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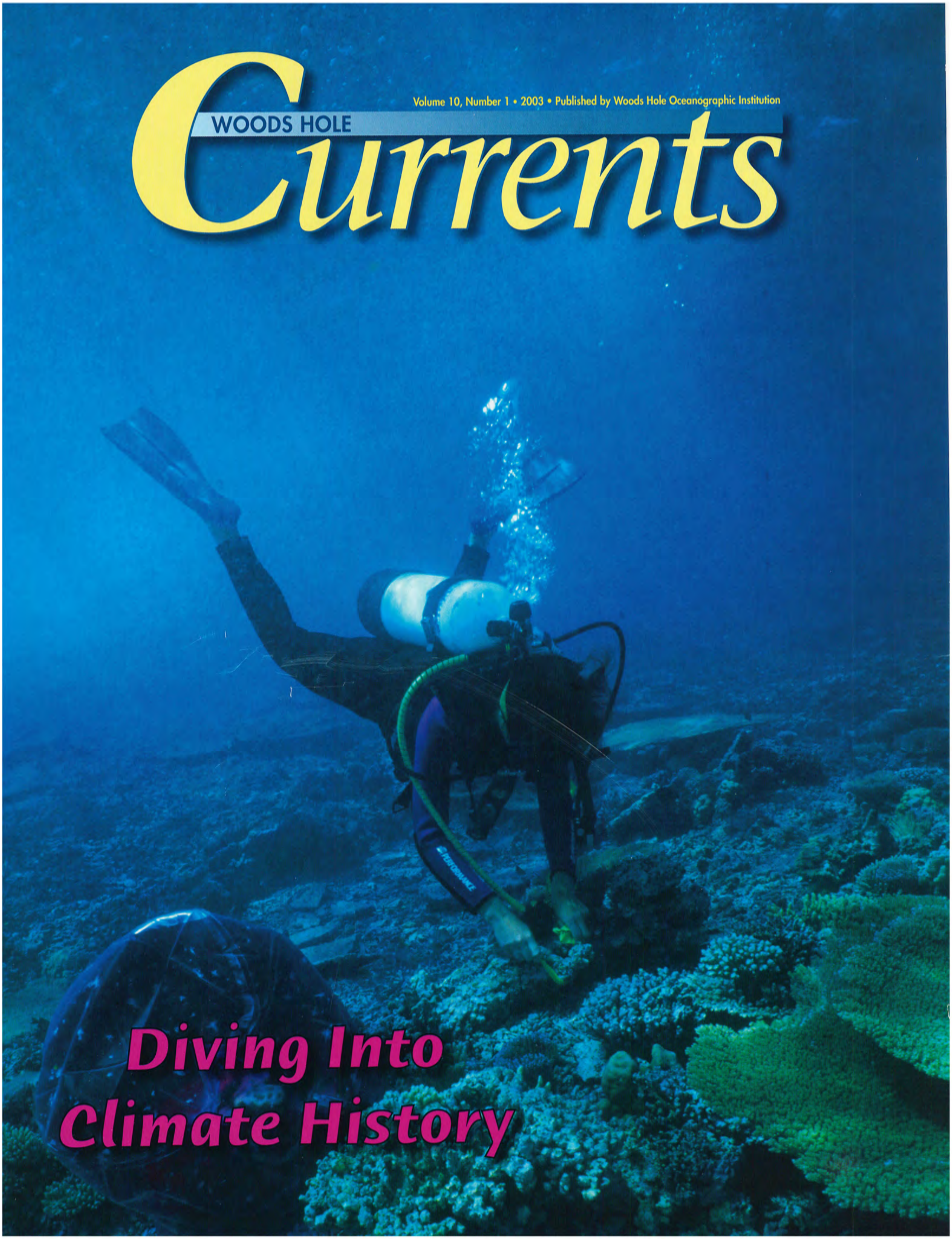

Diving Into Climate History

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WOODS HOLE *Currents*

COVER: WHOI Research Associate Anne Cohen stains a live coral on Johnston Atoll in order to determine the time of year when most growth occurs. Such data helps her interpret the climate record she reconstructs from coral skeletons. Photo by Phil Lobel.

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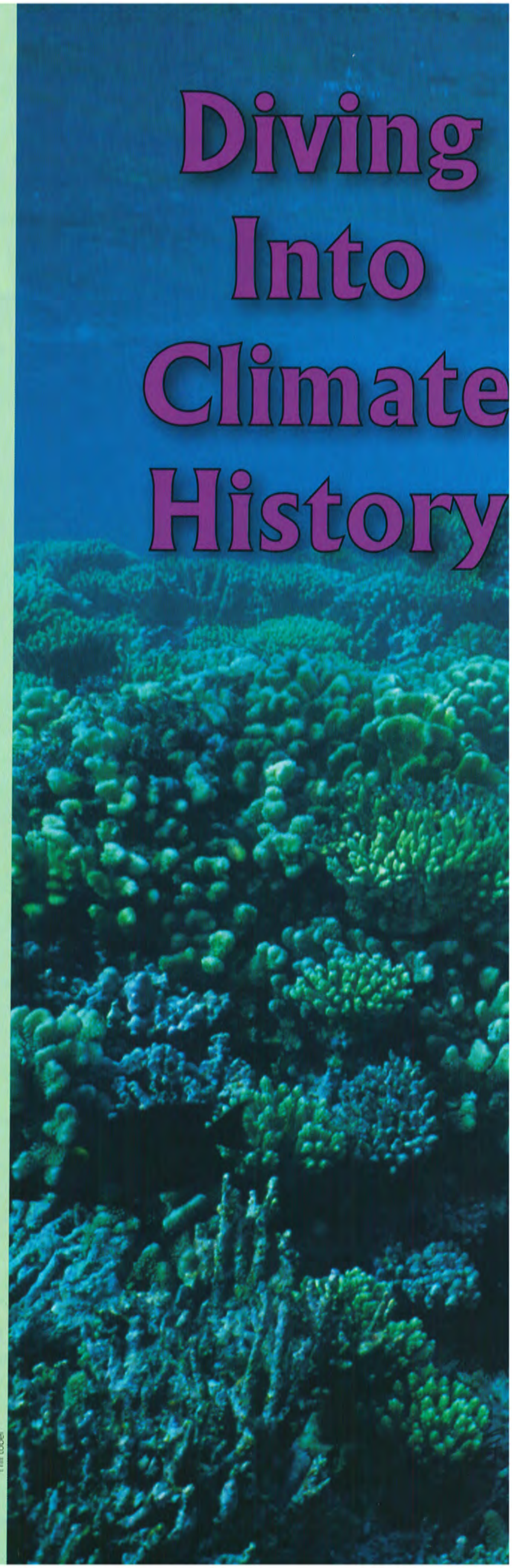


Corals Tell a Story of Past Climate

By Amy E. Nevala

Covered in pink, green, and carrot-orange polyps—and swirling with an assortment of fish just as colorful—coral reefs have a lively exterior that appeals to underwater explorers. WHOI Research Associate Anne Cohen (Geology & Geophysics) is attracted to them for a different reason. Beneath the vibrant surface of every coral lies an archive of climate history.

"Corals look like rocks," Cohen said. "They don't move and they are silent. But they are continuously growing, all the while acting as tape recorders of information we need to track variations in climate."

Those records are written in the coral's calcium carbonate skeleton, and they tell a story of centuries of intense storms and climate flip-flops. Cohen, in her quest to understand major climate events in Earth history, has collected corals from Hawaii, South Africa, Australia, Bermuda, and other far-flung locations.

After plucking coral samples from the sea, Cohen dissects them like a coroner conducting an autopsy. She slices them into cross-sections, then takes X rays and computed tomography scans. She is initially interested in the alternating light and dark bands—a zebra-striped indicator of annual growth that is invisible to the naked eye but clear on an X-ray image (see inset above). Within this banded timeline she can accurately date the coral's growth to the years of the first Moon landing, the invention of the Frisbee, and the introduction of television.

The next step is to couple the age of the coral with chemical analyses. Living coral is sensitive to small variations in ocean temperature, salinity, and light, leading to changes in the chemical composition of the coral skeleton. These signatures of a changing environment are recorded in the coral's growth bands.

