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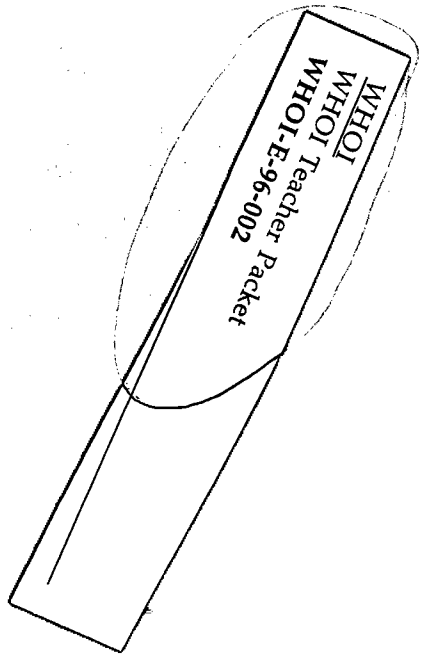

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"The oceans are continuing frontiers of exciting discoveries that offer excellent examples of teaching the principles of science and engineering."

– John W. Farrington, Ph.D.
Associate Director for Education and Dean of Graduate Studies, Senior Scientist, WHOI

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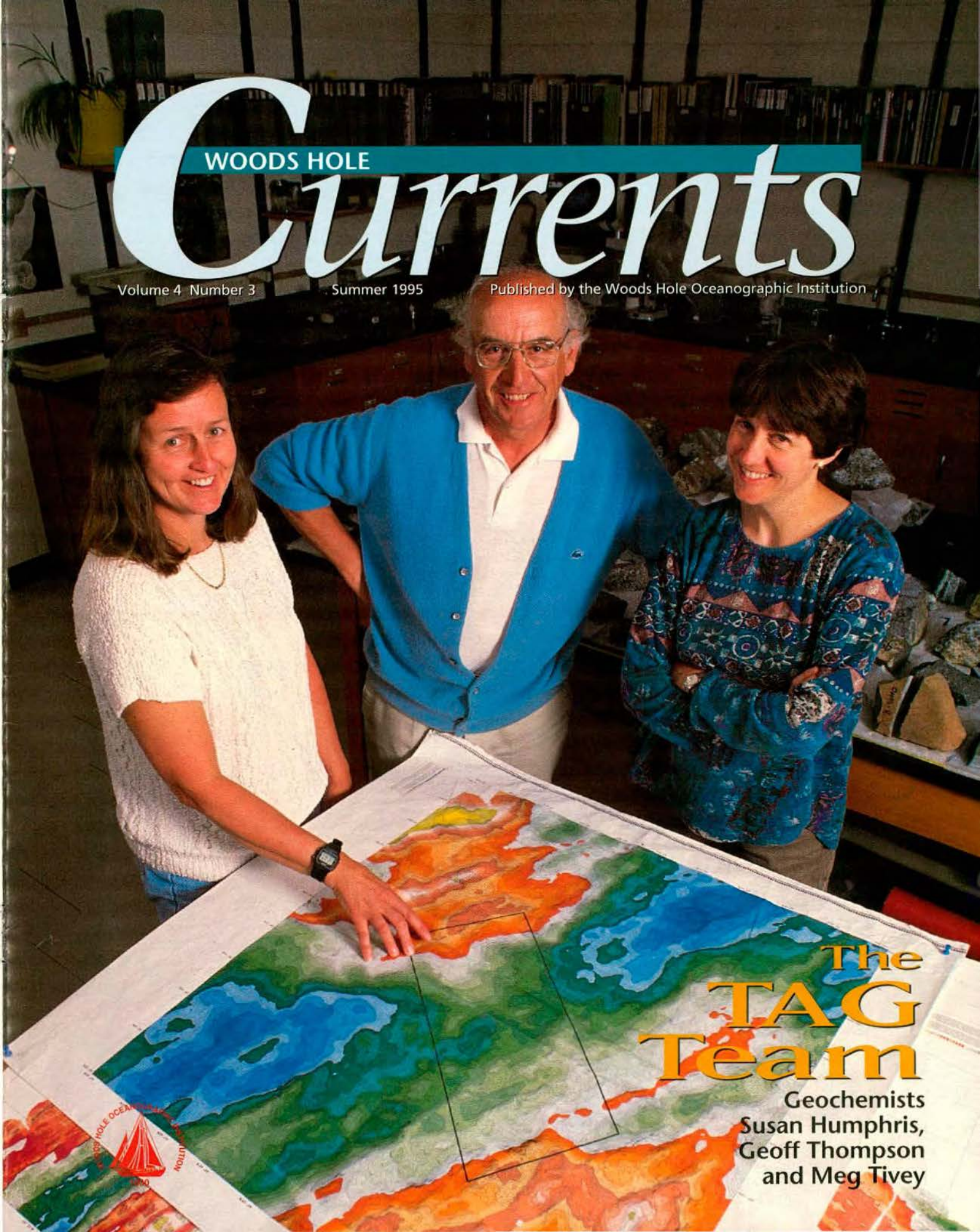
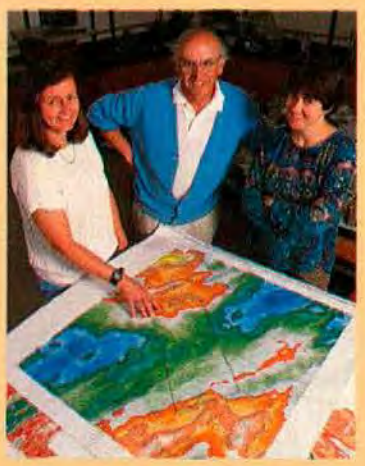


WOODS HOLE Currents

Volume 4 Number 3 Summer 1995 Published by the Woods Hole Oceanographic Institution

The TAG Team

Geochemists Susan Humphris, Geoff Thompson and Meg Tivey



ON THE COVER

This issue of *Currents* focuses on three WHOI geochemists—Susan Humphris, Geoff Thompson, and Meg Tivey—and their pioneering work at an important hydrothermal vent site on the Mid-Atlantic Ridge. They are pictured here with a bathymetric map of the vent site.
Photograph by Tom Kleindinst.

Published by the Woods Hole Oceanographic Institution

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Printed on recycled paper

WOODS HOLE Currents

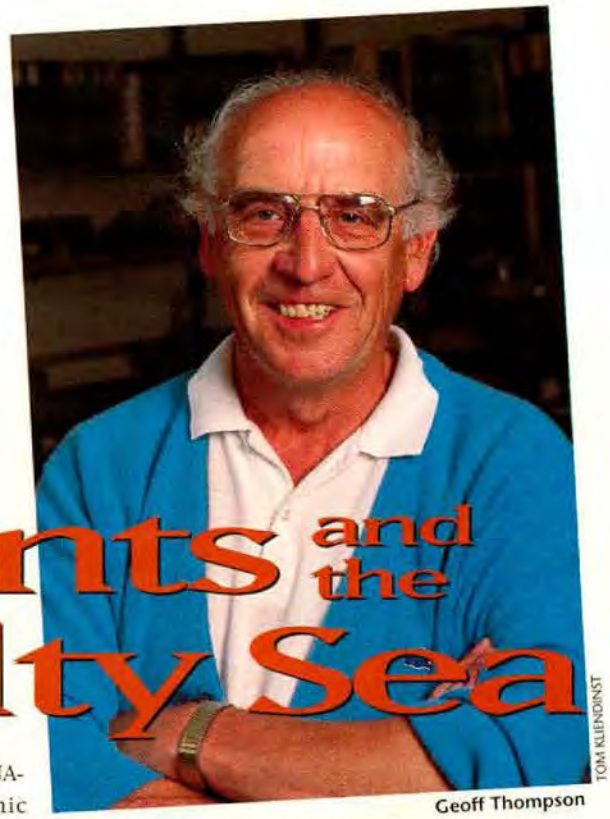
Volume 4 Number 3 Summer 1995

The Woods Hole Oceanographic Institution is a private, independent, not-for-profit corporation dedicated to research and higher education at the frontiers of ocean science.

WHOI's primary mission is to develop and communicate a fundamental understanding of how the oceans function and interact with the earth as a whole.

It is the goal of the Institution to be a world leader in advancing and communicating a basic understanding of the oceans and their decisive role in addressing global questions.

Two thousand miles east of Miami, two and a half miles below the surface in the abyssal darkness of the Mid-Atlantic Ridge, is a hellish mound the size of the Astrodome that is spewing hot, sulfurous, metal-laden plumes. ◆ The mound is topped with hydrothermal vents, volcanic-related, submarine fountains formed when seawater, heated by molten rock deep within the crust, shoots up out of the seafloor. It stands in the midst of a sprawling hydrothermal zone that includes a field of manganese slabs and small iron chimneys that weep clouds of shimmering water; sediment glittering with fool's gold; swarms of eyeless shrimp, and vast tracts of ghostly, towering vent chimneys that have been dead for centuries. ◆ Hydrothermal vents are some of the ocean's most important and least understood features, and this is the oldest, largest, and deepest known hydrothermal vent site of all. ◆ Many WHOI scientists have made discoveries here, but three geochemists—Geoff Thompson and his former students Susan Humphris and Meg Tivey—have devoted years to the site. They've worked together for the better part of a decade and form a spirited team. This special issue of Currents will explore how their partnership is shedding light on a process that cools the planet's core and mantle, balances its chemistry, and perhaps gave birth to life.



TOM KLEINDINST

Geoff Thompson

Vents and the Salty Sea

IN 1972, THE NATional Oceanic and Atmospheric Administration research ship *Discoverer* was over the Mid-Atlantic Ridge, when its clawed dredge hoisted a hundred-pound slab of black, crumbly, astoundingly pure manganese oxide to the surface. NOAA scientist Peter Rona guessed immediately that it had precipitated from mineral-rich fluid venting from the Ridge below. To help explain the finding, he turned to WHOI's Geoff Thompson.

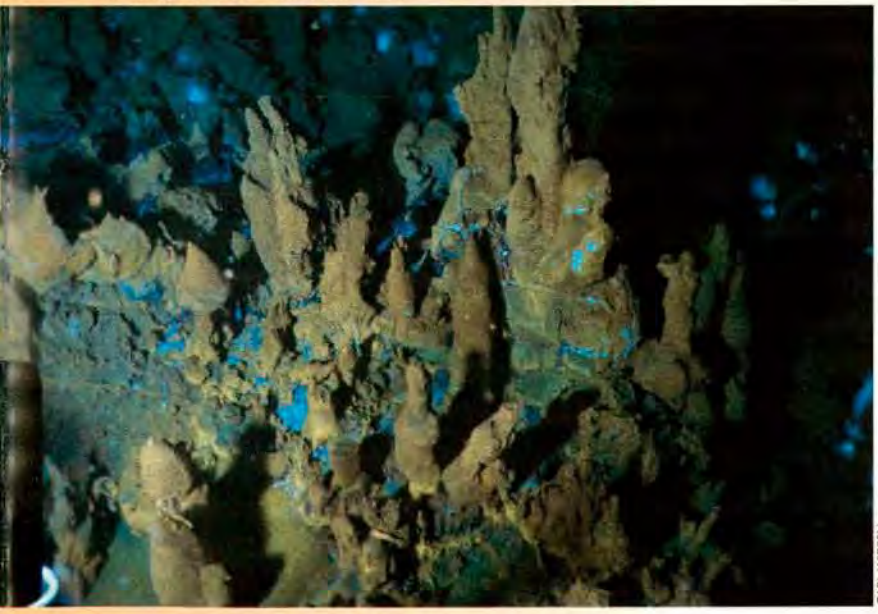
"We looked around for the best people in each discipline to help us," says Rona, now a professor of marine geology and geophysics with Rutgers University. "Geoff is a remarkable scientist, and we knew his capabilities as a geochemist and petrologist. He's certainly the best in his field."

Rona and Thompson made repeated voyages and submersible dives at the site, which was soon known as TAG, after the Trans-Atlantic Geotraverse project, the seafloor survey of the Atlantic in which the *Discoverer* was taking part. Their findings not only confounded theorists who had predicted that the slow-spreading Mid-Atlantic Ridge could not generate enough heat to create hydrothermal vents, but they gradually unveiled a tweny-five square kilometer zone that proved to be the largest, most varied vent site in the world.

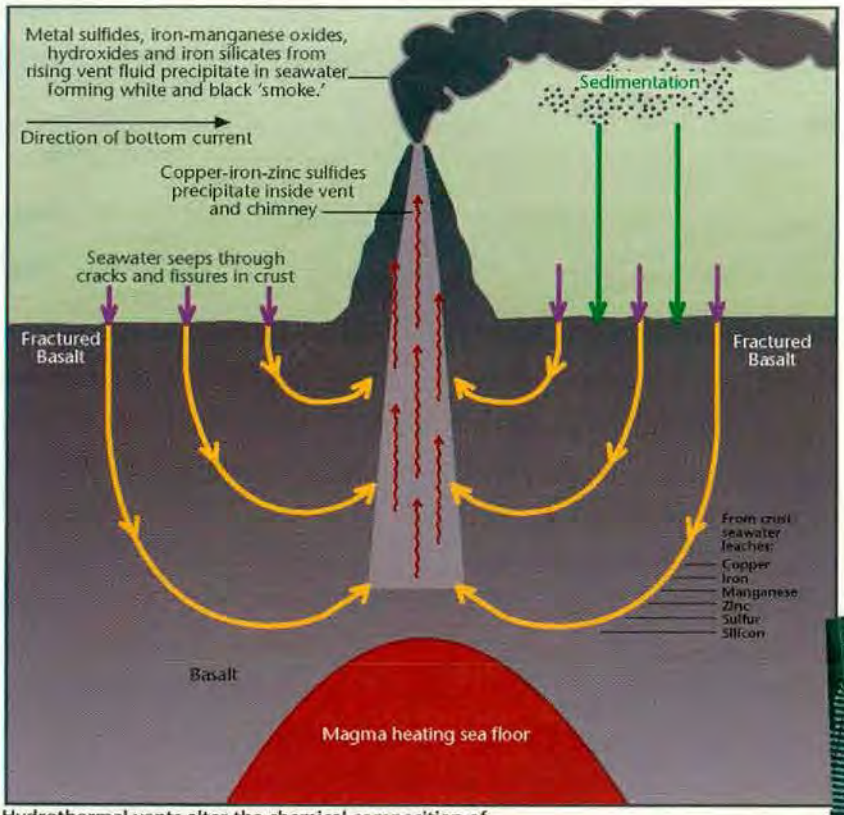
HYDROTHERMAL VENTS PROVOKE EXCITEMENT because of their bizarre wildlife, complex mineralogy, and strange shapes. Thompson studies TAG, however, to understand how vents might answer one of the most basic questions about the ocean—why seawater remains salty.

"If you think about it, the sea shouldn't be salty," says Thompson, a vigorous, white-haired Englishman with a crooked grin and a broad Yorkshire

Chimneys at TAG's "Kremlin" area.



CARL WIRSEN



Hydrothermal vents alter the chemical composition of circulating seawater and the earth's crust.

THE SEAFLOOR FOUNTAINS

Discovered less than twenty years ago, hydrothermal vents have a global impact: They dissipate heat from the earth's hot mantle, influence the chemistry of the air and oceans, and provide a home for sulfur-eating bacteria that some researchers say were the first forms of life.

Vents form where magma rising from the earth's hot mantle nears the seafloor—at volcanic centers, island arcs, deep trenches, and at spreading ridges between tectonic plates.

At spreading ridges such as the Mid-Atlantic Ridge, bodies of 1,100°C (2,000°F) magma rise from the mantle to form new crust. These hot, molten rock chambers slowly rise as the plates move apart. As the new crust cools, it contracts and cracks. The seawater above the ridge presses down on this new crust, percolating into the cracks and fissures as far as three miles deep, until it meets the hot rock adjacent to the rising magma.

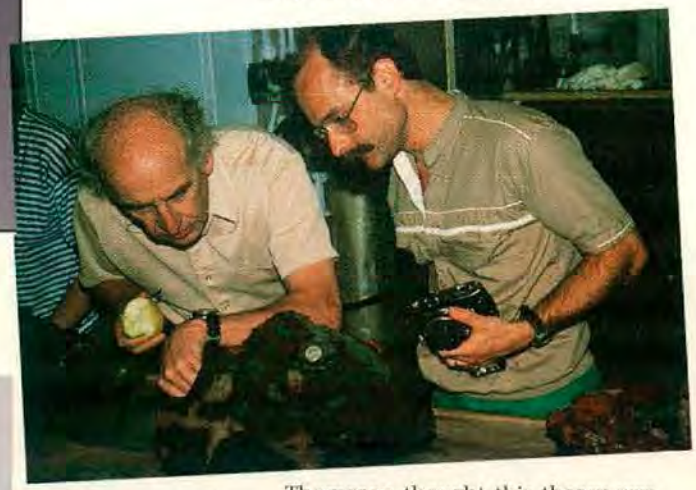
The water quickly warms to over 360°C (680°F). Although the pressure of the overlying sea prevents it from boiling, it expands with the heat and, now extremely buoyant, shoots back towards the seafloor. On the way, it deposits magnesium and sulfate in the crust, and in return takes up copper, iron, manganese, zinc, and sulfide.

This scalding brew jets from the crust into the near-freezing seafloor water. The dissolved minerals from the hottest vents precipitate into dark plumes of copper, zinc, and iron sulfides. These plumes of black 'smoke' can rise up to a thousand feet above the seafloor, and chimneys of calcium sulfate form around these 'black smoker' vents. Cooler vent water forms lighter plumes and chimneys called 'white smokers.' More water enters the seafloor to fill the void left by the rising vent fluid, and a convection cell forms. The cycle continues until the smokers seal up, the underlying magma cools, or the vent field migrates off the hot spreading ridge.

Oceanographers have found dozens of vent fields in the world's oceans, and some predict hundreds more will be found, strung intermittently like beads along the ridges. Some scientists estimate that each year a volume of water equal to the annual flow of the Amazon River passes through the ocean's hydrothermal vents, a rate fast enough to filter the entire ocean every ten million years.

brogue. "All the world's rivers flow into the sea, so the sea should either get diluted, or the minerals from the rivers should build up. In fact, the sea should be an alkaline lake, not a sodium-chloride-rich brine. But the remarkable thing about the sea is that it retains its composition and has retained it for over 200 million years. So something has to be going on."

This question first intrigued Thompson when he was a graduate student more than thirty years ago, when he became dissatisfied with the accepted theory that explained the salty sea. The theory added up the chemical reactions between rivers, the sediments they carried, and seawater itself.



Geoff Thompson and Mark Hannington of the Geological Survey of Canada inspect TAG sulfide samples recovered by *Alvin*, 1990. Credit: Peter A. Rona.

Thompson thought this theory was like an out-of-whack account book. "When you tried to balance what's coming into the sea with what's going out, it didn't balance. The budget was off by large amounts."

For example, millions of tons of magnesium flow into the sea every year, but magnesium's concentration in seawater and sediment remains constant. According to the theory, this influx somehow vanished.

Thompson set to work on his own theory, an enormously complex set of equations and analyses that has grown to follow the trail of more than thirty of seawater's ninety dissolved elements.

"Some people just play with one element, but that only defines parts of the process. You've got to do a lot of elements. Each one tells you a little bit more of what goes on."

For years the seafloor was dismissed as a static, chemically inert, abyss. But in the 1960s, Thompson discovered

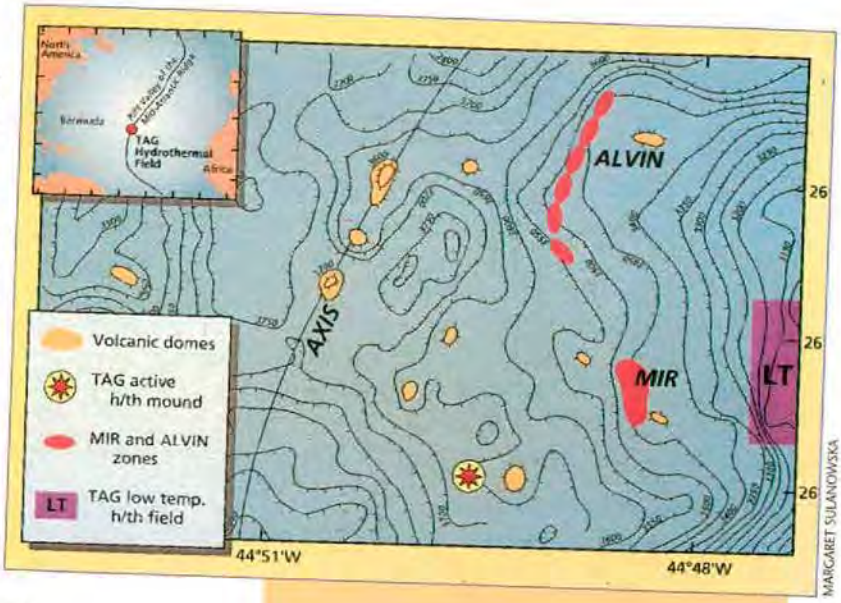
that the ocean reacted chemically with the volcanic rocks that form the basement of the seafloor. The interchange is slow at low temperatures, but it has been going on for aeons and accounted for a measurable part of the budget.

Thompson also discovered in the 1960s that high temperature reactions occur in the crust near the ridge axes. In the 1970s Susan Humphris, under Thompson's direction, studied rocks altered by high temperature for her graduate thesis. They predicted that a hot, acid, metal-laden solution would return to the ocean from the basement rocks. But they did not know the form it would take—they envisioned a cooler solution, mixing with cold seawater in the crust and seeping out in a diffuse fashion.

The sources of these high temperature reactions remained unknown until the discovery of hydrothermal vents in 1977 at the Galápagos Rift in the Pacific Ocean. Minerals from this new chemical source and analyses of the venting solutions provided Thompson with new clues on the exchange of elements. In essence, vents are submarine refineries that cycle some minerals from seawater to rock, and dissolve others back into seawater (See sidebar, p. 4). The fluid exiting the hydrothermal vent systems is from one-third to twice as salty as the seawater that enters.

TAG presented Thompson with a spectrum of hydrothermal fluids and structures, from copper-sulfide-belching black smokers to fossil stacks long dead to tiny cracks venting water scarcely hot enough to warm a pot of tea. In the 1980s, Thompson brought his former student Susan Humphris and then post-doctoral fellow Meg Tivey onto his team. Since then, they've been dissecting the vent structures, the chemical reactions inside, and the rock beneath the mound.

But Thompson could not put their findings into his theory without knowing the pace at which TAG developed. To do that, he and French colleague Claude Lalou dated TAG chimney samples collected during *Alvin* dives. Just as archaeologists use radioactive carbon 14 to date Egyptian mummies, they measured how much radioactive lead, uranium, thorium, and carbon remained from when the chimneys formed. It is a long, exhausting processs that can take a year to yield a single date. But the technique is precise enough to date deposits to within decades, and it provided Thompson with the timetable he needed to refine his theory.



MARGARET SULANOWSKA

A bathymetric map of the TAG site. Depth contours are in meters.

TAG IS LIKE A GIANT METALS FACTory that runs in fits and starts. It started up about 125,000 years ago, when 200°C (390°F) manganese-rich fluid began to rise from seafloor cracks. Twenty-five thousand years later, 360°C (680°F) vents appeared. These vents smoked on and off for 100,000 years; the last inexplicably fell dormant about 200 years ago. TAG's active mound, the site of today's black smokers, came to life at least 20,000 years ago. It vents in 50 to 200-year spurts, then shuts down for 4,000 to 6,000 years. Its present cycle, one of five or six such cycles, has been underway for about fifty years.

This geochronology allows Thompson to estimate the rate at which vent sytems add or remove chemicals from the ocean, and he factors this into his oceanwide accounting. In its broadest outlines, his theory attributes half of some of the sea's chemicals, such as magnesium, to river input, and half to a mix of reactions from seafloor volcanic rock and hydrothermal activity.

Yet, the more Thompson studies hydrothermal vent systems, the more variables he has to define. And though he recently retired from the WHOI staff, he's eagerly seeking new answers. "Within the TAG mound itself there's a whole fascinating subset of science," Thompson says. "People like Meg and Susan are looking at the subtleties. There's still a whole mess of stuff to be done, a whole fascinating area of research." ▲

THE MOTHER OF ALL VENT FIELDS

TAG is located on the Mid-Atlantic Ridge where a lifted, tilted block of basement rock pinches the Ridge's nine-kilometer-wide rift valley to two-thirds its normal size.

Since 1972, towed cameras, sonar imagers, and dozens of dives at TAG by WHOI's *Alvin*, the Russian *Mir* submersibles, and the Japanese *Shinkai 6500* have revealed a large number of earthquake faults, two extensive inactive vent zones, a low temperature hydrothermal field, and the enormous active chimney mound. Ten gently sloping volcanic domes scattered across the site may mark the magma chambers that have supplied TAG's heat.

Scientists attribute TAG's wealth of features to the Ridge's slow spreading rate—since new crust spreads out from the axial valley at only about two centimeters per year (the speed that fingernails grow), the vent features have not spread far apart since hydrothermal activity began 100,000 years ago.

The eighteen-story active mound covers an area the size of two football fields. Formed of minerals and metal ores, calcium sulfate slabs, and the rubble of collapsed chimneys, it is riddled with cracks and orifices venting diffuse black and white smoke. At its apex is a spectacular cluster of black smokers that are home to millions of blind shrimp, and white anemones dot its cooler portions. Farther down the sloping mound is an area of strangely shaped chimneys called "the Kremlin," named for their likeness to Moscow's onion-shaped domes. The Kremlin vents white smoke and shimmering water at temperatures from 260°C to 300°C.

The *Alvin* and *Mir* zones, named for the submersibles that explored them, are inactive zones that include thousands of relict chimneys, some standing twenty-five meters tall.

TAG's energy output is immense: It annually releases enough heat to electrify the city of Chicago for a year.

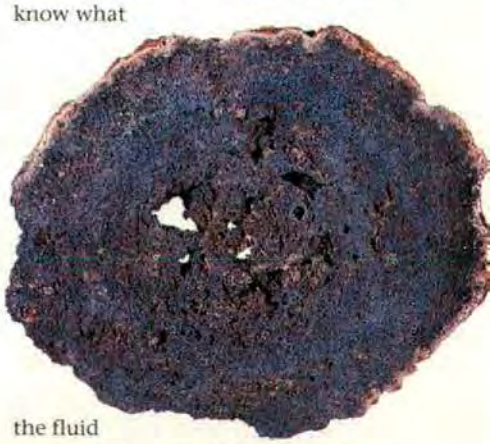
Stone Soup

Geochemist Meg Tivey is deciphering the recipe that turns the scalding fluid from hydrothermal vents into mineral chimneys and mounds.

Meg Tivey peered out of *Alvin's* viewport, straining to see beyond the sub's headlights into the darkness at the bottom of the sea. Rock music was playing over the sub's sound system, but the atmosphere in the cramped cabin was tense—for almost an hour, ever since they had arrived at the bottom, Tivey, colleague Susan Humphris, and pilot J. Patrick Hickey had been flying over nothing but acres of white sediment. They could not find TAG's active mound.

If TAG were on land they could have followed its hydrogen sulfide stench. Instead, they had to fly up above the seafloor and use the image on *Alvin's* sonar screen to detect the ninety-story black plume rising from the mound.

Within minutes of driving toward the image shown on the screen, an immense cloud of black smoke boiled up and engulfed the sub, shrouding its windows and startling its occupants. *Alvin* was directly atop the chimney mound.



Meg Tivey

TOM KLEINDINST

"Smoke! We're in smoke!" someone called.

"I can't see anything!"

"A huge cloud is in front of us!"

"Oh my god, look at this!"

As Hickey quickly backed the sub away, Tivey experienced the mix of emotions she often feels in *Alvin's* six-foot diameter cabin at the bottom of the sea. "Its exciting whenever you dive on a new site," she confides, "but I do get a little nervous."

