FINAL TECHNICAL REPORT

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Development of a Long-Term Earthquake Record for testing of Rupture Scenarios at the South End of the San Andreas Fault: Collaborative Research - Williams Associates and SDSU

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Abstract

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 and geodetic slip rate (15-25mm/yr) (Van der Woerde, 2005); 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.

As part of a larger effort to characterize the southernmost San Andreas faultworking on the Coachella Valley section (CVS) we continue to develop a longpaleoearthquake record for the southern Coachella Valley fault segment (CVS) at the SaltCreek-South site (SCS). Salt Creek is the only “deep water” Lake Cahuilla site, 70 mbelow the high shoreline, with an additional ~60 years of lacustrine sediment record perlake episode relative to high shoreline sites. Considering that we are observing 5 lakeepisodes that translates into an additional 300 years of record and thus potentiallyproviding more complete event-recording than the only other event sites near the highshoreline at Indio.

Our latest work has expanded our view of the fault zone and further clarified thesite’s lacustrine stratigraphy. It has also confirmed that as we excavate to the north of ourcurrent exposure the sediment record for the most recent events improves.

During 2006 we maintained our strategy to excavate the Salt Creek South (SCS) site in a

minimally invasive manner. We believe that this is warranted here because this site very likely contains the best or one of the only remaining paleoseismic records for the southernmost SAF along the east edge of the Salton Sea, and it is contained within a fairly limited volume of material. Our systematic excavation plan was designed to avoid destroying of event and offset evidence before documentation.

We identified a 6 event (AD 850) gully edge that trends towards the fault from the west. Additionally, the extensive exposure has allowed us to begin mapping out the edges of the former Salt Creek riverbank, which appear as steep, high-angle unconformities that parallel the most prominent present day riverbank. These two features are interpreted to intersect the fault plane, and if preservation and geometry is sufficient, they may provide an offset. This has been proposed as future a target.

Overall we were able to confirm a 6-event record within the past 1200 years. As proposed we extended the excavation both to the west and east to make certain that we have fully exposed the entire fault zone and understand it's structure. With these more extensive exposures, correlations of the event horizons across unconformities reduced our event count to 6. The chronology was improved with the discovery of in-situ radiocarbon samples.

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 and geodetic slip rate (15-25mm/yr) (Van der Woerde, 2005); 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. As part of a larger effort to characterize thesouthernmost San Andreas fault working on the Coachella Valley section (CVS) we seekfunding to continue development of a long paleoearthquake record for the southernCoachella Valley fault segment (CVS) at the Salt Creek-South site (SCS). Our in-progress SCEC funded work has expanded our view of the fault zone and further clarifiedthe site's lacustrine stratigraphy. It has also confirmed that as we excavate to the north ofour current exposure the sediment record for the most recent events improves. Salt Creek is the only "deep water" Lake Cahuilla site, 70 m below the high shoreline, with anadditional ~60-years of lacustrine sediment record per lake episode relative to highshoreline sites. Considering that we are observing 5 lake episodes that translates into anadditional 300 years of record and thus potentially providing more complete event-recording than the only other event sites near the high shoreline at Indio.

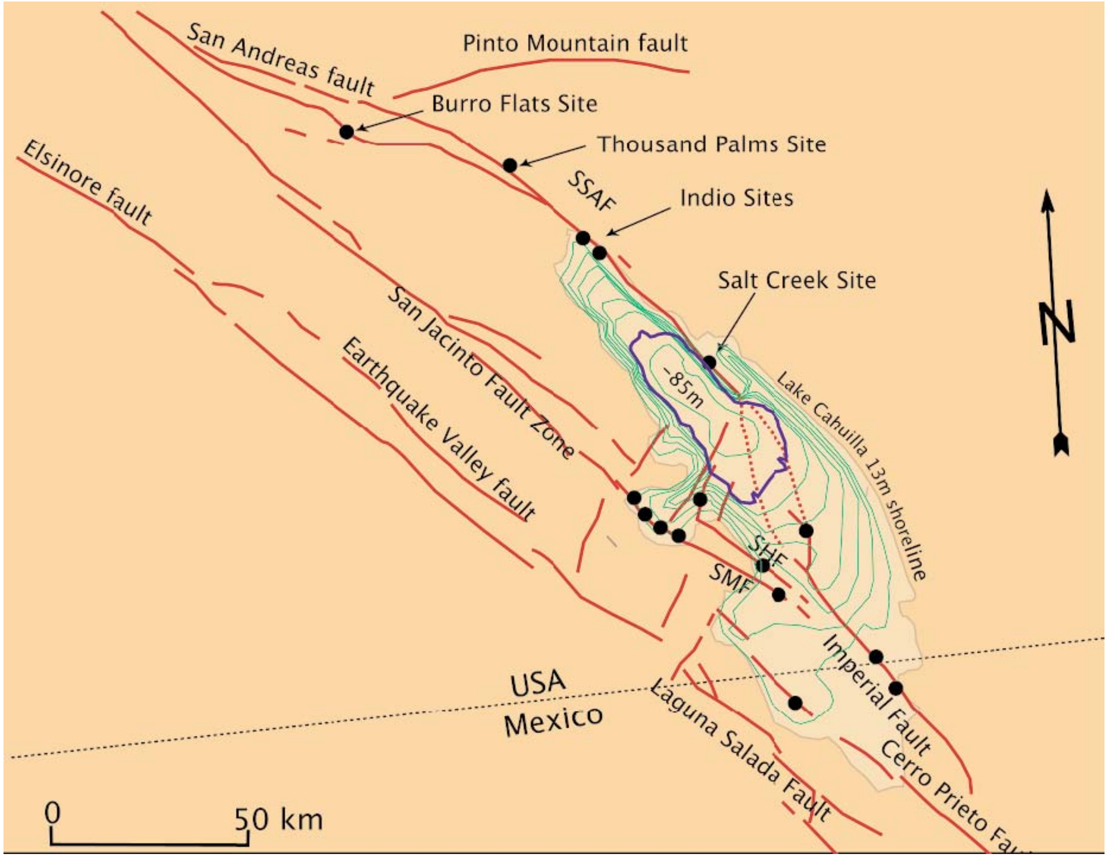


Figure 1.**Map of Paleoseismic Sites in the Lake Cahuilla Basin**. Note the outline of ancient Lake Cahuilla and heavy lines representing active faults. . Salt Creek is the only "deep water" Lake Cahuilla site, 70 m below the high shoreline, with an additional ~60-years of lacustrine sediment record 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.

