotos. We used a total station to document the trench locations, record channel geometries, and establish a network of ground control points used in our structure from motion models. We sampled channel fills for radiocarbon and optically stimulated luminescence (OSL) age control but these data are currently pending.

C. Results

Three of the four beheaded gullies have associated sub-surface channel deposits from which we refined existing (and debated) surface slip measurements and sampled for radiocarbon and OSL estimates of initial channel incision/fill ages. At one site (T1) we found no associated sub-surface channel deposits from the "beheaded gully" and conclude that the swale is actually a fosse (depression) between two small (~10 m radius) offset alluvial fans (Figure 3). In the same trench, we found three buried channel deposits with >10 m of displacement. In total, we have four distinct fault-offset geomorphic features: the recent ~10 m radius alluvial fan and three sub-surface channel fills - all potentially sourced from the same channel feeder. We await OSL dates for confirmation. Individual offset measurements for these features are 3.8 m, 13.8 m, 16.4 m, and 26.3 m, respectively, corresponding with slip increments of 3.8 m, 10 m, 2.6 m, and 9.9 m. Based on reconstruction of the alluvial fan apex, these data suggest that slip in the Mw 7.9 1857 event was ~4 m at the VMR site. The additional 10 m of offset for the buried channel fill (offset a total of 13.8 m) occurred in at least one and possibly more prior earthquakes. The 26.3 m offset channel is a consequence of at least 4 events. The configuration of these landforms suggest that there have been no major incision events at VMR since the incision and filling of the ~14 m offset channel, and the current channel emanating from T1 feeder is a result of great storms such as that of 1862.

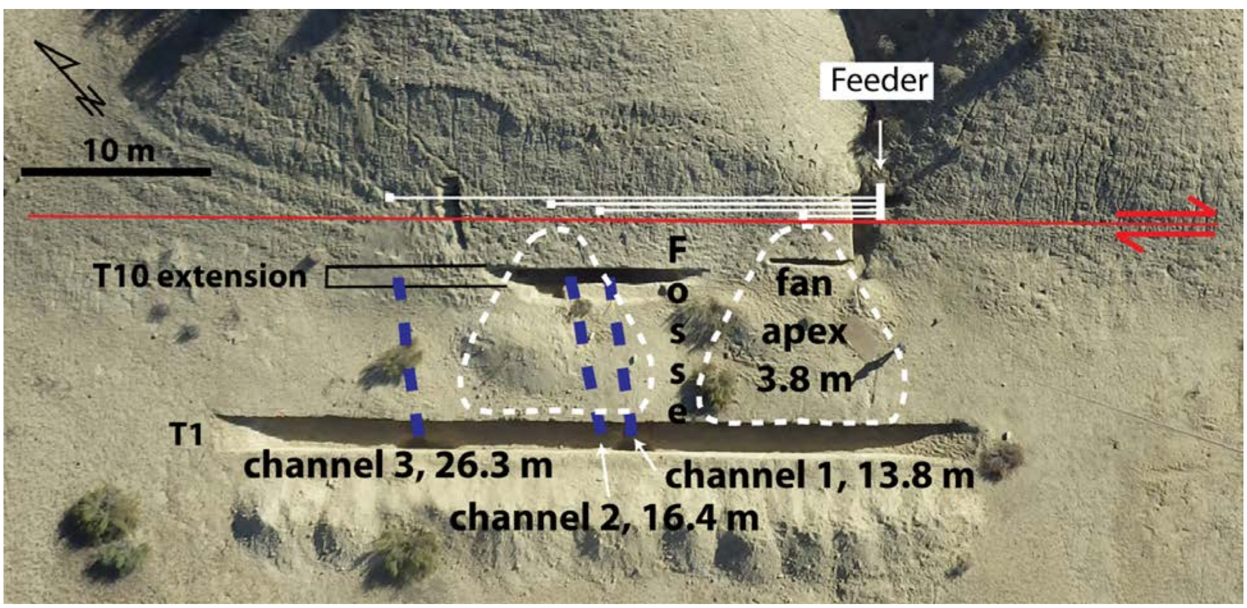

Figure 3. Annotated air photo showing T1 with additional hand trenches. Approximate fan outlines are shown with white dashed lines and buried channel thalwegs are shown as dashed blue lines. All offset measurements are made using T1-T10 projections into the fault trace (pinpointed in T9 and T5-6-.7

D. References

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