SEISMIC ACTIVITY

TSUNAMIS·TSUNAMIS·TSUNAMIS·TSUNAMIS·TSUNAMIS IN THE SIERRAS

The calm summer waters across Lake Tahoe mask the area's potential for earthquakes, landslides, and destructive tsunamis. **Inset** *(L to R) Graham Kent, Jeff Babcock, and Alistair Harding prepare to study Lake Tahoe's deep fault lines in detail for the first time.*

AND ENVIRONMENTAL CONDITIONS UNDER INVESTIGATION AT LAKE TAHOE

BY MARIO C. AGUILERA

Set against the buzz of slot machines, rolling dice, and nonstop entertainment, the serene blue waters of Lake Tahoe offer more than just ideal conditions for skiing and sailing. These waters provide scientists with a closed laboratory to study possible natural disasters and to investigate environmental and oceanographic phenomena.

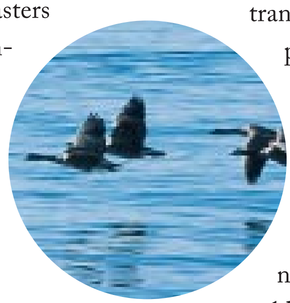
Geophysicist Graham Kent has studied the fault lines beneath Lake Tahoe's waters in detail. As a researcher with the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics (IGPP) at Scripps, Kent, with colleagues, conducted groundbreaking investigations in 1999. Along with Jeff Babcock, Neal Driscoll, Alistair Harding, and Gordon Seitz of Livermore National Laboratory, Kent mapped in detail the deep fault lines beneath the lake's surface.

A RICH TECTONIC HISTORY

Lake Tahoe is located in the central Sierra Nevadas and straddles the California/Nevada border in a fault basin prone to earthquakes and landslides. Kent, a Lake Tahoe area native, is part of a multi-institutional research group examining the lake's seismic activity and its potential role as a model for solving global environmental problems.

Seismic activity occurring along or under the lake could create tsunamis (sometimes called tidal waves), great destructive waves usually associated with submarine earth movement or volcanism under the oceans.

"The Lake Tahoe shoreline is ringed by a shallow, broad shelf, which abruptly transitions into a steep slope. Sections of this shelf have collapsed in the past, causing large tsunami waves," said Jeff Babcock, a project scientist at IGPP.

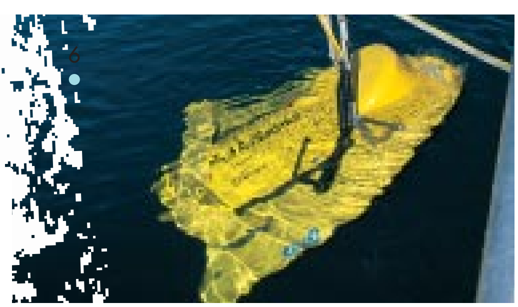


A Lake Tahoe tsunami is no small threat. Tahoe is one of the world's deepest freshwater lakes, with an area of 193 square miles (500 km) and it is more than 1,600 feet (500 m) deep. Recent work by researchers at the University of Nevada, Reno, suggests that a magnitude 7 earthquake centered on a major fault within the Tahoe basin could trigger seiche waves 32 feet (10 m) high. Seiche waves are oscillations of the lake's surface that could slosh back and forth across the lake for hours.

"The tsunami danger, in addition to the earthquake risk, is devastating because more than 17,000 people enjoy the Lake Tahoe shoreline every day in the summer.

There are also hundreds of houses and boats on the lake," Kent said. "People in Lake Tahoe will not take these dangers seriously unless a smoking gun is found," Kent said. "When you can prove that a fault moved or you see a tsunami deposit, you have the necessary evidence." Thus, Kent and his team set out to find the scientific proof needed to verify these dangers.

To better understand Lake Tahoe's evolution and fault structures, Kent and his team used a recently developed, three-dimensional acoustic imager known as the subscan chirp. This two-part instrument can obtain both past and current records of an ocean or lake floor. One part, the "*sub*-bottom," can penetrate sediment layers and obtain seismic data history while the second part or, "side-*scan*," can profile current details of the lake floor. Kent's group used research vessel *John Le Conte* from UC Davis to tow each part independently across the water.