Figure 2. **Oblique View of the Salt Creek Site.** View is towards the north with the uplifting Mecca Hills as the skyline. The Salt Creek South site is indicated, and the limited amount of latest Holocene-age faulted sedimentary section is shown as the meander point. The section extends to a depth less than the current Salt Creek channel. Because this may well be the best and perhaps only section that contains a complete record of events from 850 AD until present, exercising special caution in minimizing the impact of excavations is warranted.

Site Description

The Salt Creek drainage is antecedent to the broadly antiformal Durmid Hill uplift. The Creek occupies a distinctive canyon cut through the uplift, and the course of the stream is offset 600-800m by the San Andreas fault. The youthful geomorphic surface of Durmid Hill was cut by energetic wave action before uplift, probably during late Pleistocene fillings of Lake Cahuilla (Babcock, 1974).

The offset of Salt Creek formed a large shutter ridge that protected the site from Lake Cahuilla waves. This barrier has caused unique preservation of what appears to be the best late Holocene sedimentary record of Lake Cahuilla.

Salt Creek cuts the Palm Springs and the Borrego formations. The SAF has juxtaposed these units in the area of Salt Creek. The SCS site is located on a meander point terraced by Salt Creek. The 1907 shoreline is expressed as a clear shoreline angle and swash surface. Older and younger recessional shorelines and stream terraces record the former stream and lake interaction

(Fig. 2,3).**Structure**

As the logs show (Fig 5,7,8) 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 Y-shaped stepover graben which is about 10 m wide at the surface and narrows to ~ 3 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. Many high quality event evidence features exist that clearly mark event horizons, such as: extrusive liquefaction sand blow domes, fissure fills, folding associated with faulting overlain by flat lying deposits. The highly defined stratigraphy, i.e. layered to laminated, with varying grain size and color allows detailed investigations of each feature. Also many event features are clearly defining event, increasing our confidence of an event occurrence. Stratigraphic thickness changes across faults indicate significant lateral movement along faults.**Site Paleoseismology**

This study addresses the earthquake chronology at the Salt Creek South (SCS). A two-event record of lateral displacement was defined in the original Salt Creek investigation (Williams, 1989), the latest lake beds were found to be offset 3.2 meters, and beds of the prior lake are offset 6.3m. Our redating of the Salt Creek sediments indicates that the Salt Creek slip measurements are consistent with those at the Indio site.

In our 2005 SCEC-funded trench studies at the new SCS site we interpreted field evidence for up to 8 events within a stratigraphic section of 5 Lake Cahuilla episodes. The exposures followed an existing cross-fault zone trending tributary gully along which we excavated to minimize the destruction of potentially event-recording section. Rectified trench photo mosaic with logging is presented in Figures 4 and 6.

In 2006 we continued this effort with NEHRP funding. Due to budget cuts we modified our field plan as follows. We significantly increased the exposure of the main fault zone graben by deepening and widening the cross-fault trench T1. This included extending this excavation at full depth to the natural Salt Creek arroyo cut to the east. Here we cleared off more of the natural exposure, and extended a few hand dug pits to confirm the positions of deeper marker beds. At the west end of T1 we extended the trench as a shored vertical trench approximately 20 m. This trench was excavated to verify that we have encompassed the entire fault zone. From this westward-extension trench we extended a fault-parallel trench to the northwest for a distance of approximately 30 m. The purpose of this trench was twofold: 1) to expose several liquefaction features in 3 dimensions, in order to better understand their origin; 2) to target fault-crossing features that could be used to measure slip per event and/or slip rate. As proposed we extended this excavation both to the west and east to make certain that we have fully exposed the entire fault zone width. With these more extensive exposures correlations of the event horizons across unconformities reduced our event count to 6. Here we present photo mosaic logs (Fig 5,7,8)

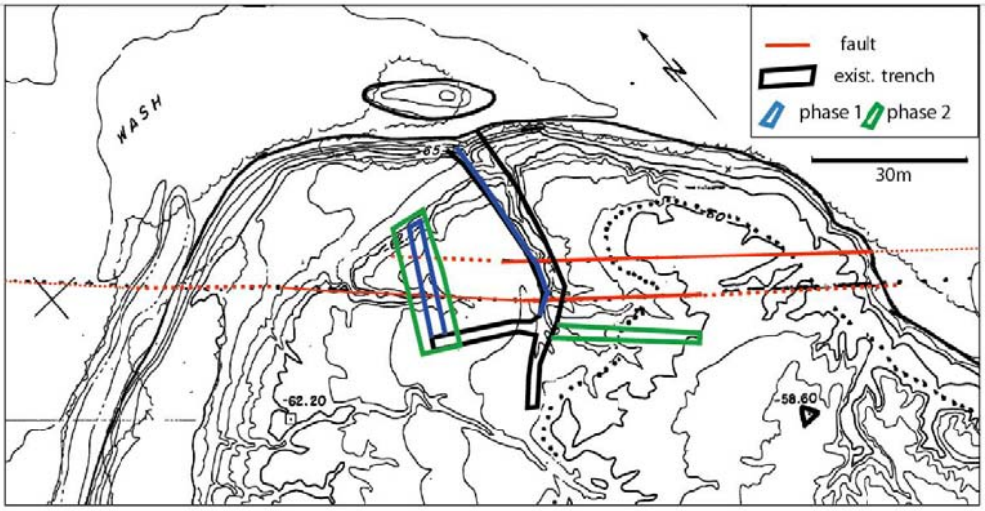


Figure 3 Detail Topographic Site Map. Taken from 1:500 original site map, it shows fault location and stepover structure, new trench location as excavated and studied as part of this grant shown in black, proposed trench layout shown in green. Contour interval is 50 cm. Note expression of 1907 shoreline shown as a dotted line.

Site is located ESE of the Salt Creek Rail Road trestle beside the Highway 111 Salt Creek bridge. Dotted line is the 1907 high stand at -60.5m, with abundant railroad ties providing field markers. We are currently funded by SCEC to pursue phase 1. Phase 2 has been proposed to NEHRP as a way to leverage this effort with more extensive work targeting the deeper record and getting multiple cuts in the younger section. Additionally the fault parallel southern extension will facilitate site characterization and the targeting of additional offset markers that parallel the 1907 shoreline.

