2012 SCEC Annual Report

A High Resolution Lake Cahuilla Chronology to Constrain Earthquakes on the Southern San Andreas System

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Summary of Major Research Findings

Our work focused on developing a higher-resolution chronology of Lake Cahuilla in which to place the rupture history of several major elements of the southern San Andreas fault system. Towards that end, our work focused on two fundamentally different aspects: 1) correlation of lake strata using oxygen and carbon isotopic ratios to test whether this method could be used to uniquely correlate the many sites with shells to those radiometrically dated; and 2) direct dating of dead stumps that grew below the shoreline of Lake Cahuilla and required the absence of water at those times.

Preliminary oxygen and carbon isotopic analyses shows that lakes have distinctive $d^{18}O/d^{13}C$ values that appear to evolve through the life time of a lake, and that different species record different $d^{13}C$ values at a single time in a lake. More samples are being analyzed to work out the best target species to uniquely distinguish lakes.

We found many stumps that were inundated by the last highstand of Lake Cahuilla. Dating the outer and inner portions of the wood yields ages that, along with the historical record, indicate that the stumps grew sometime in the interval between AD 1705 and 1720. Combined with the historical record, tree ring records from the Colorado Plateau, and calculations that require lake desiccation to be mostly complete by 1774, the most recent lake must represent a fairly brief filling around AD 1717-1726. As the most recent large rupture of the southern San Andreas fault occurred during the last lake, and these new dates move the timing of this earthquake forward by several decades into the 18th century.

Summary of Outreach Activities

Training of graduate students, Erik Haaker, SDSU, and Ashley Streig, UO.

Undergraduate Nick Weldon analyzed oxygen and carbon samples.

Introduction

The Salton Trough is a unique laboratory to examine fault interaction models. Lake Cahuilla, a large ephemeral body of fresh water produced when the Colorado River spills northward into the Salton Trough, has inundated portions of the SAF, SJF, IF and CPF numerous times during the Holocene (Fig. 1). Over the past 1200-1400 years, there are at least five and as many as seven major lake episodes documented at various sites throughout the basin (Sieh, 1986; Rockwell and Sieh, 1994; Gurrola and Rockwell, 1996; Thomas and Rockwell, 1996; Rockwell et al., 2000; Meltzner et al., 2006; Philibosian et al., 2011). However, because paleoseismic sites sit at different elevations around the basin, and good ^{14}C dates are rare, correlation of earthquakes from site to site remains a challenge (Philibosian, et al., 2011). We are developing an integrated chronology that combines the lakes and the ages of earthquakes at each site around the basin. This record will allow for an unprecedented level of relative age control with broad spatial coverage that will allow for precise ordering of large earthquakes that ruptured the SJF, the southernmost SAF, and the IF, all of which have established long paleoseismic records.

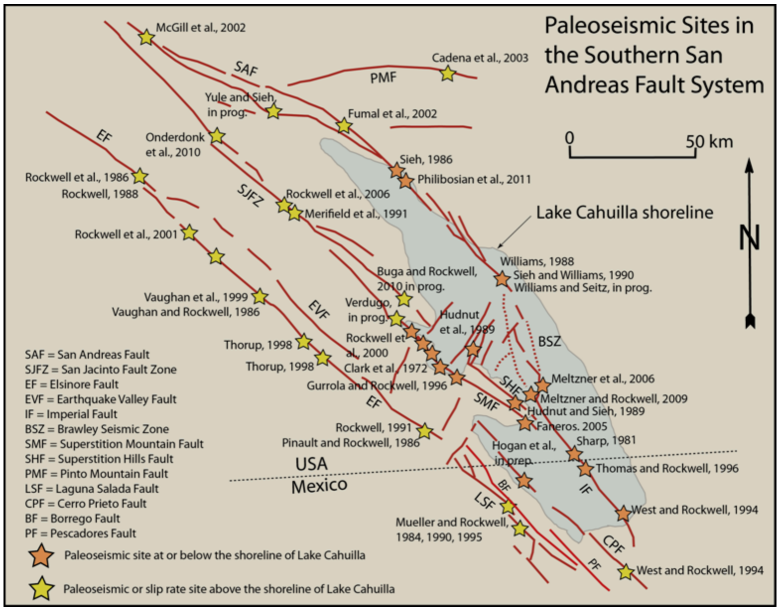


Figure 1. *Map of paleoseismic and slip rate sites in the southern SAF system. Orange stars are sites with Lake Cahuilla strata.*