Two transducers fixed on the base of the sub-bottom shoot acoustic signals directly at the lake floor. Operating in the low 1- to 15-kHz range allows the signals to penetrate deeply through several hundred feet of sediment layers. These signals then bounce back to a receiver where the information is transmitted digitally, in real time, to a computer system on the vessel. The data are instantly depicted as a high-resolution image.

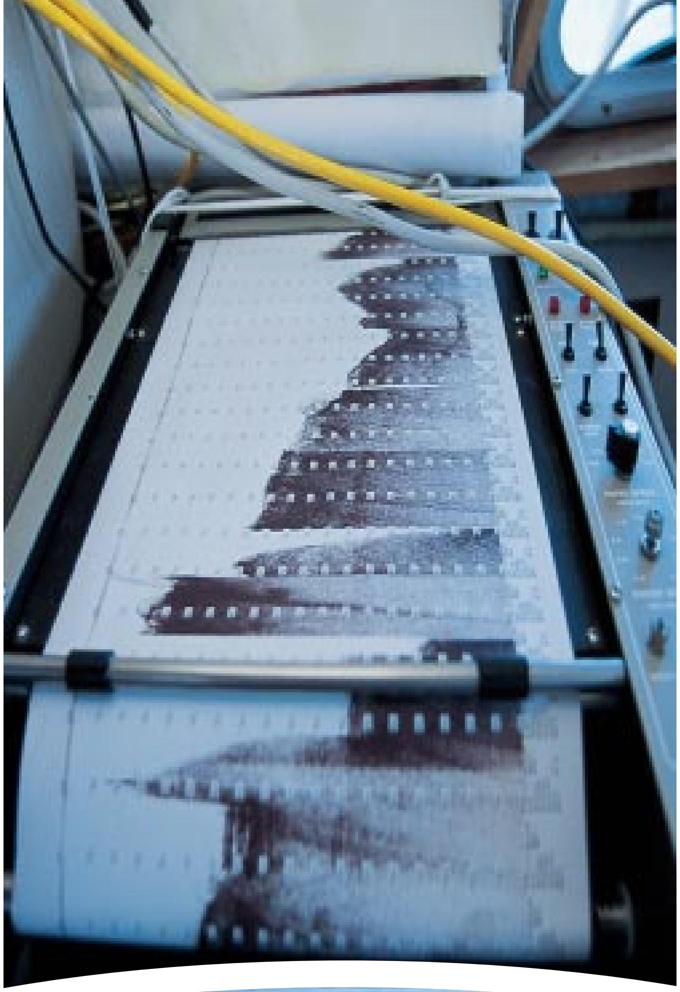
"With the deep sub-bottom component you can read the layers of the lake floor much like a textbook illustration," said Neal Driscoll, a professor in the Geosciences Research Division and developer of the chirp instrument. "We use data on these layers to study the interplay between sediments, climate, and tectonics. This information will help us understand the previous events that shaped the earth here."

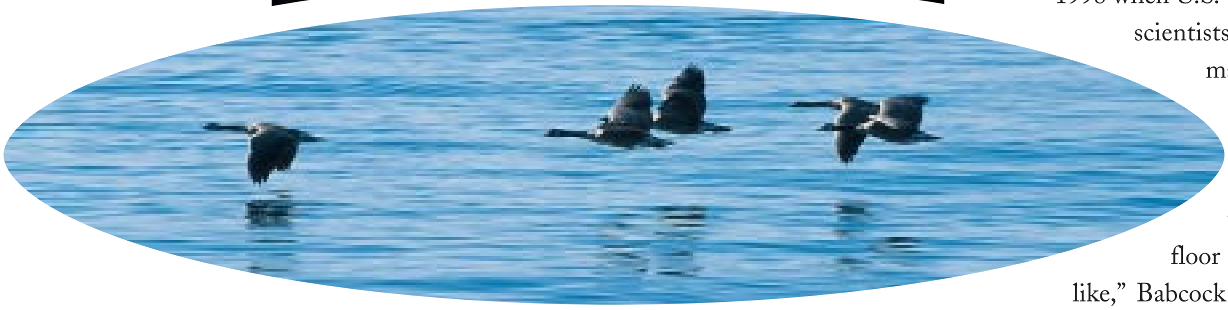
Left, *The UC Davis Tahoe Research Group's R/V* John Le Conte, *captained by Bob Richards.* **Opposite page top left,** *Alistair Harding, Graham Kent, Neal Driscoll, and Jeff Babcock shown with subscan chirp. Remaining pictures show team deploying the instrument.*

The side-scan sends signals to the lake floor at various angles up to 45 degrees. Driscoll likens the side, scan to an aerial photograph that relays detailed information about the surface, but which lacks depth penetration. By gliding back and forth over an area and taking shots from different perspectives, researchers can see more detail of the lake floor, thus allowing more accurate mapping.