Subaqueous Event Evidence

As indicated in the stratigraphic column several events occurred during lake high stands when the site was covered with ~70 m of water. Although this has resulted in deformational features that are less common than in typical trench studies, we maintain that they still provide reliable evidence of onfault movement during earthquakes. On the right side of figure 8, at the westside of the fault zone during lake 5 two events have been interpreted based on liquefaction features. These are not the only features to support these events. For example the detail shown in figure 7 is a correlative event feature that exhibits lake bottom soft sediment deformation resulting in a very clearly defined event horizon. We interpret this as follows, the ~ 50 cm lake bottom surface layer detached and folded as a result of onfault movement. This was facilitated by strong shaking, however we note that the strongest folding is in the proximity of the fault breaks. Because this surface layer experienced this plastic deformation the brittle faults are obscured within this layer. Although gravity slumping has been suggested as an alternative cause, we interpret this to be at most a supporting condition, but the deformation with consistent event horizons appears to be triggered by on fault earthquakes. In particular a sand blow, liquefaction dome or sand volcano that formed during an event and was subsequently displaced during a later event. The origin of this feature, unit 49, has been questioned by some reviewers. Our reasoning is based on these points: 1) the geometry of the feature is analogous to typical sand domes. It is thickest at the center, localized on a fault that also shows evidence for being a sand conduit. The material of the dome is fine sand, again typical of extruded sand domes. Granted, most descriptions of sand domes are land based. However, we present a very close analogy from the 1995 Elat, Red Sea, earthquake, that caused the formation of sand domes with very similar characteristics in shallow water (Fig. 4).

Photo 12. A cluster of 3 sandblows observed below the Ardag fish cages. Note the flat appearance of the mounds (as compared to Photo 11) and their light color relative to the surrounding sediment. Dimensions of the mounds: height - 8 cm; diameter at the base - 30 to 35 cm.

Figure 4 Analogous Subaqueous Sand Blows. Note the almost identicaldimensions of these features.

During field reviews there was considerable discussion concerning the origin of unit 49. One interpretation was that this was also a portion of a sand dome, just a much larger one from a previous shaking event. The coarse grain size, and cyclical thin layering did not seem typical of san domes. We excavated this feature in 3d, by cutting through this deposit with the northwest-trending faultparallel trench. This showed that the unit was dipping towards the former river, and did not show dome geometry. We conclude that this is a delta deposit.

Stratigraphy and Chronology

Lake Cahuilla sediments cross the fault and consist of beach, delta, prodelta and deep-water clay deposits, with silt being the dominant grain size. Unusual sedimentary features of the site are subaqueous liquefaction and shaking related underwater seismites. Evidence of subaerial conditions between lakes at the site include alluvial deposits, weathering, burrow horizons, desiccation cracks, and distinctive massive unit textures at the base of lacustrine sequences.

The sedimentary history of the site is summarized in a stratigraphic column (Fig.6), and consists of 5 lacustrine packages resulting from fillings of the ancient Lake Cahuilla and intervening subaerial exposure. The age estimates are based on dated C-14 samples to a depth of lake 5 with an age of ~ AD 850. The column was constructed using rectified photo mosaic 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 (Figures 5,7,8), the stratigraphy is characterized by 2 major east dipping angular unconformities, 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.

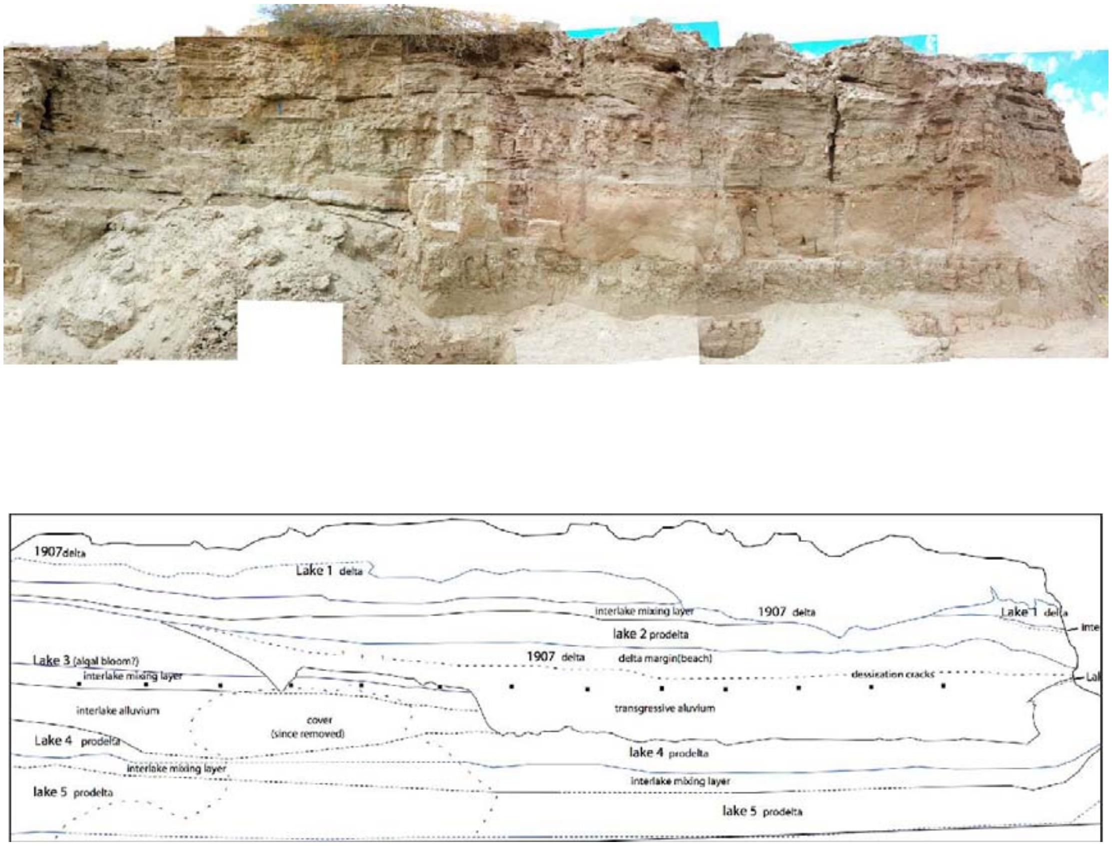


Figure 5 Salt Creek Bank Exposure and Log. This is the Salt Creek bank, the right side merges into our trench exposure, view to the southwest. Greater preservation of each lake's deposits occurs locally. Blue lines are at base of lake units. Centerline of black square dots are meter marks. Height of exposure is 4.5m. Five prehistoric lakes are unambiguously recorded by alternate lake and Interlake deposits. Discussed from the top to the bottom: historic filling of the Salton Sea to the level of site and the associated 1907 deposits contain milled lumber and railroad ties. Prehistoric Lake 1 deposits overlie an typical interlake soil layer that forms due to slope processes, biological activity, and weathering. Lake 2 is represented by a prodelta (distal delta) unit deposited on a thick layer of alluvial and transgressive sediments. Lake 3 includes a distinctive light tan and textured basal silt we refer to as the "cottage cheese" layer. Subsequent delta and prodelta materials are preserved. A mixing layer is present below Lake 3. Lake 4 is prodelta facies over a mixing layer. Lake 5 is a prodelta unit over alluvium.

