Final Report—02HQGR0072
Offshore Characterization of Active Lake Tahoe Basin Faults: Combining Sub-Meter Resolution Seismic Imagery With C-14 Dated Sediment Cores

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Summary

In the summer of 2002, an ambitious seismic CHIRP and coring program was undertaken at Lake Tahoe to provide slip-rates across the West Tahoe and Stateline fault zones. During this two-week program, funded through grants from the USGS NEHRP program (02HQGR0072) and an award from Lawrence Livermore and IGPP (02-GS-008), seismic CHIRP was collected across an old paleo-shoreline that encircles the lake, and throughout Emerald Bay, where nearby displaced moraines suggest either significant slip-rates on dip-slip faults or large-scale block sliding associated with the catastrophic McKinney Bay debris slide. In addition, sediment cores were collected to age-date (OSL/AMS C-14 methods) the now deformed paleo-shoreline (vibra-core) and displacement across the Stateline fault (piston-core). Based on sedimentation-rates from a previous sediment core collected in 2000, inferred slip-rates across both fault zones is on order 0.4-0.7 mm/yr, which might correspond to a M7 tsunamic event, on average, every 3000 years. The seismic images and sediment cores collected this past summer will help tighten age constraints for both the deformed paleo-shoreline (up to 15 meters) and the age of the McKinney Bay slide (vertically offset some 21-25 m across the Stateline fault) with the addition of several long sediment cores that will provide either a direct age estimate (e.g., paleo-shoreline), or allow a robust sedimentation rate to be determined, thereby allowing an extrapolation backward to age-date the displaced surface (e.g., McKinney Bay slide). The cores are presently located at Scripps (vibra-cores) and the University of Nevada, Reno (piston-cores); the analyses of these cores are being conducted by Drs. Gordon Seitz, Alan Heyvaert and Robert Karlin. New OSL & AMS-based C-14 age-dates were obtained 2003 and 2004 and confirm that the paleoshoreline terrace was inudated at 19.2 +/- 1.9 ka neat the time of last glacial maximum.

2002 Field Program

Beginning on July 29th, through August 16th, 2002, investigators from Scripps Institution of Oceanography (SIO), Lawrence Livermore Laboratory (CAMS), University of California, Davis (UCD), University of Nevada, Reno (UNR) and Coastal Carolina University took part in a multi-faceted geophysical investigation of the active fault zones beneath Lake Tahoe. Seismic CHIRP profiles were collected to augment profiles shot in 1999 and 2000, with careful attention to locating sites suitable for vibra-coring. This strategy was especially true for locating sites to sample through the paleo-shoreline that now shows as much as 15 m of deformation. In addition, seismic CHIRP was collected across the shallowest location of this pre-historic shoreline, off-shore Rubicon, and in Emerald Bay, which is of critical interest with the discovery of several offset lateral moraines that were likely displaced due to either dip-slip faulting (on-shore), or blocking sliding of a large sliver (5 km by 15 km) of shoreline associated with the McKinney Bay slide. Two full days of seismic CHIRP was collected, with one day devoted to the eastern shoreline near Cave Rock, and the final day focusing on Emerald Bay and several discontinuous strands of paleo-shoreline near Rubicon and Sugar Pine Point. The paleo-shoreline was mapped in detail between Cave Rock and Zephyr Cove, with the exciting discovery that a second paleo-shoreline can be seen about 4-5 m beneath youngest paleo-shoreline (Figure 1). This is an important observation for several reasons: (1) the discovery of several vertically-stacked paleo-shorelines beneath the eastern shore might be related to large displacement earthquakes that down-drop the eastern shoreline (located on the hanging wall of both West Tahoe and Stateline faults zones), inundating this erosional surface, thereby allowing new deltaic sediments to prograde outward, ultimately infilling this tectonically derived accommodation. (2) mapping variations in thickness between paleo-shorelines, between Zephyr Cove and Incline Village, along with OSL/AMS C-14 dated cores, would allow timing of these events, and give a quantitative sense of any variations in offset along the strike of either the Stateline