Using a mass spectrometer—which determines the abundance of various elements in a sample—Cohen can measure small but telltale changes in the coral's chemistry. A dip in the ratio of strontium to calcium, for example, signals a rise in ocean water temperature. A spike in a certain isotope of oxygen can indicate the occurrence of a typhoon or hurricane. Since Cohen can calculate exactly when the bands were formed, she can determine the calendar years in which those changes took place.

Taking the Temperature of the Ocean

Records of ocean temperature date to about 1900, but the older measurements are sparse and often unreliable. (Prior to 1940, readings were taken by lowering buckets over the side of a ship or dock, and then dipping thermometers in the water-filled buckets). Measuring temperatures became more sophisticated in the 1970s, when computerized monitors were mounted on buoys and docks to record long series of temperatures for months and even years. By the early 1980s, satellites began tracking sea surface temperatures.

But as Cohen points out, these recent temperature records are too short to tell researchers

Phil Lobel

Research Associate Anne Cohen sizes up a Pavona coral on Johnston Atoll for its potential to provide a climate record.

whether the climate changes in recent decades are unusual or just natural variations. That's where corals prove valuable.

Coral reefs are built slowly by polyps, tiny animals the size of pencil erasers. Living together in vast colonies, polyps draw in calcium and bicarbonate from the ocean to build a hard skeleton that they use for support and protection. Some species continue to grow for many years, forming massive colonies. Over time these may be cemented together by algae, forming the reef structure.

"Corals are natural climate recorders," said Cohen. "They grow continuously, so there are no gaps in the record. And they grow for a long time, sometimes reaching 1,000 years old."

Corals can provide a useful, uniform tool for reconstructing the chronology of ocean and climate conditions. Take, for example, our understanding of hurricanes. Scientists do not have a sufficiently long record of weather data to accurately determine the probabilities of these catastrophic storms. But hurricanes dump large amounts of rainfall into the oceans. Hurricane rainfall has a unique isotopic composition that is recorded as a distinctive chemical spike in coral skeletons.


Anne Cohen

Brain coral skeletons are sensitive to changes in ocean conditions.

"It is like dumping ink into the ocean," Cohen noted. "The signal remains preserved for centuries or even millennia as a record of each hurricane's passage."

Using this sampling method with corals from St. Croix, Cohen found unmistakable evidence for two recent hurricanes, Hurricane Marilyn in 1995 and Hurricane George in 1998. She plans to apply this technique to older corals in order to find undocumented hurricanes from the past, filling in gaps in the weather record and improving our understanding of hurricane frequency. Cohen's work could help improve the calculations of storm risk and boost scientists' understanding of the relationship between hurricane frequency and long-term climatic cycles in the ocean.


Courtesy of Anne Cohen

Anne Cohen (left), Robbie Smith, and Graham Webster secure harnesses to a 1,500-pound brain coral (*Diploria labyrinthiformis*) as they retrieve it from a reef off Bermuda.


© Corbis

As they grow, brain corals assimilate chemical signals from the ocean that reveal changes in the global environment.

Tales of the Reconstruction

Cohen's goal is to build records of past climate variability in order to give context to the patterns we are experiencing today. Climate reconstructions based on proxies such as corals may help determine whether recent climate changes are part of a natural, recurring cycle or if they are unprecedented changes related to human activity. When viewed with this longer perspective, she said, "our perception of climate history might change completely."

Toward this end, Cohen has been examining a 276-year-old, 1,500-pound coral she removed in 2001 from a reef in Bermuda (see page 5). That brain coral may have some interesting things to say about a recurring climate phenomenon known as the North Atlantic Oscillation (NAO).

Like El Niño and La Niña—which periodically rearrange ocean conditions in the Pacific and spread their effects around the globe—the NAO is a periodic climate phenomenon

Continued on page 6

Bringing home

the big guy

with floats and a four-ton winch

She found it on a clear spring afternoon in May 2001. Just by looking, she knew that the massive coral would be perfect for her research.

For ten days, Anne Cohen and two colleagues had donned scuba gear and combed the reefs two miles southeast of Bermuda for the best specimen for reconstructing centuries of climate conditions.

"It had a nice, big, round shape, like a mushroom," said Cohen about the 1,500-pound brain coral she affectionately calls "the big guy." "I estimated that this one was a few hundred years old."

She chose the big coral not only because of its size and likely age, but also because of its condition and location. The venerable coral's days seemed numbered: its stubby stem was eroded, making a collapse imminent. And it was somewhat isolated on the reef, so the researchers could avoid interfering with other corals in the area.

But hauling the massive coral from 50 feet below the surface proved tricky. Cohen and colleagues Robbie Smith and Graham Webster from the Bermuda Biological Station for Research (BBSR) had to hire a local salvage boat with a four-ton winch to haul it in. They labored underwater to secure the coral with harnesses and a float and to score and weaken the stalk with handsaws.

After hours of cutting, the coral broke free and quickly rose to the surface, despite its staggering weight. "It must have taken about 10 seconds," Cohen recalled. "I didn't even capture it on the underwater video camera. It all happened too fast, and I was more concerned with getting out of the way."

Tom Kleindinst

Back on shore, a curious crowd gathered to peer at the rough, maze-like surface of the coral skeleton. A forklift hauled it from the salvage boat to the dock, and a truck carried it to BBSR for packing and shipment. On earlier expeditions, Cohen had her prized specimens held up by US Customs agents. But this time, the coral had a quick and safe passage to Woods Hole.

Tom Kleindinst

Anne Cohen (above) had to find help from rock-cutting experts to slice a section from this 276-year-old coral skeleton. She took her "big guy" to Fletcher Granite Company in Westford, MA, to extract a workable section (below left).

Then her research hit an unexpected wall. When Cohen tried to slice into the skeleton, "the saw just disintegrated," she said. "The coral ate the chainsaw." It took several months to locate someone who could help.

Cohen finally found a quarry that routinely cuts large slabs of marble for buildings, foundations, and statues. Like marble, coral is just another form of limestone or calcium carbonate. Still, the quarry saws had never sunk their teeth into such an unusual rock, so the workers gathered around Cohen's specimen with great interest.

They set up a commercial saw, and after an hour or so, sliced a cross-section of the coral that she could X-ray. The Bermuda brain coral turned out to have been born about seven years before George Washington, dating to 1725.

Today, as Cohen digs into that long climate history book, she is also working with colleagues from Boston University to develop ultrasound-imaging equipment to study corals underwater. In the future, she hopes to collect skeletal data from living corals without having to cut them down and haul them back to the lab.

"We hope to go right in the water with the ultrasound equipment so we don't have to bring the coral out of the water," she says. "We could look at several corals on the same dive, allowing the coral to keep growing and saving us the trouble of having to cut it up."

—Amy E. Nevala

Tom Kleindinst

Associate Scientist Hanumant Singh and Research Associate Anne Cohen examine a section of a brain coral skeleton before inserting it into a computed tomography scanner for three-dimensional imaging. Along with Singh and Boston University colleagues, Cohen is looking for novel ways to "get inside" her coral specimens.

in which the ocean and atmosphere seem to feed back upon each other.

In the "positive" phase of the NAO, a low-pressure atmospheric system lodges near Iceland and a high-pressure system hovers over the Azores. These conditions result in generally milder winters in the eastern US and northern Europe. Ocean temperatures in the northwestern and southeastern parts of the North Atlantic become cooler, but warm up around Bermuda.

Phil Lobel

Bleached coral on Johnston Atoll reveals a 1996 warming event.

In the NAO's "negative" phase, the low- and high-pressure systems move south. Winters in the eastern US and northern Europe become more severe, and storms track farther south, bringing rain to the Mediterranean. Ocean temperatures also change in the North Atlantic, causing temperatures to decrease around Bermuda.

Since the 1970s, the NAO has been "stuck" in a positive phase more intense than any on record. Because the ocean near Bermuda changes in response to NAO, Bermuda brain corals can be used as an NAO recorder. During the positive phase of NAO, when ocean temperatures at Bermuda are higher than normal, the brain corals respond by growing a denser skeleton with a telltale chemical composition. Cohen wants to know: Has the NAO done this sort of thing before, or has the climate crossed some new threshold, perhaps triggered by global warming?

