Contents

Craig Dickson

The *Atlantis II* A-frame lifts *Alvin* from the water following a dive off Mexico.

Cover Photo: Foam from a passing wave frames a rosette water sampler and conductivity/temperature/depth instrument being recovered aboard R/V *Knorr* in the Antarctic in January 1994. Line handlers (back cover), top to bottom of photo, are Mike McCartney, Jason McKay, Marshall Swartz and Tom Whitworth (Texas A&M University). Photo by Craig Dickson

1994 Annual Report

Woods Hole Oceanographic Institution

Woods Hole, MA 02543 · (508) 457-2000

Editor: Vicky Cullen · Designer: Jim Canavan

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Looking back on my first year as Director, I must say there has been quite a share of challenges and accomplishments. Changes on both national and international levels require a more competitive and innovative Institution stance as we continue to build upon our strengths in basic ocean science research and education.

With Jim Luyten's new appointment as Associate Director for Research, the Institution, and, in particular, the science departments and centers, are well served not only by Jim's vigorous and accomplished scientific background, but also by his seasoned understanding of the Institution and its culture.

The year 1994 brought other new names and shapes: The keel laying of the new *AGOR 25* was accompanied by its official naming as *Atlantis*, continuing a WHOI tradition of seagoing excellence that dates to our founding; *Oceanus* returned from a mid-life refit that offers increased laboratory space and scientific berthing, and the recently stretched *Knorr* left in superb condition on a remarkable 43,000-mile expedition to the Indian Ocean. In addition, *Atlantis II* continues to maintain a Herculean schedule with the submersible *Alvin*. The US Navy increased *Alvin's* operating depth certification from 4,000 to 4,500 meters in 1994, allowing the submersible to investigate 86 percent of the world ocean floor—25 percent more than was previously accessible to *Alvin*.

An international research highlight of 1994 was a very productive cooperative project with the Japan Marine Science and Technology Center (JAMSTEC),

Courtesy of Halter Marine, Inc.

Bob Gagosian, immediately to the right of the sign, and Joe Coburn, fourth from right, joined US Navy and Halter Marine officials to celebrate the keel laying for the new *Atlantis* in Moss Point, Mississippi.

Tom Kleindinst

Bob Gagosian chats with Japan Marine Science and Technology Center President Mitsusu Ishizuka during the festivities surrounding the July visit of the Japanese submersible *Shinkai 6500* and its tender *Yokosuka*.

and other Japanese institutions. During a multi-phased expedition to the Mid-Atlantic Ridge, many technologies were brought together to carry out controlled experiments on areas of the ocean floor never before accessible. During this project, Woods Hole was the occasion for the visit of JAMSTEC's R/V *Yokosuka* and its 6,500-meter submersible *Shinkai* 6500, an Institution event enjoyed by the more than 1,200 staff and family members who came to tour the ship and meet our international colleagues. This was a milestone in our relationship with Japanese scientists, and it serves as a foundation for future collaboration.

Over $10 million was raised in 1994, bringing to $34 million the total secured or committed toward the $50 million Capital Campaign goal. The dedication and commitment of our Trustees and Corporation Members have really made a difference. Because of this success, we were pleased to announce that the Institution would, for the first time ever, be able to provide some endowed salary support to Assistant Scientists in their second and third years, beginning in 1995. Although the start is small (one month's support) it clearly marks a different way of doing research at WHOI and is a major step toward a permanent underpinning for scientific innovation and flexibility. This is what the campaign is primarily about: providing

Tom Kleindinst

More than 1,200 WHOI people visited R/V *Yokosuka* during the ship's July visit to Woods Hole.

resources to our researchers so that they can devote more time to creativity and innovative ideas. We continue working very hard to complete or exceed the campaign goal in the next two years, securing the kind of support that is critical for the continuing excellence of the Institution.

Changes in the National Science Foundation (NSF) and the Office of Naval Research (ONR), our two major federal research sponsors, are directly related to the urgency of raising private funds for the advancement of ocean science research. With increased national proposal competition, the demand for cost competitiveness, and federal emphasis on "vertical integration" at ONR and "relevance" at NSF, we must ensure that we are knowledgeable about the needs of the country and articulate about how our research applies to those needs. As Director, I will continue to conduct straightforward dialogue with federal agency leaders to ensure that our research and scientific resources are well known and stay highly placed in the national agenda's priority list.

In addition to altered climates at NSF and ONR, the new Congress's committee overhauls and the Contract with America's initial recommendations also present changes and challenges. It is imperative that we effectively communicate the value and importance of ocean science to the country and the world. Only through dialogue with the new leaders can we hope to ensure that useful information gets to policy makers and influences their decisions.

Developing a trusting and respectful relationship with the new leaders will require careful planning; it is our biggest task for the year ahead. We must formulate a Washington, DC, strategy as well as guidelines for internal decisions aimed toward continuing excellence in a cost-competitive manner. We must develop an Institution goal-setting process that includes, perhaps for the first time in recent history, specific implementation plans to ensure that the goals are met. This will be a complex exercise, one which will involve new roles for scientific staff, senior management, and others so that an integrated and formidable presence in both the scientific and political arenas can be secured for the future.

With the benefit of 1994's challenges and accomplishments, we at the Woods Hole Oceanographic Institution look forward to opportunity and change that will enhance our mission and establish our firm footing in national and international agendas. This Institution has tremendous vitality and strength as well as unique individualism. All will be called upon more and more as we optimize the challenges and opportunities ahead and progress, with clear vision, towards our goals.

Robert B. Gagosian
Director

Tom Kleindinst

A cheering crowd welcomes R/V *Knorr* home from a summer research voyage.

Tom Kleindinst

Ken Prada displays the "PC in a Can," which brings the computer power of a desktop computer to a variety of oceanographic instruments.

The Applied Ocean Physics and Engineering (AOP&E) Department, with 145 staff members and 36 graduate students, had a very productive year in 1994. Forty-two principal investigators led 130 basic and applied research projects in ocean acoustics, coastal and ocean fluid dynamics, ocean systems and moorings, deep submergence, and oceanographic instrumentation.

Personnel actions included the promotions of acoustical oceanographer Timothy Stanton to Senior Scientist and ocean physicist James Ledwell to Associate Scientist with Tenure. In addition, surface and interfacial chemist Erik Bock was promoted to Associate Scientist and electrical engineer Thomas Austin to Senior Engineer.

AOP&E personnel were the recipients of several awards in 1994. Albert Bradley, Barrie Walden, and Dana Yoerger received the *Popular Mechanics* Design and Engineering Award for the Autonomous Benthic Explorer (ABE). They were also nominated for the *Discover* magazine Design and Engineering Award for their work on ABE. W. Kenneth Stewart received a Certificate of Recognition as part of the *Computerworld* Smithsonian Awards for his contributions to real-time visualization of oceanographic data. Robert Ballard received honorary degrees from the Maine and Massachusetts maritime academies as well as the International Pioneer Award from the Association for Unmanned Vehicle Systems and the Kilby Award, named for the inventor of the integrated circuit, for his "imaginative contributions to society through science, technology, innovation, invention and education." Ballard also received the Circumnavigators Club 1994 Order of Magellan Award and the first annual *Science/Science News* Award for contributions to science, youth and exploration.

AOP&E research and development activities encompass laboratory experiments, field programs, and theoretical work. Three projects representative of these efforts are described here.

"PC in a Can" Supports Extensive Computing In Ocean Instruments

Modern scientific needs require ever more capable tools for gathering information. Most oceanographic instruments now have some sort of internal microcomputer. While instrument capabilities vary, computing power must always be weighed against energy consumption, particularly in buoys and underwater instruments that may need to function for long periods unattended. Funded by the Advanced Research Projects Agency, the Surface Suspended Acoustic Receiver (SSAR) project supports extensive computing in a drifting instrument, yet uses very little energy. A new generation of microcomputer circuits developed by Ken Prada has made this possible, essentially allowing a desktop computer to be placed in an underwater instrument. Sometimes called "The PC in a Can," its technology builds on industry-standard,

small, form-factor (PC104) circuit boards, and combines commercially available computer boards with special-function boards designed at WHOI.

The SSAR controls a complex series of tasks in a surface buoy and an acoustic receiver 500 meters below the surface. These tasks include navigation from the Global Positioning System (GPS), satellite telemetry, precision time keeping, large-volume disk data storage, communication between surface and subsurface computers, power consumption control, sampling various sensors and hydrophones, and processing data results. Each computer consumes less than .75 watt when active and approximately 7.5 milliwatts when idle, yet provides all the features of a desktop PC (minus the video display). Energy is further conserved by the SSAR's ability to switch power to other internal circuits as necessary.

The PC in a Can has many advantages. It uses off-the-shelf technologies such as high-volume disks, networking protocols, high-speed sampling devices, and other standard products, which cost far less than specially designed instrumentation. Operational software is conveniently developed and tested on an actual desktop PC, then transferred to the instrument for final testing and use. When necessary, an instrument can be connected to a desktop PC or workstation to transfer programs or data. In fact, during preparation for a buoy deployment last spring, an instrument in Miami was networked to the Internet, where it established communication with a lab workstation at WHOI, and loaded the previous night's program changes.

Other projects have used the PC in a Can to create new or improved instruments. Two new systems include Gene Terray's wave-motion buoy and Jim Irish's and Jim Lynch's scanning-sonar instrument. Peter Wiebe's BIOSPAR (BIOacoustic Sensing Platform And Relay system) buoy has been substantially improved, and several other applications are also in progress.

Shear Meter Measures Small-Scale Differences in Horizontal Velocity

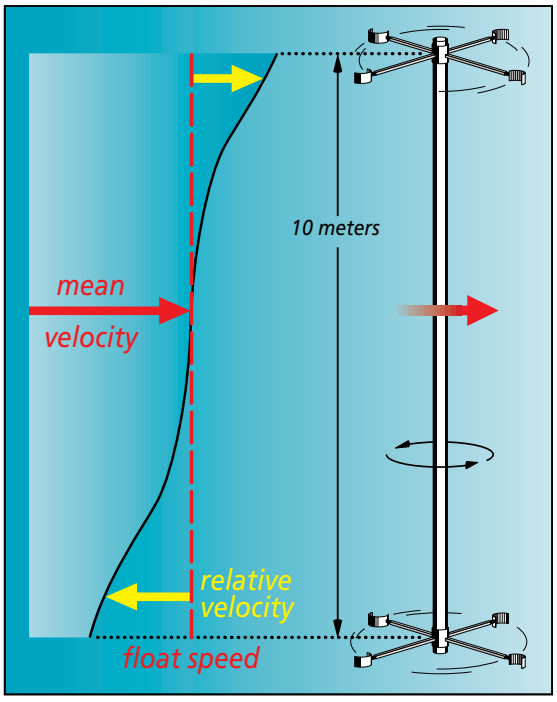
The broad range of physical and temporal scales that characterize oceanography makes one-size-fits-all measurement impossible. Oceanic and atmospheric flows generally have a "red" energy spectrum, that is, motions at slower and/or larger scales have higher energy than those at faster or shorter scales. Sensors for measuring at the smaller scales are often more challenging to make than those for the routinely measured larger scales, in part because the small-scale signals are weaker.

Shear (the velocity difference between two water masses) in the ocean at the scale of a few meters is one of the less-routinely measured quantities, and it requires special instrumentation. Vertical shearing of horizontal velocity is believed to be responsible for much of the ocean interior's vertical mixing. Such vertical mixing manifests itself as a heat or density flux, and affects density distributions and, thus, currents. The shear falls in the "weak signal" category at an important scale: The height of typical transient turbulent layers, which is a few meters. Shear at these scales can be unstable, and the flow can break down into turbulent eddies as small as a few centimeters, which mix until they are dissipated by viscosity.

With support from the National Science Foundation, Tim Duda, collaborating with Webb Research Corporation, is developing an exploratory sensor for measuring vertical shear at a separation of 10 meters. The 10-meter shear is close to the scale of interest, but the slightly longer separation boosts the signal a bit. Not too much, however: It is usually less than 1 centimeter per second in the deep ocean, or one-fiftieth of a knot, which is still too small to measure reliably with general-purpose current meters. The measurement is exploratory because the probes will drift freely for a year and record shear along an unplanned track.

The shear meter is essentially a drifting pole with vanes at each end that rotate in the presence of shear. Since it will drift with any strong mean flow, it can be designed to respond to weak shear. The cup-shaped vanes resemble a wind-speed indicator in shape and arrangement, but they are rigidly attached to each end of the pole, causing the whole device to spin. Rotation is measured with a compass. Initial tests of the vanes show that about one-tenth of a gram of force can be generated by 1 centimeter per second of current, which can provide 1/10 inch-ounce of torque if the vanes have a 56-inch wingspan. This should be more than enough torque to overcome the miniscule skin drag of the rotating pipe.

An important complication in shear-meter design is

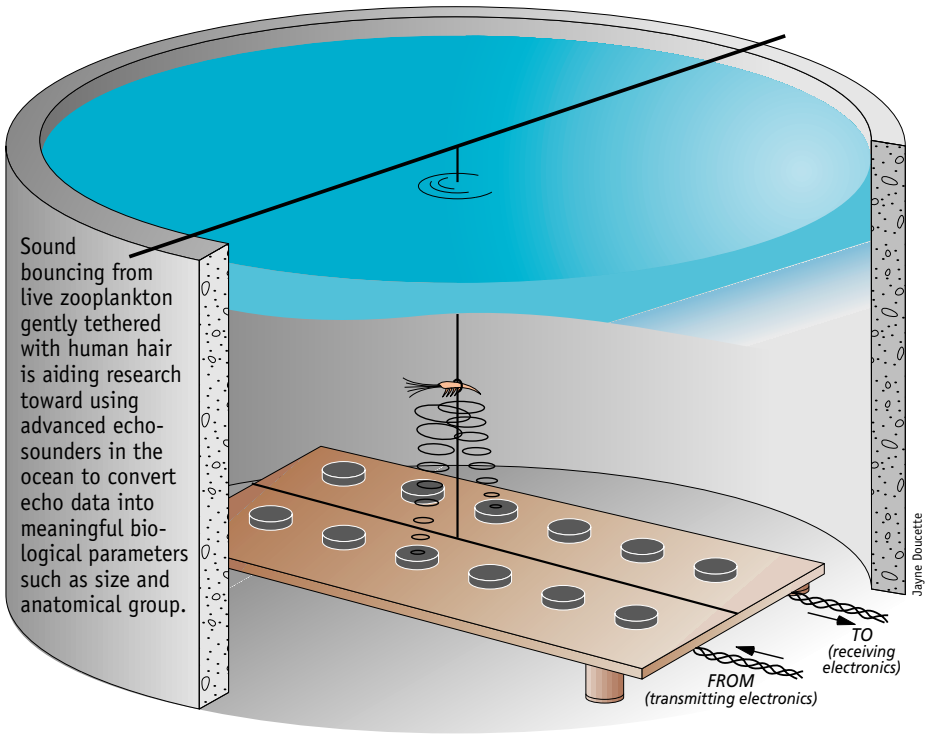


Jayne Doucette

The float moves laterally with the mean velocity (red arrow). The relative velocities (yellow arrows) due to the shear flow make the float rotate.

avoiding a record of vertical currents that move past the instrument, which hovers at a pressure surface. In areas of rough bottom topography, such as mid-ocean ridges, where shear and mixing may be enhanced, accelerators can give a simple indication of undesired bottom bounces.

After a drifting, rotating mission of 1 year, the shear meter will surface and transmit its rotation (or other) information by satellite, completing its exploratory mission. Neutrally buoyant floats similar to this are used worldwide. In fact, their inventor, the late John Swallow, recently received the first Henry Stommel Medal in Oceanography from WHOI. These floats often transmit or receive long-range acoustic signals that are used to reconstruct the float paths. The shear meters could be tracked in this same fashion and serve the same purpose, measuring the large-scale current, but giving additional, new information about deep-ocean shear.



Acoustic Experiments Work Toward Mapping Zooplankton Distributions

Recent acoustic pulse-echo experiments in tanks both on land and on the decks of ships at sea have enabled WHOI scientists Timothy Stanton and Peter Wiebe and their colleagues to make significant progress in their quest toward using sound to map zooplankton distributions in the ocean. Echo sounders have long been used to survey fish and zooplankton populations; sound travels great distances in the ocean, and large areas can be surveyed in short periods of time.

The challenge lies in interpreting the echo data. Zooplankton, especially, come in many sizes, shapes, and compositions. Describing the physics of sound scattered by every single zooplankton type is complicated. Often, researchers draw a simple one-for-one relationship between echo strength and the animals' biomass. While this approach has proven successful for fish populations that may be composed of animals of similar size and species, it can produce huge errors (up to orders of magnitude) in analyzing a typical zooplankton aggregation.

For their experiments, Stanton and Wiebe placed a variety of live zooplankton in a tank of seawater and used acoustic transducers to scatter sound off the zooplankton, one at a time, over a wide range of acoustic frequencies. The experiments were conducted on land with locally caught decapod shrimp, and at sea on the decks of R/V *Oceanus* and R/V *Endeavor* (University of Rhode Island) with animals caught over or near Georges Bank. The experiments were funded by the Office of Naval Research, the National Science Foundation, and the Office of Naval Technology.

Analysis of the sound-scattering data showed that the echo energy per unit biomass for gastropods (a marine snail with a hard, elastic shell) is about 19,000 times greater than that of salps (a gelatinous zooplankton). Other animal types had intermediate values of that ratio. This wide range of values demonstrated that there is not a simple relationship between echo energy and biomass, and one must carefully take animal type into account when interpreting echo data.

Stanton and Wiebe are currently putting their new-found knowledge to work in two ways: First, they are using the newly developed acoustic scattering models to help interpret acoustic survey data collected in 1992 over Georges Bank as part of the US Global Ocean Ecosystems Dynamics program. This region exhibits a wide range of zooplankton types, including gastropods. Although the gastropods make up no more than 25 percent of the biomass at any of the sampling stations, they sometimes dominate the acoustic echoes and needed to be taken into account in the analysis. Second, the researchers are developing new acoustic classification methods that may help further differentiate animals by anatomical types (such as hard-shelled, fluid-like, or gas-bearing). Preliminary analysis indicates potential for advanced echosounders to automatically classify animals according to anatomical group.

Research interests within the Biology Department continue to be varied and topical. They range from attempts to integrate new molecular biological techniques in basic research on the systematics and physiology of the smallest marine microbes in oceanic waters to applied programs dealing with the environmental impact of waste products on marine biota and resources in estuarine and coastal marine waters. This diverse activity of 25 staff scientists, 14 Technical Staff members, 9 postdoctoral scholars and investigators, 32 students, and 26 support personnel led to 43 scientific publications and 140 proposals submitted in 1994. The diverse interests and successes of our staff are illustrated vividly by the following three scientific reports. They demonstrate the tremendous difficulties biological oceanographers face in studying marine organisms residing at depths from the surface to the ocean floor and the successes our group has had in developing and using modern and sophisticated technologies to overcome these obstacles.

Major personnel changes within the Biology Department in 1994 included the retirements of two eminent scientists, Holger Jannasch and John Teal, and the appointment of two new Assistant Scientists, Heidi Sosik and Jesús Pineda. Although retired, both Jannasch and Teal continue their association with the department and maintain active research programs. Sosik brings expertise to the department in marine bio-optics and remote sensing of primary productivity, and Pineda adds talent in marine benthic ecology with an emphasis on the role of physics in controlling benthic-organism distribution in coastal waters. Also, with great sorrow, we report the December 1994 passing of Senior Scientist Frank Carey, who was actively engaged in acoustic telemetry studies of large marine fish at the time of his death.

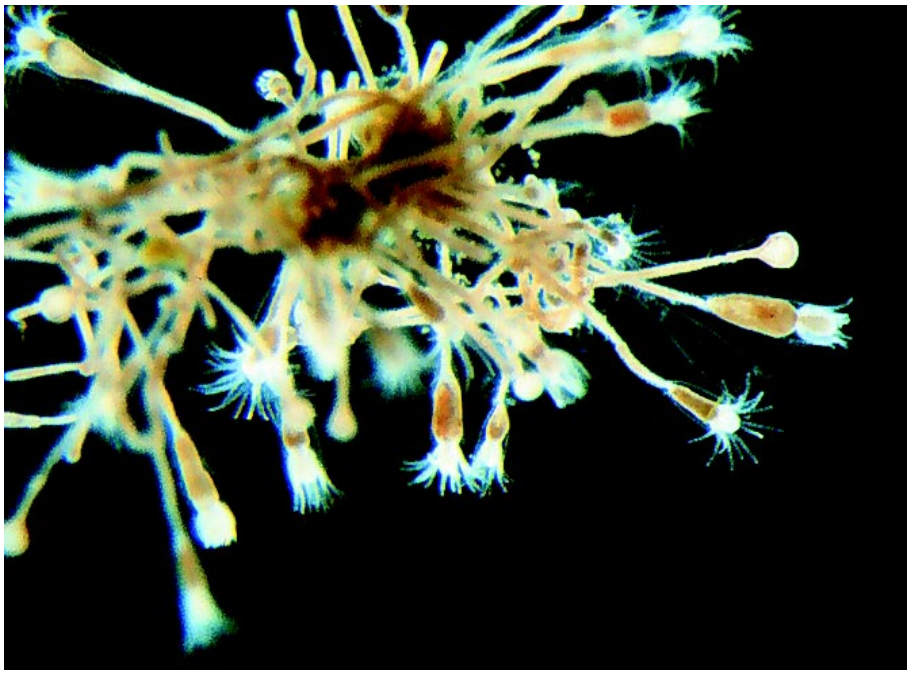
Among 1994's notable achievements, Associate Scientist Larry Madin was awarded the Seward Johnson Chair in Oceanography and will serve as Education Coordinator, replacing Senior Scientist Judith Capuzzo McDowell, who stepped down after a four-year term, Associate Scientist John Waterbury was elected a fellow of the American Association for the Advancement of Science for "pioneering research on picoplankton and for establishing the importance of cyanobacteria in the marine environment," and Associate Scientist Peter Tyack was awarded a fellowship for a sabbatical leave at the Center for Advanced Study in the Behavioral Sciences at Stanford University to prepare a new book on cetacean behavior. In addition, Senior Scientist Peter Wiebe established the Georges Bank Program Service and Data Management Office at WHOI for the US Global Ocean Ecosystems Dynamics (GLOBEC) Program, a major research initiative supported by the National Science Foundation and the National Oceanic and Atmospheric Administration. The office is being administered by Research Specialist Robert Groman, who joined the department this year.

