SCEC progress report 2009 for:

SoSAFE- San Jacinto: Quaternary slip rates and late Holocene earthquake history of the Claremont Fault, northern San Jacinto fault zone, California

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Project Description

The purpose of this research was to fill gaps in both paleoseismic data and slip-rate data along the northern San Jacinto Fault Zone to better understand temporal and spatial distribution of plate boundary strain across the southern San Andreas fault system. Recent geologic, geodetic and modeling work has produced results that suggest the San Jacinto Fault Zone may be accommodating an equal or greater amount of slip than the southern San Andreas fault south of Cajon Pass (e.g., Kendrick et al., 2002, Becker et al., 2005; McGill et al., 2008a,b). However, the lack of solid geologic slip-rate data along the northern San Jacinto fault makes this difficult to evaluate. Published slip rates for the northern San Jacinto fault zone range from 6-20 mm/yr (Prentice et al., 1986; Morton and Matti, 1993; Kendrick et al., 2002). Because of ambiguities related to each of these studies a clear consensus for the rate has not yet emerged. The identification and evaluation of several slip-rate sites along the Claremont strand of the northern San Jacinto Fault Zone was a major component of this project and we report the results of our work in 2009 below.

In addition to new slip-rate data along the Claremont fault, new paleoseismic data was sought in order to answer questions regarding the earthquake history along this major strand. A long and detailed earthquake history has resulted from work at Hog Lake (Rockwell, 1990; 2007) along the central San Jacinto fault, and other studies in the Borrego Valley and western Imperial Valley area provide some continuity to the south along the fault zone. However, almost no paleoseismic data has been published from the Claremont fault that makes up the northern San Jacinto Fault zone. Slip history data along the Claremont fault is needed to see how strain along the entire fault zone is distributed temporally and to see if large events along the Casa Loma/Clark Fault recorded at Hog Lake have jumped across the San Jacinto valley releasing step-over and ruptured the Claremont Fault.

Highlights from this year's work include:

1. Preliminary investigation and trenching of a new paleoseismic site, Mystic Lake (Figure 1), that was shown to contain excellent stratigraphy, a record of at least 6 events in the upper 2 meters of strata, and great potential for a long and detailed earthquake history that will be developed over the coming years.
2. A preliminary slip-rate of 17 ± 2 mm/yr calculated from the age of offset paleochannel deposits at the Quincy site (Figure 2).
3. New OSL and radiocarbon dates from terrace deposits that have been vertically displaced by movement along the Claremont Fault suggesting uplift rates of about .5 mm/yr.
4. Expansion and refinement of our fault structure map.

5. New data regarding the relative age of individual fault strands and fault zone development.

Statement of Project Goals for 2009

Fault Zone Structure-

Continue detailed mapping and field investigations of the Claremont Fault to better understand the tectonogeomorphic setting of the slip rate and slip history sites (Figure 1), and to document the development of the fault zone through time.

Slip Rate-

Evaluate previously identified slip rate sites using geomorphic mapping, trenching, and dating of Quaternary deposits using ^{14}C and OSL techniques.

Paleoseismology-

Identify and explore potential paleoseismic sites along the Claremont fault.

Work Completed and Results

Fault Zone Structure

A combination of field mapping, air photo analysis, and LiDAR analysis was used to extend and add detail to mapping done during the previous year of SCEC funding. Most of the work was concentrated along sections of the fault where information regarding slip-rate could be obtained or around potential paleoseismic sites (Figure 1). Significant advances were made in understanding both the structure and geomorphic development of these sites as well as the overall fault zone structure and relationship to topographic development along the Claremont fault.