The answer is crucial to predicting future climate changes, which may have wide-ranging economic and environmental ramifications. The recent positive NAO has saved fuel bills and caused fewer weather-related disruptions of transportation in the US and northern Europe. But farther south in the Mediterranean region, it has limited rainfall and hampered water supplies. Some impacts are less obvious. In the Grand Banks, for instance, colder winters are thought to hamper cod reproduction.

In testimony that Cohen delivered to the US House of Representatives in June 2002, she reported that her Bermuda coral research reveals that ocean water temperatures have fluctuated over the past 300 years, but the magnitude and persistence of the warm temperatures since 1980 are clearly an unusual phenomenon. The coral shows that sea temperatures in the 1990s off Bermuda averaged a full degree Celsius higher than in the previous 300 years.

Ironically, the rapid warming of the surface oceans in the past three decades coincides with basin-wide changes in the very reefs that record the climate signals. Higher sea surface temperatures cause corals to lose their colorful polyps—and thus their lives—in a phenomenon known as "bleaching." On some reefs, bleaching has claimed up to 90 percent of the living corals. Higher levels of industrial carbon dioxide in the atmosphere may also acidify the ocean, causing parts of the reef to dissolve and reducing corals' ability to make new skeletons.

"The instrumental record gives us a limited, 50-year perspective on ocean temperatures," said Cohen. "That's simply not long enough to say, with any degree of confidence, whether the recent warming is natural or due to a human influence on climate. It is only through a long-term perspective—such as we get from paleodata like corals—that we can say the mass coral bleaching is unprecedented in the last 1,000 years."

"To learn more about Anne Cohen's work, visit www.whoi.edu/science/GG/people/acohen/

REMUS: Between Iraq and a Hard Place

They look like torpedoes—long and sleek and sturdy. But they do not bring harm; in fact, they sometimes help prevent it.

Remote Environmental Monitoring UnitS (REMUS) are low-cost, programmable, autonomous underwater vehicles (AUVs) designed and operated by Chris von Alt, Ben Allen, and colleagues in the WHOI Oceanographic Systems Laboratory. They were conceived for monitoring coastal environments, mapping shallow seafloors, and conducting multiple-vehicle surveys. But in the past year, REMUS vehicles have been adopted for more immediate public service.

In March and April of 2003, the US Navy enlisted several REMUS vehicles to detect mines in the Persian Gulf harbor of Umm Qasr during Operation Iraqi Freedom. While a few Navy-trained dolphins starred in front-page headlines, the REMUS vehicles quietly tracked back and forth through the harbor, making detailed sonar maps of the likely locations of mines. Navy officials told the media that they preferred using the AUVs because each REMUS could do the work of 12 to 16 human divers, and they were "undeterred by cold temperatures, murky water, sharks, or hunger."

In June 2003, a custom-designed REMUS swam several hundred feet below the Catskill Mountains and Hudson River to inspect a 45-mile section of the Delaware Aqueduct. It was the culmination of a three-year journey for the REMUS team.

As the largest and most crucial link in New York City's upstate water transportation system, the Delaware Aqueduct carries as much as 900 million gallons of water daily. For a decade, the NYC Department of Environmental Protection (DEP) has been monitoring leaks in the aqueduct's Rondout-West Branch Tunnel, which have allowed 10 to 36 million gallons of water to escape each day. Yet inspectors could not simply shut off the water and walk inside for a visual inspection because the water pressure in the tunnel—about 240 pounds per square inch—might be the only thing that keeps the aqueduct from collapsing.

In 2000, the DEP issued a call for proposals to develop an untethered, unmanned vehicle that could inspect and photograph the 13.5-foot wide tunnel while the water kept flowing. The REMUS team saw it as an unprecedented challenge, and bid for the contract. They won.

Over the next three years, the team designed and extensively tested an oversized, customized version of REMUS, known as the Tunnel Inspection Vehicle. The TIV was equipped with five digital cameras angled for 360° imaging, as well as pressure sensors, hydrophones, and navigational gear.

Tom Kleindinst

Ben Allen views test images from five cameras mounted on a REMUS vehicle that was specially built for inspection of a 60-year-old water tunnel.

On June 6, 2003, the TIV completed the 15-hour survey, emerging from the aqueduct with 160,000 digital photographs and 600 gigabytes of data that fills 150 DVDs. Engineers will now analyze the TIV data to determine the nature and location of the leaks, said DEP Commissioner Christopher Ward.

Courtesy of New York City Department of Environmental Protection

Workers position a launch frame with the Tunnel Inspection Vehicle over a 1,000-foot access shaft before lowering it into the New York aqueduct system.

REMUS was invented and continues to be developed at WHOI, and is now manufactured by Hydroid Inc. of East Falmouth, MA. The Naval Sea Systems Command recently contracted with Hydroid for $30 million of REMUS technology. Several other municipalities with water issues are closely watching the results of the NY survey, with an eye toward perhaps acquiring a TIV of their own.

To learn more about REMUS and the Oceanographic Systems Laboratory, visit www.whoi.edu/science/AOPE/dept/OSL/

—Mike Carlowicz

Tom Kleindinst

Oil Spill

a Bane for Buzzards Bay, a Boon for Coastal Science

Chris Linder

Bob Nelson examines a "pancake" of oil that he collected from Buzzards Bay.

By Mike Carlowicz

If any good can come from the recent oil spill in Buzzards Bay, Assistant Scientist Chris Reddy and Research Associate Bob Nelson hope to find it. In pickup trucks and small boats, Reddy, Nelson, and colleagues have been scouring the waters, beaches, and marshes west and north of Woods Hole for samples and data that could change what we know about oil spills in coastal waters.

On April 27, a single-hulled barge carrying 4.1 million gallons of Number 6 "Bunker C" fuel oil was gashed open (likely by rocks) while being tugged through Buzzards Bay to a power plant in Sandwich, MA. Within hours, an estimated 22,000 to 55,000 gallons of viscous, tarry petroleum had spilled into the waters of one of New England's richest tourist and shell-fishing grounds.

In the days after the spill, Reddy and Nelson left their offices in the Marine Chemistry and Geochemistry Department and cruised from Cuttyhunk to Cleveland Ledge on several small boats, including WHOI's *Mytilus*. They scooped up floating "pancakes" of thick oil and filled bottles with water slicked by a thin blue sheen. In the following weeks, they were joined by Research Associate Li Xu (Geology and Geophysics), Guest Investigator Emily Peacock, Summer Student Fellow Brian Kile, and Oceanographer Emeritus George Hampson (Biology) as they surveyed beaches and marshes around the bay and collected oil-covered cobbles and sediments.

Chris Linder

Chris Reddy hunts for oil-stained cobbles on a Falmouth beach.

"This is a unique opportunity to study oil as it is weathering," said Reddy, whose team has collected more than 60 samples. "We have a chance to determine the original chemical composition of the oil and assess its potential toxicity. Over time we can observe how the oil decays as it is acted on by the environment."

In the laboratory, the researchers are using comprehensive two-dimensional gas chromatography, a novel process that separates and identifies the chemicals in a sample. Oil mixtures such as No. 6 fuel oil are complex, made up of hundreds of individual chemicals. These chemicals vary in their characteristics (volatility, solubility, etc.) and in their toxicity. A more complete knowledge of the chemical makeup will guide scientists and policymakers to a better understanding of its effects.

"Chris and his colleagues have taken a new, very sensitive, and remarkably discriminatory analytical method from chemical research and brought it to bear on the fate of oil in the environment," said John Farrington, WHOI Vice President of Academic Programs and an expert on the effects of oil spills. "They are looking in fine detail, over time, at how different environmental and biological factors affect that oil, right down to the constituent molecules. This is fundamental knowledge that we just don't have."

Reddy and colleagues are a long way from publishing their findings, but the early results show a large amount of napthalenes in the oil. Those compounds appear to be less persistent than other fractions of petroleum, but more volatile and toxic to fish and shellfish populations. On the positive side, Reddy reports that no salt marshes "appear to have been affected in a notable way." Reddy has been passing his data along to the response team headed by the National Oceanic and Atmospheric Administration.