Paleoseismologist Gordon Seitz, a member of Kent's team, used the seismic images to target locations for extracting sediment cores from the lake floor. Once Seitz, and Office of Naval Research scientists led by Robert Karlin, Richard Schweickert, and Mary Lahren, had removed the cores, he analyzed them for occurrences of past earth-

Above, *This United States Geological Survey bathymetry map highlights Lake Tahoe's largest fault lines, which represent a significant risk of triggering tsunamis through ground movement and landslides. The box outlines an area of collapse at McKinney Bay (see detailed image on page 11).*





Above, top, *A printout instantly relays data from the subscan chirp to the deck of the* Le Conte. *The information depicts the layers of sediment beneath Lake Tahoe's floor.* **Above, bottom,** *geese fly over Lake Tahoe.*

quakes and measured the radiocarbon content of plant remains in the sediment, making it possible to assign actual dates. This sediment analysis will provide researchers with unprecedented insights into the lake's earthquake history.

A U-TURN TO INNER SPACE

Onboard R/V *Le Conte*, as the summer sun reaches its peak, the subscan chirp continues to scour for new lake-floor data. Kent gazes across the pristine waters that he knew so vividly from his childhood.

Throughout his teens, Kent spent summers at the lake working as a jack-of-all-trades at a lakeside estate. He saved for college tuition by working as a waiter at a restaurant overlooking the lake. South Lake Tahoe High School brought Kent and his future wife together. Now he's back with a new outlook—as a scientist defining his environs by data and seismic imagery.

Kent's first interest in science was astronomy. But as his passion for rock climbing in the Sierras grew, his scientific career took a U-turn from the outer space of astronomy to the inner space of geophysics.

"When I was growing up in the Lake Tahoe area, people didn't think it was a very tectonically active or interesting area from a geological standpoint," Kent said. "That seems to be far from the truth now."

Indeed, with the Lake Tahoe Presidential Forum in 1997, at which President Bill Clinton and Vice President Al Gore took actions to protect Lake Tahoe, research in the Sierra Nevadas has increased.

One such call to action occurred in 1998 when U.S. Geological Survey (USGS) scientists led by James Gardner mapped the topographic features of Lake Tahoe.

"The USGS mapping was the first time we saw what the lake floor topography really looked like," Babcock said. "There was definitely more interest in the lake after the mapping. The research we are conducting with this subscan chirp technology is directly related to some of the other issues going on here. For example, any major landslide or fault movement will impact Lake Tahoe's water quality."

Scientists have been researching different aspects of Lake Tahoe for decades. In the early 1960s, Scripps Professor Edward Goldberg studied

Left, *Jeff Babcock (near) and Neal Driscoll lower the side-scan part of the subscan chirp instrument. The side-scan retrieves detailed information of the lake floor by gliding back and forth over an area and characterizing features from various angles.*

Left, *A close up of subscan chirp data reveals the eroded layers of lake sediment, indicating previous changes in the lake level.*

the lake's sedimentation rates. For more than 40 years, the UC Davis Tahoe Research Group has conducted detailed investigations of the lake's water clarity, an issue of paramount importance to residents and the tourism industry.

A WORLD MODEL

Charles Goldman, a UC Davis professor of limnology and director of the Tahoe Research Group, recognizes Lake Tahoe as a model for the world's oceans, where oceanographers can conduct certain experiments at a fraction of the cost of conducting them at sea. Researchers can test and fine-tune research equipment in the lake's calmer aquatic conditions before subjecting it to the harsher elements of the oceans. Goldman also believes Lake Tahoe is ideal for researching environmental events.

"Lake Tahoe is a microcosm for environmental problems around the globe," Goldman said, highlighting examples such as pollutants from streams and groundwater run-off, erosion, sediment influx, and recent urbanization that has led to a complex array of environmental stresses. "The lake also suffers from atmospheric pollution from vehicles and the smoke of forest and brush fires that often originate far away from the lake basin," he explained.