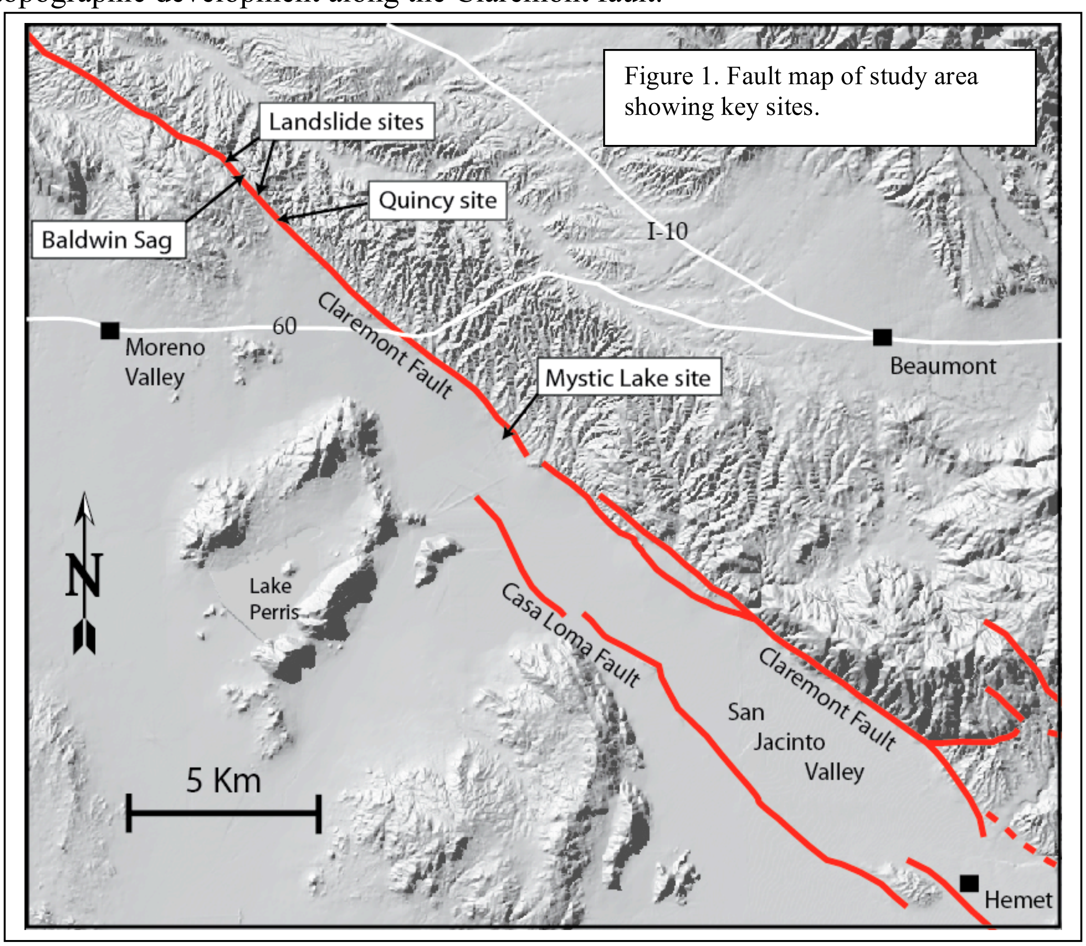


Figure 1. Fault map of study area showing key sites.

At the Quincy slip-rate site, two trenches installed across the fault zone supplemented the mapping data and allowed us to document the relative timing of the two main fault strands in the area (Figure 2). The southwestern fault strand marks the front of the San Timoteo Badlands that have been lifted up along the northeast side of the fault. The northeast fault strand cuts across the small canyons and ridges that have developed in the uplifted badlands and consistently deflects these drainages by approximately 20 to 25m right-laterally. Two trenches were excavated along the front of the badlands and cross both fault strands. Stratigraphic relationships and ^{14}C dating in both trenches show that the southwestern strand has not ruptured in the last 1500 years and that the northeastern fault is currently accommodating the displacement and has ruptured once prior to 230 ± 20 BP and at least twice since then. These data, along with the tectonic geomorphology of the site, show that movement along the southwestern fault that marks the front of the badlands has ceased as slip was transferred to the northeastern fault. This shows that the locus of displacement along the fault zone has switched between fault strands and strengthens interpretations of slip rate based on deflected and abandoned paleochannels in the area (see slip-rate section).

