Oceanus

Finding a new species in a local salt pond PAGE 14

The hunt for 18° water PAGE 22

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THROUGH THE LENS

◄ **Rainbow-colored minerals, pine cone-shaped animals called foraminifera, and spiky remnants of sea sponges form a kaleidoscope when seafloor sediment samples are swabbed on a glass slide and viewed through a microscope. A purple polarizing filter helps WHOI scientists clearly identify each speck of organic and inorganic materials found in cores, which provide clues to Earth's evolution and climate in the past.** **(See stories on pages 6, 10, and 26.)**

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Oceanus

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FEATURES

Terry Joyce, WHOI

COVER: **It's not every day that you discover a new species. Sheri Simmons, a graduate student in the MIT/WHOI Joint Program, found a previously unknown bacterium in her proverbial backyard: Salt Pond in Falmouth, Mass. The bacteria incorporate magnetic minerals, making "internal compasses" to orient themselves to Earth's magnetic field. But unlike other magnetotactic bacteria that steer to the north, this one appears to head south.** **(See story on page 14.)** Photo by Tom Kleindinst, WHOI

In a crater, scientist seeks clues to one of the greatest volcanic shows on Earth

Adam Soule, WHOI

About 50,000 years ago, a huge meteorite smacked into our planet, gouging a hole more than a mile wide and 790 feet deep in India. Of the roughly 150 known meteorite impact sites on Earth, Lonar Crater is the only one that struck in an area layered with volcanic rock—a massive plateau made of ancient lava flows called the Deccan Traps.

That makes Lonar Crater a unique and relatively convenient place for earth scientists to study how meteors scar the volcanic surfaces of other crater-dented planets, such as Mars. In January 2006, Adam Soule, a volcanologist at Woods Hole Oceanographic Institution, joined researchers from Harvard, MIT, and Princeton on a nine-day expedition to map and study Lonar Crater.

But while his colleagues compared the landscapes of the crater and Mars, Soule focused on Earth history. He looked for clues to learn how the Deccan Traps formed. He is also investigating whether the dinosaurs' extinction was caused by the massive volcanic eruptions that created the Deccan Traps—rather than, or perhaps in addition to, another larger asteroid that collided with Earth 65 million years ago.

At about that time, one of the greatest episodes of volcanism in Earth history occurred in what is now western India. Huge eruptions of lava flooded onto Earth's surface, coating and recoating more than a million square miles, like layers of paint, to form a vast terraced plateau.

Even after eroding over millions of years, the Deccan Traps are still 1½ miles thick and cover 200,000 square miles (518,000 square kilometers), roughly the size of the states of Washington and Oregon combined. The eruptions that created the Deccan Traps would have released huge quantities of particulates and heat-trapping greenhouse gases—carbon dioxide, sulfur dioxide, and water vapor—that could have caused catastrophic global climate changes.

The key scientific debate, Soule said, is whether the Deccan Trap lava flows erupted too fast for the Earth to absorb the excess gases, or whether they erupted much more slowly, as lava does today on a much smaller scale in Hawaii, for example.

The Lonar Crater meteorite drove deeply into the Deccan Traps, giving Soule access to ancient lava layers that might provide answers. He returned to Woods Hole with about 100 pounds of rock samples, which he'll slice and examine under a microscope. By looking at variations in their textures, Soule hopes to determine if they erupted gradually or more quickly to hasten the dinosaurs' extinction.

—*Amy E. Nevala*

Soule's research is supported by the WHOI Geology and Geophysics Department and the National Aeronautics and Space Administration.

Google Earth

Princeton graduate student Nick Swanson-Hysell (above) was part of a team that studied Lonar Crater, a mile-wide, 790-foot-deep crater in India. It was created by a meteorite that hit the Deccan Traps, an ancient lava flow that covers more than 200,000 square miles (518,000 square kilometers). WHOI volcanologist Adam Soule joined the expedition to learn about the massive volcanic eruptions that formed the Deccan Traps.

Tria Giovan Photography

Christine and Leo Yeomans of British Columbia made a rare find when they spotted WHOI float 312 in the Bahamas.

Float 312, where are you?

The ocean is so enormous, even a fleet of 2,338 ocean-monitoring instruments can sail into it and go largely unnoticed. That's what floats 312 and 393 were doing until something extraordinary happened: People found them.

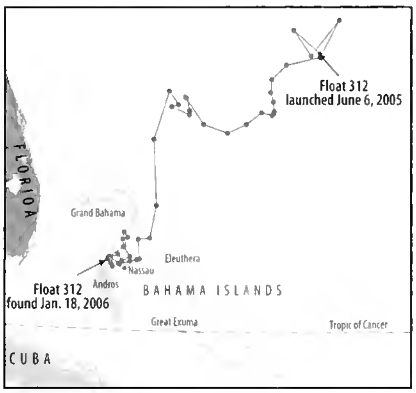
"To have folks stumble on these two in one week is a real surprise," said Jim Valdes, an engineer at Woods Hole Oceanographic Institution who designs and builds floats.

During the past six years, scientists have been releasing 5-foot-long, torpedo-shaped floats throughout the ocean—part of an international program called Argo. The instruments mostly drift at depths of 5,900 feet (1,800 meters). Once a week or so, they poke their skinny black antennas above the surface for about 12 hours to transmit temperature and salinity data to shore via satellite and then submerge again.

Valdes estimates that fewer than three floats a year go missing. Then, this winter, float 312 beached in the Bahamas, after traveling more than 1,000 nautical miles (1,850 kilometers) since its launch east of central Florida in June 2004. Float 393 ended up aboard a fishing boat off Barbados.

Valdes has subsequently pieced together their journeys. Before launch, every float is tagged for monitoring via satellite, so scientists do see where they are and where they shouldn't be. Float 312, for example, began to concern physical oceanographer Breck Owens in late January. He saw on his computer screen at WHOI that it was making a beeline to land, likely tossed by currents into shallow water and then spit onto shore.

"I was pretty sure that it was going to be a loss," Owens said. Then he received a surprise e-mail on Jan. 18 from a Canadian tourist who noticed the marooned float while snorkeling east of Andros Island.



The blue line marks float 312's 1,000-mile track. Dots show where it surfaced temporarily to transmit data via satellite.

She traced the float to WHOI's Ocean Instruments Web site. Assured that it wasn't dangerous, the tourist, Christine Yeomans of British Columbia, returned with a motorboat to collect the 80-pound instrument.

"My husband and I swam it back to the boat (no mean feat)!!!" Yeomans wrote in an e-mail. "Then he and our Bahamian guide pulled it into the boat. My husband unfortunately cracked his rib in the process. So we are hoping that this recovery will be somewhat useful and 'not for naught.' "

Yeomans sent Valdes photos, which showed that float 312's O-ring seal was compromised and had let seawater inside its pressure case. It was a goner. Valdes contacted a U.S. Navy acoustic test facility on Andros Island, which retrieved the instrument to dispose of it properly.

Float 393 had a happier fate. It was picked up 29 miles south of Barbados on Jan. 25 by a fisherman, Erwin Clark Breedyland. He made inquiries that eventually led back to Valdes.

Onshore, float 393 continued to transmit data, suggesting that it was intact and functioning, Valdes said. "I made arrangements for Breedyland to deploy the float 150 to 200 miles off Barbados on his next fishing trip."

—*Amy E. Nevala*

The research is funded by the Cooperative Institute for Climate and Ocean Research, a joint institute of Woods Hole Oceanographic Institution and the National Oceanic and Atmospheric Administration.

To catch an active volcano

Augustine, an island volcano 170 miles southwest of Anchorage, Alaska, began erupting in December 2005. By February, Uri ten Brink of the U.S. Geological Survey in Woods Hole had mobilized a team to seize the rare opportunity and deploy five portable ocean bottom seismometers (OBS) on the seafloor around Augustine.

The OBSs came from the National Ocean Bottom Seismic Instrumentation Pool at Woods Hole Oceanographic Institution, a lending library of deep-sea seismic equipment for the scientific community.

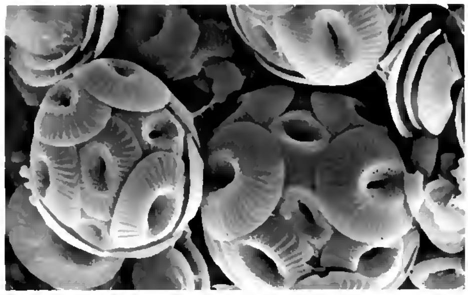
"We put OBS technology to use, capturing volcanoes and other seismic events as they happen, where they happen," said WHOI Senior Engineering Technician Vic Bender (at right, deploying a 100-pound OBS from the U.S. Coast Guard Cutter *Roanoke Island*).

"He knows the OBS inside and out," ten Brink told a local newspaper, *The Homer News*. "He is part of the team that actually built them, and when something doesn't work, he is the guy you want to have."

After six weeks, the team retrieved the OBSs. The seismic recordings they collected should reveal what goes on inside and underneath an active volcano.

—*Lonny Lippsett*

McKibben Jackinsky, The Homer News



Photos by Richard D. Norris, SIO

◄ **Fossilized shells from microscopic marine organisms in seafloor sediments, including the two varieties at left, were used by WHOI scientist Karen Bice to show that past ocean temperatures were surprisingly high. Her research suggests that future ocean warming from the buildup of greenhouse gases may be much greater than predicted.**

An ocean warmer than a hot tub

Scientists have found evidence that tropical Atlantic Ocean temperatures may have once reached 107°F (42°C)—about 25°F (14°C) higher than today. The surprisingly high ocean temperatures occurred millions of years ago when carbon dioxide levels in Earth's atmosphere were high, the scientists said. The findings indicate that computer models now used by scientists and policymakers to forecast climate change may be underestimating future ocean warming from the buildup of heat-trapping greenhouse gases.

"These temperatures are off the charts from what we've seen before," Karen Bice, a paleoclimatologist at Woods Hole Oceanographic Institution, reported Feb. 17 at the annual meeting of the American Association for the Advancement of Science. She was also lead author of a study to be published in 2006 in the journal *Paleoceanography*. "If the models are not right, society is not well-informed or well-served."

Warmer ocean temperatures cause more evaporation, which could shift where and how much precipitation falls. They could also generate more frequent and intense hurricanes and winter storms, Bice said.

To determine ancient ocean temperatures, a multi-institution team of scientists analyzed three long sediment columns cored from the seafloor off Suriname in South America by the International Ocean Drilling Program's drillship *JOIDES Resolution*.

International Ocean Drilling Program

The sediments contained both carbon-rich organic matter and the fossilized shells of microscopic marine organisms that had settled and piled up on the seafloor over tens of millions of years.

The scientists analyzed the shells' chemistry, which changes correspondingly with temperatures in the surface waters where the organisms lived. The researchers determined that ocean temperatures in the region ranged between 91°F and 107°F (33°C and 42°C) between 84 million and 100 million years ago, in an era when dinosaurs roamed the Earth. In the same region, temperatures now range between 75°F and 82°F (24°C and 28°C).

For the first time, scientists used the same sample to estimate ocean temperatures and atmospheric CO_2 levels, so they could precisely correlate both phenomena. When ocean temperatures were high, CO_2 levels were 1,300 to 2,300 parts per million (ppm), Bice and colleagues found, compared with 380 ppm today.

Current climate models may be missing a critical factor that amplifies heating, Bice said. During past warm periods, oceans and wetlands may have released large amounts of methane gas to the atmosphere. Methane traps heat 10 times more effectively than carbon dioxide.

"This study addresses how the ocean-climate system changed in the past, long before people had any impacts," said paleoceanographer Mark Leckie of the University of Massachusetts, Amherst, who reviewed the study for *Paleooceanography*. "I think Karen's research should be another wake-up call to the rate at which we are changing the system today."

—Lonny Lippsett and Amy E. Nevala

This research was funded by the WHOI Ocean and Climate Change Institute, a WHOI independent study award, Joint Oceanographic Institutions, The Andrew W. Mellon Foundation, and Deutsche Forschungsgemeinschaf.

Richard D. Norris, SIO

► **WHOI scientist Karen Bice (right) works with Florida State University nanofossil specialist Sherwood "Woody" Wise to examine seafloor sediment cores retrieved by the International Ocean Drilling Program's drillship *JOIDES Resolution*, above.**

Roger T. Hanlon, MBL

Courtesy of Kenneth G. Foote, WHOI

Strips of sonar images (right) together create a composite map of the seafloor off Monterey, Calif., where squid gather each spring to spawn and lay egg clusters (left). A close-up (below) reveals a mottled pattern that represents squid egg clusters, giving scientists a way to take a census of next year's potential squid population.

New sonar technique offers window into squid nurseries

Every spring the swallows return to Capistrano, and farther up the California coast, hordes of squid arrive to mate and lay eggs on the sandy seafloor off Monterey. Right on their tentacles come fishermen seeking calamari.

California's $30-million-a-year squid fishery has quadrupled in the past decade, with no way to assess how much fishing is too much. Now, a multi-institution team of scientists has developed a new sonar technique to locate squid eggs in the murky depths.

"This method provides an efficient way to map distributions and estimate the abundance of squid eggs. In effect, it can take a census of next year's potential population," said Kenneth G. Foote, a marine acoustics expert at Woods Hole Oceanographic Institution and lead author of an article published in the February 2006 *Journal of the Acoustical Society of America*. "It has immediate potential to give resource managers sound scientific information to make decisions on how to sustain the fishery. Otherwise, they're just guessing."

The scientific team combined the expertise of Foote; Roger T. Hanlon from the Marine Biological Laboratory in Woods Hole, an authority on squid behavior; and Pat J. Iampietro and Rikk G. Kvitek, seafloor mapping experts at California State University, Monterey Bay (CSUMB). The research was funded by the Sea Grant Essential Fish Habitat Program.

Squid (*Loligo opalescens*)—a staple in the diets of many fish, birds, and marine mammals—return annually to spawn a few hundred yards off Monterey's Cannery Row. They deposit gelatinous capsules, each containing 150 to 300 embryos. The finger-sized capsules form small clumps called mops that later cluster into egg beds up to several meters in diameter. Surveying the 4-square-mile (10 square-kilometer) spawning grounds with divers or underwater cameras is too difficult, time consuming, and expensive.

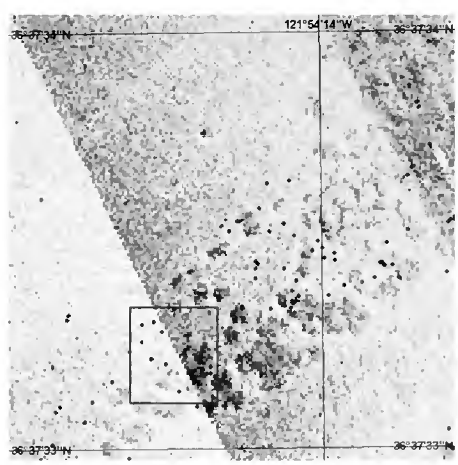
"We needed a way to detect egg clusters," Hanlon said. "So I went across the street and approached Ken, one of the world's sonar experts, who said, 'I'll see if I can help you.' "

"I wasn't optimistic," Foote said. "You have to be able to distinguish weak sound signals echoing off small targets—the egg clusters—from powerful signals echoing off much larger targets—the seafloor."