Nervous or not, Tivey has made fifteen dives to hydrothermal vents. A geochemist in the Department of Marine Chemistry and Geochemistry, she is one of the world's leading experts in the processes that turn scalding mineral-laden hydrothermal vent fluid into sulfide chimneys and metal-rich mounds. For Tivey, a vent chimney is an ever-evolving object, a stony palimpsest on which crustal minerals and cold bottom water write an engrossing history that she's eager to decode. Her goal is to create a model that can describe a vent chimney's future and past.

"The sulfides from the vents have very complex minerals and textures, and those textures record the history of how the mixing occurred," Tivey says. "I've been trying to see if I can actually pick up a sample, look at the texture, and say, 'Based on this, I know what the fluid composition was that formed it, I know how fast the fluid was moving, I know how much seawater was mixing in.'"

Her hydrothermal studies begin with a descent to the seafloor to collect samples and make observations. They continue at Woods Hole where such tools as X-ray diffraction, electron microprobes, and computer models help her figure out how vent chimneys grow.

In a way, Tivey's fascination with vent morphology is similar to the pleasure most of us find in counting the rings in a tree stump or admiring how falling snow collects on a winter's day. But where our imaginations are satisfied with the simple events of the everyday, Tivey likes to contemplate phenomena at the furthest reaches of physics, where the temperature climbs into triple digits and high pressures can squish theories flat: At TAG, the water pressure exceeds 6,000 pounds per square inch, and the vent fluid is hot enough to melt lead.

"A striking feature of black smoker chimneys is how thin their walls are," Tivey says. "They vary in thickness

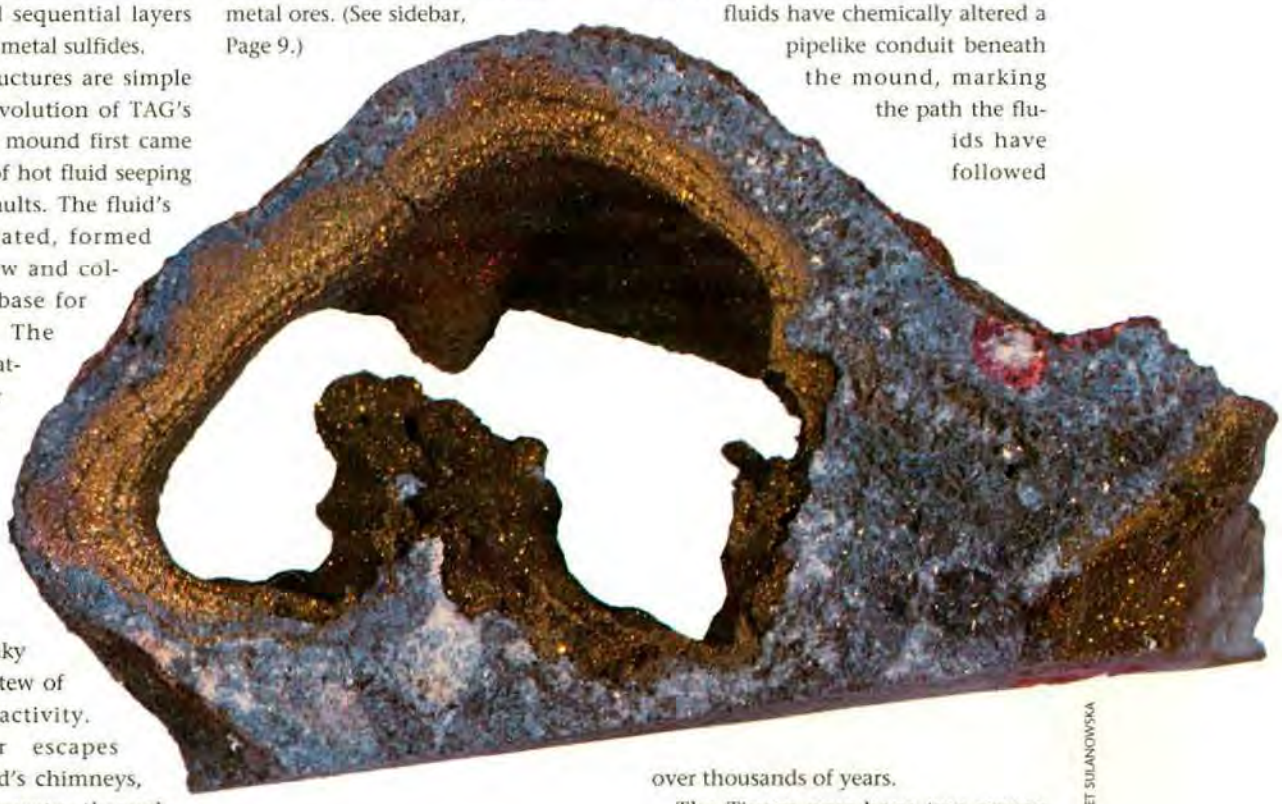
from about five inches to as little as a quarter of an inch." The porosity of the chimney walls changes throughout their lives—the pressurized, frigid seawater passes through these thin walls to mix with the hot vent water in constantly altering ratios. As a result, a chimney cross-section can reveal well-ordered sequential layers or a hodgepodge of metal sulfides.

But chimney structures are simple compared to the evolution of TAG's active mound. The mound first came to life as a stream of hot fluid seeping through seafloor faults. The fluid's minerals precipitated, formed chimneys that grew and collapsed to form a base for more chimneys. The cycle has been repeating off and on for 20,000 years—to date the mound has accumulated over five million tons of sulfides.

Tivey likens the mound to a leaky oven baking up a stew of intense chemical activity. Hot vent water escapes through the mound's chimneys, drawing in cold seawater through cracks in its sides and the surrounding seafloor. These continuous infusions of hot vent water and cold seawater cause the minerals within the mound to combine, precipitate, dissolve, and reprecipitate. The metal ores cycle into ever-purer deposits of ore—in fact, small nuggets of pure gold have been found in TAG chimneys.

This process, called zonation, leads to complicated plumbing. "One of the fascinating things at TAG is that there are black smokers and white smokers seventy meters apart," Tivey says. The white smokers on one side of the mound vent ten times as much zinc but have less copper and a lower temperature than the black smokers on the mound's other side. "The simplest explanation is that inside the mound the zinc sulfide is dissolving and concentrating at the white smoker chimneys." Zonation was initially described based on observations of ancient mineral deposits on land. "At TAG, we're seeing it go on right now. We can go down, study and measure the metals in the fluid."

And these studies are more than academic: Hydrothermal vent research has already helped landbound geologists in their search for precious metal ores. (See sidebar, Page 9.)



SMOKER CROSS-SECTIONS: MARGARET SULANOWSKA

Above Left: A white smoker chimney cross section, lined predominantly with zinc sulfides.

Above Right: A black smoker cross-section. The inner layer, which was adjacent to 360° C fluid, is copper-iron sulfide. The outer layer is mostly calcium sulfate.

TIVEY BEGAN STUDYING VENTS DURING her second year in graduate school at the University of Washington while she was on a cruise to the Pacific's Juan de Fuca Ridge off Washington. When the dredge picked up chunks of sulfides, the find resulted in the discovery of the Endeavour vent field, and she was hooked.

On that same cruise she met Maurice Tivey, a Canadian geophysicist. A year later, on another cruise, they became engaged. The next year, a week after their marriage, they were again at sea on their first *Alvin* cruise. Maurice Tivey, now a WHOI geophysicist, has joined in the TAG studies. Using data collected in 1990, he and his colleagues found a magnetic low beneath the TAG site that may indicate the hot fluids have chemically altered a pipelike conduit beneath the mound, marking the path the fluids have followed over thousands of years.

The Tiveys now have two young children, and they carefully plan their research cruises so that one of them is always at home. Although the Tiveys send e-mail messages from ship to shore, and the kids beam computer drawings out to sea, the separations can be difficult and lengthy. "For instance, I'm going to be out at sea for almost three weeks this summer," Tivey says, "and then Maurice walks on the ship right after."

WHEN TIVEY FIRST SET OUT TO predict the chemical reactions that take place inside vent chimneys, some of her colleagues said her goal was impossible. "At first, I thought, 'Wow, we've got the fluid composition, we've got the rocks, we should to be able to link these together.' But I was told 'You're not going to be able to do that. You're too close to the critical point of water.'"

When a substance under pressure is

KARELISA V. HARTIGAN/PICTURES OF RECORD

Artisans throughout the ancient Mediterranean made tools, weaponry, and household implements from Cypriot copper. This suit of armor is from Mycenae, the ancient Greek kingdom where Agamemnon is said to have ruled in the 13th Century BC. It is made of bronze, an alloy of copper and tin.

ANCIENT TREASURE FROM THE DEEP

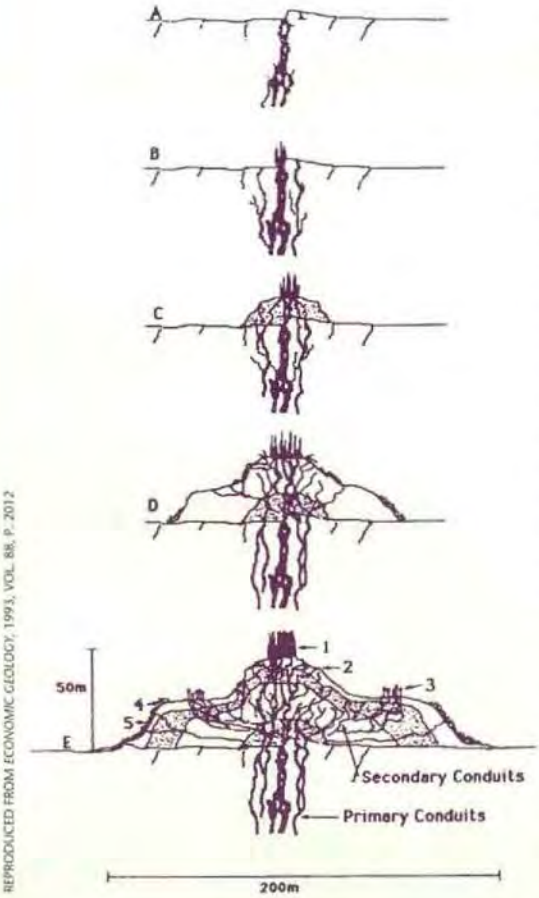
In Homer's *Iliad*, Agamemnon, military chief of the Greeks at the siege of Troy, dons an ornate metal breastplate, a gift from the King of Cyprus. What Agamemnon does not know as he marches into battle is that he is protecting himself with a chunk of hydrothermal vent.

The Troodos Mountain chain that makes up Cyprus's rocky spine is an ophiolite—a section of oceanic crust and upper mantle that plate tectonics has lifted high on land. Millions of years ago those mountains lay at a spreading center at the bottom of the sea. At that ancient spreading center, just as at TAG today, hydrothermal vents were precipitating metal ores in concentrated deposits. As a result, scattered through the Troodos Mountains are copper-iron-zinc sulfide deposits, rich ore bodies that have been mined for thousands of years. So central did these ore bodies eventually prove to the economies of the ancient Mediterranean that the island, then known as Kypros, lent its name to copper.

The Troodos ophiolite with its hydrothermal ores is only one of many similar ophiolites that have been mined in the Middle East, the Americas, Europe, the Himalayas, and the islands of the western Pacific. Geologists have found vent fragments embedded in many of these ophiolites.

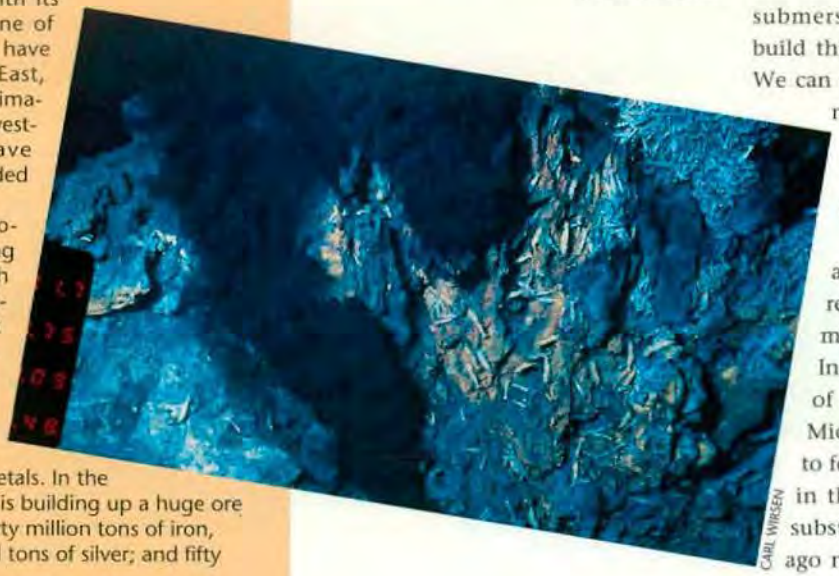
The deposits at contemporary vent systems on spreading ridges, however, are much smaller, because the precipitating metal sulfides drift away in the rising plumes. But in steep, narrow rift valleys, which are typically found in young ocean basins, falling sediment can bury the vents and trap the metals. In the Red Sea, a buried vent system is building up a huge ore body that contains at least thirty million tons of iron, zinc, and copper; six thousand tons of silver; and fifty tons of gold.

Deep-sea vent deposits are uneconomical to mine at current mineral prices, although a pilot mining project in the Red Sea has begun.



REPRODUCED FROM ECONOMIC GEOLOGY, 1993, VOL. 88, P. 2012

A hypothetical diagram of the TAG mound's growth. Numbered features are: 1) Black smoker chimneys at 350-360°C 2) black and white diffuse smoke at 240-260°C 3) "The Kremlin:" clear solutions and white smokers at 260-300°C 4) standing and toppled inactive chimneys 5) sulfide debris.



CARL WIRSEN

heated to its critical point, its customary properties change markedly: Its liquid and vapor states become virtually identical, and the vibrating molecules lose much of their polarity. At TAG, the seawater presses down with the weight of three tons per square inch, and its boiling point approaches 400°C (752°F). To replicate these pressure-temperature conditions on land requires an extremely strong pressure vessel and very small samples that do not precisely replicate a vent's flowing, superheated, ultrapressurized fluids.

Tivey, however, was undaunted by her colleagues' doubts. She realized that when she descends in *Alvin* to observe a vent, the conditions are the same as in any conventional laboratory, except they're turned inside out: On the seafloor, the researcher is in the pressure vessel instead of the samples, and the high pressure-high temperature phenomena unfold in the open.

"The seafloor vents are perfect natural laboratories. We have to sit in a submersible, but we don't have to build this huge apparatus in the lab. We can study the fluid transport and metal complexing at high temperature and pressure. We can test the thermodynamic data and the theories."

Tivey points out that although many questions remain, the pace of hydrothermal knowledge is accelerating. In the last two years the number of confirmed vent sites on the Mid-Atlantic Ridge has doubled to four. "The progress we've made in the last fifteen years is pretty substantial," she says. "Not long ago no one had ever seen a black smoker chimney. Now they seem to be found at mid-ocean ridge crests whenever we take a close look." ▲

Ground Zero

BY JODY ERICSON

IN OCTOBER 1994 WHOI geochemist Susan Humphris and a cadre of other scientists boarded the research vessel *JOIDES Resolution* to embark on one of oceanography's most ambitious geological explorations—drilling deep into TAG's active hydrothermal mound.

The drilling would remove the first core samples ever taken from a hydrothermal vent, and Humphris had been preparing for this moment for almost two years. As one of the voyage's two chief scientists, she had overseen a five-week cruise on WHOI's RV *Knorr* that had mapped the site with thirty thousand photographic and sonar images; she had planned where and how deep the drill would go; and she had helped amass an international team to analyze the drill cores on board the ship. Even before the ship set sail, a score of additional scientists were counting on Humphris' success—instruments from the United States, the United Kingdom, and Japan were already anchored on the bottom, waiting to monitor the drilling's impact on the mound's hydrothermal activity.

In the beginning, the work was fruitful. The crew, lowering a hollow, five-inch pipe through miles of water, hauled up core samples every few hours, and the scientists kept busy analyzing and cataloguing the material. Then, partway through the two-month voyage, the ocean floor suddenly stopped cooperating. Everything came to a standstill.

As Humphris explains it, much of the TAG mound is not solid rock but an amalgam of tiny pieces of rock cemented together by various minerals including sulfides, sulfates, and quartz. The drilling "broke up the cement and caused the hole to cave in around the drill string," she says. "We kept getting stuck in the bottom."

The crew spent hours wriggling the drill string free of the debris, only to have to punch a new hole nearby. Other times the drill bit wore out, and the drillers, working beneath the ship's twenty-story derrick, would spend an entire afternoon pulling up two and a half miles of pipe a ninety-foot section at a time.

Before long, days had gone by without any new samples. The scientists, tracking the drilling operation on television monitors in their labs, began to grow restless. "At first, everyone's level of excitement was really high, so everything that came up was quite exciting," says University of Michigan research scientist Jeff Alt, who worked on the project. "Then we went through that dry spell, and I think Susan felt lots of pressure. Things were tense for a while. We all wanted the project to be a success."

JOIDES RESOLUTION IS A CONverted oil-drilling ship that has been taking scientific seafloor cores since 1985 as part of the Ocean Drilling Program (ODP). Competition for ship time is intense, and the process for acceptance and scheduling of a scientist's research proposal by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES), an international group of scientists in charge of the drilling, can take several years.

JOIDES Resolution's target must also be worthy of the effort—and the TAG mound qualified in spades. It is one of the largest mineral deposits yet found on the seafloor, and drilling into its active hot springs was sure to benefit a number of oceanographic disciplines. In fact, three months before, a joint WHOI-Japanese team had wired the mound with instruments to measure how the drilling would affect TAG's output of heat and fluids (see sidebar, page 12). Three fifty-meter seaweed-shaped temperature arrays, dubbed Giant Kelp, measured the black smoker plumes; the *daibutu* (Japanese for octopus) hugged the mound with eight arms of temperature recorders; and a video camera kept watch. A month later, a joint British-Russian submersible expedition added still more instruments to measure the mound's flow rates and chemistry.

WITH SO MUCH AT STAKE, HUMphris labored feverishly, sometimes staying up twenty-four hours at a stretch, working with the dozens of people behind the ship's operations—the drillers, engineers, and technicians from Texas A&M, the

Susan Humphris

TOM KLEINDINST

JOIDES Resolution's derrick towers 202 feet above the waterline. Here riggers are connecting a section of the drill string.

OCEAN DRILLING PROGRAM

Below: Susan Humphris prepares for an *Alvin* dive.

MARGARET SULANOWSKA

ODP's science operator. Though she had participated in previous drilling voyages, Humphris now realized for the first time the enormous round-the-clock effort involved in moving the project forward, how inordinately complicated it is, for instance, just to keep the ship over the drilling area.

"We were trying to position all of our drilling sites on a piece of seafloor 200 meters across while avoiding all the instruments down there," says Humphris. "The ship is 143 meters long, so by walking from one end to another, you were essentially walking that piece of seafloor." The ship had to maneuver constantly, holding itself steady with its twelve computer-controlled thrusters and an internal 400-ton mechanism that keeps the drill string stable relative to the seafloor.

For Humphris, learning such mechanical intricacies meant mastering the drillers' lingo, one rife with oil-rig acronyms. "They would say, 'Should we use an MDCB?' or 'Are we going to RCB or use such and such a bit?'" says Humphris. "And you're sitting there saying, 'First of all, what is a bit?'"

Jay Miller, ODP staff scientist, says many drilling tools are named after animals. "That's standard, oil field stuff," he says. The doghouse, for instance, is where the head driller stands, and a "Go Devil" and a "Rabbit" are tools that travel down the hole.

There are also the operational reports to decipher. "They're all in shorthand," says Humphris. "'POOH at 3 p.m.,' for example, means 'pull out of hole at 3 p.m.'"

To everyone's relief, the tension and

MARGARET SULANOWSKA

Above right: In the summer before the *JOIDES Resolution's* cruise, Humphris and her colleagues made detailed studies of the TAG area to guide the drilling project. The *Argo II* imaging sled was towed to within a few yards of the mound's surface, and returned still and video images to the ship via a fiber optic cable. Thousands of *Argo II*'s images were combined to make a photomosaic of the mound.

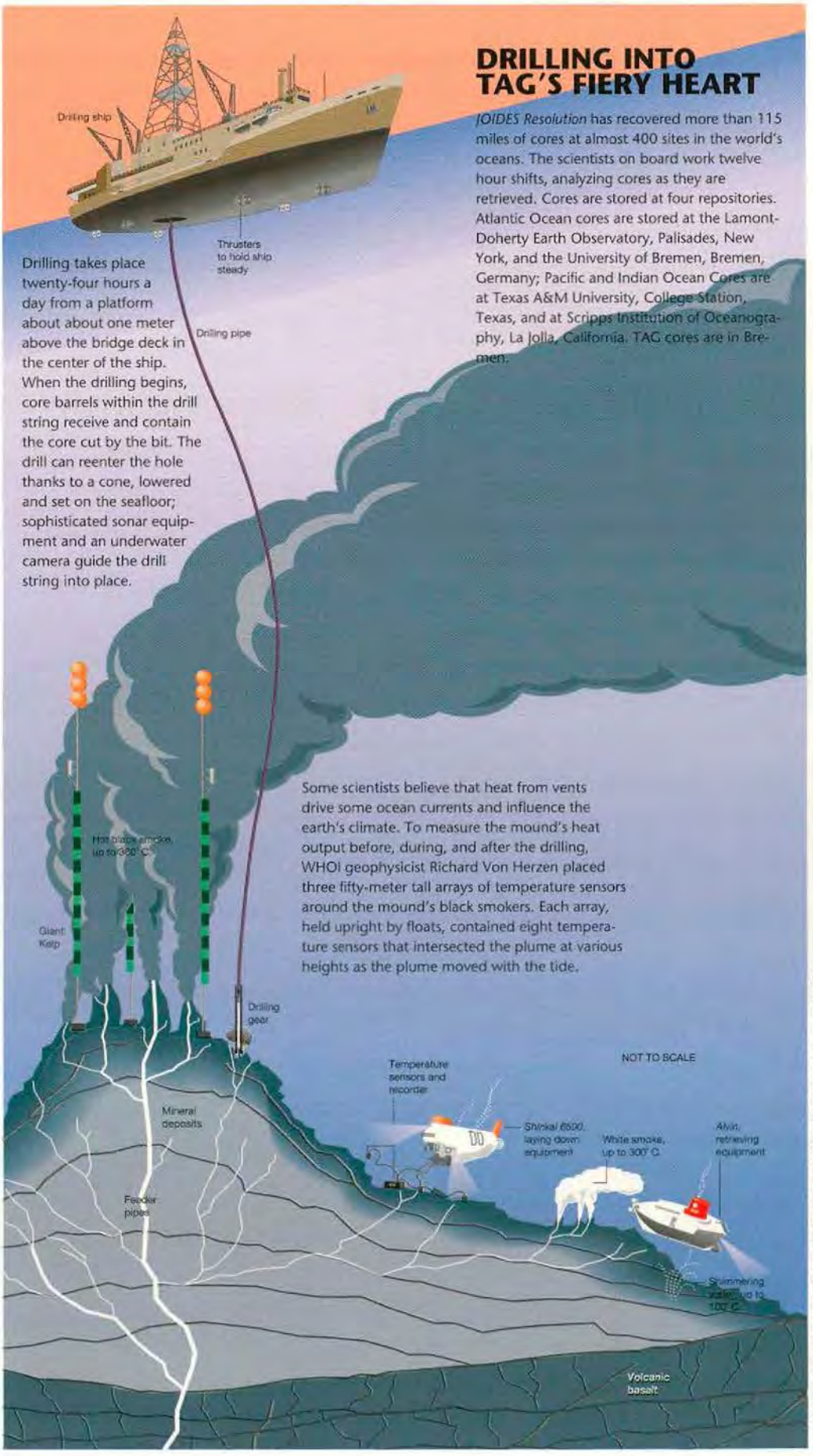
tedium aboard the ship broke in about a week's time as more core was recovered from a different part of the mound. However, the difficulties were far from over: The drillstring became hopelessly stuck with about forty meters of pipe inside the mound.

Dynamite was twice sent down the hole to blow off the drill bit at the very end of the pipe, but the drillstring still did not come free. The crew feared their only option would be to blow the drillstring apart at a joint above the seafloor, leaving a piece of drill pipe sticking up like a lance. This could potentially have put an end to future operations at the TAG active mound, for "Alvin could have run into it or gotten stuck on it," Alt explains.

Humphris, however, persuaded them to try once more, this time setting the charge to explode a few feet below the seafloor. The pipe came free, and as the drilling crew drew the drill pipe up through the "moon pool," an open shaft seven meters across that extends through the bottom of the ship, Humphris and her shipmates anxiously waited to see how much pipe had been blown off. As the last piece emerged from the water, they saw that the explosion had indeed occurred below the seafloor. Humphris was so happy that she posed for a photograph pointing at the blasted-off piece of pipe. Little did she know that the picture would appear the next day as a screen saver on the ship's computers. "Susan blows up the mound!" the headline said, and there was Humphris grinning broadly.

Though most scientists on board agree there was not a lot of core to go around, what the crew did "catch" was extremely useful. It was the first time anyone had drilled in an active hot spring system where the deposit sat on exposed volcanic rocks, and it was quite an accomplishment. "Usually, you drill through sediment first, which acts as a stabilizer," says Humphris. "This time, we had to pierce sheer rock."

Humphris says the cores have yielded some important findings. "The mound doesn't form by continuously spewing out minerals that accumulate on the seafloor," she says. "It goes through many cycles." When the vents



EAST MEETS WEST

JAMSTEC

JAMSTEC's *Shinkai 6500* is two meters longer than *Alvin*, and carries two pilots and one scientist, rather than one pilot and two scientists.

For over twenty years, scientists from WHOI and the Japan Marine Science and Technology Center (JAMSTEC) have been sharing information and reseach. So when the Japanese were planning their first Atlantic Ocean research trip, they asked WHOI to help. In the summer of 1994, the two institutions performed joint experiments at TAG and the Kane Fracture Zone, one hundred kilometers to the south on the Mid-Atlantic Ridge. The work involved three research ships, two submersibles, and a variety of unmanned vehicles.

JAMSTEC is the product of an intense Japanese effort to learn about the ocean and the earthquakes that wrack their island nation. Its research fleet includes the world's deepest diving manned submersible, the five-year-old *Shinkai 6500*, which can descend to 6,500 meters (WHOI's *Alvin* can dive just under 5,000 meters).

WHOI and JAMSTEC have had a formal relationship since 1987. Ongoing projects include arctic research, an Earth data and information network, and experiments in physical oceanography, biology, and geochemistry.

"JAMSTEC scientists are the world's experts in the type of deep sea trenches found near Japan," says WHOI geologist Sus Honjo, a Japanese native and American citizen who helps coordinate the JAMSTEC-WHOI research. "But they are unfamiliar with spreading ridges such as the Mid-Atlantic Ridge. Although the two institutions have very different histories, habits, and languages, our relationship is very solid and enormously fruitful."

Geophysicist Richard Von Herzen spent three weeks with the Japanese at TAG. "They were very cooperative and their submarine was really first class," says Von Herzen. Although *Shinkai 6500* was inspired by *Alvin*, it boasts a slew of innovations, including a video system that allows scientists on the surface to watch and contribute to the work below.

The scientists left instruments from both countries at TAG to monitor the effect of *JOIDES Resolution*'s drilling. *Alvin* recovered the equipment in March. "The whole cycle of activities made for the kind of research that normally scientists just dream about," Honjo says.

are active, the vent fluid's minerals precipitate in the cold seawater and fall to the bottom. When venting pauses, the seafloor fissures and breaks up the mineral deposit. "The next phase of hot spring activity then cements the broken fragments together."

ONCE HUMPHRIS AND HER CO-chief, Peter Herzig of the Institute of Mineralogy in Germany, had the core samples on board, a different set of challenges arose. The ship's company included petrologists, geophysicists, water chemists, and geochemists, all eager to work on the samples. Due to the shortage, Humphris and Herzig had to dole out the material carefully. "That was hard," says Alt, a geochemist. "There were so many scientists, and sometimes when two of them have a conflict, neither backs down. I've been on cruises when scientists have left with bad feelings."