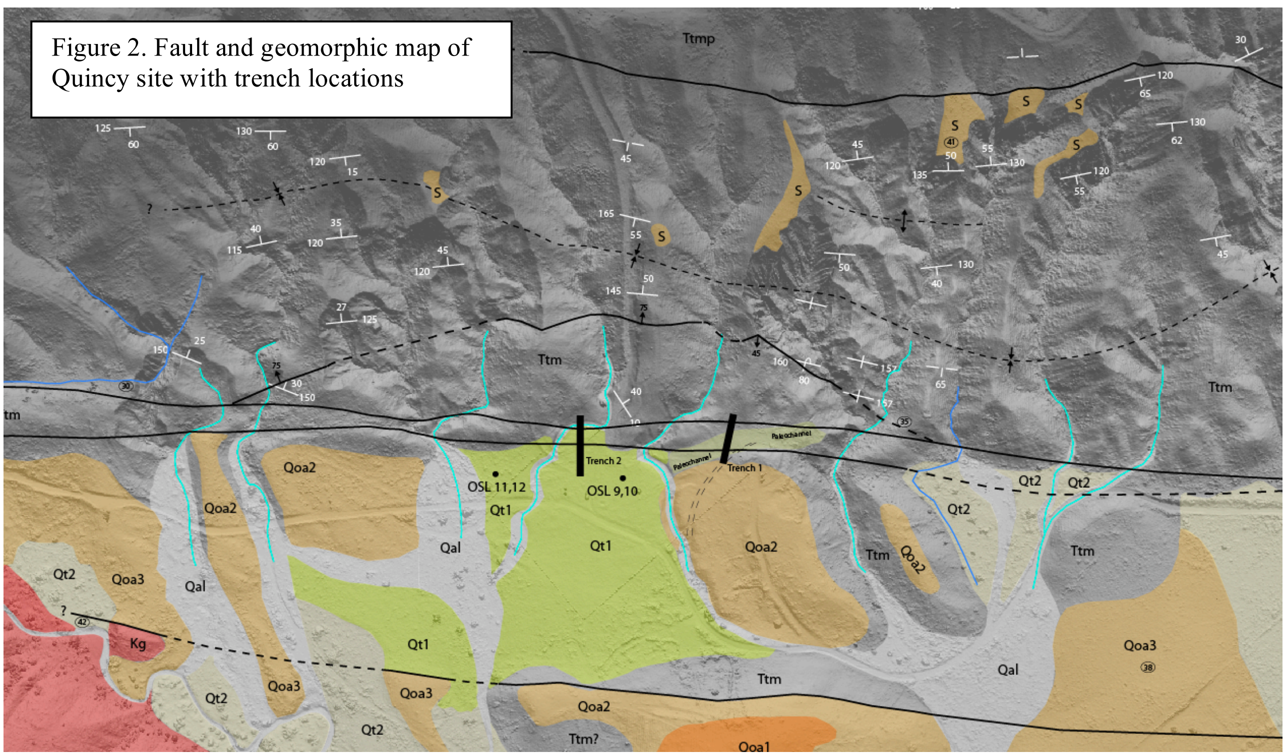


Figure 2. Fault and geomorphic map of Quincy site with trench locations

Mapping, trenching, and dating of Quaternary deposits at the Mystic Lake paleoseismic site (Figure 3) has allowed us to test the validity of potential offsets identified during previous years of funding, determine the origin and age of scarps along the north edge of Mystic Lake, and has provided a better understanding of the geomorphology and fault structure setting of the site. Scarps developed in Quaternary terrace deposits at the north edge of the ephemeral Mystic Lake were previously hypothesized to be due to fault displacement, shallow seated landslides, or the result of erosion by lake highstands (as they are only present along the fault where it intersects the edges of the lake). Two trenches were excavated across the scarps and provided clear evidence that the scarps are tectonic. In both trenches fault surfaces were observed that truncated alluvial fan and shallow lake deposits dated with ^{14}C to be 8645 ± 45 BP. This age agrees with the OSL age of approximately 8.3 ± .5 Ka that we obtained from samples collected within the alluvial fan strata that comprise the upper section of the terrace deposit. These new dates yield a local uplift rate of at least .5 mm/yr and help document the local geomorphic development of the Mystic Lake paleoseismic site. The geomorphic mapping, recognition of older uplifted surfaces in the area, and fault data collected from trenches reveal a complicated fault structure in the area that has most likely evolved with the locus of activity switching basinward (to the southwest) through time. The currently active strands lie out in the basin and exhibit relatively minor vertical displacement, while the older strands mark the edge of the badlands and exhibit significant vertical displacement that has resulted in the uplift of abandoned Quaternary surfaces. Further work is needed to fully understand the geomorphic and structural development along this stretch of the fault zone and we will be committing time this coming summer to resolving the complex structural arrangement and fault interactions to enhance our interpretations of the paleoseismic data collected at the site. The recognition that the scarps at the front of the badlands here are tectonic and not due to lake high stands, brings into question their use in estimating offset and calculating a slip rate along one of the main fault strands in the area. So we no longer believe that the roughly 15.3 mm/yr slip rate that we reported at the SCEC meeting in 2009 from this site is valid.

