Annual Report
2008 SCEC Proposal

Establishing the Southernmost Long-Term Earthquake Record on the San Andreas Fault

Gordon Seitz
Principle Investigator
Department of Geological Sciences
San Diego State University
San Diego, CA 92182
seitz3@earthlink.net

Pat Williams
Co-Principle Investigator
Department of Geological Sciences
San Diego State University
San Diego, CA 92182

Introduction

The southernmost San Andreas fault (SSAF) is one of the most likely faults to generate a great earthquake in southern California in the foreseeable future (WGCEP, 1995). Its high geologic (Van der Woerde, 2005;Behr et al., 2008)and geodetic slip rate (Bennet et al., 1996) (15-25mm/yr) ; and regional deformation pattern (Fialko, 2006), long quiescence (~325 years) compared to the average recurrence interval of 180 years, and single-event displacements of greater than 3 meters for the last 3-4 events, make this portion of the fault appear ready for a rupture sooner than other faults in California.

The episodically filling and desiccating late Holocene Lake Cahuilla (Waters, 1983) covered the southern 60 km of the SSAF (Fig. 1), and the associated lacustrine sediments provide a unique high-resolution recorder of past earthquakes. Although other long record sites have been developed in the Coachella Valley, they are all located at or above this high shoreline. The Salt Creek South (SCS) site is the only "deep water" Lake Cahuilla site, 70 m below the high shoreline, which translates into an additional minimum of ~60-years of lacustrine deposition per lake episode or an additional 300 years of record in the past 1300 years, compared to the other records from the high shoreline (Indio: Sieh, 1986; Philibosian et al., 2006). The longest published record at Thousand Palms (Fumal et al., 2002) is located on one of two strands of the fault and appears to not capture all SSAF ruptures.