The department continues to be well represented in several of the ongoing global oceanographic research initiatives including GLOBEC, the Joint Global Ocean Flux Study Program (JGOFS), and the Ridge InterDisciplinary Global Experiment (RIDGE).

How Do Changing Environmental Forces Affect Georges Bank Fish Stocks?

The catastrophic decline of rich northeast fishing grounds such as Georges Bank is cause for considerable worry for the future of these resources. Over-fishing is an obvious factor, but human impacts on fisheries must be assessed in a larger context, with such natural forces as temperature and circulation patterns that affect fish stocks over long periods. These physical and biological factors may be shifting with more general global-climate changes, so it is vital to investigate them now.

In 1994, a consortium of scientists at WHOI and 25 other institutions began a long-term study, the GLOBEC (Global Ocean Ecosystems Dynamics) Northeast Atlantic Project, to understand how



Larry Madin

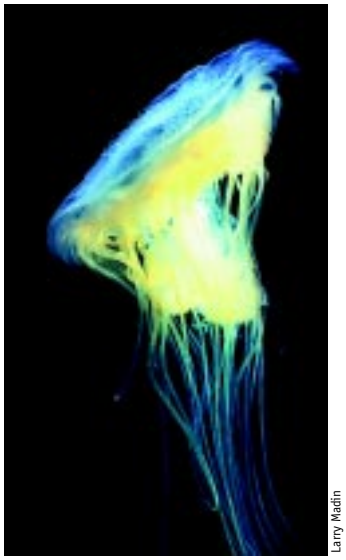
Hydroid polyps like these normally live attached to the bottom, but on Georges Bank huge numbers of them are torn off the bottom and suspended in the water, where they function as floating predatory colonies.

Larry Madin

The copepod *Calanus finmarchicus* is the dominant grazer on the bank, and the main food of developing cod and haddock.

changing environmental forces may affect commercial fish stocks on Georges Bank. As part of this, WHOI biologists Larry Madin and Steve Bollens, with colleagues at the University of Rhode Island and the National Marine Fisheries Service, are investigating the importance of zooplankton and fish predation on larval cod, larval haddock, and the copepods these larvae eat. Although cod and haddock spawn huge numbers of eggs, the mortality rates for eggs and young larvae can be enormous. Stiff competition for copepods from other predators can lead to the larval-fish starvation, while other predators take their toll on the fish directly.

Predation mortality is hard to measure in the "real world." With funding from the National Oceanic and Atmospheric Administration, Madin and Bollens are now trying to discover who the predators are, where they occur relative to their prey, and how much they eat. Initial surveys turned up jellyfish, comb jellies, various shrimp, crab larvae, and arrow worms as likely predators. A surprising find was huge numbers of tiny polyps that usually live on the bottom were stirred up into the water, where they were feeding voraciously on the eggs and larvae of the copepods that baby fish eat, and even on the larval fish themselves. Working out the feeding biology requires a different approach for each kind of predator. Some predators can be collected in nets, some only by scuba divers. In transparent jellyfish, the prey can be seen and counted right in the stomachs; crustaceans, however, chew everything into unrecognizable bits. For these and other predators that chew their food "too well," new antibody techniques can help detect which prey species are in their stomachs.



Larry Madin

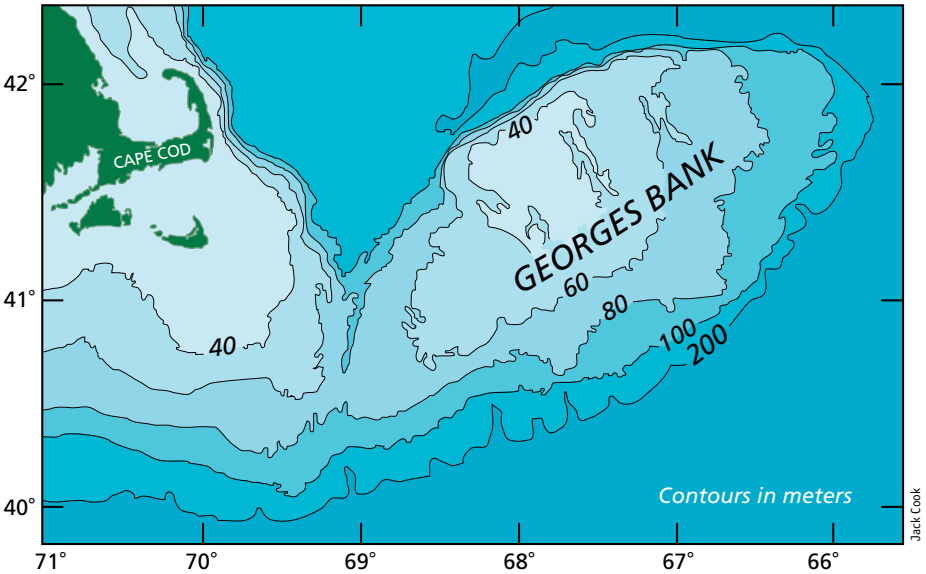
The "lion's mane jellyfish," which can be more than 30 centimeters in diameter, is an important Georges Bank predator on larval and juvenile fish.

A series of cruises in spring 1995 will provide a wealth of data on predator diversity, distribution, and feeding habits. This information will be used to calculate the mortality rates specific to different times, places, and predators on Georges Bank, which can then be compared to other physical and biological forces that affect fish survival on Georges Bank.

Vent Larvae Must Disperse Widely For Species To Survive

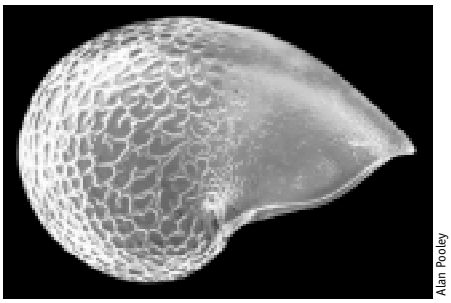
Consider for a moment the plight of a tubeworm population living at a deep-sea hydrothermal vent. The tubeworms must live in the hot fluids that rise from the vents—these fluids supply reduced chemicals for the symbiotic bacteria that live within their tissues and provide their food. But the source of hot vent fluids is ephemeral, and can shut off after a period as short as decades or even years. When this occurs, the tubeworms, which are not mobile as adults, are faced with a problem: How do they avoid extinction of the entire population?

The tubeworms' solution is to produce larvae that can disperse through the water column and colonize other suitable vent habitats. Each vent species has evolved a strategy for ensuring that progeny can move to neighboring vents, sometimes hundreds of kilometers away. Recent research in Lauren Mullineaux's laboratory indicates that these dispersal strategies often include interactions between the larvae and the ocean's hydrodynamic character at the vents, particularly the buoyant, hydrothermal plume flows and the local oceanic currents.



Jack Cook

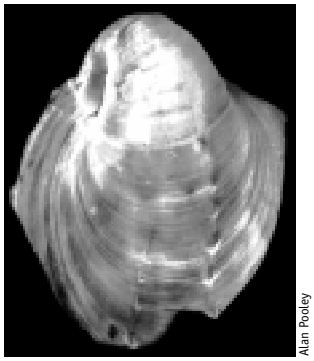
The shallow central part of Georges Bank has long been a fertile nursery ground for cod and haddock.



Alan Pooley

Larval shell of vent snail, *Cyathermia natocoides*. (250 microns)

Larvae of vent species may adopt a low-risk or high-risk dispersal strategy, depending on where they are released relative to boundary-layer or buoyant flows, or on their behavior. Some larvae appear to settle in the same habitat as their original population; others drift in near-bottom flows along the ridge axis to vents a few tens or hundreds of meters away. This is a low-risk approach for the short term, because the larvae have a high probability of finding suitable habitat. Other larvae are entrained into the buoyant plume that emanates from the vent, and carried several hundred meters off the seafloor into currents that can transport them far from their original population (as the figure shows). These larvae are at a much higher risk of not locating another suitable vent, but they may be the only ones to survive if local vents are closing down.



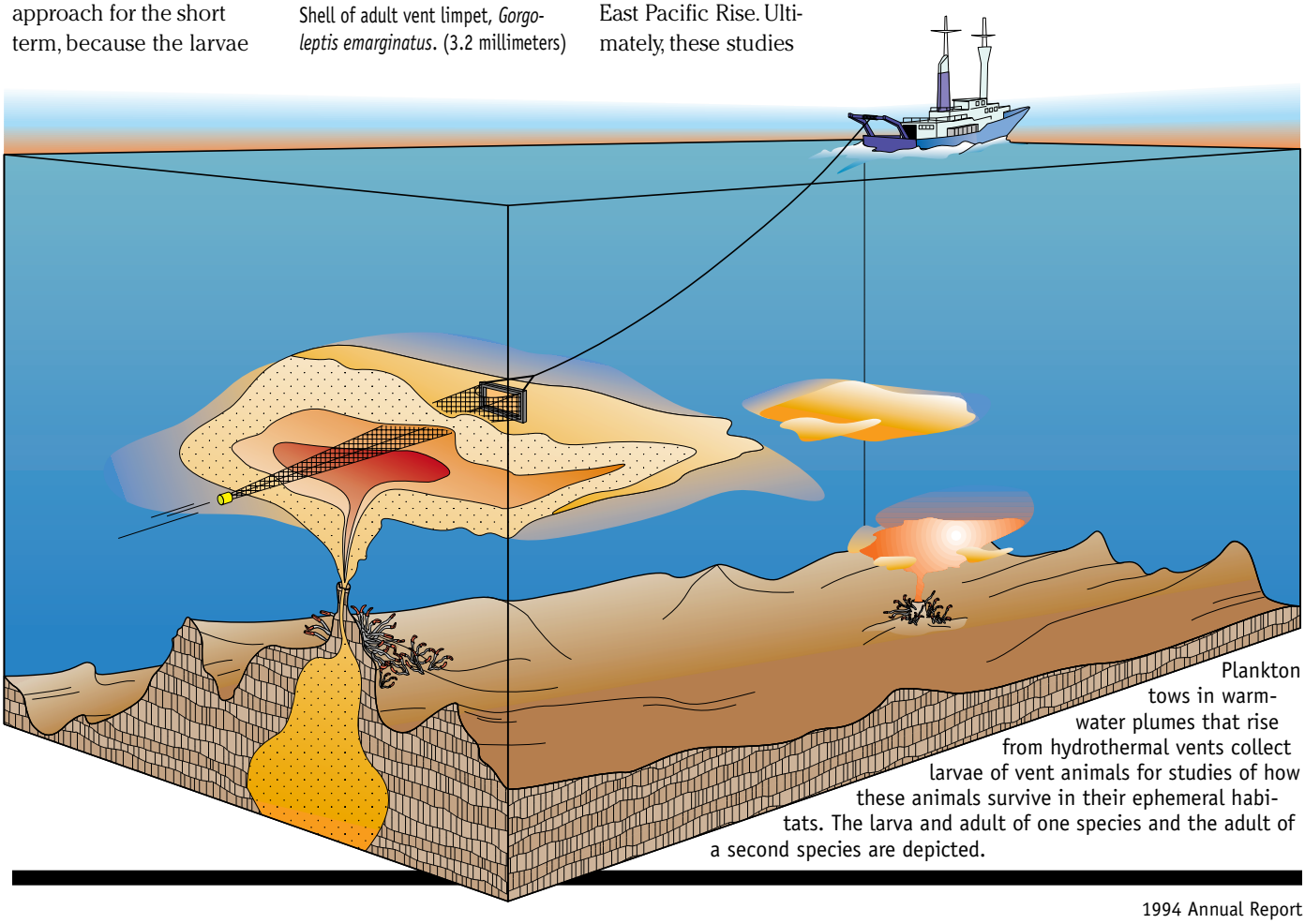
Alan Pooley

Shell of adult vent limpet, *Gorgoleptis emarginatus*. (3.2 millimeters)

The study of larval dispersal at vents in Mullineaux's lab is funded by the National Science Foundation, and is a precursor to a multi-investigator study of reproduction, larval metabolism and behavior, recruitment, and gene flow in vent environments. This program, named LARVE (Larvae At Ridge VEnt), is intended to coordinate projects from as many as 12 different institutions over a five-year period at vents along the East Pacific Rise. Ultimately, these studies should elucidate the mechanisms that control the global distribution of vent species, and how these species have survived and evolved in their uncertain, patchy vent environment.

Alan Pooley

Shell of adult vent snail, *Cyathermia natocoides*. (3.2 millimeters) Note larval shell retained in first whorl.



Jayne Doucette

Plankton tows in warm-water plumes that rise from hydrothermal vents collect larvae of vent animals for studies of how these animals survive in their ephemeral habitats. The larva and adult of one species and the adult of a second species are depicted.

Fin Whale Tracked Using Satellite Tag

Fin whales off Iceland have been studied in detail at least since 1950, so Bill Watkins and colleagues were tempted to think they could anticipate the animals' movements. The researchers had seen hundreds of these whales congregate in summer to feed on rich patches of krill about 130 kilometers off Iceland's western shore—but where were they in winter, when the humans weren't watching?

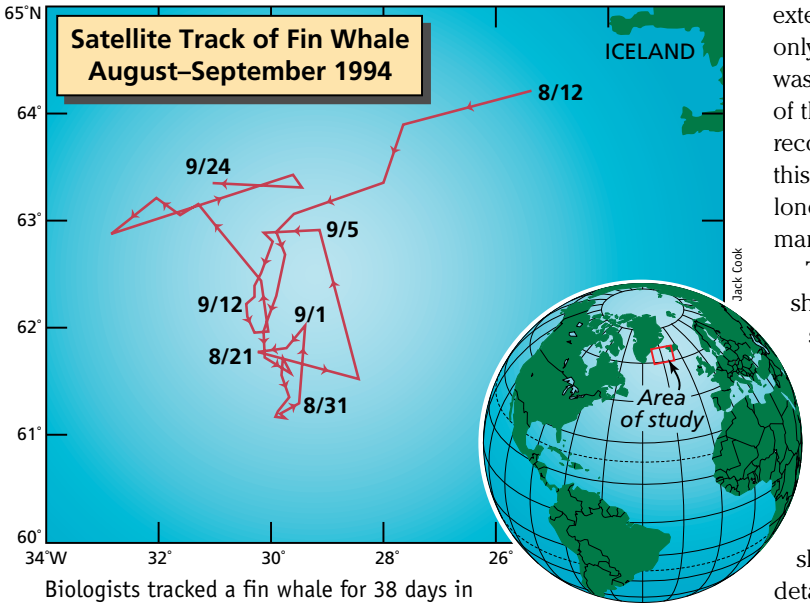
Because they knew that other whale species migrate between feeding and breeding areas, the scientists thought fin whales might also migrate, although such movements hadn't been defined. Therefore, they decided that tracking a late-season fin whale leaving the Iceland feeding area would be a useful test of a new satellite-monitored whale tag. If the tag performed as expected, they would have new and reliable information about the paths of migrating fin whales.

The satellite tag was developed with Office of Naval Research support, using the same system for attaching the tags used previously for radio and sonar-transponder tracking studies of six other whale species. The satellite tag produces a signal each time its antenna is exposed above water during whale surfacings. These signals are picked up by satellites passing overhead, and are then processed by ARGOS, a central facility that calculates the tagged whale's position and relays the telemetry data, in this case to Woods Hole.

In mid-August 1994, collaborating with Iceland's Marine Research Institute, Watkins and colleagues tagged a 16-meter fin whale and tracked it as it moved away from the concentrated feeding area. This large whale was accompanied by a smaller juvenile whale, so it was probably female, and they thought it a good candidate to show them fin-whale migration, because it appears that reproductive females drive the migration of other whales. For the first three days, the tagged whale moved southwest, then it slowed and began swimming back and forth in a small area only about 400 kilometers from Iceland—for the next 38 days! In this area, the whale was consistently more active during the day, and moved only slowly at night. Finally, during the last three days, it swam back to the north to end up only 240 kilometers west of its position at tagging—after 45 days and 1,600 kilometers of track.

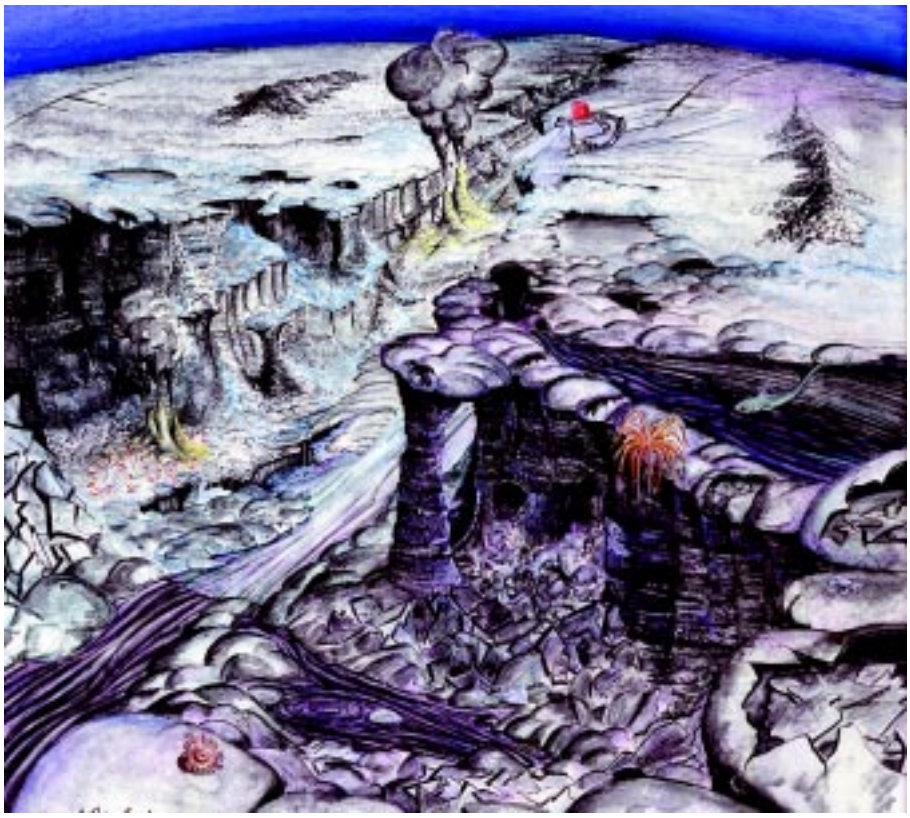
The tagged whale apparently did not have migration on its mind. The researchers found no obvious reason (such as temperature, currents, or concentration of prey) for the whale to remain in the southwestern area for the extended period. They can only speculate that the whale was attracted, instead, by one of the "songs" previously recorded in such areas during this season—a serenade by a lonesome, eligible, beautifully marked, male fin whale.

This successful whale track shows the potential for satellite tracking. It allows extended observations at other times than the summer feeding season, over long tracks that would be prohibitively expensive if attempted by ship or aircraft, and yields detailed data in spite of bad weather or darkness. Plans for the next generation of whale tags include telemetry of dive depth and measures of body and external water temperature, as well as monitoring of whale vocalizations.



Biologists tracked a fin whale for 38 days in waters south of Iceland using a satellite tag that promises to yield new information on marine-mammal travels.

Artist's rendition of the seafloor on the crest of the East Pacific Rise at 9°46–51'N. The narrow depression running from lower left toward upper right along the axis of the East Pacific Rise crest, called the axial summit caldera, is the location of the majority of ridge volcanic and hydrothermal activity. Hydrothermal vents are most often found within and along its margins. In this region, the axial summit caldera can be as wide as 100 meters and as narrow as 40 meters, and the wall height varies from 8 to 15 meters. *Alvin,* shown in the background, if drawn to scale, would be nearly invisible.