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 east, and north as the creek turns to the west (Figure 2). Because these angular unconformities are fairly steep they may provide offset markers where they intersect the fault. Analogous to the gully that we excavated along, other 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. This is a potential target for determining slip for ~ 6 events. However, the high-angle unconformity between lakes 4/5 may complicate this situation by truncating this margin before it reaches the fault. Also the fault zone is up to about 30 m wide at this location, so tracing this margin displaced an estimated 21 m is not a trivial endeavor. We have future plans to extend the fault parallel trench further north in hopes of encountering a younger marker that intersects the fault further north where it may well be a much narrower fault zone.

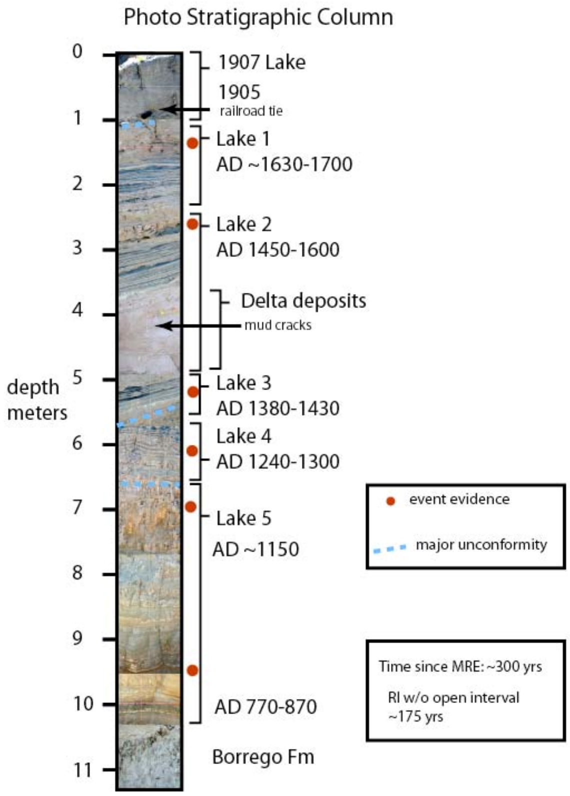


Figure 6 Photo-Mosaic Stratigraphic Column. This is a composite column constructed from the most complete section of each unit.

All of the southern Coachella Valley paleoseismic sites include unique lacustrine deposits resulting from multiple fillings of the closed Salton basin and are collectively termed “Lake Cahuilla”. From our work and others one can conclude that this depression filled to its spill point in at least five high stands of "Lake Cahuilla" during the past 1300 years (Waters; 1983; Sieh and Williams, 1990; Rockwell and Sieh, 1994; Seitz and Williams, 2004).

At Salt Creek strata recording distinct near-shore deposition, or onset of deep water conditions directly over a evidence of a sub aerial hiatus, indicate at least six distinct lake episodes at the Salt Creek site These deposits represent "occupations" of the site by the lake. Preservation of these sediments within the fault presents a particularly unique opportunity for correlation of paleoearthquakes between sites (Sieh, 1986; Williams, 1989; Sieh and Williams, 1990; Gurrola and Rockwell, 2000). The Salt Creek site is situated at minus 60 m elevation, 72 m below the 13 m high-shoreline at Indio (and basin sill). When the Salton basin captures the Colorado River, it fills rapidly to its spill point. During 1905 to 1907, the basin filled 25m to the elevation of the Salt Creek site, with the major input occurring during the single runoff of spring 1906. It is not certain that the basin always fills to its spill point, however, and some lake episodes may be recorded at Salt Creek that do not exist at the high shoreline, i.e. Indio and Coachella sites. In particular it is possible that shoreline deposits at the Salt Creek site can record two phases of shoreline deposition, during both filling and drying phases, as is indeed the case in the latest Cahuilla episode. In addition, because evaporation of the lake takes longer, with rates of 1.5-2 m/yr, deeper water deposits record a longer lake history at Salt Creek than at Indio. An example is paleoseismic during an interlake period at Indio Event 2, which appears to correlate to a lacustrine period at SCS Event 2. A final point of relevance for the potential for a longer, more complete earthquake record deep in the basin is evidence of sustained high water conditions during some of the earlier late Holocene fillings (Waters, 1983). This appears to be the case at the Salt Creek site, where two distinct liquefaction events within a single thick prodelta sequence probably record successive San Andreas earthquakes.

