2011 SCEC Annual Report

11104: *Multi-earthquake slip rate, Frazier Mountain paleoseismic site*

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SUMMARY
Like slip per event, multi-earthquake slip rates provide critical data for refining earthquake correlations between paleoseismic sites. We have collected sufficient trenching data on the faulting and geometry of tilted bedding at the Frazier Mountain paleoseismic site (San Andreas fault) to show that the site has been a pull-apart basin for at least the last ~1000 years. We do not, however, have sufficient data to map the evolution of the basin, which we need to calculate robust multi-earthquake slip rates. The goal of this project was to complete a cone penetrometer (CPT) survey of the western portion of the site in order to (1) test the feasibility of this approach at Frazier and (2) add to the 3D database of the site structure without using the destructive and time-consuming process of trenching. The CPT field effort was successful, and we are now integrating the results into our 3D map of the site structure. In order to confidently correlate units the spacing of CPT holes needed to be closer together than we originally planned so the survey extent was smaller than proposed. However, the utility of the data is sufficient that we will be investigating other sources of funds to complete a larger survey at the site. The CPT survey shows that the syncline associated with the Frazier pull-apart has been active for at least 2000 years, and that the location and orientation of the syncline has not changed. As proposed, the CPT survey informed our future excavations and is being incorporated into our 3D database of the site structure.

1. Project Objectives

Through trenching investigations over the last four summers (funded by a combination of NSF, SCEC, and NEHRP funds), we have established that the Frazier Mountain paleoseismic site is located at a small transtensional pull apart (Fig. 1). Deformation at the site includes many of the classic features of pull apart basins, such as basin sidewall faults that bound an elongate depocenter and cross cutting strike slip faults. Repeated movement on the faults and subsequent deposition of alluvial fan and pond deposits into the depression has produced a remarkable set of growth strata relationships that both record the timing of earthquakes and the cumulative slip across the pull-apart. We are currently working on a manuscript that details the deformation and timing of the past eight earthquakes at the site, which have occurred on average every 136 years since ca. 900 A.D. Recurrence at the site appears temporally variable, including a cluster of three earthquakes in only 100 years, and shows strong similarities to the neighboring Bidart Fan record.

In addition to earthquake ages, we have been working to determine slip per event at Frazier. This goal has been challenging, however, because the factors that improve event recognition – distributed deformation and fast sedimentation rates – make displacement data more difficult to obtain. We have taken two approaches to solving this problem. The first approach was to dig a network of “shallow” trenches, ~2 m deep, around the site (Fig. 1). Shallow trenches are both quick to dig and easier to photograph and map, so they have provided us with a general understanding of the shape and size of the pull-apart basin. Specifically, we can now isopach deposits deformed by the last five earthquakes across the eastern third of the site (Streig and Weldon, 2011); know the orientation and ages of basin side wall faults; and are compiling a 3D map of the deeper section exposed in T1. The second approach was to excavate serial exposures of deep (up to 6 m) trenches in the middle of the site. These trenches have sloping walls and are below the water table, so are technically challenging and take significantly more time and funds to complete. The important benefit of deep excavations, however, is that T1 is centered at the deepest part of the depocenter, where strain markers (bedding) are most tilted and offset, and thus will produce narrower uncertainties in the slip calculations. Trenching, however, is very time consuming and thus costly, and provides a limited view of the structure. The goal of this project is to explore the use of CPT at Frazier to more efficiently map out the 3D structure at the site and use this to constrain multi-earthquake slip rates.

2. Methodology

CPT studies provide an efficient measure of the sediment and pore fluid properties in the shallow subsurface. In this technique, a truck-mounted penetrometer is pushed into the ground and continuously measures resistance at the tip of the cone, frictional sliding resistance of the sleeve of the cone, and pore pressure. These values are correlated at 5 cm intervals to a soil behavior type (effectively sediment grain size), based on work summarized by Lunne et al. (1997). Due to the size of the CPT probe (3.8 cm diameter), this technique works well in the types of sediment we have at Frazier and is faster than traditional drilling because is produces no waste and requires no backfilling.