The team tested different sound wave frequencies, sonar angles, and towing speeds and heights off the seafloor—all in an effort to optimize sound signals reflected back from the egg clusters. They processed the raw acoustic data and displayed the results in the form of seafloor maps that showed characteristic patterns of mottling—squid egg clusters—distributed on the seafloor images. Using underwater video and the CSUMB ship's precise positioning capabilities, they verified the correlation between the egg clusters and the patterns on the sonar images.

With the new sonar methods, the entire Monterey spawning area could be surveyed and analyzed in less than 40 hours at relatively low cost, with a suitably equipped boat towing a sidescan sonar, Foote said.

Since fishing usually commences as soon as squid appear in Monterey Bay, Hanlon said, fishermen may be catching large numbers of squid before they can complete their complex and competitive mating behaviors and subsequently lay eggs.



Courtesy of Kenneth G. Foote, WHOI

"The next challenge is to convince the fishermen to wait a few days for squid to complete their mating cycle," Hanlon said, "so that gene mixing in the population will proceed by natural, not unnatural, selection processes. The squid need to lay enough eggs to provide squid next year—for fishermen and for the oceans, too."

—*Lonny Lippsett*

Strandings keep new facility busy

The necropsy suite and computed tomography scanning facilities in Woods Hole Oceanographic Institution's new Marine Research Facility (MRF) were terribly busy this winter. An unprecedented number of fatal dolphin and pilot whale strandings near Cape Cod brought many veterinarians and marine biologists to Woods Hole to examine and dissect the animals.

More than 120 marine mammals beached themselves on the peninsula in December and January, according to the Cape Cod Stranding Network (CCSN), which includes several WHOI researchers. CCSN is charged by the National Marine Fisheries Service (NMFS) with resuscitating stranded animals, if possible, and investigating why strandings occur.

Following a stranding in mid-January, seven dead common and white-sided dolphins were brought to the MRF (right) for necropsies by researchers from WHOI, New England Aquarium, NMFS, the Massachusetts Institute of Technology, and Tufts University. They examined tissues for parasites and potential toxins, as well as signs that the strandings might have been caused by human activity (particularly noise) in the ocean. Researchers also collected and preserved tissue samples for ongoing investigations.

This research is funded by the John H. Prescott Marine Mammal Rescue Assistance Grant Program and the National Oceanic and Atmospheric Administration's Ocean and Human Health Initiative.

Emily Miller, WHOI

◄ **WHOI engineer Andy Girard (left) and biologist Scott Gallager installed a cabled underwater observatory off the west coast of Panama at the Liquid Jungle Laboratory.**

Live from the tropics, it's an ocean network

With a click of his computer mouse, Scott Gallager was swimming with the fishes off the west coast of Panama. Virtual reality? Well, the fish, corals, and currents are real; Gallager, however, is virtually there, connected by an electro-optical cable back to shore and via the Internet to his office at Woods Hole Oceanographic Institution.

In January 2006, Gallager, a WHOI biologist, led a dive team that installed this cabled observatory off the island of Canales de Tierra. It's the latest in a series of what he calls "underwater laboratories" that can monitor marine ecosystems over long periods and transmit live images and data back to scientists.

The new observatory gives scientists "tele-presence," he said. A 0.75-mile (1.2-kilometer) cable runs power and data between a shore-based facility (the Liquid Jungle Laboratory) and a node 50 feet (15 meters) below the sea surface. Plugged into the node are sensors to continuously measure the temperature, salinity, pH, and turbidity of the water, as well as currents, chlorophyll, oxygen, and light levels. The observatory also has a pan-and-tilt camera.

Together, the sensors give scientists unprecedented ability to observe and begin to unravel all the factors that combine to sustain the ecosystem—how fresh water, plant detritus, sediments, chemicals, and other materials run off the coast; how they mix into the sea, increase turbidity, change the penetration of light, and add nutrients; how all these influence marine life, from the microscopic plants at the base of the food chain to the corals and fish; and how these change after storms and over seasons.

Tom Kleindinst, WHOI

To launch the project with a tight budget, Gallager, WHOI engineers Andy Girard and Steve Lerner, and research assistant Emily Miller frugally used cable left over from previous WHOI projects. "It's old, but heavy and tough," Gallager said. "We put it to good use."

The observatory can be expanded with more instruments, more nodes, and cable extensions. Gallager also envisions wiring the jungle floor, the tree canopy, and nearby mangrove swamps with sensors so that scientists can observe interactions between terrestrial and marine ecosystems.

And the observatory provides tele-presence not only to scientists. Gallager hopes classrooms around the world will click onto the observatory's Web site (http://4dgeo.whoi.edu/panama), "invoking the scientific method, designing experiments, and critically analyzing real-time data."

WHOI operates the Martha's Vineyard Coastal Observatory in temperate waters. In June, Gallager and Vernon Asper of the University of Southern Mississippi will install the National Science Foundation-funded Polar Remote Interactive Marine Observatory (PRIMO) off Antarctica, which will be the first cabled observatory in Antarctic waters. The LJL observatory, funded by the WHOI Ocean Life Institute, is the first in tropical waters.

—*Lonny Lippsett*

Changing the course of rivers and history

Punjab means "five rivers." The region in northern Pakistan is named for the great rivers that branch through the landscape, creating an ancient cradle of civilization and a modern agricultural breadbasket. But two geologists have found strong evidence that it was not always so.

The Sutlej, Ravi, Chennab, and Jellum Rivers flow westward to join the Indus River and drain into the Arabian Sea, west of Pakistan. But the rivers once flowed eastward into the Ganges River and drained into the Bay of Bengal, east of India, the scientists say. The rivers were rerouted 5 million years ago, probably as the ongoing collision of the Indian and Eurasian tectonic plates bulldozed the terrain, tilting it westward or lifting up river-diverting mountains.

To reconstruct this momentous continental and historical shift, Peter Clift of the United Kingdom's University of Aberdeen and Jerzy Blusztajn of Woods Hole Oceanographic Institution found telltale clues beneath the ocean—in the Indus Fan, an apron of sediments pumped onto the seafloor over millennia by the mighty Indus River (which gave India its name). The fan is 6 miles (10 kilometers) thick and extends about 900 miles (1,500 kilometers) into the Arabian Sea.

The scientists analyzed seismic surveys of the fan's sedimentary layers. They found that the layers started to accumulate twice as fast sometime after about 5 million years ago—indicating a large and geologically sudden increase of the Indus outflow.

Clift and Blusztajn also analyzed sediment samples cored from the seafloor and found that the sediments' isotopic compositions switched dramatically 5 million years ago. Before then, the relatively high ratios of neodymium-143 to neodymium-144 in the sediments indicated that they came from the Karakoram Mountains, far north of Punjab, and were eroded from the old southern edge of the Eurasian Plate. After 5 million years ago, the neodymium ratio was much lower, indicating that the sediments were eroded from the front edge of the Indian Plate and came from the Himalayan Mountains to the east—the source of the four modern Punjabi rivers that now flow into the Indus. The scientists concluded that the rivers were once Ganges tributaries that were "captured" by the Indus River.

"This is the first time such a major sediment capture event has been dated," Blusztajn said. It shows the potential "to use ancient sediments to reconstruct what mountains looked like in the past."

The scientists reported their findings in the Dec. 15, 2005, issue of *Nature*, which called the research "an extraordinary piece of detective work."

—*Lonny Lippsett*

Today four rivers flow west into the Indus River and the Arabian Sea (right). The rivers once joined the Ganges River and emptied into the Bay of Bengal (above). They were rerouted about 5 million years ago by the collision of the Indian and Eurasian Plates.

Jian Lin (yellow hard hat), a geophysicist at Woods Hole Oceanographic Institution, was U.S. chief scientist aboard two voyages of China's new research vessel in 2005—the first American ever invited to co-lead a Chinese deep-ocean research cruise. He and Professor John Chen of Peking University deploy a Miniature Autonomous Plume Recorder to search for hydrothermal vents.

Mingyu Mi, China Central Television

Chinese cruise brings back clues to past tsunamis near Sumatra

Exactly one year after the devastating 2004 Indian Ocean tsunami, Jian Lin found himself on a Chinese research vessel off Sumatra, floating above the epicenter of the seafloor earthquake that spawned the great wave.

He participated in a solemn ceremony to honor the estimated 280,000 people killed by the tsunami. Then he hauled up cores of ancient sediment from the ocean bottom—cores that could reveal the history of tsunamis, help predict their likelihood, and perhaps save lives in the future.

"You are looking at a book," said Lin, a geophysicist, pointing to a 1½-meter-long column of mud in his office at Woods Hole Oceanographic Institution. "Now we must learn to read the pages and hope it contains chapters that will teach us how—and how frequently—earthquakes create tsunamis in this region."

The tantalizing sediment samples culminated two 40-day voyages for Lin as U.S. chief scientist aboard China's new research ship, *Dayang 1*. It was the first time an American scientist has been invited to co-lead a Chinese deep-ocean research cruise (see page 34).

During 2005, *Dayang 1* sailed an ambitious 300-day series of expeditions to explore mineral and biological resources in the ocean, particularly at hydrothermal vents. To this unique collaboration, Lin brought seafloor maps from previous WHOI expeditions and a WHOI-built deep-tow magnetometer to detect mineral-rich ocean crust around vents. He also brought six Miniature Autonomous Plume Recorders (MAPRs), on loan from Edward Baker, Lin's colleague at the National Oceanic and Atmospheric Administration.

Lin described MAPRs as "sniffers." Lowered on wires into the depths, they detect hot, buoyant, particle-filled fluids emitted from seafloor vents. The fluids rise several hundred meters above the seafloor and spread sideways into mushroom-shaped plumes above

Dayang 1 science party

◄ WHOI scientist Jian Lin (right) looks at a sediment core just retrieved from the site of the seafloor earthquake off Sumatra that caused the 2004 Indian Ocean tsunami. Lin hopes the core contains a record of past tsunamis.

the vent "stems." MAPRs measure temperature, as well as the scattering of light (by dissolved particles) through seawater.

With these and other tools at their disposal, the international team aboard *Dayang 1* discovered new regions of strong hydrothermal plumes in the eastern Pacific Ocean and atop of the Southwest Indian Ridge (SWIR). They also recovered microorganisms that live under extreme conditions in the deep ocean and many samples of sulfide rocks from hydrothermal vents. These represented firsts for China. By flying the magnetometer on an underwater vehicle only tens of meters above the seafloor, Lin and colleagues measured Earth's magnetic field at very close range to determine the magnetic properties of unusual rocks found on the ultra-slow-spreading SWIR.

"The Indian Ocean cruise was probably the most fruitful expedition I have ever co-led," Lin said. On a little-explored region of the SWIR, the MAPRs found a extremely robust hydrothermal plume, though the team did not have time to follow the plume trail to the vents that created it.

"This vent site is just waiting to be confirmed," Lin said, "and scientists are now actively planning to go back as soon as possible. It would be the first large active vent ever found on the Southwest Indian Ridge and would fill in a missing geological and biological piece in the seafloor jigsaw puzzle."

In December 2005, *Dayang 1* headed east toward Indonesia. Near the tsunami-generating earthquake site off Sumatra, the MAPRs found a surprise: One year after the tsunami, the bottom 2,000 feet (600 meters) of the ocean were still murky and filled with particles.

Hongjie Qiu, Xinhua News Agency

◄ One year after the 2004 tsunami, with their research vessel above the site of the submarine earthquake that spawned it, Lin and the entire ship's crew participated in a solemn ceremony to commemorate the tsunami's victims, casting origami cranes and flowers into the waves.

"Major seafloor earthquakes and tsunamis send huge amounts of seafloor sediments whirling into the ocean," Lin said. "Our hypothesis was that big sediment grains would settle first, then medium grains, then fine grains, and then very fine grains."

Stirred and sorted by tsunamis, the resettled fine-grained particles could leave telltale layers in sediments. "If we can find these layers in the cores I brought back, correlate them with previous known quakes, and date others deeper down in the cores," Lin said, "then we may actually be able to read the history of earthquakes and tsunamis in this region."

During a moment of silence in the tsunami memorial ceremony on *Dayang 1*, with everyone lined up on deck, "I thought about the immeasurable suffering of those affected by the tsunami," Lin said, "and an enduring need to better understand and eventually forecast earthquakes and tsunamis."

Then the ship's horn blew for a full minute, and the ship's party sank an inscribed concrete memorial to the tsunami victims into the sea. They cast origami cranes and flowers into the waves, as well as paper money, a Chinese tradition to pay respect to those in heaven.

—Lonny Lippsett

Lin's research was funded by the U.S. Office of Foreign Disaster Assistance and a WHOI Independent Study Award.

Do fishing rules lead to more accidents?

Fishermen have argued that regulations about when and where they can catch fish have contributed to sinkings and fatal accidents at sea. But a new statistical analysis by Woods Hole researchers has found no hard evidence to support that argument.

Di Jin of the Woods Hole Oceanographic Institution's Marine Policy Center and Eric Thunberg of the National Marine Fisheries Service (NMFS) examined 20 years of reports on the number of fishing trips, days at sea, and serious accidents and ship losses for fishermen from Virginia to Maine. They found that the accident rate for commercial fishing vessels in the northeastern United States has remained stable since 1994, when NMFS tightened regulations and limits on ocean fish catches.

Jim Canavan, WHOI

The accident rate showed an overall downward trend from 1981 to 2000, the researchers reported in the October 2005 issue of *Safety Science*. The total number of accidents has declined over the years, while the number of vessels going to sea and the number of days they stay out has risen. Fishing remains one of the most dangerous occupations in America, with a death rate 16 times higher than that of police officers and firefighters.

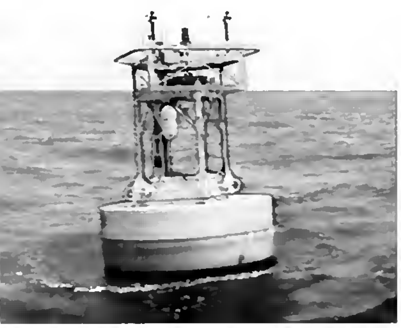
Jin and Thunberg did find a slight increase in the accident rate around the Gulf of Maine, but no specific regulation can account for the change.

"I certainly hear anecdotal evidence that fishermen are taking more risks and may be deferring maintenance on their boats, but these are not observable, so we can't test whether these actions have affected accident rates," Thunberg said. "Regulations don't force fishermen to endanger their lives, but the economics of fishing certainly have changed. It is possible that some boats are making longer trips with fewer crew or taking more risks in tough financial times."

—Mike Carlowicz

Dust Busters for the oceans

A new instrument collects answers blowing in the wind


Ed Sholkovitz, WHOI

Like most living things, microscopic marine plants need iron and other minerals to live and grow. On land, soil provides a ubiquitous source of minerals, but how do essential nutrients get into vast watery stretches of the open ocean?

The question has long mystified oceanographers. According to one theory, large swirling currents, called eddies, pump nutrients from the depths up toward the sunlit surface, giving phytoplankton the ingredients they need to flourish (see page 18). But a larger source of iron may be dust storms, which blow huge quantities of mineral-rich soil particles (called Aeolian dust) out to sea, particularly from desert regions in Africa and Asia.