With so many people wanting a piece of the pie, Miller agrees feathers can get ruffled. "You have people on board for two months working fourteen to sixteen hours a day," he says. "Even the smallest conflict can aggravate."

According to Alt, Humphris and Herzig essentially told their colleagues they had to share. "They said, 'Look, we're going to have to work together,' and I think people came away feeling pretty good," he says.

Relaxing now in her office at WHOI, Humphris, dressed in a T-shirt and baggy pants, still has a cloud of relief about her when discussing her experiences on *JOIDES Resolution*. "It was not the easiest cruise I've ever been on," she says, sighing.

How Humphris came to be the project's co-chief is a story in itself, particularly for someone who says she used to think the ocean was strictly for "building sand castles and watching the waves come in."

In England, Humphris' father was a dentist, who supported his daughter when she decided to concentrate on science in high school. Humphris moved on to environmental science in college and decided on her true calling in a typically collegiate fashion.

"I was taking a marine chemistry course and learning about scientists who actually went to sea. That sounded like a good idea," says Humphris. "Then I saw some of the boats they went on, and they were sort of nice."

"Sort of nice" landed Humphris in the WHOI/MIT Joint Program, working toward a Ph. D. under the tutelage of Geoff Thompson. Her graduate thesis, done prior to the first actual sighting of a hot spring, was on some rocks in the WHOI collection that had clearly been altered by hot water. Humphris also met her future husband, Pat Lohmann, a WHOI paleoceanographer ("He works on sediments that cover up what I'm working on," says Humphris).

At the time, Humphris already had decided to return to England to do postdoctoral research. "But Pat called me there, and we spent an expensive year and a half conducting a transatlantic relationship." In 1979 Humphris returned to WHOI as a visiting investigator and also became a staff scientist for the Sea Education Association, an independent marine education program in Woods Hole.

She continued working with Thompson, and in the spring of 1986, during the first submersible dives at the TAG site, she made her first *Alvin* dive and saw the TAG mound up close.

In 1990, Thompson and Humphris made another series of dives, this time accompanied by Meg Tivey. Inspired by what they saw, they immediately began to rewrite an earlier proposal to drill for samples. When that project was approved in December 1992, Humphris was a natural choice for its co-chief. She'd worked on TAG almost as long as anyone.

In March, four months after the *JOIDES Resolution* voyage, *Alvin* returned to the TAG site to collect the monitoring instruments on the mound. Humphris feared that the drilling somehow may have changed the activity of the hot springs. After all, they had planned on punching only four holes in the volcanic mass, but wound up with seventeen because of the collapsing rock.

However, the scientists who dove in *Alvin* put her fears to rest. "The mound was still blasting away," she says, "so I guess we didn't do anything too drastic." ▲

Some Like It Hot

The seafloor was long thought to be inhospitable to life, a muddy, rocky desert of enormous pressures, near-freezing temperatures, eternal darkness, and limited food supply, where few creatures could survive.

But in 1977, in a vent field on the Galápagos Rift, scientists in *Alvin* observed and sampled strange sea creatures reeking of hydrogen sulfide. The discovery turned the field of marine biology on its ear.

The vents were deep sea oases, crammed with three-meter tube worms, giant clams, mussels, strange fish, and bizarre crabs that formed the densest communities of living organisms in all the oceans. Far beyond the reach of the sun and the realm of photosynthesis, this world was built on chemosynthesis, where inorganic chemicals like sulfur, methane, ammonia, and iron formed the staff of life.

Oceanographers have discovered hundreds of species at the vents, and the fauna varies widely between Atlantic and Pacific Ocean vents. Common to all the vents, however, are the bacteria at the bottom of the vent food chain. These micro-organisms live off geothermal energy supplied by the earth's molten core—they consume the hydrogen sulfide and other energy-rich chemicals in the hot vent fluid. Many bacteria grow in both "warm" and "hot" vent environments, the latter at temperatures where the pressure of overlying water keeps the fluid from boiling.

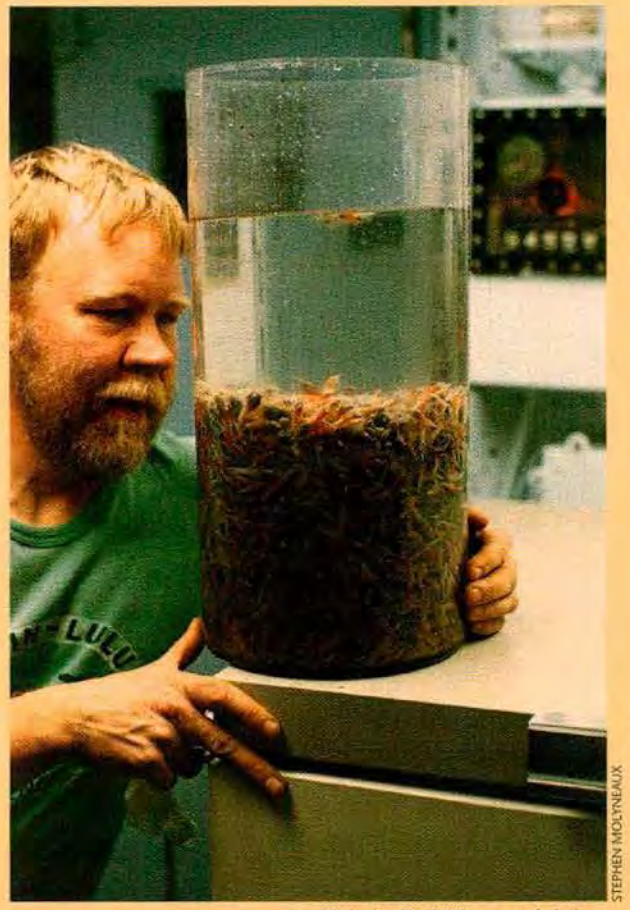
One group of vent micro-organisms, called hyperthermophiles, populate "hot" vent sites and thrive in an environment that would be toxic to most of the rest of the globe's creatures. These primitive bacteria are closely related to the first life forms that arose in the primeval oceans, and traces of their not-so-distant ancestors have been found in ore deposits hundreds of millions of years old. In fact, some scientists think they may prove that life can exist in harsh environments elsewhere in the universe.

The more complex animals live off the chemosynthetic vent bacteria that grow at "warm" temperatures, either eating them directly or harboring them in their bodies and living off the organic compounds the bacteria produce.

At TAG, the most striking creature is the gray shrimp that throngs the vent area in dense hordes like swarming bees. The shrimp were originally thought to be blind and one species was named *Rimicaris exoculata*, Latin for "eyeless rift shrimp." Further research showed that the shrimp have a reflective organ on their backs that contains rhodopsin, a light-sensitive material common to the eyes of many creatures. This organ, scientists proposed, meant there had to be a light source at the vents. Special cameras sent down on *Alvin* revealed that the vents glowed, but at a wavelength humans cannot see. Proposed light sources include crystallizing chemicals, the sound of collapsing bubbles, cracking rocks, and the decay of radioactive elements.

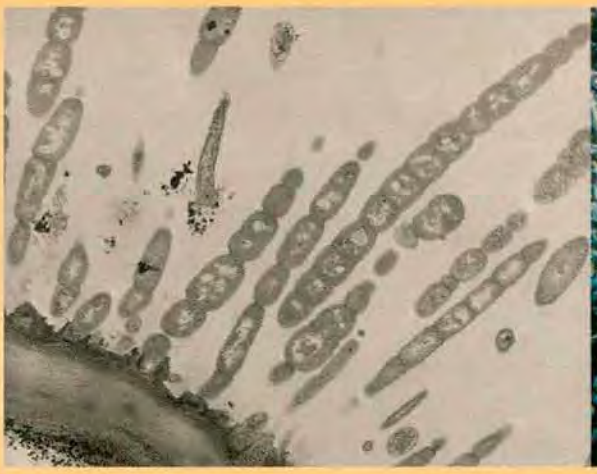
As many as 1,500 of these shrimp have been counted in a little over a single square meter, and when *Alvin*'s probes brush them from the rocks they rush back in a single-minded frenzy.

According to WHOI researcher Carl Wirsen, the shrimp feed on two bacteria sources. They graze on a layer of sulfide-utilizing bacteria that covers the mound's metal-sulfide rock surfaces. They also jostle to bathe in the sulfide-rich fluids that flow past the surface of the rocks. These fluids in turn feed colonies of unique bacteria that grow on the shrimp. "The shrimp can harvest the attached bacteria at will, and, naturally, as the shrimp climb over each other, these bacteria break off and the shrimp will consume them," says Wirsen. "Basically these shrimp are carrying an important food source on their own bodies. It's almost like the shrimp are ranching these microorganisms."



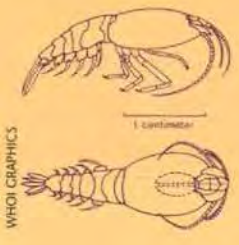
STEPHEN MOLYNEAUX

Biologist Carl Wirsen and shrimp collected from the TAG mound.



CARL WIRSEN

Left: A cross section of the leg of the shrimp *Rimicaris exoculata*, showing the filamentous bacteria that attach themselves to the shrimp's mouth parts, bodies and legs. The shrimp's leg is in the lower left corner; the bacteria extend into the water on the right. Right: Shrimp cluster around a vent orifice.



WHOI GRAPHICS

Guy Nichols Receives Cecil Green Award

DAVE GRAY

Guy Nichols (left) and Trustee Walter A. Smith

On May 19, Guy Nichols, retiring Chairman of the WHOI Board of Trustees, received the Woods Hole Oceanographic Institution's Cecil Green Award.

The award, established in 1991, is presented to an "individual who has made outstanding contributions to oceanographic research at WHOI." The award is named after the Texas Instruments founder and philanthropist who has had a long association with the Institution.

Nichols has been a corporation member for the last nineteen years and Chairman of the Board of Trustees for the last ten years. An active fund raiser, Nichols has long been respected for his interpersonal skills, his management insights, and his enthusiasm for oceanography. During his tenure he has overseen WHOI's structural, financial and managerial reorganization.

WHOI Director Robert Gagosian lauded Nichols's dedication to the Institution. "Guy loves the science and technological development at WHOI," Gagosian said. "He loves the sea and the people who study it—their ideas, their entrepreneurial flavor, their intelligence, their drive and determination."

Nichols is past chairman and president of New England Electric System. He and his wife Shirley live in Boston.

Previous Cecil Green Award recipients are: former WHOI board chairman Charles Adams, scientist Stanley Watson, and Cecil Green himself.

Associates Activities

JULY 22
Clambake
sponsored by the Employee Capital Campaign Commitee

SEPTEMBER 15
Associates Day of Science: GLOBEC

OCTOBER 1
Whale Watch
sponsored by the Employee Capital Campaign Commitee

JANUARY 30-FEBRUARY 9
and
FEBRUARY 7-FEBRUARY 17, 1996
Associates Trips to the Galápagos Islands

For more information on these activities, call Leslie Reilly, Associates Program Manager, at (508) 457-2000, ext. 3313.

The Adams Challenge

One of the major goals of WHOI's Capital Campaign is to establish five endowed chairs for senior scientists. Each chair, which offers a senior scientist three months of salary support per year for five years, requires one million dollars.

On May 19, Charles Adams, past Chairman of the WHOI Board of Trustees and 1993 winner of the Cecil Green Award, generously stepped forward to help WHOI reach its goal.

Adams has donated $500,000, which he has offered to double to $1 million to endow a chair, if two additional donors will step forward and each match his million dollar challenge.

"I'm deeply convinced that research in the oceans is essential to the future welfare of the earth and the people who live on it," Adams said.

WHOI now has six endowed chairs for senior scientists. They are awarded for demonstrated, sustained excellence in research and in the education and mentoring of junior scientists.

The chairs give senior scientists resources for projects outside the normal grant process, such as funding to join research cruises, support for graduate students, to review and analyze years of past research, or to explore ideas or directions presented by new technology.

The goal is to endow enough chairs so that each senior scientist can reasonably expect to occupy one of these chairs at least once during his or her tenure.

Geologist Stan Hart commented on the importance of endowed chairs when he was awarded the Iselin Chair in 1994. "It would be hard to overstate the likely importance of the Iselin Chair to my life here at WHOI," Hart said. "These endowed chairs provide a place of comfort and security to operate from; they provide the freedom and support to make forays and take risks; and they provide a place of refuge when all else fails."

The chairs provide what Hart calls "green money"—"Most government sponsored money is money you 'don't have,'" Hart said. "'Green money' to a scientist is money you do have because you can spend it when you want and when you need, on what you want or what you need. When writing a proposal, you have to wait a year, and then it still is money you 'don't have.' The assets of this chair will be multiplied many fold in helping me follow the WHOI tradition of excellence in oceanographic research."

The Benefits of Giving

A gift to WHOI brings lasting benefits to the Institution and often to the gift's donors. For instance, with a life income gift, you can secure income for life, receive a charitable tax deduction, and help the Institution maintain its leadership role in ocean science. A bequest reduces estate taxes and helps provide for the Institution's future.

In 1974, the Reverend William D. Henderson and his wife Margaret wanted to establish an endowed fund in memory of Rev. Henderson's grandfather, Ernest R. Knorr, the pioneering engineer and naval cartographer for whom the WHOI research ship is named.

The Hendersons, then in their mid-eighties, used three different giving vehicles to create the endowment. This gave them the satisfaction of making a substantially larger contribution than they could have made outright, increased their annual spendable income, and reduced their taxes.

Woods Hole is extremely grateful to the Hendersons for their generosity and faith in the Institution.

1. CHARITABLE REMAINDER ANNUITY TRUST
The Hendersons used appreciated securities worth $94,446 to establish a Charitable Remainder Annuity Trust. This trust gave them an annual income of 5% of the original gift's fair market value ($4,722 a year) and a current tax deduction for a portion of the gift. By 1992, when Reverend Henderson terminated the trust and turned the assets over to WHOI, the Hendersons had received nearly $85,000 in income, and the Institution received $207,912 to establish the Ernest R. Knorr Fund. (Rev. Henderson used his annual income from the trust to make additional donations to WHOI.)

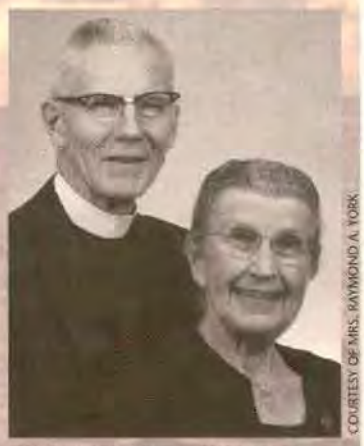
2. CHARITABLE REMAINDER UNITRUST
The Hendersons named Woods Hole as one of several beneficiaries of a Charitable Remainder Unitrust. With a Unitrust, donors receive a fixed percentage of the trust's market value, which is revalued annually. As the trust principal grows, the income to the beneficiary grows as well. In 1994, when the trust was terminated, WHOI received $150,528 for the Knorr Endowment.

3. BEQUEST
The Hendersons made a charitable bequest to WHOI in their wills, thus reducing their estate taxes. Rev. Henderson died in 1994. WHOI expects to receive approximately $150,000 from his estate.

For over twenty years, WHOI has helped donors and their financial advisors plan long term gift strategies. For more information, call Robin Kaiser at (508) 289-3359.

WHOI ARCHIVES

Ernest R. Knorr



COURTESY OF MRS. RAYMOND A. YORK

William and Margaret Henderson in the late 1970s.

OCEAN DRILLING PROGRAM

Capital Campaign Update

Since January 1, 1995, the Institution has received these leadership gifts of $50,000 or more towards the Capital Campaign:

Mr. and Mrs. Rodney B. Berens, establishing the Rodney B. Berens Coastal Research Endowed Fund.

The Estate of William D. Henderson, an additional gift towards the Ernest R. Knorr Endowed Fund for general Institution support.

An anonymous gift in support of scientific staff.

Violet S. Thoron, supporting the Coastal Research Endowed Fund.

The Hewlett-Packard Company, data visualization equipment for the Department of Physical Oceanography.

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WHOI at Work: Focus on the Future

George Tupper shows Young Associates some equipment used in mooring systems.

SHELLEY LAUZON

One of the questions that young people most often ask WHOI scientists is "What's it like to be an oceanographer?" On Saturday, April 29, six WHOI researchers hosted a seminar for fifty Young Associates and gave them detailed answers.

The Young Associates heard how specialists in each of WHOI's five disciplines study the Mid-Atlantic Ridge. Presenters discussed black smokers, moored instruments, deep sea submersibles, hydrothermal vent life, and ocean circulation. Alvin pilot Robert Grieve, geochemist Susan Humphris, geology associate scientist Dan Fornari, physical oceanography research associate George Tupper, biologist Carl Wirsen, and biologist and WHOI Sea Grant Director Judy McDowell took part. Students from Massachussetts, New York, Pennsylvania and Connecticut attended the event.

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WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

OCEAN explorer

For the Young Associates of Woods Hole Oceanographic Institution VOL. 1, NO. 4 MAY, 1992

Ocean Explorer is no longer being published and is included as information only.

You never know what you'll run into on a dive in the deep, dark sea. You just might see two-inch wide "Dumbo" (an octopus whose scientific name is *Opisthoteuthis agassizii*) flutter by.

LARRY MADIN, WHOI

TRAVELING TO INNER SPACE

Until the mid-1960s, the only way scientists could collect samples from the deep sea was to dangle nets, buckets, and other devices over the sides of research ships. They scooped up whatever was within reach. The scientists learned a lot from what they collected, but they didn't know much about the environment their samples came from. It was as though they were reaching blindfolded into a big bag — they didn't know what they would pull out, or what they might have missed.

With the development of manned deep-sea submarines such as *Alvin*, this unknown world began to be revealed. More recently, oceanographic engineers have developed much smaller vehicles, remotely-controlled from surface ships to which they are connected by a tether (an electronic cable). These smaller subs, which carry no passengers, are called remotely-operated vehicles, or ROVs.

Woods Hole Oceanographic Institution has long been a pioneer in developing deep-sea research equipment. The Institution developed and operates the deep-sea submarine *Alvin*, and the ROV *Jason*. Engineers at WHOI are developing yet another new technology: a very small sub called ABE. ABE, called an AOV (autonomously-operated vehicle), will operate like a robot, untethered and with no passengers. ABE will operate following a computerized set of instructions.

In this issue, *Ocean Explorer* enters the world of deep-sea technology. You'll meet engineers who invent these devices, and scientists who are inspired by the discoveries the equipment makes possible.

SEEING IS BELIEVING: Deep Sea Dives Reveal Underwater Mysteries

Submersibles have introduced hundreds of people to the mysteries of the deep sea. *Ocean Explorer* asked two scientists to describe the impact of submersibles on their work.

THE BIG PICTURE

On her first dive in *Alvin* in 1986, WHOI geochemist Susan Humphris felt like an astronaut travelling to the moon. All the time she had spent beforehand wondering what the deep sea would look like could never have prepared her for what she saw: the utter darkness, except for a few meters that were lit up by *Alvin's* spotlights; the towering underwater rock structures that looked like mere specks on a map; the strange creatures that appeared and disappeared suddenly before the sub's portholes. Susan was also struck by "the excitement of actually seeing something I had tried to understand for so long."

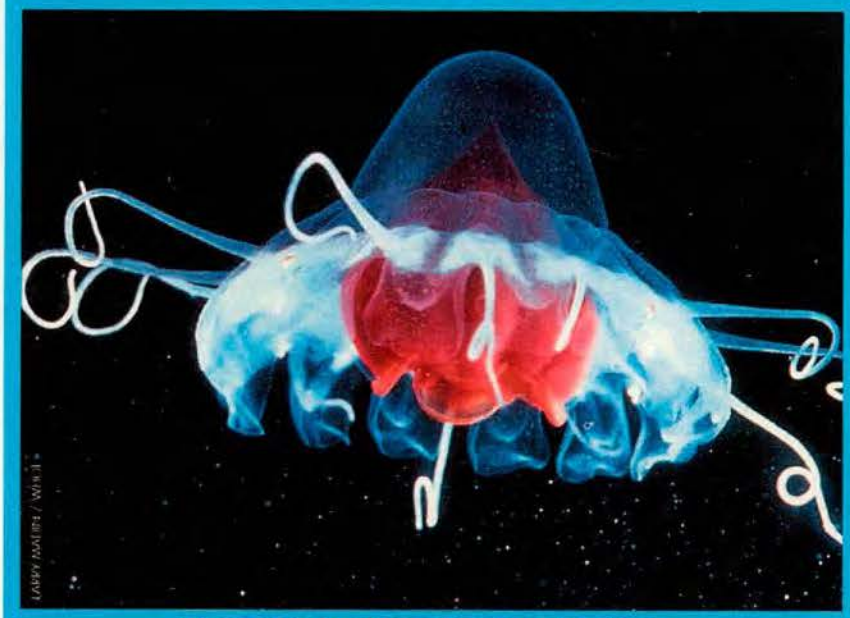
MARGARET SULANOWSKA / WHOI

Susan Humphris begins another dive in *Alvin*.

Though diving in *Alvin* can be uncomfortable, as three people crouch together inside a metal ball with a seven-foot diameter, peering out of tiny windows at the undersea world, awareness of those inconveniences disappears pretty quickly during a dive. "You're so busy," says Susan. "You're so excited and so interested in everything that you see."

Susan had studied the Mid-Ocean Ridge (the underwater mountain chain that cuts through all the world's oceans) for about fifteen years before she actually got down to see it in person. Travelling to the deep sea has changed her perspective on the meaning of the rock samples she works with. "Before I had dived in *Alvin,* I used to work with big bags of rocks that had been dredged from the ocean floor." She could learn a lot by studying the rocks, but something was missing. "I had no idea what the area they came from looked like. I didn't understand where they had been before they were collected." Now that has changed. Diving in *Alvin* has added an important dimension to Susan's scientific work.

MEETINGS WITH REMARKABLE CREATURES



LARRY MADIN / WHOI

One of the creatures that Larry Madin has observed on his many deep-sea dives is *Periphylla periphylla*, photographed during a dive in *Alvin*.

Voyagers to the deep sea have met up with many species of animals that probably would never have been seen otherwise. Each time WHOI biologist Larry Madin dives in *Alvin* or another deep-sea submarine, he hopes this will happen to him. Sometimes it does.

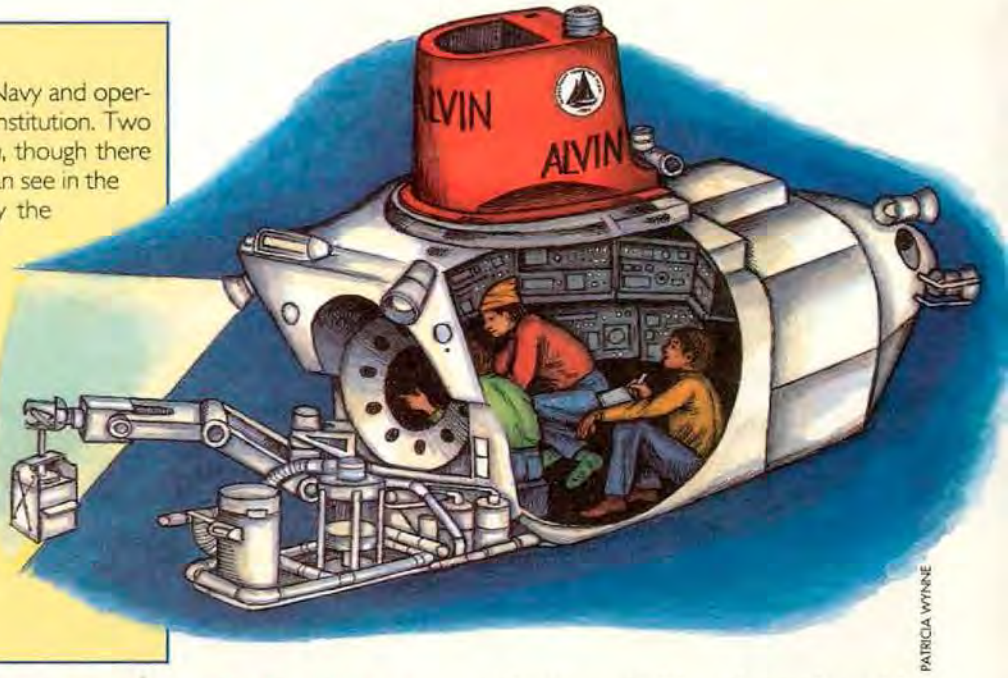
Larry studies jellyfish. Since gooey jellyfish bodies are often too fragile to collect, the best way to study jellyfish first-hand, or even to see them at all, is to travel to their world.

When Larry is on a dive and comes across a jellyfish, especially one that has not been seen before, he photographs it quickly and tries to describe as much about it as he can before it swims away, possibly never to be seen again. He describes what it looks like, how it behaves, what it eats, how it moves, and how its body works.

The weirdest creature Larry ever saw on a dive to the deep sea was a kind of jellyfish nobody had ever seen before. "Unlike most jellyfish, it had no tentacles. It was like a big open sack," says Larry. "If something swam inside, it shut, as though it were pulling a drawstring on a bag. We knew it was something that had never been seen before. It tried to eat our submarine!"

WHAT IS *ALVIN*?

Alvin is a research sub, owned by the U.S. Navy and operated by the Woods Hole Oceanographic Institution. Two scientists and one pilot can travel in *Alvin*, though there isn't much room to move around, as you can see in the drawing, in which the artist has cut away the sub's side. *Alvin* can dive to 4,000 meters (13,000 feet), deep enough to reach many, though not all, of the important features on the ocean floor. Here you see *Alvin*'s robot arm carrying a tube of deep-sea mud to the sampling basket, located directly in front of the porthole. Three video and two 800-frame 35 mm cameras are mounted outside *Alvin*, and can be operated by the scientists inside. Because there is no light in the deep sea, more than twelve lights surround the outside of the sub. An *Alvin* dive usually lasts about eight hours.



PATRICIA WYNNE

CINDY LEE VAN DOVER: Two Hats, One Head

For almost two years, biologist Cindy Lee Van Dover held two very different jobs. She was a deep sea biologist, and she was an *Alvin* pilot — the only scientist and the only woman yet to earn that position.

Biologist Cindy Lee Van Dover studies creatures that live near hydrothermal vents — warm-water oases on the deep sea floor. "I want to be the best deep-sea biologist I can be," she says. "To do that I need to see as much of the ocean floor as possible." Just about the only way to get there is by diving in a sub like *Alvin*. Many scientists want to dive to the deep sea. But very few subs can take them there. Scientists are lucky if they can get to dive even once or twice a year.

The only people who dive more often than scientists are the sub pilots themselves. Cindy realized that if she became a pilot, she would get to see a whole lot more of the sea floor. No scientist had ever become a pilot before. And no woman had, either. That didn't stop Cindy. "I'm a dreamer," she says. At first, "becoming a pilot was a daydream."

Other scientists found Cindy's desire to be a pilot surprising. "They said to me, 'What do you want to do *that* for?'" Fred Grassle, her graduate advisor, understood, though he was afraid becoming a pilot would take too much time away from Cindy's scientific career.

But Cindy was determined, and her determination won out. She was accepted in *Alvin's* Pilot-in-Training program.

As part of her training, Cindy worked as an *Alvin* technician. She had to learn everything about the sub's mechanical and electronic systems from the inside out. The chief pilot, Dudley Foster, constantly told his trainees: "Attention to detail. Attention to detail."

ROD CATANACH / WHOI

Scientist and former *Alvin* pilot, Cindy Lee Van Dover, with *Alvin*.

"It was not hard to pay attention to detail," says Cindy. "But sometimes it was hard to keep up the effort, twenty-four hours a day, seven days a week." Though most of the other pilots had some background in mechanics or engineering, Cindy had none. She was starting from scratch. After her long work days ended, she read technical manuals. "I'd study my wits out," she remembers. "I thought I'd burst with details." After a rigorous one-year training period, Cindy was awarded the dolphin pin that all submarine pilots wear.