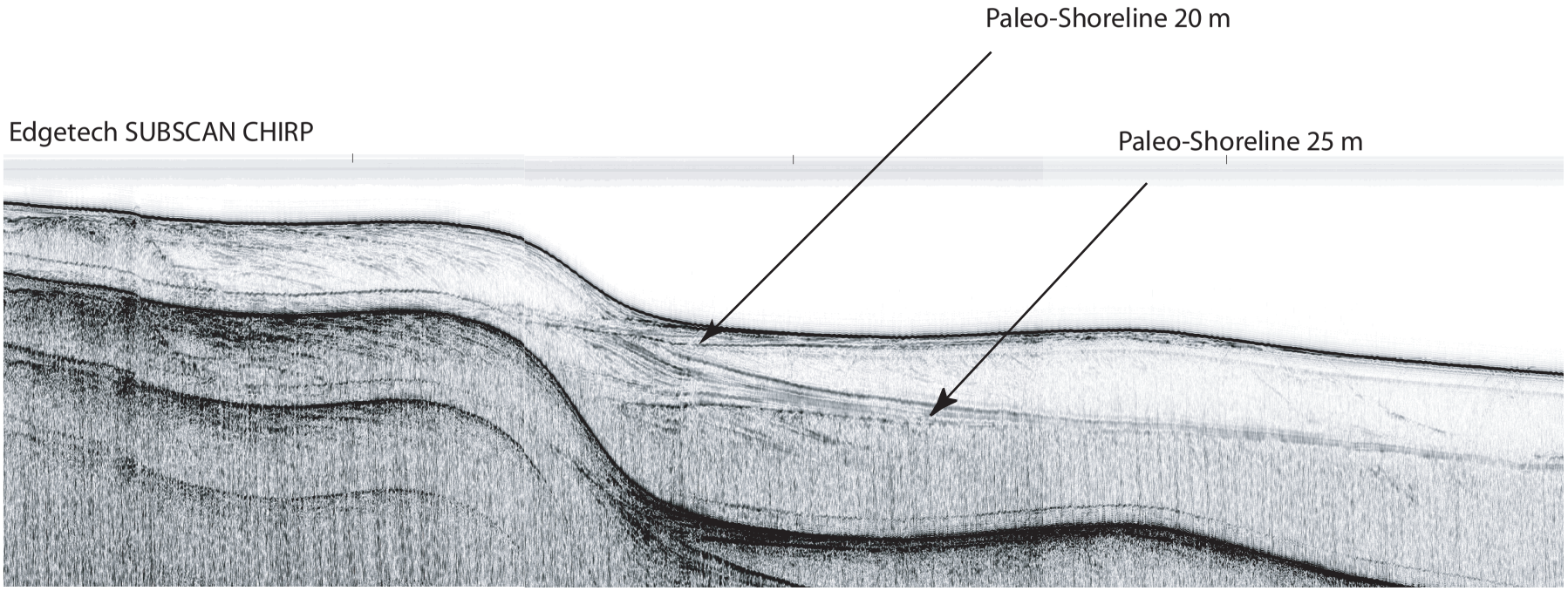

Fig 1: Paleo-Shorelines: Cave Rock (Hanging Wall Location)

Fig. 2 Vibra-core set-up at Lake Tahoe, summer 2002. Crane and vibra-core were place on 80' by 40' barge. Several cores in excess of 8 meters in length were recovered from the shores of Lake Tahoe, and represent the longest cores recovered from Tahoe to date.

and/or West Tahoe faults. Paleo-shorelines imaged near Rubicon and Sugar Pine Point confirm earlier observations from ROV dives that these surfaces are submerged paleo-shorelines, and range in depth between about 11 to 13 m; these beveled surfaces are anywhere from 9-15 m shallower, when compared to counter parts on the eastern shoreline. The paleo-surface on the western shore is relatively shallow, since it is located on the footwall of both active fault zones. CHIRP images of Emerald Bay show layer-caked Holocene sediments that are draped across several significant scarps, although preliminary analysis of these data suggest that there has been no recent (i.e., Holocene) movement across these scarps. If true, this observation would strengthen the argument that these features are not fault-related, but likely remnants of a large crustal block that failed, but did not slide into Lake Tahoe, in comparison to the McKinney Bay portion of the slide.

While seismic acquisition was taking place, Dr. Paul Gayes and crew from Coastal Carolina University were setting-up their vibra-core equipment on a barge supplied by Matt Daniels at Tahoe Excavation and Salvage (Figure 2). This operation required rental of not only a large barge, but a drive-on crane was required for deploying and recovering the vibra-core unit (about 10,000 lbs). A test 8-meter-long core was taken near Obexer's Marina (west shore of Lake Tahoe) to shake-down the equipment before transiting across the lake toward Cave Rock. Several long cores were recovered along the eastern shoreline, including a 9-m-long core that allow age dating of the sedimentary sequence just above the paleo-shoreline; another 1-m-long core through the paleo-surface (collected outboard of the deltaic sediments) provided a complementary measurement of age of inudation of this surface. The date of inudation of this surface was found to be 19.2 +/- 1.8 ka, or at the time of last glacial maximum. These cores also represent the longest sediment cores collected at Lake Tahoe to date. We were able to use this vibra-coring unit thanks to an Arctic program (NSF) that brought the equipment through the Tahoe area, before shipment to Seattle, and ultimately Nome, Alaska.

For deeper coring targets, namely the Stateline fault, we worked with Dr. Robert Karlin (UNR) and his piston-coring system that was run-off the R/V John LeConte (the same UCD vessel used for CHIRP studies). Over a 5 day period some additional 10 deep water cores, up to 5 meters in length, were collected in Lake Tahoe. Notable cores include: two cores on both the footwall and hanging wall of the Stateline fault (about 100 m either side of fault zone), two 5-m-long cores in Emerald Bay to help estimate the slip-rate (if any) along faults in this enclosed basin, and several widely distributed cores to test whether several coarse-grained layers are associated with turbidites derived from large floods (localized to a particular drainage system) or shaking events (more widely distributed). These dozen or so cores are located at UNR and will be age-dated in the near future.