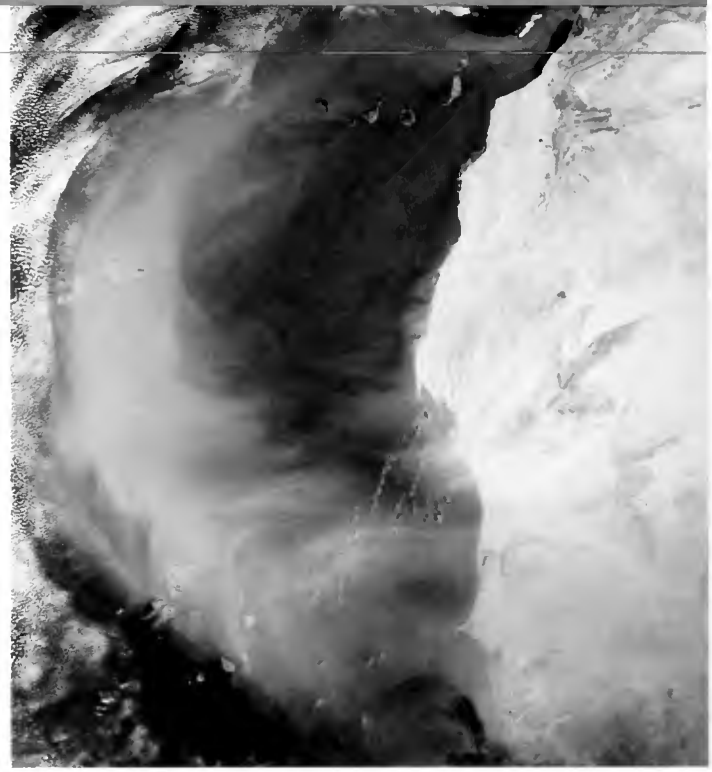
Until now, scientists investigating the latter theory have been stymied by an inability to measure—when, where, and how much—dust falls into the oceans, said Ed Sholkovitz, a marine geochemist at Woods Hole Oceanographic Institution. They have had to rely on dust samples collected on islands.

To remedy this situation, Sholkovitz teamed with three WHOI engineers—Geoff Allsup, Dave Hosom, and Mike Purcell—who collectively call themselves the "Dust Busters." They designed a device, mounted atop a moored buoy, that collects windblown particles over the open ocean. Unlike islands, which aren't portable, buoys can be placed in scientifically strategic locales.

The heart of their device is a motorized carousel that rotates 24 dust-collecting filters under a small intake opening. As air passes through the opening, the filters catch samples of wind-borne particles, which are eventually chemically analyzed back at WHOI.

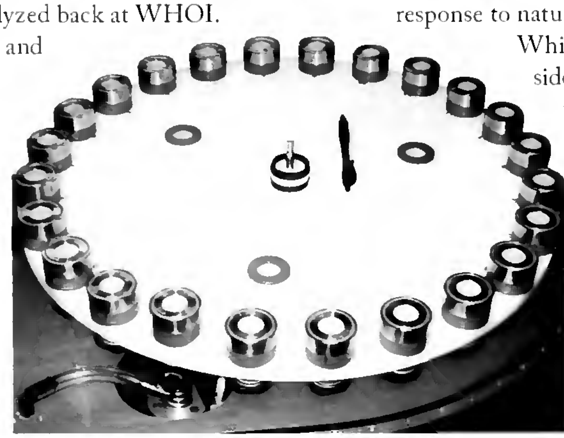
The particle sampler had to be rugged and watertight to survive months at sea. Software ran the device automatically, coordinating it with meteorological instruments on the buoy to pause sampling when high waves or winds might clog the filters with sea spray.

The Dust Busters collaborated with Peter Sedwick, a marine geochemist at the Bermuda Biological Station for Research, to test their particle sampler from May to September 2004 on a buoy moored off Bermuda. Reporting in the journal *Deep-Sea Research*, the scientists said the instrument successfully captured dust throughout the summer, including pulses of brown-yellow particles from two large African dust storms in June and August.


Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC

An intense storm in 2003 sent a massive plume of Saharan Desert dust over the Atlantic Ocean. It extended more than 1,000 miles (1,600 kilometers), from the Cape Verde Islands (lower left) to the Canary Islands (top center). Dust storms may be a way for iron and other essential minerals to get into the open ocean to fuel blooms of marine life. WHOI scientists and engineers designed a device with an automated carousel of filters (below) that collects windblown particles in the open ocean. It is mounted atop a moored buoy (left).

The instrument's initial success persuaded the National Science Foundation to fund redeployment of an improved particle sampler in 2007 and 2008. With a grant from the WHOI Access to the Sea Program, Sheri White and Norman Farr, engineers in WHOI's Applied Ocean Physics and Engineering Department, were enlisted to develop a sensor that can measure and monitor color changes in captured dust (indicating its source) in real time. New two-way communications will let scientists modify sampling procedures in response to natural events.


Ed Sholkovitz, WHOI

While the particle sampler monitors the supply side of the question, Sholkovitz's collaborators, Sedwick and Thomas Church from the University of Delaware, will focus on the demand side: How is iron from continental dust chemically transformed and released in seawater to catalyze blooms of phytoplankton at the base of the marine food chain? The research will help unravel a fundamental process that fuels life in the ocean.

—*Lonny Lippsett*

Going wireless in the deep blue

You're exploring how ocean currents develop, or how salt and spray are exchanged with the atmosphere, or how lava erupts from the seafloor.

You could make observations from a ship, but expeditions provide only snapshots. They don't allow you to observe changes in the ocean over months or years, nor can you capture sudden, unpredictable events such as earthquakes or eruptions.

Instruments on satellites offer useful broad, long-term observations. But the view is only skin deep, as cameras and lasers penetrate only the top few meters of water.

[illegible]

moored buoy—and brought it into the 21st century. They designed and built a wireless buoy observatory that allows researchers to send or receive "calls" from instruments in the middle of the ocean. Collaborating with colleagues from the University of Washington and Scripps Institution of Oceanography, they deployed the buoy for a trial run from May 2004 to July 2005 along the Nootka Fault off Vancouver Island.

The keys to the system are satellite transmitters and acoustic modems. Outfitted with two Iridium satellite transceivers, the Nootka buoy sent data from instruments on the ocean back to shore six times a day. [illegible]

signals much like those passing through the phone line and modem to your home computer. Acoustic modems relayed the signals through the water between seafloor instruments and the surface buoy.

Because instruments don't need to be hooked into the system by cables, researchers were able to add a new instrument four months after the initial setup. They simply reprogrammed the observatory's computers to listen for a new voice.

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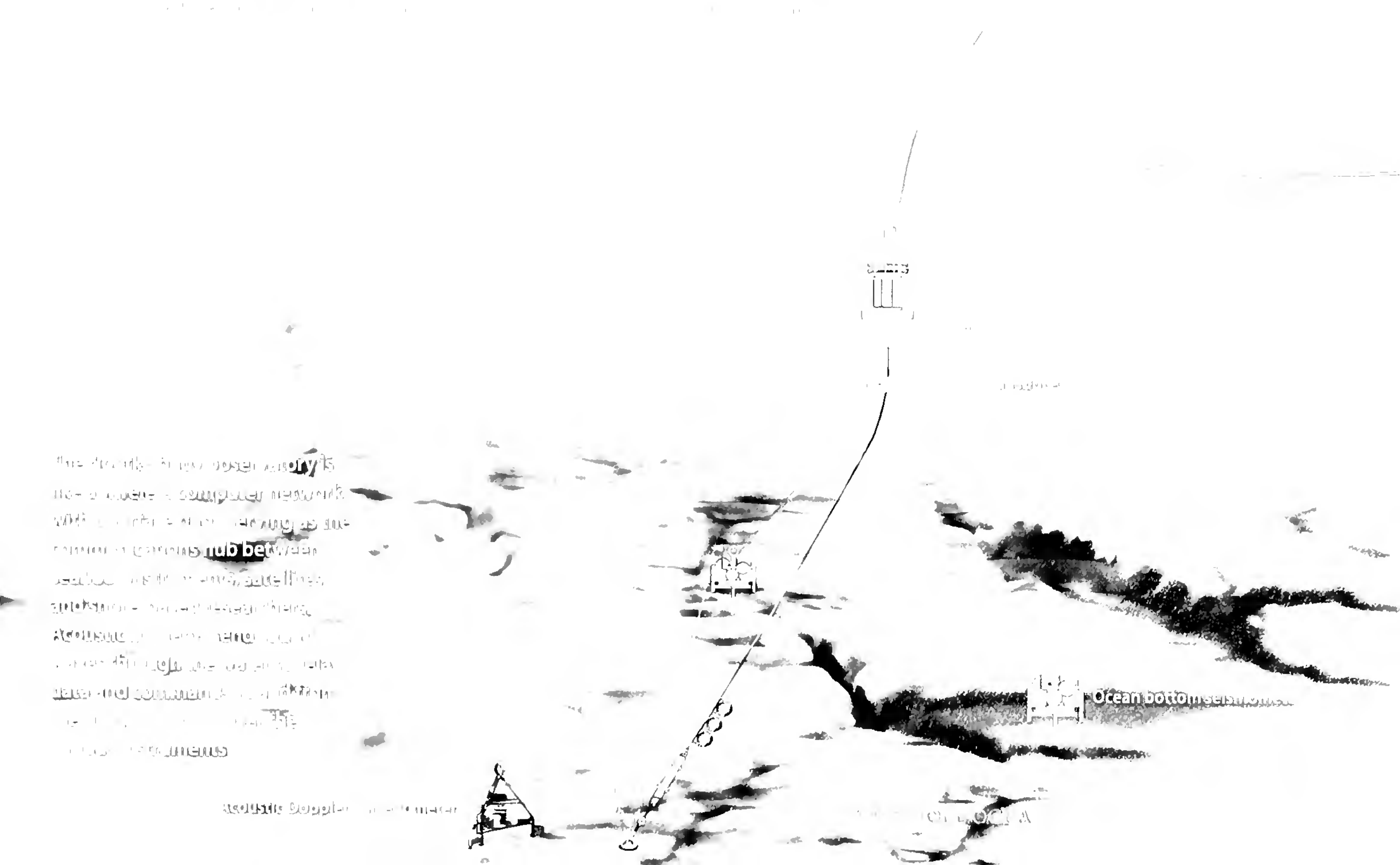


A bacterium with its own compass

Sheri Simmons gets into the rugged wilderness as often as she can, backpacking in Newfoundland, the Adirondacks, and Alaska—where she once encountered a grizzly bear on a trail. She skis every chance she gets, on notoriously rough and sometimes forested slopes.

But her research as a graduate student in the MIT/WHOI Joint Program took her to sleepy Salt Pond, in the middle of Falmouth, Mass., in a tame little rowboat, and sometimes stuck in the marsh mud. In this seemingly uneventful spot, she discovered a previously unknown bacterium that has turned some conventional wisdom upside down—literally.

Simmons studies magnetotactic bacteria, so named because they take in iron and sulfur from their environment to form internal chains of iron minerals, magnetite (Fe_3O_4) and greigite (Fe_3S_4). That makes them magnetic.

"The bacteria act like swimming compass needles," orienting themselves to Earth's magnetic field, Simmons said. She is interested in finding out how abundant these bacteria are, where they live, how much iron and sulfur they take up, and how they cycle these elements through the environment.

The magnetotactic ability of these bacteria helps them find a niche that suits their particular chemical needs: They require high sulfur but low oxygen levels. Such niches form in places where water is not turbulent and can settle into stable layers, each with distinct chemical makeups that are exploited by distinct types of bacteria.

Such stratified environments develop in coastal ponds, such as Salt Pond. In summer, winds that mix the waters die down, and microscopic marine plants bloom in the pond's oxygen-rich surface waters. Zooplankton and bacteria use oxygen as they consume plants, depleting oxygen in upper layers. At the same time, other bacteria convert sulfur compounds in the lower layers into sulfides, which are toxic to most life, but important raw material that magnetotactic bacteria use to make greigite.

Between the upper and lower layers is a thin interface—with ample

Graduate student Sheri Simmons and colleagues refer to their newly discovered, as-yet unnamed bacterium as the "barbell" bacterium because of its shape.

sulfides, but not too much oxygen. In this middle ground, Simmons found her as-yet unnamed bacterium. Simmons and her advisor, microbial geochemist Katrina Edwards, and their colleague, Dennis Bazylinski of Iowa State University, refer to it as the "barbell" bacterium because of its shape.

Laboratory experiments have demonstrated that in the Northern Hemisphere, magnetotactic bacteria will swim toward the geomagnetic north when they find themselves in water with too much oxygen. Why? Because in the Northern Hemisphere, Earth's magnetic field angles downward into the planet, so bacteria that head north effectively swim down into more congenial, low-oxygen waters. Since the 1970s, when magnetotactic bacteria were first discovered, scientists have repeatedly found this behavior and logically assumed that all magnetotactic, oxygen-intolerant bacteria should behave this way.

But when Simmons exposed the barbell bacteria from Salt Pond to high-oxygen water, they swam south instead of north.

"We have found magnetotactic marine bacteria with behavior that's exactly the opposite of the textbook explanation that researchers have believed for decades," she said. "We don't know why they do this. We don't think they do it in the pond, since it wouldn't make sense ecologically for them to swim upward into greater oxygen concentrations."

Simmons was lead author of a paper describing the newfound organism, which was published Jan. 19, 2006, in the prestigious journal *Science*—a rare occurrence for a scientist who is still a graduate student. The discovery opens whole new lines of inquiry.

Simmons received grants to pursue her research from the WHOI Ocean Life Institute, the WHOI Coastal Ocean Institute, and the WHOI Ocean Ventures Fund, which sponsors special projects by graduate students. She expects to finish her Ph.D. degree in 2006.

To collect samples, Simmons used a rowboat and a novel device, designed with WHOI biologist Craig Taylor, that gently draws in water samples from separate stratified layers, rather than pumping up a mixed sample vertically through the water column. Back in the lab, Simmons studies the ribosomal RNA of her collected bacteria to learn more about them.

She has also learned to row better. "I couldn't row when I came here," she noted, "I'm a skier, not a crew person."

— *Kate Madin*

Photo by Tom Kleindinst, WHOI

steers research in new directions

A thin line to a deep trench

MARIANAS TRENCH—The cable is nearly as thin as a strand of human hair (inset photo shows a human hair, top, and the cable) and stretches 20 miles (32 kilometers) long, far enough to reach into Earth's deepest seafloor trench. On an April 2006 expedition to the Marianas Trench, WHOI engineers were set to give the new cable its first test in extreme depths. Ultimately, the cable will be used to relay real-time data and communications between shipboard researchers and a deep-sea vehicle under construction called the Hybrid Remotely Operated Vehicle (HROV). Just 250 microns in diameter, the cable will allow HROV to maneuver at depths of 36,000 feet (10,972 meters) without the drag of heavy cables on traditional deep-sea vehicles.