Cindy worked as an *Alvin* pilot for twenty-one months. She was Pilot-in-Command 48 times. As a scientist or a Pilot-in-Training, she dived 15 times. Her piloting experience allowed her to spend much more time on the seafloor than she might otherwise have done.

Though she loved being a pilot, she was eager to get back to her scientific work. "It was hard to do quality science during those 21 months," she says. "I'd come back from a cruise, spend two weeks here, which was just enough time to get back into the routine of scientific work, then I'd head back to sea again to work as a pilot for several months."

These days, Cindy is focused on her scientific work once again. But she will always be glad she challenged herself to earn the dolphin pin.

NEW VIEWS OF THE DEEP: *JASON* Struts Its Stuff

JOSEPH H. BAILEY © NATIONAL GEOGRAPHIC SOCIETY

As *Jason* makes its first scientific dives, its design team works to perfect the ROV's systems

Andy Bowen at sea. Andy says a high school teacher who was an avid sailor first gave him the idea of studying the ocean.

"I'd say there is a time lag of about six years from when a new device is conceived until it is a useful scientific tool," says Andy Bowen, who builds remotely-operated vehicles and manages their operation for WHOI's Deep Submergence Laboratory. "These are very complicated systems, loaded with engineering challenges." In Andy's experience, the process of taking an idea from the drawing board to a working device is long and hard. The first prototype (working model) of *Jason* was tested in 1988. Since then, Andy Bowen and others have worked hard to modify *Jason's* design as necessary.

"*Jason* was Robert Ballard's brainchild," says Dana Yoerger, the research scientist who designed *Jason's* control system *(see page 7)*. Says Dana, WHOI geologist Robert Ballard "saw the potential of ROVs early on. He came up with the the basic idea for *Jason*. He raised the money and hired the staff to build it."

USA GARLAND

Covered with deep sea mud, Rose Petrecca works on the deck of the *Betty Chouest* during the Dump Site 106 cruise.

Last summer, *Jason* took part in its first two fully scientific missions. The first cruise took *Jason* to Dump Site 106, off the coast of New Jersey. The scientists on that mission were trying to understand if sewage sludge, dumped into the ocean from barges, was affecting deep sea marine life.

Scientists used *Jason* as their underwater eyes as they sat on the deck of a ship and watched video images made by the ROV. "It is much more comfortable to work with *Jason* than with *Alvin,*" says Rose Petrecca of the Institute of Marine and Coastal Sciences at Rutgers University, a biologist who was on the Dump Site 106 cruise and who has dived many times in *Alvin* and other submersibles. "Working with *Jason,* we could sit in the big control van and watch the deep sea through ten different television monitors. In *Alvin,* you're just looking out a very small porthole."

On that voyage, *Jason* ran into technical problems, which is typical of a new piece of equipment. For example, some fiber optic cables in *Jason's* tether broke. These very thin glass fibers are used to transmit information between the sub and the control van on the surface. Luckily, the cables were fixed.

More frustrating, the scientists were counting on *Jason* to bring up cores of mud from the ocean floor. These cores contain microscopic animals that deep-sea biologists want to study. But *Jason's* arm and claw could not easily grasp the t-bar shaped handle of the mud sampler. The t-bar sampler, a simple plastic tube, is successfully used by *Alvin's* hands. Scientists and engineers thought *Jason* could use it just as well. It couldn't. Over and over again, *Jason's* pilot patiently approached the t-bar, trying not to stir up mud on the bottom, trying to maneuver the ROV's delicate pincers into place.

After several hours, *Jason* had managed to collect six samples, when disaster struck. The pilot had directed *Jason* to plunge yet another sampling tube into the seafloor. But the amount of torque (force of rotation) necessary to collect the sample at this spot was more than anybody expected. The sub's hand was ripped off. *Jason* was quickly recalled to the surface. The engineers reattached the hand with longer screws.

Scientists like Rose Petrecca welcome the chance to work with new vehicles like *Jason,* in spite of occasional technical difficulties. "It's very exciting and beneficial for scientists and engineers to take their new instruments and inventions into the field," she says. "It gives us all practical experience. What might look good on the drawing board might not work. The only way to find out is to try it."

PATRICIA WYNNE

Jason's second scientific expedition, to the Juan da Fuca Ridge off the coast of Washington State, revealed the vehicle's great strengths at taking photographs and making measurements of an extremely large area of the seafloor.

"We figured out a way to program *Jason* to move in an 'etch-a-sketch' pattern (forward, left, back, right) over a 70 meter (230 ft.) cube-shaped path," remembers Dana Yoerger. "This allowed the scientists on the cruise to analyze the water in a specific area very precisely."

Jason's next mission will be early in 1993, when the ROV will visit the Sea of Cortez off the coast of California. In the meantime, engineers and scientists will work together to continue to enhance and improve its systems.

Inside the control van on the Dump Site 106 cruise, Dana Yoerger and others watch video images make by *Jason*.

JOSEPH H. BAILEY © NATIONAL GEOGRAPHIC SOCIETY

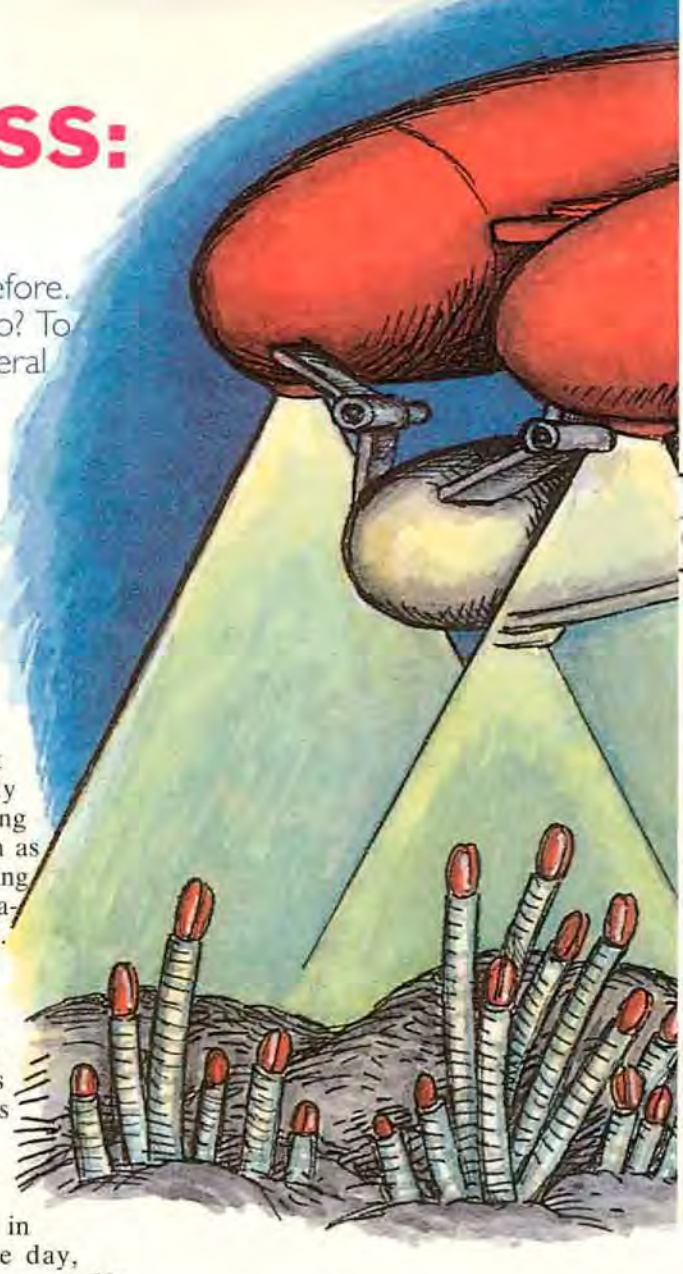
WHAT IS *JASON*?

Named for the Greek hero who searched for the golden fleece, *Jason* carries no passengers. This remotely-operated vehicle is attached to a surface ship, or mother ship, by a tether made of fiber optic cable.

An ROV is not a robot, because it depends on people to control it. On the mother ship's deck is a van filled with television monitors, scientists, engineers, and a pilot, who uses a joystick to maneuver the ROV. Those in the van watch the monitors to see what *Jason* "sees" with its three video cameras, located on the front of the sub. *Jason* also carries a 35 mm camera and other equipment. Scientists can tell the sub to take photographs which they later put together like a mosaic to show extremely large areas of the sea floor. Jason can dive to 6,000 meters (18,000 feet). Do you see *Jason*'s robot arm? It can lift, pull, push and grasp.

WORK IN PROGRESS: Making ABE

It's not easy developing a device that never existed before. What should it look like? What should it be able to do? To learn about this process, *Ocean Explorer* talked to several people who are creating a deep-sea discovery device called ABE, short for Autonomous Benthic Explorer.



PART ONE: DESIGNING ABE

At first, ABE's designers thought the new sub should be shaped like a flying saucer. A blob. A lima bean. They built a model of this lima bean and tested it underwater in a laboratory. It swooped and twisted as it dived. That was no good. ABE has to be very stable. It has to be able to travel in a straight line for about the length of a city block, without wobbling.

The team went back to the drawing board, and finally came up with a design that looked so much like *Star Trek's Starship Enterprise* that the model of ABE actually has the numbers from that more well-known craft painted on its bow (front end).

Developing a new piece of equipment is complicated, expensive, and very slow. "By the time we began designing ABE, we were already behind schedule," says Al Bradley, as he conducts a tour of his cheerful, cluttered workshop, where every surface is covered with electronic devices in various stages of construction or deconstruction. Spools of wire of ten different bright colors hang from one wall. Each wire stands for one of the numbers in the decimal system, Al explains. A soldering iron, useful for making circuit boards or, occasionally, making earrings out of cast-off electronic products, is plugged in at a workbench. Computers and other electronic devices are everywhere.

Al is an ocean engineer, though he refers to himself as a "toymaker." He invents equipment that helps scientists study the ocean. These days, Al is busy creating the electronics for a new device called ABE, short for Autonomous Benthic Explorer.

First of Its Kind

Nothing like ABE has ever been built before. When ABE is up and running, it will be able to stay underwater for months at a time, swimming on a pre-programmed track. Unlike *Alvin*, it will have no onboard pilots. Unlike *Jason*, it will not be tethered to a mother ship. It will operate completely independently, performing tasks assigned to it, such as taking pictures and making measurements of temperature and ocean currents. Between tasks, ABE will go to "sleep," returning to an underwater mooring and powering down to conserve energy until it is time for it to perform its tasks again.

The Design Team

How did Al get involved in developing ABE? "One day, Barrie Walden came to see me. He had an idea." Barrie is the manager of Operational Scientific Services at WHOI. His group is responsible for operating and maintaining vehicles, such as *Alvin*, as well as other technical devices used in oceanographic research. "Barrie knew that I had made a piece of equipment that could hit a target at the water's surface. He said, 'How about making something that can hit a target at the bottom?'"

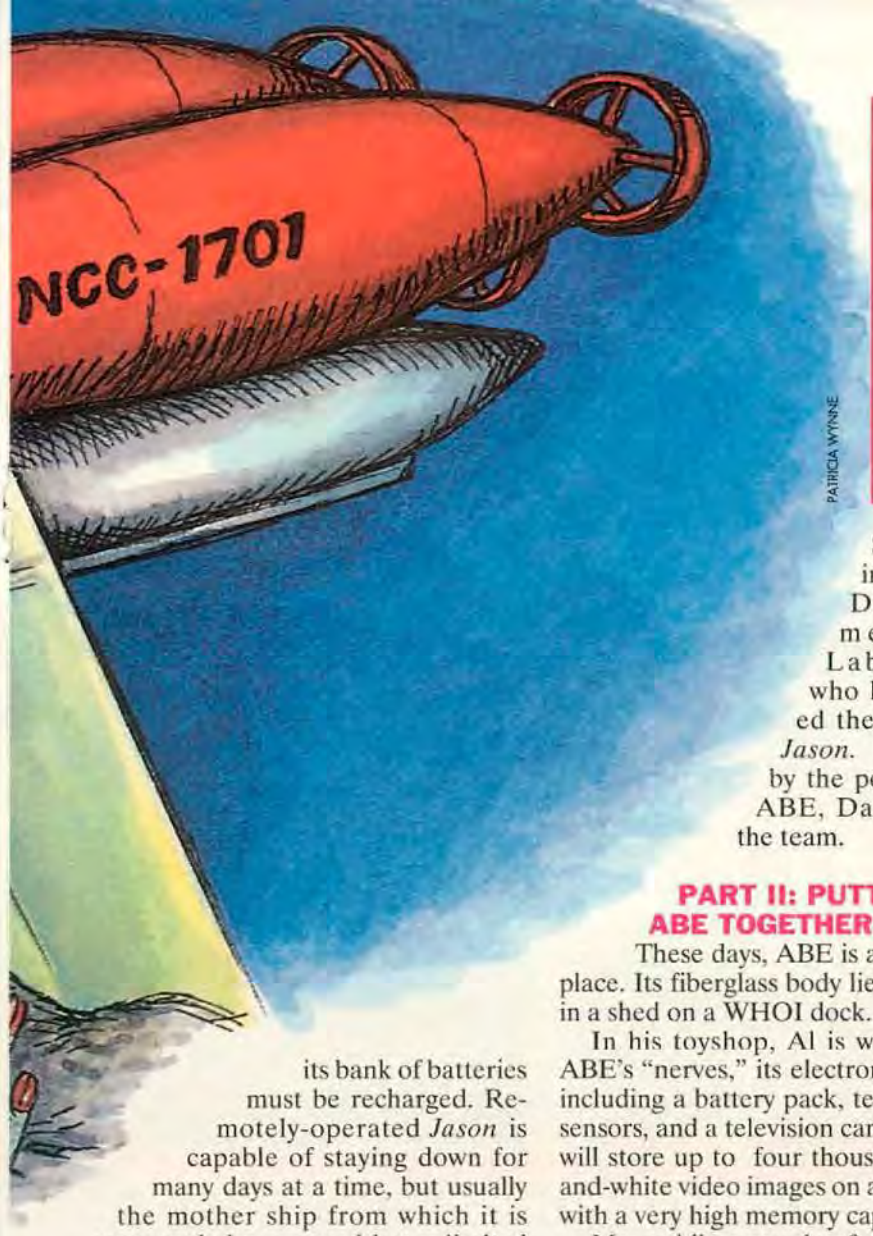
Barrie's idea was to have the deep-diving submarine *Alvin* place a beacon on the ocean floor. The device he wanted Al to help him make would be able to find the beacon, latch on to it, and then go off on research missions in certain pre-programmed directions for specified amounts of time, returning to the beacon at the end of each foray. Ideally, it could perform this same task every day for many days—up to a year.

Al Bradley in his "toyshop," with a model of ABE.

TOM KLEINDINST / WHOI

"A lot of the work that *Alvin* does is repeat business on continuing experiments," says Barrie. "Every year, we re-visit the same area." If a device could be created that could stay in one place for a long period of time, much more information could be gathered about one spot, without the cost and complications of returning frequently in *Alvin* or another sub.

Al liked Barrie's idea. He knew that scientists were often frustrated with the limited dive capability of the deep-submergence vehicles currently available. The deep-diving submarine *Alvin*, for example, can stay underwater for only six to twelve hours before



PATRICIA WYNNE

WHAT IS ABE?

An autonomous vehicle like ABE can move on its own, just like a robot: no on-board pilot, no tether to a ship floating overhead. ABE's tasks will be pre-determined by the scientists and technicians using it. They will be able to direct ABE to move around and collect data within an area about the size of a city block. For up to a year at a time, ABE will wake up, day after day, run around a track, making videos, taking photos, taking measurements, and then return to its "garage," an underwater mooring, where it will turn itself off for a certain amount of time to save power.

its bank of batteries must be recharged. Remotely-operated *Jason* is capable of staying down for many days at a time, but usually the mother ship from which it is commanded can spend but a limited amount of time in one place. An autonomous (self-sufficient) vehicle could be useful for many tasks—even if it did not have as many capabilities as a manned or remotely-operated tethered vehicle.

The Team's Task

Al and Barrie divided their tasks. Barrie, whose background is in mechanical engineering, would build ABE's body and "muscles" — its moving parts. Al, who specializes in electronics, would build its "nerves" — the systems that operate the sub's motor, its cameras, its temperature sensors. But they needed somebody to build ABE's "brain" — a control system that could teach the device to power itself up and down on command, that could tell it where to go and when, and that could instruct it to make measurements and record observations.

The right person for the job, they knew, was Dana Yoerger, a Research Scientist in WHOI's Deep Submergence Laboratory who had created the brains of *Jason*. Intrigued by the potential of ABE, Dana joined the team.

PART II: PUTTING ABE TOGETHER

These days, ABE is all over the place. Its fiberglass body lies in pieces in a shed on a WHOI dock.

In his toyshop, Al is working on ABE's "nerves," its electronic system, including a battery pack, temperature sensors, and a television camera. ABE will store up to four thousand black-and-white video images on a videodisk with a very high memory capacity.

Meanwhile a couple of miles away, Dana is creating ABE's "brain" by writing computer programs for ABE's control system that will command ABE to move up, down, sideways, forward and backward. They will tell ABE where to go, and when, and what to do when it gets where it is going.

"ABE only knows how to do a few things: wake up once a day, run around a racetrack, collect data and go back to sleep," says Dana. Still, it is the vast number of consecutive days that ABE will be able to perform its simple tasks that make it a very useful tool.

Hylas Tests ABE's Brain

To test ABE's control system, Dana uses a remotely-operated vehicle that never goes to sea. Called *Hylas,* it is named for Hercules' pageboy, who accompanied him on the quest for the Golden Fleece. The mythical Hylas was sent to shore to search for water. There he discovered a fountain. He also discovered water nymphs that were so charmed by his beauty that they convinced him to stay behind with them and live in their pool. Likewise, *Hylas* never leaves the two-story tank in which it performs its programmed tasks — except when it's hauled out at night to keep it from corroding.

When Dana uses *Hylas* to test programs for a remotely-operated vehicle such as *Jason,* he instructs it to obey commands from a joystick operated by a pilot standing on a deck above the tank. If *Hylas* is testing software for an autonomous vehicle like ABE, Dana sets some switches in a control panel that direct the sub to follow a pre-set list of instructions. As Dana says, "I let the computer fly the vehicle."

Using *Hylas* in the lab to develop software for ocean-going vehicles allows Dana to test new programs for up to a year before they become operational, making changes as necessary. "I learn lessons on *Hylas,*" says Dana. "By the time I put the control system in ABE or in any vehicle I'm developing, I want to know that my programs are going to work."

ABE's Future

In its first years of use, ABE will only be able to follow the set of instructions already in its memory when it is placed underwater. But it may get smarter in time. ABE's developers look forward to the day when an antenna attached to a mooring on the sea surface will link ABE with a satellite. The mooring-to-satellite connection is now possible. What is yet to be developed is a way for ABE to send information to the antenna attached to the mooring. When that can be done, it will be possible to change ABE's instructions while it is in the middle of a mission.

And someday, ABE's developers hope, television images will be beamed directly from ABE up to a satellite, and down to a computer on a scientist's desk anywhere in the world.

Come On Down and See Me Next Time

EMORY KRISTOF © NATIONAL GEOGRAPHIC SOCIETY

Next September, *Ocean Explorer* will visit hydrothermal vents, oases of hot water on the deep sea floor. Vents are home to all kinds of grotesque creatures, such as the *Alvinella pompejana,* or Pompeii worm, shown here. The worm is named after *Alvin,* in which the scientists who discovered it were travelling. Covered with hairlike appendages, Pompeii worms live in tubes that they build directly on black smokers, underwater chimneys that send up chemicals and very hot water — as hot as 350°C (662°F). What else is down there? Dive in with us. You'll be amazed!

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CALLING ALL OCEAN EXPLORERS!

We'd like to hear from you! Address your letters to Editor, *Ocean Explorer,* Associates Office, Woods Hole Oceanographic Institution, Woods Hole, MA 02543.

The Woods Hole Oceanographic Institution

Scientists and students of the Woods Hole Oceanographic Institution (WHOI) are internationally known for their contributions to basic research in the oceanographic sciences and oceanographic engineering as well as marine policy.

More than 170 scientists and engineers, assisted by a scientific, technical, and support staff of about 850, work in modern laboratories located both in the historic village of Woods Hole and on the nearby Quissett Campus.

Some 100 marine personnel operate our three large research vessels—R/V *Oceanus* (177 feet), R/V *Atlantis II* (210 feet), and R/V *Knorr* (279 feet)—in addition to the 25-foot, deep-diving (to 14,700 feet) submersible *Alvin*, and a small coastal research vessel, R/V *Asterias* (46 feet).

Computer support is provided for a variety of platforms throughout the Institution, with telecommunication links to other institutions. The 24-hour, open-stack library facilities operated jointly by the Marine Biological Laboratory (MBL) and WHOI are supplemented by the collections of the other institutions in Woods Hole: the Northeast Fisheries Center of the National Marine Fisheries Service and the Branch of Atlantic Marine Geology of the United States Geological Survey.

This scientifically-oriented tourist and fishing village is situated on the southwest corner of Cape Cod, Massachusetts about 80 miles southeast of Boston and 20 miles west of Hyannis.

Institution Education Programs

Students from virtually all U.S. and foreign universities that have marine interests have participated in the research at WHOI since it was founded in 1930.

The Institution's educational role, at the post-graduate level, was formalized in 1968 with a change in its charter and the signing of an agreement with the Massachusetts Institute of Technology for a Joint Program leading to doctoral (Ph.D. or Sc.D.) or engineer's degrees. Joint master's degrees are also offered in selected areas of the program. Woods Hole Oceanographic Institution is also authorized to grant doctoral degrees independently. During recent years, an average of 140 students per year have been involved in the MIT/WHOI Joint Program.

A number of Postdoctoral Scholar awards are given each year to recent recipients of doctorates in scientific and engineering fields, and there are Research Fellowships in Marine Policy and Ocean Management available to professionals in the social sciences, law, or natural sciences.

Summer Student Fellowships are awarded annually in ocean sciences and marine policy. Graduate and postdoctoral fellowships are also available for each summer's seminar in Geophysical Fluid Dynamics.

Special arrangements can sometimes be made to accommodate students who would benefit from access to the Institution's facilities outside these formal programs. These include Guest Student and Special Student appointments.

The Institution Education Programs also include educational outreach, focusing principally on K-12 teachers and curricula supplementation.

Graduate Programs
in Oceanography and Oceanographic Engineering

Students admitted to the MIT/WHOI Joint Program in Oceanography/Oceanographic Engineering have access to the faculties and the staffs as well as the extensive physical facilities of both institutions. All decisions from admission to the conferring of the degree—a single document issued by both institutions—are made by consensus of joint MIT/WHOI committees.

For qualified students whose interests are not best served by the Joint Program, programs of advanced study and research may be offered leading to the awarding of a Ph.D. in oceanography by the Woods Hole Oceanographic Institution alone. Cross-registration arrangements with Harvard University and Brown University, and other less formal cooperative agreements with other schools, provide opportunities to develop special academic study programs tailored to the individual needs of the student.

Those pursuing the Ph.D. or Sc.D. may concentrate in one or more of the following areas: chemical oceanography, marine geology, marine geophysics, physical oceanography, biological oceanography, or oceanographic engineering.

Each student formulates, with the assistance of academic advisors from each institution, a program of studies involving courses, seminars, and research activities that will provide both a general knowledge of the various fields of oceanography and an in-depth understanding of at least one major field of specialization. Doctoral degrees in the oceanography subdisciplines are offered by the Joint Program through the Biology, Marine Chemistry and Geochemistry, Geology and Geophysics, and Physical Oceanography departments at WHOI in conjunction with the Biology and Earth, Atmospheric, and Planetary Sciences departments at MIT.

Doctoral, engineer's, and master's degrees in oceanographic engineering are offered through WHOI's Applied Ocean Physics and Engineering Department and any of the following departments at MIT: Chemical, Mechanical, or Ocean Engineering, Materials Science and Engineering, Electrical Engineering and Computer Sciences, or Civil and Environmental Engineering.

Postdoctoral Awards
in Ocean Science and Engineering

Eighteen-month Postdoctoral Scholar awards are offered to recipients of new or recent doctorates in the fields of chemistry, engineering, geology, geophysics, mathematics, meteorology, physics, and biology as well as oceanography. The awards are designed to further the education and training of the applicant with primary emphasis placed on the individual's research promise.

Summer Student Fellowships

Undergraduates who have completed their junior year and beginning graduate students may apply for Summer Student Fellowships in applied ocean physics, chemistry, engineering, geology, geophysics, mathematics, meteorology, physics, biology, oceanography, or marine policy.

Each Fellow pursues an independent research project under the guidance of a member of the Institution research staff. No courses or services are required of the Fellows, but each must give a presentation of research progress at the end of the 12-week summer period and submit these results in a paper for staff review and approval. The Institution's aim in this program is to give a promising group of science and engineering students early experience in oceanographic research that will assist them in their career choices.

Research Fellowships
in Marine Policy and Ocean Management

Marine Policy and Ocean Management Fellowships are offered to professionals in the social sciences, law, or the natural sciences who wish to apply their training to investigations of problems involving the use of the oceans. The Institution's objective is to provide a year-long advanced learning experience in ocean policy problems involving the interdisciplinary application of social science and natural science to marine policy problems. Fields currently emphasized are: economics, international law, statistics, and engineering.

Summer Study
in Geophysical Fluid Dynamics

A ten-week research and study program is conducted in Woods Hole each summer to explore specific topics in the general area of geophysical fluid dynamics. Invited staff members, advanced graduate students, and postdoctoral fellows exchange ideas through lectures and seminars and work together on the formation and exploration of tractable research problems in a designated area of current interest in the field.

Traineeships
in Oceanography for Minority Group Undergraduates

The Institution offers special educational opportunities in oceanography for minority undergraduates who are enrolled in U.S. colleges or universities. These awards provide a training and research experience in Woods Hole for students who have completed at least two semesters of undergraduate study and who have academic interests in physical or natural science, mathematics, or engineering.

Traineeships may be awarded for a ten- to twelve-week period in the summer or for a semester during the academic year and may be renewed the following year. A Trainee is paid the same salary as that paid other employees with similar experience.

For information and application forms write to:

Education Office
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
Telephone: (508) 457-2000 x2200
E-mail: education@whoi.edu

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Woods Hole Oceanographic Institution

Information for Groups Visiting the WHOI Exhibit Center

The Woods Hole Oceanographic Institution (WHOI) is a private, nonprofit research and graduate education organization dedicated to the study of all aspects of marine science. Its shore-based facilities are located in the village of Woods Hole and on the 200-acre Quissett Campus, a mile and a half away.

Although the laboratories are not open to the public, WHOI maintains a small, public Exhibit Center at 15 School Street in the village of Woods Hole. Visitors of all ages are welcome, although the exhibits are focused primarily on adult audiences. The following information will answer some questions and help you with your planning.

When can we visit the Exhibit Center?

WHOI's Exhibit Center is open according to the schedule printed on the enclosed sheet. Please feel free to call (508) 289-2252 if you have questions about the schedule, or call (508) 289-2100 to hear recorded information about the Exhibit Center hours.

Is there an admission fee?

We request a donation of $2.00 per person for visitors 10 years and over.
For groups below age 10 a donation in any amount that you feel would be appropriate.

Are reservations required?

Yes, we strongly encourage advanced reservations for groups of ten or more.
The Exhibit Center is small, and parking is extremely limited; therefore, making a reservation will help you with logistics.

How do I make a group reservation?

Please call the Information Office at (508) 289 -2252 to make a reservation. Adult chaperones should accompany K-12 groups (a minimum of one adult for every ten students). We request that you call again a few days prior to your visit to reconfirm the time and number of people in your group. If you must cancel your visit, please call the WHOI Information Office (see phone number above).

Is the group size limited?