We contracted a total of four days of work with Gregg Drilling and Testing, using their 30 ton CPT rig. The CPT team completed a total of 35 CPT holes to depths of 30 to 80 feet below the ground surface. The CPT locations were later surveyed (Fig. 1) and Master’s student Lauren Austin at the University of Oregon correlated the lines based on cone resistance, sleeve friction, the friction ratio, pore pressure, blow count, and the soil behavior type as described for CPT studies by Lunne et al. (1997).

3. Results

We have completed a correlation of the primary CPT lines (Fig. 2). These lines show the following:

Line 1: Line 1 is parallel to the main fault zone and shows that layers dip to the northwest, consistent with our trench observations, until position 1.4 and then flatten out. This change is co-located with the die-out of the main fault zone in trench 14 (Fig. 1). The fault steps to the north of the line at station 1.5; trenches that extend south of the main fault zone show that units on the southern half of the site are largely undeformed and flat-lying, consistent with the correlations in this line.

Line 2: Line 2 is oriented perpendicular to the axis of the syncline as revealed in our trenches, and shows that layers much deeper/older than those we have explored are folded similarly. Based on preliminary correlations with known units in T31, the dramatic thickening between the second and third correlation lines is likely the same section that expands in the deep cuts of T1 (units 60-45, which contain earthquakes 6-8). Note that upper units flatten out to the southwest after they cross the continuation of the main fault zone (locations 2.2 through 2.0).

Line 3: Line 3 is parallel to line 2 and shows a similar pattern, revealing the broad syncline produced by the pull apart structure. CPT location 3.6 is very close to the west wall of Trench 1 cut 4, which will enable us to confidently correlate the upper portions of the CPT with known units.

Line 4: Line 4 is parallel to the west wall of T31, and shows the gently southwest dipping structure of the NE limb of the fold clearly.

Line 6: Line 6 is quite short, but when these points are connected in syncline-parallel transects and tied to our deepest excavations in T1 (6 m deep), we expect to be able to map out the volume clearly.

We are presently working on integrating these results into a 3D database of key horizons. Exact correlation with specific dated units requires that we adjust the elevation of the CPT lines and trenches based on many survey years. Integrating the data has gone slowly since the ground surface at the trench site has varied over time due to our excavations, our original surveys were less precise, and small mismatches must be avoided to properly map the broad structure.

4. Intellectual Merit

This project represents a small portion of our larger field effort to understand the timing and size of prehistoric earthquakes. Because the instrumental and historical records of large earthquakes are too short to discern fault-specific patterns of rupture timing, size, and extent, field data from paleoseismic studies remain necessary to provide key constraints on fault behavior. These data feed into controversies about strain partitioning in the crust over century to millennial timescales, inform on fault connectivity and crustal behavior, and provide fundamental data for probabilistic seismic hazard assessments.

5. Broader Impacts

The Frazier Mountain paleoseismic site has provided training in field methods for over a dozen undergraduate students and three female graduate students. Training has spanned a wide variety of tasks, from detailed field mapping (1:8), photography, trenching techniques, surveying, modeling data in matlab, and use of GIS and other 3D programs to image the data. The three undergraduate students from Appalachian State University (one male Iraq war veteran, two female) that completed a Senior Honors Thesis based on work and data from the site have gone on to graduate school in the geological sciences.

6. Presentations directly tied to this project

Streig, A. R., Weldon, R. J., 2011. Evaluating the relationship between lateral slip and repeated fold deformation along a transtensive step-over on the San Andreas fault at the Frazier Mountain site, Abstract T21A-2308 presented at 2011 Fall Meeting, AGU, San Francisco, CA, 5-9 Dec.

Streig, A. R., Weldon, R. J., 2011. Evaluating the relationship between lateral slip and repeated fold deformation along a transtensive step-over on the San Andreas fault at the Frazier Mountain site, Abstract A-139 presented at 2011 SCEC Annual Meeting.

