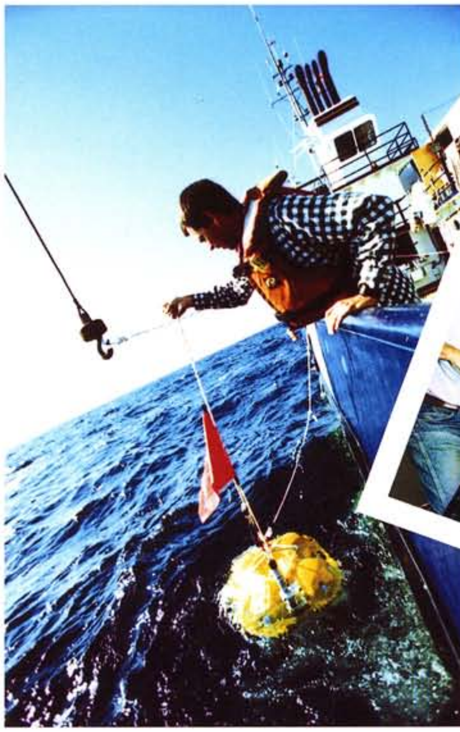
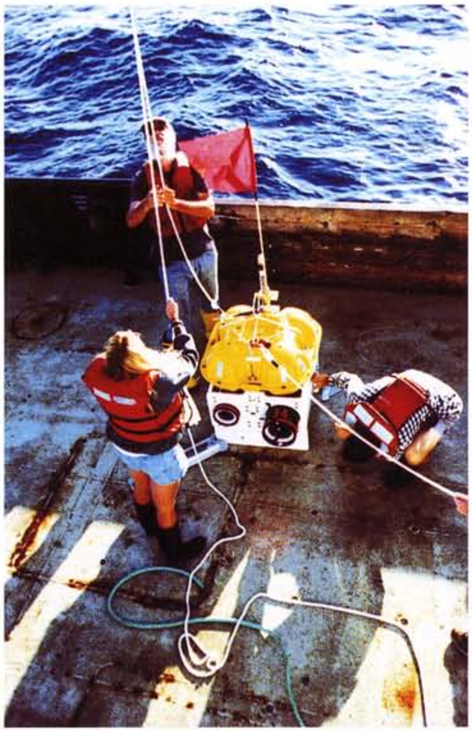
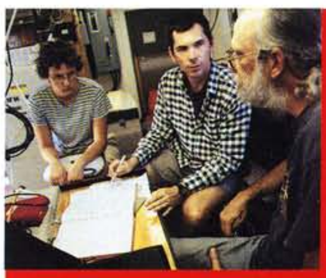
FINDING





Filling in a geophysical jigsaw puzzle, Scripps researchers are building, deploying, and, and retrieving new seismographic units designed especially for the ocean.



FAULTS

A SEISMIC JIGSAW PUZZLE TAKES SHAPE

BY ROBERT MONROE

JEFF BABCOCK SHOULD have heard his future calling him back in grade school. When the teacher told the class it was free drawing time, he was the kid sketching volcanoes.

But it wasn't until he was an undergraduate student at UC San Diego, taking an earth sciences class from a Scripps professor, that he considered making geophysics a career.