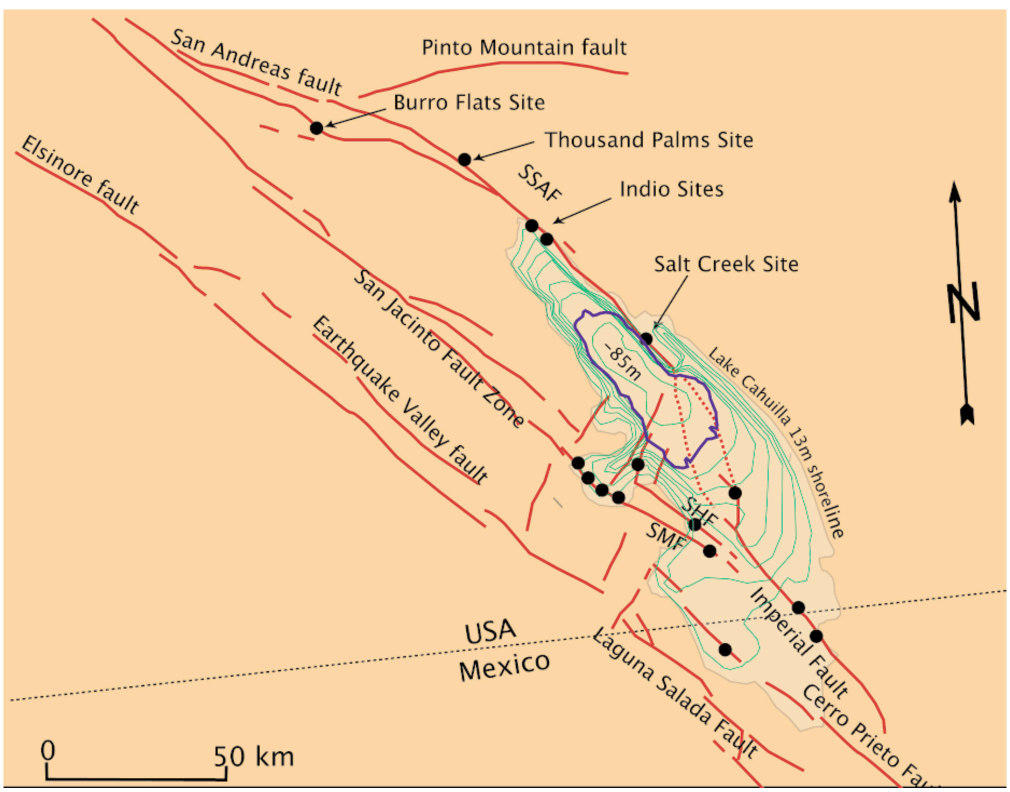


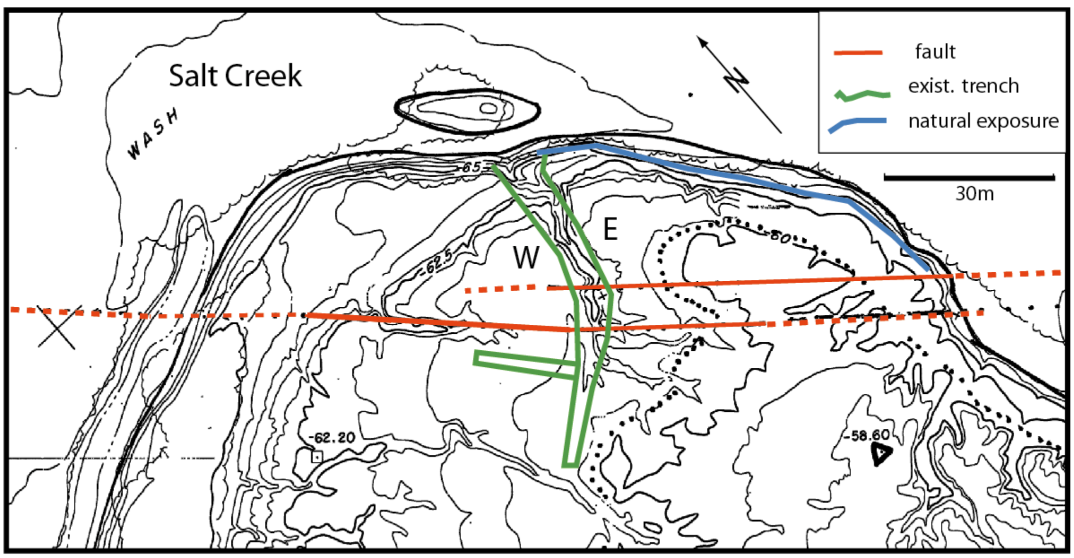
Figure 1. Paleoseismic sites along the southernmost San Andreas Fault. Note the

outline of ancient Lake Cahuilla and heavy lines representing active faults. Salt Creek is the only "deep water" Lake Cahuilla site, 70 m below the high shoreline, with an additional ~60-years of lacustrine sediment record per lake episode relative to high shoreline sites. Considering that we are observing 5 lake episodes that translates into an additional 300 years of record and thus potentially providing more complete event-recording than the only other event sites near the high shoreline at Indio. Several paleoseismic sites on the San Jacinto fault are associated with the Lake Cahuilla shoreline as compiled by T. Rockwell. This Figure modified from unpublished figure of T. Rockwell, by permission.

Project Progress

We had proposed a 2-phase project strategy to SCEC in 2006, in anticipation of the greater availability of funding associated with the SOSAFE effort. We secured SCEC/SOSAFE funding for phase 1. We presented updates of our paleoseismic interpretations (Seitz) and fault offsets (Williams) at the 2008 annual SCEC SoSafe meeting.

A)



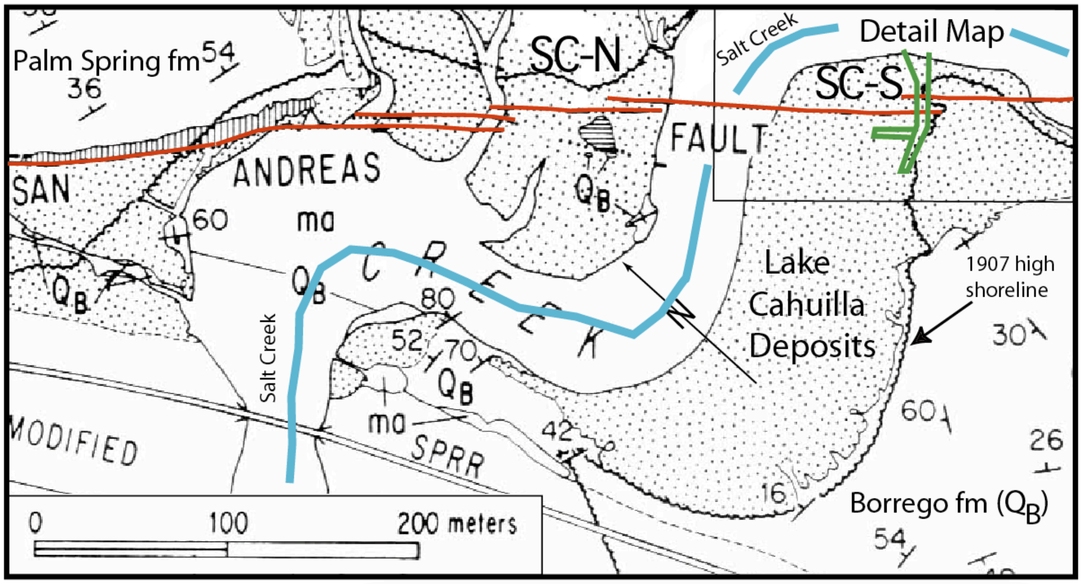
B) 

Figure 2 Site map showing fault location, trench layout (in green) and fluvial and lacustrine landforms (B). Detail at top (A), with contours (interval is 50 cm). Note expression of 1907 shoreline. Deepening and widening of the previous the exposure clarified complex stratigraphic relationships resulting from unconformities. Site is ESE from Salt Creek RR trestle beside Highway 111 Salt Creek bridge. Major geology of site area. Dotted line is the 1907 highstand at -60.5m, with abundant railroad ties providing field markers.