The rapid response to the April spill hearkens back to the response by another generation of WHOI researchers who tracked a 1969 spill in Wild Harbor of West Falmouth, MA.

"Reddy's work is a next-generation leap from the ground-breaking studies by Max Blumer, Howard Sanders, and John Teal" said Farrington of the former WHOI Senior Scientists who were his mentors. "In those days, once an oil slick was gone, it was out of sight, out of mind. When the Wild Harbor spill occurred, Max, John, and Howard were able to sample it and show that even after the oil was no longer visible, it was still in the water and the mud. No one had brought the latest analytical chemistry techniques and geochemical and biological knowledge to bear on oil spills. They fundamentally changed our view of the impact of oil spills."

Reddy was already scheduled to give a talk at the Coalition for Buzzards Bay's annual State of the Bay Conference on his own studies of the 1969 Wild Harbor spill (see *Currents*, Volume 9, Number 4) when the new spill occurred. He soon found himself speaking at a community briefing on the April 2003 oil spill instead. Reddy has since been flooded with calls and email requests for information, and The Island Foundation Inc. has awarded a grant to support Summer Student Fellows to accelerate studies of the new spill.

More information about the Buzzard's Bay spill is available at www.whoi.edu/institutes/coi/currenttopics/ct_oilspills_buzzards.htm

A Few Good Men...Actually, Two

One of the world's most elite clubs just doubled its membership. On May 16, Expedition Leader Pat Hickey made his 500th dive in the Deep Submergence Vehicle *Alvin*, becoming the second pilot to make that many dives in the submersible.

Hickey completed his milestone dive during an expedition to the Lost City hydrothermal vent field along the Mid-Atlantic Ridge (see www.lostcity.washington.edu). On *Alvin* dive 3881, Hickey submerged to 890 meters depth (2,900 feet) with Chief Scientist Deborah Kelley and doctoral student Mausmi Metha, both of the University of Washington. During a break in their six hours of underwater work, the group placed a special marker on the 18-story-high "Poseidon" hydrothermal vent structure to commemorate the dive.

Deborah Kelley

A commemorative marker at the Poseidon hydrothermal vent alerts sea creatures and future explorers of Pat Hickey's noteworthy dive.

In the 39 years that *Alvin* has gone to sea, only one other pilot has made more than 500 dives. In March 1996, WHOI Research Specialist Dudley Foster became the first member of the 500-dive club. Of the 34 people who have piloted *Alvin*, Foster and Hickey have now made more than one quarter of all dives since *Alvin* was commissioned in 1964.

Hickey never thought he would stick around long enough to see this day. He came to Woods Hole for a break from a career as a pilot of submarines and remotely operated vehicles in the oil and gas industry. "I had intended to stay only five years, a sort of sabbatical before I returned to that career," Hickey said. "But the people I've met and places I've seen have extended that sabbatical indefinitely."

"Over the past 15 years I have seen some of the most spectacular submerged sights in the world," Hickey added, recalling his many pioneering visits to the Mid-Atlantic Ridge,

E. Paul Oberlander

Artist's rendering of *Alvin* Pilot Pat Hickey signaling to *Atlantis* crewmembers as they set up for another dive.

Endeavour Ridge (in the Northeast Pacific), and the East Pacific Rise. "All have left impressions with me."

Hickey has spent more time underwater—at least 150 days of cumulative dive time, seated on a padded box—than most astronauts have spent in space. So how does he feel after all that time in a six-foot-sphere?

"My back is extremely sore!"

—*Mike Carlowicz*

Jason and the Golden Fleece

The Epic Quest of Woods Hole's ROV Engineers

By Michael Carlowicz

In the early 1980s, the WHOI Deep Submergence Laboratory (DSL) launched a quest. Lab director Bob Ballard and his team set out to design a remotely operated vehicle (ROV) to give scientists and explorers a virtual presence on the seafloor, long before the word "virtual" was in vogue. They named their brainchild *Jason*, after the mythical Greek adventurer and ocean explorer.

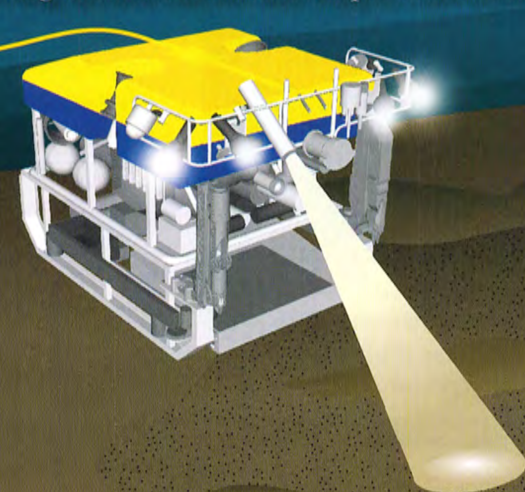
Many oceanographers were skeptical of the effort, seeing it as improbable at best, a novelty act at worst. There was no way a remotely controlled probe could be as valuable to scientists as being on the seafloor in a submersible.

"When we started, the scientific community was not convinced that this effort would be worth it," said Research Specialist Andy Bowen, a mechanical engineer who came to WHOI in 1985 after working with ROVs for the oil and gas industry. "*Jason* was a unique opportunity...a real challenge to prove that we could work in extreme water depths."

After two decades of steady improvements, WHOI's engineering Argonauts have pieced together their own golden fleece. Jason of mythology won a lady's heart, a community's admiration, and a wondrous treasure. *Jason* of oceanography garnered the acceptance of the scientific community and the ultimate prize: a chance to build a second-generation vehicle.

An ROV is a robot tethered to a support ship by a cable carrying power and transmitting data. Industrial versions of these vehicles are widely used by the offshore oil and gas industry for underwater inspections and manipulation tasks.

ROV *Jason*, on the other hand, is built for deep-ocean science. It is primarily a mobile observation platform for imaging and sonar mapping of the mid-ocean ridge and hydrothermal vent systems. The premise behind the creation of the *Jason* system was to allow ship-based pilots to remotely control the vehicle on the ocean floor while scientists looked over their shoulders, directing measurements and sample collection.



The prototype, known as *Jason Jr.*, was built for a WHOI expedition to survey RMS *Titanic* in 1986 (following the discovery of the wreck one year before). *Jason Jr.* served as the testbed for development of a novel fiber-optic tether and winch system needed for the full-scale ROV.

WHOI News Office

Jason Jr. peers into a window on *Titanic*.

The first full-scale *Jason* was built in 1987 and went to sea for the first time in 1988 accompanied by its underwater mate *Medea*, which allows the ROV to roam without being affected by the motion of the surface ship. DSL engineers conducted tests, found sunken ships, and discovered hydrothermal vents in the Mediterranean during an expedition of The JASON Project, an educational program that transmits deep-sea, rainforest, and other imagery to thousands of schoolchildren.

Mission Improbable

"When *Jason* went into the water, it was not widely acknowledged that you could do world-class science with an ROV," said Louis Whitcomb, an associate professor of mechanical engineering at The Johns Hopkins University and a WHOI visiting investigator who helped design the control systems for *Jason* and *Jason 2*. "It was considered a gimmick, and there was a 'wait and see' attitude.' Just a few courageous scientists were willing to write proposals to use an ROV."

The early years presented many technical hurdles. From 1987 to 1991, DSL engineers struggled with failures due to unreliable cables and broken connections. "We had to build our own fiber-optic telemetry system because it could not be readily purchased," said Bowen. "A lot of the systems were brand new."

Associate Scientist Dana Yoerger and DSL colleagues also had to develop an unprecedented vehicle command, control, and navigation system. They were integrating numerous cutting-edge technologies from different sectors of ocean engineering, and they had to do it in a way that would allow pilots and scientists to carry out precision tasks with a robot several miles below the surface.

Aside from the obvious engineering challenges, the *Jason* team had to prove that their vehicle was not just capable, but reliable. With funding cycles that limit most oceanographers to perhaps one major expedition every few years, researchers were wary of proposing research programs tied to such a raw and novel tool.