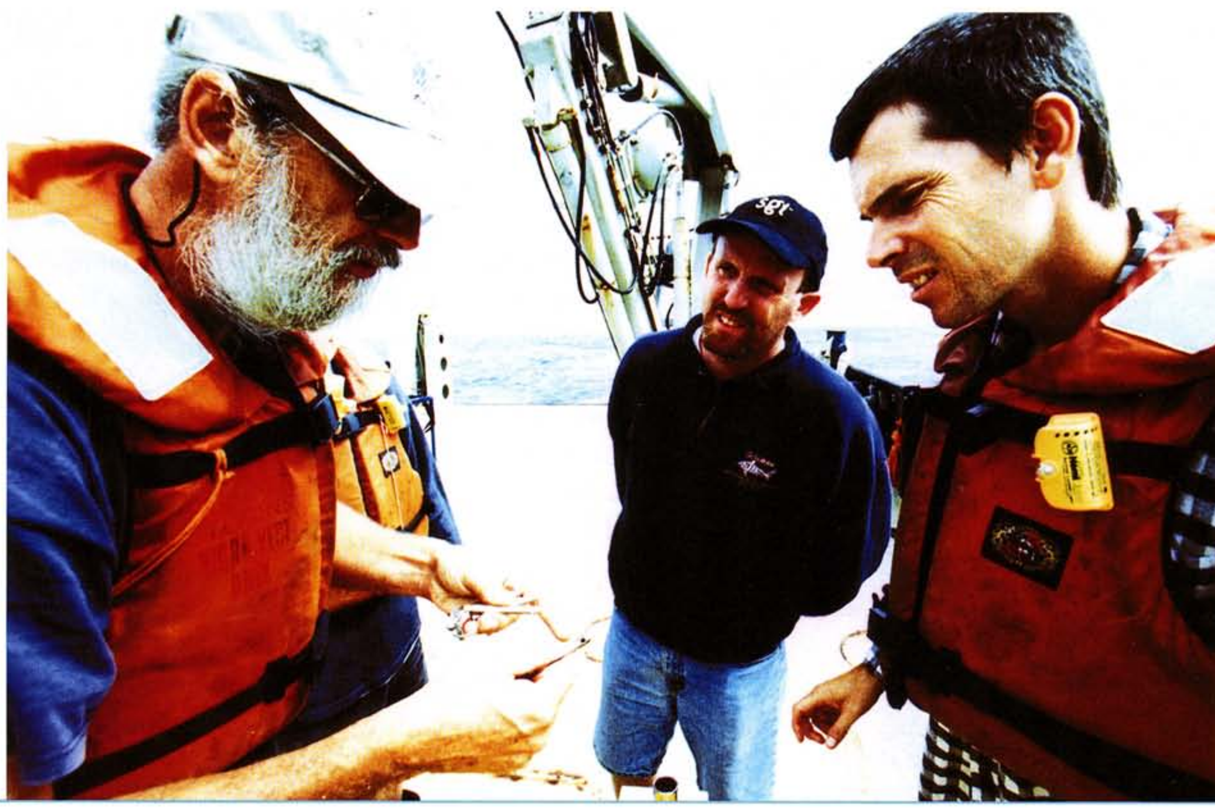
Today, Babcock is sketching out a different kind of image—four years after earning his doctorate at Scripps. Play has become work aboard R/V *Robert Gordon Sproul* as Babcock maps in detail an offshore earthquake fault system. He uses an innovative seismometer developed by his team at Scripps.

"Call it foreshadowing, but I guess it's in my blood," he said.

On this October day, Babcock, fellow geophysicists Graham Kent and Alistair Harding, and graduate students Renee Bulow and Jeff Dingler are retrieving eight of the instruments from the ocean floor.

There's still some time to play, though. In the hour it takes to get from one drop location to another, the scientists improvise a game of ring toss in the shipboard lab with a roll of tape and a door latch. Last one to ring the tape on the latch fetches drinks at dinner.

Earthquake-producing faults, like the one the team is cruising over off Oceanside, California, and volcanoes are the most



A different breed of mapmakers aboard R/V Robert Gordon Sproul: *Crispin Hollinshead (l), Graham Kent (center), and Jeff Babcock (right).*

Babcock and Hollinshead load an OBS unit into a crate on the deck of R/V Robert Gordon Sproul.

concentrated expressions of global tectonic activity. Such activity is also manifested in areas of the seafloor that move like conveyor belts and in continental plates that merge into each other like slow-motion car crashes, turning the "crumple zones" into mountains.

Many details of these faults have been effectively invisible to science because the action takes place under the ocean. Underwater seismic observations have been hampered by a lack of affordable technology and the expense of getting instruments to places of tectonic activity. A team of Scripps geophysicists and engineers at the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics (IGPP), however, has achieved successful seismic monitoring with its creation—a fleet of ocean-bottom seismographs (OBS) that records ground movement and changes in acoustic pressure. These seismographs have been designed and built at a cost that is no longer prohibitively expensive, allowing scientists to make more frequent tectonic observations. The OBS fleet goes by the name Low-Cost Hardware for Earth Applications and Physical Oceanography, L-CHEAPO for short.