Yes, due to its small size, large groups are asked to divide into subgroups of not more than 30 and tour the Exhibit Center at different times. The ideal situation is to have half the group come to WHOI's Exhibit Center while the other half visits another place of interest in Woods Hole village [for example, the National Marine Fisheries Service (NMFS) Aquarium which is within walking distance] and then rotate groups at a prearranged time.

How much time should we allow for our visit?

This depends on group size and average age of participants but we would suggest allowing 30-45 minutes to view the exhibits and the brief repeating videos.

Who will guide us through the Exhibit Center?

Your visit to the WHOI Exhibit Center is self-guided. Usually only one or two staff members or volunteers are on duty. Group leaders are urged to visit on their own prior to bringing groups. Due to the small staff of the Exhibit Center, the nonprofit, private status of the Institution, and the large number of requests we receive, we are very rarely able to provide special programs and tours.

Is the Exhibit Center accessible to the disabled?

Handicapped parking and an access ramp to the upper level are located on Maury Lane, a side street to the left of the Exhibit Center. The building does not have an elevator, but visitors requiring handicapped access may enter the lower level off School Street via a ground-floor side door. The hearing-impaired may ask a staff member for a printed copy of the narration of our videotapes.

Is there a gift shop?

Yes, we have a gift shop offering books, clothing, jewelry, caps, mugs, and numerous other items.

Where can we eat lunch?

The WHOI Exhibit Center offers neither food service nor a lunchroom. There are fast-food establishments in Falmouth that can handle large groups. The restaurants in Woods Hole are good, but they are small and keep irregular hours in the off-season. The Food Buoy store has a deli but no tables. We suggest that you bring lunches and eat them either on the bus, or weather permitting, at the waterfront park on Water Street (see map on page 3).

Does the Exhibit Center have rest rooms?

Yes, the WHOI Exhibit Center has a single, unisex, handicapped- accessible rest room. If you are coming from a long distance, we recommend that you stop en route to allow your group to use other facilities. The nearest public rest rooms in Woods Hole village are inside the terminal at the Steamship Authority (two blocks from the Exhibit Center).

Where can we park?

Public parking in Woods hole village is extremely limited. There are meters along Water Street and paid parking at the Steamship Authority lot. Prearranged groups visiting our Exhibit Center, whether coming by bus, van, or private car, may obtain a special pass to park in WHOI's School Street parking lot. Parking in the lot is available only on a first-come, first-served basis and is limited to two hours. Parking in the School Street lot for other than visiting the WHOI Exhibit Center is prohibited, and violators will be towed at their own expense.

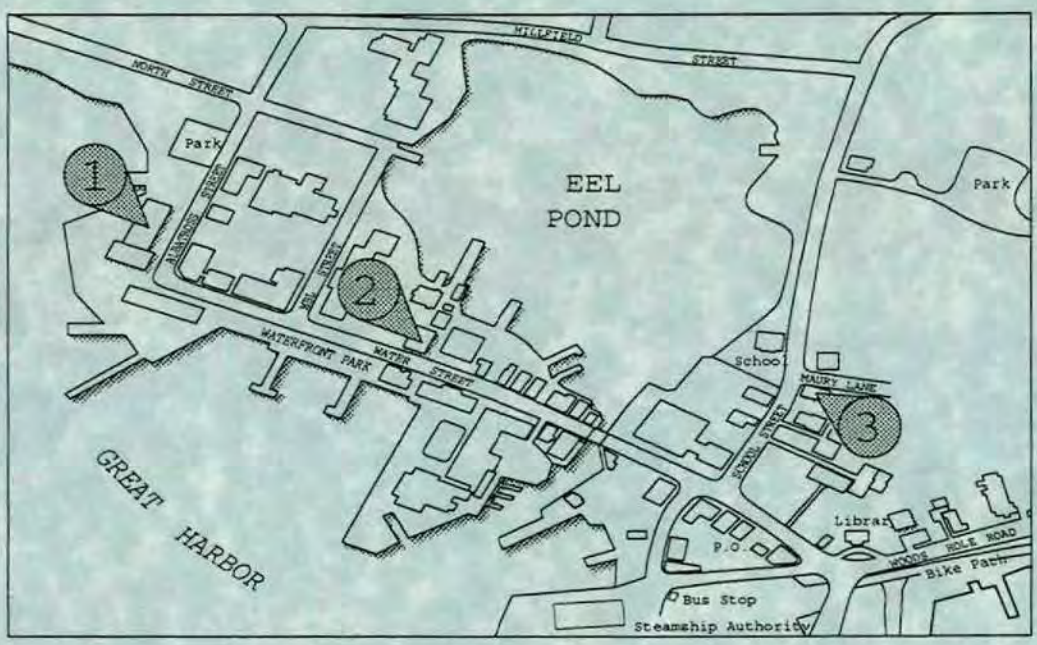
If a parking pass has not been included with this letter, please stop at the Exhibit Center upon your arrival to pick one up to display on your windshield. **Please avoid discharging passengers in front of the Exhibit Center**, since it is located on a narrow road. Instead, send one person inside for the parking pass and continue down the hill to the parking lot to unload (it is only a short walk back to the Exhibit Center).

What other public places of interest are in Woods Hole?

Aquarium, National Marine Fisheries Service (NMFS), (508)548-5123, ext. 267
Marine Biological Laboratory (MBL), (508)548-3705, ext. 423

Please note that WHOI's Exhibit Center is separate from the other public places of interest in the village of Woods Hole. You must contact other Woods Hole village organizations directly to get information and make arrangements to visit. Reservations are required for group visits to all of these sites.

We hope this information is helpful, and we look forward to your visit!



1 NMFS Aquarium 3 WHOI Exhibit Center
2 MBL

Woods Hole Oceanographic Institution

EXHIBIT CENTER

15 School Street, Woods Hole, MA

The Woods Hole Oceanographic Institution (WHOI) is a private, nonprofit research and education organization dedicated to the study of all aspects of marine science. Its shore-based facilities are located in the village of Woods Hole and on the 200-acre Quissett Campus, a mile and a half away.

Although the laboratories are not open to the public, WHOI maintains a small, public Exhibit Center on School Street in the village of Woods Hole.

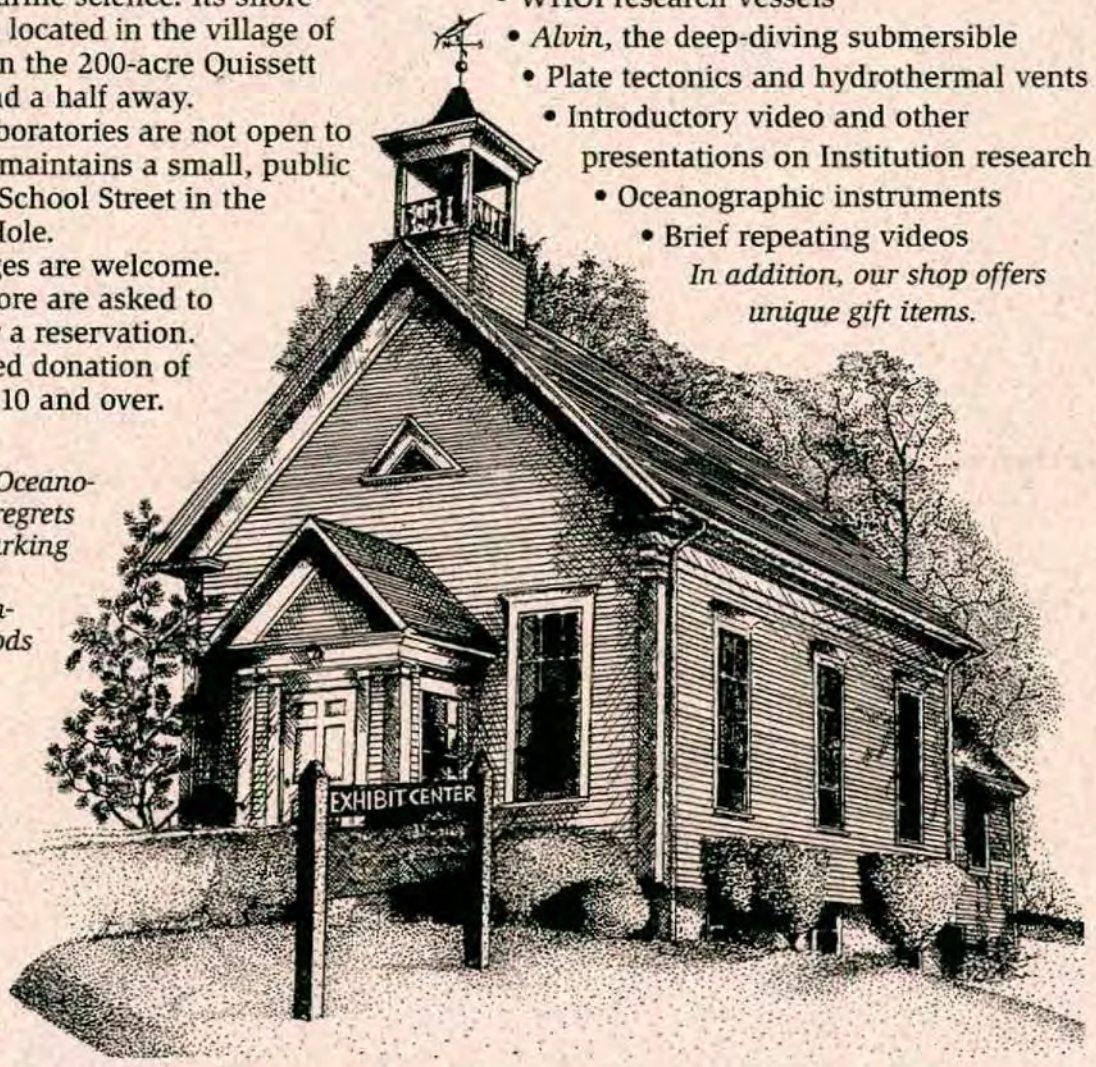
Visitors of all ages are welcome. Groups of 10 or more are asked to call in advance for a reservation. There is a requested donation of $2 per person age 10 and over. (Under 10 free.)

The Woods Hole Oceanographic Institution regrets that only limited parking is available in the village. Note that on-street meters in Woods Hole are patrolled regularly. Summer visitors are encouraged to park at the free municipal lots in Falmouth and ride the trolley to Woods Hole. Please phone ahead to make arrangements for buses or other large vehicles.

Informative & educational displays feature:

- WHOI research vessels
- *Alvin*, the deep-diving submersible
- Plate tectonics and hydrothermal vents
- Introductory video and other presentations on Institution research
- Oceanographic instruments
- Brief repeating videos

In addition, our shop offers unique gift items.



1996 Exhibit Center Hours

Closed January, February, & March

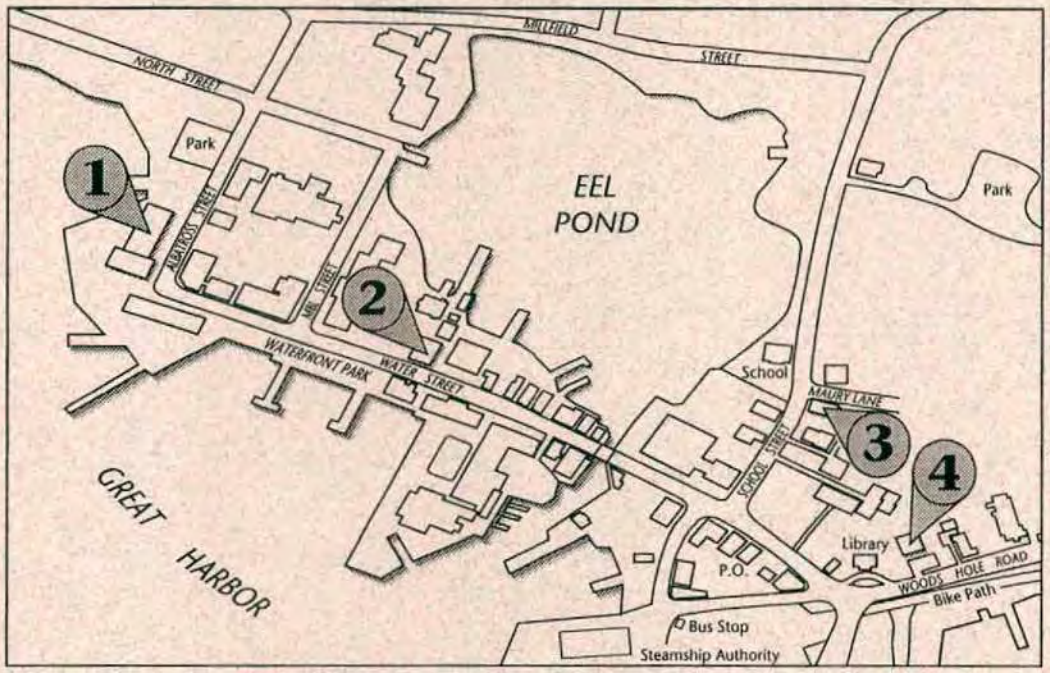
April, November & December
Friday and Saturday, 10 to 4:30
Sunday, Noon to 4:30 (except Easter, April 7)
Please call for year-end holiday hours

May, September & October
Tuesday through Saturday, 10 to 4:30
Sunday, Noon to 4:30

Memorial Day to Labor Day
Monday through Saturday, 10 to 4:30
Sunday, Noon to 4:30

For additional information please call (508) 289-2252

Things To Do In Woods Hole
1996



1. **Aquarium, National Marine Fisheries Service (NMFS)**

Albatross Street. *Summer hours:* Open daily June 17 through September 13, 10:00 am to 4:00 pm. *Winter hours:* Monday through Friday, 10:00 am to 4:00 pm. Closed for holidays during off season. Free admission.
Phone (508) 548-7684.

2. **Candle House, Marine Biological Laboratory (MBL)**

Water Street. Gift Shop. The Marine Biological Laboratory offers three afternoon tours: Monday through Friday in July and August. Tours are free, but reservations are strongly recommended. For information and reservations, visit the Candle House, Monday through Friday, 10:00 am to 4:00 pm, or contact MBL Office of Communication. Phone (508) 289-7623.

3. **Exhibit Center, Woods Hole Oceanographic Institution (WHOI)**

15 School Street. Requested donation $2.00 per person 10 and over; under 10 free. Gift Shop. *Memorial Day to Labor Day:* Monday through Saturday, 10:00 am to 4:30 pm and Sunday, Noon to 4:30 pm. *May, September & October:* Closed Monday. Tuesday through Saturday 10:00 am to 4:30 p.m. and Sunday, Noon to 4:30 pm. *April, November & December:* Friday and Saturday, 10 am to 4:30 pm and Sunday, Noon to 4:30 pm (except Easter). Please call for year-end holiday hours. Closed January, February, and March. Phone (508) 289-2252 or 289-2663.

4. **Woods Hole Historical Museum and Collection**

573 Woods Hole Road. Gift shop. *Summer hours:* 10:00 am to 4:00 pm, Tuesday through Saturday, June 18 through September 29. Exhibits feature an 1895 scale model of Woods Hole village, a display celebrating the 100th anniversary of Woods Hole Yacht Club, E.E. Swift's 19th century barn with displays of local small water craft, 1890s workshop featuring the varied interests of Dr. LeRoy Yale. Walking tours of Woods Hole village at 4:00 pm Tuesdays in summer. Special off-season hours by arrangement.
Free admission.
Phone (508) 548-7270.

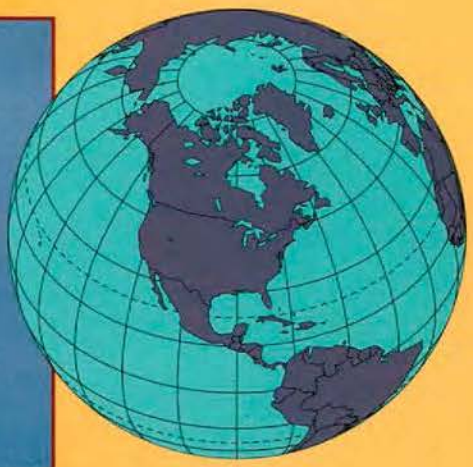
WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

Courtesy of Information Office,
Woods Hole Oceanographic Institution

VESSELS & VEHICLES

OF THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

Dave Gray



R/V Knorr
Length: 279 feet
Beam: 46 feet
Cruise Speed: 12 knots
Accommodates 24 crew and 34 scientists for as long as 60 days. Delivered in 1970, lengthened and re-outfitted in 1991. Owned by the US Navy.

The Woods Hole Oceanographic Institution has more than 60 years of sea-going research experience. This expertise is currently concentrated in two large, one intermediate, and one small research vessel as well as the submersible *Alvin*, remotely operated and automated vehicles, and several small surface craft. Scientists from this institution and many other research laboratories use these vessels and vehicles for exploration and research in all the basic marine disciplines—biology, chemistry, physics, geology, geophysics, and engineering. They use them to study marine animals from the tiniest microbes to large whales, for following and measuring currents, to discern varying chemical balances and pollutants in the ocean, to launch instruments that record seafloor earthquakes, and to study Earth's oceanic crust.

WHOI operates three of the 29 research vessels in the US academic fleet. These ships are specially designed for efficient operation by small crews. Depending on the size of the ship and the area to be studied, research cruises may last from a day to several weeks. The ships are equipped with winches, cranes, A-frames, small boats and other gear for over-the-side work, and with versatile laboratory space that is re-outfitted for each cruise.

This month a ship laboratory may be bursting with the computers and other monitoring equipment needed for geophysical research. The scientists aboard send sound through the water column into the seafloor and then receive its echoes for studies of crustal structure. Next month, the ship may accommodate aquaria, microscopes, and other equipment for studying marine animals, and after that chemists may collect and analyze thousands of water samples during their time at sea.

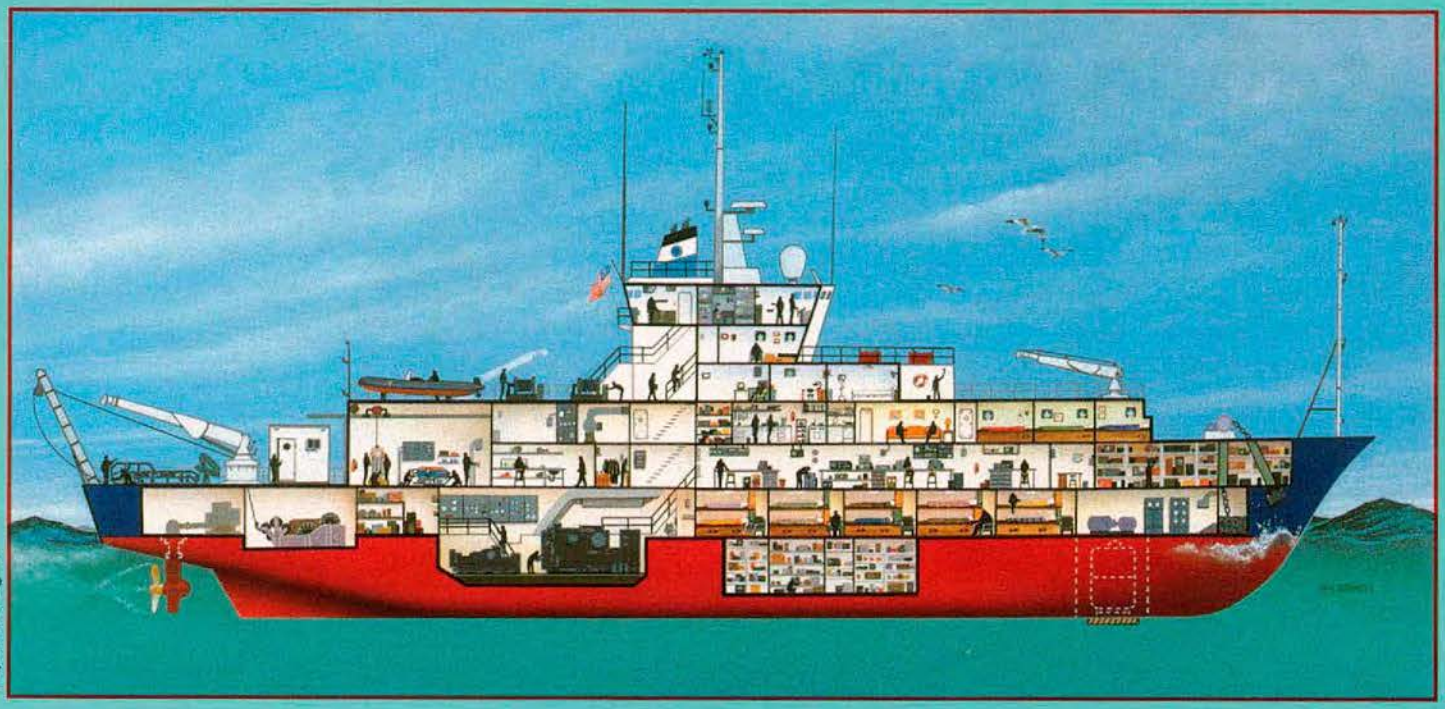
R/V Atlantis II
Length: 210 feet
Beam: 44 feet
Cruise Speed: 12 knots
Mother ship for submersible *Alvin*. Accommodates 27 crew, 19 scientists, and 9 *Alvin* crew for as long as 45 days. Delivered in 1963, converted for *Alvin* handling in 1983. Owned by WHOI.

R/V Oceanus
Length: 177 feet
Beam: 33 feet
Cruise Speed: 12.5 knots
Accommodates 12 crew and 14 scientists for as long as 30 days.
Delivered in 1975, midlife refit in 1994.
Owned by the National Science Foundation.

R/V Asterias
Length: 46 feet
Beam: 15 feet
Cruising Speed: 9.5 knots
Generally used for one-day operations, but can accommodate the captain and three scientists for several days. Built in 1979.
Owned by WHOI.

R/V Atlantis
Length: 274.5
Beam: 52.5
Cruising Speed: 15 knots
Will accommodate 22 crew and 36 scientists for as long as 60 days. Owned by the US Navy. *Under construction to replace* Atlantis II.

Research at Sea



Wayne McLoughlin

This illustration shows some of the activity on a large research vessel. It is based on the design of a sister ship of the new *Atlantis*.

The mast supports (from the top down) wind measuring instruments, warning lights, electronic and satellite navigation antennae, and the ship's primary and backup radars. The egg-shaped unit is a satellite communications antenna used for voice, fax, and high-speed data communications.

Here on the starboard side, beginning at the top level, forward, are the pilot house, the radio room, and the aft control/chart room with the captain's stateroom just below. The next level down shows a member of the crew painting near a life ring, officers' staterooms, winches, and a workboat. The top of the port-side crane is visible.

At the next level, there are three staterooms forward, the library, the scullery, and the galley.

Science storage occupies the forward area of the next deck; there is a science office, a large laboratory, the diving locker, a wet lab with running seawater, a staging bay where a remotely-operated vehicle and a water sampler are being serviced, a portable van that may be specially outfitted as a laboratory, large and small cranes, and a camera sled on the trawl wire that is threaded on the aft A-frame. Additional vans are accommodated on the other side of the staging bay.

Left to right below are the propulsion system, the trawl winch, storage, the engine room, several staterooms, bow thruster apparatus, and anchor chain storage.

Hidden from view on the port side are several laboratories, the mess, a darkroom, a workshop, the laundry, an exercise room, additional storage, and more staterooms.

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

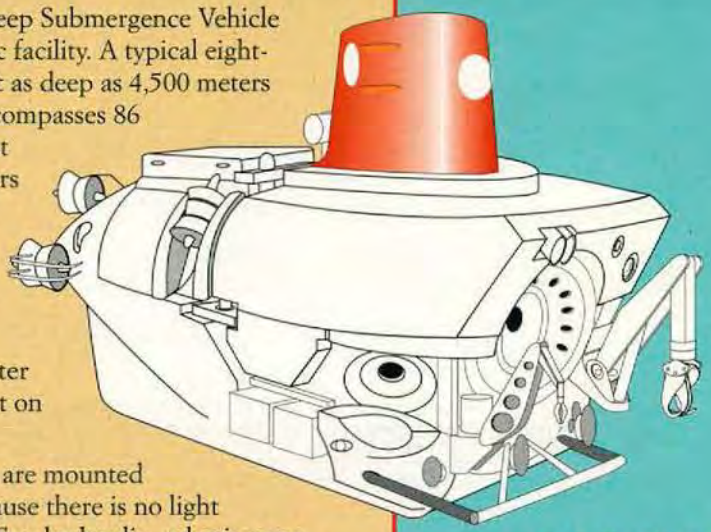
The Woods Hole Oceanographic Institution is a private, nonprofit research facility dedicated to the study of all aspects of marine science and to the education of marine scientists. With staff and students numbering about 1,000, it is the largest independent oceanographic research institution in the nation.

The 60-year-old Institution is organized into five scientific departments: Applied Ocean Physics and Engineering, Biology, Marine Chemistry and Geochemistry, Geology and Geophysics, and Physical Oceanography. Cross-disciplinary work is conducted within the departments and also under the auspices of the Center for Marine Exploration, the Coastal Research Center, and the Marine Policy Center, where social scientists work on legal and policy problems associated with human use of the oceans.

More than 350 research projects are underway at the Institution at any given time. About 140 students are enrolled in the Oceanographic's joint graduate program with the Massachusetts Institute of Technology. Postdoctoral Fellow, Summer Student Fellow, and other education programs are also offered.

For further information, contact: Information Office, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, 508-457-2000 ext. 2252.

Ship and vessel illustrations on inside by E. Paul Oberlander, WHOI Graphics. *Alvin* photo courtesy of Rod Catanach, WHOI. *ABE* photo by Tom Kleindinst, WHOI. *Jason* photo courtesy of Robert Ballard, WHOI.
Design by Jeannine Pires, WHOI Graphics.



ALVIN

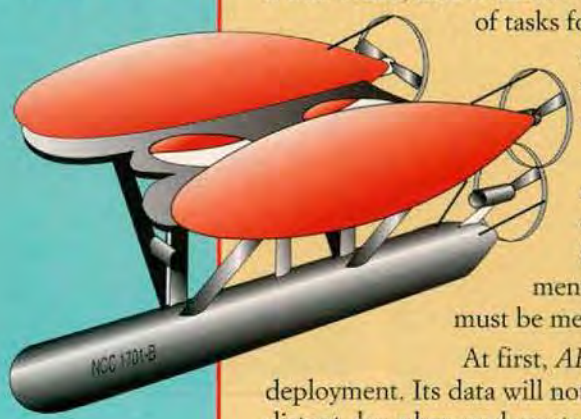
WHOI operates the US Navy-owned Deep Submergence Vehicle (DSV) *Alvin* as a national oceanographic facility. A typical eight-hour dive takes two scientists and a pilot as deep as 4,500 meters (14,764 feet), a depth capability that encompasses 86 percent of the seafloor. When working at maximum depth, it takes about two hours for the sub to reach the seafloor and another two to return to the surface. The four hours of working time on the bottom are crammed with carefully planned photography, sampling, and experiments conducted by the scientists using three 12-inch-diameter viewports. *Alvin* can hover, maneuver in rugged topography, or rest on the bottom.

Typically, three video and two 800-frame, 35-mm cameras are mounted on *Alvin*'s exterior for either automatic or selective operation. Because there is no light in the deep sea, the sub carries 12 lights to illuminate the bottom. Two hydraulic, robotic arms manipulate sampling and experimental gear specially designed to work with their "hands."

A sample basket or sled mounted on the front of the sub carries a variety of instruments that include sediment corers, temperature probes, water samplers, and a biological sample pump. Scientists using the sub can bring up to 1,000 pounds of their own gear.

Alvin is especially useful to such observational sciences as biology and geology, but marine chemists, physicists, and engineers are also among its users. The sub is probably most famous for locating a hydrogen bomb accidentally dropped into the Mediterranean Sea in 1966, for its exploration of deep-sea hydrothermal vents discovered less than two decades ago, and for its survey of the sunken ocean liner *Titanic*.