We accomplished our main objective to excavate the cross-fault trench to a full depth, which encompasses the 1300-year continuous event-recording section and an additional two older late Holocene-age lake sequences. Our efforts which included additional excavations have contributed the following improvements:

1) - understanding of stratigraphic relationships across the fault zone.
2) - chronology due to the collection of additional C-14 samples.
3) - event confidence resulting from the observation of additional event evidence.

We used a smaller tracked loader to extend the excavation in the fault zone (Figure 2 A, area from the fault to the natural exposure labeled W and E). The material was transported to the top of the excavation away from Salt Creek. This deepening also seamlessly connected the trench exposure to the natural exposure as shown in figure 2a. These extended exposures greatly clarified stratigraphic relationships across the fault zone that were previously obscured by only partially exposed unconformities.

Figure 3 Incised Salt Creek channel. View to the north. The riverbanks are direct analogs of the landscape during periods of desiccation.

Observations

After lake inundation, during periods when the lake was lower than the site, we observe evidence that the landscape reverted back to a general shape that we see today. Salt Creek has incised and formed a flat-bottomed canyon, with relatively steep sidewalls. When the lake level has risen above the site this canyon has been filled with coarse clastic delta deposits. As this has happened repeat ably overtime it has resulted in the formation of unconformities that may often reoccupy the same location, resulting in a series of nested unconformities. In figure 4 we schematically show how this process can explain the exposure observed in figure 6, and presented in a model in figure 5. Here the post lake 5 desiccation is prominently expressed as an angular unconformity that truncates lake 5 deposits and parallels the present day Salt Creek canyon slopes.