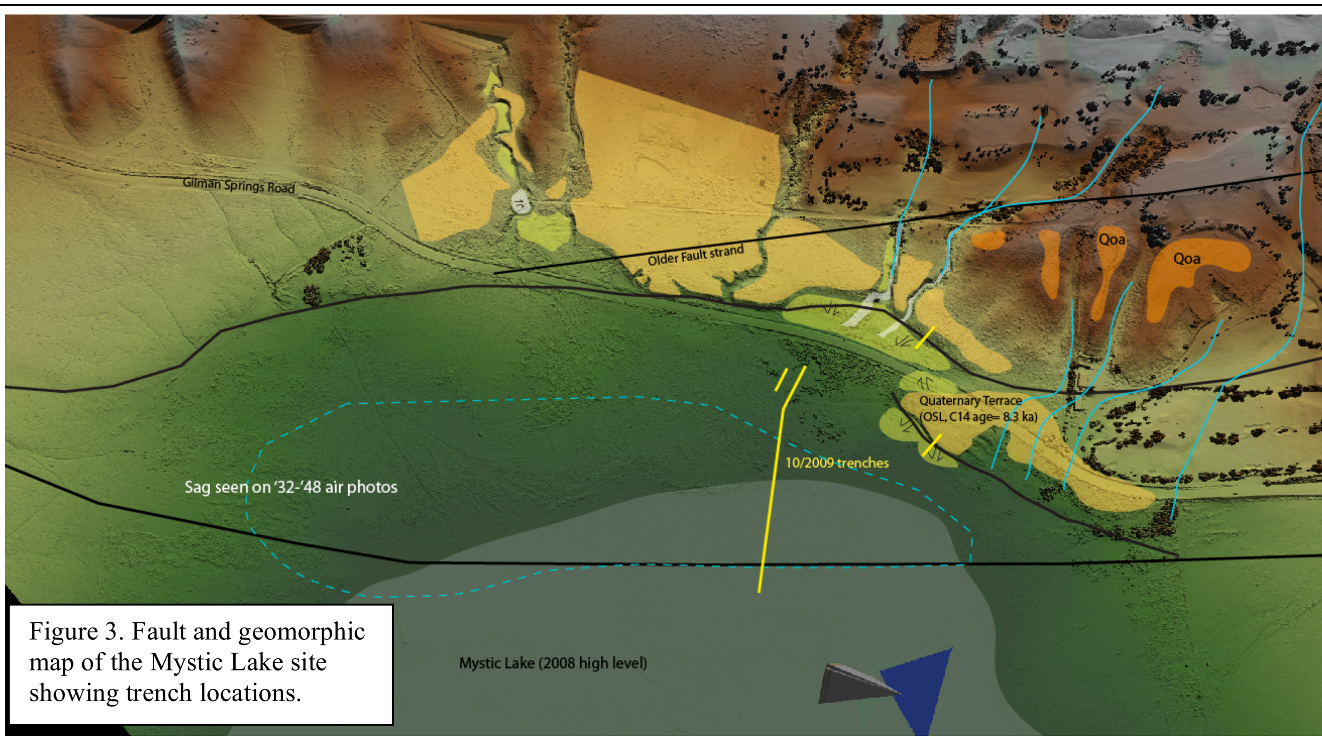


Figure 3. Fault and geomorphic map of the Mystic Lake site showing trench locations.

Slip-rates

Efforts to determine a slip rate for the Claremont fault were concentrated at 3 sites along the fault zone this year. At the Mystic Lake site, a 15.3 mm/yr slip rate was calculated based off the age of apparently offset paleoshoreline scarps. Trench work at the site revealed that the scarps are in fact tectonic and possibly not offset at all. This is the third time a potential slip rate site has been proven to be invalid and exemplifies the caution and detailed investigation needed to locate and evaluate slip rate sites along the Claremont Fault. It also emphasizes the need to devote serious effort to finding and documenting a valid dateable offset to remedy the lack of slip rate information along the northern San Jacinto Fault zone.

Two other sites were also investigated using field mapping, LiDAR analysis, trenching, and geochronology where possible. These sites have yielded some valuable results and are summarized below.

Quincy Site-

At the Quincy site multiple streams developed in the elevated badlands on the northeast side of the fault zone are consistently deflected approximately 23 ± 3 m in a right-lateral sense (Figure 2). At one of these deflections, a paleochannel was developed, abandoned, and subsequently offset 18 m to 25 m. A Trench excavated across the paleochannel revealed paleochannel deposits that were dated at 1300 ± 25 BP based on ^{14}C dates from paleosols developed near the base of the channel deposits (Figure 4). Other paleosols well below the channel deposits were dated to be 2125 ± 35 BP. Using the full range of possible max and min ages and reconstructions, we calculate a slip rate between 9.5 mm/yr and 23.26 mm/yr across the northeastern fault strand. Our preferred age is 17 ± 2 mm/yr based on the most probably age and reconstruction. The 23 m reconstruction used to estimate this slip rate agrees with the deflection amounts of 5 other streams across the northeastern fault strand. The estimate is also supported by paleoseismic data in two trenches across both fault strands that show that displacement across the zone has been concentrated on the northeastern strand for the last 1500 to 2000 years. The story that emerges is that the paleochannel developed due to deflections across the southwestern strand, but was abandoned when continued slip brought a new drainage in line with the upstream equivalent of the paleochannel and avulsion occurred. Around the same time, the southwestern fault strand stopped slipping as the northeastern fault developed and began to deflected drainages that had developed within the badlands due to prior uplift along the southwestern strand. The avulsed channel was then deflected roughly 23 m along with parallel drainages by the northeastern strand.