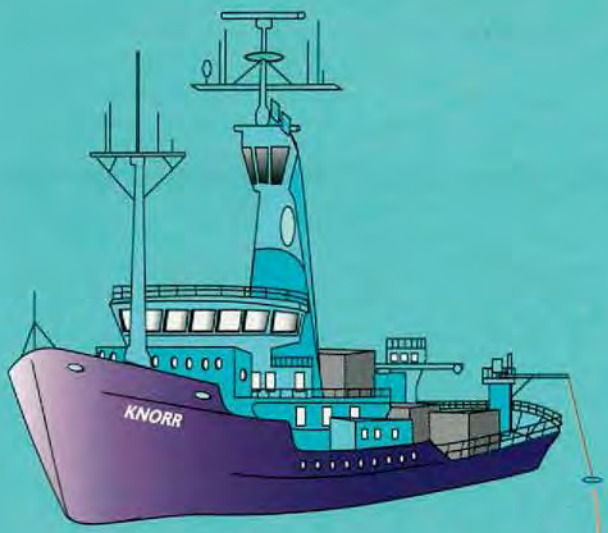
ABE



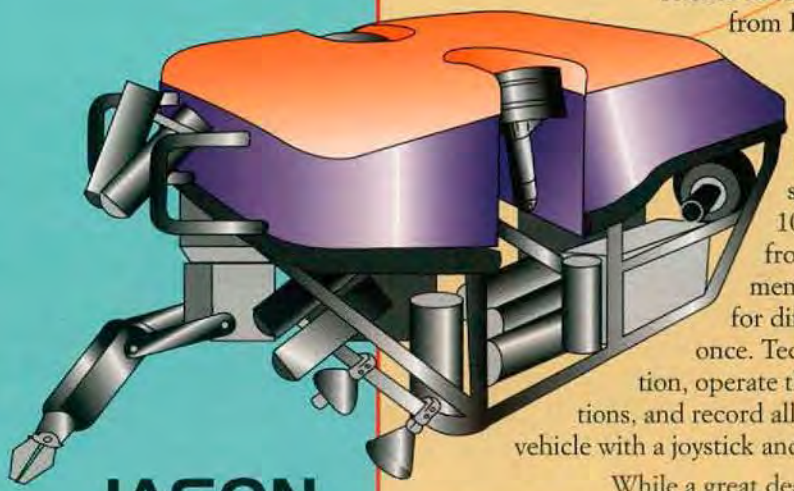
The newest underwater WHOI vehicle, named ABE for Autonomous Benthic Explorer, is the first of its kind and is still in the development stages. *ABE* was born of scientists' frequent need to monitor an area over long periods of time, which is very expensive using a surface ship or repeated visits with *Alvin* or *Jason*. *ABE* will be a true robot, able to move on its own with no pilot or tether to a ship, designed to perform a predetermined set of tasks for several months. It may, for example, be programmed to "wake up" daily and set out on a predetermined course to take photographs and collect data and samples within an area about the size of a city block. It will then "go back to sleep," conserving power for months of repeating these tasks.

ABE is being developed by a team of engineers, who are assembling what might be called the robot's body, muscles (thrusters), nerves (cabling and power to operate the motor, cameras, and sensors), and brain (computer systems for powering up and down and for determining where to go and when to make measurements). Each of these components presents a very complex design challenge, which must be met before *ABE* is placed on the seafloor to operate on its own.

At first, *ABE* will only be able to follow the set of instructions placed in its memory before deployment. Its data will not be accessible until the robot is recovered. But its developers envision the not-too-distant day when underwater acoustic data transmission systems now being developed will allow scientists anywhere in the world to receive video and data from *ABE* and to control its movement and measurements from their home laboratories.



Rather than taking scientists to the seafloor, Remotely Operated Vehicles (ROVs) bring the seafloor to the surface through television and other imaging techniques. Scientists and engineers in WHOI's Deep Submergence Laboratory spent about six years developing the complex systems that make up ROV *Jason*. Named by the laboratory's director, Robert Ballard, for the Greek hero who searched for the golden fleece, *Jason* undertook its first science mission in 1991. A smaller prototype, *Jason, Jr.*, was operated from DSV *Alvin* during the *Titanic* exploration in 1986.



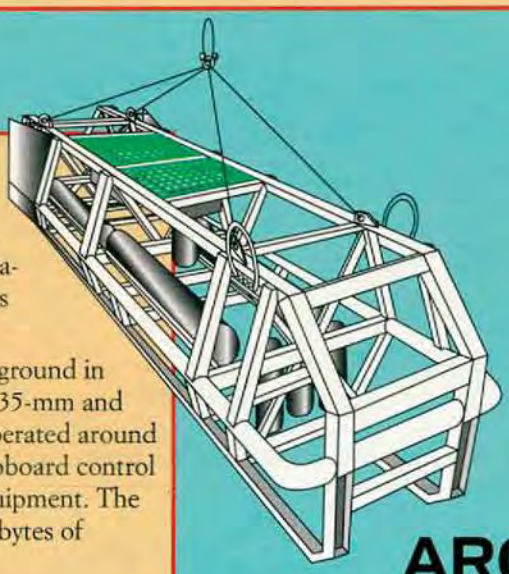
JASON

Using a specially outfitted van on the deck of the support ship, scientists watch monitors that display what *Jason* "sees" with its three video cameras, sidescan sonar, and other equipment. During *Jason* lowerings, teams of scientists and technicians work in round-the-clock shifts as a 10-kilometer-long, fiber-optic cable carries signals to and from the ROV. One scientist directs the dive, and other members of the team, seated at work stations, are responsible for different aspects of *Jason*'s operation as many tasks proceed at once. Technicians take navigation readings, record sonar information, operate the video and still cameras mounted on *Jason*, enter observations, and record all the images that are transmitted. The *Jason* pilot flies the vehicle with a joystick and may direct it to take samples using its manipulator arm.

While a great deal is learned on the cruise itself, scientists spend months, even years, analyzing the wealth of data the ROV provides. For example, various kinds of data are combined to create virtual-reality images of seafloor topography, still photographs are arranged into mosaics, and samples are cross-referenced with the images.

A great deal of oceanographic research depends upon instruments that are lowered into the water to perform various tasks. The most common, known as a CTD, makes conductivity (for salinity readings), temperature, and depth measurements that are continuously displayed in the ship laboratory. Scientists can electronically trip accompanying water sampling bottles when the readout indicates the conditions are of interest to their work.

Towed sleds, like *Argo*, allow researchers to cover a great deal of ground in lowerings that may last for several days. *Argo* carries three video cameras, 35-mm and electronic still cameras, and several different acoustic sensors. It can be operated around the clock at nearly 20,000 feet, sending acoustic and video signals to a shipboard control center, where five technicians fly the vehicle, record data, and monitor equipment. The resulting suite of data, which may include 10,000 still images and 200 gigabytes of information, requires many months of analysis following the cruise.



ARGO

Oceanus Back Issues

(While Supplies Last)

___	38:2	Marine Biodiversity I	$5.00
___	38:1	Ocean Engineering & Technology 1995	$5.00
___	37:2	Arctic Research	$5.00
___	37:1	Atlantic Ocean Circulation	$5.00
___	36:4	25 Years of Ocean Drilling	$8.00
___	36:3	Marine Protected Areas	$8.00
___	36:2	Coastal Science & Policy II	$8.00
___	36:1	Coastal Science & Policy I	$8.00
___	35:4	*Marine Geology & Geophysics	$8.00
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___	35:2	*Physical Oceanography	$8.00
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___	31:4	DSV *Alvin*: 25 Years of Discovery	$8.00
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___	23:1	A Decade of Big Ocean Science	$4.00
___	22:3	Ocean/Continent Boundaries	$4.00
___	22:2	General Issue	$4.00

*Components of Primer Set

Short descriptions of the issues listed above are available through the mailing address and phone and fax numbers shown on the order form.

Issues not listed are out of print. However, they are available on microfilm through: University Microfilms International, 300 North Zeeb Road, Ann Arbor, MI 48106, USA

Oceanus Back Issue Order Form

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Address _____

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Country* _____ Phone _____

Total Amount _____ ❑ Check enclosed ❑ Charge VISA/MC

VISA/MC number _____ Exp. Date _____

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Signature _____

Total Issues Ordered _____

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2-4 issues	$5.90
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11-15 issues	$9.95
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31-50 issues	$17.95

Mail order form to: *Oceanus*, Woods Hole Oceanographic Institution, Mail Stop #5, Woods Hole, MA 02543-1109

Phone your order to: (508) 289-3516 • Fax your order to (508) 457-2182

If enclosing a check, payment must be in U.S. funds, drawn on a U.S. bank, and made payable to: Woods Hole Oceanographic Institution.

Please allow 3 to 4 weeks for delivery. *For international orders, call or fax us your order and we will calculate applicable shipping charges.

TP01

NOW AVAILABLE

Marine Science Reading List

A 52-page booklet published in September 1995 by the joint library of the Marine Biological Laboratory (MBL) and the Woods Hole Oceanographic Institution (WHOI). Resources cited in the booklet cover these topics:

- *Aquaculture*
- *Aquaria*
- *Archaeology / Anthropology*
- *Cape Cod*
- *Marine Biology (Birds, Fish, Sharks, Invertebrates, Shells and Corals, Marine Ecology, and Marine Mammals)*
- *Marine Models in Biomedical Research*
- *Oceanography (Chemical Oceanography, History of Ocean Sciences, Marine Geology / Geophysics, Meteorology, Ocean Engineering, and Physical Oceanography)*
- *Resources and Future Uses of the Oceans*
- *Seashore*
- *Ships and Submersibles*
- *Underwater Exploration*
- *Careers in Marine Science*
- *Greenhouse Effect*
- *Pollution*
- *Science Projects*
- *Information Sources*
- *Marine Science Information on the Internet*
- *Dictionaries, Encyclopedias, Films, and Videos*

Single copies may be purchased **by mail for $2 plus tax and shipping/handling.** Checks should be payable to **WHOI** and drawn in US dollars on a US bank. Send payment to:

Woods Hole Oceanographic Institution
Information Office, MS #16
93 Water Street
Woods Hole, Massachusetts 02543-1050

Please send me the publication **Marine Science Reading List**. Enclosed is my check.

	QUANTITY	PRICE
Name: _____	_____	@ $ 2 each: _____
Address: _____		5% MA Tax: _____
City: _____ State: _____ Zip: _____		Shipping/handling: $ 1.50
		TOTAL ENCLOSED: _____

Woods Hole Oceanographic Institution

SEA GRANT PROGRAM

1994-1996 Project Guide

RESEARCH

During the 1994-1996 funding cycle, the Woods Hole Oceanographic Institution (WHOI) Sea Grant Program will support 12 concurrent research projects and several smaller "new initiative" efforts aimed at taking the first steps into promising new areas. Many of the projects address local and regional needs while others have national or even global implications. A major by-product of this research is outreach, in the form of publications, workshops and lectures. Since 1973, WHOI Sea Grant support has resulted in over 500 scientific publications including journal articles, theses, books and maps.

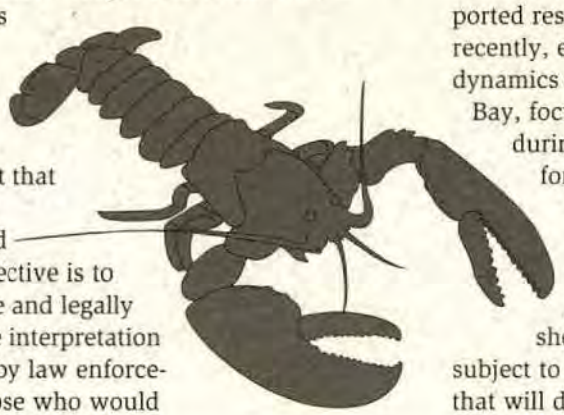
Research and outreach efforts involve the following research and academic institutions, as well as private industry: Woods Hole Oceanographic Institution, Marine Biological Laboratory, University of Pennsylvania's Laboratory for Marine Animal Health, University of Massachusetts at Dartmouth, Medical University of South Carolina, Tufts University, Molecular Probes, Inc., and Hydros, Inc.

FISHERIES AND AQUACULTURE

▶ **Development of Laboratory and Field-Based Techniques for the Detection of Illegally Altered Lobsters**

Robert A. Bullis and Roxanna M. Smolowitz, Laboratory for Marine Animal Health, University of Pennsylvania at Marine Biological Laboratory, Woods Hole.

The illegal practice of dipping female, "berried" lobsters in chlorine to remove their eggs has, according to recent reports, become increasingly widespread within the fishery. Up to now, a staining test of the swimmerets that can detect animals whose eggs have been removed by scrubbing has been successful in exposing and limiting the illegal use of berried females. The process of chlorine dipping, however, avoids detection by this method. WHOI Sea Grant is supporting the research and development of a field-based test that would be capable of detecting chlorine-dipped animals. The overall objective is to provide a comprehensive and legally sound framework for the interpretation of guilt or innocence — by law enforcement personnel — of those who would illegally remove berried females from the fishery. Once a testing mechanism has been established, a technical manual will be prepared outlining techniques, procedures and interpretations for use by the regulating agencies who monitor the lobster fishery.



▶ **Toxic Red Tides in Massachusetts Bay: Nearshore Processes and Transfer of Toxins Through the Pelagic Food Web**

Donald M. Anderson, Woods Hole Oceanographic Institution and Jefferson T. Turner, University of Massachusetts at Dartmouth.

For the past several years, WHOI Sea Grant has supported research on toxic dinoflagellate blooms. Most recently, efforts have focused on understanding the dynamics of toxic dinoflagellate blooms in Massachusetts Bay, focusing on management issues that have arisen during the construction of a controversial new outfall for sewage effluent. This area experiences recurrent episodes of Paralytic Shellfish Poisoning (PSP) and is poorly studied with respect to bloom dynamics of toxic *Alexandrium* species. Also, it is "upstream" from important offshore shellfish resources on Georges Bank that are now subject to PSP toxicity, and "downstream" from the outfall that will discharge up to 1.2 billion gallons per day of

The Woods Hole Oceanographic Institution (WHOI) Sea Grant Program supports research, education, and advisory projects to promote the wise use and understanding of ocean and coastal resources for the public benefit. It is part of the National Sea Grant College Program of the National Oceanic and Atmospheric Administration (NOAA), a network of 29 individual programs located in each of the coastal and Great Lakes states to foster cooperation among government, academia and industry.

Since 1973, WHOI Sea Grant has channeled the expertise of world-renowned ocean scientists toward meeting the research and information needs of users of the marine environment, especially in Massachusetts.

FISHERIES AND AQUACULTURE

effluent beginning in 1995 or 1996. Current research will provide data both before and after sewage effluent is diverted from Boston Harbor and is instead released from the controversial outfall nine miles offshore in Massachusetts Bay. Also, the manner in which PSP toxins accumulate in different zooplankton size fractions and fish known to be preferred food for humpback and right whales that feed in the Bay will be investigated. Knowledge gained from this study will help assess possible effects of the change in effluent discharge within the Bay with respect to *Alexandrium tamarense* bloom dynamics and the transfer of PSP toxins through the food chain.

► Biomarkers of Reproductive Damage in Coastal Shellfish Populations from Contaminated Habitats

Dale F. Leavitt and Judith E. McDowell, Woods Hole Oceanographic Institution.

The ecological effects of "in place" toxins is a problem for many coastal ecosystems as sediment reservoirs of contaminants such as PCBs and PAHs may be a long-term source even after significant reduction in point-source inputs has been achieved. This Sea Grant-supported study will provide quantitative assessments on the effects of petroleum hydrocarbons on population processes of a valuable commercial resource, the soft shell clam *Mya arenaria*. Through field collections and laboratory analyses, this study will allow predictions of changes in population parameters of this species with improvements in water and sediment quality. Also, this study will apply data to a demographic model assessing the interactive effects of contaminant exposure and other environmental variables on population dynamics of soft shell clam populations.

NOAA Coastwatch satellite image of sea surface temperature, on May 23, 1992, at 3 a.m. A warmer (darker) coastal current or plume formed principally from spring runoff from the Kennebec River (KR) in southern Maine (SM) and the Merrimack River near Cape Ann (CA) in Massachusetts was detectable in the imagery. The toxic dinoflagellate Alexandrium sp. *has been shown to be associated with the less-saline, warmer (darker) surface waters of the plume. The plume extends several hundred kilometers along the coast from the Kennebec River (KR) in Maine to the east of Cape Cod (CC) affecting nearshore shellfish and may also potentially impact shellfish resources on Georges Bank (GB) as it travels south and further offshore.*

MARINE POLICY

► Public Risk Perception and Coastal Flood Insurance

Yoshiaki Kaoru, Graham S. Giese, and Di Jin, Woods Hole Oceanographic Institution.

Coastal storms, sea level rise, and erosion represent continuous threats of flood damages to coastal residents. To date, most attention of storm and flood impacts has been devoted to monetary damages to residential and commercial properties. Flood risk as perceived by the public has not been systematically investigated, despite the fact that the public's perception of risk significantly influences policy decisions. If the risk of coastal flood as perceived by the public significantly deviates from flood risk estimated by scientists, policy makers need to decide how to weigh public risk perceptions and those of scientists in making coastal management policies. This Sea Grant-supported economic analysis will estimate the flood risk perception of coastal residents, compare these perceptions with those of expert scientists, and measure how individual socio-economic characteristics and flood risk information influence the public's willingness to pay to insure against future flood damages. The results of this project will determine the importance of public risk aversion and lead to better risk communication between the public and scientists and, as no systematic information about public perception of coastal flood risk currently exists, the results will be of use to local, state and federal coastal resource managers.

► An Optimal Risk Sharing Strategy for Marine Oil Transport

Di Jin, Hauke L. Kite-Powell, and John W. Farrington, Woods Hole Oceanographic Institution.

Under the Oil Pollution Act (OPA) of 1990, oil carriers effectively face unlimited liability in U.S. waters. Attempts by the U.S. federal government to implement regulations in keeping with OPA 90 have led to an impasse as the established marine insurance industry refuses to back certificates of financial responsibility under OPA 90. All tankers coming into U.S. ports must have such a certificate. Under this project, researchers will develop an analytical model, based on economic theory and a review of relevant factors in environmental law, damage assessment, and marine insurance, to determine the optimal level of risk sharing (liability limits) in marine transportation of oil. Also, researchers will apply the model, using empirical data on oil transport markets and spill damage assessment, to develop preliminary guidance regarding an optimal liability limit. This study will provide analytically defensible suggestions for an economically optimal level of liability to help resolve this impasse.

MARINE BIOTECHNOLOGY

▶ Molecular Probes for Cytochrome P4501A: Provision and Use in Chemical Effects in Research and Monitoring

John J. Stegeman, Woods Hole Oceanographic Institution.

Detecting and interpreting the significance of chemical effects on marine biota continues to be an important environmental and scientific issue. These studies involve the use of highly specific molecular probes for establishing the degree, sites of action, and significance of effects of critical environmental contaminants. Continuing Sea Grant support for studies of a family of enzymes, cytochrome P4501A, yield important clues about contaminant detection. This project will produce, evaluate and provide highly specific molecular probes for establishing details about marine environmental contaminants and their effects. The assessment and interpretation of chemical effects in resident biota in estuarine and marine resource species will be greatly enhanced by methods for examining cytochrome P4501A regulation in specific cells. The approaches and probes may be applied in biomarker analysis of commercial, endangered and rare species, to conclusively address questions of chemical effects in the marine environment.

▶ Detection and Quantification of Harmful Species Using Molecular Probes: Phase II

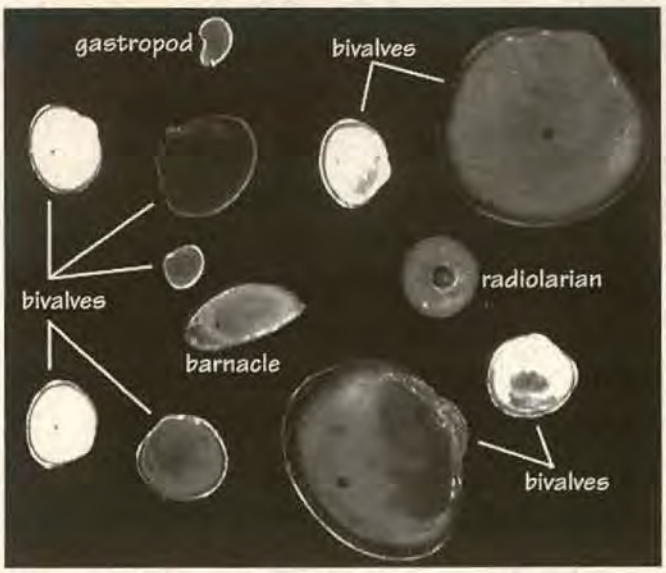
Donald M. Anderson, Woods Hole Oceanographic Institution; Victoria L. Singer, Molecular Probes, Inc.; and Gregory J. Doucette, Medical University of South Carolina.

Over the last two decades, the economic and public health impacts from harmful algal blooms ("red tides") have increased dramatically in the United States and throughout the world. One result of this expansion is that regulatory officials and the fishing industry now face a broad array of affected species spanning all levels of the food chain, many of which can be contaminated by several different toxins. These changes have forced a major reevaluation of strategies to monitor seafood products for marine biotoxins, now a time-intensive and costly process. This project — a collaboration between academia, commercial interests, and a federal marine biotoxins and seafood safety program — will investigate two promising approaches to the rapid and accurate detection and enumeration of harmful algal species, with the goal of developing molecular probe-based assays that can be used in the laboratory and the field by personnel with varied levels of technical expertise.

▶ Development of Species-Specific Immunofluorescent Markers for Larvae of Benthic Invertebrates

Cheryl Ann Butman and Elizabeth D. Garland, Woods Hole Oceanographic Institution.

The need for easy, rapid, reliable identification of benthic invertebrates and other small, morphologically indistinguishable marine organisms at the larval stage is undisputed. The recent addition of molecular methods to the arsenal of techniques for use in species identification is revolutionizing sytematics, ecology and applied science; such methods are sure to improve the state of larval taxonomy. This project will develop species-specific immunofluorescent markers for broad-scale applications in processing large numbers of field samples for planktonic larval distributions. Proving the concept and application of immunofluorescent, species-specific markers for the identification of planktonic larvae would be invaluable for monitoring environmental quality (as "biosensors" for early detection of environmental deterioration or other biological hazards); for in situ aquaculture (identification of potential food items, predators and competitors or the targeted culture species); for ecosystems research (providing information on the biggest black box in the system, larval supply); for fisheries management (providing critical information for analyses of food-web relationships); and for early detection of invasions of exotic species that may displace local dominant endemics.



During the planktonic larval phase, different species of bivalves—several of which are shown here—are extremely difficult to identify, due to subtle differences in shell shape and hinge structure. With Sea Grant support, researchers are working to develop species-specific fluorescent probes, that would enable biologists to quickly identify organisms beyond the level of major taxonomic group, to a level that has greater ecological significance and impact.

PUBLIC OUTREACH & EDUCATION

Tracey I. Crago and Sheri D. DeRosa,
Woods Hole Oceanographic Institution.

The primary goal of the WHOI Sea Grant Program's communications, public outreach and education effort is effective and active dissemination of Sea Grant information and research. Achieving this goal involves effectively translating and transferring the results of Sea Grant-supported research to individuals, agencies, and other user groups in need of information about the coastal and marine environment. The WHOI Sea Grant communications program reaches out to its audiences in an attempt to answer questions, increase environmental awareness, improve science literacy, and bridge the gap between scientific research — especially marine and coastal research — and an informed and knowledgeable public.

WHOI Sea Grant sponsors an annual, community-wide storm drain painting project. Hundreds of storm drains have been stenciled with the message "Don't Dump. Drains to Ocean."

Audiences we interact with on a frequent basis include educators, students, scientists, members of coastal outreach organizations and local regulatory agencies, visitors to the Woods Hole Oceanographic Institution, members of the general public interested in marine and coastal issues, commercial and recreational fishermen and boaters, and local business owners, among others. Some of the ways WHOI Sea Grant reaches its audiences include:

- WHOI Sea Grant's annual public lecture series, "Oceans Alive;"
- On-line accessibility to WHOI Sea Grant information and resources, as well as pointers to other useful information, via Mosaic and Gopher applications, for Internet users;
- Distribution of a WHOI "teacher packet" including materials and resources available to educators;
- Sponsorship of "Sea Urchins," an annual, hands-on, educational summer program for children ages 5-7, emphasizing exploration of the marine and coastal environment;
- Dissemination of Sea Grant and other marine-related publications and availability of the new WHOI Sea Grant publications catalog;
- Co-sponsorship, along with Massachusetts Coastal Zone Management (MCZM), of the cable access television series "SHOREWATCH: A Forum for Coastal Issues and Outreach," now reaching a potential audience of over one million viewers throughout Massachusetts and California;
- Organizing and participating in events throughout the year such as annual beach cleanups and guided coastal walks during "Coastweeks;" storm drain painting projects to inform citizens of the dangers associated with dumping waste down storm drains; feature articles in *Nor'easter* magazine, a regional Sea Grant publication, as well as contributions in numerous marine educational newsletters and magazines;
- WHOI Sea Grant's involvement in several annual educational events, including local science and technology fairs, conferences, and symposia.

A "Sea Urchin" examines his catch while exploring the seashore at Nobska Beach, Woods Hole. The program encourages a "hands-on, get-wet-and-muddy" philosophy to introduce children to the environment.

COASTAL PROCESSES

▶ Ecologically-Based Environmental Management

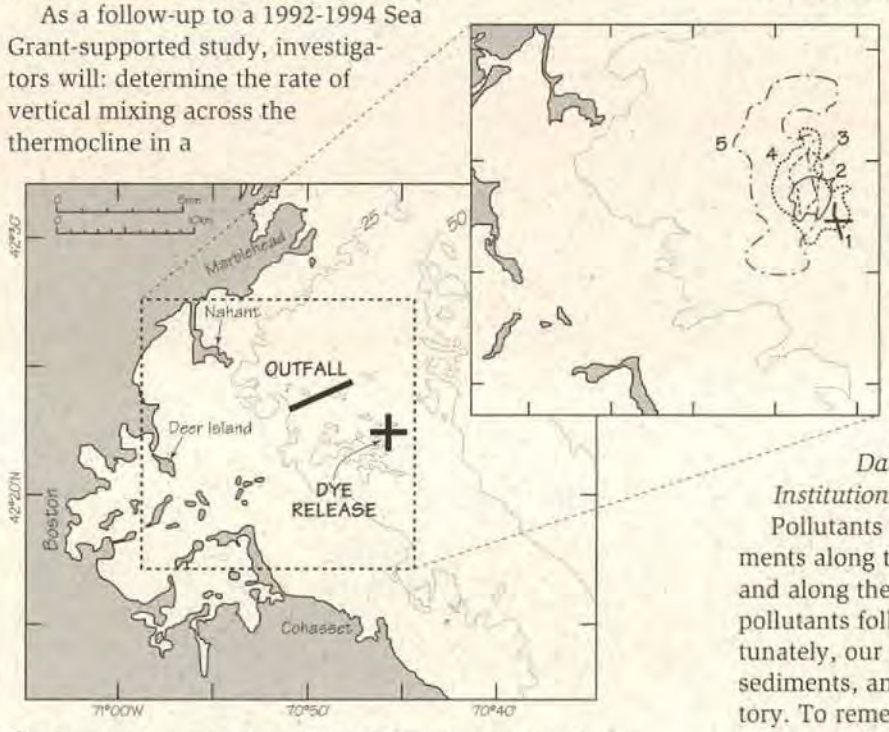
Brian L. Howes and Dale D. Goehringer, Woods Hole Oceanographic Institution.

This Sea Grant-supported study is designed to encompass all of the major ecological processes dominating the water quality and productivity of a coastal system, Nantucket Harbor: nutrient conditions, high frequency oxygen monitoring, groundwater inputs, sediment nutrient regeneration, circulation, submerged macrophyte production, and fish, shellfish and infaunal populations. By choosing Nantucket Harbor as the study site — a healthy system which has only recently begun to show signs of nutrient-related stress in some of its associated, smaller water bodies — researchers will have a basis for comparison to the many studies that look at already eutrophied waters. Also, this study represents a new approach to coastal water quality management in that it seeks to manage coastal waters at the ecosystem level, and is designed to represent a model upon which management plans for other coastal communities can be based.