The Problem with the existing Lake Cahuilla Chronology

It is well known that shells that grew in Lake Cahuilla (or its modern equivalent, the Salton Sea) give radiocarbon ages that are too old by an unknown amount (due to the presence of abundant old or "dead" carbon in the Colorado River water that formed the lakes). Thus, modern workers have avoided dating shells even though they are ubiquitous in essentially all sections of Lake Cahuilla sediments.

An additional problem is that most of our organic (non-shell) dates on lake deposits are from detrital charcoal derived from vegetation that grew in a subaerial environment and likely predate the actual inundation of the lake itself (because most charcoal is from the lake basin not the surrounding area). Further, most of the fires that burned the wood are of Native American origin and it was common to burn dead wood rather than live (green) wood for cooking fires. Hence, virtually all detrital radiocarbon ages from the basin have an inheritance factor of some unknown amount and therefore provide maximum ages of the actual lakes, which in turn provides maximum ages for the timing of past earthquakes.

Towards better dating the lakes, we collected wood from dead stumps that were drowned by one or more episodes of Lake Cahuilla with the purpose of dating the periods when the lake was dry (intra-lake periods). We found many stumps sticking out of washed-out shrub-coppice dunes that were either covered with gastropod shells or directly buried by lake deposits, or both. We collected entire stumps from which we cut wood sections from the outer and inner portions of the stumps to determine the length of growth time by radiocarbon dating. The results presented here are the first direct dating of dry periods between the past 2-3 lakes and directly constrain the maximum age of the ensuing lakes. Continued work will potentially extend the record of dry periods back to more than 1200 years, and combined with the nearly 400 detrital radiocarbon dates, provide the necessary constraints to develop a high-resolution history of Lake Cahuilla fillings and desiccations.

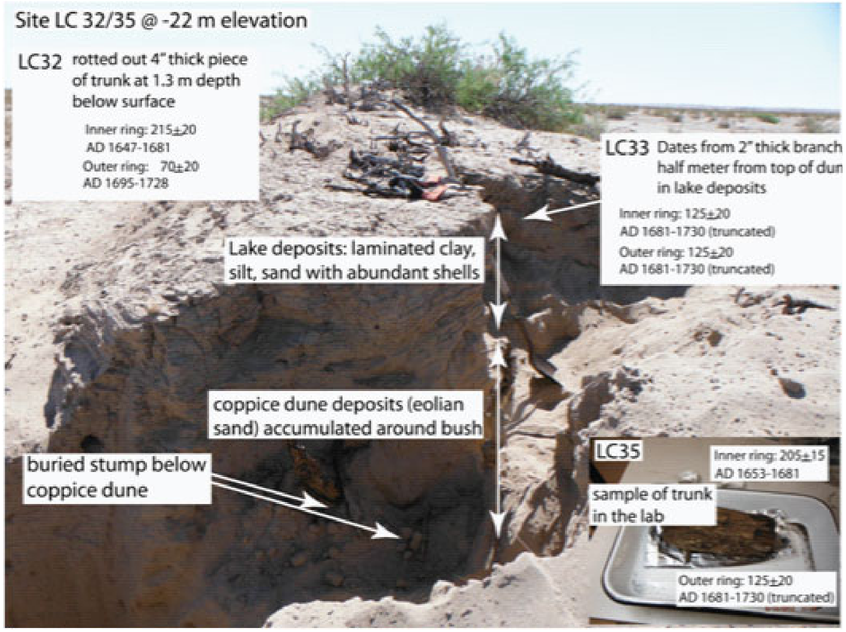


Figure 2. *Small trench through a shrub-coppice dune at -22 m elevation. Lake sediments with abundant shells bury coppice dune deposits around a buried bush; the top branches of the bush are still sticking above the lake sediments, in spite of being several hundred years in age. Samples were collected from various stump/bush elements, including the basal trunk at the bottom of the trench.*