Offset Landslides-

Northwest of the Quincy site are several landslide deposits that have been shed off the southwest side of the fault, across the fault, and offset by fault movement. These slides were investigated this year as potential slip rate sites through continued mapping of the deposits and an attempt to date one of the landslides by trenching ponded sediments collected within a sakungen on top of the slide deposit. Mapping indicates that the Quincy Ridge slide has been offset at least 1.17 km. This slide contains small closed basins within it that appear to have collected sediment. In June of 2009, we excavated two shallow trenches in these basins in hopes of finding dateable material in ponded sediments that would give us a minimum age for the landslide. Unfortunately, the trenches revealed only coarse colluvium with a well-developed soil on top and provided no dateable material. We are now trying to date this landslide with ^{10}Be techniques in collaboration with Lewis Owen at the University of Cincinnati and will continue this work as part of our 2010 SCEC funded efforts.

The second landslide (Ebenezer slide) is located farther to the northwest along the fault zone. Mapping was conducted in this area to delineate the edges of the slide and we estimate that the slide edges have been offset approximately 200 m. Continued mapping is needed to narrow down the offset estimate and we are attempting to date this deposit with ^{10}Be as well.

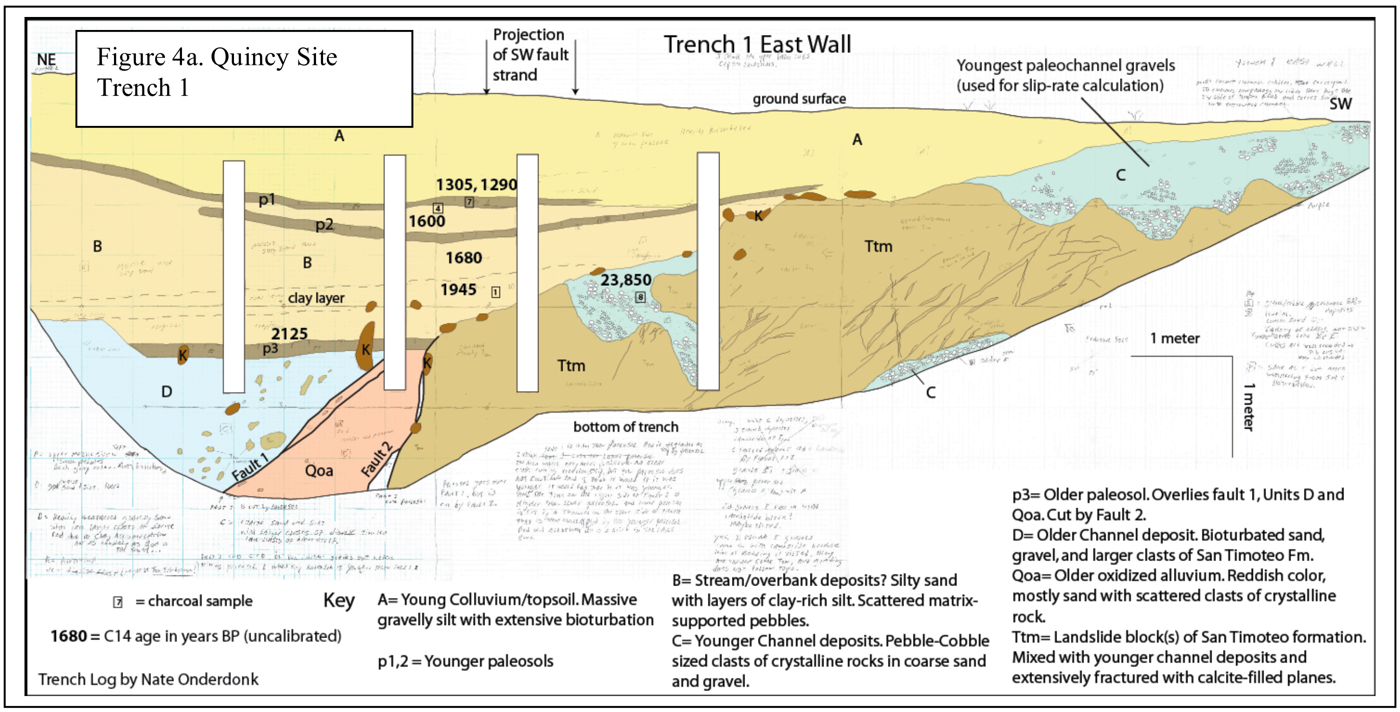


Figure 4a. Quincy Site Trench 1

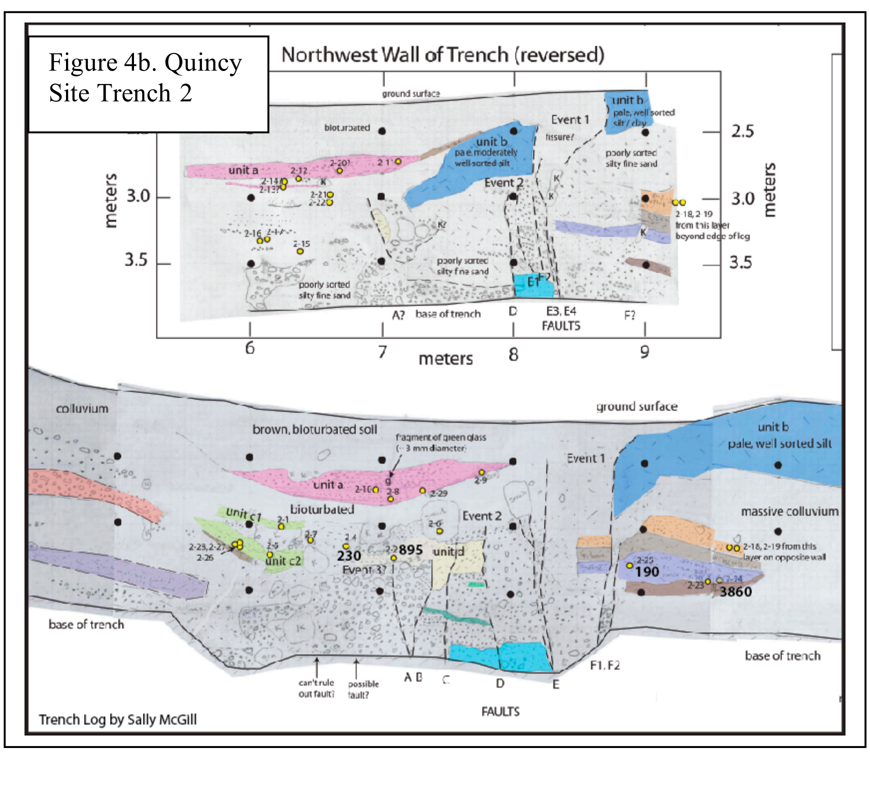


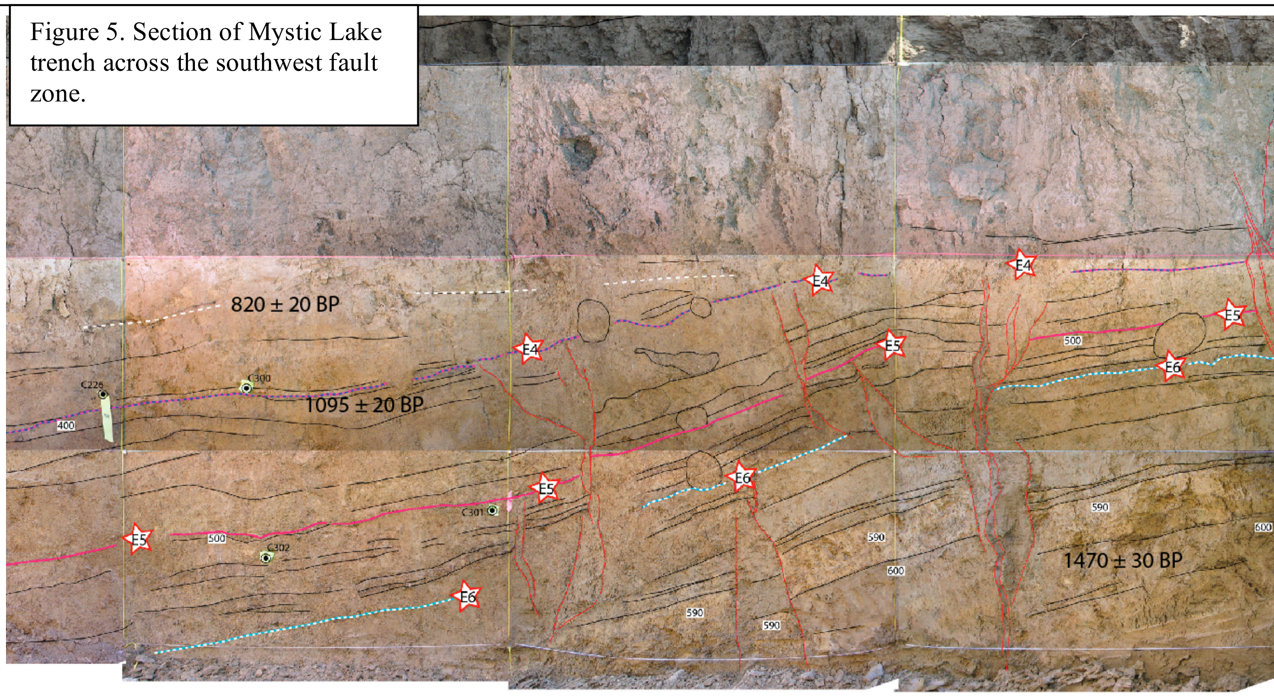
Figure 4b. Quincy Site Trench 2

Paleoseismic Sites
Three potential paleoseismic sites were trenched this year. Two of these, Mystic Lake and Quincy, yielded valuable data and the Mystic Lake site has proven to be an excellent paleoseismic setting that we expect will provide a long and detailed slip history of the Claremont Fault.