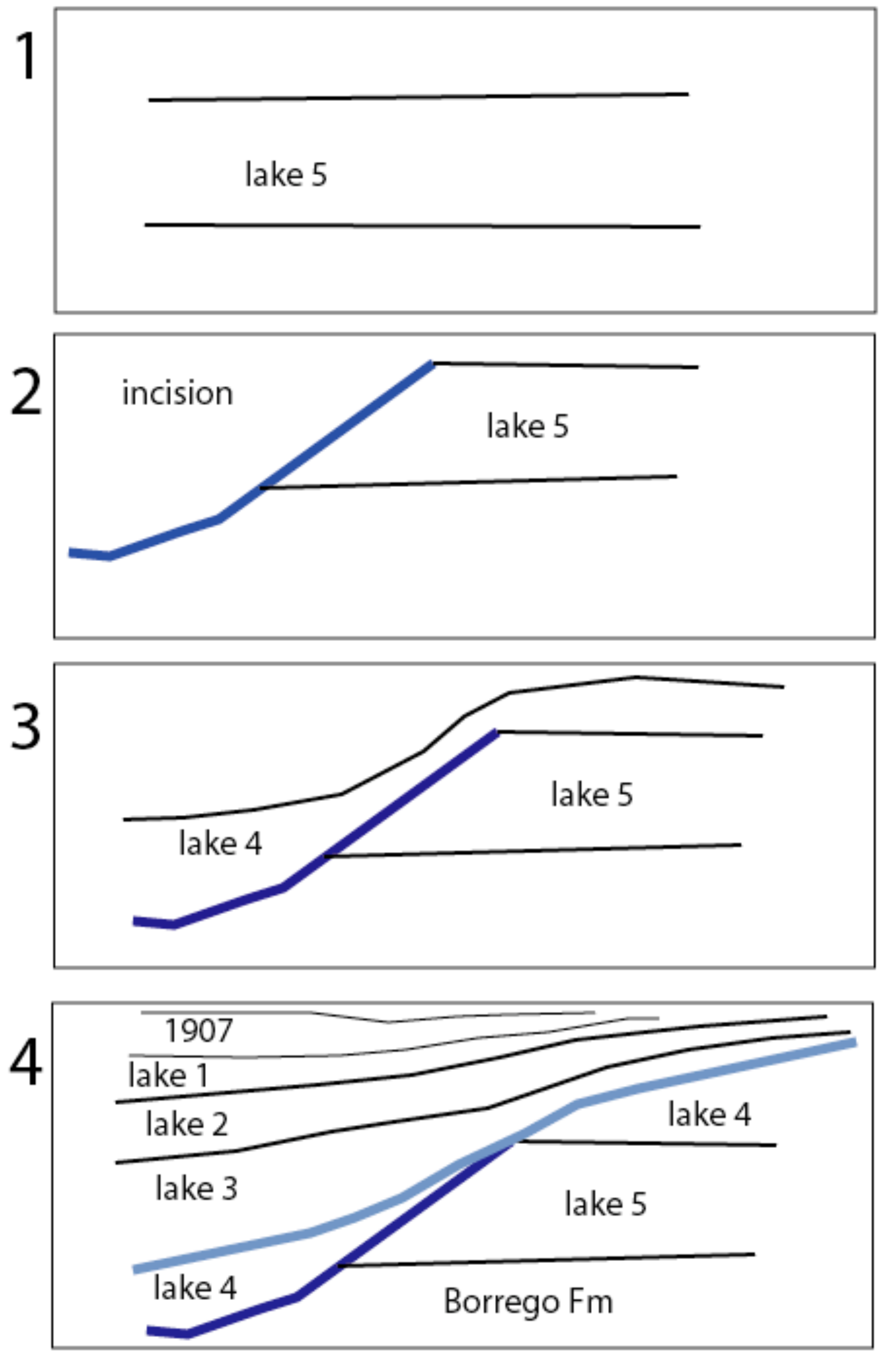


Figure 4 Schematic Unconformity Model. The episodically filling and desiccating late Holocene Lake Cahuilla resulted in a series of laterally nested unconformities. Examples of how these unconformities formed are presented. During periods of desiccation incision occurs along Salt Creek (2). Subsequent inundation by Lake Cahuilla results in the deposition of lacustrine units (3). The dark and light blue lines indicate older and younger unconformities, respectively.

Salt Creek Lake Sequence

The criteria that we use to define each lake unit are deep-water deposits separated by terrestrial deposits. Erosion caused by sub aerial exposure forms unconformities, and when they are angular or include prominent channels they are easily recognized. However, more level landscape positions located above the canyon, experience less erosion and little deposition resulting in difficult to recognize disconformities. Hence at any one location it may be very difficult to distinguish separate lake deposits, though by tracing the unconformities laterally they are clearly recognized. Typically the interlake period is expressed by an angular unconformity that parallels the Salt Creek canyon slope, at the highest elevation of the unconformities they flatten and become less angular. The base of the unconformities on the steeper sloping portions often include smaller incised gullies. This is analogous to what we presently observe (figure 3), where the Salt Creek canyon slopes are incised by gullies.

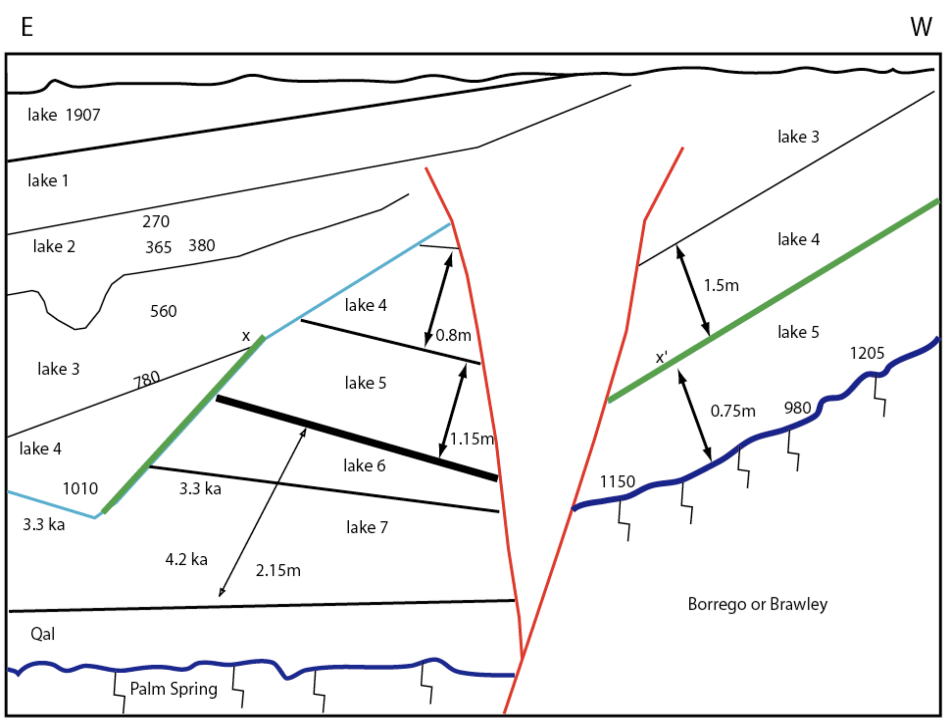


Figure 5 Schematic Stratigraphic Model. East view of the fault zone showing the distribution of lacustrine units resulting from the episodic lake fillings. The units are labeled as lake. The plain numbers indicate raw C-14 ages. The most recent lacustrine unit; 1907 at top of the section partially overlies the fault zone. Major unconformities are shown with green lines. The stratigraphic unit thicknesses support this interpretation, which adds 2 older lakes on the northeast side (E) of the fault zone.