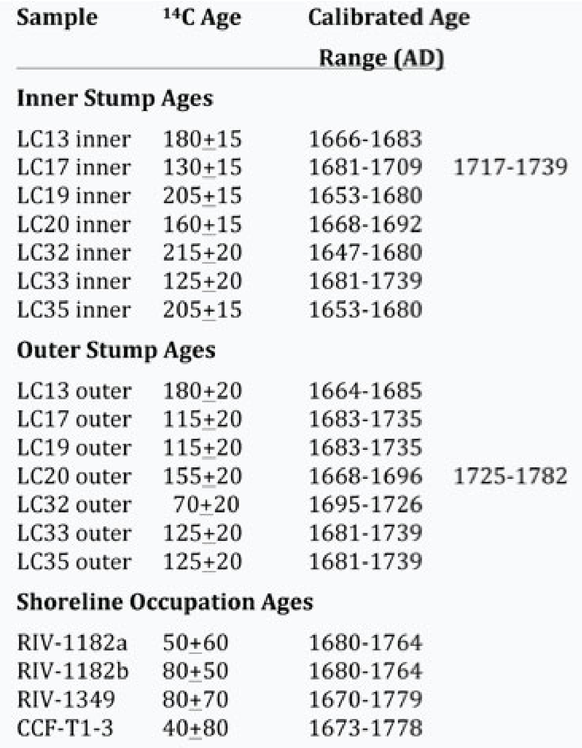
The second major problem is correlation of lake deposits at the various paleoseismic sites around the basin. Because individual sites occupy different elevations and don't record or preserve the same number of lakes, correlation is difficult. Miscorrelation of lakes will mean incorrect dating and ordering of large earthquakes in the southern SAF system. To develop an alternative method of lake correlations that is not based solely on radiocarbon dating, we have begun analysis of the isotopic content of shells collected from lake levels at several sites. The purpose is to resolve whether we can correlate lake deposits independent of local dating, and correlate the lake strata at all sites to a common integrated lake stratigraphy.

Results

We collected stump samples from 20 sites ranging in elevation between +7m to -45m. The rationale for collecting stumps at various elevations is that the desiccation rate for the basin is known at 1.55-1.6 m/yr so the potential relative age limits of each lake can be estimated if we have enough samples that represent a dry period at various elevations.

Figure 2 shows one of the washed-out shrub-coppice dunes that is capped by lake deposits. We hand-excavated a trench through the dune to determine the stratigraphic relationship between the stump, the dune sand, and the overlying lake deposits. In this case, we interpret one lake episode with deposition of bedded silt and fine sand overlying the eolian coppice dune that accumulated around the stump when it was a live bush. The branches sticking out of the top of the dune converge downward, and sample LC32 is the basal stump. Radiocarbon analysis of the basal stump shows that it began growing in the period between AD 1647 and 1681, and that it died between AD 1695 and 1728. Dates from the other parts of the stump complex at this site, as well as other buried stumps at other sites, yield similar age ranges (Table 1) that indicate initial growth in the period between AD 1647 and as late as 1709, with growth ending for most samples between 1681 and the 1730's. Notably, one of the outer ring dates is in the range of AD 1668 to 1696, where another falls between 1695 and 1726. All of these dates argue that wood was growing in the basin from as early as ca 1650 through the early 18th century.

Also shown in Table 1 are radiocarbon dates from a village site on the shoreline of Lake Cahuilla (samples RIV-XXX) and from an archeological site at the shoreline where it crosses the Coyote Creek fault (CCF-T1-3). These shoreline dates conclusive argue that water filled the basin after AD 1680 but before the late 18th Century. Considering that the Anza expeditions first came through the region in 1774 and found Native Americans living at San Sebastian’s Wash (west side of Highway 86, south of Highway 78 at ~-50 m elevation) and harvesting acacia, and considering that a 1.55-1.6 m/yr desiccation rate (based on the desiccation rate following the 1905-1907 flooding of the Salton Sea) requires a minimum of 40 years for water to recede to that level and as much as 60 years for complete desiccation, most workers have assumed that the highstand of the lake could not have existed after about AD 1715 or 1720. However, the diaries from Anza’s expeditions suggest that some water may have remained in the basin, and there are marshes reported that also suggest water. If true, it is plausible that desiccation was not complete, which would allow the highstand to be later than previously inferred.