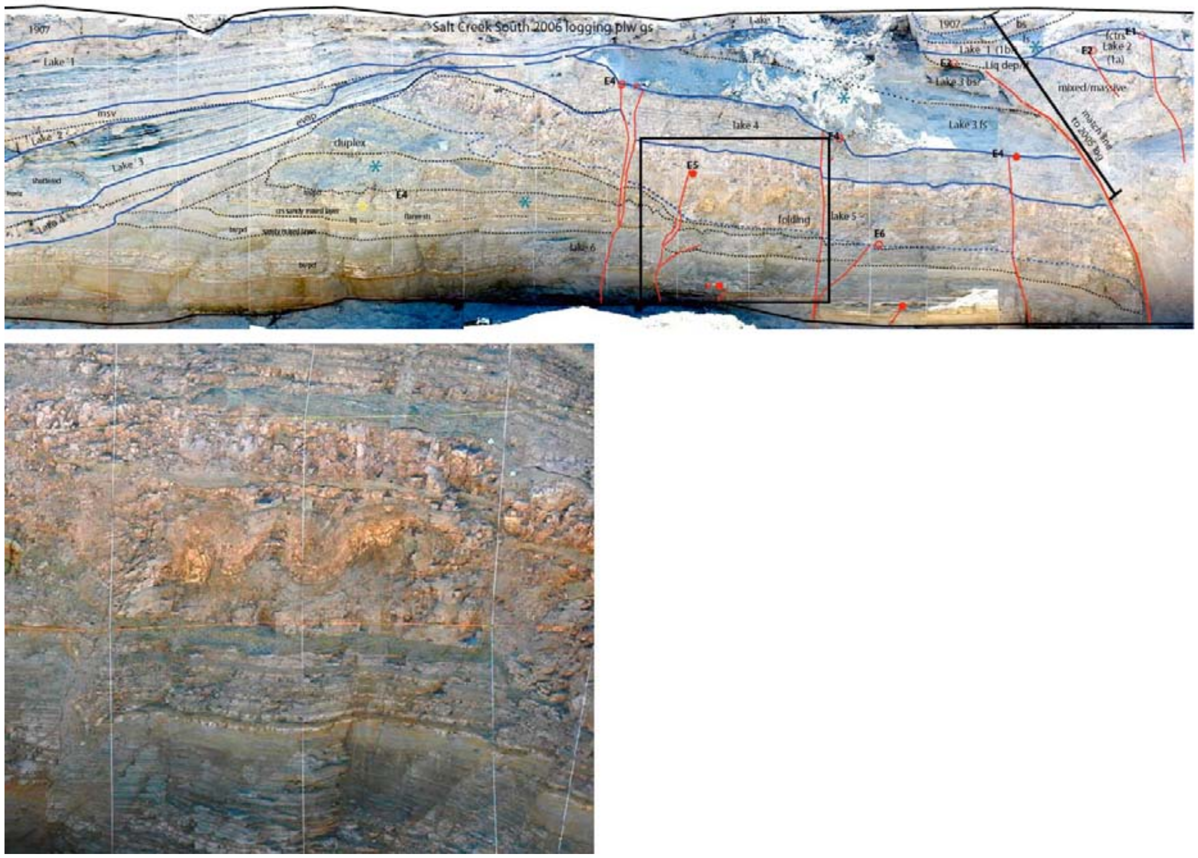


Figure 7 **South wall east side Trench 1 Log**. Detail shown in lower photo. The graben-bounding fault on the right comprises the main zone of displacement, yet the best event data is found in the more distributed deformation shown here. Size of shown exposure is 4.5 x 20m. Additional exposures developed to the west also support events 4, 5 and 6. Site stratigraphy results from interaction of interlake cutting of lake beds by Salt Creek, and subsequent lacustrine mantling of eroded stream banks by lake deposits. Exposure is comprised almost entirely of lacustrine beds except for massive, weathered inter-lake layers. Other lake boundaries are defined by unconformities and weathering. Clear upward terminations provide good evidence of events 3, 4 and 5 (filled red circles). Event 5 is also recorded by soft sediment deformation, a spectacular seismite (detail shown with box). This event occurred during deep-water deposition of silty clays, when the site was submerged by ~ 73 meters. The upper 50cm of clay layers folded, hence it is very difficult to trace the brittle break to the event horizon, yet the event horizon is very well defined by the subsequent deposition of flat-lying clay layers. Events 1 and 2 are conditionally recorded by small-scale upward terminations. (open red circles). Event 6 is conditionally recorded by upward terminations.

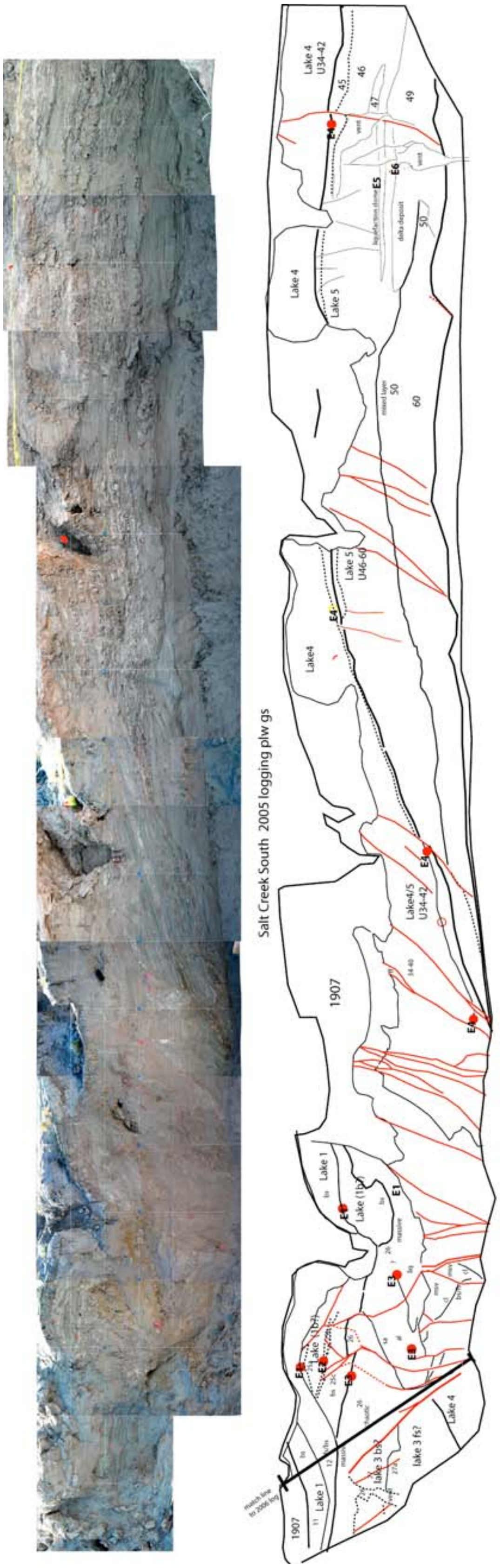


Figure 8 Trench 1 Southeast Wall, West Side. This matches figure 7 on the right side.

The oldest exposed lacustrine unit is Lake 5, from which samples at the base pin the chronology. Our field effort has greatly increased the area of exposure, and also has exposed units with concentrations of datable samples. We expect that this will result in a greatly improved site chronology.