"The seismographs can fill in the part of the story that complements the surveys you have on land," Babcock said. "Tectonics doesn't observe borders, whether they're political or the ones between land and water."

Scientists have tended to stop at such boundaries, but the unknown fault might harbor even more destructive power than realized. Just as the IGPP team, which includes institute Director John Orcutt, was getting funding

to build the seismographs, other scientists suggested that the Oceanside Fault could produce quakes with magnitudes exceeding 7.0 on the Richter scale, the same size as the temblors that damaged San Francisco in 1989 and Northridge, California, in 1994.

The Oceanside Fault, located about 32 kilometers (20 miles) off the southern California coast, scuttles across silent seas in the shadow of the San Andreas Fault. The fault occupies the farthest reaches of the friction zone between the Pacific and North American plates, an area geophysicists know as the "borderlands." A few of its neighboring faults are the San Clemente Fault farther out to sea and the inland Rose Canyon Fault. Scientists consider the latter to be probably the most dangerous in San Diego County because the fault travels through a densely populated area of the city of San Diego; it runs in a north–south direction across Mission Bay where two pieces of earth headed in opposite directions are colliding. The fault slithers in an S-curve around Mt. Soledad, which owes its elevation to the extra compression at the center of the curve.

The fault then disappears into the Pacific at La Jolla Cove after following a path studded by pricey hillside houses. Once underwater, the Rose Canyon Fault, the Oceanside Fault, and several others form a nebulous network that may link to other faults in Orange and Los Angeles counties.

L-CHEAPO, developed by Scripps engineers Crispin Hollinshead and Dave Willoughby, not only can trace the paths of these faults but will also provide their dimensions and temblor frequency as researchers accumulate data over time. Additionally, researchers using L-CHEAPO can illuminate a number of geophysical problems: from the structure of continental margins to the traits of volcanic hot spots. Babcock hopes that this newfound knowledge will create an appreciation for the potential danger of earthquakes, at least in southern California.

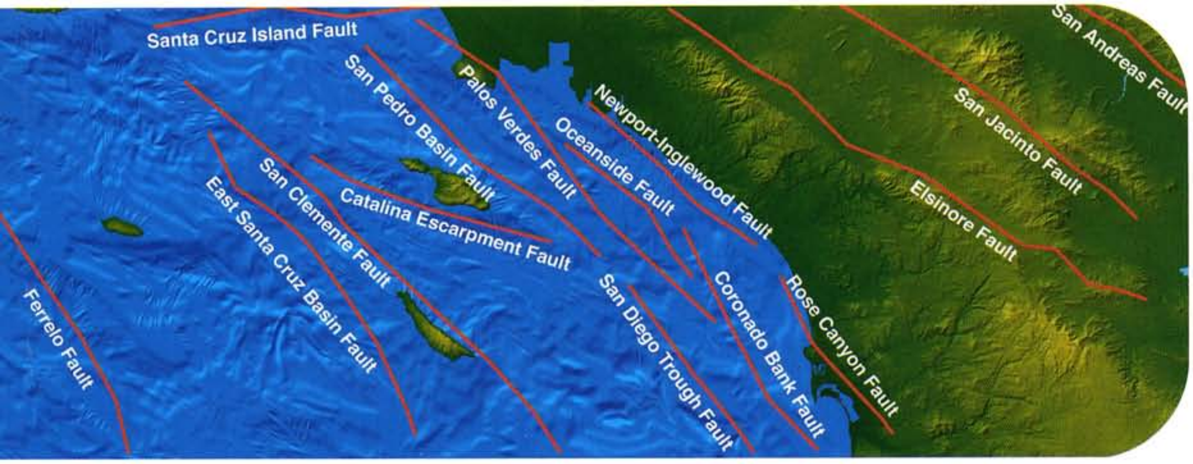
"We don't have the major fault lines like San Francisco or Los Angeles," said Babcock, a Mission Viejo native who has lived most of his life in shaking distance of the Oceanside Fault, "but San Diego does have a certain amount of seismic risk."