Sample	^{14}C Age	Calibrated Age Range (AD)	
Inner Stump Ages			
LC13 inner	180±15	1666-1683	
LC17 inner	130±15	1681-1709	1717-1739
LC19 inner	205±15	1653-1680	
LC20 inner	160±15	1668-1692	
LC32 inner	215±20	1647-1680	
LC33 inner	125±20	1681-1739	
LC35 inner	205±15	1653-1680	
Outer Stump Ages			
LC13 outer	180±20	1664-1685	
LC17 outer	115±20	1683-1735	
LC19 outer	115±20	1683-1735	
LC20 outer	155±20	1668-1696	1725-1782
LC32 outer	70±20	1695-1726	
LC33 outer	125±20	1681-1739	
LC35 outer	125±20	1681-1739	
Shoreline Occupation Ages			
RIV-1182a	50±60	1680-1764	
RIV-1182b	80±50	1680-1764	
RIV-1349	80±70	1670-1779	
CCF-T1-3	40±80	1673-1778	

Table 1. *Paired dates that predate the last infilling of Lake Cahuilla, and that limit when water could have filled the lake. The “inner” date is the dendrocalibrated age range for the innermost wood growth, whereas the “outer” date with the same number (ie., LC35) is the outermost few mm of the same part of a stump. Samples LC32, LC33, and LC35 are all from the same site, and presumably part of the same bush complex. All samples calibrated in Calib 6.03 (Reimer et al., 2009). The age range is truncated for everything after ca 1730, as the historical record precludes the initiation of desiccation after about then. The last four dates are from archeological sites along the shoreline that were occupied during the lake highstand.*

Figure 3 shows rainfall patterns interpreted from tree ring records for the Colorado Plateau region since about AD 1300 (Salzerand Kipfmueller, 2005). We plot the dates when various explorers noted water from the Colorado River flowing to the Gulf of California (indicated as RTS – river to south). Some also provided detailed accounts that demonstrate the absence of water in the Salton basin (Lt. Hardy, Lt. Derby), and we note when water was documented to be in the basin during the historical period (1868 Bancroft map, 1891 flow to the Salton depression, 1905-1907).

Of particular note is the observation that during the times water is known to flow to the Salton Trough in the historical period correspond to periods of high rainfall in the Colorado Plateau (indicated by the blue bands) and the times that water is known not to be in the basin, or is flowing to the Gulf, are during lower rainfall periods. A further observation is the 1891 flow to the Salton Depression when rainfall reached about 35 inches (Sykes, 1937), which may approximately reflect a threshold for flooding into the Trough. Further, a three-year period in the 1860’s when rainfall exceeded this value resulted in a partial filling of the basin, as indicated on the 1868 Bancroft map that shows the water level a little higher than was achieved by the 1905-1907 filling that resulted in the Salton Sea. Together, we interpret this to suggest that multi-year periods of elevated rainfall provide the necessary conditions to allow a Lake Cahuilla filling event, even though many such periods may not have resulted in a complete filling if other conditions were not satisfied.

The stump dates on the inner wood fall within a period that is generally dry (1645-1675) and so suitable tree habitat, whereas one of the outer wood samples suggest the tree drown by 1695, and suggest filling of the Salton basin at that time. The calendar year1695 is at the end of a wetter 20 year period between 1675 and 1695. A date from a tree producing growth rings in this 20-year wet period implies that this 20-year interval was not accompanied by a complete filling of Lake Cahuilla, at least up to the -22 m elevation where the sample was collected.

The next wet period occurred between 1717 and 1724, barely long enough to fill the Cahuilla Basin but within the timeframe indicated by the stump and shoreline dates. After this, it was dry until at least 1740, which is too late for a filling and desiccation prior to Anza's expeditions.