Jack Cook, WHOI, Inset Tom Kleindinst, WHOI

Amy Nevala, WHOI

Noxious gas from the mouth of hell

MASAYA, NICARAGUA—In the 1500s, a visiting friar looked into Masaya Volcano's hot, smoking pit lined with rows of teeth-like rocks and dubbed it "the mouth of hell." For WHOI geochemist Ken Sims, it is a laboratory. Most experts in volcanic gases work atop crater rims. But Sims (seen here in March 2006) possesses both climbing skill and scientific knowledge to safely collect noxious gas samples directly from highly concentrated plumes in the caldera. By gathering gas samples from volcanoes worldwide, Sims is exploring how our planet is evolving and how volcanic gases cause climate changes that may even have led to the extinction of dinosaurs.

• Manzanill
Mexico

R/V *Knorr*
Jan.–March 2006

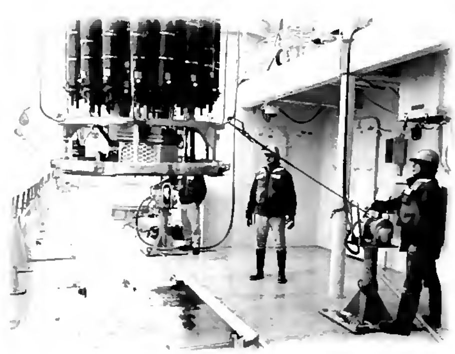
Mak Saito, WHOI

A titanic struggle of tiny plants

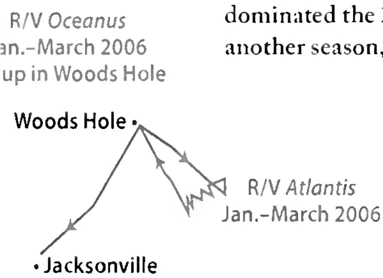
ROSS SEA—WHOI marine geochemist Mak Saito joined an international team of researchers aboard the icebreaker *Nathaniel B. Palmer* in the austral summer of 2005-06 to explore the ecological struggle between two major groups of algae: diatoms and phaeocystis. The team studied the algae and a number of elements in seawater that algae need to survive: carbon, nitrogen, phosphorus, iron, and cobalt. Because the algae have different nutritional preferences, the scientists hypothesize that changes in seawater chemistry will allow one group to out compete the other. The outcome has implications for climate change, because photosynthetic algae use huge amounts of heat-trapping carbon dioxide. On Jan. 14, 2006, cruise members claimed to make history by sailing farther south than anyone in recorded history, in the Bay of Whales.

Exploring the ocean's interior

SOUTHERN OCEAN—Oceans are layered with distinct water masses that vary in size, temperature, and saltiness. Researchers on the research vessel *Knorr* spent seven weeks in the winter of 2006 surveying the source of a dense, low-salt layer that flows north from Antarctica and fills almost all the Southern Hemisphere and tropical oceans at depths of 2,600 to 3,200 feet (800 to 1,000 meters). Still unknown is how this water mass forms, then sinks, rises, and flows, and how it affects global climate, said the expedition's co-leader Lynne Talley, a physical oceanographer at Scripps Institution of Oceanography and a 1982 graduate of the MIT/WHOI Joint Program.



Amy Simoneau, WHOI



Is the tide coming back in?

MASSACHUSETTS BAY—The historic 2005 "red tide" of the harmful algae *Alexandrium fundyense* was the most widespread and intense in New England since 1972. It kept the WHOI sampling team, led by Bruce Keafer, going to sea on coastal research vessel *Tioga* and other vessels through December to see if the toxin-producing plants left cysts to seed future outbreaks. Meanwhile, Deana Erdner (right), Linda McCauley, Kerry Norton, and others in WHOI biologist Don Anderson's laboratory have been isolating and culturing cells to figure out which genotype of *Alexandrium* dominated the 2005 bloom. In April 2006, Keafer and crew saddled up for another season, making several trips on *Tioga* to see if history repeats itself.

Mike Carlowicz, WHOI

A density battle off the Outer Cape

CAPE COD—In winter, shallow waters off the National Seashore on Cape Cod cool and get more dense. But as snow melts in northern New England in spring, a fresher coastal current appears off Cape Cod. These two phenomena oppose each other: The winter-cooled, dense shallow waters are potentially capable of flowing offshore into the center of the Gulf of Maine; the fresher waters are less dense and more likely to travel long distances along the coast. In the winter of 2005-06, WHOI physical oceanographers Glen Gawarkiewicz and Andrey Shcherbina have investigated the water masses off Cape Cod, using a combination of observations from a REMUS autonomous underwater vehicle, moored current profilers, and hydrographic measurements from WHOI's coastal research vessel *Tioga*.

Chris Linder, WHOI

Alvin's last ride; *Sentry's* first

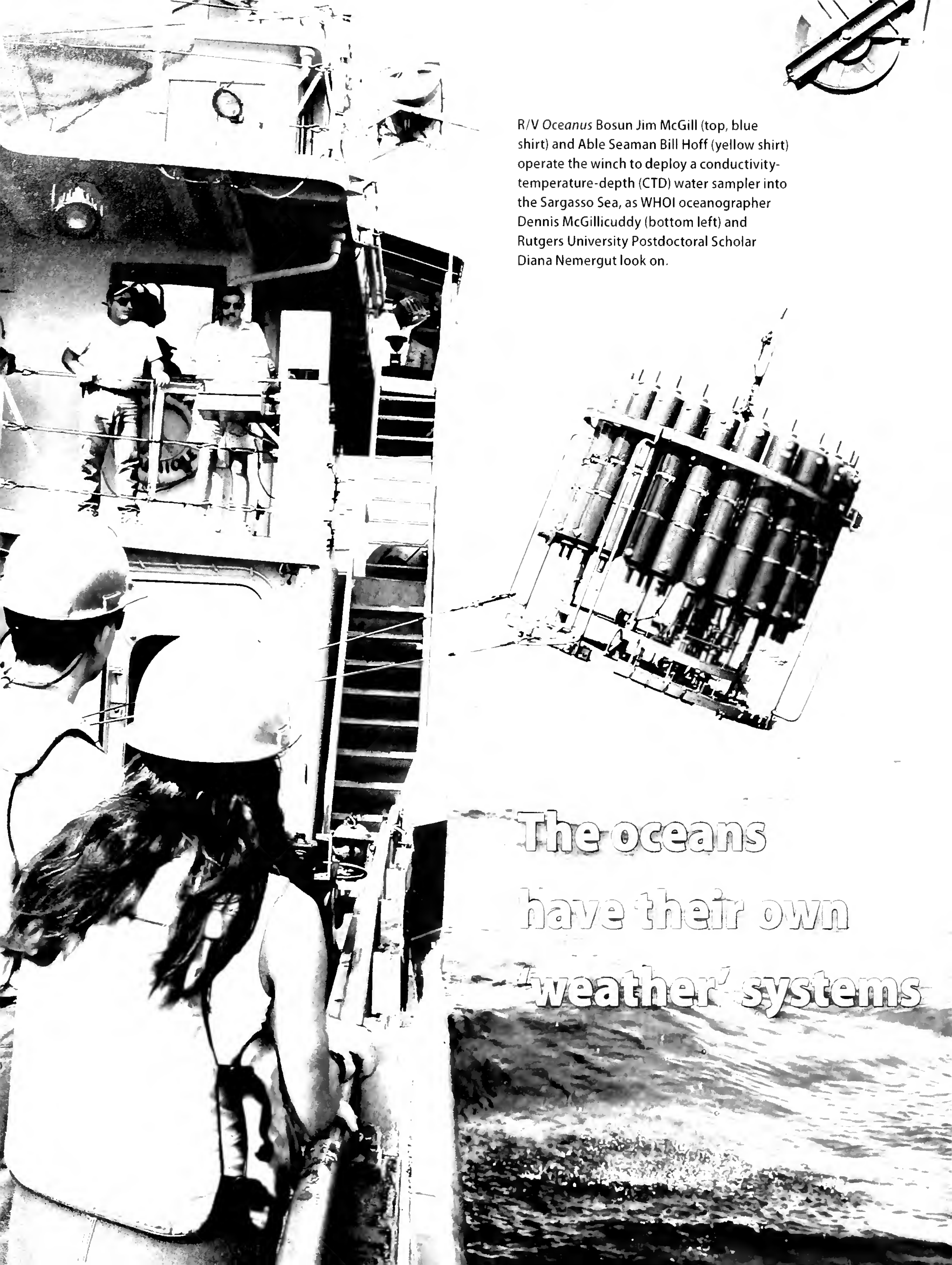
SARGASSO SEA—After six months of maintenance, the deep-sea submersible *Alvin* is returning to work. In April 2006, the sub's engineers and pilots were scheduled to make recertification dives, submerging first in shallow waters then deeper to *Alvin's* maximum 14,700-foot (4,500-meter) depth. On the same expedition on R/V *Atlantis*, engineers were set to conduct the first deep-water dunks of the new autonomous vehicle *Sentry* (below). The fast-moving, four-winged vehicle—slightly smaller than a Volkswagen Beetle—will perform sonar surveys over rugged undersea terrain. Trials allow engineers to see how *Sentry* handles navigating and maneuvering at depths of 16,400 feet (5,000 meters).

Tom Kleindinst, WHOI

The hidden world of salps

OFF THE ANTARCTIC PENINSULA—Biologists Larry Madin (WHOI) and Patricia Kremer (U. Connecticut) led a month-long cruise aboard the ice-strenghtened ship *L.M. Gould* to learn more about a little-known species of salps, a gelatinous, tube-shaped planktonic animal that may be getting more numerous in the Southern Ocean. Changes in the climate and sea ice around Antarctica may create conditions in which salps thrive instead of krill, a critical food for penguins, seals, and whales. Researchers used net sampling, scuba diving, lab experiments, and a prototype imaging instrument (LAPIS) to study salps' feeding, reproductive biology, and ecosystem impacts. The cruise was featured on WHOI's "Dive and Discover" Web site (www.divediscover.whoi.edu).

Brenna McLeod, Trent University, Ontario



R/V *Oceanus* Bosun Jim McGill (top, blue shirt) and Able Seaman Bill Hoff (yellow shirt) operate the winch to deploy a conductivity-temperature-depth (CTD) water sampler into the Sargasso Sea, as WHOI oceanographer Dennis McGillicuddy (bottom left) and Rutgers University Postdoctoral Scholar Diana Nemergut look on.

The oceans have their own 'weather' systems

Pioneering expeditions investigate how eddies make life bloom in oceanic deserts

In the 87 days that Dennis McGillicuddy and colleagues spent in the Sargasso Sea in the summer of 2005, they were tossed around or chased by four hurricanes and two tropical storms: Franklin, Harvey, Irene, Maria, Nate, and Ophelia.

Not one of those massive storms was as powerful as the one swirling in the water beneath them.

From June to September, McGillicuddy and a team of more than 20 scientists from Woods Hole Oceanographic Institution and five other marine science labs tracked an eddy named A4. It was the oceanic equivalent of a hurricane—a huge mass of water spinning like a whirlpool, moving through the ocean for months, stretching across more than 62 miles (100 kilometers), stirring up a vortex of water and material from the depths to the surface.

"Eddies are the internal weather of the sea," says McGillicuddy, an associate scientist in the WHOI Applied Ocean Physics and Engineering Department. But unlike destructive hurricanes, eddies can be productive. As certain types of eddies stir the ocean, they draw nutrients up from the deep, fertilizing the waters to create blooms of microscopic marine plants in the open ocean, where little life was once thought to exist.

Stephan Duller, Rutgers University

▲ Dennis McGillicuddy helps prepare to lower the Video Plankton Recorder (VPR) from R/V *Oceanus*. The VPR found billions of microscopic plants blooming in eddy A4.

"The open ocean is twice as productive as we can explain based on what we know about nutrients in the water," said McGillicuddy. "Where do all the nutrients come from to make these oases in the oceanic desert?"

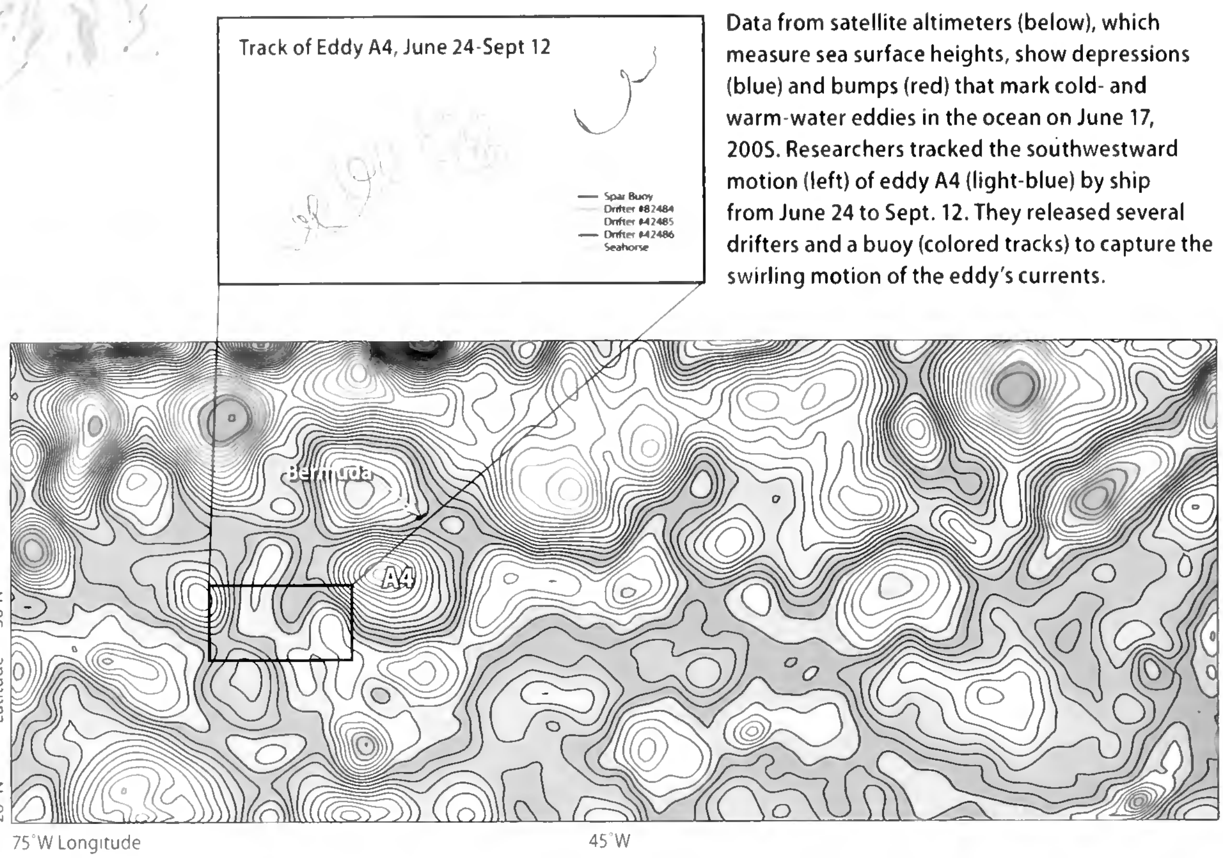
The Sargasso Sea—south and east of the Gulf Stream—forms the geographic center of the North Atlantic Ocean. It is warmer, saltier, bluer, and clearer than most other parts of the North Atlantic, except for the floating mats of *sargassum* seaweed that gave the sea its name. For centuries, prevailing wisdom was that such open ocean waters were mostly desert-like, unproductive regions.