The criteria we use to define separate lake episodes consists of evidence of sub aerial exposure coupled with indicators of multiple season duration. A single layer of mud cracks in a fluvial or lacustrine unit represents a single event and would not suffice.
Massive sand units up to 35 cm thick separate the 5 most recent lake sections. During field reviews the origins of these units attracted special attention.
General description:
Medium to coarse sand, poorly sorted, shell rich, with some gravel lag concentrated near the base, detrital charcoal rich contains fish bones. No laminations, some sub-horizontal parting, generally weathers into a caving unit with very little cohesion. Incipient soil development. Occurs above unconformities and these units have a distinct composition that is different from the units that they cover. Three possible origins are considered:

1) Beach Deposit
The composition and the grain sizes, including abundant shells, charcoal and fish bones are consistent with this environment. However, the sedimentary structure being massive is not consistent with typically well sorted and clearly laminated near shore beach sands. For example the deposits that contain beach derived organic fiber layers are well laminated**.**

2) Debris Flow Deposit

Debris flow deposits often show layers, i.e. laminar flow layer at the base. Debris flows often float coarse clasts to the surface showing upward coarsening. These sedimentary characteristics are not observed. The deposits in question are thickest on the slopes and often extend upward onto the former terrace surfaces. If these deposits were the result of debris flows their plausible source areas are very difficult to envision. If they originated in Salt Creek, then why do the deposits exist high up onto the riverbanks? Only the bank slopes of Salt Creek are steep enough to trigger debris flows, there are essentially no proximal areas above the former river terraces. After the 1907 filling and draining to its current level, debris flows were not observed. Instead the Lake Cahuilla delta sand deposits, which are the source of the interlake sand units, were washed out of there channel filling locations, and were subject to colluvial collapse onto the surfaces below. Again in a similar category, deposits originating from delta collapse would not be deposited on the steep slopes that these deposits are located on. There exists no modern analog at the site, and similar modern deposits in the Salt Creek drainage have not been observed.

3) Colluvial Soil
Colluvial deposits are characterized by having a massive structure, thickening on slopes or near their base, lag deposits at their base, and a nearby source. We observe these deposits draping underlying units, with thickening on slopes and

at their base. The material composition is consistent with an abundant supply of eroding delta sands after a lake regression, again with the typical high concentration of shells and detrital charcoal. This sets it apart from debris flows, which generally fill in lows, and are not deposited on slopes, let alone thicken on slopes. There is a consistent occurrence of these deposits between each deep-water lake clay. These deposits have experienced a small amount of transport by a combination of sheetflow, eolian, and bioturbation processes, resulting in down slope creep and a massive structure typical of colluvial soils. These deposits have been redistributed from the tops of banks and river terraces towards the banks. This is not the case for debris flows, which should show some kind of morphology that includes lobes, levees etc.

The colluvial soil origin is our interpretation of this unit as it explains the distribution, their source, composition and sedimentary structure. The alternative interpretations each have several serious inconsistencies.

Paleoseismic Evidence

The faulting has occurred within a zone of over 30 meters in width. That said it is clear that the major zone of displacement over the last ~1300 years has been confined to the in cross-section Y-shaped stepover graben which is about 10 m wide at the surface and narrows to ~ 2 m at a depth of 5 m. This distributed deformation is ideal for recording earthquakes, because overprinting from successive events is less of an issue outside of the graben. Here we present two logs that are representative of the deformation. High quality event evidence features exist that clearly mark event horizons, such as: extrusive liquefaction sand blow domes, fissure fills, and folding associated with faulting overlain by flat lying deposits. The highly defined stratigraphy, i.e. layered to laminated, with varying grain size and color contrasts, allow detailed investigations of each feature. Also many event features are now being found at the same stratigraphic level, which increases our confidence of an event occurrence. The record appears to be complete to the base of lake 5 at which a hiatus in deposition exists.

T1 east, Salt Creek South

Figure 6 Photomosaic Trench log T1 southeast. Major layers are outlined in solid black, faults are red. E# and red dots (circles less certainty) indicate event deformation attributed to certain earthquakes. Arrows show transport directions. On the leftside of the log the left sloping contact represents an unconformity that was reoccupied by the interlake periods between lake 4 and 5 and then between 3 and 4. The younger unconformities, and associated interlake colluvial soils are evident above this unfonformity. Event 5 is a example of an earthquake that occurred during a lake highstand. The folding is a particurlary well manifested earthquake, with a detailed image figure 7. The main fault zone is shown on the right margin of this log.