"If it was my million-dollar project, I would have wanted a proven vehicle, too" said WHOI Senior Engineering Assistant Will Sellers, a former pilot of Deep Submergence Vehicle *Alvin* and now the chief *Jason* pilot. "I would have wanted *Alvin*."

"There is nothing quite like seeing with your own eyes, to get that three-dimensional sense of where you are," added Paul Tyler, a professor of ocean and earth sciences at the Southampton Oceanography Centre in the United Kingdom, who has explored the depths in *Alvin* and with ROVs.

From the first launch in 1988 through early 1993, *Jason* made just seven oceanographic cruises, only one with a full science mission. "Scientists do not like double jeopardy," said Ballard, now WHOI Scientist Emeritus, head of the Institute for

Dan Fornari

Project Leader Andy Bowen (right) handles the fiber-optic cable for a *Jason 2* launch from *Atlantis* during engineering trials in July 2002.

Exploration in Mystic, CT, and a professor of oceanography at the University of Rhode Island. "They will take intellectual risks, but most are not willing to take technical risks at the same time. That is a natural reaction to technology development. So it took a few pioneers to take some risks with *Jason*."

By the mid-1990s, those brave few scientists started reporting *Jason* data at American Geophysical Union meetings and other science gatherings. "They were coming back from expeditions with quality bathymetric maps," Whitcomb recalled. "They were talking about how they could take more sensors and equipment to the bottom, how they could consistently take quantitative measurements and gather scientific samples."

In 1996, WHOI Senior Scientists Susan Humphris and Dan Fornari (both from Geology & Geophysics) led the first National Science Foundation-funded expedition with ROV *Jason* to the Lucky Strike Seamount on the Mid-Atlantic Ridge. The broader scientific community was catching on to the idea that there were some things *Jason* was especially well equipped to do. Without the endurance limitations of crew and batteries, tethered ROVs could work uninterrupted for extended time periods, making precision bathymetric and photographic surveys—missions that can take days, not hours.

Bob Ballard

Jason was fully loaded with deep-sea sensors for its first full science mission in 1991, an investigation of hydrothermal vents on the Juan de Fuca Ridge.

One Porthole, Hundreds of Viewers

Perhaps the most intriguing new capability of ROV *Jason* was that it allowed multiple scientists—both at sea and ashore—to view the same seascapes and data simultaneously.

"On any expedition, you don't know what you are going to discover, but you do know that you are probably not going to have the right expert onboard," said Ballard. "Telepresence is how we get them there."

The *Jason* team can use a combination of marine satellite communications systems to beam imagery and data from the high seas to colleagues ashore. The era of oceanographic "telepresence" was launched in 1993 when, during a Ballard-led expedition to the hydrothermal vents of Guaymas Basin in the Sea of Cortez, scientists on land were connected in real time to an ongoing expedition at sea. After

© Quest Group

Jason inspects a Roman shipwreck in the Mediterranean.

mapping and surveying an active vent area—then sharing maps and imagery with colleagues via satellite—*Jason*'s floating science team made measurements and took samples in collaboration with scientists in shore-based laboratories.

In its current incarnation, telepresence via ROV includes two pieces: a "virtual" control van and a connection via SeaNet, a satellite-based web server that allows high-bandwidth connections between ships at sea and the Internet. The virtual control van is a computer system that automatically captures information—images from four video cameras, vehicle telemetry, and scientific instrument data—in the ship-based control van and integrates it into a computer display that mirrors what the shipboard team sees.

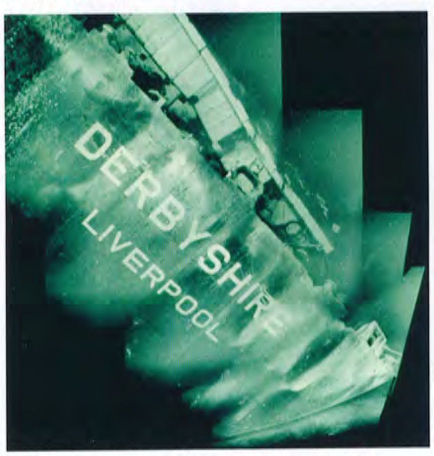
Moonlighting in Archaeology, Forensics, and Recovery

Aside from its role as a submersible science platform, ROV *Jason* has found a niche in underwater archaeology and forensics. In fact, the first non-test dives for the vehicle in May 1989 were made during a JASON

Project expedition to the final resting place of a fourth-century Roman trading ship in the Tyrrhenian Sea. The next summer, Ballard and colleagues explored the wrecks of two American warships, *Hamilton* and *Scourge*, lost in Lake Ontario during the War of 1812. "Our waters are filled with history," said Ballard. "They are the biggest museums on the planet."

Jason also has been called to participate in forensic investigations. The most important opportunity came in 1997 when the British government and the European Union asked the United States to investigate the wreck of *Derbyshire*, a 964-foot bulk ore carrier that went down about 400 miles from Okinawa during Typhoon Orchid in 1980. Forty-four people died when the ship sank in just three minutes.

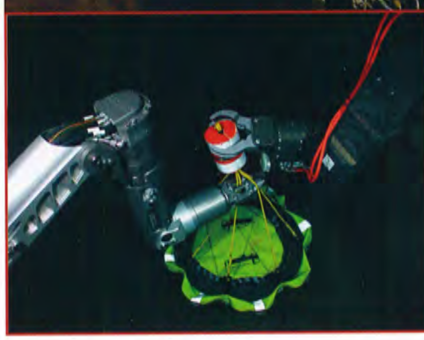
Using the ROV with WHOI's *Argo II* towed imaging system and the *DSL 120* sidescan sonar, the *Jason* team spent 52 days at sea surveying and photographing the wreckage beneath 2.6 miles of Pacific waters. The data from that search allowed British maritime investigators to determine that *Derbyshire* sank because protective hatch covers near the bow failed during the typhoon, allowing catastrophic amounts of water to flood the cargo areas.



© Crown 1998

Images collected by *Jason* in 1997 helped researchers decipher clues about what sank *Derbyshire* in 1980.

Tom Kleindinst



H. Paul Johnson

Chief Pilot Will Sellers (in white shirt) and colleagues control ROV *Jason 2* from a shipboard control van. Precise command and navigation systems allow pilots to grab samples and place instruments on the seafloor with the ROV's two manipulator arms (left).

The performance of *Jason* and the expertise of its operators contributed to Britain's recent decision to acquire its own WHOI-built ROV. In February 2003, Bowen and his DSL colleagues delivered *Isis* to the Southampton Oceanography Centre, giving the UK its first ROV dedicated to deep-ocean research. "*Isis* will launch the UK's marine science community into the forefront of deep-sea research," said Tyler, who oversaw the development of *Isis* as it was built in tandem with ROV *Jason 2*.

On its maiden voyage, ROV *Isis* returned the favor to WHOI for the *Derbyshire* investigation. During the training and testing expedition aboard *Atlantis* in the equatorial Atlantic, the next-generation ROV recovered six moorings from two experiments led by WHOI Senior Scientist Mike McCartney (Physical Oceanography). The moorings had been stuck underwater due to failed acoustic release systems, so *Isis* pilots, together with the *Jason* pilots who trained them, used the ROV to attach specially designed, acoustically triggered wire cutters. In three cases, the pilots used hydraulic cutters mounted on the ROV's manipulator arms to directly snip the mooring cables.

This ability to perform such delicate operations makes *Jason* and other ROVs crucial to another development: seafloor-based observatories. The first prototype observatory became a reality in 1998 when WHOI Senior Scientist Alan Chave (Applied Ocean Physics & Engineering) enlisted *Jason* to install, service, and maintain the Hawaii-2 Observatory, the first permanent American deep-water observatory. This summer, *Jason 2* returns to the scene to install new instruments in the H2O system.

Reluctant Users Become Eager Converts

In the summer of 2002, Bowen and colleagues rolled out the second-gen-

Bob Elder

Isis, the ROV clone of *Jason 2,* is launched into the Atlantic Ocean for testing in March 2003. *Isis* was purchased by the British government for science operations by the Southampton Oceanography Centre.

eration *Jason*, thanks to $3.5 million from the National Science Foundation, the Office of Naval Research, The W.M. Keck Foundation, and WHOI. The engineers and technicians who had nurtured the first *Jason* had earned the chance to put their years of experience into a more capable vehicle [see page 15].