E. Paul Oberlander

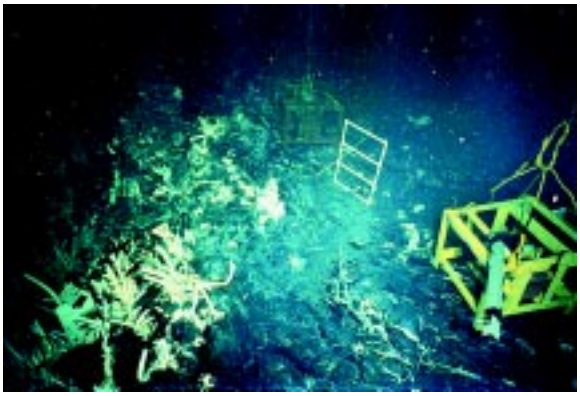
The 31 members of the Geology and Geophysics (G&G) Department scientific staff again in 1994 excelled both in the quality of their research endeavors and in their proficiency at raising funds from federal agencies despite increasing levels of competition. Indicators of the health of the department, and the field of marine earth sciences research as a whole, are the total of 57 new research projects initiated during the year, along with more than 20 separate research cruises. Most importantly, two superb new Assistant Scientists were recruited: Graham Kent, whose expertise in the mechanisms of formation of the oceanic lithosphere and the processing of marine multichannel data adds new capabilities to the department's seismology group, and Rob Evans, who joins Senior Scientist Alan Chave to further augment our rapidly growing endeavors in marine electro-magnetics. Stan Hart's continuing contributions to our understanding of the most fundamental earth processes were recognized in 1994 with the award of the Columbus O'Donnell Iselin Chair.

But all was not joy and success. It was with profound sorrow in January that the department staff learned of the death of Allyn Vine. He was a fountain of stimulating ideas throughout his life and had been a positive stimulant around the G&G department and the Institution for tens of years. Senior Scientists Bill Bryan and Dave Ross retired, but are continuing their research unfettered by administrative worries and fund-raising responsibilities. Associate Scientist Kathy Gillis went on a leave of absence to take an appointment at the University of Victoria, Canada.

The department's most visible event of the year was the July visit to Woods Hole of the JAMSTEC research vessel *Yokosuka*. Department scientists had been working with Japanese colleagues for almost a year planning the details of joint submersible diving operations on the Mid-Atlantic Ridge. The complete success of these two one-month legs of cooperative operations, and the amazing publicity that this visit generated were sources of great satisfaction to all.

Close Monitoring Brings New Insights On Hydrothermal Vents

The largest, most continuous geologic feature on the face of the earth is the mid-ocean ridge (MOR) system,a nearly continuous chain of volcanoes that extends almost 64,000 kilometers throughout all the world's ocean basins. The crest of the MOR is a dynamic environment, where seafloor spreading occurs on a daily basis and the earth's crust is born, beginning its tens- to hundreds-of-millions-of-years-long journey, eventually to be consumed in the deep trenches adjacent to some continental margins. One of the principal MOR crest processes is volcanism, and it is through lava eruption that the earth's crust is constructed. While theory and seismic evidence from shallow earthquake epicenters indicate that submarine volcanic eruptions occur most frequently along the ridge crest, they had never been directly observed.



DSV Alvin, Pat Hickey/Bob Grieve

A December 1993 *Alvin* photograph, taken at 2,550 meters, shows the tube-worm community on the floor of the axial summit caldera that is being monitored by time-lapse cameras and temperature probes. The yellow frame houses the video camera, which takes 20 seconds of video each day; the red frame in the background takes two 35-millimeter photographs each day. Each frame encompasses an area 1 meter on a side. The animal community at lower left is growing over a low-temperature hydrothermal vent that is being monitored by a temperature-probe array.

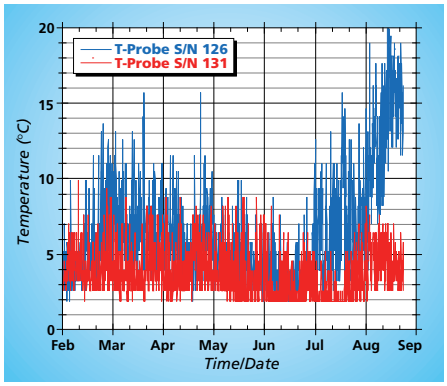
In April 1991 that changed, with the first witnessed volcanic eruption on the crest of a fast-spreading (about 11 centimeters per year) MOR—the East Pacific Rise between 9°46'N and 9°51'N (about 800 kilometers due south of Acapulco, Mexico).

Dan Fornari and colleagues from five universities have been studying this part of the MOR for the past six years. Their DSV *Alvin* diving studies since the 1991 discovery have led to insights into the effects of submarine volcanism on the geology of the ridge crest and the biology of the hydrothermal vent communities that live there.

One of the most startling results of the April 1991 dives, during which the scientists observed the effects of the submarine eruption, was that the heat generated by the lava caused the bacteria living within and near the seafloor to "bloom," in much the same way that temperature increases at the sea surface cause red tides. The bacteria's enormous productivity was sufficient that it completely coated the black, basaltic seafloor with its spongy, white gelatinous mass. In a geological instant the normally black volcanic terrain became a ghostly white environment with every lava pillar and flow surface coated with bacteria. This biological indicator of very recent lava eruption has now been observed twice on an erupting MOR crest (the other occurrence was in July 1993 at the CoAxial site on the Juan de Fuca Ridge off the Washington coast), and it provides investigators with a key to determining whether a ridge crest has recently experienced a volcanic episode.

Because of the eruption, the existing biological communities and the geological structure of the axial summit caldera—a narrow cleft only 40 to 70 meters wide and 8 to 15 meters deep, where all the hydrothermal and most of the volcanic activity occurs—changed from their pre-eruption condition, which had been documented by Fornari and colleague Rachel Haymon (University of California, Santa Barbara), using WHOI's *Argo-I* towed imaging system in 1989. New hydrothermal vents started to grow from the fissures that served as outlets for the erupted lava. Parts of the axial summit caldera wall were breached by the new lava flow, and, in other areas, channels of lava broke through the walls and portions of the new flow traversed the seafloor outside the summit caldera.

An important facet of Fornari's ongoing collaborative experiment, which is funded by the National Science Foundation's RIDGE (Ridge Inter-Disciplinary Global Experiment) program, is studying the changes in the geology of the axial summit caldera and the biology of the communities inhabiting the vents. To document the changes, Fornari and Mark Olsson at Deep Sea Power & Light (a manufacturer of deep ocean imaging equipment that is also used on DSV *Alvin*) developed an inexpensive temperature probe that can record changes in the vent water temperature at both the low-temperature vents (about 5° to 30°C) and the hot, black-smoker vents (up to 400°C) over periods of time ranging from a few days to a year. The temperature measurements are correlated with biological and geological/hydrothermal changes recorded by deep-sea-video and 35-millimeter, time-lapse cameras deployed near the temperature probes. Using vent temperature as a proxy for the physical processes that are occurring within the seafloor's uppermost basaltic carapace, Fornari is trying to determine the subsurface connection between the hot vents and the cooler ones where the biological communities flourish.



Dan Fornari

Plot of vent water temperature versus time for the animal community shown in the photograph above over a 290-day interval from December 1993 to August 1994. The plot shows the data from two probes at either end of the 24-inch-long array. Probe 126 recorded consistently higher temperatures than 131. The four other probes, spaced evenly in the array, also indicate very short-term temperature variations over short spatial scales within the flow. The overall pattern of temperature variation during this recording cycle shows an approximate two-month period of increased temperatures in March-April, a minimum in June, and then an abrupt increase in July-August, especially in the area of probe 126.

These research efforts continue, and the next field program using DSV *Alvin* is scheduled for November 1995. In the meantime, the cameras and temperature probes are on the seafloor capturing the pulse of the mid-ocean ridge crest.

MELT Experiment Explores Magma Genesis and Migration

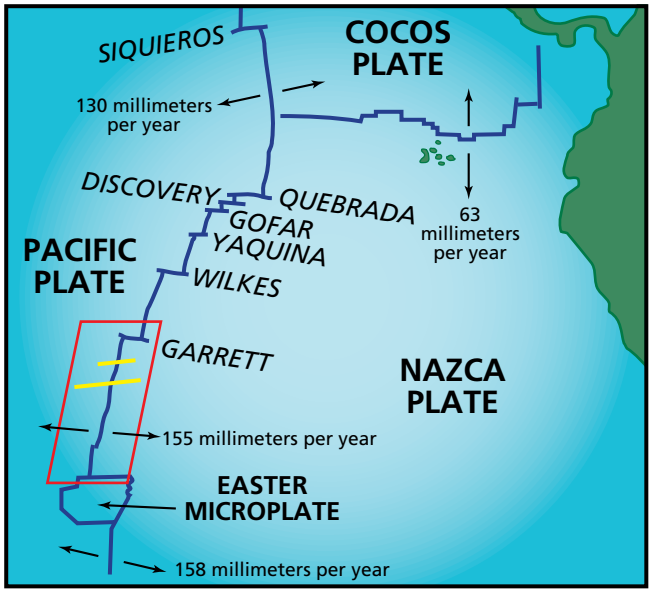
Observations of mid-ocean ridges collected in the Mantle Electromagnetic and Tomography (MELT) experiment, the largest marine geophysical field program ever attempted, promise to increase our understanding of how melting occurs in the Earth's mantle and how the resulting magma is transported to a ridge crest. Most of what we know about mantle structure beneath ridges comes from gravity and seismic-reflection profiling and studies of the composition of basalts erupted at ridge crests, techniques that focus on Earth's outer 5 kilometers or so.

The MELT experiment will dramatically extend our knowledge of Earth structure by using deep geophysical measurement techniques to look 100 to 200 kilometers beneath the planet's surface. These techniques include body-wave tomography, surface-wave dispersion, and magnetotelluric sounding. In body-wave tomography, distant earthquakes provide a source of seismic body waves, and an array of seismometers crossing a mid-ocean ridge crest measures how long it takes the seismic waves to traverse different parts of the ridge. From these data scientists can construct a picture of the ridge's internal velocity structure to identify such physical properties as the extent of melting, the geometry of the melt, and the location and interconnections of isolated pockets of melt. Surface-wave dispersion uses a different kind of seismic wave, whose travel time from the earthquake source to the seismometer varies with the wave's frequency. By measuring the change in travel time with frequency, it is also possible to assemble a model for the ridge's internal velocity structure.

Alan Chave

The horizontal electrometer, which measures the horizontal electric field, is among the instruments to be used in the MELT experiments.

Magnetotelluric sounding uses an entirely different approach. It is based on measurements of the time-varying electric and magnetic fields induced in the earth by electric current systems flowing hundreds to thousands of kilometers out in space. These very weak electromagnetic fields contain information about how electrical conductivity varies inside a ridge. The MELT experiment's strength lies in combining these three separate yet complementary approaches to construct a more complete picture of the melting process.



Jack Cook

Geological setting for the Mantle Electromagnetic and Tomography Experiment. The project will focus on the Garrett segment of the East Pacific Rise, outlined in red, south of the Garrett Fracture Zone. It is one of the fastest spreading sections of the mid-ocean ridge. Ocean bottom seismometers will be deployed along both lines shown in yellow, electromagnetic instruments along the southernmost.

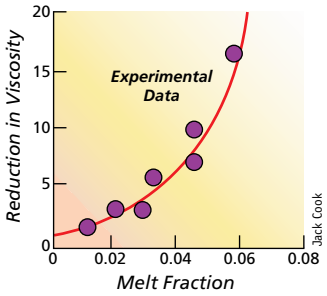
WHOI scientists are contributing to MELT in several ways. The 50 seismic instruments for MELT are being provided by investigators at WHOI and the Scripps Institution of Oceanography. Of these, 15 modern ocean-bottom seismometers will come from Mike Purdy's research group. Most of MELT's 55 electromagnetic instruments belong to Alan Chave's laboratory, with the remainder coming from researchers in France, Australia, Japan, and the United Kingdom. Other Geology & Geophysics Department staff, including Robert Detrick and Rob Evans, will be involved in analyzing and interpreting the MELT data.

MELT is funded by the National Science Foundation as part of the Ridge Inter-Disciplinary Global Experiments program. Beginning in fall 1995, MELT scientists will mount three major cruises at about 17°S on a section of the East Pacific Rise called the Garrett segment. One of the most remote pieces of ridge crest on Earth—about nine days from the nearest ports, Tahiti and Valparaiso—the Garrett segment is one of the fastest spreading and longest known continuous, unbroken stretches of mid-ocean ridge. Because it runs 1,000 kilometers between offsets, MELT scientists expect the data to be two-dimensional rather than three-dimensional and therefore easier to interpret than data from a more structurally complex area. During the first cruise, they will deploy the seismometers to collect information on the deep seismic velocity structure. On Leg 2 in mid-1996, they will recover the seismometers and deploy the electromagnetic instruments. These will be retrieved a year later, during Leg 3 in mid-1997. Analysis of this large and multifaceted data set will occupy the attention of many scientists over the next few years and should yield enlightening new images of Earth's deep structure and processes.

Understanding the Viscosity of the Earth's Mantle

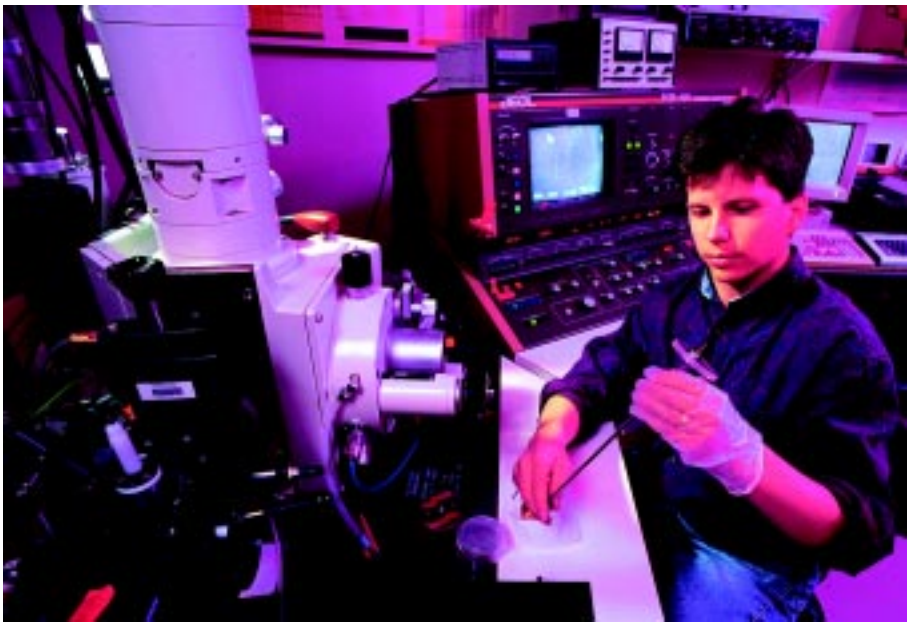
The processes that control the movement and formation of the earth's rigid plates, the migration of melt to volcanoes, and the dynamics of mid-ocean ridges all depend on the viscosity of the upper mantle. Peridotite, the rock type in the upper 400 kilometers of the earth's mantle, is comprised of approximately 60 percent olivine. Scientists have long known that the key to determining the upper mantle's viscosity is understanding olivine's chemical and physical properties. However, despite at least 25 years of study, the influence of melt on the viscosity of olivine aggregates was not well understood. This shortcoming was significant, because both geophysical and geochemical observations demonstrated that small fractions of melt could be present in the mantle, especially in the vicinity of hot spots (such as Hawaii) and mid-ocean ridge spreading centers.

Over the last four years geologist Greg Hirth has worked in collaboration with David Kohlstedt at the University of Minnesota on a National Science Foundation-funded program to determine the influence of melt on the viscosity of olivine aggregates. They attacked the problem by running carefully controlled laboratory experiments on partially molten olivine aggregates. The experiments were conducted using a custom-designed deformation apparatus, in which rock viscosity can be measured at temperatures up to 1,400°C (2,550°F) and pressures up to 500 MPa (5,000 times greater than atmospheric pressure). One fundamental advancement of this study was that the influence of melt was studied independently of other variables (such as temperature) over a wide range in melt fraction. These measurements were made possible by using fine-grained (10-micron) aggregates that were fabricated from crystals found in natural lava flows. The advantage of using fine-grained aggregates is that an equilibrium distribution of melt can be attained in a few hours. In the mantle, olivine grains have a diameter of about 1 millimeter. If experiments were conducted on an aggregate with a grain size of 1 millimeter it would take more than two years for the melt distribution to equilibrate, an obvious deterrent to any experimental program.



At melt fractions greater than about 0.05, the viscosity of partially molten aggregates is reduced by more than an order of magnitude

The study results show that the melt's influence on the viscosity of olivine aggregates was modest at melt fractions less than approximately 0.04 (that is, 4 percent melt). However, the figure shows that, at melt fractions greater than about 0.05, the viscosity of partially molten aggregates is reduced by more than an order of magnitude. A correlation of the experimental data with microstructures observed using the SEM demonstrated that the reduction in viscosity occurs when a significant number of grain boundaries become "wetted" with melt. (An analogy would be that a drop of water beads on glass while a drop of oil spreads out and "wets" the glass, in this case, the two substances behave differently because of varying surface tensions.) Previous theoretical studies, based on the average surface tension between melt and olivine, predicted that it would take approximately 20 percent melt to promote a significant decrease in viscosity. However, the microstructural observations of the experimental samples showed that the anisotropic properties of olivine resulted in the wetting of some grain boundaries at much lower melt fractions (that is, some crystal faces are wetted more than others). These results indicate that under certain circumstances the presence of melt may not have a strong effect on the mantle's flow behavior. However, if the melt fraction exceeds approximately 0.05, the processes that control mantle flow and melt migration will be strongly affected.


Tom Kleindinst

Greg Hirth works at the Marine Biological Laboratory's scanning electron microscope with "synthetic" rock samples fabricated from crystals in natural lava flows for studies of mantle viscosity.

Sources of arctic radioactive contamination include nuclear facilities in Russia's Ob River drainage basin, weapons testing on the island of Novaya Zemlya, nuclear reactors dumped into the Kara Sea, and ocean-current-borne materials from British and French fuel-reprocessing plants.

The Department of Marine Chemistry and Geochemistry (MC&G) consists of 19 scientific staff, 21 technical staff, 24 graded and administrative staff, and 3 postdoctoral investigators working on a total of approximately 100 research projects. In addition there are 16 Joint Program students, 8 of them in residence at Woods Hole.

Research in the department covers a broad spectrum of topics related to global climate change, ocean circulation, biogeochemical cycles, remote sensing of the ocean, trace metals, radioactive contamination, organic geochemistry, sediment diagenesis, and the geochemistry of seafloor hydrothermal systems. Material transfers within the ocean and across boundaries with the air, land, and oceanic crust are common themes of much MC&G research. Many projects are parts of large national and international programs such as the Joint Global Ocean Flux Study (whose national administrative office is housed in the department), World Ocean Circulation Experiment, Earth Observing System, Ridge Inter-Disciplinary Global Experiment, and Ocean Drilling Program.

The year saw a number of personnel changes in the department, including the retirement of department chairman Geoff Thompson and his replacement by Mike Bacon. Associate Scientist Neil Blough left us to take a position in Maryland, and Kathleen Ruttenberg, a sedimentary geochemist, was added to the scientific staff as an Assistant Scientist.

Three of the department's many diverse research projects are highlighted.

River Sediments Record Russian Nuclear Waste

Since the 1991 collapse of the Soviet Union, reports have reached the West concerning various forms of nuclear waste that represent present or future environmental concerns. In addition to nuclear waste and reactors dumped directly into arctic-shelf seas, Siberian rivers that flow toward the Arctic have been likewise contaminated. Major nuclear weapons plants (many equal to the US plutonium-production reactor complex at Hanford, Washington) lie in upper-Siberian river systems, which drain into the Arctic Ocean. These include the Chelyabinsk-65 and Tomsk-7

plants on the Ob River and its tributaries, and the Krasnoyarsk plant on the Yenisey River. In addition to several notorious accidents and discharges that caused severe local contamination, approximately half the total waste produced by these plants was injected as liquid into relatively shallow wells in geological formations for permanent storage. These situations reveal the need for accurate information about present and past contamination, and forecasts of the risks of future releases.