▶ Boundary Mixing in Massachusetts Bay

Wayne R. (Rocky) Geyer and James R. Ledwell, Woods Hole Oceanographic Institution.

As a follow-up to a 1992-1994 Sea Grant-supported study, investigators will: determine the rate of vertical mixing across the thermocline in a boundary region of Massachusetts Bay through a controlled dye release; determine mechanisms responsible for the mixing; and determine the contribution of boundary mixing to the overall vertical exchange rate in the bay. Completion of these objectives will provide better understanding of nutrient exchanges and enable investigators to quantify the transport of natural and anthropogenic materials across the nearshore zone. Also, this study will add to the understanding of how the controversial Boston Harbor sewage outfall, now under construction, will impact Massachusetts Bay.



Rhodamine dye was released into Massachusetts Bay in the shape of a '+' in August, 1993. The vertical and horizontal spreading of the dye was monitored for the next 4 days. Horizontal spreading of the dye is depicted in the inset (numbers correspond to days, 1 being the deployment day). The spreading of the dye patch allows the mixing rates of the Bay to be quantified, which will lead to more accurate estimates of the dilution and transport of the sewage effluent.

▶ Benthic Processing of Sewage Additions: Controls of Denitrification in High Energy Environments

Anne E. Giblin and Charles S. Hopkinson, Jr., Ecosystems Center, Marine Biological Laboratory.

Another continuing project taking place in Massachusetts Bay related to the multi-million dollar Boston Harbor sewage outfall project, this study investigates the importance of benthic processing of sewage inputs into coastal waters. By looking at and comparing benthic environments with fine grained and coarse grained sediments — the latter considered a "higher energy environment" due to more intense mixing and flushing — the project will yield information such as whether different treatment options are more appropriate in some sedimentary environments than others. These results will be of use to coastal communities involved in developing nutrient loading bylaws. In addition, the project will provide information on the basic controls of benthic nutrient regeneration that are essential for further development of a linked hydrodynamic and water quality model for Massachusetts Bay.

▶ Tidal Flat Deposition: Processes and Rheology

David G. Aubrey, Woods Hole Oceanographic Institution.

Pollutants are known to accumulate with fine sediments along the coastal zone, within estuaries, in lagoons and along the open coast. The fate of some of these pollutants follows the fate of these fine sediments. Unfortunately, our present ability to predict transport of fine sediments, and therefore certain pollutants, is unsatisfactory. To remedy this problem, researchers will develop a consistent theoretical methodology to examine fine sediment deposition in tidal flats, areas that commonly surround heavily polluted harbors. The approach is to combine divergent methodologies of hydrodynamic modeling (tidal propagation and nonlinear interaction) with improved models of rheology and accurate field observations.

MARINE ADVISORY PROGRAM

Graham S. Giese and Dale F. Leavitt,
Woods Hole Oceanographic Institution.

Transferring the results of research and providing general marine-related information are important components of the WHOI Sea Grant Program. The following examples demonstrate how WHOI Sea Grant's Marine Advisory Program facilitates communication among users and managers of marine resources, including members of the fishing community, local officials, environmental regulatory agencies and the public:

• *The Directory of Cape and Islands Coastal Outreach Organizations* is a compilation of local, private, and public organizations that regularly deal with issues pertaining to the coastal and marine environment.

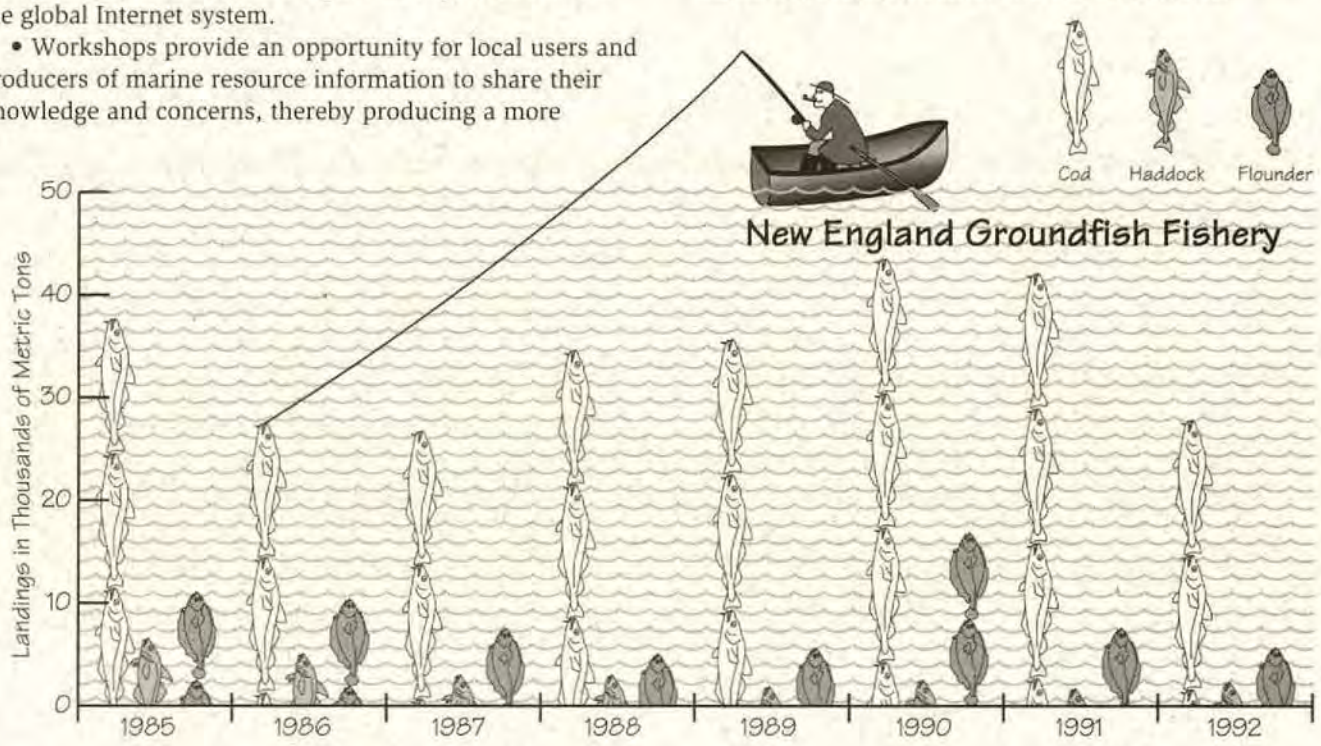
• MOGNET is a computer-based network designed to (1) link together and provide communication between the region's environmental outreach organizations, and (2) provide access by those organizations to new research results and synthesis of existing knowledge available on the global Internet system.

• Workshops provide an opportunity for local users and producers of marine resource information to share their knowledge and concerns, thereby producing a more efficient and effective resource management system.

Two areas of particular interest in the region, and therefore main focus areas of the WHOI Sea Grant Marine Advisory Program, are:

• Fishing & Aquaculture—two interrelated areas where our outreach efforts have been required. With the proposed fishing restrictions soon to be enacted in the Northwest Atlantic Ocean, many New England fishermen are looking to marine aquaculture as a means to provide an income while allowing them to continue to derive their livelihood from the sea. The WHOI Sea Grant Marine Advisory Program has been providing assistance to potential aquaculturists by conducting literature searches and providing grant writing and technological advice and referrals to help them optimize their farming efforts.

• Coastal Processes—another major focus of our outreach activities. In particular, we are striving to maintain or restore the sustainability of the region's salt marshes, beaches, dunes, and barrier beaches.



Sea Grant Program, Woods Hole Oceanographic Institution

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Sea Grant
National Sea Grant College Program

WHOI Sea Grant Educational Publications

Available by writing to the WHOI Sea Grant Program, MS #2, 193 Oyster Pond Rd., CRL 209, Woods Hole, MA 02543-1525, or by calling (508) 289-2398 (*be sure to reference publication numbers*). For publications requiring payment, please make checks payable to: WHOI.

Booklets

Marine Science Careers: A Sea Grant Guide to Ocean Opportunities

Steve Adams and Tracey Crago

A new publication geared for junior high and high school students interested in pursuing a career in a marine science-related field. The 40-page guide is also useful for college undergraduates, middle school students, and the parents, educators, and guidance counselors who will be helping them plan their futures. *Marine Science Careers* was compiled by Sea Grant as a guide to the possibilities and probabilities in this field for today and the years to come. The guide focuses on four major career areas: marine biology, oceanography, ocean engineering, and related fields. It contains question-and-answer profiles and photos of 38 marine scientists and other professionals from around the country, who represent a wide range of specialties, geographic locations, employment situations, and educational backgrounds. WHOI-E-96-001; 40 pp. $5 each (shipping included).

All About Oceanography: A Fun-Filled Activity Book

Tracey I. Crago and Lee Anne Campbell, Editors; E. Paul Oberlander, Illustrator

Not just your average coloring book, *All About Oceanography* features factual information and illustrations depicting the various disciplines of oceanography. The book, highlighting research conducted at the Woods Hole Oceanographic Institution, also includes interesting oceanography trivia, crossword and word search puzzles, and a comprehensive glossary. Examples of subject areas covered include: hydrothermal vent communities, marine exploration through the ages, the use of satellites in oceanographic research, the Gulf Stream, the hydrologic cycle, erosion, marine mineral deposits, ocean floor topography, aquaculture, red tide, the importance of computers in oceanographic research, cetaceans, the chemistry of seawater, exploring historic shipwrecks, and much more. Useful for any age, the book can be used as a coloring book, a reference book, or both. WHOI-E-92-002; 32 pp. **Special educator discounts:** 1-20 copies, $1.50 each; 21-30 copies, $1.25 each; over 30 copies, $1.10 each.

Groundwater Resource Guide

Marsha Alibrandi, et. al. (eds.)

This 8-page guide on the topic of groundwater contains information on the water cycle, the water budget, zones of aeration and saturation, hydrogeology, and groundwater pollution. Also included are classroom activities, a brief glossary, and useful references and resources for further information. WHOI-H-90-002; 8 pp. Single copies free.

International Directory of Marine Science Libraries and Information Centers

Carolyn P. Winn

The directory represents a network of cooperating libraries and information centers willing to provide assistance not only to other cooperating members, but to any investigator or interested individual seeking information in the marine sciences. The directory is available from the Office of the Research Librarian, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 **(Do not send requests to the WHOI Sea Grant Program)**. Make checks payable to: WHOI. $22.00. ISBN 0-932939-03-1.

Network for Environmental Science Education in Southeastern Massachusetts. A Resource Book for Educators.

This resource booklet lists the members of the Network for Environmental Science Education in Southeastern Massachusetts and provides basic information about their goals and programs. A complete listing of member organizations of the Network and a map showing their locations in southeastern Massachusetts is located in the centerfold of this booklet. The booklet may be of help to teachers and group-leaders who are planning environmental field trips or seeking specific information. 1991. Single copies free.

Marine Education: A Bibliography of Educational Materials Available from the Nation's Sea Grant Programs
This updated bibliography has proven useful to a wide range of educators as a tool to help students explore and understand our oceans and Great Lakes. Includes curricula and supplemental materials, including fact sheets, posters, booklets, field guides, how-to guides for classroom experiments, projects and field trips, and other useful materials. 1994. 51 pp. $2.00.

PAMPHLETS

Oceanography Reading List
(Previously issued in two versions–Young Students and Adults.) The Office of the WHOI/MBL Research Librarian recently updated and compiled the information into one publication. The new bibliography lists oceanography reading materials, films, videos, and on-line resources by category. Publications suitable for young students are so noted. $2.00.

Nor'easter Magazine Back Issues List/Order Form
This brochure lists all of the *Nor'easter* articles available since the premiere issue in the spring of 1989 through 1995, and includes a mail-order form for reprints. WHOI-L-95-001; 6 pp. No charge.

FACT SHEETS

WHOI Sea Grant-Supported Research Relating to the Boston Harbor Outfall Project
Tracey I. Crago (ed.)
This fact sheet describes the history of the Boston Harbor cleanup project and discusses three ongoing research projects supported by WHOI Sea Grant, including: toxic red tides, the role of benthic processing of sewage additions in anoxia and nitrogen cycling, and the vertical mixing processes in Massachusetts Bay. WHOI-A-93-001; 2 pp. Free.

FIELD GUIDES

Field Guides for Eastern Shore Marine Environments
Barbara Waters; illustrations by Carole Eldridge
This set of five field guides, recently reprinted by popular demand, includes: Salt Ponds, Tidal Flats, Rocky Shores and Wooden Structures, Sandy Shore and Dunes, and Salt Marsh. The oversized guides (11" x 17") describe, on one side, the characteristics of each environment, and, on the other side, illustrate a cross-section of each environment and the plants and animals that inhabit it, labeled with common and scientific names. We suggest laminating them for years of use in the classroom or in the field. WHOI-H-78-001; $1.00/set.

POSTERS

The Raindrop Journey (poster)
Barbara S. Waters
This poster follows the journey of a raindrop once it falls from the sky and into a pond on Cape Cod, Massachusetts. The story follows the raindrop through swamps, streams, rivers, wetlands, and finally to an estuary. The reverse side of the poster provides information on the Waquoit Bay Watershed, including a diagram of the area. WHOI-E-92-001; 2 pp. Single copies free.

Over the Wedge: Where Fresh and Saltwater Meet (poster)
Barbara S. Waters
Written as part of a watershed curriculum, this 12" x 18" poster is especially designed for students at the grades 3-6 level. The text on the back is written in a story format called "A Journey Through the Wedge," which describes an estuary, a marsh, and the interaction of humans and the environment. The front features a graphic depicting a "wedge" and the common plants and animals. WHOI-G-93-002; 2 pp. Single copies free.

ARTICLES

Sea Grant's Role in Marine Education
Robert D. Wildman et al.
Reprinted from *Oceanus* 33(3): 39-45. In this article, the authors summarize Sea Grant's involvement in marine education in the 21st century. The authors examine the problem of declining student enrollment in the marine science fields, compounded by rapid technological changes in those fields. The article then outlines the current educational activities of the Sea Grant College network that attempt to reverse this trend. WHOI-R-90-005; 7 pp. $1.

Women in Marine Science: Good Girls Don't?
Lee Anne Campbell
Though women have succeeded in breaking into many previously male-dominated fields in recent years, it is still unusual to find them in science and technology careers; women now earn only 16 percent of the doctorates in physical sciences, 10 percent in computer science, and 7 percent in engineering. This article, which originally appeared in the Fall 1990 issue of Nor'easter magazine, describes some of the specific trails faced by women in science, as well as the changes taking place in attitudes and institutions. The article also stresses the need for recruiting more women to the sciences. The personal stories presented here illustrate the wide variety of marine science careers that exist and the uniqueness of the women who pursue them. WHOI-R-90-010; 6 pp. $1.

Recycling Marine Science
Tracey I. Crago and Lee Anne Campbell
The community of Woods Hole-Falmouth, Massachusetts, is fortunate to have numerous programs that contribute to the recycling of marine science and education. The article, which originally appeared in the Fall/Winter 1992 issue of Nor'easter magazine, highlights various institutions, programs, and organizations in the Falmouth area which are examples of creative linkages and networking among local scientific establishments and the greater community. Similar networks between research and outreach can be set up in virtually any town, and the article includes a side-bar featuring a checklist of activities that can be undertaken in your community. WHOI-R-92-008; 5 pp. $1.

VIDEOS

Unless otherwise noted, the following videos are from WHOI Sea Grant's popular lecture series "Oceans Alive: Plain Talk on Current Topics in Marine Science Presented for the General Public." Videos are approximately 60 minutes each, and are available on a loan basis for a $3.00 fee, or for purchase at $10.00 each.

Science Fair Winners ***V1*** Falmouth High School, Falmouth Academy	*Student Science in Falmouth 1993*	3/23/93
Molly Benjamin ***V2*** Cape Cod Times	*Clammy Wynette & the Steamers: Clam Farming on Cape Cod*	3/30/93
Donald Anderson ***V3*** WHOI Biology Department	*Poisons in Your Seafood: The Myths and Realities of Marine Biotoxins and Red Tides*	4/6/93
Robert Oldale ***V4*** U.S. Geological Survey	*Geology of Cape Cod*	4/13/93
Tom Goux ***V5*** Falmouth School System	*The Maritime Muse: Songs & Poetry of the Sea*	4/20/93
Science Fair Winners ***V6*** Falmouth High School, Falmouth Academy	*Student Science in Falmouth 1994*	3/29/94
Kenney Abrames ***V7*** Saltwater Fisherman	*Saltwater Fly Fishing for Striped Bass*	4/5/94
Laela Sayigh ***V8*** WHOI Biology Department Mass. Maritime Academy	*Communication in Whales and Dolphins*	4/12/94
Chris Weidman ***V9*** WHOI Geology & Geophysics Dept.	*Clams and Climate*	4/19/94
Dave Aubrey ***V10*** WHOI Geology & Geophysics Dept.	*The Caspian Sea: Jewel of Two Continents*	4/26/94

Wayne "Rocky" Geyer ***V11*** WHOI Applied Ocean Physics & Engineering Department	*Look What the Currents Dragged In: Coastal Currents and Their Effect on Marine Debris* (Special lecture in celebration of "Coastweeks '94")	9/20/94
Madeleine Hall-Arber ***V12*** MIT Sea Grant Program	*Would you Rather be an Old Maid or a Fisherman's Wife: Social Impacts of Changing Fisheries*	2/28/95
Mary Malloy ***V13*** Sea Education Association	*Science Under Sail: History of Scientific Voyages*	3/7/95
Mark Hahn ***V14*** WHOI Biology Dept.	*Biomarkers and Bioassays: Assessing the Risks of Environmental Pollutants*	3/14/95
Science Fair Winners ***V15*** Falmouth High School, Falmouth Academy	*Student Science in Falmouth 1995*	3/21/95
Brad Butman ***V16*** U.S. Geological Survey	*Understanding the Fate of Contaminants in the Coastal Ocean: Massachusetts Bay and Deepwater Dump Site 106*	3/28/95
Mike Rice ***V17*** University of Rhode Island	*The Westport Scallop Project: An Example of University and Grass-roots Community Cooperation*	4/4/95
WHOI ***V18***	*Science and the Seas* – available on a loan basis only –	1991

WHOI Sea Grant Educational Publications Order Form

Booklets

_____ Marine Science Careers: A Sea Grant. . . ($5)
_____ All About Oceanography *(see discounts)*
_____ Groundwater Resource Guide
_____ Network for Env. Science Educ. . .
_____ Marine Education Bibliography ($2)

Pamphlets

_____ Oceanography Reading List ($2)
_____ *Nor'easter* Back Issues List/Order Form

Videos ($3 rental; $10 purchase; *please specify*)

_____ V1 _____ V2 _____ V3 _____ V4
_____ V5 _____ V6 _____ V7 _____ V8
_____ V9 _____ V10 _____ V11 _____ V12
_____ V13 _____ V14 _____ V15 _____ V16
_____ V17 _____ V18-*(loan only)*

Fact Sheets

_____ Boston Harbor Outfall Research

Field Guides

_____ Eastern Shore Marine Env. ($1/set)

Posters

_____ Raindrop Journey
_____ Over the Wedge

Articles ($1 each)

_____ Sea Grant's Role in Marine Educ.
_____ Women in Science
_____ Recycling Marine Science

POSTAGE: Please add $.50 per item, max. $3.00 (Make checks payable to: WHOI)

Name _____

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City, State, Zip Code _____

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Return this order form, with payment, to: WHOI Sea Grant Program, MS #2
193 Oyster Pond Road, CRL 209
Woods Hole, MA 02543-1525

Thank You!

Marine Science Careers

A Sea Grant Guide to Ocean Opportunities

The Need

Students thinking about careers in the marine sciences often picture themselves working with marine mammals. Within the marine science fields, however, very few scientists specialize in this area. Today's marine scientists pursue a great variety of wide-ranging careers, using the latest in technology to address the problems and issues that face our marine resources. There is a need to introduce tomorrow's marine scientists to the realities of today's marine science.

"Opportunities for people interested in environmental issues are increasing." — Frank Hall, oceanographer, Univ. of Delaware

"Exploring the Monterey Canyon is enthralling because of all the incredible creatures that inhabit the ocean depths." — Janice Tarrant, ocean engineer, Monterey Bay Aquarium Research Institute

"Oceanography is an exciting field because it combines intellectual challenges with physical adventures." — John Buck, electrical engineer, Massachusetts Institute of Technology/ Woods Hole Oceanographic Institution

"Deciding you want to be an underwater filmmaker is a little like deciding you want to be a rock star." — Bill Lovin, underwater filmmaker, Chapel Hill, N.C.

The Guide

Marine Science Careers has been compiled by Sea Grant as a guide to the possibilities and probabilities in this field for today and the years to come. The guide focuses on four major career areas — marine biology, oceanography, ocean engineering, and closely related fields — as well as on careers that involve both the oceans and the Great Lakes. It is intended for high school students, but it will also be of interest to college undergraduates, middle school students, and the parents, teachers, and guidance counselors who will be helping them plan their futures.

The Scientists

This career guide contains question-and-answer profiles and photos of 38 marine scientists and other professionals from around the country. These scientists represent a wide range of specialties, geographic locations, employment situations, and educational backgrounds. They were chosen to reflect the diversity of today's high school population rather than that of today's work force. The scientists talk about what they do, what they like and dislike about their careers, what they see for the future, and much more. The quotes printed here are a sampling of their comments.

"The hours are long and the work is hard, but the results are the most gratifying you will ever experience." — Ann Bull, marine biologist, Texas Marine Mammal Stranding Network

"Maritime archaeology is a fabulous discipline and it's new." — Carmen M. Márquez-Marín, archaeologist, San Juan, P.R.

The Source

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NOR'EASTER

Nor'easter is published twice per annum and is compiled by the Sea Grant programs of the Northeast: Connecticut, Maine/New Hampshire, Massachusetts (MIT and WHOI), New York, and Rhode Island.

Sea Grant is a national program dedicated to the wise use and conservation of marine and Great Lakes resources for the public benefit. Patterned after the successful Land Grant Act of the 1860s, Sea Grant was established in 1966 with passage of the Sea Grant Program and College Act. Funding comes primarily from the U.S. Department of Commerce's National Oceanic and Atmospheric Administration, with matching funds provided by states and private funding sources.

Please see insert for ordering information.

NOR'EASTER, Volume 1, Number 1, Spring 1989

NOR'EASTER, Volume 1, Number 2, Fall 1989

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- **In Search of the Perfect Stroke** *Carolyn Levi, MIT Sea Grant*
  The basic shape of competition oars has remained essentially unchanged since the late 1950s. However, competitive rowing is beginning to bend to modern technology. N16

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  A multibillion-dollar cleanup is now under way in Boston Harbor. But dirty sediments may muddy the water for a long time to come. N17
- **Investigators Hunt for Great Lakes Enemy #1: Zebra Mussels** *Avery Klauber, New York Sea Grant*
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- **Collision-tolerant Pile Structures: Slalom Gates for Tugs and Barges** *Steve Adams, Maine/New Hampshire Sea Grant*
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- **Harvesting Sea Urchins: A Prickly Business** *Kathleen Lignell, Maine/New Hampshire Sea Grant*
  The soft, tasty innards of the sea urchin demand a high price. But can harvesters consistently deliver a high quality product without depleting the resource? N20
- **Women in Marine Science...Good Girls Don't?** *Lee Anne Campbell, WHOI Sea Grant*
  It's still unusual to find women in science and technology careers. Successful women scientists and others explore the reasons why. N21
- **Discovery on Block Island: 2,500-Year-Old Village Predates Agriculture** *Carole Jaworski, Rhode Island Sea Grant*
  Archaeologists are exploring the site of an ancient year-round village with an economy based on marine resources. N22
- **Can the "Effluent Society" Deal with its Waste?** *Peg Van Patten, Connecticut Sea Grant*
  A billion gallons of sewage effluent are discharged into Long Island Sound every day–resulting in problems that may cost billions of dollars to solve. N23

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  Public access to the shore is a contentious issue in many coastal areas, and solutions are neither clear-cut nor simple. N24
- **Growing Fish Salad: An Experiment in Integrated Aquaculture** *Carolyn Levi, MIT Sea Grant*
  A recipe for success: Combine resource conservation, sustainable agriculture, fish farming, and on-the-job training for prison inmates. N25
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  The public loves seafood, but worries about its wholesomeness. Are the fears justified by the facts? N26
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  Extended maritime claims are constraining research in the world's coastal oceans, but with the headaches may come new opportunities for international collaboration. N27
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  While other fisheries are in decline, Maine lobsters are plentiful. But the reasons why are a mystery. N28
- **Seeking a Safer Solution to Biofouling: Boating's Billion-Dollar Burden** *Steve Adams, Maine/New Hampshire Sea Grant*
  Barnacles, seaweeds, and tubeworms that grow on ship hulls create drag, resulting in increased fuel costs. Researchers are hunting for environmentally safe and economically feasible antifoulants. N29
- **Coastal Habitat Restoration: Can the Damage Be Undone?** *Heather Crawford and Peg Van Patten, Connecticut Sea Grant*
  Restoration ecologists try to prove true the ancient Chinese adage, "What has been spoiled through man's fault can be made good again through man's work." N30

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- **Nor'plankton** *Carolyn Levi, MIT Sea Grant*
  Many of the ocean's tiniest organisms–the phytoplankton–have never been identified. But with the latest technology, researchers are finally beginning to classify and characterize these minute mysteries of life. N31
- **Troubled Waters: Taking Stock of the Gulf of Maine** *Lee Anne Campbell, WHOI Sea Grant; Kathleen Lignell, Maine/New Hampshire Sea Grant; and Melissa Waterman, Gulf of Maine Program*
  Increasing pressures from coastal development, competing resource use, and pollution are putting one of the world's most productive ecosystems at risk. Only through coordinated efforts can the Gulf's productivity be sustained for years to come. . N32
- **Hurricane Bob** *Carole Jaworski, Rhode Island Sea Grant*
  Chronology and statistics of the first hurricane to strike the Northeast since 1985. ..... N33
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  Map drawing was once painstakingly done by hand. Geographic Information Systems have changed all that, and their potential uses are just being uncovered. N34
- **Is Rainfall Polluting Our Waters?** *Peter Groffman, University of Rhode Island, and Carole Jaworski, Rhode Island Sea Grant*
  Nitrogen is a major pollutant in coastal waters throughout the world. But only recently have scientists discovered that a significant portion of that pollution is arriving in rainfall. N35
- **Scientists–The Next Generation** *Avery Klauber, New York Sea Grant*
  Sea Grant-sponsored graduate students discuss why they decided on a career in science, their interests in research, and their plans for the future. N36
- **Atlantic Salmon Restoration: An Upstream Battle** *Marie Polk, Maine/New Hampshire Sea Grant*
  With the completion of major dams by the mid-1800s, the

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NOR'EASTER, Volume 6, Number 1, Spring/Summer 1994

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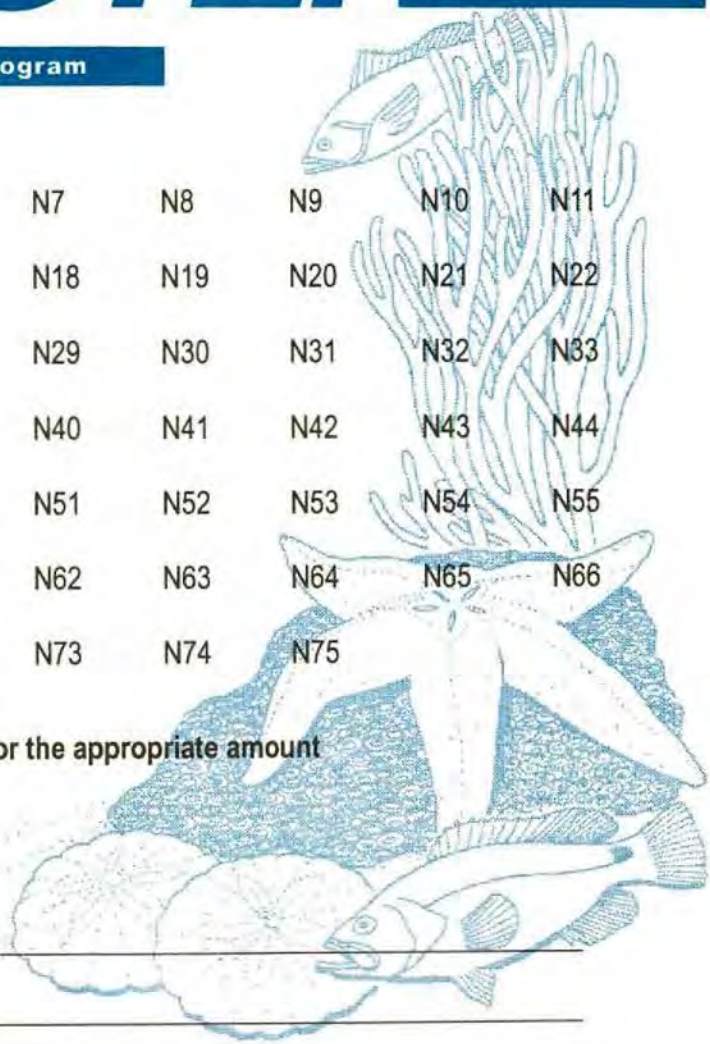

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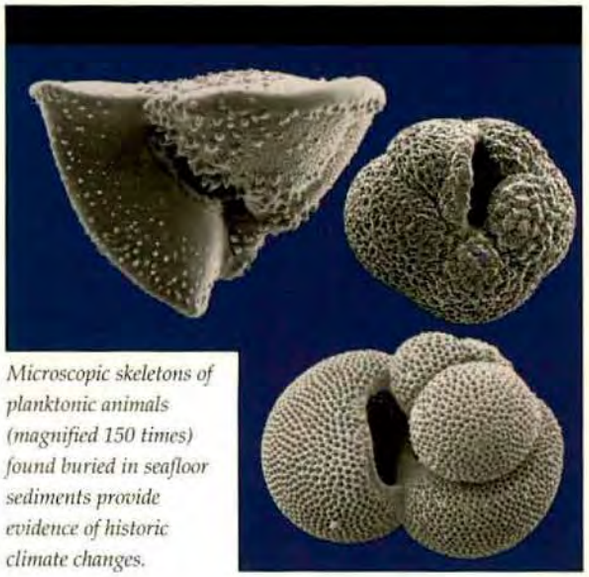


Microscopic skeletons of planktonic animals (magnified 150 times) found buried in seafloor sediments provide evidence of historic climate changes.