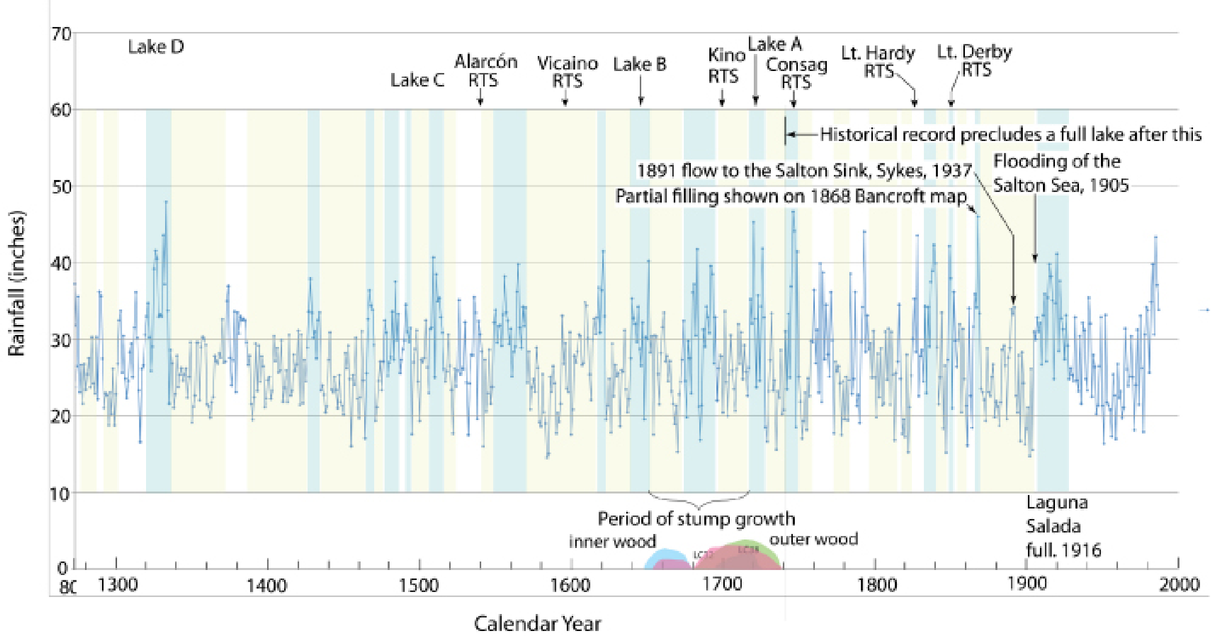


Figure 3. *Plot of rainfall patterns interpreted from tree ring records for the Colorado Plateau region since about AD 1300 (Salzerand Kipfmueller, 2005). Here, we plot the dates when various explorers noted water from the Colorado River flowing to the Gulf of California (indicated as RTS – river to south).*

Taken together, these new data in conjunction with previous radiocarbon data, the historical record, and rainfall records point to only a single short time interval that may correspond to the final filling of Lake Cahuilla. A brief lake is consistent with shoreline exposures at the northern Superstition Mountain site (Gurrola and Rockwell, 1996), where Lake A produced a notch into the previously deposited shoreline berm. A 1724 date also barely allows for desiccation of most or all of the lake prior to Anza's visits. Consequently, we take this brief period in the early 1720's as the timing of Lake A.

Several studies place the timing of the most recent large southern San Andreas fault rupture in Lake A, the youngest full filling. If correct, and if our dates for Lake A hold up with future work, this implies that the lapse time or open interval for the southern San Andreas fault may be as much as 40 years less than currently assessed in UCERF3.

Part 2 - The Problem with Correlation of Lake Cahuilla Stratigraphy

Once we have dated lakes at the rare sites that provide useful ^{14}C samples we still need to correlate to sites without ^{14}C. Because the filling and desiccation of individual lakes can be accomplished within a century, and there have been as many as seven full fillings and an unknown number of partial fillings between about AD 800 and 1700 (the last full lake), radiocarbon dating alone is unlikely to provide the necessary resolution to distinguish short-lived lakes.