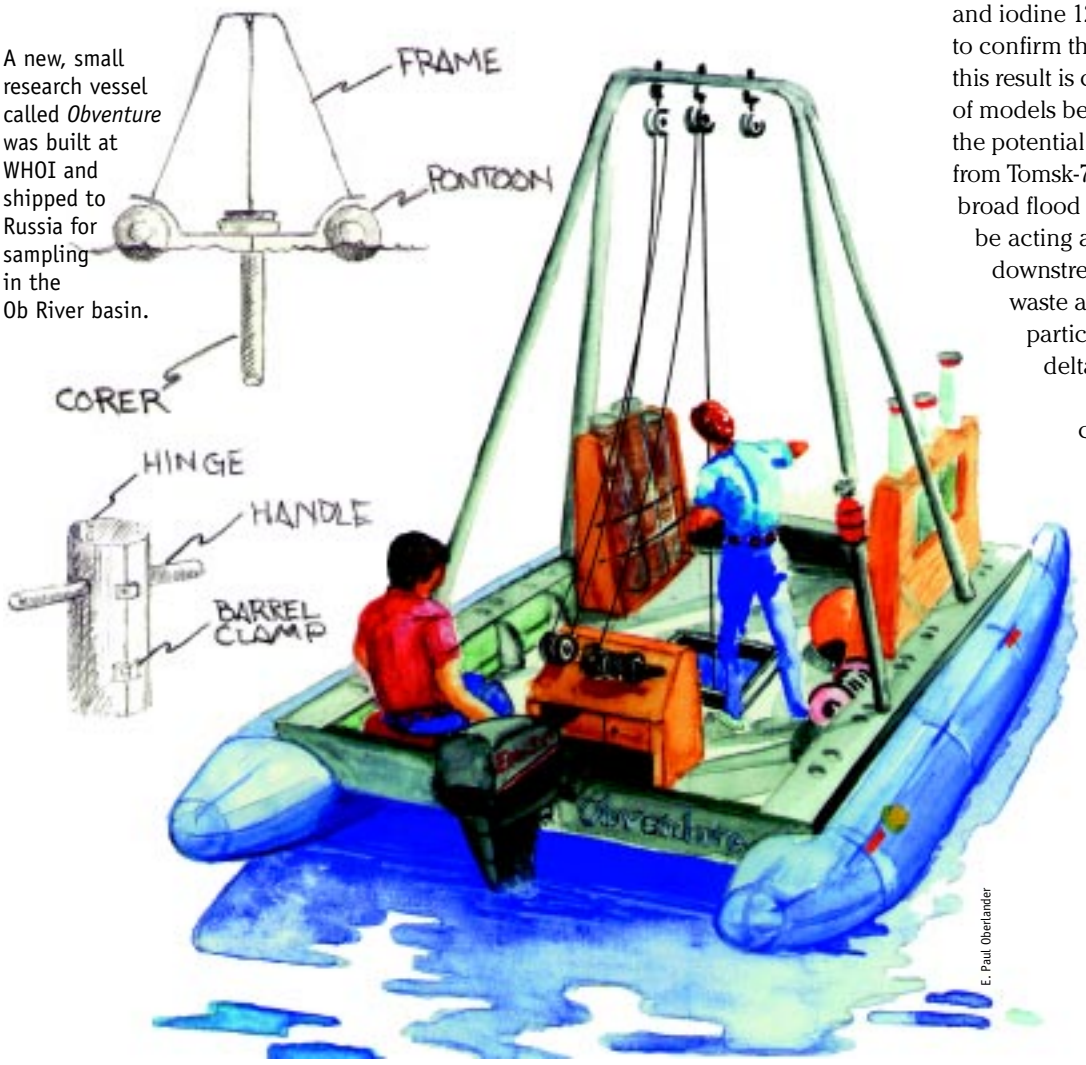
Concerns about the threat this contamination represents to the Arctic and Alaskan waters led Alaska Senator Ted Stevens to initiate the Arctic Nuclear Waste Assessment Program, funded through the Office of Naval Research, to study the hazard. Under its auspices, Hugh Livingston and Fred Sayles are analyzing Ob River sediments to try to understand the history of contamination recorded there. Joint Program student George Panteleyev headed a summer 1994 expedition to the Ob River delta near its mouth at Salekhard, Siberia.

Using a WHOI-built catamaran deployed from a Russian Ministry of Fisheries Protection ship, a team of American and Russian scientists collected sediment cores at 15 locations in the Ob's delta and estuary regions. These cores were taken where sediment accumulates annually in countless small Ob River system lakes that are flooded annually when the Siberian spring sends melted water downstream.

The cores were returned to WHOI for analysis for radionuclides and other sediment parameters. In addition to human-source contaminant radionuclides, such as cesium 137 and plutonium, natural radionuclides, such as lead 210, were identified and measured. Lead-210 measurements are especially useful in dating sediment layers, and hence developing a chronology of contamination laid down in these sediments over the past several decades.

Results so far indicate that the cores collected indeed contain such a chronology. For example, buried within these sediments are the records of fallout from atmospheric nuclear weapons from the 1950s and 1960s and contamination from the 1986 Chernobyl nuclear reactor accident. Thus far, no signs of contamination attributable to the upstream nuclear waste sources have been detected. Although more detailed analyses of plutonium isotopes and iodine 129 have yet to be completed to confirm this preliminary conclusion, this result is consistent with predictions of models being developed to evaluate the potential fate of materials released from Tomsk-7 and Chelyabinsk-65. The broad flood plains of the Ob River may be acting as a trap, retarding the downstream transport of radioactive waste associated with the sediment particles moving towards the delta.

These studies are being continued to understand more completely the processes controlling pollutant transport in the Ob River, and researchers hope to extend them to other Siberian rivers that can contaminate the Arctic. These preliminary results are encouraging, since they suggest that the Arctic may not be seriously contaminated by Russian nuclear waste—that this problem may be more serious for the terrestrial environment.



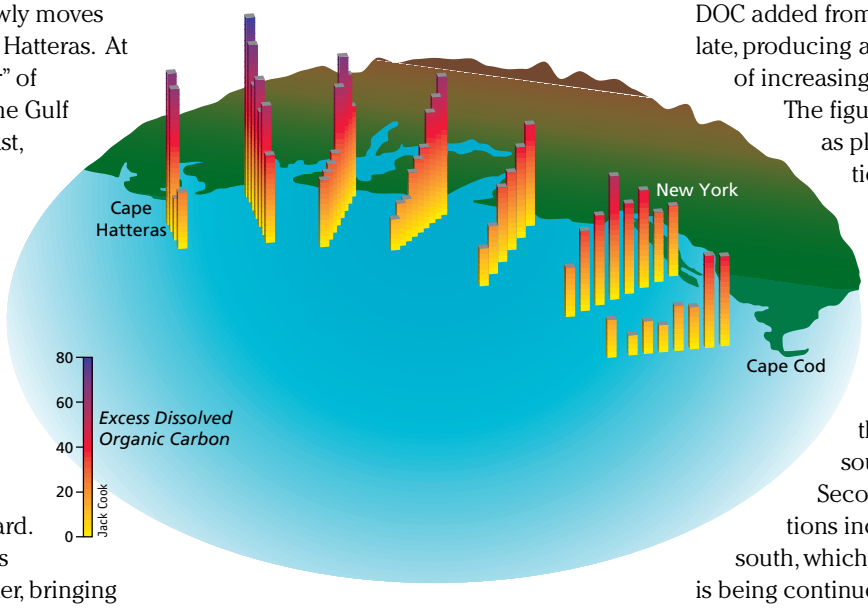
A new, small research vessel called *Obventure* was built at WHOI and shipped to Russia for sampling in the Ob River basin.

What Happens To River-Borne Carbon When It Reaches The Ocean?

The Mid-Atlantic Bight (MAB) is the region of the US eastern seaboard that stretches from Cape Cod, Massachusetts, to Cape Hatteras, North Carolina. Between the coast and the edge of the continental shelf, the water in the MAB behaves like a giant river. Coastal water enters the shelf from the Gulf of Maine, flows south over Georges Bank, then turns southwest and slowly moves along the coast to Cape Hatteras. At Cape Hatteras, this "river" of seawater collides with the Gulf Stream and is carried east, out to sea. As the water moves south along the coast, it is modified by the major rivers in the MAB, the Hudson, Delaware, and Susquehanna (through Chesapeake Bay), along with the several hundred smaller rivers and streams that drain the eastern seaboard. Water from these rivers is added to coastal seawater, bringing dissolved and suspended constituents that have washed out of coastal soils.

Over the past three years, the Department of Energy's Division of Health and Environmental Research has conducted a pilot program to study the accumulation and transport of material in the MAB. A number of cruises were conducted in 1993 and 1994 to measure dissolved and suspended material in coastal seawater, the dynamics of algae and other biological processes on the shelf, and the deposition of material to the seafloor. Results from this study are now being used to design and execute a much more intensive four-year study of the coast that will take place from 1996 to 1999.

The Department of Energy is interested in the export of energy-related waste products from the shelf, and, in particular, carbon dioxide that is generated as a waste product of fossil fuel combustion. When oil, gas, or coal is burned, carbon is converted into carbon dioxide (a colorless gas), and released to the atmosphere. Long-term accumulation of carbon dioxide in the atmosphere may lead to a slow global warming, or "greenhouse" effect. One way to counteract this process is through photosynthesis, which converts carbon dioxide back into plant material, removing it from the atmosphere. However, if plants are degraded and turned back into carbon dioxide each year, carbon is simply recycled, and there is no net removal from the atmosphere. When terrestrial plants die and fall to the ground, some of their carbon is dissolved by rainwater and carried through the soil to rivers. Once in rivers, this dissolved organic carbon (DOC) can be carried out to sea and effectively "buried" in the ocean. Although DOC is abundant in rivers, it is unclear if it ever makes it into the ocean. Some evidence suggests that all the DOC is consumed in the rivers, and that very little is exported off the coast.



The distribution of "excess" dissolved organic carbon (DOC) in the Mid-Atlantic Bight in April 1994. "Excess" dissolved organic carbon is the amount of carbon added to a parcel of water after it entered the study area. Two distinct trends are apparent, a general decrease in DOC from inshore to offshore, and an increase in carbon from north to south. This pattern can be explained by a near-shore source of DOC and a gradual accumulation of carbon as the water moves south through the Mid-Atlantic Bight.

In 1994, Dan Repeta and colleagues from the Marine Biological Laboratory, Virginia Institute of Marine Science, Brookhaven National Laboratory, and the National Aeronautics and Space Administration conducted a survey to see if river-borne DOC was present in the MAB. They theorized that as seawater moves south along the coast, DOC added from rivers should accumulate, producing a north-to-south gradient of increasing DOC concentration. The figure shows survey results as plots of DOC concentration along cross-shelf transects at six locations in the MAB. Two trends are very distinct: First, the highest DOC concentrations are nearest the coast, suggesting that the coast is the source of the DOC. Second, the DOC concentrations increase from north to south, which is as expected if DOC is being continuously added by rivers.

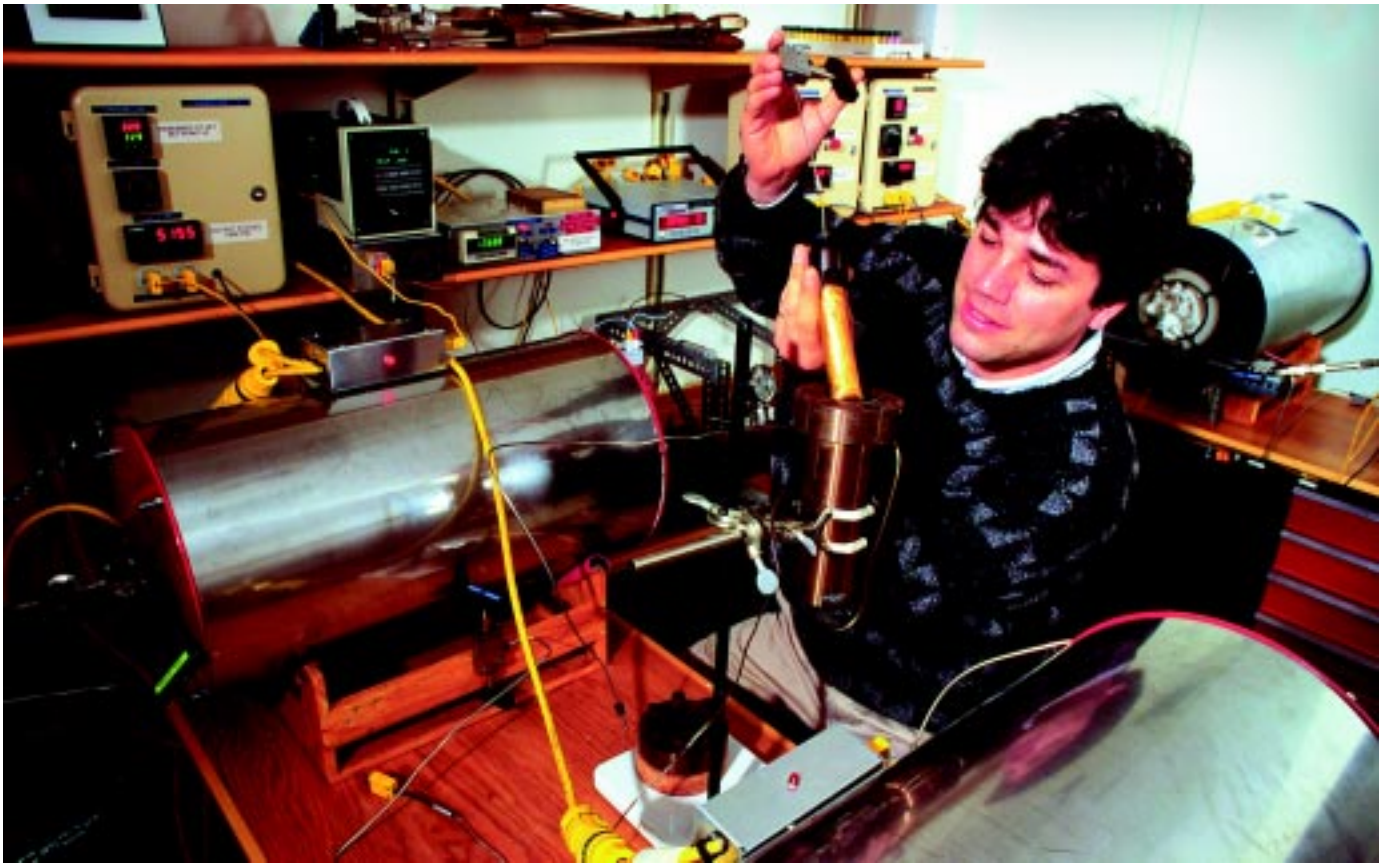
Over the next four years, scientists will make detailed studies of the chemical composition and biological characteristics of the coastal DOC, and try to follow the DOC plume as it moves off the coast into the open ocean. Many questions need to be answered, including: How much DOC is exported from the coast per year? and, How much time does it take to degrade DOC back into carbon dioxide, once it enters the ocean? Chemists, physicists, biologists, and geologists from over a dozen universities and oceanographic institutions will be working together on ships, in aircraft, and in the laboratory using a variety of sophisticated chemical and molecular biological techniques to answer these and other questions.

Water May Provide Reactive Hydrogen For Hydrocarbon Formation

Heating of organic-rich sediments during burial in sedimentary basins results in the production of oil and natural gas. Our ability to locate petroleum reserves of economic proportions is critically dependent on the effectiveness with which the timing, location, and composition of hydrocarbon generation can be predicted. Although the composition of oil and natural gas has been well characterized, we are just beginning to understand in detail the chemical processes that transform sedimentary organic matter to petroleum and natural gas.

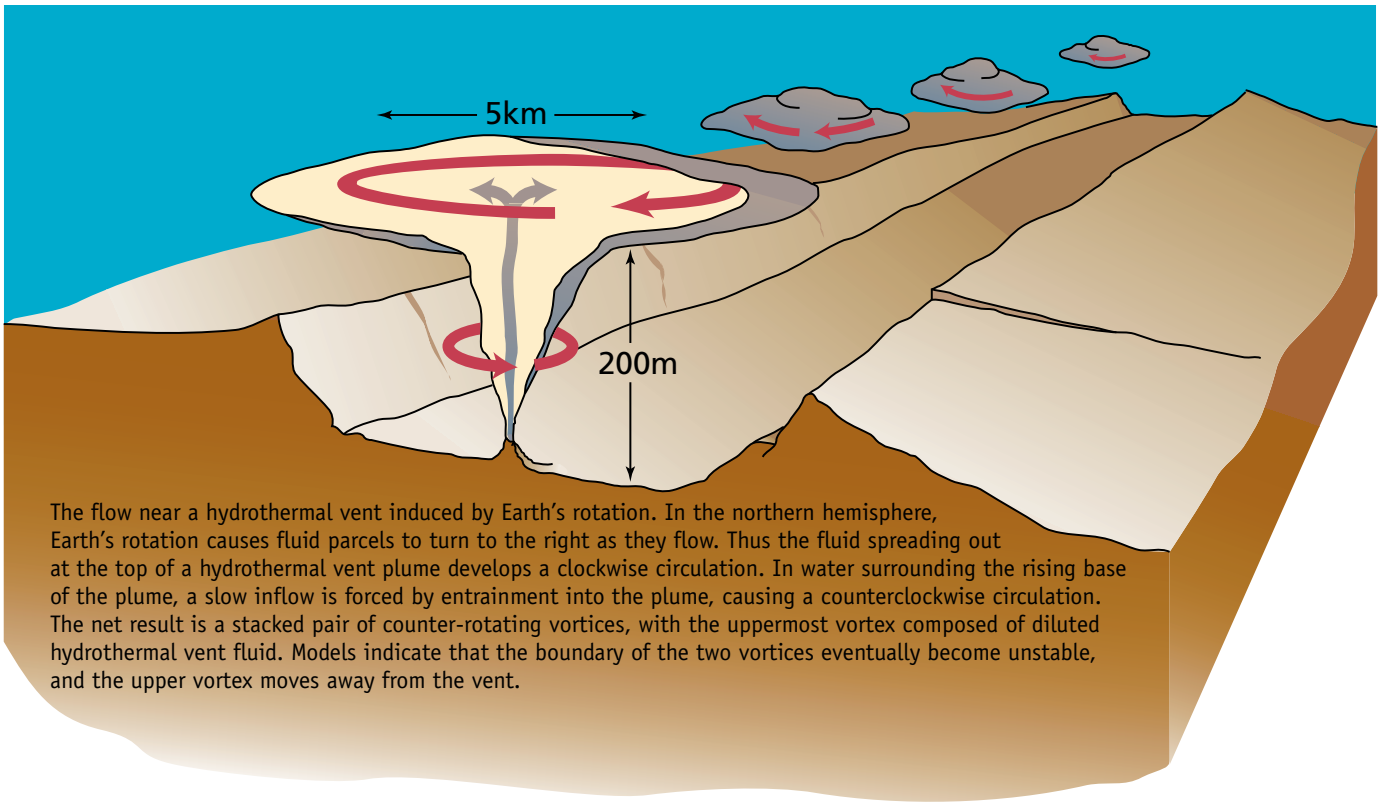
Jeff Seewald, with National Science Foundation and Department of Energy funding, conducts laboratory experiments to study the chemical reactions associated with the production of hydrocarbons at elevated temperatures and pressures. Using specially designed, flexible reaction-cell hydrothermal apparatus, chemical reactions between fluids and minerals can be studied at temperatures and pressures as high as 450°C and 500 bars, respectively, to simulate conditions that occur deep within the Earth. Owing to the extreme complexity of natural systems, key processes that regulate the stability of organic compounds are often obscured. Laboratory experiments allow individual reactions to be studied under well-constrained physical and chemical conditions that permit important cause-and-effect relationships to be unambiguously established.

Recent experiments have demonstrated that the abundance and relative distribution of some hydrocarbons in sedimentary basins are controlled by thermodynamic equilibrium involving water and iron-mineral assemblages. These results provide the first experimental evidence for a reactive link between inorganic and organic sediment components in oil- and gas-producing sedimentary basins. Perhaps the most important result to date is that water may act as a reactive source of hydrogen for hydrocarbon formation. In the past, conventional wisdom has advocated that the hydrocarbon generation potential of sediments is limited by the hydrogen content of the organic matter. Because water is ubiquitously present in most sedimentary basins, however, Seewald's results suggest that the hydrocarbon generation potential of sedimentary organic matter may be substantially greater than that predicted by previous models. Experiments are continuing in an attempt to create and verify new paradigms for the description of natural processes involving organic compounds in nature.



Tom Kleindinst

Jeff Seewald uses specially designed laboratory equipment to illuminate the chemical processes that transform sedimentary organic matter into oil and gas.



Jack Cook

The flow near a hydrothermal vent induced by Earth's rotation. In the northern hemisphere, Earth's rotation causes fluid parcels to turn to the right as they flow. Thus the fluid spreading out at the top of a hydrothermal vent plume develops a clockwise circulation. In water surrounding the rising base of the plume, a slow inflow is forced by entrainment into the plume, causing a counterclockwise circulation. The net result is a stacked pair of counter-rotating vortices, with the uppermost vortex composed of diluted hydrothermal vent fluid. Models indicate that the boundary of the two vortices eventually become unstable, and the upper vortex moves away from the vent.

Scientific research interests in the Physical Oceanography Department range in scale from broad, general circulation in ocean basins over years and centuries to mixing and dissipative processes that occur on scales of millimeters and seconds. Department staff members both conduct individual research programs and participate in large, cooperative interinstitutional and international field programs. Specific research efforts include theoretical and field work, analysis of observations, remote sensing, laboratory experiments, and analytical and numerical modeling programs. Areas of special interest are the structure and dynamics of the deep circulation; air-sea interaction and the role of fresh water, through evaporation and precipitation, in the formation and modification of water masses; and how fronts affect coastal circulation.