A lecture on the Sargasso Sea in the early 1990s sparked McGillicuddy's curiosity. In the talk, Bill Jenkins, a senior scientist in the WHOI Marine Chemistry and Geochemistry Department, pointed out that scientists were finding more oxygen being produced and consumed in the open ocean than anyone expected. The suspects were phytoplankton, microscopic marine plants that produce oxygen in photosynthesis, and zooplankton (microscopic animals) and bacteria, which use oxygen as they consume plants and organic detritus that sink to the seafloor.

Scientists found 10 times more microscopic life in the Sargasso Sea than anyone

David Menzies, University of California, Santa Barbara

▲ From left, researchers Jim Ledwell, Brian Guest, Blair Greenan, Penelope Howe, and Nathan Buck prepare to lower an "integrating sampler." Arrays of these samplers were slowly towed through the ocean to track how the eddy had spread harmless chemical tracers through the ocean.



Data from satellite altimeters (below), which measure sea surface heights, show depressions (blue) and bumps (red) that mark cold- and warm-water eddies in the ocean on June 17, 2005. Researchers tracked the southwestward motion (left) of eddy A4 (light-blue) by ship from June 24 to Sept. 12. They released several drifters and a buoy (colored tracks) to capture the swirling motion of the eddy's currents.

could explain, given the dearth of nitrate, phosphate, trace metals, and other nutrients that plants need to grow in sunlit surface waters. Researchers slowly developed the hypothesis that vortices of cold or warm water—eddies—might somehow act as a biological pump.

"I had proposed a problem, and Dennis suggested a solution," Jenkins said. "He had the clever idea that eddies were perturbing the layers of the water column, mixing different waters, and bringing nutrients up from below." The upwelling of nutrients into the euphotic zone (the top 330 feet or 100 meters of the ocean, where light penetrates) would stimulate prodigious blooms of phytoplankton, which attract zooplankton and other animals up the food chain.

The Eddies Dynamics, Mixing, Export, and Species composition (EDDIES) project was born.

"Dennis has wanted to do this experiment since he was a graduate student," said Dave Siegel, a longtime collaborator with McGillicuddy and an oceanographer from the University of California, Santa Barbara (UCSB).

McGillicuddy mustered chemists, biologists, and physical oceanographers from WHOI, UCSB, Rutgers University, Bermuda Biological Station for Research (BBSR), Virginia Institute of Marine Sciences, and the University of Miami. Together, they secured $3.5 million from the National Science Foundation, as well as five months of ship time over two years on the WHOI-operated research vessel *Oceanus* and the BBSR-operated *Weatherbird II*.

▲ **The WHOI-operated *Oceanus* and BBSR-operated *Weatherbird II* worked in tandem for two summers, tracking different aspects of eddy dynamics. The ships met at sea several times during the two-year operation.**

The goal: to make detailed chemical, biological, and oceanographic measurements of a specific eddy by getting right into the middle of it.

"We didn't want to just sit on the fence and watch from one point," said Ken Buesseler, chairman of the WHOI Department of Marine Chemistry and Geochemistry. "Eddies move and develop, so we decided to follow a parcel of ocean as it moved. This was the first time anyone has really studied an eddy in this way."

Eddies are distinct parcels of water that move and jostle within the ocean, much like warm and cold air masses or high- and low-pressure systems in the atmosphere. Eddies are formed by differences in ocean temperature and salinity that give water different densities. Like oil and water, water masses of different densities tend to keep separate, rather than mix.

The largest eddies can contain up to 1,200 cubic miles (5,000 cubic kilometers) of water and can last for months to a year. Earth's rotation—the Coriolis force—gives eddies their spin.

To hunt for their target, McGillicuddy and colleagues used data from satellites, whose measurements of sea surface heights show telltale signs of eddies. Warm-water eddies form bumps in the ocean; cold-water eddies form depressions. The team examined several eddies and settled on anticyclone No. 4, or A4, a "mode water" eddy (see page 22) that stretched some 93 miles (150 kilometers) in diameter at the surface.

The EDDIES program took a truly integrated approach, combining many tools—satellites, ships, moorings, drifters, robotic vehicles, computer models—and many types of scientists.

From June 20 to Sept. 14, 2005, the researchers zigzagged across the eddy as it drifted southwest about 3.7 miles (6 kilometers) per day. The team on *Oceanus* buzzed around collecting water and nutrient samples, measuring current speeds and directions, and towing WHOI biologist Cabell Davis' Video Plankton Recorder through the turbulent swirl. Bill Jenkins and his lab mates measured natural chemical markers such as tritium, an indicator of the amount of plant-fueling nitrate being raised from the depths. WHOI Senior Scientist Jim Ledwell, an expert on using tracers in the ocean, injected sulfur hexafluoride, a harmless chemical, into the middle of the eddy and tracked how it spread up, down, and across the sea.

At the same time, a research team on *Weatherbird II* made targeted measurements in the core of the eddy, measuring plant and animal productivity, the movement of particles, and thorium, a radioisotope that marks how much organic material is sinking from surface waters. Siegel used a radiometer to measure whether the eddy was disturbing the light penetrating the blue water.

"Ocean scientists are moving toward a more holistic view of their research problems," said Siegel. "Ocean science grows by filling in the cracks between disciplines. If you put a smart and diverse group of people together in a boat, a lot of good things can happen. People start to think outside of their own little research worlds, and together we can tell scientific stories that we couldn't put together individually."

Valery Kosnyrev, WHOI

▲ Sarah Bender, a Rutgers University researcher, processes water samples in the laboratory on R/V *Oceanus*. She is measuring how nutrients affect the abundance of microscopic plants in the eddy.

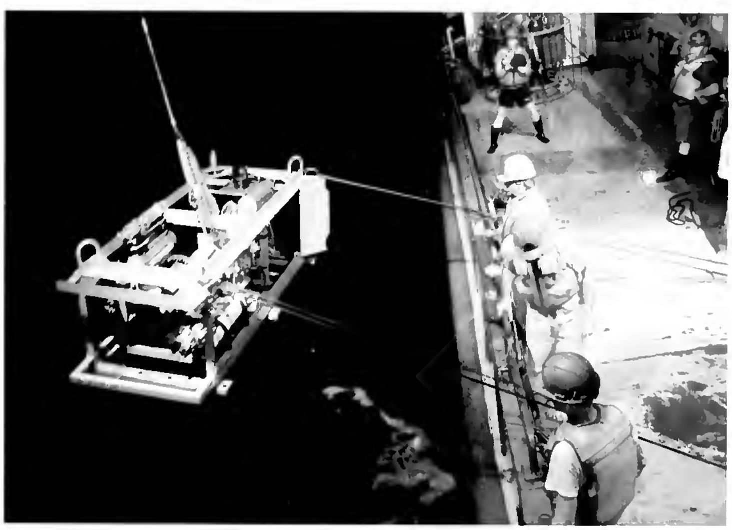
Fueled by nutrients from the deep, diatoms bloomed to concentrations 10,000 to 100,000 times the norm—among the highest ever observed in the Sargasso Sea.

At the same time, the team was surprised to find historically low concentrations of oxygen in the depths, a sign of zooplankton and bacterial population explosions. It also meant that an awful lot of heat-trapping carbon dioxide may have been drawn out of the atmosphere and ocean surface, transformed by phytoplankton, and sunk to the bottom of the ocean.

Six months after the last EDDIES researcher stepped off *Oceanus*, the scientists are still assessing and analyzing the wealth of data they collected on A4. The team met in February 2006 at the international Ocean Sciences Meeting in Hawaii to share observations and collectively make sense of what they saw. Ultimately, the goal is to develop high-resolution computer models—McGillicuddy's specialty—that can simulate and predict the full range of eddy dynamics.

The EDDIES project is a critical step toward comprehending these great ocean storms, whose sheer size and scale are daunting. During the expedition, tropical storm Harvey made a direct hit in early August, cutting a path right across eddy A4. The eddy hardly felt Harvey; the monstrous atmospheric storm never came come close to breaking up the potent, voluminous swirl of water in the ocean.

—*Mike Carlowicz*



David Menzies, University of California Santa Barbara

▲ Researchers deploy a sampling sled to detect chemical tracers that helped them track how an eddy mixes water layers of the ocean.

The EDDIES project received funding from the Chemical Oceanography, Biological Oceanography, and Physical Oceanography branches of the National Science Foundation.

Terry Joyce, WHOI

The hunt for 18° water

Oceanographers examine "mode waters" that save the signals of past winters

Terry Joyce is looking for Val Worthington's water.

In 1959, Woods Hole oceanographer Valentine Worthington gave a name and identity to a long-observed but poorly understood phenomenon of the North Atlantic Ocean. Analyzing data from as far back as the H.M.S. *Challenger* expedition of the 1870s, Valentine described how the interior of the Sargasso Sea contained distinct parcels of water with remarkably constant salinity, density, and temperature—roughly 18°C (64° F). To Worthington, the appropriate name for this quirky mass was simple and straightforward: 18° water.

In the early 1970s, Worthington persuaded colleagues and funding agencies to mount an expedition to study 18° water. He saw connections between these peculiar water masses and the circulation of the entire North Atlantic, as well as the weather above it. But when he finally went to sea in 1974 and 1975, he couldn't find what he was looking for.

Researchers now know that 18° water is produced by a critical energy transfer between warm Gulf Stream water and the cold winter atmosphere. Unfortunately for Worthington, he went to sea in the midst of a warm winter, an ebb time in the assembly line of production of 18° water.

Decades later, his successors in the Physical Oceanography Department at Woods Hole Oceanographic Institution and from eight other oceanographic institutions have launched a far-reaching program to examine the formation and evolution of Worthington's famous water and how it might influence North Atlantic climate. The CLIVAR Mode Water Dynamics Experiment (CLIMODE) began its own series of expeditions in November 2005, and this time researchers seem to be finding what their predecessor was looking for.

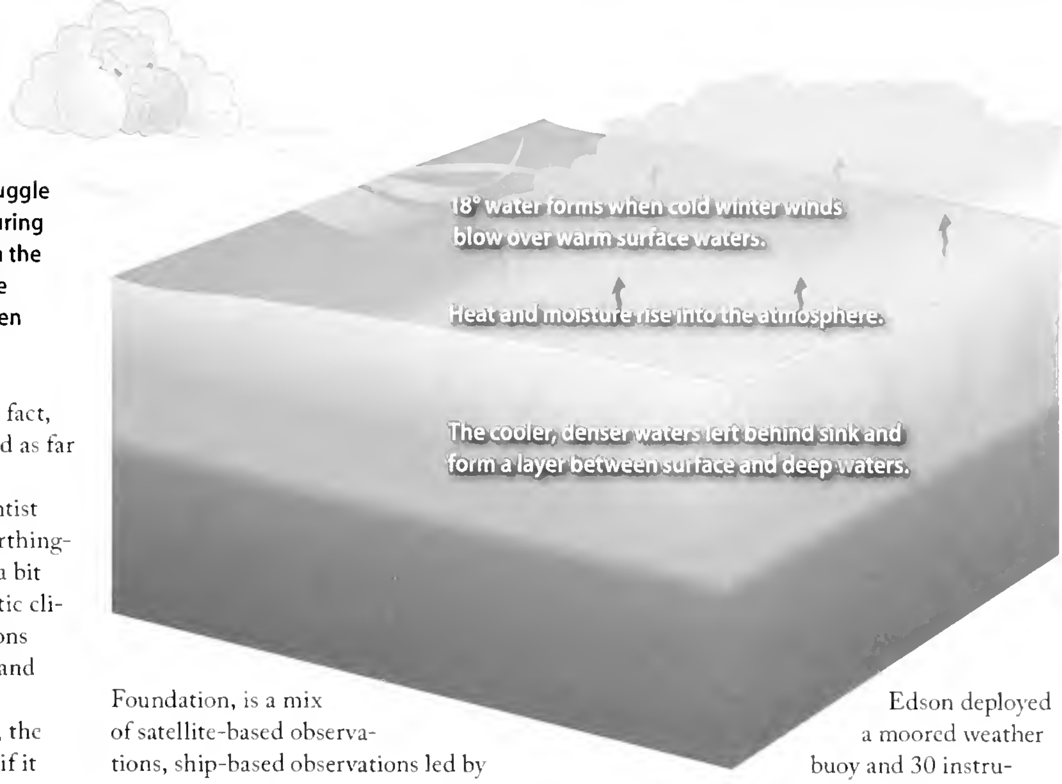
During winter, chilly winds blow from the Arctic and North American interiors out to sea, where the warm Gulf Stream rides east over the Sargasso Sea. The cool, dry winds pull heat and moisture from the Stream and carry them off to Europe and North Africa. The cooler, salty water left behind forms a layer on top of the ocean that can extend 1,300 feet (400 meters) deep.

Spring and summer heat eventually warms the surface again, but the chilled waters formed in winter do not dissipate. They are denser than warm waters, so they sink—not to the seafloor, but to the middle of the sea. This layer of water hangs suspended between warm surface waters and even colder deep waters, wedged like butter cream in the midst of a layer cake.

Oceanographers call 18° water and other water masses like it "mode water," a statistical term for a mass of water that has homogeneous temperature and other characteristics. Mode waters are like pools within the deeper and wider pool of world oceans, and they form in the middle latitudes all over the world. (The Kuroshio Current in the northwest Pacific and the Agulhas Current in the southwest Indian Ocean are also famous for mode-water creation.) Once they form and sink, layers of mode water remain relatively intact for several years and are swept around by the ocean's circulation.

As Worthington wrote in 1959, "the 18° water is of more than usual interest" because it can often be found hundreds of miles to the south and west of where it is formed, "in places where the winter surface temperature is far higher than 18° and there is no pos-

◄ **Researchers and crew members struggle to deploy a spar buoy in rough seas during a January 2006 cruise of R/V *Atlantis* in the North Atlantic. The buoy measured the exchange of heat and moisture between the atmosphere and the ocean.**



sibility of it being formed locally." In fact, Worthington's 18° water can be found as far south as the Caribbean.

Terry Joyce, a WHOI senior scientist who worked down the hall from Worthington for many years, said 18° water is a bit like a memory bank for North Atlantic climate: It freezes a memory of conditions from the winter when it was formed and carries them as far as the tropics.

"At the end of each winter season, the Sargasso Sea puts this water away as if it were going to a safe deposit box, storing it away for sometime later," Joyce said. Researchers believe this stored water can later influence and regulate how quickly or slowly the ocean and atmosphere can change in future seasons. After migrating to warmer climes or drifting back to the Gulf Stream, it eventually mixes with and tempers warmer surface waters.

The CLIMODE team of investigators is doing everything it can to chronicle and understand the water that so excited their predecessor. They have so many questions.