On the first science mission for *Jason 2*, researchers took the ROV to the Endeavour hydrothermal vent field in the northeast Pacific to study microbial populations in the ocean crust. They lowered the vehicle into the water 11 times for a total of 323 hours without a single dive-ending failure. The complex mission included driving three-meter titanium spikes into the tops of seamounts and then extracting gallons of hydrothermal fluid.

"I had some serious misgivings about being the first scientific user of a brand new ROV," said Paul Johnson, a professor of marine geology and geophysics at the University of Washington and the chief scientist on the expedition. "Our program was complex, and would have been a severe test of even a mature and well-tested ROV. Vehicles of this complexity normally require a year or two of shakedown before they can be considered reliable, and I had little enthusiasm for being first. But *Jason 2* performed fantastically, right out of the box. There may have been, somewhere at some time, a more productive cruise. But in my view, it doesn't get any better than this."

"It was a validation of all of our work," Bowen recalled. "After a few days on that cruise, I was actually able to go to sleep and think 'I am not going to get a call to fix a problem.' I could wake up hours later and see smiling faces."

In fifteen years, *Jason* has progressed from engineer's dream to scientific star. Scientists no longer quibble over whether they should use *Jason 2*; they fight for time on it. The testament is that the new vehicle is already scheduled well into 2004.

"It's rewarding to see the enthusiasm of the scientists working with the vehicle," Bowen said. "We have an opportunity to work with people who are similarly motivated, and our work leads to real discoveries. This is our reward."

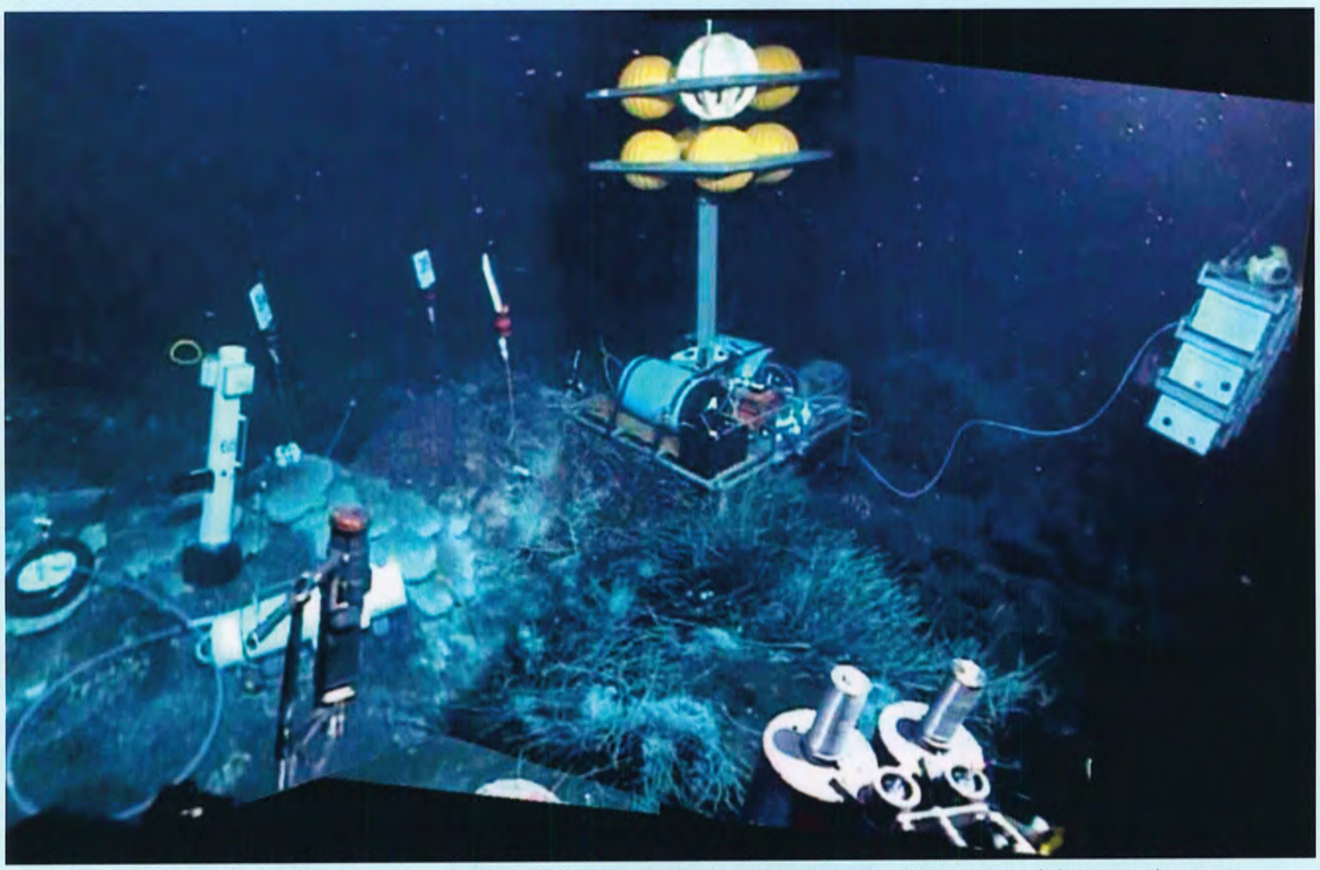
Dan Fornari

The *Jason 2* team with their brainchild: (from left) Barrie Walden, Chris Taylor, Dana Yoerger, Matt Heintz (with sunglasses), Louis Whitcomb, Jim Varnum, Andy Bowen, Bob Elder, Peter Collins, Katy Croft, Dolly Dieter, Jon Howland, Tom Crook (with black dog shirt), Will Sellers (with sunglasses and hat), Matt Naiman, Steve Lerner Chris Roman, and P.J. Bernard.

Going Deep with *Jason 2*

- *Jason 2* can work at 6,500 meters depth (21,320 feet), allowing access to 98 percent of the ocean floor. The first *Jason* could work as deep as 6,000 meters.
- *Jason 2* has two dexterous and complementary manipulator arms (compared with one on the original vehicle), which together can lift 150 pounds. "The two robotic arms are so adept," said Paul Johnson, "I think they could tie a shoelace."
- The control system, designed by Louis Whitcomb and Dana Yoerger, allows pilots to control the vehicle's position with great precision, like an airplane flying on autopilot. "The pilots are no longer stick-and-rudder guys," said Andy Bowen. "They are now masters of the control systems, reacting to data coming in."
- *Jason 2* navigates with a state-of-the-art, north-seeking gyroscopic compass, which finds true north by sensing gravity and the rotation of the earth. Pilots can figure the position of the vehicle globally, not just relative to buoys that might drift, dramatically improving the accuracy of bathymetric surveys. The new system is an order of magnitude more precise than its predecessor.
- So what is it like to fly ROV *Jason 2*? "It's a bit like playing a video game," said Will Sellers. "But it also can be intimidating because you have information coming at you from a dozen screens. You need a situational awareness and the ability to steer by visual clues. If there is a black smoker belching superheated water behind you, you'd better know it's there."

Learn more about Jason 2 *in* Currents *Volume 9, Number 4, and at www.whoi.edu/marine/ndsf/vehicles/jason/*



Jon Howland and H. Paul Johnson

A photomosaic from the first science cruise of *Jason 2* illustrates the vehicle's broad sampling capabilities. At the Main Endeavour Field of Juan de Fuca Ridge, scientists used the ROV to deploy: the "barrel sampler" (with yellow floats), capable of taking 100 liters of hydrothermal fluid per sample; the LANG fluid sampler, the white boxlike elevator (right) which will collect samples for a year; the one-meter-tall MAVS current meter (vertical white tube on left); and a flow meter/temperature monitor (horizontal white tube on left) with a black rubber ring that presses the collector into the uneven seafloor.