WHOI physical oceanographers are involved in planning, fieldwork, and analysis for five major World Ocean Circulation Experiment cruises as part of the program's Core I (Global Survey) in the Pacific and Indian Oceans, and they are continuing fieldwork and analysis in three elements of Core III (Process Studies): the Deep Basin Experiment, the Subduction Experiment, and the North Atlantic Tracer Release Experiment. In addition, department members are increasingly involved in such multidisciplinary programs as Global Ocean Ecosystems Dynamics (GLOBEC) and Ridge Inter-Disciplinary Global Experiments (RIDGE).

Following Department Chair Jim Luyten's appointment as Associate Director for Research, Nelson Hogg and Terry Joyce each served two months as Acting Chair, and Phil Richardson became the new Physical Oceanography Chair on June 1. Claire Reid also moved to the Associate Director's office as Executive Assistant, and Karin Bohr succeeded her as Department Administrator. A noteworthy event of 1993 was the award of American Meteorological Society's Sverdrup Gold Medal to Senior Scientist Jim Price "for important interpretations of observations of upper ocean time dependent variability, including Ekman layers, inertial observations, responses to a hurricane, oceanic eddies, and mixed layer physics."

Studying the Long Reach of Hydrothermal Vent Plumes

As more of the world's mid-ocean ridge system is explored and mapped, scientists are discovering that high-temperature hydrothermal venting is quite common. This realization, combined with observations that hydrothermally derived water can be detected several thousands of kilometers from its ridge-crest source, has led physical oceanographers to consider the role of hydrothermal venting in driving mid-depth ocean circulation. How the transition is made from isolated, high-temperature plumes that rise several hundred meters above their sources to this large-scale flow is the subject of Karl Helfrich's modeling studies. Supported by the National Science Foundation under the RIDGE program (Ridge Inter-Disciplinary Global Experiments), he is assessing rotationally controlled flow around and above hydrothermal vents.

As hot fluid rises from a vent, it mixes with surrounding seawater and cools. Eventually it reaches a height where it begins to spread laterally and becomes an "intrusive lens." During this stage, Earth's rotation causes this outward flow—or plume—to rotate as well. The surrounding water below the intrusion is forced to rotate in the opposite direction. The result is a stacked pair of counter-rotating vortices several kilometers across. The upper vortex is an intrusive lens of diluted hydrothermal-vent fluid. Theoretical and laboratory modeling studies show that this combined flow is unstable and that it tends to break away from its source. But rather than coming completely apart, the plume vortex remains intact as it moves away from the vent, retaining a distinct "plume-fluid signature." The process then repeats, with one continuous vent producing numerous vortices in this manner.

These modeling studies point to some intriguing—and potentially important—consequences. For example, if the plume vortices remain intact for long periods of time as they move away from the vent site, can they act as "taxis" to transport delicate vent-organism larvae to new and unpopulated hydrothermal sites? The answer to this question, and the potential role of plume vortices in maintaining the mid-depth flow far removed from vent sites, is unclear. As yet, these modeling studies are idealized, and leave out many important parts of the actual ridge-crest vent environment.

To address these real ocean questions, Helfrich and Terry Joyce along with Glen Cannon (National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory) have begun a study to determine if this hypothesized flow does indeed occur, and, if so, to outline its actual characteristics. In summer 1994, an instrument array was placed around the Juan de Fuca Ridge's high-temperature "Organ Pipe" vent, just 200 miles off the Oregon coast. The instruments measured the temporal and spatial structures of water flow near the vent in an effort to characterize the variability in the vent neighborhood and detect plume-induced vortices. The instruments have recently been recovered, and data analysis is under way.

US-French Cruise Examines Antarctic Bottom Water Mixing In Fracture Zone

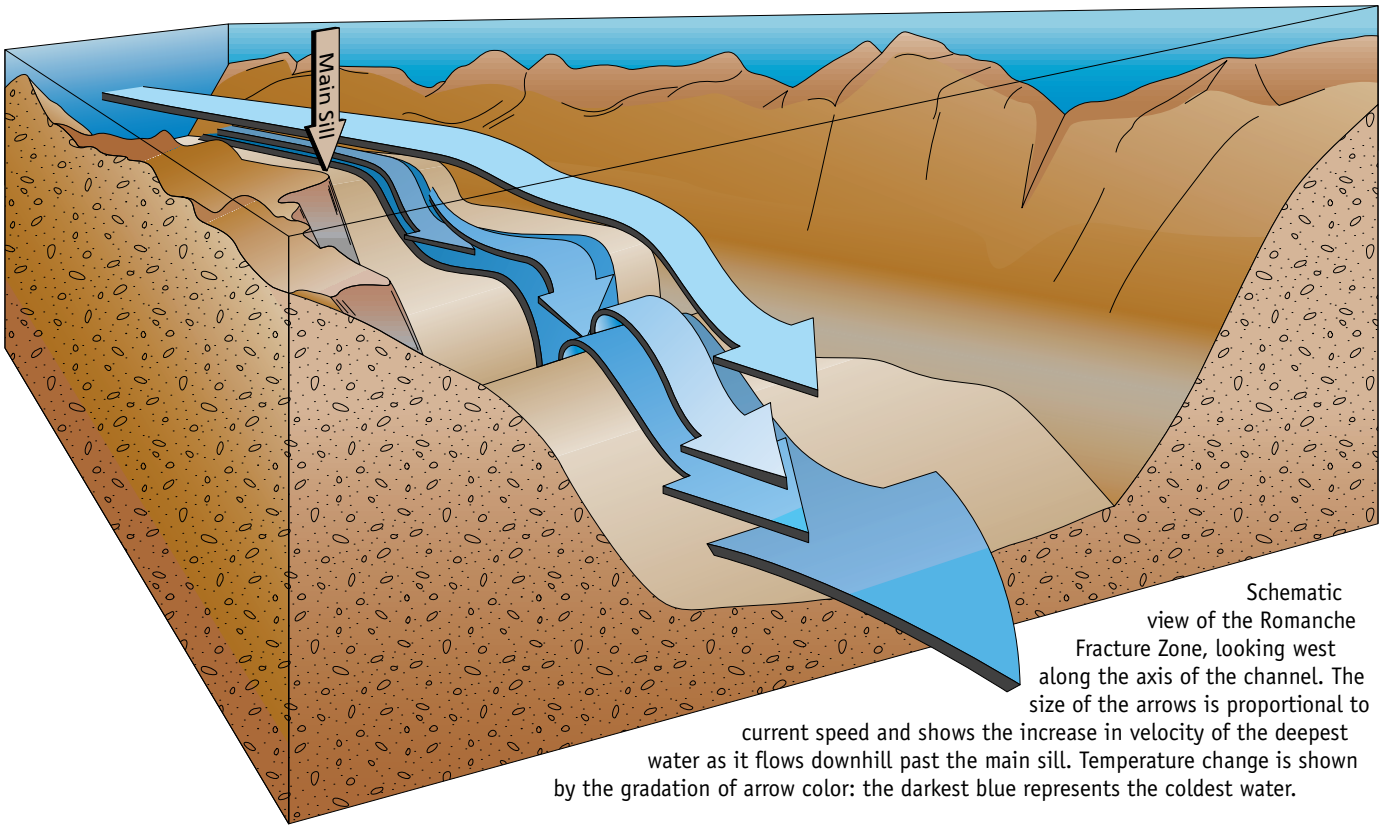
Mixing within a series of rapids in an ocean-bottom river—a river approximately five times the size of the Amazon—was the focus of a US-French exploratory cruise to the Romanche Fracture Zone of the equatorial Atlantic Ocean in November 1994. The Mid-Atlantic Ridge represents a formidable barrier to the spread of Antarctic Bottom Water in the Atlantic. Formed in the Weddell Sea and modified in the Southern Ocean, the Antarctic Bottom Water is confined by bathymetry to the western basins of the South Atlantic as it moves north. The Romanche Fracture Zone near the equator is the deepest pass across the mid-ocean ridge, and its channel is the principal conduit for the densest waters found in the Sierra Leone, Guinea, and Angola basins of the eastern Atlantic.

Circulation diagram of Antarctic Bottom Water (AABW) in the South Atlantic. Entering the Brazil Basin from the south through the Vema Passage, AABW escapes eastward through the Romanche Fracture Zone, and northwest through the Ceara Gap.

Working aboard the French research vessel *Noroit* and funded by the National Science Foundation, John Toole and Raymond Schmitt, along with colleagues from the University of Washington (UW) and the Institut Française pour Recherche et Exploitation de la Mer (IFREMER), collected high-vertical-resolution velocity profiles of the Antarctic Bottom Water (AABW) flow through the Romanche Fracture Zone (RFZ), and documented the turbulent mixing experienced by these waters during their transit. The colleagues included two MIT/WHOI Joint Program graduates, Kurt Polzin (UW) and Kevin Speer (IFREMER).

The principal instrument employed was the High Resolution Profiler (HRP), a WHOI-built, free-fall device ballasted to sink on deployment at a rate of 50 to 70 centimeters per second. On preprogrammed command, such as when a specified pressure is attained, ballast weights are released and the HRP returns to the surface for recovery. The HRP carried an acoustic altimeter interfaced to its microprocessor to facilitate close approach to the bottom by releasing ballast at a prescribed height above the bottom. Fine-scale data recorded internally during each dive are reduced to half-meter vertical resolution profiles of ocean temperature, salinity, and horizontal velocity. Microstructure sensors mounted on the HRP sample velocity and temperature variability on scales directly affected by molecular viscosity and diffusivity (around 1 centimeter). This information is used in turbulence models to deduce the rate of mixing.

The data collected show AABW in a 300-to 700-meter-thick layer at the bottom of the RFZ. Many sills within this channel inhibit its eastward motion, much as dams in a river block flow. The coldest, densest AABW spilling over the

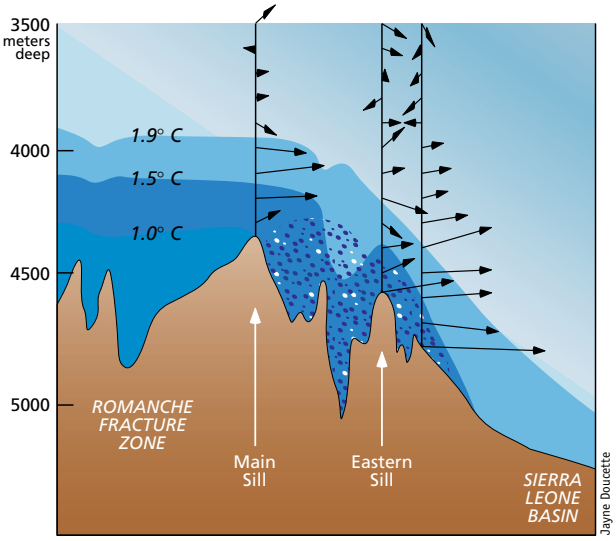


Schematic view of the Romanche Fracture Zone, looking west along the axis of the channel. The size of the arrows is proportional to current speed and shows the increase in velocity of the deepest water as it flows downhill past the main sill. Temperature change is shown by the gradation of arrow color: the darkest blue represents the coldest water.

main sill (4,400 meters deep) was approximately 0.9°C; there the eastward bottom water flow was around 25 centimeters per second. Based on a channel width of 10 kilometers, the researchers estimate the AABW transport to be approximately one million cubic meters per second, roughly five times the Amazon River's transport. Thereafter these waters flow downhill towards the Sierra Leone Basin, whose bottom depth exceeds 5,000 meters. The AABW layer accelerates down this slope, reaching maximum speeds of 50 centimers per second 80 kilometers east of the main sill, where the bottom depth is 4,800 meters.

As the AABW accelerates, the shear between it and the overlying waters appears to become unstable, causing intense turbulence in the bottom-most 500 meters of this region. (The intensity of the velocity microstructure was comparable to that seen in the upper ocean when winds blow 15 to 20 knots.) The turbulent eddies mix the AABW with the warmer, less dense, overlying waters.

As a consequence, the coldest waters exiting the RFZ and entering the Sierra Leone Basin are about 1.4°C, fully half a degree warmer than those flowing over the main RFZ sill. Thus, turbulent mixing appears to be as important as blocking by sills in setting the bottom water characteristics of the Atlantic Ocean's eastern basins. This is one of the best examples of how ocean turbulence at scales as small as 1 centimeter can influence major-ocean-basin water properties. Accurate parameterization of these mixing processes, key to achieving realistic models of ocean circulation, remains an important problem in physical oceanography.



Cut-away view of the area in the figure above viewed from the south with velocities derived from High Resolution Profiler measurements shown by arrows (the longer the arrow, the greater the observed velocity). Flow direction is indicated by arrow angle. A horizontal arrow denotes the flow aligned with the axis of the channel. The region of most intense mixing is indicated by dots.

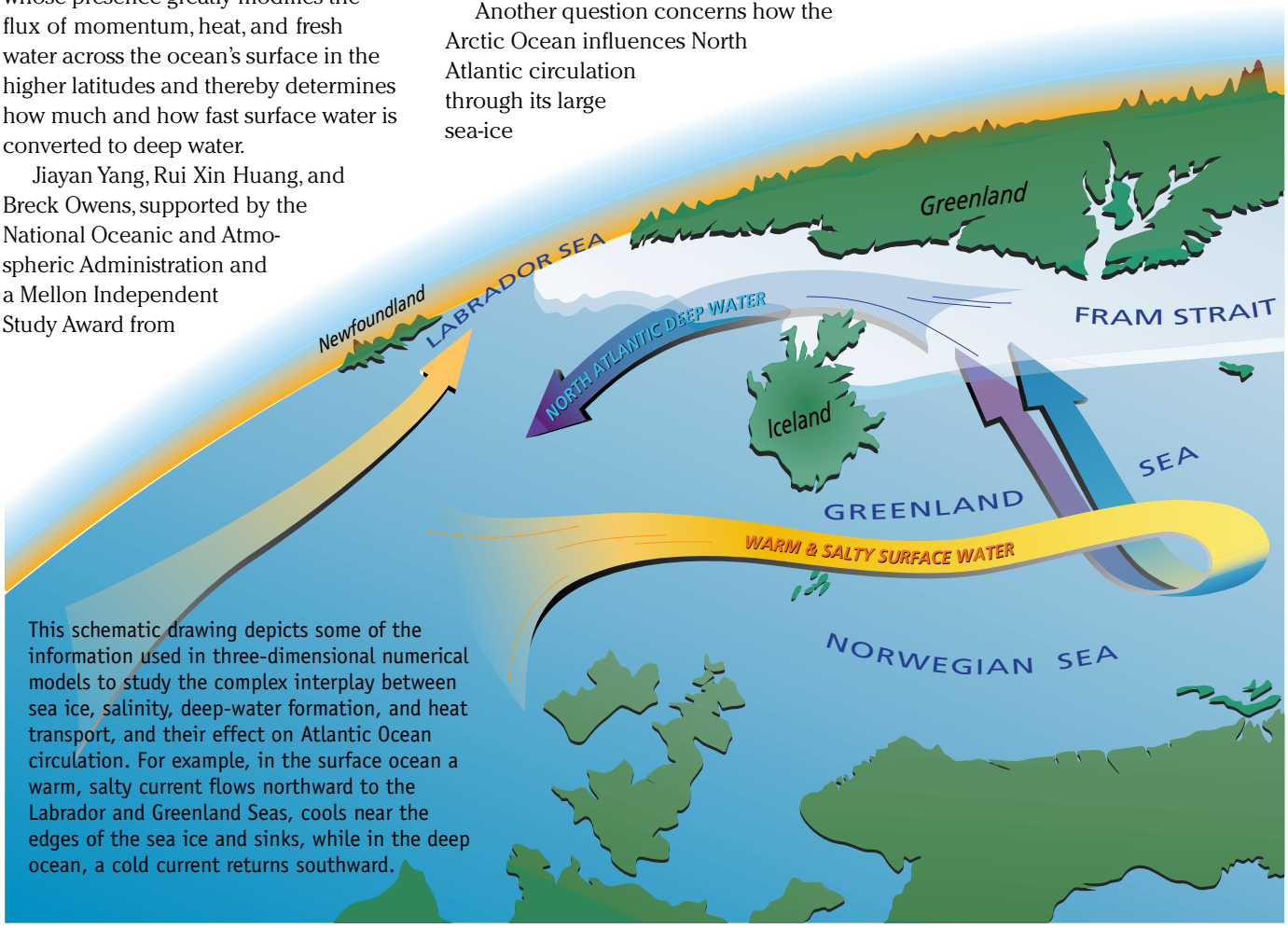
Uncovering How Sea Ice Affects Ocean Circulation

In the North Atlantic, warm and salty surface water flows northward from low latitudes to the Labrador and Greenland seas. There, it is cooled by the atmosphere and subsequently sinks to form North Atlantic Deep Water, which then returns southward as deep western boundary currents. Driven by this deep-water-formation process, the North Atlantic thermohaline circulation (THC) transports about 15 million cubic meters of water per second, carrying a tremendous amount of heat toward the poles. Paleoclimatological records and modern observations suggest that variations in THC may cause large-scale climate changes. The subpolar North Atlantic is partially covered by sea ice, whose presence greatly modifies the flux of momentum, heat, and fresh water across the ocean's surface in the higher latitudes and thereby determines how much and how fast surface water is converted to deep water.

Jiayan Yang, Rui Xin Huang, and Breck Owens, supported by the National Oceanic and Atmospheric Administration and a Mellon Independent Study Award from WHOI, are using three-dimensional numerical models to study ocean-ice interaction and its effect on Atlantic thermohaline circulation. Their model comprises a three-dimensional ocean model that produces velocity, temperature, and salinity fields, and a sea-ice model that calculates sea-ice drift and local melting and freezing. The interplay between sea ice, salinity, deep-water formation, and heat transport is very complex. The model will help explore such fundamental scientific questions as how freshwater flux associated with sea-ice freezing and melting affects surface salinity, and thus the deep-water conversion rate. For instance, if the surface-layer salinity is diluted by fresh water because of sea-ice melting, there will be less sinking, due to a "cap" of lighter and fresher surface water. This will alter the THC's heat transport, which, in turn, will affect sea-ice distribution.

Another question concerns how the Arctic Ocean influences North Atlantic circulation through its large sea-ice export to the Greenland Sea through Fram Strait. This sea-ice flux, estimated to average about 2,800 cubic kilometers per year, is by far the largest freshwater source in the Greenland Sea, and any changes in it can considerably affect the salinity and water-mass conversion rate there. This provides a linkage between variations in the arctic climate system and Atlantic thermohaline circulation, since the deep water formed in the Greenland and Norwegian Seas is the main source for the deeper layers of the THC.

About eight percent of the world's ocean surface is covered by sea ice, either permanently or seasonally. Better understanding of sea-ice effects on North Atlantic THC will advance knowledge of similar effects at work in the broader areas of the world ocean that are covered by sea-ice.



This schematic drawing depicts some of the information used in three-dimensional numerical models to study the complex interplay between sea ice, salinity, deep-water formation, and heat transport, and their effect on Atlantic Ocean circulation. For example, in the surface ocean a warm, salty current flows northward to the Labrador and Greenland Seas, cools near the edges of the sea ice and sinks, while in the deep ocean, a cold current returns southward.

Jayne Doucette

Marine Policy Center

At the Marine Policy Center (MPC), scholars engage in social scientific research to improve the conservation and management of coastal and marine resources. Their work integrates economics, policy analysis, law, and statistics with WHOI's basic ocean sciences strength.

Center staff were deeply saddened by the loss in September of MPC Director James Broadus, who died while attending a conference in Hawaii. Broadus came to WHOI in 1981 and had been Center Director since 1986. He was internationally known for his work on the economics of marine minerals and seabed mining and more recently on the economics of climate change, and he was involved in numerous national and international marine policy programs.

Statistician Andrew Solow was named Acting Center Director in October and then Director in January 1995.

In 1994, MPC made important contributions in several areas of public policy concern, including biological diversity, global climate change, coastal pollution and coastal resources management, waste management, oil spill prevention, National Oceanic and Atmospheric Administration (NOAA) fleet replacement and modernization, and digital navigation technologies.

Biological diversity and global climate change are policy issues that continue to attract unusually broad international interest. They also have in common the necessity for policy makers to reach decisions under substantial scientific uncertainty. During 1994, Solow and recent Research Fellow Stephen Polasky made an important contribution to the analysis of policy decisions in conservation and economic ecology: They defined criteria that must be satisfied by a measure of diversity and introduced a measure, "the effective number of species," that satisfies those criteria, thereby providing a mathematical structure to the theory of diversity. In the area of global climate change, Solow published a paper outlining the current state of scientific knowledge concerning the response of sea level to global warming and, with Anand Patwardhan, developed an approach to estimating the sensitivity of global temperature to changes in atmospheric composition based on historical temperature variability rather than trend. This approach avoids the problem of reconstructing secular changes in historical radiative forcing, such as the possible suppression of warming by sulfate aerosols. Their results were in close agreement with those based on fitting the trend.