Figure 9 Photos of newly discovered (2006) insitu organic samples. These consist of essentially in place formed organic matter. These types of samples are greatly improving the chronology at SCS, however they are very rare and extensive exposures are required to find them. From left to right: SC-42-06:In growth position carbonized plant stem, note the buried mud cracks indicating the exposed dried out surface, SC-43-06: fibrous plant litter matte; “desert-peat”, these are short-lived plant fibers that were deposited in the beach facies. Microscope image of very small fish bones, these are datable at the AMS facility at CAMS/LLNL that is a leader in very small sample size C-14 dating, scale 0.5 mm. All samples were pretreated by Seitz at CAMS. Of the other components, seeds, pollen and bones are the most commonly preserved, and are easily overlooked in routine field sampling. Routine microscope searches of sieved and unsieved material have been conducted to detect and identify dateable material.

We are working at the limits of present radiocarbon dating methodology, particularly by including replicate measurements to achieve a higher level of confidence. Our experience investigating the scatter in radiocarbon dates from single horizons clearly shows that chronologies are improved with greater sample specificity. The AMS ^{14}C method makes this specificity possible, because the sample size requirement has been reduced by a factor of over 10,000, as compared to conventional decay counting methods. This gives us the opportunity to date nearly any individual detrital charcoal fragment that we can find, and to avoid composite samples. This combining of many individual samples to produce a single composite sample with enough carbon has been used quite extensively in the past, and it has led to very precise results with low analytical uncertainties, which nevertheless may not be sufficiently accurate, because one has measured an average ^{14}C activity and cannot recover age information from the individual samples that were combined in the measurement.

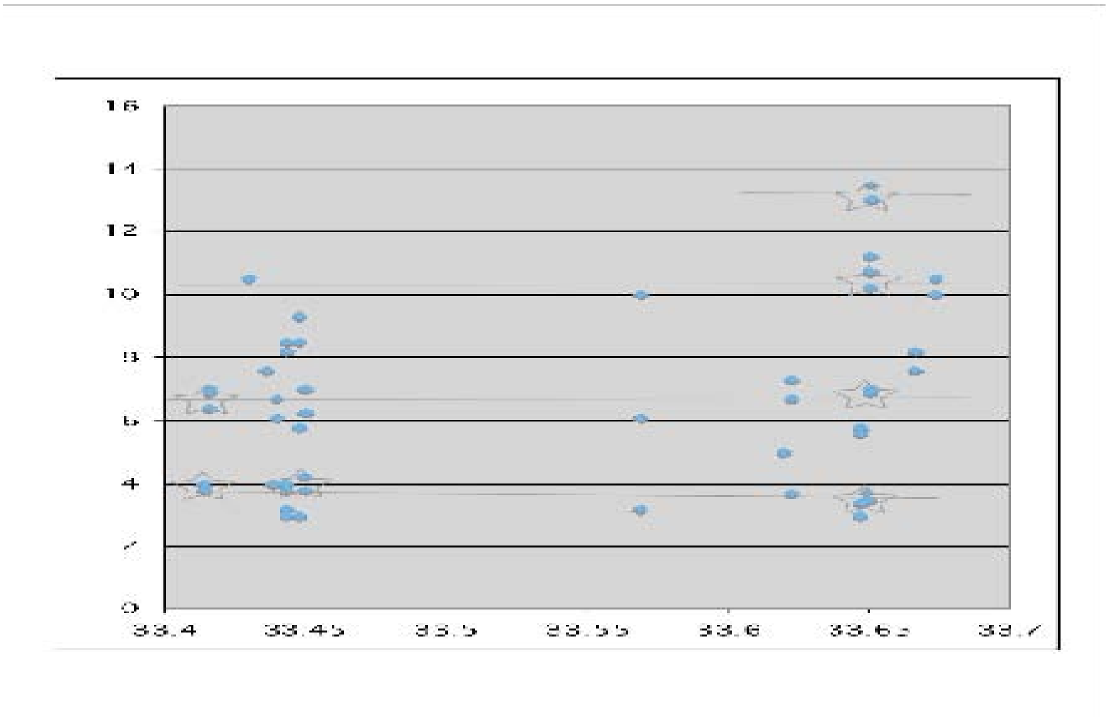
We are acutely aware of the chronological challenges posed by this depositional environment, and hence we are following this approach: a) use bayesian statistical modeling of chronological data, which allows the incorporation of all chronological data, particularly superposition, and known dates such as the 1907 filling of the Salton Sea; and the observation of no significant lake during de Anza’s 1774-1775 expeditions (de Anza exploratory journal, University of Oregon: http://anza.uoregon.edu/). b) analyze multiple samples from individual layers and use the youngest age envelopes, when bioturbation can be excluded, to best represent that unit’s age; this “brute force” strategy has proven to be successful here and elsewhere (Lienkaemper et al., 2004); c) Date multiple types of samples, i.e. do not rely simply on detrital charcoal. A very promising set of samples consists of fish bones found in Lakes 2,3 sediments. We have received subsamples from these collections (we were required to have State Park paleontologists study them prior to destructive C-14 analysis). We are now targeting insitu samples, to minimize the context uncertainty (Fig 9). Of these other components, seeds, pollen and bones are the most commonly preserved, and are easily overlooked in routine field sampling. To find these types of samples extensive excavations are generally needed, which allows one to search a larger volume of sediment. AMS dating was conducted at the Center for Mass Spectrometry at Lawrence Livermore National Laboratory, where Seitz has visiting scientist privileges. We have integrated all chronological tasks, field and laboratory, for all samples.

Repeated fillings of Lake Cahuilla have resulted in the deposition of late Holocene-age lacustrine sediments, which make ideal targets for paleoseismic investigations because they may be correlated over great distances and they generally contain datable material. This latter point is crucial in this extremely arid environment that usually produces insufficient organic matter for high-resolution AMS ^{14}C dating. In preliminary analysis we have included three other chronology sites that have exposed Lake Cahuilla deposits. Two of these sites, Indio and SC, include SAF faulting. These age and process-equivalent deposits provide a very unique opportunity to refine the accuracy of the paleoseismic chronology, because it provides a basis for integrating chronological data from different sites.

We are involved with an OSL/C-14 focused chronology effort to date Lake Cahuilla sediments throughout the basin (T. Rockwell and L.Owen, SCEC 2006). Seitz has visited several of the other basin sites to do parallel sampling to assess each method better. Ultimately this should help improve our chronological understanding of Lake Cahuilla filling and draw downs, and be an excellent opportunity to participate in vetting of the OSL technique for paleoseismic applications. Preliminary results from Lewis and Rockwell with samples from here show that the C-14 chronology we are developing most likely will help improve the understanding of the OSL method in this setting.