Left, *After an OBS is retrieved from the ocean, Hollinshead and Babcock remove the beacon and flag that helped researchers spot it.*

SAN DIEGO AT RISK

Earthquake risk isn't always apparent. In recent decades, quakes felt in San Diego, a city lacking a big disaster in its history, have

Above, *While at sea, Babcock and Hollinshead review coordinate readings.* **Left,** *In his lab at Scripps, Hollinshead assembles additional units for the L-CHEAPO fleet.*



Left, *Alongside more famous neighbors like the San Andreas Fault, ocean faults rest at the borderlands between tectonic plates.* **Below,** *Down time and haute cuisine aboard of R/V* Robert Gordon Sproul.

tended to be faraway temblors with a long reach. By luck of geography, the San Andreas Fault avoids San Diego County, swinging eastward through Imperial County before petering out in the Salton Sea.

On a Sunday morning in July 1986, the county received a strike to call its own. A magnitude 5.3 temblor struck the northern part of the county and was felt along much of the southern California coast. It was the second largest temblor to primarily strike San Diego County since officials began taking seismic readings. Fortunately for local residents, damage was light.

Scientists said the epicenter was in the ocean 45 kilometers (28 miles) southwest of Oceanside City Hall. At the time, the source fault wasn't known as the Oceanside Fault. It wasn't known as anything. Then, as now, scientists could not be sure exactly where the epicenter was. All of the earthquake sensors were miles away on land and on surfaces that were nearly a mile higher in elevation than the estimated epicenter. There was no way to accurately locate this event or the subsequent aftershocks in three dimensions as scientists are able to do on land, which they accomplish by using measuring devices planted right on the fault lines.

Another reason to look at the fault more closely materialized in 2000 when a group led by Harvard University researcher Carlos Rivero announced that the fault is capable of producing earthquakes greater than a magnitude of 7.0. Rivero's team estimated seismic risks to southern California and created various movement scenarios. In one such account, the Oceanside, Rose Canyon, and Newport-Inglewood faults all rupture at once and produce a magnitude 7.6 quake.

In addition, the Oceanside Fault is part of a submerged blind thrust system. This kind of system forces one chunk of crust over another, with the possibility of displacing millions of tons of seawater during a quake. Scientists theorize that a rupture along this fault could produce a coast-drenching tsunami. But Babcock is quick to note that evidence for a tidal wave scenario is merely "circumstantial" at the moment.

Rivero's findings suggest that more study is needed. Babcock points out, for example, that the Oceanside Fault's northern terminus is not yet known. If it continues in a straight line, it could hit land somewhere around Long Beach.

Below, *In the lab, Babcock hooks an L-CHEAPO up to diagnostic equipment.*

There is some evidence, though, that it might curve to the right and run through Dana Point in Orange County, several miles to the south.

HI-HO HI-HO IT'S OFF TO SEA WE GO

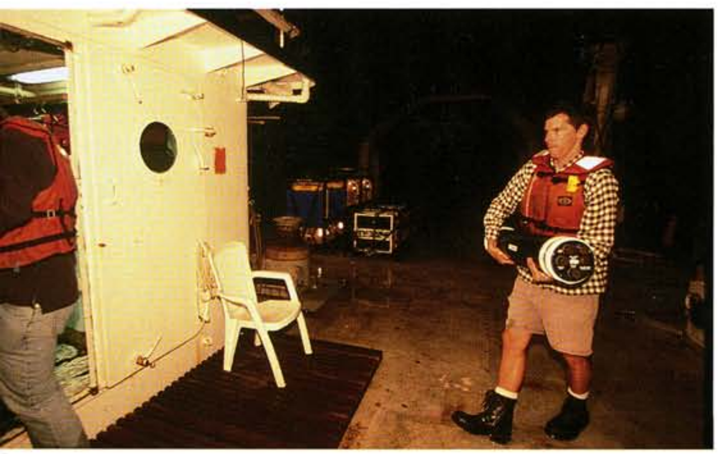
On this deployment with Babcock and his team, the OBS units are named after Snow White and the Seven Dwarfs. Around midmorning, the first instrument package, Dopey, bobs to the surface at 32° 53′ north, 117° 44′ west after a 900-meter (3,000-foot) ascent. The engineers attached a red flag before deployment to distinguish Dopey from the black water, and the team of scientists uses