Management of coastal resources, on scales ranging from the local to the international, was the subject of several MPC research projects during 1994. Porter Hoagland, Arthur Gaines, and Mary Schumacher completed an Environmental Protection Agency-supported study begun by Broadus to enhance the effectiveness of an international protocol, which is in the early stages of negotiation, for the control of land-based marine pollution in the wider Caribbean region. The study evaluated the relevant scientific, economic, and institutional factors in the region in light of lessons gained from earlier international programs to control regional land-based marine pollution, and it identified elements of a suitable framework for coordinating scientific collaborations, funding and compliance mechanisms, technology transfer, and other arrangements for relevant trade. Closer to home, Gaines conducted several studies to improve coastal management on Martha's Vineyard, including one that outlined the likely impact of a proposed wastewater treatment facility on nutrient loading, phytoplankton and submerged aquatic vegetation, aesthetic value, and recreational uses of Sengekontacket Pond.

Jim Broadus served as Marine Policy Center Director from 1986 to 1994.

Other MPC studies evaluated the economics of alternative waste management options, marine pollution prevention and navigational technologies, and NOAA fleet requirements. Di Jin, Hauke Kite-Powell, and Broadus developed an integrated model and cost estimates for the disposal of sewage sludge and municipal incinerator ash via four alternative ocean waste emplacement system concepts at five abyssal sites identified by the Naval Research Laboratory's Abyssal Plains Waste Isolation Project. The study concluded that abyssal ocean emplacement is competitive with present land-based disposal costs in New York City, and it identified several important areas and objectives for further research, such as reducing uncertainty as to the fate and effect of waste in the ocean and analyzing how perceptions and political forces influence policy decisions and the future viability of the ocean disposal option under US and international law.

Broadus, Kite-Powell, and Jin also worked with an expert committee established under the National Research Council's Marine Board to review NOAA's Fleet Replacement and Modernization Plan, focusing on questions of economic efficiency and strategic issues affecting NOAA's future fleet requirements. Jin and Kite-Powell began work on a project for NOAA's National Ocean Service to examine the benefits and costs of new digital navigation technologies for commercial shipping in US

waters, with emphasis on avoiding environmental damages and improving efficiencies. The project follows a related study with Broadus to examine the relative cost-effectiveness of double hulls, mandated by Congress in the wake of the *Exxon Valdez* spill for oil tankers in US waters, and alternative pollution prevention technologies. They concluded that electronic charts may be a far more cost-effective approach to marine pollution control.

Coastal Research Center

The Coastal Research Center (CRC) encourages and initiates interdisciplinary research on fundamental coastal ocean processes and communicates the results of this research to the scientific, resource management, and policy communities and to the general public. The Center also develops the intellectual and technical infrastructure necessary to support advanced research on coastal ocean processes. Foundation funding is a cornerstone for CRC activities, providing a unique source of support for innovative research, rapid response to coastal events, and cost sharing to leverage other funding sources.

In 1994, CRC developed a "spending strategy" to allocate the resources of the $900,000 challenge grant received in 1993 from the Andrew W. Mellon Foundation. During the six-year lifetime of this grant, WHOI intends to raise funds to permanently endow coastal research, and an endowment fund for this purpose was established in 1994. In the interim, funds from the original grant are being used to support coastal research, including various small projects in all disciplines, cost sharing for Sea Grant and W.M. Keck Technology Innovation Awards, and partial support of a postdoctoral scholar in environmental biogeochemistry and student thesis research projects. The Mellon grant also provided cost-sharing funds toward additions to the CRC Coastal Instrumentation Pool as the result of a proposal to the Office of Naval Research Defense University Instrumentation Program. The three new instruments purchased under this grant are:

- ▶a conductivity/temperature/depth profiling system with various sensors and rosette water sampler array;
- ▶an underwater spectral radiometer to study interactions between planktonic processes and ocean optics; and
- ▶a heat/momentum flux measurement system to study air-sea interactions and surface boundary-layer processes.

The newly-prepared spending strategy will permit CRC to focus its resources on one or two interdisciplinary research themes selected by WHOI scientists in order to provide "scientific venture capital" for emerging research topics of importance to scientists and to resource managers. In 1994, CRC again received Exxon Corp. funding in support of a postdoctoral scholar award.

In 1994, a new 5-meter Boston Whaler joined the small-boat fleet CRC maintains to benefit coastal researchers. It replaced an aging boat that has seen many years of hard use; the old boat was donated to the University of Massachusetts Field Station on Nantucket where it will continue to be used in sheltered waters for research and education. In addition to maintaining the small boats, CRC staff compiled and shared with the research community the Coastal Instrumentation Pool listing of instruments available for loan from various scientists noted above. Similarly, CRC created a database of Gulf of Maine research vessels available for charter in response to Georges Bank and Gulf of Maine research needs.

During 1994, CRC was active in Gulf of Maine research, including assistance in the organization and coordination of the National Science Foundation-National Oceanic and Atmospheric Administration Global Ocean Ecosystems Dynamics (GLOBEC) Northwest Atlantic/Georges Bank Program. This program's intensive fieldwork began in the spring of 1994. CRC also provides the WHOI link to the Regional Association for Research of the Gulf of Maine (RARGOM), and participated in several RARGOM activities including a habitat workshop. RARGOM has become an effective focal point for regional discussions of research activities and CRC ensures that WHOI remains a full participant in those discussions.

The International Mussel Watch coastal monitoring program has been based at CRC since 1991. A report on the initial phase of this program, focusing on field sampling in Latin America and analysis of the tissue samples collected for chlorinated hydrocarbon biocides was completed

Tom Kleindinst

Olimpia McCall and Bruce Tripp pack standard reference material for shipment to International Mussel Watch researchers in Central and South America.

in 1994. A total of 370 samples collected at stations along both the Atlantic and Pacific coastlines of Central and South America were analyzed. Results of this project provide a unique overview of coastal contamination in this global region. As the second International Mussel Watch sampling phase begins in the Asia-Pacific region, program headquarters will move to Ehime University in Japan. However, CRC will continue to be involved in the program, including attempting to fund projects that provide technical support to the established network of scientists in Latin America. For example, in 1994, CRC organized a training workshop in Woods Hole for several Caribbean area scientists.

CRC also continues to play a regional outreach role. In 1994 this included cooperation on several fronts with regional organizations such as:
▶serving in an advisory capacity to Waquoit Bay National Estuarine Research Reserve and the Barnstable County Coastal Resources Committee,
▶initiating, with WHOI Sea Grant and the United States Geological Survey Woods Hole branch, a prototype electronic journal, "Coastal Briefs," a series of summary papers on coastal topics of general interest (A collaborative proposal with Sea Education Association, Inc. to support this and other educational activities is pending.),
▶assisting with teacher training by participating in a Buzzards Bay area teachers' conference,
▶participating in a high school student coastal science training program,
▶co-sponsoring, with the Town of Orleans, the fall meeting of the New England Estuarine Research Society, and
▶sponsoring several special seminars on topics of interest to the scientific staff and to the broader community.

As usual, CRC hosted a large number of visitors and guest investigators in 1994 for various periods of time. These guests, ranging from government agency staff to visiting scientists, provide an opportunity to explain Center research results and to exchange ideas.

Center for Marine Exploration

In 1994, the Center for Marine Exploration finished developing the *Medea/Jason* system and transferred it from the Deep Submergence Laboratory to WHOI's Marine Operations Group. This remotely operated system, along with its complementary towed-vehicle systems *Argo II* and the *DSL-120* mapping system, now provide Institution scientists with a unique set of investigative tools that were previously unavailable.

Medea/Jason will continue to work primarily in basic research, including efforts to better understand the tectonic, volcanic, and hydrothermal processes associated with the Mid-Ocean Ridge's central axis. The Center for Marine Exploration is working, however, to broaden the system's applications. The Center has joined scientists at Harvard University to examine the potential for exploring the Black Sea's ancient, deep-water trade routes with remotely operated vehicles. Unlike most large bodies of water, the Black Sea lacks free oxygen below 200 meters, and it is likely that archaeological artifacts would be found there in a high state of preservation.

This joint study effort with Harvard will be completed in 1995, and a major Black Sea search effort is scheduled for summer 1997. In addition to this archaeology program, the Center continues to work with JASON Project archaeologists to analyze and report upon the archaeology program begun in the Mediterranean Sea in 1988. In 1994, Anna McCann and Joann Freed authored a major monogram in the *Journal of Roman Archaeology*, entitled "Deep Water Archaeology: A Late-Roman Ship from Carthage and an Ancient Trade Route near Skerki Bank off Northwest Sicily." This report not only documented the 4th-century Roman trading ship that *Argo* discovered at 800 meters in 1988 and *Medea/Jason* explored in 1989, it also described numerous artifacts spread over a 50-square-kilometer area. Analysis of several artifacts recovered by *Jason* suggests that at least six additional ancient shipwreck sites exist within this area, dating to several centuries before the birth of Christ.

Quest Group, Ltd.

The remotely operated vehicle *Jason* hovers over a late-Roman wreck site during 1989 exploration in the Mediterranean Sea. Additional work is scheduled at this site, which shows evidence of a total of seven ancient shipwrecks, and additional archaeological work in the Black Sea is in the planning stages.

The results of this report have lead to the organization of a major search effort for 1995 to thoroughly map this area using the US Navy nuclear submarine *NR-1*. A follow-up effort is planned for summer 1997, when Deep Submergence Laboratory scientists will assist project archaeologists in conducting the deepest excavation effort ever attempted, using both crewed and remotely operated vehicle systems.

Sea Grant Program

The WHOI Sea Grant Program supports research, education, and advisory projects to promote the wise use and understanding of ocean and coastal resources for public benefit. It is part of the National Sea Grant College Program of the National Oceanic and Atmospheric Administration, a network of 29 individual programs located in each of the coastal and Great Lakes states to foster cooperation among government, academia, and industry. WHOI Sea Grant-supported projects provide both linkages between basic research and applied aspects of research and communication among the scientific community and groups that utilize information on the marine environment and its resources.

In 1994 WHOI Sea Grant supported 12 concurrent research projects and several smaller "new initiative" efforts aimed at developing promising new areas of research, outreach, or education. Many of the projects address local and regional needs, while others have national or even global implications. Currently funded projects are designed to:

▶study public perception of flood risks in coastal areas,

▶develop an ecosystem-based management plan for Nantucket Harbor,

▶evaluate biomarkers of reproductive damage in shellfish populations from contaminated habitats,

▶develop molecular probes for examining the effects of chemical contaminants on marine organisms,

▶detect and quantify harmful algal species using molecular probes, and

▶develop immunofluorescent markers for species identification of bivalve larvae in plankton samples.

Sea Grant supports three ongoing projects relating to research in Massachusetts and Cape Cod bays and the Boston Harbor Outfall Project. These projects focus on red-tide bloom dynamics and transfer of algal biotoxins through the pelagic food web, benthic processing of nutrients from sewage additions, and the rate of vertical mixing across the thermocline in a boundary region of Massachusetts Bay.

Communication and outreach activities include:

▶"Shorewatch," a series of programs presented on 22 Massachusetts cable-access stations and one California station that reach a potential viewer audience of over one million each week;

▶organizing beach cleanups, storm-drain painting projects, and guided beach and coastal walks;

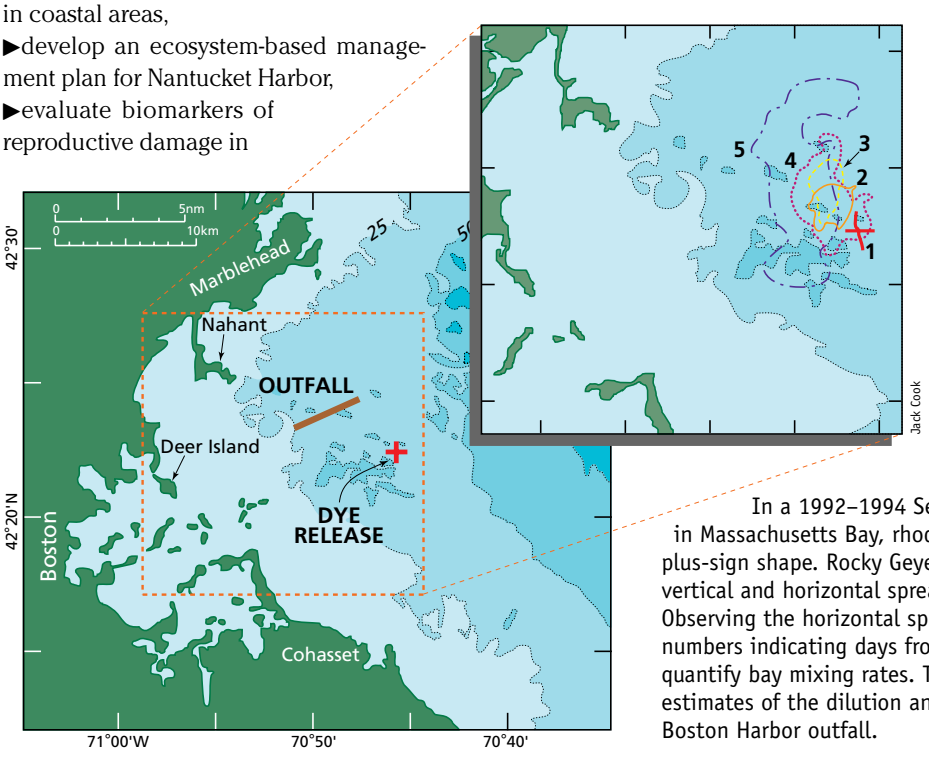
▶maintaining on-line access to WHOI Sea Grant information and resources, as well as pointers to other useful information, via Mosaic and Gopher applications for Internet users;

▶collaborating with other WHOI groups to create a WHOI "teacher packet" of marine materials and resources; and

▶disseminating Sea Grant and other marine-related publications and developing a new WHOI Sea Grant publications catalog.

"All-Cape Coastal Science Seminar" topics for 1994 included aquaculture and using the Internet for education resources. The popular "Oceans Alive" annual lecture series, designed for the general public, featured presentations on fly-fishing for striped bass, the ecology and resources of the Caspian Sea, high school student science fair projects, whale and dolphin communication, and research with ocean clams as it relates to climate change.

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. With the decline in traditional New England fisheries, many fishers are exploring other opportunities including aquaculture and the harvest of alternative species. WHOI Sea Grant staff assist local fishers by conducting literature searches and grant-writing workshops. Another focus of the advisory program is the sustainability of coastal landforms, and WHOI Sea Grant staff help local town boards to develop policies that protect salt marshes, dunes, and barrier beaches.



In a 1992–1994 Sea Grant-supported study of boundary mixing in Massachusetts Bay, rhodamine dye was released into the bay in a plus-sign shape. Rocky Geyer, Jim Ledwell, and colleagues monitored the vertical and horizontal spreading of the dye over the next four days. Observing the horizontal spreading of the dye (depicted in the inset with numbers indicating days from deployment) allowed the scientists to quantify bay mixing rates. This information will lead to more accurate estimates of the dilution and transport of sewage effluent from the Boston Harbor outfall.

Dean's Comments

The WHOI Education Office is advised by an exceptional group who give of their wisdom and time as members of the Trustees Ad Hoc Education Committee. Since my appointment as Dean in August 1990, it has been my pleasure to work closely with Lilli Hornig, chair of this committee. I have been acquainted with Professor Hornig for over 15 years, both in her capacity as WHOI Trustee and in her career as scientist and educator, most recently at Wellesley College. This year marks her transition to Honorary Trustee. Her dedication and devotion to the well-being of the Institution's Education Programs is exemplary—she has been, and continues to be, a gracious, wise mentor for all of us engaged in the WHOI education programs. I am pleased to say that Lilli Hornig will continue as a member of the committee, and I am equally pleased to welcome Nancy Milburn of Tufts University, a former dean there, as the new Chair of the Trustees Ad Hoc Education Committee.

Degree Statistics

		1994	1968-94
WHOI	Ph.D.	–	3
MIT/WHOI	Ph.D.	20	283
MIT/WHOI	Sc.D.	–	28
MIT/WHOI	Engineer	5	49
MIT/WHOI	S.M.	11	61
Total Degrees Granted		36	424

The Institution's education programs continue to provide an excellent opportunity for postdoctoral research, graduate education and research, and undergraduate introduction to scientific and engineering research. This is a particularly challenging time for our graduate students and postdoctoral scholars, fellows, and investigators as they complete their stay with us and venture forth. The end of the Cold War and several derivative or coincidental socioeconomic factors have focused attention in both private and government sectors on the role of scientific research in an increasingly complex and technological world. "Are we educating and graduating too many Ph.D.s in the sciences and engineering in the United States?" is a question that I hear or read in professional newsletters and journals with greater frequency. Conversations with our graduate students and postdocs indicate that they are increasingly concerned about their immediate and long-range career options.

A Committee of the National Academies of Sciences and Engineering is currently assessing science and engineering graduate education, and we look forward to their report, due out sometime in 1995, for guidance. This subject is also part of the purview of an internal review of our graduate education programs by an Educational Council Committee that is chaired by Senior Scientist Robert Detrick, who holds the J. Seward Johnson Chair as Education Coordinator for the Geology and Geophysics Department.

Tom Kleindinst

High School Science Teacher Fellow Valerie Bell studies the biology of open-ocean organisms in Larry Madin's lab.

Thus far, informed by the nationwide debates and conversations with colleagues, students, and postdocs, my assessment is that there are no compelling reasons for fundamental changes in the Institution's approach to graduate education. However, it is clear that career opportunities for our graduates will be less focused in expanding, or replacing, faculty of the larger graduate

New 1994-1995 High School Science Teacher Fellowships

Jeffrey Bernier - Martha's Vineyard Regional High School, Computer Applications and Programs Teacher. *Advisor:* Rich Signell, U.S. Geological Survey. *Topic:* Computer Modeling of Tide and Wind Induced Flushing of Katama Bay/Edgartown Harbor

Nancy Dennis - Wareham High School, Biology, Earth Science, Chemistry Teacher. *Advisor:* Alan Kurzirian, Marine Biological Laboratory. *Topic:* Molecular Biology Investigations of Pollution Effects. *Topic:* Aquaculture

Joseph Masi - Sacred Heart High School, Oceanography Teacher. *Advisor:* Dan Fornari, WHOI Geology and Geophysics Department. *Topic:* Mid-Ocean Ridge Geology

Kate McEowen - Martha's Vineyard High School, Biology Teacher. *Advisor:* Mark Hahn, WHOI Biology Department. *Topic:* Molecular Biology Investigations of Pollution Effects

Tom Kleindinst

Kate McEowen, a High School Science Teacher Fellow, uses molecular techniques to investigate pollution effects with her WHOI Advisor Mark Hahn.

education and research-oriented oceanography schools and departments. Instead, career opportunities are more likely to arise at four-year colleges and universities and nonprofit organizations, in business and industry, and at all levels of government.

In 1994 we initiated "value added" educational opportunities for Institution graduate students and postgraduate appointees in three ways:

▶ We increased the number of fellowships that provide teaching experience.

▶ With a generous endowment challenge grant from The Henry L. and Grace Doherty Charitable Foundation and increased annual giving from the Devonshire Trust, we expanded our postdoctoral scholar appointments from one year to eighteen months, providing more time for postdoctoral scholars to transition from graduate studies to their first career appointments.

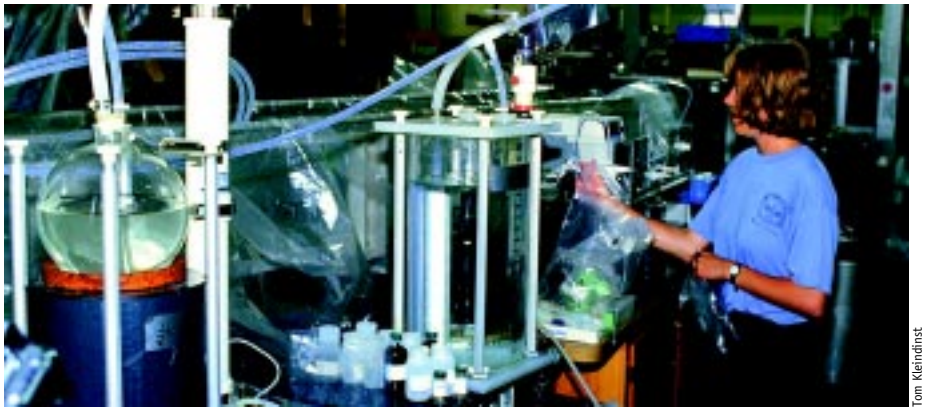
▶ We inaugurated career seminars to bring a diverse representation of our alumni/ae and others to the Institution to discuss the attributes of and opportunities in their areas of employment. We are very proud of the MIT-WHOI Joint Program alumni and alumnae for their continued interest and involvement in the activities of the Joint Program. In 1994, this group continued the spirit of last year's celebration of the 25th Anniversary of the formal graduate programs by chartering the Association of the Alumni/Alumnae of the MIT/WHOI Joint Program.