Geomorphic and Stratigraphic Displacement Record

Evaluating past fault displacements in geomorphic and stratigrahic offset records is the primary means by which the magnitude of past earthquake displacements can be recovered. During the past two years we began a complementary study of stream offsets and have mapped over 50 locations from southern Durmid Hill to the northern Mecca Hills to associate southern CVS event ages with high quality geomorphic event evidence. These data (Fig. 10) will yield a multiple event displacement record and slip rate, and help characterize the magnitudes of the past 1 to 4 events. In short, the past four events appear to have produced 3.4 m average displacements (Williams and Seitz, 2006).



Coachella Valley Paleoseismology

Although the Salt Creek South event evidence is preliminary and the timing of individual events will improve, a compelling correlation emerges if one examines the number of events in the dated time span (Figure 11): 1) the Salt Creek record has 6 events versus 5 at Thousand Palms; a possible explanation: the Mission Creek fault has a longer recurrence time than the SAF proper; 2) Each Salt Creek event may correlate to a Pitman Canyon event, if true this means that the CVS ruptures in conjunction with the San Bernardino segment. Incidentally, preliminary results from the Coachella site (Philibosian et al., 2006), adjacent to the Indio site, appear to show a similar frequency of events as the Salt Creek site (pers. com. Fumal). If we add the SCS record on the south side another possibility emerges: Event T at Pallett Creek and Event 4 at Pitman Canyon may extend to SCS Event 3. The Wrightwood site experienced a sedimentation hiatus at that time and may be incomplete (pers. com. Fumal, Weldon), whereas the Thousand Palms site encompasses only one of 2 strands of the SAF and individual ruptures may bypass it. These are the type of scenarios that we can develop and test with the addition of potentially longer and probably more complete paleoseismic records from SCS.

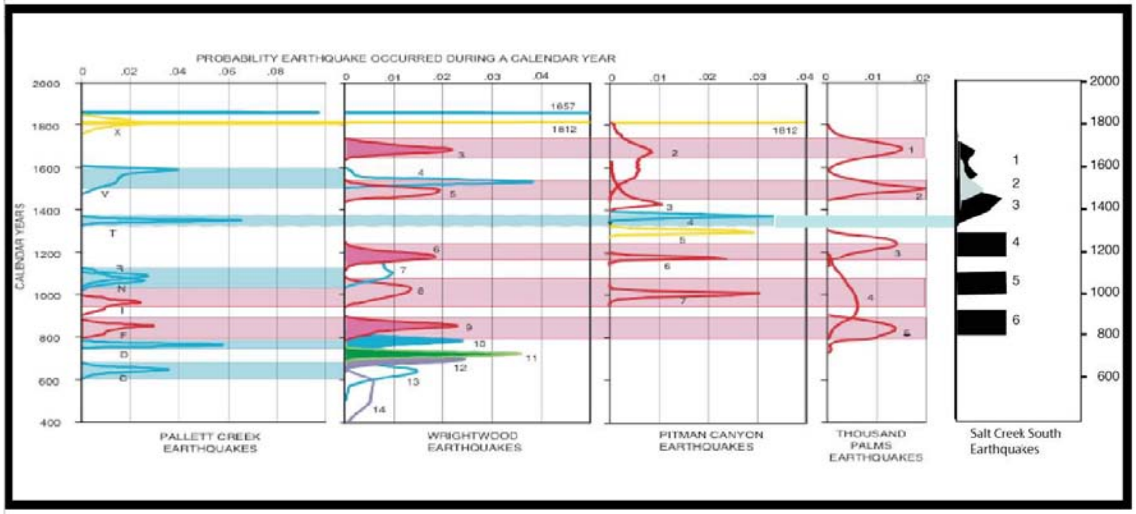


Figure 11 Speculative San Andreas Fault Paleoseismic EventCorrelations. The SCS project results add valuable constraints to help correlate among the Coachella Valley sites. Coachella Valley sites: Thousand Palms Oasis on the Mission Creek fault, one of two faults that comprise the SAF zone here (Fumal et al., 2002). (Figure Credits: Pallett Creek and Wrightwood events calculated by Glenn Biasi using own Bayesian modeling software, UNR; Pitman Canyon calculated by Seitz using Oxcal Bayesian modeling software; Thousand Palms Oasis record modeled by Fumal and Seitz using Oxcal; first 4 sites of figure compiled by Fumal, USGS and modified here with the addition of the preliminary Salt Creek site record).

Reviews, Outreach, and Lobbying

We recognize the importance of substantial field reviews. For this purpose, in addition to the more common typical trench viewings often referred to as trench parties, we organized several in depth trench reviews. These were performed by the most experienced paleoseismologists that were interested, available, and motivated, including, but not limited to: Tom Fumal, Tom Rockwell, David Schwartz, Graham Kent, Neal Driscoll. We find that these reviews cannot be effectively combined with the large group field trips. Ideally these reviews would include a clear record from each reviewer, and we hope to work towards that in the future. In summary the reviewers agreed that this site has great potential, they generally advised to collect more supporting data on each event. Although individual event features are convincing, they said that the overall contribution of the record would be stronger if we could confirm each event. Next they urged us to collect stratigraphic slip per event data. Until now we can only interpret slip per event from correlated geomorphic offsets in the surrounding area. Again although they appear quite convincing, more validation would give greater confidence. Lastly, anything we can do to improve the chronology that would result in the most precise event dates possible was urged.

For general outreach we have led the last two annual SCEC meeting, several university classes, and State Park field trips, to this site. In support of the new high-profile initiative SoSafe we have led additional field trips for State and Federal representatives and their staffers, some requested by the USGS.

References

Agnew, D. C., Evidence on large southern California earthquakes from historic records, U. S. Geol. Survey Open File Rept., 85-507, 76-90, 1985.

Anderson, G., D.C. Agnew and H.O. Johnson, Salton Trough regional deformation estimated from combined trilateration and survey-mode GPS data BSSA 2003

Bennet, R.A., W. Rodi and R.E. Reilinger, 1996, Global Positioning System constraints on fault slip rates in southern alifornia and northern Baja Mexico, J. Geophys. Res., 101,21,943-21,960.