Mystic Lake-
Mystic Lake is an ephemeral body of water that fills the lowest elevations of the San Jacinto pull-apart basin (Figure 1). The lake forms during wet years from overflow of the San Jacinto River and local canyons that drain the San Timoteo Badlands. The lake has a peanut shape when full due to encroachment by the Jackrabbit Canyon alluvial fan that has been deposited along the side of the lake. The Claremont Fault passes through the northeastern end of the lake just within the limits of the lake high stand mark. This location looked like an ideal place to investigate the slip history of the fault due to the high probability of encountering organic-rich lake stratigraphy interbedded with distal alluvial fan deposits from Jackrabbit Canyon.
The trench location was picked based on the fault structure and geomorphology constructed from field mapping over the last two years, combined with analysis of LiDAR imagery and historic air photos. The air photos from the 1940's revealed a small water-filled sag with a linear edge that appeared to be a fault scarp. In October 2009 we trenched across the full length of this sag feature (approximately 400m) and found the sag to be well represented in the exposed stratigraphy. Numerous faults were also found with the main deformation zone occurring at the southwestern side of the sag and correlating with the small scarp seen on the air photos.
The stratigraphy is primarily lacustrine clays, silt, and sand that grade to slightly coarser deposits northeast towards the edge of the lake. At the southwest side of the sag, the stratigraphy is faulted and folded and a pattern of rupture with associated subsidence of the sag followed by infill and onlap at the sag edge is apparent (Figure 5). We were able to correlate the stratigraphy along the entire length of the trench and collected over 200 samples for ^{14}C dating. An initial batch of 25 samples were dated last December and show that the 2 meter exposed section in the trench spans an age of about 1724 ± 20 BP to present. At least 6 events were identified and our preliminary slip history is as follows:
Event 1= between 195 ± 20 BP and modern
Event 2= between 820 ± 20 BP and 670 ± 90 BP
Events 3, 4, 5 all occurring between 960 ± 25 BP and 865 ± 20 BP
Event 6= between 1685 ± 25 BP and 1550 ± 20 BP
More dating and future work will help narrow down the timing of these events, but an interesting outcome of the preliminary data is the possible occurrence of an earthquake flurry around 1100 years ago (events 3, 4, and 5). A similar flurry was seen at Hog Lake along the Clark Fault at Anza. This suggests that events maybe jump the San Jacinto pull-apart basin that separates these two faults, or that stress changes due to an event on one fault trigger closely timed events on the other fault.
This initial trenching of the Mystic Lake site shows that it is an ideal location to collect paleoseismic data for the Claremont Fault. Three years of searching for and investigating potential paleoseismic sites along the fault also suggest that this may be the only suitable

location to obtain slip history data on the fault. We intend to devote considerable effort in the coming years to further develop this site and obtain a longer and more detailed paleoseismic record for the northern San Jacinto fault zone.

Figure 5. Section of Mystic Lake trench across the southwest fault zone.



Quincy Site-

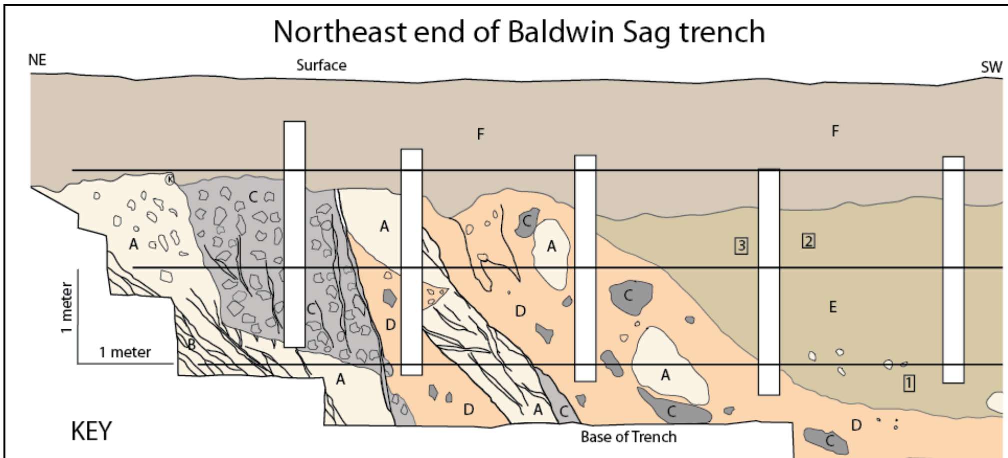
The main purpose of trenching at the Quincy site was to evaluate slip rate, but some paleoseismic information was obtained from the two trenches across the fault. A total of 5 events were recorded in the exposed trench walls- 2 events on the southwestern fault, and at least 3 events on the northeastern fault. Trench 1 extended across both faults, but was significantly deeper across the southwestern fault (approximately 4 meters deep) and exposed two events that occurred on the fault. The first occurred prior to 2125 ± 35 BP and the second occurred between 2125 ± BP and 1600 ± 20 BP (Figure 4). There was no evidence of movement along the fault since 1600 ± 20 BP and we believe that slip has been concentrated on the northeastern strand since that time.