Goldman and the other researchers believe that cooperation among a variety of institutions will be mutually beneficial, leading to a new understanding of the environmental conditions in and around the lake. Recent projects have brought together researchers from Scripps Institution, UC Davis, the Lawrence Livermore National

EAST COAST TSUNAMI RISK

Underwater landslides on the outer continental shelf and slope in the world's oceans could trigger tsunamis that may have devastating effects on populated coastal areas. Recently discovered cracks along the U.S. East Coast shelf indicate the seafloor could slump, or slide downhill like an avalanche, triggering tsunamis.

A recent study has shown that wave heights similar to the storm surge from a Category three or Category four hurricane, up to several meters above normal, could occur along the Virginia/North Carolina coastline and lower Chesapeake Bay, the areas of highest risk.

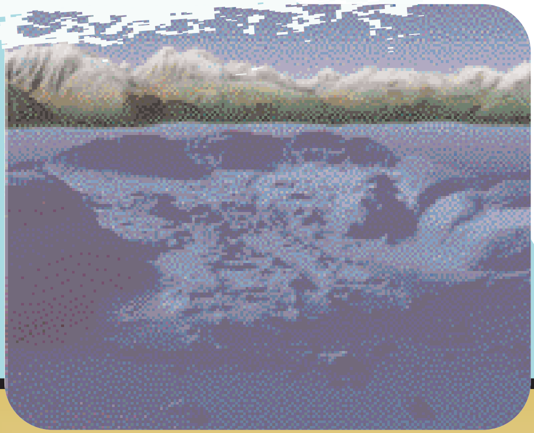
"Coastal areas face increasing threats from a number of natural hazards. The public is aware of the damage to coastal areas caused by severe storms like hurricanes thanks to better storm tracking and media coverage. Tsunamis resulting from offshore earthquakes, landslides, and volcanic activity are just as destructive but are not as common," said Neal Driscoll, a new associate professor and researcher at Scripps, and the leader of the team that discovered the cracks and identified the potential East Coast tsunami risk. As a result, public awareness of tsunamis is limited, as is our ability to forecast when and where they will strike. The tsunami that struck northern Papua New Guinea in July 1998 with almost no warning killed some 2,000 people."

Laboratory, the University of Nevada, Reno, and the USGS.

With this interdisciplinary thrust, Goldman believes Lake Tahoe will become a place where the results of multi-institutional research—from earthquakes to tsunamis to water clarity—will deliver environmental solutions.

"Lake Tahoe is one of the country's greatest natural resources," Goldman said. "People from around the world are looking toward Tahoe as a model for solving environmental problems. If we don't solve the problems in Tahoe, with the affluence and interest and industry here, what chance do we have with the rest of the world?"

"By joining forces with researchers at the Tahoe Research Group and the University of Nevada, we hope that the Scripps research will bring some of the puzzle into sharper focus so that we can understand the regional framework of Lake Tahoe," Driscoll said.



A 1998 USGS image depicts a landslide at Tahoe's McKinney Bay. This major collapse generated a "mega-tsunami" that approached 300 feet (90 m) in height.

At 193 square miles (500 square kilometers), Lake Tahoe pales in size when compared with some of the world's largest lakes. However, it ranks as one of Earth's deepest lakes, with a maximum depth of more than 1,640 feet (500 m) deep.

A LOOK AT SOME OF THE WORLD'S LARGEST LAKES

	Area sq m	(sq km)	Greatest Depth ft	(m)
1. Caspian Sea, Europe-Asia*	143,250	(371,000)	3,363	(1,025)
2. Superior, North America	31,700	(82,102)	1,333	(406)
3. Victoria, Africa	26,828	(69,484)	270	(82)
4. Huron, North America	23,000	(59,569)	750	(229)
5. Michigan, North America	22,300	(57,756)	923	(281)
6. Tanganyika, Africa	12,700	(32,900)	4,708	(1,435)
7. Baikal, Asia	12,162	(31,500)	5,315	(1,620)
8. Great Bear, North America	12,100	(31,338)	1,463	(446)
9. Aral Sea, Asia*	11,853	(30,700)	170	(51)
10. Malawi, Africa (aka Lake Nyasa)	11,100	(28,749)	2,300	(701)

** Saltwater*

Source: Major Lakes—National Geographic Atlas of the World—Revised Sixth Edition