- How much heat is gained, lost, and stored in the ocean-atmosphere exchange that creates 18° water? How high into air and deep below the ocean surface does this interaction reach?
- Where does 18° water go after it forms? How does it move horizontally through the ocean?
- How big are these wedges of water, and how do they affect other elements of ocean circulation?
- What role does sinking mode water play in sequestering carbon dioxide, nutrients, and heat from the surface in the ocean depths, and how does that affect climate and marine life from year to year?

From 2005 through 2007, the CLIMODE team will spend 107 days at sea, crisscrossing the Gulf Stream by ship and spreading instruments all over it. The project, funded by the National Science Foundation, is a mix of satellite-based observations, ship-based observations led by Joyce and computer modeling led by John Marshall of the Massachusetts Institute of Technology.

The first two cruises—19 days in November 2005 and 14 days in January 2006 on the WHOI-operated research vessels *Oceanus* and *Atlantis*—were typical of what is to come. Joyce and colleagues from the Scripps Institution of Oceanography lowered conductivity-temperature-depth (CTD) samplers and water-sampling bottles into the sea dozens of times to characterize the ingredients, dimensions, flows, and properties of the 18° layer.

WHOI researchers Dave Fratantoni and John Lund and NOAA scientist Rick Lumpkin cast surface drifters and special bobbing floats that can drift horizontally and vertically with the water as it sinks, meanders, and sometimes gets stirred up into circularly spinning currents called eddies (see page 18).

To measure the interaction between sea and sky, WHOI's Bob Weller and the University of Connecticut's Jim Edson deployed a moored weather buoy and 30 instrumented weather balloons. A specialized buoy was released by Edson and WHOI oceanographer John Toole to drift with the Gulf Stream; it was then recaptured after simultaneously measuring conditions above and below the ocean's surface.

All the while, the researchers were hoping for 35- to 40-knot winds and 5°C (40°F) air temperatures that could cool and churn the sea enough to start the mode-water assembly line. Nature did not disappoint this winter, and the CLIMODE team is hoping for cold, windy conditions when it goes back to sea for another six weeks next winter.

Worthington would be pleased.

—*Mike Carlowicz*

▲ **Atmospheric scientist Jim Edson launches a radiosonde—an instrumented weather balloon—from R/V *Atlantis*.**

What brings the food that brings the whales?

▲ Welcome to Barrow, Alaska, where Iñupiat people rely on the annual migration of bowhead whales to coastal waters.

Scientists investigate delicately balanced ecosystem off Alaska

Watching the gray, pitching ocean from the beach in Barrow, Alaska, Carin Ashjian, a biologist at Woods Hole Oceanographic Institution, wonders if the seas are too rough for the *Annika Marie*, the 43-foot boat she and her colleagues will use to conduct their research. The late August weather hasn't been good, and they have only this week and next to gather the information they need.

Ashjian and a team of researchers from several institutions have come to Barrow ahead of the annual migration of bowhead whales. Whales need food—a lot of it. They eat zooplankton (little marine animals called copepods and krill), which the whales scoop up and strain from seawater through their baleen plates.

In late summer, multitudes of plankton may aggregate in dense swaths in the coastal waters off Barrow. Sunlight, currents, nutrients, winds, sea ice, water temperature and salinity, topography on land and on the seafloor, and other factors conjoin in the right combinations at the right time in the right place to spur the growth of tiny marine plants (phytoplankton) that feed the zooplankton that feed the whales. Ashjian's mission is to sort out the oceanographic and biological conditions that sustain this fertile Arctic food web.

Driving the research is a larger question: What will happen if climate change shifts oceanic conditions in the Arctic, as appears to be happening? Will the delicately balanced ecosystem change? Will the whales continue to come to Barrow's coastal waters?

The researchers' presence in these waters has to be carefully timed. They want to be there when conditions are right to see plankton aggregations form, but they must leave when the whales arrive, to avoid disturbing them. If weather conditions don't change, the researchers will have to wait a full year to catch the right season again. Every day here counts.

Phil Alatalo, WHOI

▲ Carin Ashjian, a biologist and fellow of the WHOI Coastal Ocean Institute, updates the Barrow community about 2005 coastal ocean fieldwork at a public lecture.

Barrow, the northernmost town in the United States, sits northwest of the Bering Strait, where water flowing north between Siberia and Alaska curls into the Arctic Ocean.

Bowhead whales have migrated past Barrow from time out of memory in a continuing rhythm. In the spring, they swim north through the Bering Strait to feed all summer in copepod-rich Arctic Ocean waters. In the fall, they reverse their track, lingering near Barrow to feed on zooplankton before heading back to less icy waters in the Bering Sea.

For centuries the Iñupiat people who live on the North Slope of Alaska have kept the same rhythms.

"The bowhead whale is very important to the native people who live along the Alaska coast," said Ashjian, a biologist and a fellow of the WHOI Coastal Ocean Institute. "Hunting the bowhead is an integral part of their culture and an important source of food for their survival."

Unlimited whaling devastated the bowhead population, but the stock recovered after commercial whaling ceased. The Iñupiat villages now hunt again, taking a limited number of whales annually, through the Alaska Eskimo Whaling Commission and with quotas set by the International Whaling Commission. Now, a new threat may come from climate change.

In our lifetime, the Arctic is changing—warming faster than any other part of the planet. Parts of the ice pack that were 20 feet (6 meters) thick now span only an arm's length. Melting permafrost is softening the tundra. Polar bears have drowned for lack of ice to stand on.

In Barrow, Ashjian sees the changes with her own eyes. In September, when there should be snow, there is rain. Roads, once frozen, are muddy tracks. Where there should be pack ice, there is open water, sometimes stranding bears in town.

"I have heard a lot from people in Barrow about how things are changing," Ashjian said. "It's bad—very bad."

"Coastal erosion is a huge problem now," she said, because shorelines that used to be protected by ice are now exposed to waves and storms.

"When people hear that we are studying climate change, they often bring us information about what they have seen. Grass now grows tall in the summer. Different fish and other animals are coming to Barrow these days, and migration times are changing."

No one knows what will happen to the patches of copepods and krill with continued warming. They could disappear.

"If climate change makes this a bad place for the bowhead whales to feed, it would be a huge change for these communities that depend on whales for subsistence," Ashjian said. "Alternatively, there could be more food for the whales. We're trying to gather enough information to be able to predict the effects of climate change."


Carin Ashjian, WHOI

▲ Steve Okkenen from the University of Alaska, Fairbanks, and Phil Alatalo from Woods Hole Oceanographic Institution deploy the Acrobat, an instrument towed by the boat to measure water temperature, salinity, and fluorescence. The research team deployed a variety of instruments to examine the oceanic conditions that bring copepods to coastal waters.

Ashjian is principal investigator of this National Science Foundation-funded project, which is part of an even larger program called SNACS (Study of the Northern Alaskan Coastal System). She is joined by more than a dozen scientists from several scientific fields, all examining the strands that weave together to create the tapestry that is the coastal ecosystem.

Ashjian's team used nets to sample plankton; instruments called CTDs to measure water temperatures, salinities, and depth; and a variety of sensors, including backscatter sensors to measure particles and fluorometers to measure amounts of plant pigment in the water. Other researchers examined the Iñupiat subsistence hunting culture and whale migration and feeding behavior.

Before this summer's trip, there was planning and coordination to be done with town officials, other research groups working in the area, and the Barrow Whaling Captains Association.

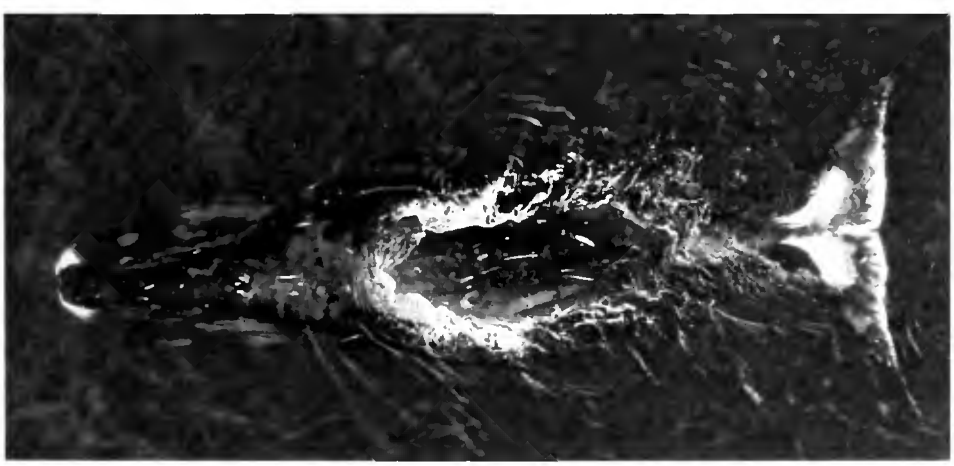
During the summer, there was rough weather. Howling wind and high seas kept the team landlocked for days, unable to gather data and fearing they would miss the aggregation of plankton. But in the end, they were able to sample on 16 days during the month and brought away a wealth of oceanographic measurements. Aerial surveys had just begun to locate the returning bowhead whales, right on schedule.

In January 2006, Ashjian was invited to speak to the Barrow Whaling Captains Association, which is considered an honor. This group conducts its meetings in Iñupiat, though all speak English. Ashjian attended while other business was conducted in Iñupiat and then presented an update on the research and answered questions in English.

"The whaling captains are very supportive and interested in knowing what might affect their whales," she said. "They voted to approve my project for another year."

So, she and her team will return to Barrow in the summer of 2006 to continue unraveling the intricacies of the remarkable Arctic coastal ocean ecosystem and working toward predicting its future.

—Kate Madin


Craig George, North Slope Borough Department of Wildlife Management

◄ Following their food, bowhead whales migrate to coastal waters off Barrow, Alaska, in the fall. Will climate change disrupt this ageless rhythm?

Photos by Tom Kleindinst, WHOI

New X-ray fluorescence core scanner reveals clues to Earth's past climate and history

Fans of the *Star Trek* science fiction series will remember the "tricorder," an all-purpose sensor that Kirk, Spock, and McCoy waved over objects, from rocks and spaceships to alien life forms, to determine what they were made of.

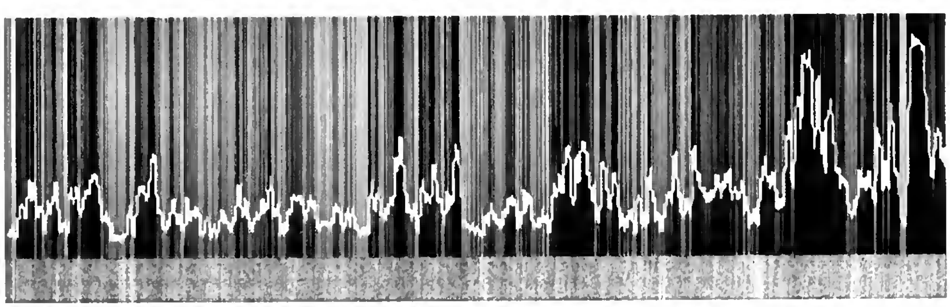
"We now have our own version of the tricorder," said Liviu Giosan, a coastal geologist who was instrumental in acquiring and setting up an X-ray fluorescence (XRF) core scanner at Woods Hole Oceanographic Institution. It is the first of its kind in the United States.

Like the tricorder (and some instruments on NASA's Mars rovers), the XRF reveals intimate details of the composition of ancient mud and rock, which can contain a variety of clues about past climate and environmental conditions on Earth. The $450,000 instrument simultaneously captures digital photographs and X-ray images of samples, while detecting measurable amounts of any of 80 chemical elements from aluminum (atomic number 13) to uranium (atomic number 92) without breaking the surface of the core. It gathers all of this information in a matter of hours.

Traditionally, scientists (or more likely, their students) spend months to years sifting through mud and sediment cores to measure carbon, trace metals, pollen, microscopic shells, and other materials that accumulate over time in marshes and dunes or on the seafloor. By analyzing the sequential layers of this preserved detritus, scientists can reconstruct past changes in ocean temperatures, rainfall, wind, and vegetation patterns. They can determine when droughts, hurricanes, or blooms of marine plankton occurred.

To study core samples, scientists must cut them down the middle and meticulously dissect them. It is a time- and labor-

▲ In a matter of hours, the new WHOI X-ray fluorescence core scanner captures digital photographs and X-ray images of a sediment core, while detecting the presence of any of 80 chemical elements—all without scratching the surface. Traditional methods of analyzing a core (inset) can take months and gradually destroy the core.



◄ Left: Liviu Giosan and colleagues extract a sediment core from a marsh to find clues to the evolution and past climate of the Danube Delta. ▲ Above: An XRF scan of a sediment core from offshore Venezuela combines a digital photograph (brown) with an X-ray image (gray and black) that reveals sedimentary layers otherwise invisible to the naked eye. The concentration of titanium (overlaid in yellow) indicates past fluctuations in atmospheric moisture and dust in the region.

► Jessica Tierney, a WHOI research assistant, aligns a sediment core for examination in the XRF scanner. Tierney previously needed three months to develop a profile of a core from Peru; with the XRF, she collected the same data—plus X-ray images—in three days.


Tom Kleindinst, WHOI

intensive process that gradually destroys unique—and not easily replaceable—cores. Sometimes cores must be shipped to other locations (in WHOI's case, a local hospital) if scientists need an X-ray view to see layers undetectable by the eye.

With the XRF scanner, researchers place a core into a motorized, computer-controlled carriage that slides the sediments past a camera and X-ray source. A charge-coupled device captures high-resolution images a millimeter at a time. Two X-ray beams are then fired into the core: One creates an X-ray image; the other stimulates the atoms in the sample, causing energy to be emitted in the form of electromagnetic radiation (fluorescent light). Each element releases radiation with a distinctive wavelength that can be detected by the XRF.

It does all this without taking a single bit of the core, meaning that other scientists can virtually dig into the same mud and pursue other chemical clues locked inside.

"We now have the ability to generate high-quality, high-resolution geochemical records very quickly," said Konrad Hughen, a WHOI geochemist who has been reconstructing ancient climate from sediments collected near Peru, Chile, and Venezuela. "The XRF is incredibly efficient and incredibly precise, and it will completely revolutionize how we do our work."

Graduate student Jon Woodruff and geologist Jeff Donnelly have already used the new tool to expand their studies of ancient hurricanes. The sensitivity of the machine allows them to see evidence of ancient storms and climate shifts that they could not detect before—and some that they would not have looked for. The speed of XRF analysis gives them the ability to examine and compare cores from many continents in the time it formerly took to analyze just one spot on the globe.

"The XRF is my favorite new toy," said Donnelly. "It has fundamentally changed the experience of studying sediments. We can ask bigger and broader questions."

The XRF also allows what may be the biggest leap forward in sediment science: the ability to quickly analyze many different environmental markers at the same time. Information about individual elements can be valuable, but scientists can learn more—and be more confident in their analyses—when they combine and compare multiple records.

For example, Hughen and others had found through previous analyses that aluminum and titanium concentrations both decreased sharply in sediments from the Cariaco Basin (off Venezuela) during a period of abrupt climate change about 11,600 years ago known as the Younger Dryas. The decreases suggested that the period was drier, with less rain causing less material to run off from land into the ocean.