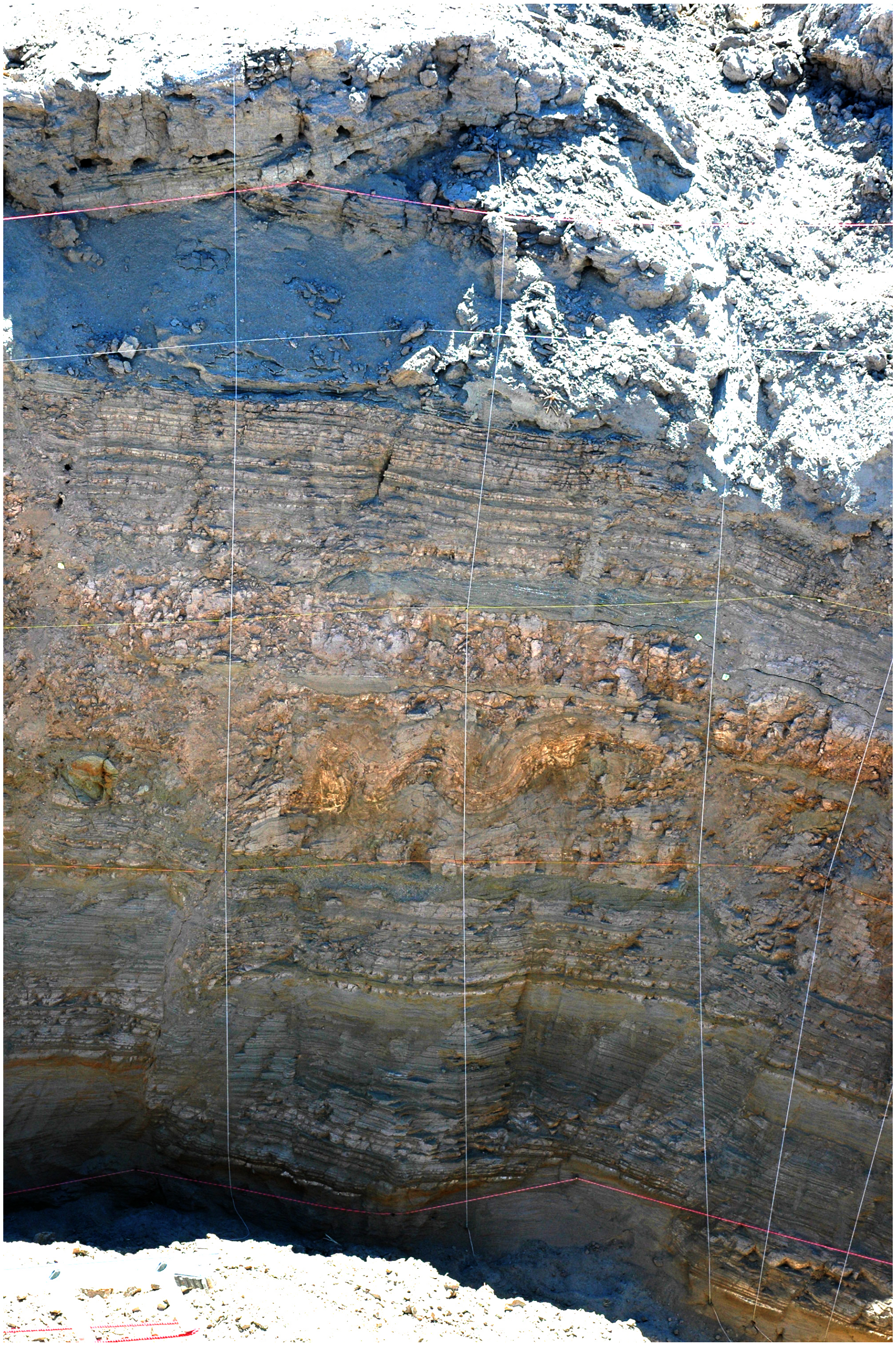


Figure 7 Detail of the event 5 subaqueous event in T1 southeast. The tightly folded lake bottom sediments are directly overlain by flat lying lake sediments. A thin layer of sand above the fold appears to be related to shaking related sediment input into the lake. Where straight the grid string lines are spaced at 1 meter.