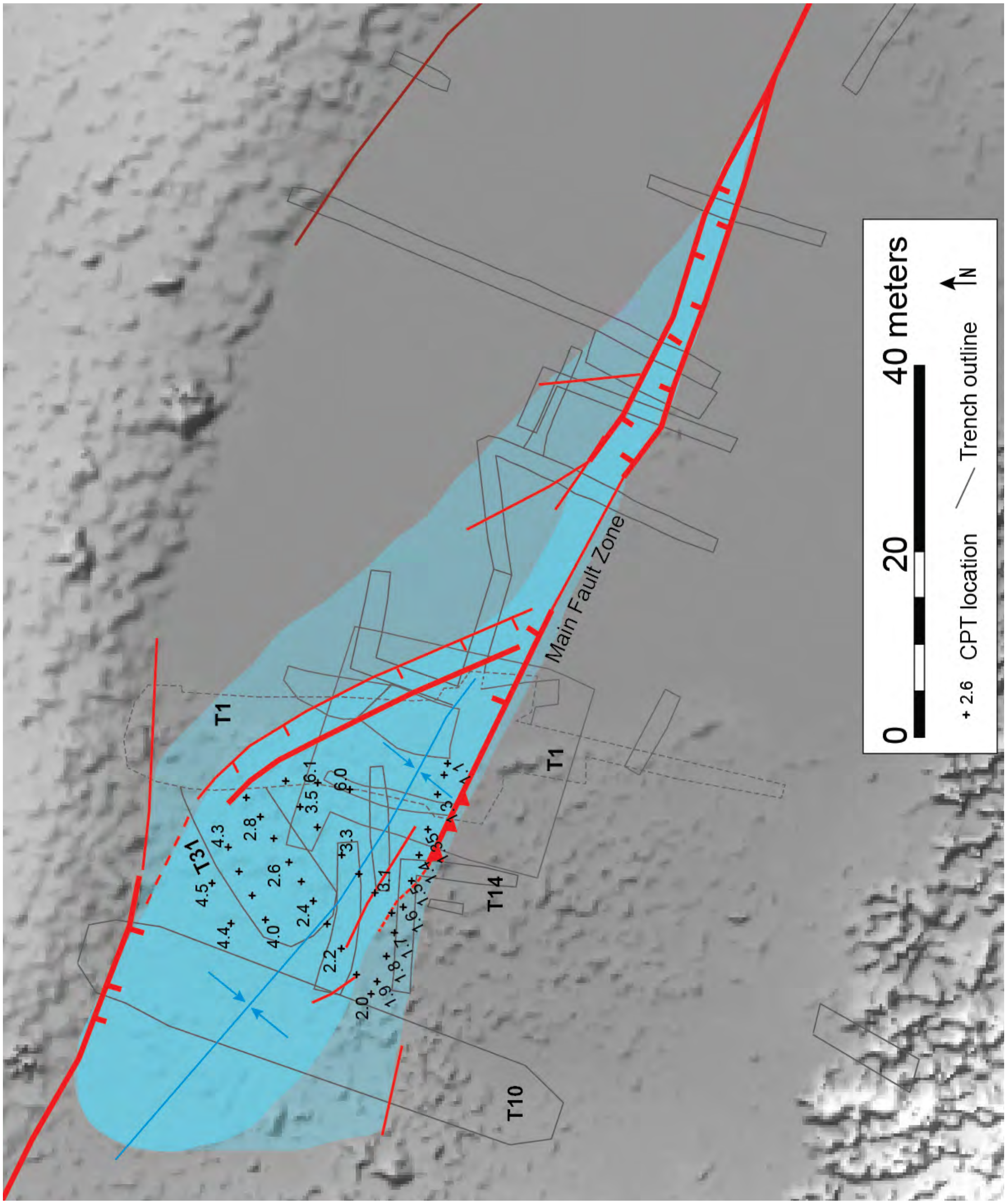

Figure 1. Trench, fault, and CPT locations at the Frazier Mountain paleoseismic site on lidar basemap. Key trenches discussed in text are labeled. Blue region shows area of transtension, where the right step from the main fault zone to the northern fault zone has created a series of small pull apart basins. The blue region has been consistently down dropped along normal and tulip structures, but fast sedimentation rates progressively fill the sag produced during each earthquake.