Dave Gray

Honjo Honored by Japanese Emperor

Senior Scientist **Susumu Honjo** (Geology & Geophysics) was awarded one of Japan's highest honors by Emperor Akihito in ceremonies at the Imperial Palace in Tokyo on May 12. The Imperial Order of the Rising Sun was bestowed upon Honjo for his research on the transfer of carbon dioxide from the atmosphere to the ocean's interior, and for his efforts to strengthen Japan's role in the international ocean science community. He is the first oceanographer to be presented with this honor.

"Dr. Honjo has been closely associated with Japanese ocean science as a reliable adviser, an enthusiastic participant, and a strong leader," the award citation said. "His activity clearly has strengthened Japan's presence internationally in the field of ocean science. He has been not only a highly significant global leader in a new and critical field of ocean science, but has made clear and strong contributions to Japanese oceanography."

In April 2000, the Japan Marine Science and Technology Center (JAMSTEC) invited Honjo to become its part-time executive director. In that role, Honjo has helped establish a new ocean research institution, the Mutsu Institute for Oceanography.

Laurels for WHOI Scientists

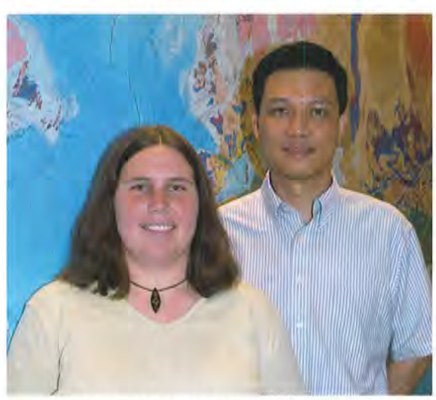
Senior Scientist **Stan Hart** (Geology and Geophysics) was designated an honorary fellow of the European Union of Geosciences (EUG) in April. The EUG chooses up to six honorary fellows every two years in recognition of achievements in earth and planetary sciences.

The EUG citation praised Hart "for his landmark contributions to isotope geochemistry, in particular to the study of the Earth's mantle...and for pioneering of many applications of ion probe techniques to trace element geochemistry."

Dave Gray

Stan Hart

Emily Van Ark, an MIT/WHOI Joint Program student in marine geophysics, received an Outstanding Student Paper Award from the American Geophysical Union (AGU). Van Ark and her advisor, Associate Scientist **Jian Lin** (Geology and Geophysics), were recognized by peers for an outstanding presentation at the 2002 AGU Fall Meeting regarding their work on hotspot flux changes in the Emperor Seamount-Hawaii volcano chain.



Jayne Doucette

Emily Van Ark and Jian Lin

Tom Kleindinst

Simon Thorrold

Associate Scientist **Simon Thorrold** (Biology) was selected by the National Science Foundation as a CAREER Young Investigator for 2002. One of the most prestigious NSF faculty awards, the CAREER program "recognizes and supports the early career-development activities of teacher-scholars who are most likely to become the academic leaders of the 21st century." Awardees are selected on the basis of career-development plans that "effectively integrate research and education" and "build a firm foundation for a lifetime of integrated contributions to research and education."

Thorrold will receive $686,000 over five years to lead a program of interdisciplinary research and educational activities on the ecological links between estuaries and the coastal ocean. Specifically, Thorrold plans to expand the development and application of a marking approach that uses variations in the geochemistry of the ear bones (otoliths) of fish as a natural signature for where the fish were hatched. The educational component of the research will include development of courses in fisheries ecology and oceanography, the development and implementation of teacher training workshops for high school teachers, and the mentoring of undergraduates on summer student fellowships.

WHOI researchers collected two of the 26 Young Investigator awards granted in 2003 by the US Office of Naval Research. The objective of the Young Investigator Program is "to attract to naval research outstanding new faculty members at institutions of higher education, to support their research, and to encourage their teaching and research careers." ONR received more than 200 proposals for the 2003 awards.

Tom Kleindinst

Chris Reddy

Awardee **Chris Reddy**, an assistant scientist in the Marine Chemistry and Geochemistry Department, proposed the use of a novel chemical technique known as two-dimensional gas chromatography to investigate how petroleum hydrocarbons buried in sediments (such as oil from spills) are altered and degraded by microbes in laboratory and field samples (see page 8).

Tom Kleindinst

Steve Jayne

Awardee **Steve Jayne**, an assistant scientist in the Physical Oceanography Department, is studying ways to characterize ocean circulation in an effort to improve operational ocean forecasts and models.

Mercedes Pascual, a 1995 graduate of the MIT/WHOI Joint Program, was named one of "The Most Important Women in Science" in the November 2002 issue of *Discover* magazine. Pascual worked with Senior Scientist Hal Caswell during her time at WHOI and is now an assistant professor of ecology and evolutionary biology at the Center for the Study of Complex Systems at the University of Michigan. She was cited for her work on complex ecological systems, especially for finding evidence that El Niño influences cholera outbreaks. It is the first quantitative evidence for an effect of global climate change on an infectious disease.

Comments on *Currents*?
Send corrections, questions, and ideas to Mike Carlowicz, editor, at mcarlowicz@whoi.edu or 508-289-3771

Red Tides Breed Red Ink

Testimony to the US House of Representatives, March 2003:

"Harmful Algal Blooms (HABs), also known as 'red tides,' are a serious and growing problem in the US. They represent a highly visible indicator of the health of our coastal ocean...HABs impact public health, fisheries, aquaculture, tourism, and coastal aesthetics...Virtually every coastal state is now threatened by harmful or toxic algal species, whereas 30 years ago, the problem was much more scattered and sporadic. The number of toxic blooms, the economic losses from them, the types of resources affected, and the number of toxins and toxic species have all increased dramatically...impacts in the United States can reach $50 million per year...Since increased pollution and nutrient loading may enhance the growth of some species, these events may be prevented by reducing pollution inputs to coastal waters...HAB problems facing the US are diverse, so this argues against funding that ebbs and floods with the sporadic pattern of HAB outbreaks or that focuses resources in one region while others go begging...We need a scientifically based allocation of resources, not one based on political jurisdictions."

Photo-Op

Don Anderson (second from right) testifies before the US House of Representatives.

—WHOI Senior Scientist Donald Anderson (Biology) speaking to the Committee on Science, Subcommittee on Environment, Technology, and Standards. Anderson is director of the National Office for Marine Biotoxins and Harmful Algal Blooms. To learn more, visit www.whoi.edu/redtide

Immersing Teachers in Ocean Science

Tom Kleindinst

Larry Madin displays a ctenophore—a "comb jelly"—to interested teachers during a workshop at the WHOI Exhibit Center.

How fish swim, the lifecycles of jellyfish, and life aboard a ship in the Arctic Ocean were among the subjects studied by 32 teachers at a Topics in Oceanography workshop at the WHOI Exhibit Center in May.

The two-year-old program gives Massachusetts teachers the opportunity to learn about cutting-edge research directly from scientists doing the work. The group is kept small in order to provide as much individual attention as possible, and each talk is followed by a discussion and demonstration on how the concepts can be taught in the classroom.

Erik Anderson, a WHOI/MIT Joint Program student (Applied Ocean Physics and Engineering), spoke about his investigations of the forces of drag on fish and squid that he conducts in the flume at the WHOI Coastal Research Laboratory. A former science teacher, Erik discussed ways to introduce the study of fluids and fluid dynamics to middle- and high-school students. He demonstrated a classroom activity that he had developed himself, using soap bubbles to visualize boundary layers in a fluid.

Senior Scientist **Larry Madin** (Biology) spoke about "The Lives of the Jellies: Aliens of Inner Space." He explained the life histories, adaptations, and impacts of jellyfish and other gelatinous marine animals from local waters and the deep sea. Larry also discussed the possible role these fragile, transparent, and little-known animals may play in transporting material from the surface of the ocean to the depths. On a tour of Larry's lab, participants observed feeding in a hydroid and learned about hydroid predation on larval cod and the cod's food sources on the historic feeding grounds of Georges Bank.

Research Associate **Chris Linder** (Physical Oceanography) recounted his experiences as researcher and writer-photographer on a summer 2002 cruise to the western Arctic Ocean. Chris presented the educators with an opportunity for classroom involvement via the "Edge of the Arctic Shelf" Web site (www.whoi.edu/arcticedge).