hook-tipped poles and a crane to bring the unit back aboard. The IGPP researchers recover about half of the OBS units they dropped to the ocean by the time they break for dinner, steak barbecued on the main deck. Meanwhile, Kent, today's loser in the high-stakes game of ring toss, is taking a survey of a different kind: "Jeff, what'll you have? There's Coke, Diet Coke, root beer . . . "

Into the night, Babcock's team retrieves, disassembles, and packs "Snow White and the Seven Dwarfs."

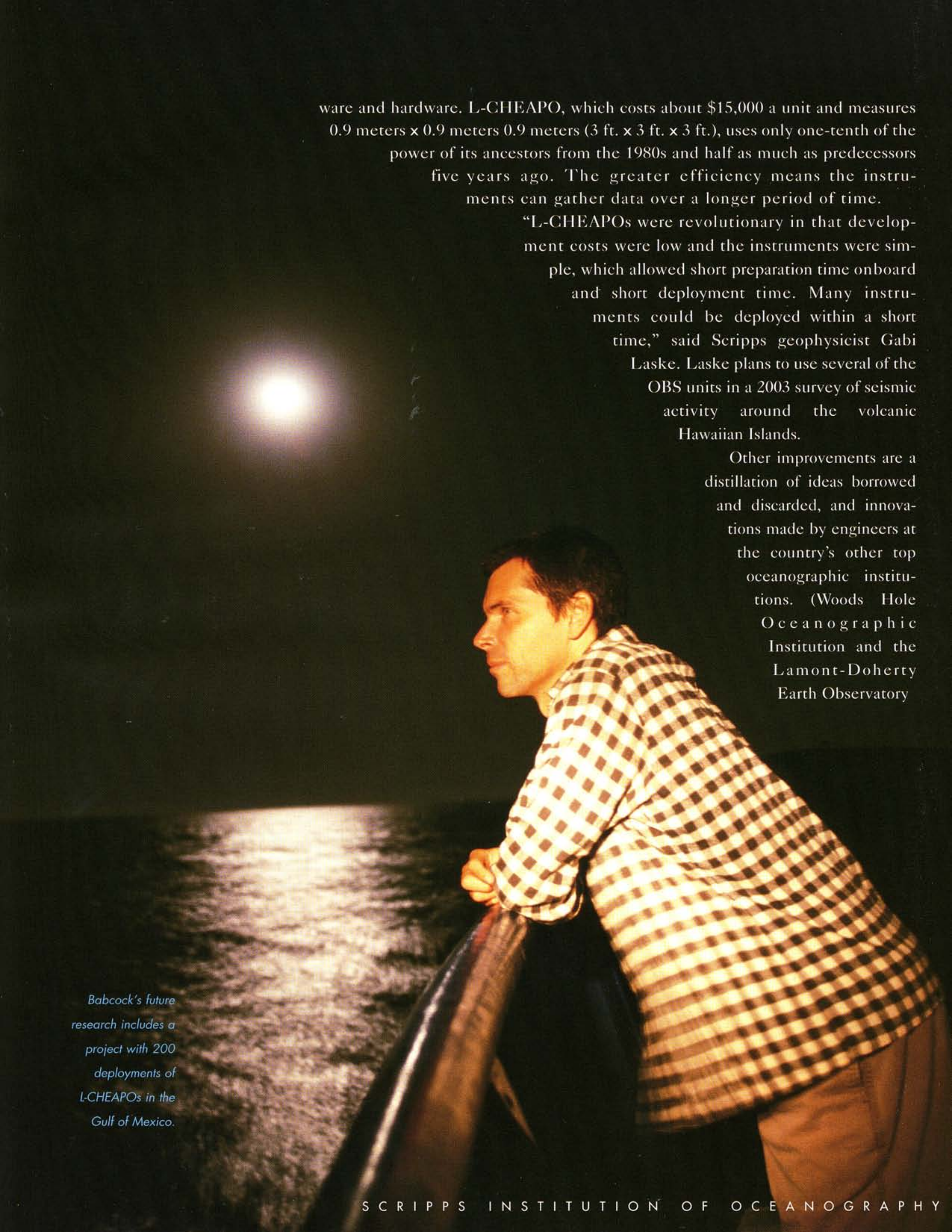
The L-CHEAPO fleet was dropped three months earlier, on July 31, 2001, in a zigzag pattern over the heart of the fault, an area stretching from due west of Scripps to due west of Oceanside. Shortly before dinner, the ship made acoustic contact with Toad, an OBS unit dropped on an earlier deployment but still unrecovered after nearly 10 months.