The Institution's Postdoctoral Scholar program received a record 171 applications for the 1994 awards, and 9 exceptional scholars were appointed from that group. (See page 44). The Joint Program also continues to attract highly qualified graduate students, and we are particularly pleased with the high acceptance rate of admission offers. In 1994, admission offers went to 45 of 216 applicants, and, for the third year in a row, over 70 percent (34 students) accepted the offer and enrolled in the Joint Program. As the result of a National Science Foundation proposal submitted jointly by the Education Office and the Coastal Research Center on behalf of the MIT/WHOI Joint Program, we were pleased this year to receive the maximum award of five graduate traineeships for a coastal ocean processes program. The award is renewable for five years, subject to available funds. The first traineeships will be awarded to members of the 1995 summer-fall entering class.

The summer of 1994 brought more than 250 postdocs, graduate students, summer student fellows, minority trainees, Geophysical Fluid Dynamics Summer Study Program participants, high school teacher fellows, and guest students to the Institution.

Geophysical Fluid Dynamics Summer Study Institute. The theme of the 37th GFD summer program, "Bio-Physical Model of Ocean Population Dynamics," drew ten graduate students and postdoctoral fellows and a mix of senior visitors and faculty to "introduce mathematical population biologists and geophysical fluid dynamicists to each other, and provide a new synthesis of ideas and methods for coupling fluid dynamics and population biology." It was a mix of differential equations and "critter" life styles!

Summer Student Fellowships. We welcomed 26 students, mainly between their junior and senior years, representing 22 colleges and universities mostly located in the U.S. They were selected from a highly competitive 234-applicant



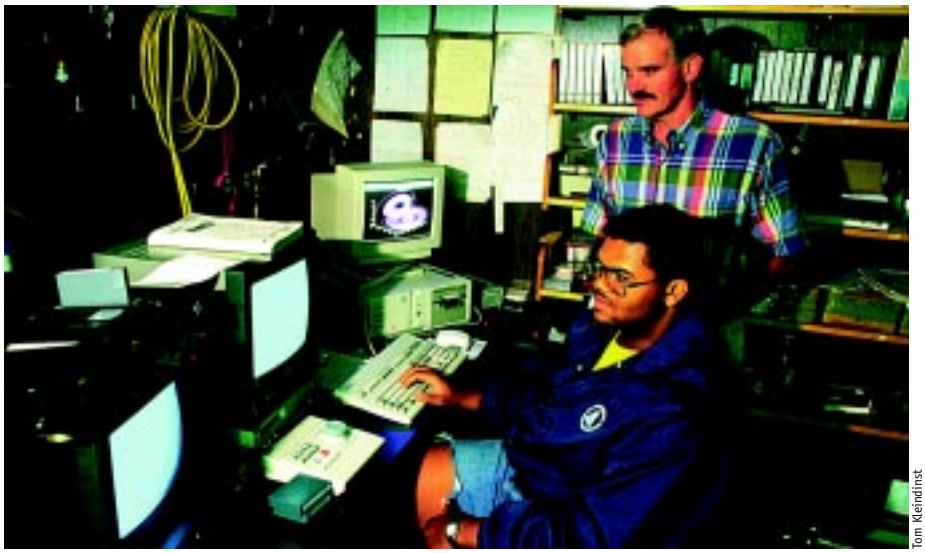
Tom Kleindinst

Graduate Student Liz Minor participated in a 1994 workshop organized by Ken Buesseler to intercalibrate devices used by WHOI and several other oceanographic institutions to collect marine colloids from seawater.

pool. Half of the fellows were supported by a grant from the Research Experiences for Undergraduates program within the Ocean Sciences Division of the National Science Foundation, and half were supported by endowment or annual philanthropic gifts. The fellows' busy schedule focused primarily around the individual research projects undertaken with their advisors. In addition, special seminars introduced them to a wide range of Institution research projects and to many general topics in oceanography and ocean sciences. Once again, with support from the National Science Foundation, two special seminar/discussion sessions considered issues of ethics in science.

Minority Traineeship Program. I am particularly pleased to report that our Minority Traineeship Program, which brings one to two undergraduate minority trainees to the Institution, usually for a summer, was significantly augmented this year by financial support from the Woods Hole laboratories of the National Marine Fisheries Service and United States Geological Survey (USGS). This enabled us to appoint five 1994 minority trainees, who joined the ranks of 40 previous Minority Trainees who have participated in the program since its inception in 1978. Associate Dean Jake Peirson and I had the pleasure of visiting with Dr. Rufus Catchings, the first of the Institution's Minority Trainees, at the American Geophysical Union meeting in San Francisco, in December. Catchings completed a Ph.D. at Stanford University and now studies earthquakes at the USGS, Menlo Park.

High School Science Teacher Fellows. Our first four High School Science Teacher Fellows returned for their second summer of National Science Foundation supported research. They continued research projects begun the previous summer and also considered methods for transferring their experience to the classroom and to other teachers. A generous grant from Wingwalkers Initiatives brought four new High School Science Teacher Fellows into the program in 1994 (see page 27).



Tom Kleindinst

Minority Trainee Ben Motten worked on zooplankton distribution in the laboratory of his advisor Scott Gallagher during the summer of 1994.

Although the main mission of the Institution is research and higher education, we contribute as appropriate to local, state, and national efforts for K-12 science and mathematics education. We advise local science educators as a member of the Woods Hole Scientific and Technology Education Partnership (WHSTEP) and the Massachusetts Partnerships to Advance Learning in Mathematics and Sciences. WHOI offers several prizes each year for Falmouth Academy and Falmouth Public Schools science fairs and many WHOI staff members serve as judges for these events. We also collaborate, largely through the efforts of WHOI Research Specialist and biologist George Hampson, with the elementary science teacher enhancement "Buzzards Bay Rim" project of the University of Massachusetts, Dartmouth and the Lloyd Center in South Dartmouth, MA.

With Bridgewater State College and the WHOI Sea Grant Program, we jointly sponsor the JASON Foundation for Education's "JASON Project" telepresence learning experience. Some 10,000 southeastern Massachusetts students attended the February-March 1994 presentations on the diversity of life in a rain forest and on a barrier reef. A revamped *Oceanus* magazine continues to provide articles conveying the latest information in ocean sciences and ocean engineering that are useful to teachers and undergraduate students as well as a general readership. *Ocean Explorer*, produced and distributed by the Woods Hole Oceanographic Institution's Young Associates Program, brings similar information to students in the sixth, seventh, and eighth grades.

Much of our K-12 educational effort depends upon WHOI staff and student volunteers, coordinated by the Information Office. The impact of such efforts, one by one and day by day, is difficult to quantify, but the response of Barnstable, Massachusetts, fifth-grade teacher Kenneth Losordo to a classroom visit by geology graduate student Gary Jaroslow articulates its value. His enthusiastic letter said, "Since the beginning of the school year, our fifth grade class has been studying the ocean…. The impact that Mr. Jaroslow's visit had on the children is immeasurable. To meet and speak to a dedicated scientist is such a motivator for future scientists! The children were extremely enthusiastic, and [his] visit was also an inspiration for me as an educator."

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

Acting Director Robert Gagosian was named the Institution's seventh Director January 7 by a unanimous vote of the Board of Trustees. Staff and students congratulated him at a January 10 reception at Clark Laboratory, attended by an estimated 500 employees.

Senior Scientist James Luyten of the Physical Oceanography Department assumed the duties of Associate Director for Research February 1. Senior Scientist Fred Sayles had been serving as Acting Associate Director for Research since August 1993, when Bob Gagosian was named Acting Director. Luyten stepped down as Department Chair and was succeeded by Senior Scientist Phil Richardson.

Dr. John Swallow of the United Kingdom, perhaps best known for the invention and development of the neutrally buoyant float named for him, received the first Henry Stommel Medal in Oceanography February 9. Swallow used the float to identify the Deep Western Boundary Current off New England that had been predicted by Henry Stommel, then went on to search for the slow poleward return flow in the ocean interior. Institution colleagues were saddened by Swallow's death in December 1994.

The US Navy approved an increase in the Deep Submergence Vehicle *Alvin*'s operating depth from 4,000 meters (13,124 feet) to 4,500 meters (14,764 feet). The certification dive for the new rating took place February 5 off the coast of Costa Rica with Dudley Foster as pilot. The new rating enables *Alvin* to reach 86 percent of the ocean floor, a 25 percent increase.

Senior Scientist Henry Dick was chosen Big Brother of the Year for 1994 by the Big Brothers/Big Sisters of Cape Cod and the Islands. He has volunteered as a Big Brother for twelve years and served on the organization's board for seven years.

Tom Kleindinst

Barbara Wickenden served as Human Resources Manager from 1984 to 1994.

Trustee and Member of the Corporation Harvey Brooks received the Philip Harage Abelson Prize in February from the American Association for the Advancement of Science (AAAS). The award was presented to Brooks for "contributions to the public's understanding of science as a cultural institution."

Scientist Emeritus Mary Sears was honored by the Women's Committee at the first annual "Women Pioneers in Oceanography" seminar March 10 in celebration of Women's History Month. Mary Sears came to WHOI in 1931 while a student at Radcliffe College to work with Henry Bigelow, WHOI's first Director.

Director Bob Gagosian gave the 18th annual Doherty Lecture on "Ocean Science and the Changing National Research Environment" April 28 at the Capital Building in Washington, DC. In June he delivered the commencement address at Falmouth Academy.

Maureen Nunez, formerly the chief financial officer at Southern Maine Technical College, assumed the duties of Controller in May. A 1980 graduate of the US Naval Academy, Nunez has a master's degree in management and worked as a financial manager at Corning Glass Works and at Black & Decker before joining the

Photos by Tom Kleindinst

WHOI welcomed the Japanese vessels *Yokosuka* and *Shinkai* 6500 to Woods Hole in July. A huge barbecue and a shipboard open house were among the attendant festivities.

college as Director of Finance in 1989.

Sea Grant Communicator Tracey Crago was honored by the Falmouth Business and Professional Women's Organization as its 1994 Young Careerist in October. The award program recognizes the achievements of young women in the early years of their careers and helps develop their public speaking skills.

Kathleen LaBernz was appointed Human Resources Manager in November following the death of Barbara Wickenden. Several dozen WHOI staff members and their families planted more than 1,200 bulbs around Nobska House in Barbara's memory and planned a spring open house, at bulb blooming time, in her honor.

Activities surrounding the May 19-20 and October 13-14 meetings of the WHOI Trustees and Members of the Corporation included time for Trustees and Corporation Members to meet with members of the scientific and senior technical staff through the Partnerships Program. The goal of the program, begun in 1993, is to encourage participants to learn more about each other. Some 60 partnerships of varying levels of involvement are now in place.

Grant and Contract Services was created in June to strengthen support for scientists' efforts to secure research funding. Staff for the new unit were drawn from the Office of Sponsored Programs, which was eliminated. The new group reports to Associate Director for Research Jim Luyten and moved to Bell House in late summer. In another administrative reorganization, staff of the former Accounting Operations, Purchasing, and Receiving groups were reorganized into a single Procurement Team, headed by Patty Duffy, and largely moved to the GEOSECS building on the Quissett Campus.

David Mann

Two traditional New England clambakes were sponsored by the Employee Capital Campaign Committee in summer 1994.

Tom Kleindinst

Mary Sears was the first "Woman Pioneer in Oceanography" to be honored by the Women's Committee.

A VISA corporate card program, which eliminated the need for most written local purchase orders and travel advance checks, was implemented beginning mid-year. The program is designed to make it easier for staff to travel and to purchase items costing less than $300, while saving overhead costs.

The first issue of *Oceanus* magazine as reports on research at WHOI was published in May and focused on deep Atlantic circulation. A quarterly magazine of international ocean science and policy for the past 20 years, *Oceanus* is now published twice a year and focuses, as it did during its first 20 years of existence, on Institution research activities. The second issue for the year, featuring Arctic Ocean research, was published in December.

Nearly 300 attended the two "Introduce a Friend to WHOI" clambakes organized by the Employee Capital Campaign Committee during July and August. Other committee activities


Tom Kleindinst


Tom Kleindinst

included planning a Mardi Gras party for February 1995 and assembling a WHOI cookbook for spring 1995 publication.

WHOI scientists participated in the first American-Japanese expedition to the Mid-Atlantic Ridge, a series of cruises over a nine-month period involving three research vessels and a drill ship, submersibles and remotely operated vehicles, and a variety of other exploration tools. The expedition began June 21 when R/V *Knorr* left Barbados for a month-long survey of the TAG (Trans-Atlantic Geotraverse) hydrothermal vent field. The Japanese submersible *Shinkai 6500* and 100-meter tender *Yokosuka,* working in the Atlantic Ocean for the first time, made two cruises in July and August with WHOI staff aboard. *Shinkai 6500*, currently the world's deepest diving crewed submersible (capable to 6,500 meters), made 30 dives at the intersection of the Kane Fracture Zone and Mid-Atlantic Ridge and at the TAG site in July and August. In the fall the international Ocean Drilling Program's *JOIDES Resolution* conducted a two-month drilling operation at the TAG site. In March 1995 R/V *Atlantis II* and DSV *Alvin* completed the program when they returned to the TAG site for additional experiments and to retrieve monitoring equipment emplaced in August.

The Japanese ship and sub made their first and only US mainland port call in Woods Hole July 24 to 29. On July 26 more than 1,200 WHOI staff, students, Associates, and their guests attended an open house aboard *Yokosuka*, followed by a barbecue under tents on the Joseph V. McKee, Jr., Ball Field behind Clark Laboratory. A science briefing for press and others was held July 27.

R/V *Knorr* departed Woods Hole August 16 for an 18-month voyage into the Indian Ocean via the Mediterranean Sea. Most of the voyage will be dedicated to the World Ocean Circulation Experiment (WOCE) and will involve conducting vertical profiles of the water column along track lines between Australia and Africa and down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At the 1994 Employee Recognition ceremony Bruce Tripp, shown above with Bob Gagosian, received the Vetlesen Award, and Rindy Osterman, photo at left, received the Linda Morse-Porteous Award. The Penzance Award went to the *Atlantis II* crew and the *Alvin* at-sea operations group. Rick Chandler, left below, accepted the award for the *Alvin* group.


Tom Kleindinst

John Swallow was chosen to receive the first Henry Stommel Medal in Oceanography. Here he shares the moment with Henry Stommel's wife Elizabeth.

toward Antarctica. During the early part of the voyage *Knorr*'s new Sea Beam bottom-mapping system was installed and tested. Year end found both *Knorr* and sister ship *Melville*, operated by Scripps Institution of Oceanography, at work between Australia and Antarctica. Extensive mid-life refits and overhauls of both ships undertaken in the early 1990s allow them to work at high latitudes for long periods of time.

Craig Dickson

R/V *Knorr* encountered pack ice during World Ocean Circulation Experiment operations in the Southern Ocean.

The keel was laid August 16 for WHOI's new ship, AGOR-25, at Halter Marine, Inc. in Moss Point, Mississippi, with Director Bob Gagosian and several other staff members participating. (AGOR stands for Auxiliary General Purpose Oceanographic Research Vessel.) In November, Secretary of the Navy John Dalton formally notified the Institution that the 84-meter *AGOR-25* will bear the name *Atlantis* (no number), the name favored by most of the respondents to a staff survey. The ship is scheduled for delivery to WHOI in late 1996.

R/V *Oceanus* returned to Woods Hole in June following a mid-life refit and upgrade at Atlantic Drydock in Jacksonville, FL. The 177-foot ship had been in Jacksonville since early November 1993. The $3.5 million project, funded by a special National Science Foundation grant and other grants, included construction of a new pilot house, new 01 deck lab and two new berths, a new wet lab and an extended main lab. Upgrades also included new autopilot/steering and heating-ventilation-air conditioning systems, and new galley equipment. Due to limited funding in the US academic research fleet, *Oceanus* remained at the WHOI pier through the end of the year in lay-up status.

DSV *Alvin* quietly celebrated its 30th anniversary June 5 at work off the US West Coast. On that date, the sub had made 2,772 dives as deep as 4,500 meters carrying a total of 8,316 "passengers" (but only about 1,500 different individuals since pilots and many scientists have made numerous dives.)

R/V *Atlantis II* and DSV *Alvin* returned to Woods Hole December 15, completing a 17-month Pacific voyage. The ship and sub remained at the dock through the holidays and were scheduled to return to service in late January 1995. The ship and sub were featured in a November Public Broadcasting System television special and *National Geographic* magazine article on research at deep-sea hydrothermal vents in the eastern Pacific.

Director Bob Gagosian and John Shepherd of the Southampton Oceanographic Center in the United Kingdom signed a Memorandum of Understanding (MOU) August 3 in informal ceremonies at Meteor House. The MOU formalizes a long-standing relationship and encourages increased collaboration between scientists and engineers at the two labs.

More than 450 attended the sixth annual Employee Recognition Celebration September 7 honoring the commitment, spirit, and hard work of all employees. Sixty-two employees received special recognition for completing more than 10, 20, 30, and 40 years of service, joining some 450 long-service employees honored over the past five years. The Penzance Award, for "sustained exceptional performance, for outstanding representation of the WHOI spirit, and for major contributions to the personal and professional lives of our staff," was presented to the Research Vessel *Atlantis II* crew and the *Alvin* at-sea operations group. Research Associ-

Tom Kleindinst

Information Office staff members Hélène Longyear, left, and Virginia McKinnon, center, chat with volunteer Marjorie Myrick at an Exhibit Center open house for volunteers.

John Porteous

Oceanus returned in June from mid-life refit with a new profile – a new upper deck house and one stack instead of two.

ate Bruce Tripp, Assistant Director of the Coastal Research Center, received the Vetlesen Award, which goes to individuals "for true selfless dedication of a major portion of themselves to the entire WHOI community over a long period of time." Research Associate Dorinda Ostermann was the 1994 Linda Morse-Porteous Award recipient. This award honors female technicians for leadership, dedication and quality of work, abilities as a role model and/or mentor to junior women, and involvement in the WHOI community. Adding to the fun of the employee recognition event were numerous door prizes and a photo-identification game featuring old photographs of employees.

Nearly 300 attended the annual Associates Day of Science September 9 at Clark Laboratory, focused this year on hurricanes. A reception followed, under a tent on the Fenno House grounds, featuring posters and demonstrations.

In October and November, employees and students were invited by Bob and Susan Gagosian to informal Tuesday get-togethers at Meteor House. Although the Gagosians don't occupy Meteor House, for many years the Director's Residence, the house is often used for official Institution functions. Many members of the WHOI community have loaned the decorations and artwork that adorn Meteor House.

Two teams from WHOI won their respective divisions in the Cape Cod Marathon October 30. The All-WHOI Relay Team won first place, mixed open (and second place overall in the relay) in the Harvard Community Health Plan Marathon Relay and first place in the open large-business category. More than 60 teams participated. The Sea Slugs won the corporate challenge for women, large business. Team trophies were on display in the Clark lobby.

During the summer, WHOI was represented on the first US ship to break through the Arctic ice and reach the North Pole, traveling from the Pacific to the Atlantic Ocean. Elizabeth Osborne of the Geology and Geophysics Department was aboard the 122-meter US Coast Guard icebreaker *Polar Sea* and collected the first ocean floor sediment samples at the North Pole. Captain of the *Polar Sea* was Lawson Brigham, a former Marine Policy Center Fellow.

A new benefits package that enhances benefits for staff while lowering costs for both the employees and the Institution is

Tom Kleindinst

Eben Franks, center, describes items from the Seafloor Samples Laboratory collection to Charley Hollister, left, and Honorary Trustee Cecil Green during a July visit.

the result of 18 months of work by the Ad Hoc Task Force on Total Compensation. The task force submitted its recommendations to the Director in July, they were presented to the staff at open meetings in September, and the changes took effect January 1, 1995.

WHOI volunteers contributed more than 3,300 hours in various capacities throughout the Institution between September 1, 1993, and September 1, 1994. The 60 active volunteers were honored at a September awards luncheon at Carriage House.

Tom Kleindinst

Senior Scientist Nobu Shimizu, left, discusses his work with his Corporation partner Nick Bancroft during lab visits following the May meetings of the Corporation and Trustees.

Forty-five Young Associates and parents participated in an October afternoon aboard *Enviro-Lab* on the waters off Falmouth, providing students with an opportunity to learn about ocean sciences through hands-on activities. The event was the first sponsored by the Young Associates Program, established in 1991 to promote ocean science education in homes and schools and to cultivate future graduate students.

Nearly $10 million was received towards the Institution's Capital Campaign in 1994, making it the most successful year in recent WHOI fundraising history. The figure brings the total raised through December 31, 1994, to just under $34 million. The $50 million campaign runs through 1996. Several major gifts were part of the year's success:

The Institution accepted the donation of the 86-foot motor yacht *Betty Jeanne II* from Mr. and Mrs. Edward W. Scripps of Charlottesville, VA, and Palm Beach, FL. The custom aluminum vessel, built in 1986, was put on the market with an asking price of $2.7 million. Proceeds from the sale will be allocated to the Capital Campaign.

Stanley Watson (who passed away in January 1995) established The Stanley W. Watson Director's Discretionary Fund with a gift of $1 million. Watson, a former Trustee and Member of the Corporation, was a visionary scientist, benefactor, mentor, and dear friend to many WHOI researchers and students.

The A. W. Mellon Foundation awarded David Aubrey, Graham Giese, and John Trowbridge a $770,000 grant for a three-year interdisciplinary program on coastal processes. WHOI matching funds will bring the project's budget to nearly $1 million.