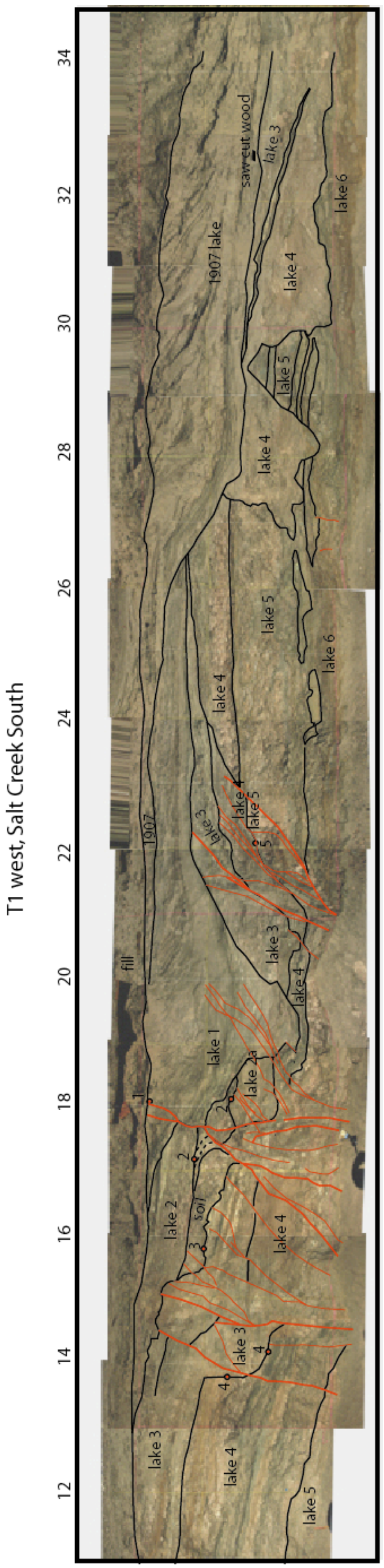


Figure 8 Photomosaic log of T1 northwest. This exposure crosses the main fault. The rightside of this log is directly across from the log in figure 6. Figure 6 ends at about meter 21. This exposure provided additional evidence for events. For example event 2 evidence is provided by folding into a fault at meter 17.5, directly overlain by flat lying deposits.

Site Stratigraphy

The sedimentary history of the site is summarized in a stratigraphic column (figure 9), and consists of 7 lacustrine packages resulting from fillings of the ancient Lake Cahuilla and intervening sub aerial sedimentary evidence. The age estimates are based on previously dated C-14 samples to a depth of lake 5 with an age of ~ AD 850. Currently a batch of additional samples are being processed to be dated shortly. The column was constructed using rectified photomosaic sections that showed the maximum thickness of each lake deposit and results in a total section thickness exceeding 10 m. As shown in the trench logs, the stratigraphy is characterized by a prominent east dipping angular unconformity, one between lakes 3 and 4, and another between lake 4 and 5. When these unconformities are traced upward they become flat disconformities that essentially parallel the surface. These steeper angular portions are interpreted to be former Salt Creek riverbanks, much like the current riverbank. The present riverbank is especially prominent and the creek incised, because with the exception of the short-lived 1905-1907 filling the site has been dry since at least AD 1774 (de Anza exploratory journal, University of Oregon: http://anza.uoregon.edu/). These former river banks appear to parallel today's path of Salt Creek, as such the stratigraphy in a general sense becomes younger to the north as the creek turns to the southwest. Because these angular unconformities are fairly steep they may provide offset markers where they intersect the fault. Like the gully that we excavated along, these tributary gullies may also intersect the fault zone at high angles suitable for offset measurements. In the fault parallel trench we encountered a gully/channel margin (lake 5 level) that trends towards the fault from the southwest at a fairly high angle.