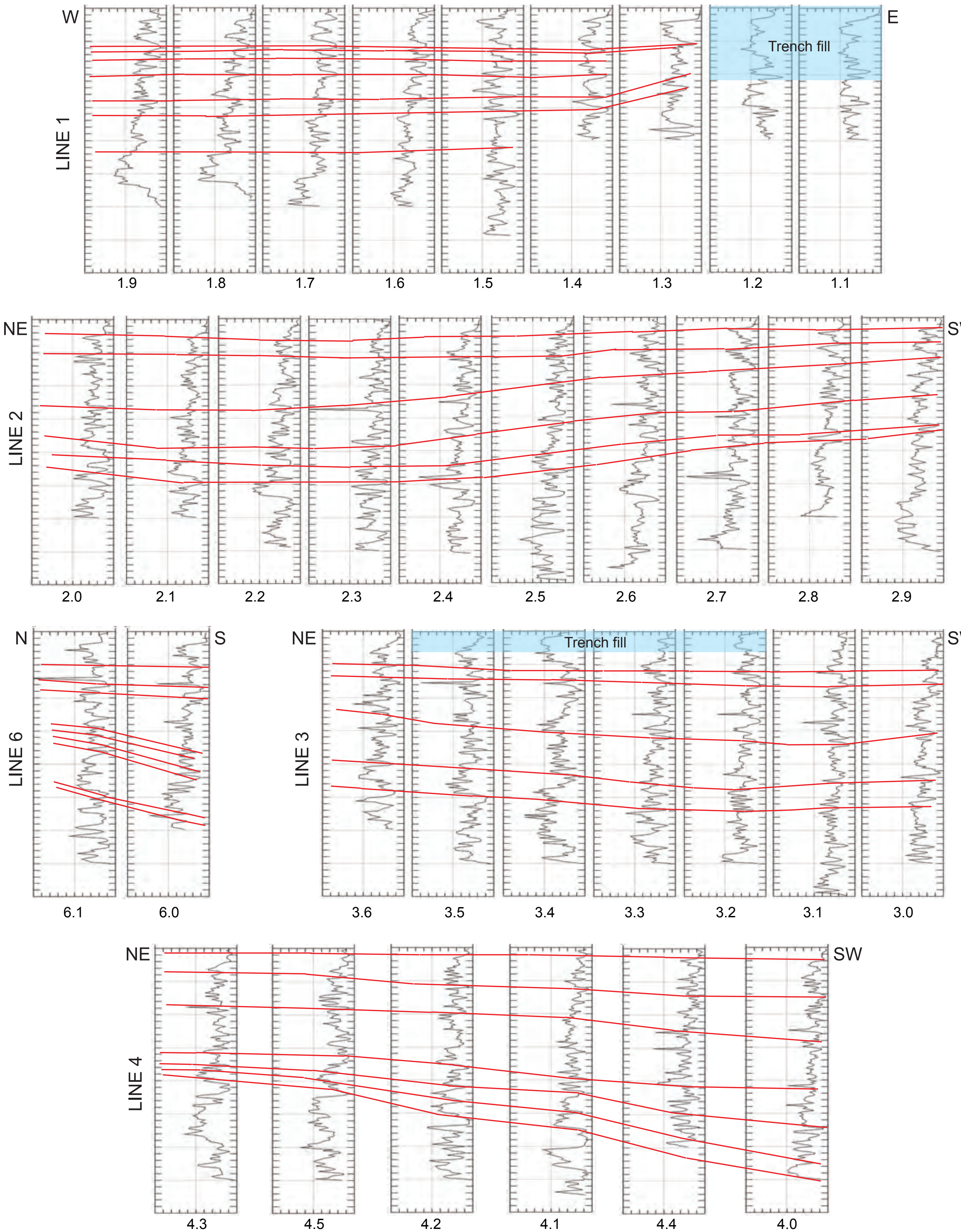

Figure 2. CPT transect correlation diagrams show broad syncline consistent with trench observations is also present in units much older than we have excavated. Curves show friction ratio, but correlations were based on all data. Vertical scale is in 2 foot increments (grey line every 10 feet), horizontal scale is variable, but most locations were ~6 feet apart.