Problems often occur with seismic surveying at sea, such as battery power that is sapped after a few months and release mechanisms that do not perform correctly. In Toad's case, its anchor got stuck in undersea mud. The device, named after one of the X-Men of comic book fame, can still send a signal, but it will take a special recovery trip by an underwater vehicle to bring it home.



Scripps researchers developed the first rudimentary OBSs around 1970, but it took another decade before sophisticated models were deployed. Older OBS units measured 1.2 meters x 1.5 meters x 1.5 meters (4 ft. x 5 ft. x 5 ft.), cost about $100,000 each, and, because of their expense, were only available in small numbers. There were too few to commit to the extended deployments needed to accurately locate faults. Imagine trying to see an image on your television screen created with only a dozen or so pixels plus a few new ones added every year.

With miniaturization of computer hardware came refinements. The most important trimmed battery power requirements by modifying and customizing operating system soft-



ware and hardware. L-CHEAPO, which costs about $15,000 a unit and measures 0.9 meters x 0.9 meters 0.9 meters (3 ft. x 3 ft. x 3 ft.), uses only one-tenth of the power of its ancestors from the 1980s and half as much as predecessors five years ago. The greater efficiency means the instruments can gather data over a longer period of time.

"L-CHEAPOs were revolutionary in that development costs were low and the instruments were simple, which allowed short preparation time onboard and short deployment time. Many instruments could be deployed within a short time," said Scripps geophysicist Gabi Laske. Laske plans to use several of the OBS units in a 2003 survey of seismic activity around the volcanic Hawaiian Islands.

Other improvements are a distillation of ideas borrowed and discarded, and innovations made by engineers at the country's other top oceanographic institutions. (Woods Hole Oceanographic Institution and the Lamont-Doherty Earth Observatory

Babcock's future research includes a project with 200 deployments of L-CHEAPOs in the Gulf of Mexico.

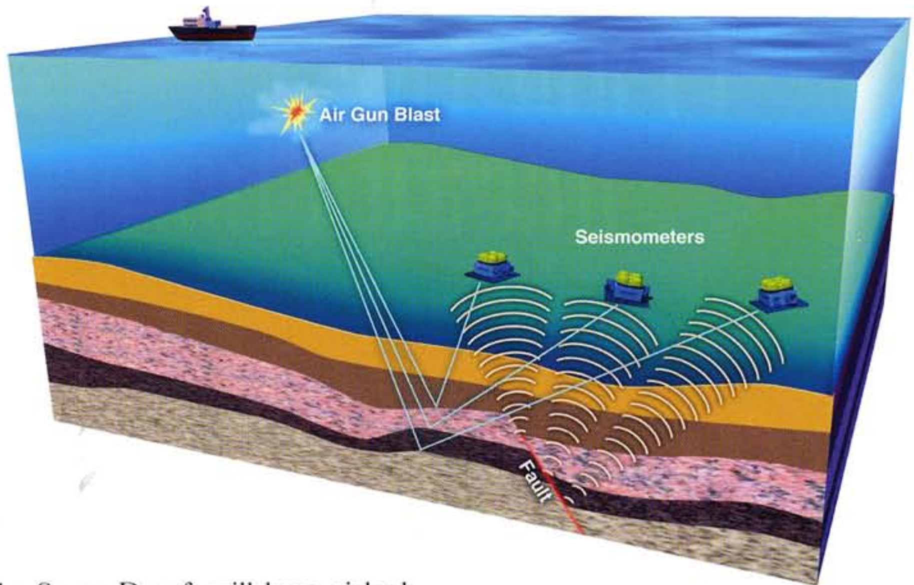
of Columbia University also won grants to develop next-generation OBS units.)