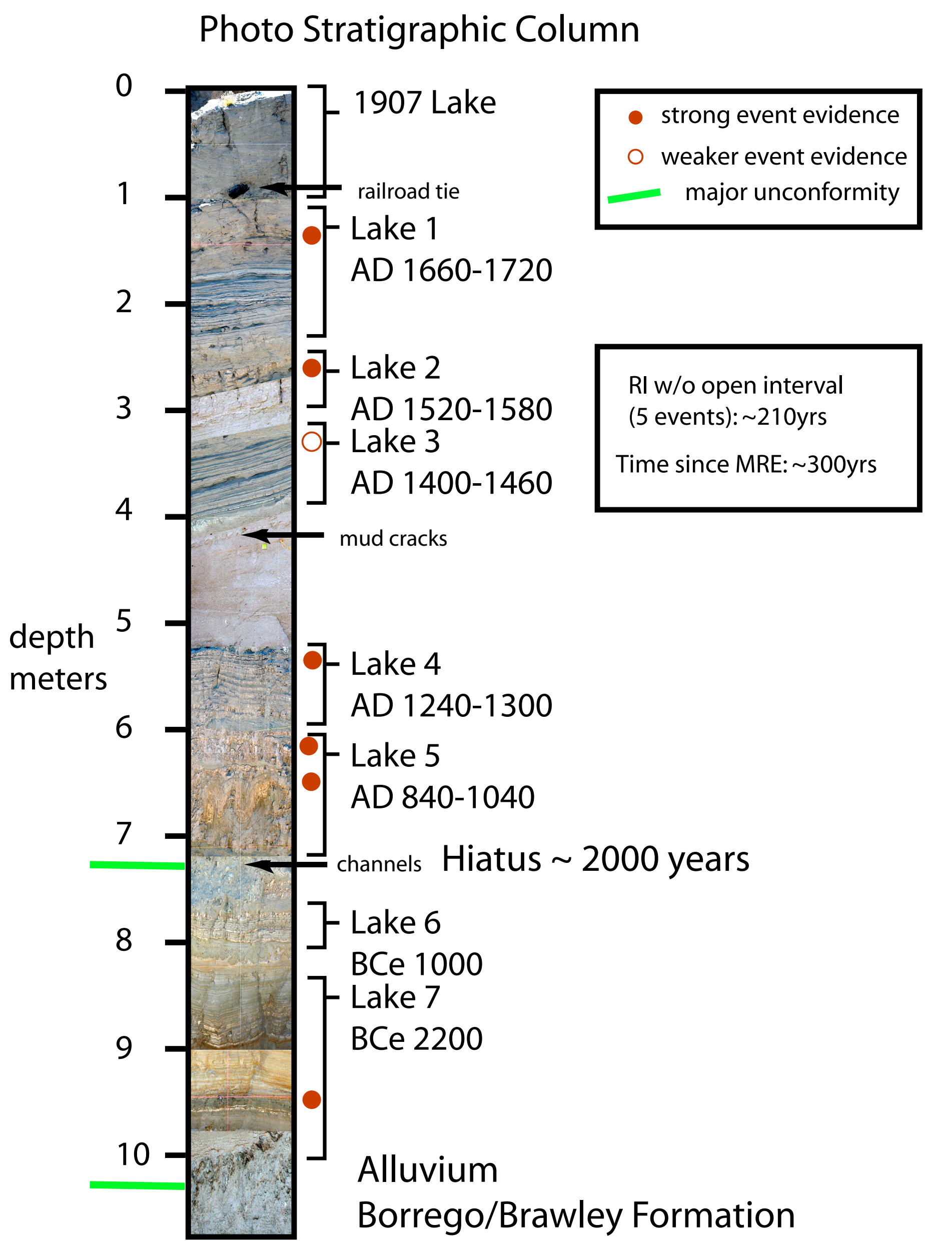


Figure 9 Photo-Mosaic Stratigraphic Column. This is a composite column constructed from the most complete section of each unit. The age estimates are based on calibrated C-14 ages.

Related Efforts at the Salt Creek site:
Excerpt from SCEC 2008 annual meeting poster:

Preview of the Next Big One: Creating a Permanent San Andreas Fault Earthquake and Salton Sea Lake History Exhibit at the Salton Sea State Park, California

Gordon Seitz, Dept. Geological Sciences, 5500 Campanile Dr., MC-1020, San Diego State University, San Diego, CA 92182-1020, seitz3@earthlink.net

Assessing the San Andreas fault's future behavior and earthquake hazard is largely based on observations of its past behavior. Evidence of prehistoric earthquakes can be observed in excavations across earthquake faults that expose deformed sediment layers. We have an unprecedented opportunity to preserve a spectacular San Andreas fault exposure with a record of 6 earthquakes and 5 lakes. There are several other examples of San Andreas fault exhibits throughout California, such as: Point Reyes National Seashore, Bear Valley Visitor Center (http://www.nps.gov/pore/naturescience/faults.htm), and Wallace Creek. interpretive trail on the Carrizo Plain (http://www.scec.org/wallacecreek), Lost Lake at Cajon Pass, Forest Service. However, none of these exhibits provides a trench exposure view. In Hokudan, Japan a fault trench has been preserved with an elaborate museum design. At this point in the planning stage, we can envision a range of possibilities from preserving the site for guided educational tours, an exhibit at the Salt Creek Campground or the visitor center, to a self-contained permanent exhibit with a self-guided trail. Much of our knowledge about the faults past behavior is based on results from this work. Perhaps of equal importance is that this exposure provides a record of ancient Lake Cahuilla, an earlier Salton Sea. The exceptionally dry climate in the Salton Sea region make it feasible to leave this site in a nearly natural state without risking excessive erosion.

Why create a permanent San Andreas Fault Earthquake and Salton Sea Lake History Exhibit?

- It would be the only exhibit in the United States that enables visitors to see an earthquake fault below the surface and in three dimensions. Other exhibits are merely trails along the fault.

- It would be the only exhibit that shows the Salton Sea's history of episodic lake fillings over the past 1300 years.

- The exceptionally dry climate in the Salton Sea region make it feasible to preserve this site in a nearly natural state.

- With the uncertain future of the Salton Sea restoration, this exhibit may provide a rare scientific view of the regions past, that would facilitate appreciation of the natural history of the region.

- The exhibit may help remind people that earthquakes cause disasters but also created our State's scenic beauty.

- Educators from University to K-12 schools can take field trips to show how earthquake research is accomplished.

- The exhibit can encourage visitors to be prepared for future earthquakes and support future research

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