But with the XRF, Hughen simultaneously measured the concentrations of each element, giving a precise ratio of one to the other. Those ratios indicated a surge of particles from African deserts blowing into the ocean off Venezuela—corroborating, but different, evidence of a drier climate during the Younger Dryas.

The arrival of the XRF in Woods Hole opens doors for the entire oceanographic community. Giosan and Donnelly are now figuring out how to share their oceanographic "tricorder" with the rest of the research world.

"Liviu took the initiative and made the case for the instrument, invested a lot of his own valuable research time, and then was open-minded enough to let others try things out," said Lex van Geen, a chemist at the Lamont-Doherty Earth Observatory and a 1990 graduate of the MIT/WHOI Joint Program. Van Geen contacted Giosan to see if the XRF could detect trace metals in sediments he extracted from the Pacific coast off Mexico as part of an effort to reconstruct past ocean temperatures and oceanic life.

"It's a credit to WHOI and the National Science Foundation for providing the support to make this possible," van Geen said. "Access to the XRF could have been much more constricted, but there is no sense of a monopoly on this instrument."

— *Mike Carlowicz*

ABE
The Autonomous Benthic Explorer

▲ Crew members recover ABE aboard R/V *Atlantis* after a dive to detect hydrothermal vents on the Galápagos Rift in 2002.

WHOI's deep-diving vehicle makes *Wired* magazine's robotic hall of fame

"Mars may belong to the rovers, but the oceans belong to the Autonomous Benthic Explorer."

With those words, *Wired* magazine enshrined Woods Hole Oceanographic Institution's deep-sea autonomous underwater vehicle (AUV) among its "50 Best Robots Ever" in January 2006 (below). The magazine's editors—alternating between tongue in cheek and feet firmly on the ground—compiled their favorite real and fictional robots. The Autonomous Benthic Explorer, nicknamed ABE, came in at No. 32. That was one below GM Unimate, a robotic arm that revolutionized the assembly line in 1961, and two below the Tin Woodman from *The Wizard of Oz*.

The list contained cinematic robotic stars such as HAL 9000 (the calmly murderous computer in *2001: A Space Odyssey*), R2-D2 of *Star Wars* fame, and the Terminator. But it also included the Mars rovers, life-saving medical devices, and military equipment such as Predator unmanned aerial vehicles and tank-treaded Packbot reconnaissance droids.

The designation tickled Al Bradley, Dana Yoerger, and Barrie Walden, who designed and built a prototype deep-submergence AUV in 1995. These were the same guys, after all, who saw their real-life robot's coincidental resemblance to the *Starship Enterprise* and playfully stenciled on ABE's flank "NCC-1701B"—the same numbers that adorned the fictional *Star Trek* spaceship.

Launched in 1995, the one-of-a-kind ABE has come of age. "It's revolutionized how we look at the seafloor," said Dan Fornari, director of WHOI's Deep-Ocean Exploration Institute.

But ABE's story had more modest beginnings. Originally, Walden, head of the group that operates WHOI's human-occupied submersible *Alvin*, noticed that scientists increasingly were requesting *Alvin* dives to return to seafloor sites to see how they had changed. He asked Bradley and Yoerger to "build something that descends to the ocean, takes a picture, docks and goes to sleep, and then wakes up and goes back to take more photos," Bradley said. The goal was to give geologists and biologists a series of photos over time, while saving *Alvin* for missions only it could do.

Bradley and Yoerger contemplated the request. "What if this device could hold its position near the seafloor?" Bradley said. "And what if we give it some thrusters so that it can move along the bottom? Why not have it go out on a line, find its homing beacon, then come back, and then go out on another line, like the spokes of wheel, so that you can survey a 50-meter circle, rather than just one place? This was an incredible step beyond the first concept. We had never built a device like that before."

Bradley and Yoerger designed a vehicle that could be programmed to steer on a preselected path, navigating by acoustic beacons placed on the seafloor. It had three torpedo-shaped compartments connected in a triangle by struts. The design gave ABE a stable center of gravity that would prevent it from rolling from side to side or pitching forward or back. The lower pod contained ABE's computer brains and batteries. The two upper pontoons contained glass balls to provide buoyancy.

They gave ABE five thrusters to propel it up and down, as well as horizontally. They programmed ABE to automatically adjust its position to maintain the same altitude above changing seafloor topography. If ABE's sonar detected a cliff ahead, it would stop, rise, and fly over the cliff, following seafloor contours and lowering itself back to the same altitude on the other side.

"If most AUVs are airplanes, ABE is a helicopter," said science writer Kristen Kusek in *Marine Scientist* magazine.

By 1995, Bradley and Yoerger had tested ABE in Woods Hole harbor and were looking for an opportunity to test it in the deep ocean. An offer came from WHOI geophysicist Maurice Tivey, who was scheduled to co-lead a cruise to the Juan de Fuca Ridge off the U.S. Pacific Northwest.

"Why don't we try out ABE?" Tivey said. "Let's get it wet."

Tivey wanted to measure the magnetic intensities of rocks on a newly erupted seafloor lava flow. He had planned to use the standard method of towing a magnetometer on a wire above the seafloor.

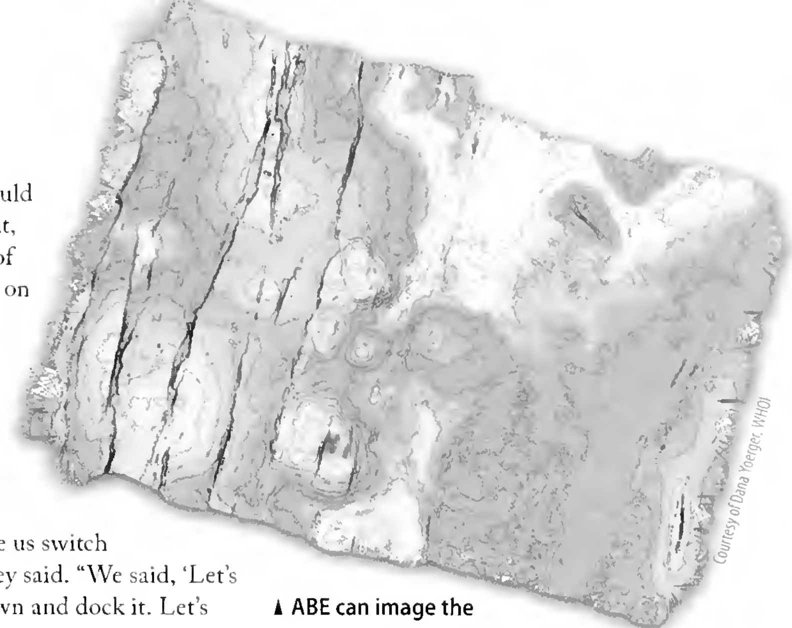
"The lava flow is a relatively small feature," Tivey said. "The ship has to make big circles around the lava flow, dragging the maggie on a wire several kilometers long. You don't have much control."

With its steady, low-flying ride and precise navigation, ABE flew straight lines back and forth over the lava flow. "It was like mowing the lawn," Tivey said. "ABE collected the data in a few lines."

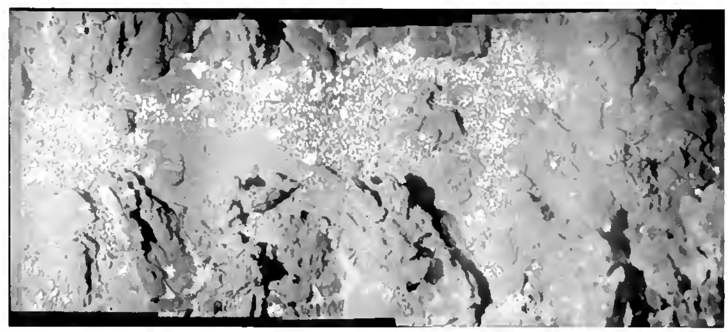
What began as an engineering test piggybacked onto a scientific cruise turned out to produce exciting new data. By superimposing ABE's magnetic measurements on ocean-bottom maps made by ABE's sonar sensors, Tivey could distinguish the extent, volume, and timing of individual lava flows on the seafloor.

"That's when I realized that ABE could be a superb deep-submergence surveying tool," Tivey said.

"That cruise made us switch our thinking," Bradley said. "We said, 'Let's not just put ABE down and dock it. Let's get that thing right back up to surface after a dive, get out the data, recharge its batteries, and send it back down as fast as we can.' That way we could get much more data and cover much more ground."



Courtesy of Dana Yoerger, WHOI



Courtesy of Dana Yoerger, WHOI

▲ ABE can image the seafloor in a variety of ways on a variety of scales. A bathymetric map from the Lau Basin off Fiji (above) covers an area of about 0.6 by 0.37 miles (1 by 0.6 kilometers), showing mounds, fissures, and hydrothermal vent spires with a resolution of about 3 feet (1 meter). A photomosaic of a smaller area from the same region (below) shows geological details and individual animals, such as clams, mussels, and snails.

ABE evolved quickly after that, as scientists began to plug different sensors into the vehicle. In 1999, on a cruise co-led by Marie-Helene Cormier and William Ryan of the Lamont-Doherty Earth Observatory, ABE "mowed the lawn" on the East Pacific Rise, using sonar to map the seafloor, a camera and strobe light to take photographs, and other instruments to measure the temperature and turbidity of seawater.

With the latter tools, scientists discovered hydrothermal vents that Ryan said they would not have found otherwise. He was also ecstatic about the quality and detail of ABE's seafloor mapping, calling the cruise "a milestone event" for the field of marine geology and geophysics.

"This new technology will unquestionably advance our science," Ryan said in an e-mail even before the ship docked. "It not only gives us a better view, but we see things that we have never been able to visualize before.

"So please tell everyone that this is not just the polite letter at cruise end that everything worked fine," Ryan continued, "but that your Deep-Submergence Laboratory and ABE group have created and now test-proven an extraordinary new tool."

The 1999 cruise launched ABE on a new career as scout and bloodhound, searching for hydrothermal vents. These active volcanic seafloor sites emit chemical-rich fluids that sustain exotic communities of life, and so they intrigue geologists, chemists, and biologists. But locating tiny, isolated vent sites along the globe-spanning mid-ocean ridge is akin to finding buttons in a pitch-black attic.

The vents, however, leave a trail. They emit hot, buoyant, particle-filled fluids that rise several hundred meters above the seafloor and spread out into large mushroom-shaped plumes. That's where ABE comes in, using its thermal, chemical, and optical sensors to "sniff" out plumes. Over 15 to 30 hours, ABE can cover a lot of territory, about 18 to 37 miles (30 to 60 kilometers).

Tom Kleindinst, WHOI

◄ **Before ABE's first deployment, ABE's inventors, Al Bradley (left) and Dana Yoerger tested the autonomous underwater vehicle in the test well at the WHOI dock in Woods Hole.**

A 2000 cruise to the East Pacific Rise tested the "A" for autonomous in ABE when its inventors cut the umbilicus. "We put ABE over the side, and R/V *Atlantis* headed 30 miles away to work at another site," Fornari said. "When we finished, we drove back to the spot where ABE was supposed to surface, and there it was, waiting like a patient pup for its master to return."

On a 2002 cruise to the Galápagos Rift, ABE showed its value working in tandem with other vehicles. Within two hours after ABE resurfaced from an all-night surveying mission, Yoerger could download data, create fresh seafloor maps of the area, and hand them to *Alvin* pilots about to descend to the seafloor.

"It was like hiking with a good topographic map," said Portland State University microbiologist Anna-Louise Reysenbach, who dived in *Alvin* on the Galápagos cruise.

On each new cruise, ABE continues to demonstrate its versatility. In 2004, in the Lau Basin off Fiji, it first flew 820 feet (250 meters) above the seafloor, into a vent plume, and homed into the vent. ("Imagine flying at night through smog over a city to find the smokestack that's producing it," Yoerger said.) On successive dives, ABE descended to 165 feet (50 meters) to make a high-resolution seafloor map. Then, it hovered a few meters above the vents, taking high-resolution photos.

In the past, researchers often needed several cruises to find plumes and then return trips to home in on vents, said Chris German, the new head of the National Deep-Submergence Facility at WHOI. Using ABE on a 2005 cruise to the South Atlantic, German said, "I came home after the cruise and could say, 'We found a new vent site, and here's exactly what it looks like.' "

ABE has come of age, and not only because of its designation in *Wired*. Having proved the value of deep-sea AUVs, the ABE Group has built a faster, more maneuverable, more economical, easier-to-operate AUV—the son of ABE. This next-generation AUV, called *Sentry* (see page 17), is scheduled for its first deep-sea baptism in the spring of 2006.

—*Lonny Lippsett*

The National Science Foundation funded the development of ABE and several ABE cruises. The National Oceanic and Atmospheric Administration also funded some ABE cruises and some additional technology development, as did the Comer Science and Education Foundation.

Name that new, one-of-a-kind, deep-submergence vehicle

A new deep-sea vehicle under construction at Woods Hole Oceanographic Institution promises to have a lot of capabilities: It will dive to the deepest ocean trenches, operate as an autonomous vehicle for wide-area ocean surveys, and transform into a tethered vehicle for close-up sampling of seafloor rocks and organisms.

What it doesn't have is a name. This spring, WHOI engineers plan to pick one from suggestions provided by students participating in the California-based Marine Advanced Technology Education (MATE) Center.

Headquartered at Monterey Peninsula College, MATE provides students in the U.S. and Canada opportunities to explore marine-related careers through internship programs and an annual remotely operated vehicle (ROV) design competition. The naming contest is open only to the 200 teams of junior high, high school, and college students involved in MATE's design competition.

The vehicle—now known as the Hybrid Remotely Operated Vehicle, or HROV—will have a depth range of 36,000 feet (11,000 meters). It should be ready for field-testing in 2007.

Jack Cook, WHOI

Contest guidelines state that the name must have a connection to WHOI or to a pioneer in underwater technology development. (For example, more than four decades ago, the deep submersible *Alvin* was named for WHOI scientist Allyn Vine.)

The name should also reflect unique technology used in the vehicle. HROV will include battery packs the size of cell phones; a hair-thin communications cable 20 miles (32 kilometers) long; and ceramic flotation instead of traditional syntactic foam.

Teams have until May 1 to submit suggestions, along with rationales for their name. The winning name will be selected by WHOI engineers and announced June 25 at an awards banquet at the NASA Johnson Space Center in Houston, Texas. The winning team will also visit the HROV at WHOI in fall 2006.

For information, visit www.marinetech.org/rov_competition.

—*Amy E. Nevala*

Funding to develop the HROV comes from the National Science Foundation, the Office of Naval Research, and the National Oceanic and Atmospheric Administration.

Courtesy of Chris German, WHOI

Chris German

Tip your hat to the new head of our deep-sea vehicles facility

For Chris German, the road to WHOI included a stop at Buckingham Palace for a medal that recognized his contributions to marine science and deep-sea technology.

"The queen wasn't there, so Prince Charles distributed the medals," said German of the 2002 honor, given to British citizens for "contributions to the United Kingdom above and beyond the normal call of duty."

In January 2006, German became the new chief scientist of the National Deep Submergence Facility. The federally funded facility, operated by WHOI, provides a small fleet of deep-sea vehicles for use by the national scientific community, ranging from the *Alvin* submersible to the remotely operated vehicle (ROV) *Jason*.