Inside L-CHEAPO is a seismometer that records vertical motion of the earth and generates the familiar zigzag lines that denote earthquake activity. The OBS also has a hydrophone, which "hears" acoustic fluctuations in the water—a redundancy that sometimes picks up seismic activity the seismometer cannot determine. The two instruments are packaged in a tube fitted with connectors at one end. Babcock can communicate with the computer through the connector without having to crack open the assembly.

Resting alongside the seismometer package in another tube is the electronics assembly, which allows L-CHEAPO to communicate from the ocean floor. Via sonar transmissions, operators from a ship instruct L-CHEAPO to respond and, when the time is right, to detach from its anchor, a 45-kilogram (100-pound) metal plate clamped to the bottom of the instrument platform.

At an operator's signal, the release sends an electric current through a burn wire attaching an anchoring metal plate to the instrument package. Cocreator Hollinshead got the idea for the burn wire assembly from other instruments he had seen. The current sends the natural corrosive properties of seawater into overdrive. The ocean eats through the metal catch in about eight minutes, and the science payload

Left, Babcock helps unload L-CHEAPOS after retrieval from the ocean. Right, To generate seismic readings, researchers use air gun blasts in "active source" surveys. Bottom, With the explosive power of dynamite, lithium battery packs help surveys stay out to sea longer.



begins its ascent to the surface, lifted on a float of four glass balls housed in a hard, yellow plastic casing. Hollinshead is developing a motorized release that could cut release time from eight minutes to eight seconds, another huge savings of ship time and money.

THE L-CHEAPO WORLD TOUR

Instruments like L-CHEAPO are often used in active-source surveys. The researchers simulate a seismic event by explosively releasing compressed air from an air-gun array just below the ocean surface. OBS units are placed on the seafloor at measured distances from the air gun blast, which creates sound waves that penetrate through sediment and rock. The waves then travel through the solid subseafloor, bounce off interfaces between sections of layered sediment, and are measured by the units. The intensity each OBS records can tell researchers about the composition of that section of seafloor. In the first few test runs of L-CHEAPO, however, Babcock's team used the instruments in passive-source surveys, which rely on natural events. Babcock is especially interested in what Snow White and the Seven Dwarfs will have picked up on this latest run. Just three weeks after their July 31st deployment, a 4.4 magnitude quake hit San Clemente Island along the San Clemente Fault a few miles to the west of the seismometer array, a stroke of luck for the researchers.

"The point of these deployments is to look at continuing seismicity of ocean faults and to refine pictures of quake activity on those faults," Babcock said. "You need to see this from land stations and at sea."

Therefore, the 4.4 quake will act as a beacon and what scientists call a "reference event." The task of downloading and crunching all of the data off the California coast falls to first-year graduate student Bulow, who might have the first data sets completed by this summer. Her analysis will provide the first visualization of the seismic faults.

"It's really cool to be going through all these data and to, all of a sudden, find an earthquake," she said.

As for Babcock, the pursuit of a lifelong interest continues nonstop. He used OBS units last fall for a seven-week continent/ocean boundary study off the northwest coast of Australia. This spring he will deploy 50 L-CHEAPO units in the West Pacific Ocean for use in studies of the Marianas Trench, located near the island of Guam. And in the fall of 2002, Babcock will deploy 70 seismometers in a four-part seismic profile of the Gulf of California that will require 200 deployments and retrievals—the most extensive undertaking to date.

"We're going everywhere and gathering little pieces of the puzzle," Babcock said. "We hope to paint a better picture of the earth."