WHOI scientists work throughout the ocean, including this shallow-water research on clams.

Alvin, *the three-passenger deep submergence vehicle, is recovered after a dive to the bottom of the ocean.*

Woods Hole Oceanographic Institution

Woods Hole, MA 02543
(508) 457-2000
Information Office ext. 2252

THE WOODS HOLE

OCEANOGRAPHIC

INSTITUTION

The Woods Hole Oceanographic Institution (WHOI) is a private, nonprofit research facility dedicated to expanding the frontiers of knowledge about the marine world.

WHOI is the largest independent oceanographic laboratory in the world. Its shore-based facilities are located in the village of Woods Hole and a mile and a half away, on the 200-acre Quissett Campus overlooking Vineyard Sound. The staff, which numbers about a thousand, includes scientists, engineers, technicians, graduate students, postdoctoral scholars, and visiting fellows from around the world.

WHOI's ships carry investigators throughout the world ocean to conduct highly diverse research that ranges from tracking currents and pollutants in coastal waters to examining ancient climates by measuring gases trapped in tiny air bubbles frozen in polar ice.

The Institution operates many specialized laboratories with state-of-the-art equipment. Examples are an accelerator mass spectrometer used by the international oceanographic community for radiocarbon dating, and a 56-foot long flume, unique in the world for its ability to precisely simulate the flow of water at the seafloor.

The success of oceanographers is directly dependent on the tools they use to observe, take measurements, and gather samples in an unpredictable and hostile environment. WHOI's engineers, like its scientists, are world renown for their excellence and innovation. Oceanographers throughout the world use instruments developed at WHOI.

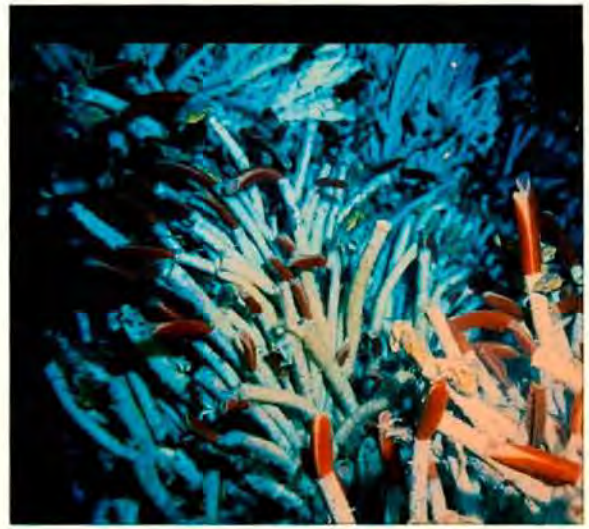
The three-person, deep-diving research submarine *Alvin* is a testament to WHOI's leadership in deep submergence engineering. With its 4,500-meter depth certification, *Alvin* can reach 86 percent of the seafloor. The Institution's engineers also have pioneered unmanned Remotely Operated Vehicles (ROVs). The *Jason/Medea* ROV system developed by WHOI's Deep Submergence Laboratory uses fiber-optic cable to send video images to banks of television monitors aboard ship. The underwater images can be transmitted live anywhere in the world via satellite.

Most of the Institution's investigators are based in five departments:

- Applied Ocean Physics and Engineering
- Biology
- Geology and Geophysics
- Marine Chemistry and Geochemistry
- Physical Oceanography

Economists and other social scientists at WHOI's Marine Policy Center assess current national and international oceanic issues, serving as a link between public policy and scientific research.

At WHOI's Coastal Research Center, investigators from all departments focus on the processes underway in the waters nearest our shores, the areas that are the most affected by the activities of human beings.



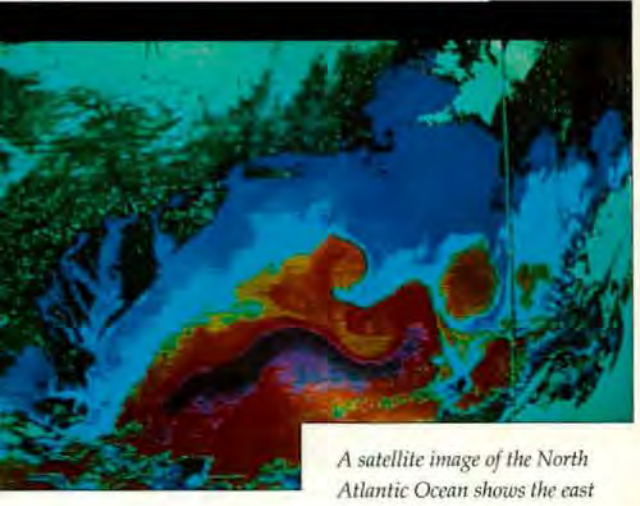
Tubeworms and other previously unknown animals living in the communities around the vents where there is no known source of light provide a laboratory for scientists studying basic life processes.

WHOI scientists work around the world, including in the Arctic and, as here, in the Antarctic.

Buoys stationed worldwide gather information about temperature, wind and current speed and direction, chemicals in the water, and interactions between air and water.

Water heated to several hundred degrees and carrying dissolved chemicals rises from underwater hydrothermal (hot water) vents, known as "black smokers," on the bottom of the ocean.

A chemist works with a mass spectrometer in his laboratory.

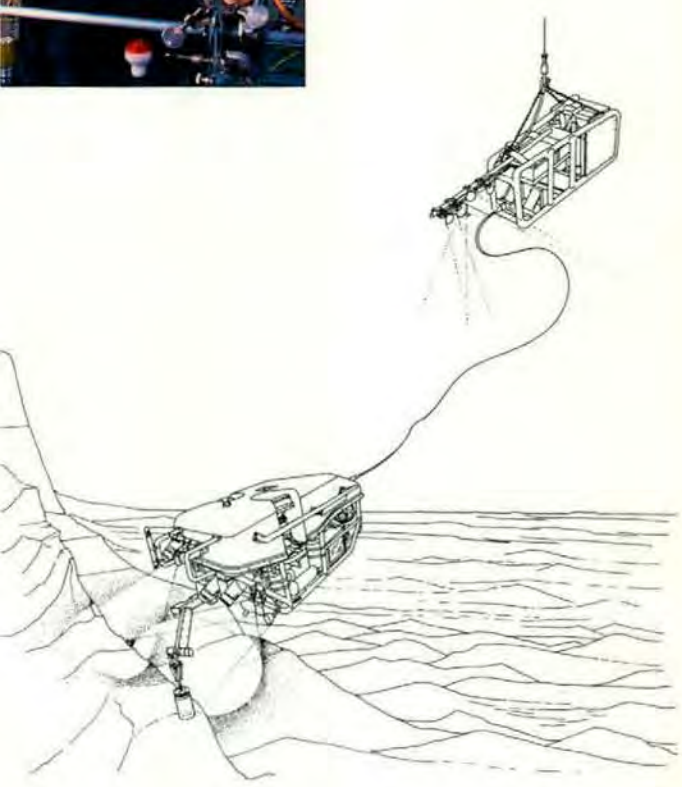


A satellite image of the North Atlantic Ocean shows the east coast of the United States and varying currents, eddies, and meanders in the Gulf Stream.

WHOI staff and students are constantly meeting the challenges of instrument development and improvement. This instument was specially designed for work on how layers of different density mix in the water column.

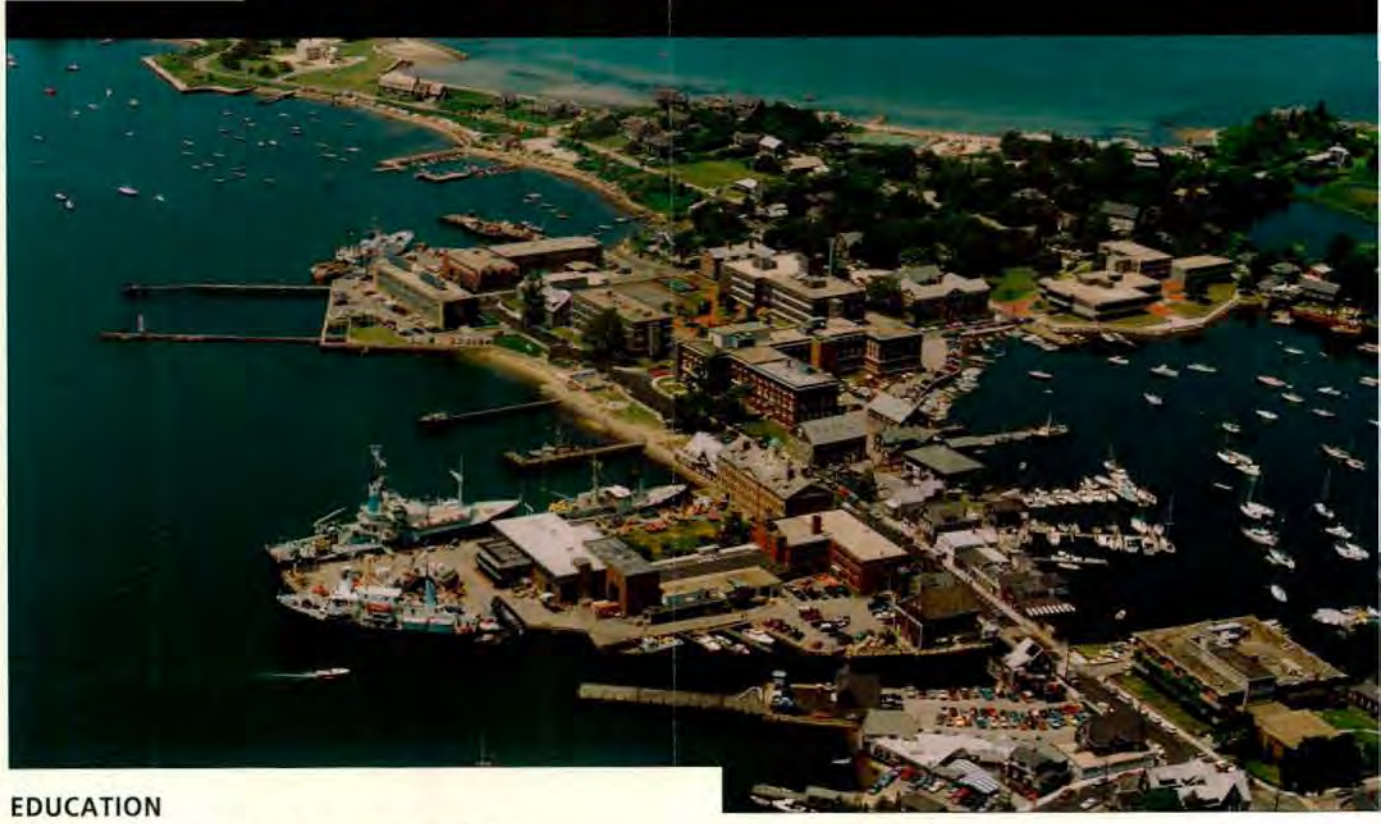
Scientists and technicians prepare an Ocean Bottom Seismometer for lowering to the seafloor where several sound sources will provide the means for recording information about the composition of the earth's crust.

A scientist prepares samples for the accelerator mass spectrometer, which dates materials such as seawater, ice, and sediment by measuring the isotopes of carbon.



Remotely Operated Vehicles (ROVs) include the Argo/Jason *system developed by WHOI engineers and technicians.* Jason's *cameras and sensors send images and information up the fiber-optic cable to scientists viewing monitors on a ship, where they also control* Jason's *actions with a "joystick."*

WHOI operates three ocean-going ships ranging in size from the 177-foot Oceanus *(second from right) and the 210- foot* Atlantis II *(second from left) to the 279-foot* Knorr *(left). A fleet of shallow-water vessels includes* Asterias, Mytilus *(far right), and several outboard power boats.*



EDUCATION

Education is an important part of the Institutions's mission. In 1968 WHOI and the Massachusetts Institute of Technology (MIT) established the Joint Program in Oceanography/Applied Ocean Science and Engineering. Every year, about 140 graduate students in the Joint Program work toward master's or doctoral degrees, either in Woods Hole or at MIT in Cambridge, Massachusetts.

WHOI offers 12- to 18-month fellowships to postdoctoral scholars, and summer fellowships to recent college graduates and undergraduates who have completed at least their junior years. In addition, guest students at both the graduate and undergraduate levels spend varying amounts of time at the Institution working with individual scientists in the laboratory or at sea.

The Institution also hosts workshops for college science teachers and participates in other projects that benefit a spectrum of educators.

For further information on education programs, contact:

Education Office
Woods Hole Oceanographic Institution
Woods Hole, Mass, 02543
(508) 457-2000 ext. 2200

OCEANOGRAPHY: A GLOBAL SCIENCE

The ocean, which covers some 70 percent of our planet's surface, is the single largest environment on earth. But the marine world encompasses much more than the sea. It embraces

- rivers, estuaries, marshes, and coasts;
- the chasms, mountains, and trenches at the seafloor, among the deepest and tallest structures on earth;
- the midwater regions where most marine life exists; and
- the sunlit waters where plants are able to photosynthesize, and where critical gases pass to and from the atmosphere in a complex process that determines the climate and, ultimately, the weather for the entire world.

Oceanographers specialize in various scientific disciplines, including biology, chemistry, geology, physics, and meteorology. In keeping with oceanography's intrinsically multidisciplinary nature, many marine scientists combine their fields of expertise into, for instance, biogeochemistry or geophysics.

WHOI'S HERITAGE

It wasn't until the late 19th century that a name was applied to the science of the sea. The great European research expeditions of the 1800s measured the depths of the deep ocean, and the salinity and temperature of different water masses. These expeditions also recorded the surprising diversity of marine life and the characteristics of bottom rocks and sediment.

In 1927 a National Academy of Sciences committee concluded that it was time to "consider the share of the United States of America in a worldwide program of oceanographic research." The Academy recommended establishing a permanent independent research laboratory on the east coast to "prosecute oceanography in all its branches." Thus, the Woods Hole Oceanographic Institution was founded in 1930 with a $3 million grant from the Rockefeller Foundation to support about a dozen scientists, to build a laboratory, and to commission a research vessel, the 142-foot ketch *Atlantis*.

FUNDING OCEAN SCIENCE RESEARCH

Each investigator decides what research problems to pursue. It is also the scientists' responsibility to acquire funding to support their research.

Most of the Institution's annual operating budget of some $90 million is supported by federal research grants, awarded through competition, primarily from the National Science Foundation and the Office of Naval Research. The balance, about 20 percent, is provided by philanthropic contributions and endowment income. Corporations also support research projects underway at the Institution.

PUBLIC INFORMATION

The WHOI Exhibit Center, located on School Street in Woods Hole, is open to the public Tuesday to Sunday from mid-May through October, and on most weekends the rest of the year. This small museum features various displays and short movies, including underwater video of RMS *Titanic* taken when WHOI investigators visited the long lost luxury liner.

The WHOI Publication Package includes the semiannual *Oceanus* magazine (reports on WHOI research), *Woods Hole Currents* (a tabloid-size newsletter featuring lively descriptions of research, profiles, and institution news), and *Ocean Explorer* (an educational publication that fosters an interest in the marine environment and ocean science among 11-to-13-year olds). The package is available for $25 ($40 outside the U.S. and Canada) from:

WHOI Package Service Center
P.O. Box 6419
Syracuse, NY 13217
1-800-825-0061

WHOI Sea Grant, part of the National Sea Grant College Program, supports research and education initiatives, such as public lectures, to promote the wise use of the ocean. Projects typically address fisheries, pollution, coastal erosion, and the development of marine resources.

MEMBERSHIP OPPORTUNITIES

The Woods Hole Oceanographic Institution has three membership programs for those interested in ocean science research and Institution activities. The Associates Program offers subscriptions to *Oceanus*, *Woods Hole Currents*, and *Ocean Explorer*, a schedule of educational and social events, and a variety of additional benefits. Associates contribute intellectually and financially to the Institution. Memberships start at $100, are partially deductible to the extent allowed by law, and support the Institution's unrestricted funds. The Friends Program, at $15 (also tax deductible to the extent allowed by law), entitles members to a *Woods Hole Currents* subscription, as well as other informational materials from time to time. The Young Associates Program offers junior-high-school-age children and/or classroom teachers a subscription to *Ocean Explorer* and an annual poster for $15. For more information about membership opportunities, contact:

The Associates Membership Office
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
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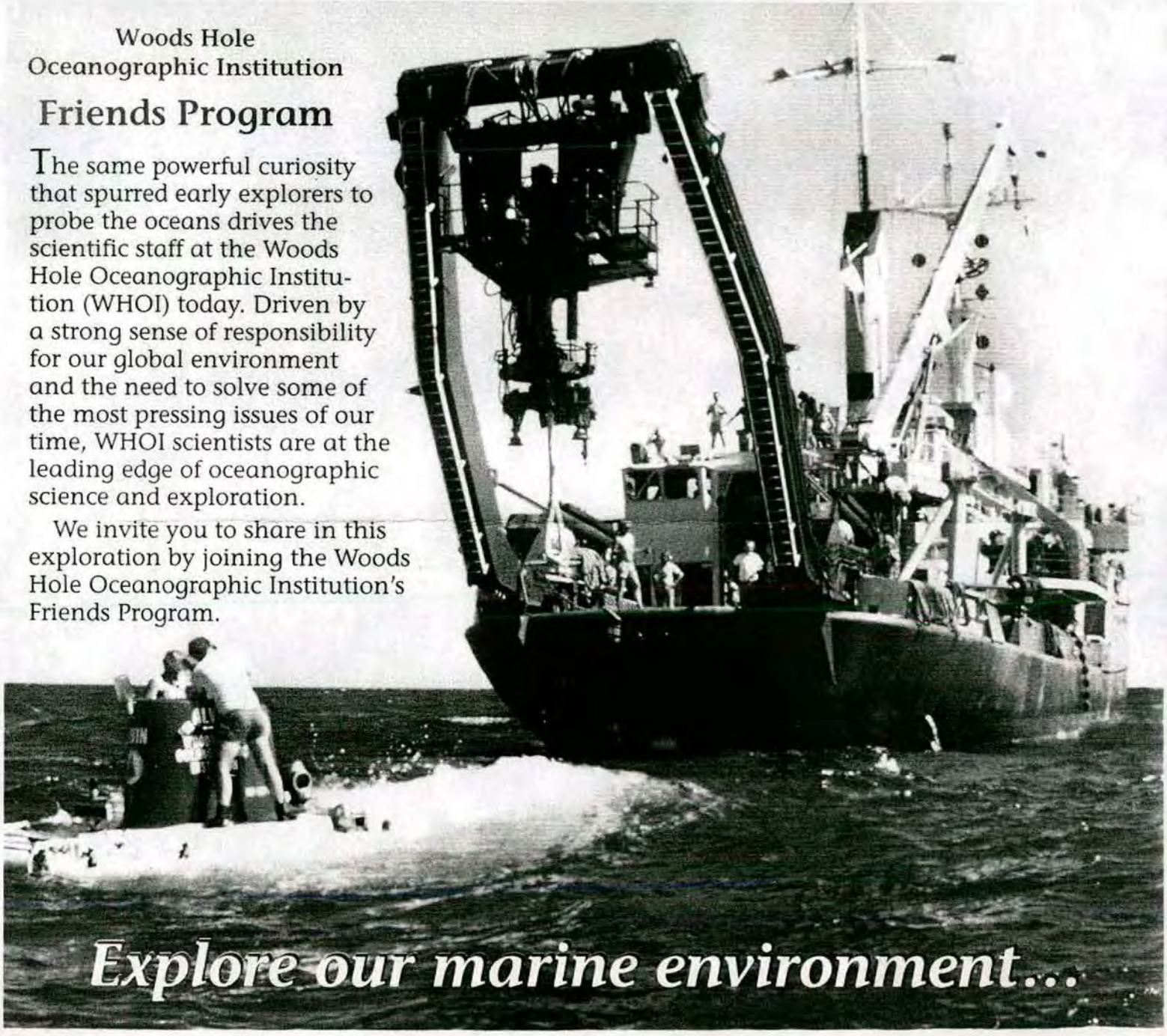
Friends Program

The same powerful curiosity that spurred early explorers to probe the oceans drives the scientific staff at the Woods Hole Oceanographic Institution (WHOI) today. Driven by a strong sense of responsibility for our global environment and the need to solve some of the most pressing issues of our time, WHOI scientists are at the leading edge of oceanographic science and exploration.

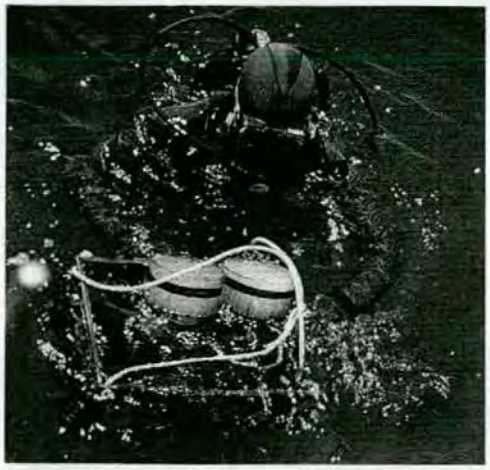
We invite you to share in this exploration by joining the Woods Hole Oceanographic Institution's Friends Program.



Explore our marine environment...

more study before we fully understand how it works.

- Most of the planet's earthquakes and volcanoes occur deep beneath the sea, but can have a devastating impact on land. To better predict these events, they require further research.



The Friends Program

You can get closer to our exciting and important research by joining the Friends Program today. You'll explore the world's oceans and waterways with our scientists through our quarterly publication, *Woods Hole Currents*. Once you join, you'll also receive information about exclusive events and unique travel opportunities.

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Make checks payable to: Woods Hole Oceanographic Institution. Contributions are tax deductible to the extent allowed by law.

What is Oceanography?

At the Woods Hole Oceanographic Institution, we study the organisms that live in the ocean, sediments that lie beneath the sea, and the flow of water around the planet. We study the forces responsible for world climate and natural disasters, and also look at biodiversity, waste disposal, and coastal pollution.

What is the Woods Hole Oceanographic Institution?

The Woods Hole Oceanographic Institution is a private, nonprofit institution dedicated to oceanographic research and education. Working around the globe, the Institution has developed an unprecedented record of excellence in oceanographic sciences, technologies and expeditions. WHOI operates three ocean-going ships, the manned deep submersible *Alvin*, several Remotely Operated Vehicles (ROVs), including *Jason*, and a fleet of vessels for coastal use.

Why is the research at Woods Hole Oceanographic Institution so important?

Without the ocean, life as we know it on our planet could not exist...

- The ocean covers more than 70% of the planet's surface, making it the earth's largest but least explored environment.
- By volume, the ocean comprises some 99% of our planet's habitable living space, yet we know little about this vast ecosystem.
- Ocean currents redistribute around the globe the vast amount of heat contained in the seas, moderating climate and generating

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W•H•O•I PUBLICATIONS

- *Oceanus*
- *Woods Hole Currents*

W•H•O•I PUBLICATIONS

Readers interested in the work of the Woods Hole Oceanographic Institution have two options for receiving WHOI publications:

1) • ***Oceanus*** magazine, a semi-annual report on research at the Woods Hole Oceanographic Institution, is available for $15.00 annually in North America, $25.00 annually outside North America. The 28- to 36-page publication is written by WHOI scientists, edited for a lay audience, and illuminated with full-color photographs and illustrations. Each issue provides several articles on a single theme, such as biodiversity, Atlantic Ocean circulation, or research in the Arctic. Formerly a quarterly publication that treated general ocean science and policy, the magazine now focuses on WHOI research.

2) The **WHOI Publication Package**, annual fee $25 in North America, $40 outside North America, brings readers *Oceanus* and the magazine-style newsletter *Woods Hole Currents*.

Woods Hole Currents is a quarterly publication for WHOI Associates and Friends. It offers lively descriptions of oceanographic expeditions and laboratory accomplishments, profiles WHOI people, discusses marine policy issues, and reports institution news.

WHOI Membership Opportunities

Two membership programs are available to those interested in the research and activities of the Woods Hole Oceanographic Institution.

The **Associates Program** offers an annual schedule of educational and social events, subscriptions to the publications included in the WHOI Publication Package, and a variety of other benefits. Associates memberships start at $100, are partially tax deductible to the extent allowed by law, and support the Institution's unrestricted funds.

The **Friends Program**, at $15 (also tax deductible to the extent allowed by law), entitles members to a *Woods Hole Currents* subscription and other informational materials.

For additional membership information, please contact:

Ms. Lesley Reilly
Woods Hole Oceanographic Institution
Woods Hole, MA 02543-1522
508-289-3313

Order Toll Free by calling 1-800-291-6458

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WHOI Publication Services, P.O. Box 50145, New Bedford, MA 02745-0005 (Fax: 508-992-4556)

❑ **Yes, I would like to subscribe to *Oceanus* ($15.00, North America, $25.00 outside North America)**

❑ **Please send me the 1996 WHOI Publication Package including *Oceanus* magazine and *Woods Hole Currents* ($25, North America, $40.00 outside North America)**

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Checks must be drawn on a US bank in US funds

❑ **Check enclosed (payable to Woods Hole Oceanographic Institution) for $** _____

❑ **Please charge $** _____ **to:**

❑ **MasterCard—No.** _____ **Exp.** _____

❑ **VISA Card—No.** _____ **Exp.** _____

Signature _____

Woods Hole
Oceanographic Institution
Woods Hole, MA 02543

508-457-2000
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Memberships—ext. 3313