Trench 2 also crossed both faults, but was only 1.5 meters deep along most of its length. No evidence of rupture on the southwestern fault was observed and stratigraphy dated at 2205 ± 20 BP extends undisturbed across the strike of the fault. At least three events were recorded at the northeastern fault zone- one prior to 230 ± 20 BP and at least two events since 230 ±20 BP (Figure 4).

The paleosiesmic data from the Quincy site shows the temporal relationship between the two fault strands that helps in understanding the geomorphic development and supports the slip rate determination. The data may also be valuable in evaluating correlation between this site and the Mystic Lake site, which is located 11 km to the southeast. The current data suggests that the second oldest event at the Quincy site may correlate with event 6 at Mystic Lake, and that one of the most recent events may correlate with event 1 at Mystic Lake. The other events are currently not defined well enough to attempt a correlation between the two sites.

Baldwin Sag-

The Baldwin Sag site is located in an uplifted area between the two landslide slip rate sites. It is a small semi-closed basin that appears to have developed between a small step over in the fault zone. A 4m deep trench was excavated across the northeastern edge of the depression and a clear fault zone was exposed (Figure 6). The fault zone consists of multiple faults that cut through and juxtapose pulverized granidiorite and bedrock landslide material derived from the southwest side of the fault. The basin is filled with finer grained sediments that contained detrital charcoal, but the lack of defined stratigraphy and clear offsets prevented us from using these strata to gain any paleosiesmic information. The finer grained deposits appear to be deposited nonconformably on the faulted bedrock and landslide deposits and no equivalent layers are exposed across the fault due to the uplift and erosion on the northeast side of the fault. This trench confirmed the location of the fault and the interpretation that older landslide deposits have been offset by fault movement, but the site provided no paleoseismic information.



KEY

A= pulverized felsic plutonic rock. Light Cceam color. 50/50 pulverized material and intact clasts

B= Reddish oxidized shear zone of weathered crystalline rock with occasional pieces of Unit A. Multiple anastomosing shearbands that cut through Unit A.

C= Shattered plutonic rock. Dark pepper diorite. Shear zones cutting through. Not as pulverized as Unit A, but very degraded. 70% intact pieces of diorite

D= Fault scarp colluvium and sheet wash. Orange gravel degraded from granitic rock with clasts of Unit A and B. Clasts range from pebbles to boulders

E= Basin fill. Gravelly silt with local lenses of sand and gravel. Gradational with Unit D.

F= Top soil. HIghly bioturbated massive silt and coarse sand.

3 = Charcoal Sample

Figure 6. Baldwin Sag trench log

Use of Funds

Funds were used to pay undergraduate and graduate students who worked on various aspects of the project, backhoe costs during trenching, and one month of summer salary for Onderdonk. Trenches were opened at the Baldwin Sag site, the Quincy Ridge landslide, the Quincy site, the Mystic Lake site, and across scarps near the Mystic Lake site. Some of the allotted money was not used during the funding period due to delays in obtaining permission to trench certain localities and will be used this summer to complete trench work at the Quincy site.

Continued Work

We submitted two separate SCEC proposals in the fall of 2009 to continue work along the Claremont Fault. One of these requested funds to concentrate on obtaining slip rate data through continued efforts at the landslide sites, the Quincy site, and the Anderson Ranch site which was not evaluated during 2009 due to delays in obtaining permission by the landowner. The other project will be to continue work at the Mystic Lake paleoseismic site using CPT coring and trenching to gain a better understanding of the fault structure and spatial distribution of stratigraphic marker layers observed in our 2009 trench work. This will allow us to extend and refine the slip history recorded at the site while gaining a better understanding of the detailed morphology of the sag feature and its development. In addition to these endeavors, Onderdonk will continue to map the fault structure and Quaternary deposits along the fault and used GIS based morphometric analysis to evaluate the fault zone development and associated topographic evolution of the San Timoteo badlands and the San Jacinto Valley.

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