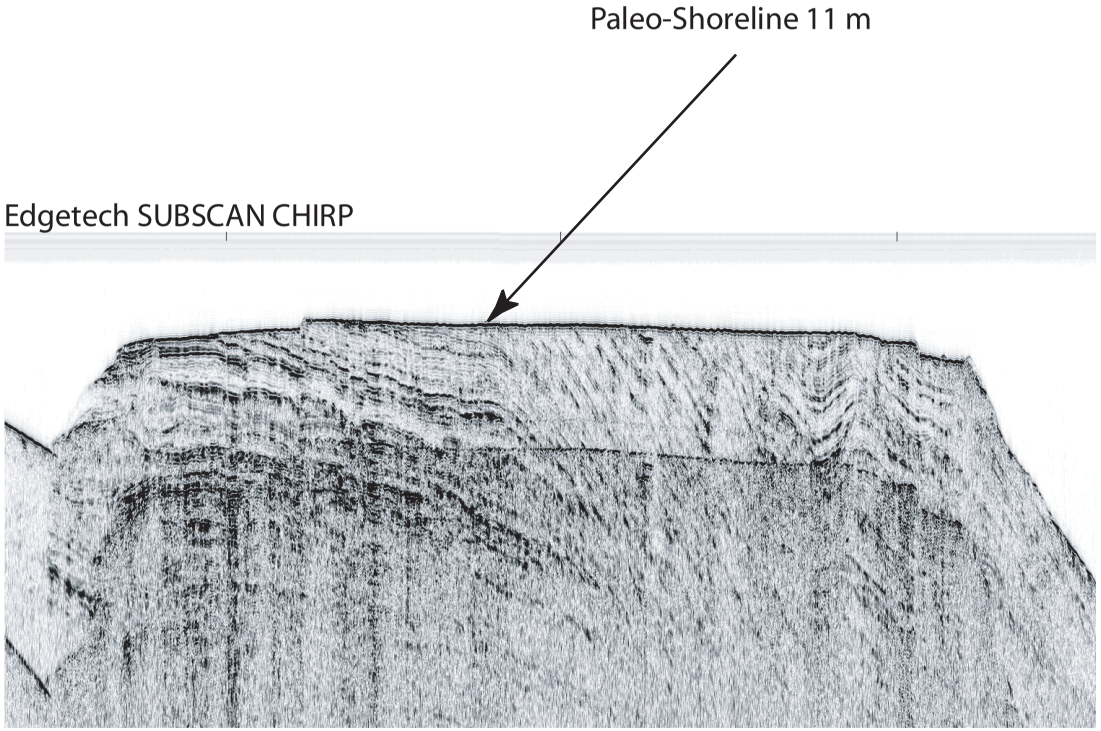

Fig 3: Paleo-Shorelines: Rubicon (Footwall Location)

New Observations and On-going Work

The seismic CHIRP work this summer was built on a foundation of two previous field seasons of work. The most exciting new observation was the clear evidence for vertically stacked, paleo-shorelines along the eastern shoreline of Lake Tahoe. This observation presents an opportunity to study large, individual events across both the West Tahoe and Stateline fault zones. Further (stunning) images of paleo-shorelines (Figure 3) confirm their existence and highlight nearly 15 m of deformation (youngest paleo-shoreline) as measured from Rubicon to Incline Village. The new vibra-cores should enable an age bracket to be determined for this beveled surface, which will aid in the determination of slip-rates for the Stateline and West Tahoe faults. Piston-cores taken this past summer will establish a better Holocene sedimentation rate at Lake Tahoe, that will help constrain a better age estimate for the McKinney Bay slide, that can then be used to distribute the nearly 30 m of slip on the Stateline fault—producing a refined slip rate for this significant fault. These cores may also answer whether the turbudite layers found in previous cores are related to large floods (and slope instability) or owe their existence to large shaking events; if the latter is true, then these cores can be used to determine the number of events in the past 12 ka or so, and by inference, the size of these events (since we know the cumulative slip). Lastly, the Emerald Bay CHIRP and piston-core data will help determine whether the offsets observed across several lateral moraines are related to dip-slip faulting that is westward of the West Tahoe fault, or a paleo-failure surface, most likely related to the catastrophic McKinney Bay slide.

Research articles based on this research include:

Kent, G. M., J. A. Babcock, N. W. Driscoll, A. J. Harding, G. G. Seitz, J. A. Dingler, J. V. Gardner, C. R. Goldman, A. C. Heyvaert, P. Gayes, R. Karlin, L. A. Mayer, C. W. Morgan, L. A. Owen, R. C. Richards, "A 60 k.y. record of extension across the western boundary of the Basin and Range Province: Estimate of slip rates from offset shoreline terraces and a catastrophic slide beneath Lake Tahoe", Geology, 33, 365-368, 2005.

Kent, G., J. Babcock, N. Driscoll, A. Harding, J. Dingler, G. Seitz and R. Karlin, Reply: 60 k.y. record of extension across the western boundary of the Basin and Range province: Estimate of slip rates from offset shoreline terraces and a catastrophic slide beneath Lake Tahoe, Geology, e114-e116, doi:10.1130/G23127Y.1, 2006