Thus, there is a critical need to develop other criteria for correlating lake events from site to site and develop a way to correlate lakes, so that we can bring our rare good dates and the combined chronologic model for the basin to bear on sections without good dates. It is possible that oxygen and carbon isotopes or their ratios may yield unique values (or trends through a lake's life time) for each late Holocene lake interval. At the Coachella-1 site, comparison of radiocarbon dates between shells and charcoal or organic layers suggests that the shells yield ages that are several hundred years too old (Philibosian et al., 2011). However, isotopic analysis of ~30 shells suggests the possibility of systematic variations in the composition of shells (e.g. lake 2 had high d^{13}C & low d^{18}O, whereas lake 3 had low d^{13}C & high d^{18}O compared to the average and the 3 lower lakes, which were quite similar to the overall average). Because few sites around the basin have sufficient organic-rich layers for constraining the earthquake ages but all have lots of shells, comparison of the shell dates and isotopic signatures from various sites could allow us to develop an independent correlation technique and chronology to identify the lake sequence across the basin.

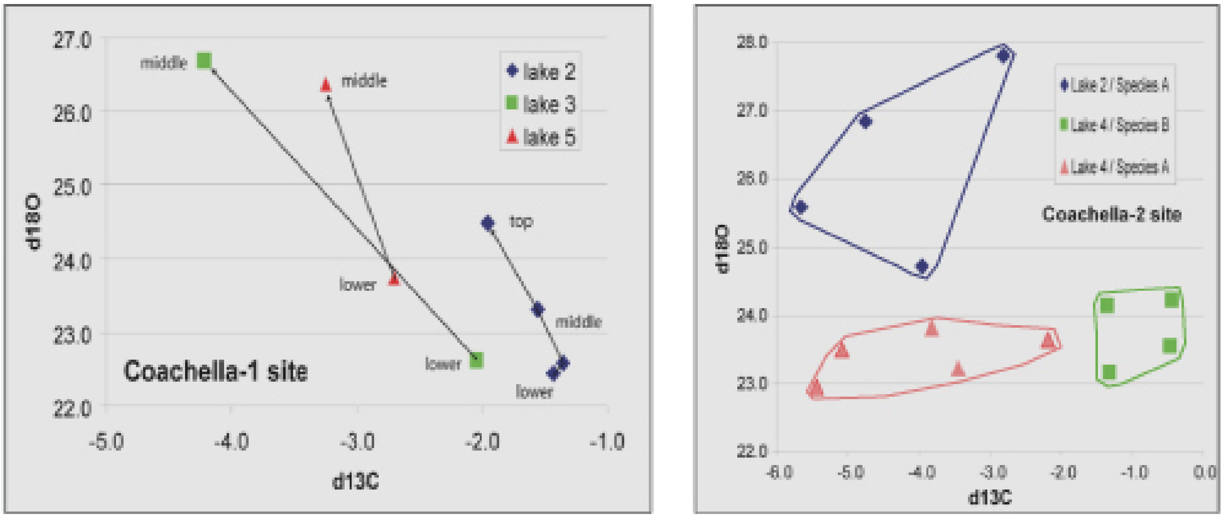


Figure 4. *Preliminary stable isotope analysis of shell samples that were collected from lake Cahuilla for possible C-14 dating in past paleoseismic investigations. Left: By chance we preserved shells of the same species from multiple layers in 3 of the most recent lakes. Analysis suggests that the shells preserved unique isotopic signatures that evolved during the duration of the lake, which is why we need to systematically analyze samples from different levels in each lake section to understand this phenomenon. Right: At our Coachella-2 site we collected multiple shells of different species from several lakes to see if different species from the same horizon yielded consistent stable isotopic and C-14 ages (see Table 1 for C-14 results). Species A has similar d13C ranges in lakes 2 and 4 but nonoverlapping d18O ranges. Different species (A&B) in lake 4 have similar d18O values but nonoverlapping d13 ranges. While these results are based on very few samples that we had fortuitously preserved (ie not collected to systematically examine stable isotope variations), they suggest that there may be patterns that we can work out with more samples. NOTE- the lake numbers at the two Coachella sites do not correspond; the Coachella-2 site is in part or completely older than the Coachella-1 site, and has only been C-14 dated with shells that currently have an unknown amount of old carbon reservoir effect. Shells analyzed by Nick Weldon and Jim Palandri in Professor Ilya Bindeman' s Stable Isotope lab.*

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