Biehler, S., R. L. Kovach, and C. R. Allen, Geophysical framework of northern end of Gulf of California structural province, in Marine Geology of the Gulf of California, Am. Assoc. Petrol. Geol. Mem., 3, edited by T. H. van Andel and G. G. Shor, 126143, 1964.

Bilham, R., and P. Williams, Sawtooth segmentation and deformation processes on the southern San Andreas fault, California, Geophys. Res. Lett., 12, 557-560, 1985. Biasi, G, R. Weldon, and K., Scharer, Rupture histories from paleosesimic records on the southern San Andreas fault, Seis. Res, Lett., 77, 270, 2006, University of Oregon, Center for Advanced Technology in Education, ©1998-2000, http://anza.uoregon.edu/

Coachella General Plan, 2004, Environmental Hazards & Safety Element www.coachella.org/pdf%20files/ generalplan/9_EnvHazSafety.PDF Smith, Peroni & Fox, Planning Consultants, Inc.

Elders, W. A., Rex, R. W., Meidav, T., Robinson, P. T., and Biehler, S., 1972, Crustal Spreading in Southern California. Science v. 178, p. 15-24.

Fuis, G. S., W. D. Mooney, J. H. Healey, G. A. McMechan, and W. J. Lutter, Crustal structure of the Imperial Valley region, in The Imperial Valley, California, Earthquake of October 15, 1979, U. S. Geol. Survey Prof. Pap. 1254, 25-50, 1982.

Fumal, T. E., M. J. Rymer, and G. G. Seitz ,2002, Timing of large earthquakes since A.D. 800 on the Mission Creek strand of the San Andreas fault zone at Thousand Palms Oasis, near Palm Springs, California, Bull. Seism. Soc. Am., vol.92, No. 7, pp 28412860.

Gurrola, L. D. and Rockwell, T. K., 1996, Timing and slip for prehistoric earthquakes on the Superstition Mountain fault, Imperial Valley, southern California: Journal of Geophysical Research, v.101, B3, p.5977-5985.

Hauksson, E., Crustal structure and seismicity distribution adjacent to the Pacific and North America plate boundary in southern California, J. Geophys. Res., 105, 13,87513,903, 2000.

Lienkaemper, J.J., P.L. Williams, T.E. Dawson, S.F. Personius, G.G. Seitz, S.J. Heller, and D.P. Schwartz., Logs and Data from Trenches Across the Hayward Fault at Tyson’s Lagoon (Tule Pond), Fremont, Alameda County, California, 2001-2003, U.S.G.S. Open-File Report 03-488; http://geopubs.wr.usgs.gov/open-file/of03-488/., 2004.

Lomnitz, C., F. Mooser, C. R. Allen, J. N. Brune and W. Thatcher, Seismicity and tectonics of the northern Gulf of California region, Mexico: preliminary results, Geofisica Internacional, 10, 37-48, 1970.

Oskin, M.E.; Stock, J.M., and Martin-Barajas, A., 2001, Rapid localization of Pacific-North America plate motion in the Gulf of California. Geology, v. 29, p. 459-462.

Rockwell, T.K. and K. Sieh ,1994. Correlation of large earthquakes using regional lacustrine stratigraphy, examples from the Salton Trough, California, Geol. Soc. Am. Abstr. Programs 26, A-239.

Shifflett, H., Gray, M. G., Grannell, R., & Ingram, B. L., New Evidence on the Slip Rate, Renewal Time, and Late Holocene Surface Displacement, Southernmost San Andreas Fault, Mecca Hills, California, Bull. Seism. Soc. Am., vol.92, No. 7, pp 2861-2877.

Seitz and Williams, 2004, San Andreas Fault in the Coachella Valley at Salt Creek: Development of Long-Term Earthquake Constraints Using High-Resolution Lake Chronology and Event offsets, SCEC abstract annual meeting.

Sieh, K. E., Slip rate across the San Andreas fault and prehistoric earthquakes at Indio, California (abstract), EOS, Trans. Amer. Geophys. Union, 67, 1200, 1986.

Sieh, K. E. and P. L. Williams, Behavior of the San Andreas fault during the past 300 years, J. Geophys. Res., 95, 6629-6645, 1990.

Stuiver, M. and G. W. Pearson, High precision calibration of the radiocarbon time scale, AD 1950-500 BC, Radiocarbon, 28, 805-838, 1986.

Thatcher, W, Horizontal crustal deformation from historical geodetic measurements in southern California, J. Geophys. Res., 84, 2351-2370, 1979.

van der Woerd et al., J.Y. Klinger, K. Sieh, P. Tapponier, F. Ryerson, 2001, First long-term slip-rate along the San Andreas fault based on 10 Be-26 Al surface exposure dating: the Biskra Palms site, 23mm/yr (15 mm/yr see text) for the last 30,000 years, EOS 82,no. 47,F934.

van der Woerd, J., Y. Klinger, K. Sieh, P. Tapponnier, F. J. Ryerson, and A.-S. Mériaux (2006), Long-term slip rate of the southern San Andreas Fault from 10Be-26Al surface exposure dating of an offset alluvial fan, J. Geophys. Res., 111, B04407, doi:10.1029/2004JB003559.

Waters, M.R. (1983). Late Holocene lacustrine stratigraphy and archaeology of ancient Lake Cahuilla, California, Quat. Res. 19, 373-387.

Weldon, R., K. Scharer, T. Fumal and G. Biasi, Wrightwood and the earthquake cycle: what a long recurrence record tells us about how faults work, 2004, Geol. Today, 4-11.

Williams, P. L., Late Holocene displacement across the southernmost San Andreas fault, California, Ph.D. Thesis (chapter 2), 30 pp., Columbia University, 1989.

Williams, P. and G. Seitz, New insights to earthquake behavior of the southernmost San Andreas fault, Seis. Res, Lett., 77, 270, 2006,

Williams, P.L. and K.E. Sieh, Decreasing activity of the southernmost San Andreas fault during the past millennium (abstract), Geol. Soc. Am. Abstr. With Prog., 19, 891, 1987.

Williams, P.L., L.R. Sykes, C.N. Nicholson, and L. Seeber, Seismotectonics and stress field, Easternmost Transverse Ranges, California: relevance for seismic potential of the San Andreas fault, Tectonics. 9, 185-204, 1990

Working Group on California Earthquake Probabilities, Seismic Hazards in Southern California: Probable Earthquakes, 1994 to 2024: Bull. Seismol. Soc. Amer., 85, 379-439, 1995.