The workshop was the fifth in a continuing series sponsored by the WHOI Sea Grant, Information, and Academic Programs offices, and the Ducommun & Gross Foundation.

Diving and Discovering the New England Seamounts

Museum of Science

Senior Scientist **Dan Fornari** (Geology and Geophysics) discussed the thrills and challenges of exploring the seafloor with visitors to the Museum of Science in Boston. Fornari (at right in photo) visited the museum as part of a five-day program held in conjunction with Dive and Discover Expedition Seven. Each morning from May 27 to 31, visitors to the museum's Current Science & Technology Center were treated to stories of ocean exploration, as scientists aboard R/V *Atlantis* and in DSV *Alvin* called in to share news of their dives to a chain of extinct, undersea volcanoes about 500 miles off the east coast of North America. Nearly 300 people participated in the program, viewing video and images from the seamounts and questioning the research team. They also examined corals, a model of *Alvin*, and one of the sub's retired manipulator arms. Information on the expedition can be found at www.divediscover.whoi.edu.

New Endowment Supports Innovative Seagoing Research

The Rinehart Initiative for Access to the Sea

In May, WHOI announced the first awards in a new program designed to support technology development and opportunity-driven research. Several "Access to the Sea" grants each year will support innovative and independent exploration of the oceans and nurture a new generation of seagoing scientists and engineers.

Longtime friend of the Institution and Honorary Trustee Gratia "Topsy" Rinehart Montgomery provided the funding to launch the "Rinehart Initiative for Access to the Sea" by committing $5 million. "Going to sea is critical to making the observations necessary to advance our understanding of the oceans," Topsy said. "Our scientists, engineers, and students need that access."

The objective of Access to the Sea is to move oceanography from an expeditionary mode of one ship at one time to an approach that blends several ships, fixed and mobile observatories, long- and short-term campaigns, autonomous vehicles, and satellites. Another ambition is to facilitate rapid-response research, such as launching cruises in the wake of natural events (storms, tsunamis, seafloor eruptions) or adding complementary specialists and instruments to strategically located expeditions.

"A large number of pioneering ideas and instruments never reach the water, so this program will help translate some of those ideas into reality," said WHOI President and Director Bob Gagosian. "Topsy is a visionary whose love of the oceans and generous support of the Institution are allowing us to be creative and take more risks on promising projects."

Private funding provides scientists and engineers with more flexibility to conduct proof-of-concept tests of new observing systems and instruments, to consider riskier field expeditions with potentially greater payoffs, to instigate interdisciplinary and international research expeditions, and to carry out extended analysis and interpretation of seagoing data sets. The endowment will also provide crucial funding for younger scientists, technical staff, and students to participate in seagoing operations.

Tom Kleindinst

2003 Access to the Sea Awardees (clockwise from top left): Jeff Seewald, Andone Lavery, Carin Ashjian, Peter Wiebe, and Amy Bower.

"This endowment program has provided us with the opportunity to address a novel and challenging research topic," said Andone Lavery, an Assistant Scientist in Applied Ocean Physics and Engineering and one of the first awardees. "The experiments that we will conduct this fall will enable us to gather preliminary data essential to the development of a competitive proposal for government funding."

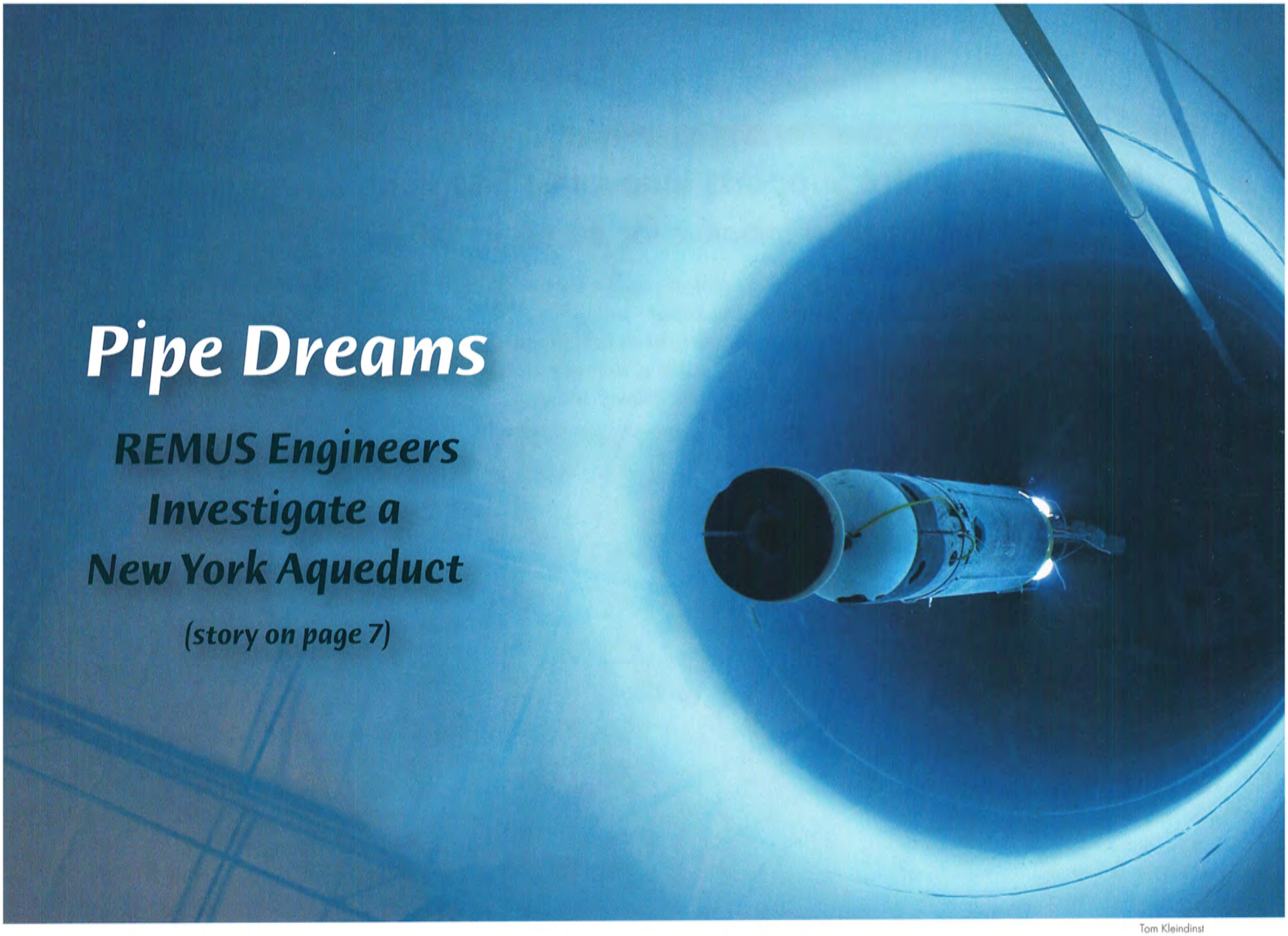
The first awards from the Rinehart Initiative for Access to the Sea will support diverse efforts:

Associate Scientist **Carin Ashjian** (Biology) will study the exchange of plankton and particles between the continental shelf and the Arctic Ocean basin near Alaska, with attention to how biological and physical processes influence the exchange.

Associate Scientist **Amy Bower** (Physical Oceanography) will trace deep-water currents that carry cold, dense water south past the Grand Banks and away from the high latitudes of the North Atlantic—an element of global ocean circulation thought to be critical in understanding climate change.

Assistant Scientist **Andone Lavery** (Applied Ocean Physics and Engineering) and Senior Scientist **Peter Wiebe** (Biology) will examine scattering of high-frequency sound waves by both plankton and small-scale physical properties (microstructure) of the ocean, as they work toward a better understanding of the distribution and characteristics of both phenomena.

Associate Scientist **Jeff Seewald** (Marine Chemistry and Geochemistry) will test methods for sampling and analyzing fluid from mid-ocean ridge hydrothermal systems. A long-term goal is to characterize organic compounds that may represent precursors to life in this extreme environment.



(story on page 7)

Tom Kleindinst

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