German comes to WHOI after 15 years at the National Oceanography Centre at the University of Southampton, where he spearheaded development of Britain's first ROV, *Isis*, which was built at WHOI.

German earned B.A. and Ph.D. degrees in geology and geochemistry at the University of Cambridge in England. He studies the geochemistry of superheated fluids emanating from seafloor hydrothermal vents, which sustain exotic communities of life in the sunless depths.

German's career-long search for vents has made him well acquainted with the deep-sea technology required to find and study them. He has sailed as chief scientist on American, British, German, and Icelandic ships and also participated on French, Portuguese, Japanese, and Russian research cruises.

He is currently co-chair of ChEss, an international project of the worldwide Census of Marine Life that steers research on deep-sea chemosynthetic ecosystems ("a lonely geochemist among biologists," he joked).

Reddy wins Leopold award to share research with public

Marine chemist Chris Reddy has been selected as a 2006 fellow of the Aldo Leopold Leadership Program, sponsored by the Stanford Institute for the Environment. He will join 17 researchers from various scientific fields and North American institutions in an intensive training program designed to help them communicate environmental research more effectively to non-scientists.

The program was launched in 1998 with the goal of encouraging and teaching scientists to share their observations and findings with policymakers, media, and the public. The program is named for Aldo Leopold, a renowned environmental scientist whose writings—including his 1949 book, *A Sand County Almanac*—helped focus the modern American conservation movement.

Tom Kleindinst, WHOI

Chris Reddy

Tom Kleindinst, WHOI

Bill Jenkins

Jenkins takes over as director of national mass spectrometer

Physicist Bill Jenkins, a senior scientist and 32-year veteran of the WHOI Marine Chemistry and Geochemistry Department, has been named the new director of the National Ocean Sciences Accelerator Mass Spectrometer (NOSAMS) facility. Jenkins is just the third director of the facility, established in 1989 on WHOI's Quissett campus to provide radiocarbon analysis (principally carbon-14 dating) of marine sediments and the organic and inorganic compounds that reside in the water.

Jenkins succeeds John Hayes, a WHOI senior scientist who had led the facility since 1996. In addition to managing a staff of 17 and a $3 million budget (half from the National Science Foundation, half from user fees), Jenkins will lead NOSAMS scientists in stretching and improving the capabilities of the national facility.

Trustees create committee to complete $200M campaign

A Trustee Campaign Committee has been established to lead WHOI's $200 million capital campaign to the finish line. To date, the campaign has raised $136 million.

The committee, chaired by Newt Merrill, comprises Rod Berens, Bob James, Nancy Newcomb, David Stone, and four chairmen of the Ocean Institute Trustee committees: Peter Aron (Deep Ocean Exploration Institute), Ted Dengler (Ocean and Climate Change Institute), Bill Kealy (Coastal Ocean Institute), and Reuben Richards (Ocean Life Institute). Jim Moltz, Tom Wheeler, and Carl Peterson are ex-officio members.

The campaign has already helped fund WHOI's new coastal research vessel *Tioga* and campus improvements, including two new buildings that increase the Institution's total laboratory space by 30 percent. Now the campaign is focused on completing endowments for the Ocean Institutes and for the Access to the Sea (ATS) Initiative.

The ATS endowment funds development of advanced seagoing technologies and opportunities for high-risk, high-reward seagoing research, often in remote, unexplored regions.

The Ocean Institutes, created in 2000, fund early-stage, high-potential research and collaborative research among geophysicists, biologists, chemists, physical oceanographers, and engineers—research unlikely to receive government funding.

To date, the Ocean Institutes have disbursed about $16 million in private funds to more than 150 scientists, engineers, and students at WHOI. Several Institute-funded proof-of-concept projects have leveraged substantial federal funding.

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Jian Lin

Worlds apart, but united by the oceans

As an 11-year-old boy in Fuzhou, China, Jian Lin recalls his father explaining why the dangling light in their house had begun to swing wildly: A major earthquake had hit Taiwan.

Lin came of age in an era of seismic shifts in China—both geological and political. "The mid-1970s were an unusually apprehensive period when several major earthquakes struck China, and the whole nation felt as if quakes could occur anywhere at any time," he said. He became a voluntary "earthquake watcher," keeping a diary of ground tilting and water level changes in wells and sending his readings to a local seismological center.

In 1976, an earthquake near the city of Tangshan killed more than 242,000 people and severely injured 170,000 more. "It left an imprint on me and other Chinese that is perhaps as profound and indelible as September 11 on today's generation," Lin said.

It was the deadliest quake in the 20th century, but little was heard about it in the West because China was shrouded in the Cultural Revolution, a period of anti-bourgeois social upheaval that halted China's economy and education system. By a twist of fate, Lin came to the United States to pursue a scientific career.

Now a geophysicist at Woods Hole Oceanographic Institution, he has studied mantle convection, undersea volcanism, hotspots, and earthquakes. A paper he co-authored was the most-cited earthquake research article of the 1990s. It established basic tenets for the concept that earthquakes can shift stress onto neighboring faults and increase the chances of earthquakes on them.

To study the submarine quake that sparked the devastating 2004 Indian Ocean tsunami, he sailed off Sumatra aboard China's new research vessel, *Dayang 1*, as the first U.S. scientist ever invited to co-lead a Chinese deep-ocean expedition. He spent more than 80 days at sea during a yearlong, around-the-world mission that heralds China's re-emergence in oceanography.

What do you remember about the Tangshan earthquake?

A series of small tremors began near the city of Haicheng in northeast China in the fall of 1974. On Feb. 3, 1975, they became more frequent. In the early morning of Feb. 4, the local government issued warnings, shutting down factories and urging people to remain outdoors. A magnitude-7.3 quake struck at 7:38 p.m. It destroyed more than one million buildings, but the death toll was low—1,328. The successful prediction probably saved tens of thousands of lives.

On July 28, 1976, a magnitude-7.8 quake struck Tangshan, a city 280 miles southwest of Haicheng. It released the energy equivalent of 400 Hiroshima atomic bombs. There were no foreshocks, no warning. The quake struck at the worst time, 3:42 a.m., when most people were sleeping.

Most of the bamboo harvest that year from my home province was sent to Tangshan to construct emergency shelters. I also recall vividly that my home city shipped out a huge quantity of large plastic bags to bury all the dead.

These events encouraged me to become a geophysicist—to seek to understand the fundamental physics of earthquakes and learn, for example, why foreshocks preceded the quake in Haicheng, but not in Tangshan. We must better understand the forces of nature to live peacefully with them.

So you prepared for a geophysics career even in high school?

No, I prepared to be "re-educated," to experience the life of a peasant and work in rice fields on a poor, remote farm, as my older brothers and sister did. That was required during the Cultural Revolution. I did not even know how many years I would be on the farm.

Then in 1976, Chairman Mao Zedong died, the radical Gang of Four was arrested, and the whole course of China changed suddenly. Deng Xiaoping became leader, and rumors began to circulate that universities, which had been closed for 10 years, might reopen.

Then the announcement: "Everyone can now take a national entrance exam." I was lucky. I was fresh out of high school, and I got into the first group of students after the Cultural Revolution to go to university. We studied like mad. Think about 10 years, there's no science, and then suddenly, you have the opportunity.

How did you come to America?

Just as I finished university, Deng Xiaoping said China should modernize, open the door to the outside, and send students to study abroad. Deng himself went on a youth work-study program in France when he was a teenager. Again, I was among the first group that the government said, "You can go now."

I had no idea what America was like. I also had no money. My parents were making $30 a month. Brown University opened its door to me.

Was coming to the United States a culture shock?

It was like going to another world. China was so poor. We had no telephones, no TVs, no cars, no refrigerators. At Brown, I remember a fellow Chinese student showed a refrigerator on the floor of his dorm room to another Chinese student and said, "This is a nice shoebox. You open it and can put your shoes in there."

Now I get shocked by how much China has developed since I left; how capitalistic it has become; how modern Shanghai is today. Students from China today will still experience some culture shock, but not nearly as powerfully as I did.

Did you maintain scientific contacts in China?

No. I went back occasionally to visit my parents, but I only began to give scientific talks in China in 1997. I wanted to encourage Chinese scientists to do ocean research.

People began to know me, and one day a young researcher said, "Our new research ship is being refitted. Could you come to take a look?"

I went to the shipyard in Shanghai, and I met a brilliant program manager of the China Ocean Minerals Research and Development Association. We toured refitted labs and then stopped at a room. He said, "We made a VIP room for guests—like you, for example." And three years later I was in that room.

Does *Dayang 1* signal a resurgence in Chinese oceanography?

China has recognized the importance of resources from the oceans: manganese nodules and cobalt-rich ferromanganese crusts on the seafloor; hydrothermal deposits rich in precious metals; also biological resources, genes and enzymes from life in extreme environments, which are useful for pharmaceuticals and for exciting microbiological work.

In 2005, *Dayang 1* went on an ambitious 300-day mission that circumnavigated the globe to search for all these. It coincided with the 600th anniversary of the first epic voyage of the famous Chinese admiral Zheng He.

Who was Zheng He?

Zheng He led seven expeditions between 1405 and 1433 that visited what is now Vietnam, Thailand, Indonesia, India, Sri Lanka, Mecca, the Red Sea, all the way to the east coast of Africa. There is a famous painting of a giraffe that Zheng He brought back to the Ming Dynasty court.

On each trip, he commanded fleets of as many as 300 ships with more than 27,000 people, including a nine-masted ship that was 120 meters (400 feet) long, longer than *Dayang 1*, which is 104 meters in length. The voyages promoted cultural and economic exchanges between China and many countries, but then the dynasty felt insecure and suddenly ended the expeditions. China has always had periods of being open and closed.

Do you perceive an opening again to work with the Chinese?

Chinese scientists were eager to go to places I also wanted to study. No country alone has the resources to do all the oceanographic research it wants, so we should collaborate. The biggest McDonald's is in China. If McDonald's can collaborate, why can't ocean scientists?

The cruises I co-led aboard *Dayang 1* were successes. We made many co-discoveries (see page 10).

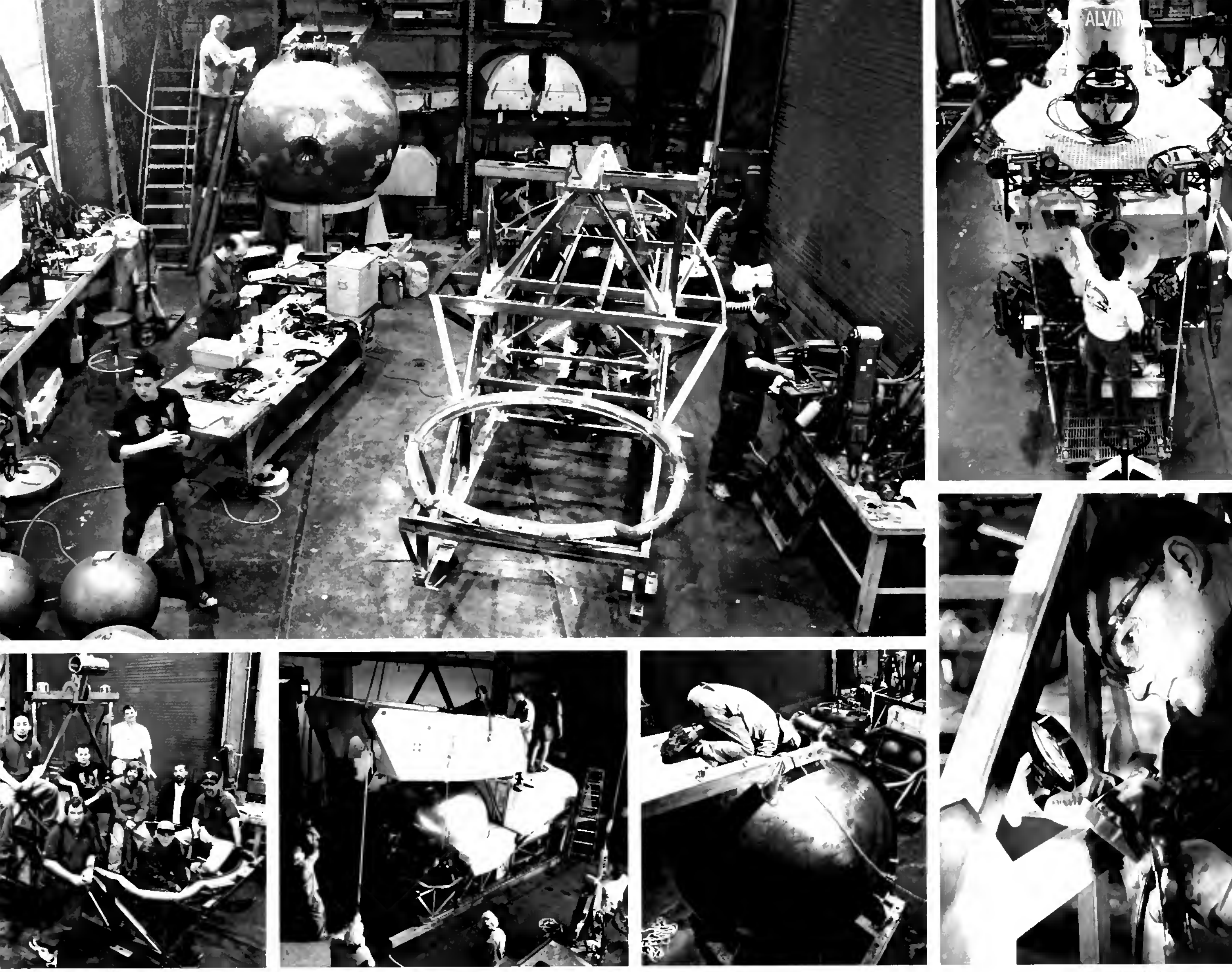
Do you think the door is about to swing wide open?

There are folks in China who will say, "We've learned all we need to; now we can do it alone." But there are also many Chinese who have been to other countries and see the great many advantages of collaboration.

Chinese society is very complex. It has old and new ideas, and a history of humiliations by Western powers. Imposing on China will backfire. Instead we must build mutual respect and trust between the U.S. and China, between ordinary folks, and between kids. In this critical transitional period when China is growing fast, we have a unique opportunity to help China become more open and be an important contributor to sciences.

—*Lonny Lippsett*

WHOI geophysicist Jian Lin became the first U.S. scientist to co-lead a Chinese deep-ocean research cruise, which retrieved a sediment core (above) from the seafloor off Sumatra, the site of the underwater earthquake that generated the 2004 Indian Ocean tsunami (see story on page 10).



It took two weeks for eight members of the *Alvin* Group to remove thousands of bolts, hoses, panels, and the submersible's 6-foot titanium sphere during its periodic overhaul this winter. Then the group put *Alvin* back together, a six-month process expected to wrap up in spring 2006. "Literally every component was taken apart and examined," said Expedition Leader Pat Hickey (standing with group, lower left). After more than four decades diving to maximum depths of 14,764 feet (4,500 meters), it was *Alvin's* last major makeover. Anticipating *Alvin's* retirement in 2009, work has begun on its replacement, which will dive to 21,320 feet (6,500 meters) and reach 99 percent of the seafloor.

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