A $500,000 challenge grant from the Kresge Foundation will support the new Northeast Regional Ion Microprobe Facility, whose centerpiece will be a $2 million ion microprobe.

The Unger G. Vetlesen Foundation has given $500,000 to the Director's Discretionary Fund. Discretionary funds allow the Institution's leadership the flexibility to support a variety of important programs what would otherwise be difficult to fund.

The Mobil Foundation awarded WHOI a $450,000 grant to help train Kazakh scientists in modern oceanographic technology. Training will be combined with research on such Caspian Sea issues as sea-level rise, wetland nutrient cycling, and circulation and mixing.

Marvin Millsap, a longtime WHOI supporter, passed away at the age of 91, leaving a bequest of $350,000 to establish an endowed postdoctoral scholarship fund. The fund is named at Mr. Millsap's request for his close friend, marine biologist and former WHOI Associate Director George D. Grice, Jr.

Patricia Odams

The motor yacht *Betty Jeanne II* was donated to WHOI by Mr. and Mrs. Edward W. Scripps.

Director's Council

As of December 31, 1994

Robert B. Gagosian
Director

James Luyten
Associate Director for Research

John W. Farrington
Associate Director for Education and Dean of Graduate Studies

Lawrence R. Ladd
Associate Director for Institution Operations

Richard F. Pittenger
Associate Director for Marine Operations

Charles D. Hollister
Vice President of the Corporation

Pamela C. Hart
Executive Assistant to the Director

Karen P. Rauss
Special Assistant to the Director

Tom Kleindinst

Lee Freitag inspects the lower electronics package on the Surface Suspended Acoustic Receiver.

Scientific and Technical Staff

As of December 31, 1994

Applied Ocean Physics & Engineering Department

George V. Frisk
Department Chair and Senior Scientist

Lane J. Abrams
Research Engineer

John J. Akens
Senior Engineer

Ben G. Allen
Research Engineer

Richard I. Arthur, Jr.
Engineer II

Thomas C. Austin
Senior Engineer

Robert D. Ballard
Senior Scientist

Alessandro Bocconcelli
Research Associate

Erik J. Bock
Associate Scientist

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Research Specialist

Andrew D. Bowen
Research Engineer

James B. Bowlin
Research Associate

Albert M. Bradley
Senior Engineer

Neil L. Brown
Principal Engineer

Cheryl Ann Butman
Associate Scientist

Josko Catipovic
Associate Scientist

Dezhang Chu
Research Associate

Kenneth W. Doherty
Senior Engineer

James A. Doutt
Research Associate

Timothy F. Duda
Assistant Scientist

Alan R. Duester
Engineer II

Robert L. Eastwood
Engineer II

Calvert F. Eck
Research Engineer

James B. Edson
Assistant Scientist

Robert L. Elder
Engineer II

Ned C. Forrester
Research Engineer

Dudley B. Foster
Research Associate

Janet J. Fredericks
Information Systems Associate II

Lee E. Freitag
Research Engineer

Daniel E. Frye
Research Specialist

Wayne R. Geyer
Associate Scientist

Denzel E. Gleason
Research Associate

Robert G. Goldsborough
Research Engineer

Mark A. Grosenbaugh
Associate Scientist

John T. Hallinan
Research Engineer

David J. Herold
Engineer II

Alan A. Hinton
Engineer II

Edward Hobart
Engineer II

Jonathan C. Howland
Research Engineer

Kelan Huang
Research Engineer

James D. Irish
Research Specialist

Mark P. Johnson
Research Engineer

Sean M. Kery
Engineer II

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Principal Engineer

James R. Ledwell
Associate Scientist

Steven Lerner
Research Engineer

Stephen P. Liberatore
Research Engineer

James F. Lynch
Associate Scientist and J. Seward Johnson Chair as Education Coordinator

Martin Marra
Research Engineer

Ann Martin
Information Systems Associate II

Wade R. McGillis
Postdoctoral Investigator

John S. Merriam, Jr.
Engineer II

David A. Mindell
Engineer I

Arthur E. Newhall
Research Associate

Walter H. Paul
Senior Engineer

Kenneth R. Peal
Senior Engineer

Donald B. Peters
Research Engineer

Robert A. Petitt, Jr.
Engineer II

Daniel F. Potter
Engineer II

Kenneth E. Prada
Principal Engineer

James C. Preisig
Postdoctoral Investigator

Bryce Prindle
Visiting Investigator

Michael J. Purcell
Research Engineer

Subramaniam D. Rajan
Associate Scientist

Edward K. Scheer
Information Systems Associate II

Cynthia J. Sellers
Research Associate

Arnold G. Sharp
Senior Engineer

Robin C. Singer
Engineer II

Jess H. Stanbrough, Jr.
Research Specialist

Timothy K. Stanton
Senior Scientist

Victoria R. Starczak
Research Associate

W. Kenneth Stewart, Jr.
Associate Scientist

Roger P. Stokey
Research Engineer

Dajun Tang
Assistant Scientist

Eugene A. Terray
Research Specialist

John H. Trowbridge
Associate Scientist

Christopher von Alt
Senior Engineer

Keith von der Heydt
Senior Engineer

Barrie B. Walden
Principal Engineer

Robert G. Walden
Principal Engineer

Ehud Weinstein
Adjunct Scientist

Robert A. Wheatcroft
Assistant Scientist

Albert J. Williams 3rd
Senior Scientist

Clifford L. Winget
Research Specialist

Warren E. Witzell, Jr.
Engineer II

Dana R. Yoerger
Associate Scientist

Jia Q. Zhang
Engineer II

Biology Department

Joel C. Goldman
Department Chair and Senior Scientist

Philip Alatalo
Research Associate

Donald M. Anderson
Senior Scientist and Stanley W. Watson Chair for Excellence in Oceanography

Mark C. Benfield
Postdoctoral Investigator

Stephen M. Bollens
Assistant Scientist

Ann C. Bucklin
Visiting Investigator

David A. Caron
Associate Scientist

Hal Caswell
Senior Scientist

Helen E. Chadd
Postdoctoral Investigator

Alexander M. Chekalyuk
Visiting Investigator

David J. Cooper
Visiting Investigator

Nathaniel Corwin
Research Specialist

James E. Craddock
Research Specialist

John W. Dacey
Associate Scientist

Cabell S. Davis III
Associate Scientist

Mark R. Dennett
Research Associate

Daniel L. Distel
Visiting Investigator

Paul V. Dunlap
Associate Scientist

Kurt M. Fristrup
Research Specialist

Scott M. Gallager
Assistant Scientist

Ronald W. Gilmer
Visiting Investigator

J. Frederick Grassle
Adjunct Scientist

Charles S. Greene
Visiting Investigator

Robert C. Groman
Information Systems Specialist

Mark E. Hahn
Assistant Scientist

George R. Hampson
Research Specialist

G. Richard Harbison
Senior Scientist

Brian L. Howes
Associate Scientist

Ione Hunt von Herbing
Postdoctoral Investigator

Holger W. Jannasch
Senior Scientist

Bruce A. Keafer
Research Associate

Dale F. Leavitt
Research Associate

Phillip S. Lobel
Associate Scientist

Laurence P. Madin
Associate Scientist

Judith E. McDowell
Senior Scientist, J. Seward Johnson Chair as Education Coordinator, and Sea Grant Coordinator

John J. Molongoski
Research Associate

Michael J. Moore
Visiting Investigator

Lauren S. Mullineaux
Associate Scientist

Michael G. Neubert
Postdoctoral Investigator

Robert J. Olson
Associate Scientist

Jesús G. Pineda
Assistant Scientist

Andrew J. Read
Visiting Investigator

John H. Ryther
Scientist Emeritus

Rudolf S. Scheltema
Scientist Emeritus

Roxanna M. Smolowitz
Visiting Investigator

Heidi M. Sosik
Postdoctoral Scholar

John J. Stegeman
Senior Scientist

Craig D. Taylor
Associate Scientist

Dale G. Toner
Research Associate

Peter L. Tyack
Associate Scientist

Frederica Valois
Research Specialist

John B. Waterbury
Associate Scientist

William A. Watkins
Senior Research Specialist

Stanley W. Watson
Scientist Emeritus

David S. White
Postdoctoral Investigator

Peter H. Wiebe
Senior Scientist

Carl O. Wirsen, Jr.
Research Specialist

Bruce R. Woodin
Research Associate

Erik R. Zettler
Research Associate

Marine Chemistry & Geochemistry Department

Michael P. Bacon
Department Chair and Senior Scientist

Mark A. Altabet
Associate Scientist

Lary A. Ball
Research Associate

Richard G. Bellerby
Postdoctoral Investigator

Peter G. Brewer
Adjunct Scientist

Ken O. Buesseler
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Peter L. Croot
Postdoctoral Investigator

Michael D. DeGrandpre
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Werner G. Deuser
Senior Scientist

Wayne H. Dickinson
Research Specialist

Ellen R. Druffel
Associate Scientist

Lorraine Eglinton
Research Associate

Timothy I. Eglinton
Associate Scientist

Judith Fenwick
Research Associate

Alan P. Fleer
Research Associate

Roger François
Associate Scientist

Nelson M. Frew
Senior Research Specialist

David M. Glover
Research Specialist

Miguel A. Goni
Postdoctoral Investigator

Catherine Goyet
Associate Scientist

Terence R. Hammer
Research Associate

Christine L. Hammond
Information Systems Associate II

John M. Hunt
Scientist Emeritus

William J. Jenkins
Senior Scientist

Carl G. Johnson
Research Associate

David P. Kammer
Research Associate

Mark D. Kurz
Associate Scientist

Hugh D. Livingston
Senior Research Specialist

Dempsey E. Lott III
Research Specialist

William R. Martin
Associate Scientist

Scott J. McCue
Information Systems Associate I

James W. Moffett
Associate Scientist

Robert K. Nelson
Research Associate

Edward T. Peltzer III
Research Specialist

Daniel J. Repeta
Associate Scientist

Kathleen C. Ruttenberg
Assistant Scientist

Fred L. Sayles
Senior Scientist

David L. Schneider
Research Associate

Brian Schroeder
Research Associate

Jeffrey S. Seewald
Assistant Scientist

Edward R. Sholkovitz
Senior Scientist

Stephen P. Smith
Engineer II

Margaret K. Tivey
Associate Scientist

Jean K. Whelan
Senior Research Specialist

Oliver C. Zafiriou
Senior Scientist and J. Seward Johnson Chair as Education Coordinator

Geology & Geophysics Department

G. Michael Purdy
Department Chair and Senior Scientist

David G. Aubrey
Senior Scientist

Jerzy S. Blusztajn
Research Associate

James E. Broda
Research Specialist

Kenneth D. Burrhus
Research Specialist

Johnson R. Cann
Adjunct Scientist

Alan D. Chave
Senior Scientist

Anne Cohen
Postdoctoral Investigator

Gregory J. Cohen
Engineer II

John A. Collins
Research Associate

William B. Curry
Senior Scientist

Robert S. Detrick
Senior Scientist and J. Seward Johnson Chair as Education Coordinator

Henry J. B. Dick
Senior Scientist and W. Van Alan Clark Chair for Excellence in Oceanography

James W. Dolan
Research Associate

Robert L. Evans
Assistant Scientist

John I. Ewing
Scientist Emeritus

Daniel J. Fornari
Associate Scientist

Alan R. Gagnon
Research Associate

Graham S. Giese
Research Specialist

Stanley R. Hart
Senior Scientist

James G. Hirth
Assistant Scientist

W. Steven Holbrook
Associate Scientist

Susumu Honjo
Senior Scientist and Columbus O'Donnell Iselin Chair for Excellence in Oceanography

Susan E. Humphris
Research Specialist

Glenn A. Jones
Associate Scientist

Lloyd D. Keigwin, Jr.
Senior Scientist

Peter B. Kelemen
Associate Scientist

Graham M. Kent
Assistant Scientist

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Research Associate

Scott J. Lehman
Associate Scientist

Peter C. Lemmond
Research Associate

Jian Lin
Associate Scientist

Sarah A. Little
Visiting Investigator

George P. Lohmann
Associate Scientist

Steven J. Manganini
Research Specialist

Daniel McCorkle
Associate Scientist

Ann P. McNichol
Research Specialist

Peter S. Meyer
Adjunct Scientist

Richard D. Norris
Assistant Scientist

Delia W. Oppo
Assistant Scientist

Elizabeth Osborne
Engineer I

Dorinda R. Ostermann
Research Associate

John C. Peden
Information Systems Associate II

Douglas G. Pyle
Postdoctoral Investigator

Gregory E. Ravizza
Assistant Scientist

Peter J. Saccocia
Visiting Investigator

David Schneider
Visiting Investigator

Robert J. Schneider
Senior Research Specialist

Hans Schouten
Senior Scientist

Peter R. Shaw
Associate Scientist

Nobumichi Shimizu
Senior Scientist

Philip D. Slack
Postdoctoral Investigator

Deborah K. Smith
Associate Scientist

Wayne D. Spencer
Research Associate

Ralph A. Stephen
Senior Scientist

Stephen A. Swift
Research Specialist

Maurice A. Tivey
Associate Scientist

Brian E. Tucholke
Senior Scientist

Elazar Uchupi
Scientist Emeritus

Karl F. von Reden
Research Specialist

Richard P. Von Herzen
Senior Scientist

Warren E. Witzell
Research Specialist

Frank B. Wooding
Research Associate

Earl M. Young
Research Associate

Physical Oceanography Department

Philip L. Richardson
Department Chair and Senior Scientist

Carol A. Alessi
Information Systems Associate II

Geoffrey P. Allsup
Engineer II

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Assistant Scientist

Frank Bahr
Research Associate

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Amy S. Bower
Assistant Scientist

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Associate Scientist and J. Seward Johnson Chair as Education Coordinator

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Research Specialist

Charles E. Corry
Research Specialist

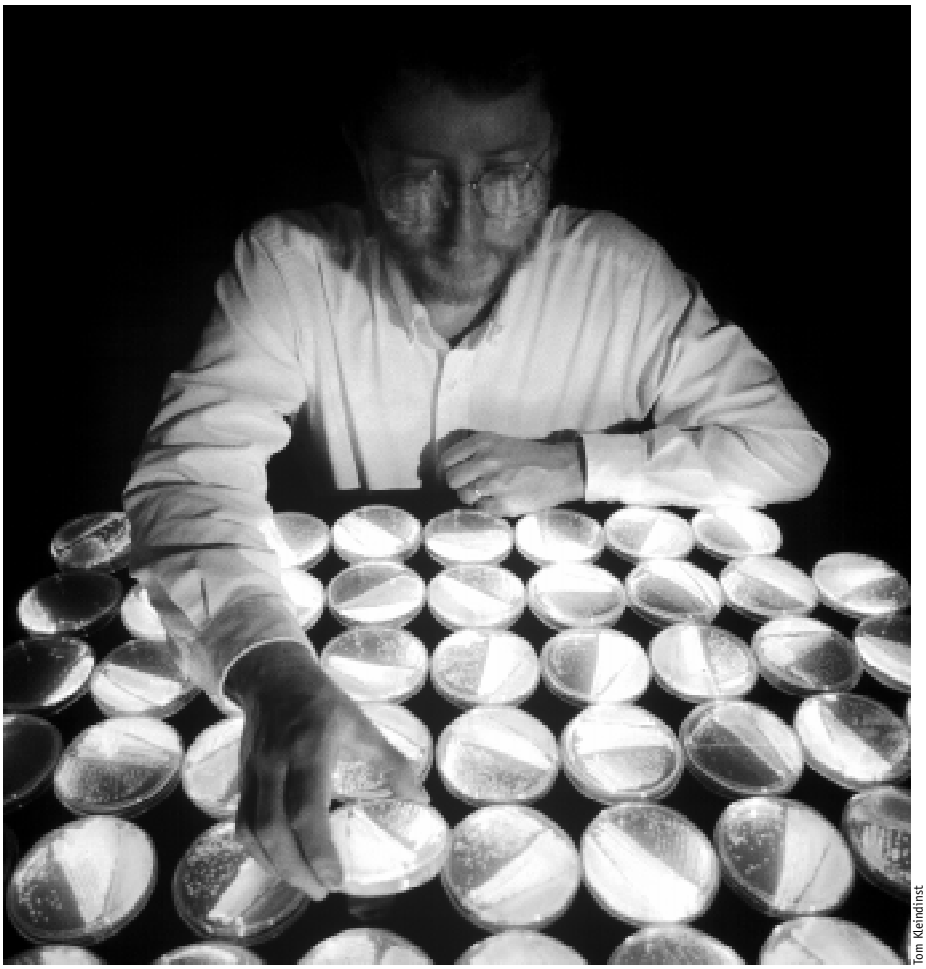
Ruth G. Curry
Information Systems Associate II

Jerome P. Dean
Senior Research Specialist

Paul D. Fucile
Engineer II

Nancy R. Galbraith
Information Systems Associate II

Glen G. Gawarkiewicz
Assistant Scientist



Tom Kleindinst

Paul Dunlap examines cultures of bioluminescent bacteria.

Anand Gnanadesikan
Postdoctoral Investigator

Melinda M. Hall
Associate Scientist

Karl R. Helfrich
Associate Scientist

Nelson Hogg
Senior Scientist

David S. Hosom
Senior Engineer

Rui X. Huang
Associate Scientist

Terrence M. Joyce
Senior Scientist

Kathryn A. Kelly
Associate Scientist

Steven J. Lentz
Associate Scientist

Richard Limeburner
Research Specialist

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Senior Research Specialist

Ellyn T. Montgomery
Information Systems Associate II

Kerry A. Moyer
Postdoctoral Investigator

W. Brechner Owens
Senior Scientist

Richard E. Payne
Research Associate

Joseph Pedlosky
Senior Scientist and Henry L. and Grace Doherty Oceanographer

Robert S. Pickart
Associate Scientist

Albert J. Plueddemann
Associate Scientist

Lawrence J. Pratt
Associate Scientist

James F. Price
Senior Scientist

Audrey M. Rogerson
Postdoctoral Investigator

Melora Park Samelson
Research Associate

Roger M. Samelson
Associate Scientist

Raymond W. Schmitt
Senior Scientist

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Michael A. Spall
Associate Scientist

Marvel C. Stalcup
Research Specialist

H. Marshall Swartz, Jr.
Research Associate

John M. Toole
Associate Scientist

Richard P. Trask
Research Specialist

George H. Tupper
Research Associate

James R. Valdes
Senior Engineer

Bruce A. Warren
Senior Scientist

Robert A. Weller
Senior Scientist and Henry B. Bigelow Chair for Excellence in Oceanography

John A. Whitehead
Senior Scientist

Geoffrey G. Whitney, Jr.
Research Associate

Christine M. Wooding
Research Associate

Jiayan Yang
Assistant Scientist

Alexander Yankovsky
Visiting Investigator

Marine Policy Center

Andrew R. Solow
Acting Center Director and Associate Scientist

Jesse Ausubel
Adjunct Scientist

Arthur G. Gaines, Jr.
Research Specialist

Porter Hoagland III
Research Associate

Di Jin
Assistant Scientist

Hauke L. Kite-Powell
Research Specialist

John H. Steele
Scientist Emeritus

Coastal Research Center

Bruce W. Tripp
Research Associate

Computer & Information Services

Julie M. Allen
Information Systems Associate II

Brian D. Betterton
Information Systems Associate II

Eric Cunningham
Information Systems Associate I

Roger A. Goldsmith
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Carolyn S. Hampton
Information Systems Associate II

John Krauspe
Information Systems Associate II

William S. Little, Jr.
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Andrew R. Maffei
Information Systems Specialist

Scott A. McIntyre
Information Systems Associate I

Elizabeth Owens
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Michael E. Paré
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George H. Power
Information Systems Specialist

Warren J. Sass
Information Systems Associate II

As of December 31, 1994

Applied Ocean Physics & Engineering Department

Alfred T. Bouchard
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Shirley J. Bowman
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Dolores H. Chausse
Charles E. Corwin
Thomas Crook
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Terence G. Donoghue
Laurel E. Duda
Carolyn E. Eck
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Naomi R. Fraenkel
Allan G. Gordon
Matthew R. Gould
Beven V. Grant
Carlton W. Grant, Jr.
Robert J. Grieve
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John N. Kemp
Wendy W. Liberatore
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George A. Meier
Stephen D. Murphy
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David S. Schroeder
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Nancy Y. Trowbridge
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Judith A. White
Martin C. Woodward

Biology Department

Katie R. Boissonneault
L. Susan Brown-Leger
Mari Butler
Marjorie K. Clancy
Nancy J. Copley
Mary A. Daher
Linda H. Davis
Matthew R. Dennett
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Andrew M. Grant
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Erich F. Horgan
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Mary C. Landsteiner
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Jane E. Marsh
Susan W. Mills
Zofia J. Mlodzinska
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Dawn M. Moran
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Daniel W. Smith
Alicia M. Soderberg
Trevor R. Spradlin
Armando F. Tamse
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Brendan A. Zinn

Marine Chemistry & Geochemistry Department

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John E. Andrews III
Ellen M. Bailey
Rebecca A. Belastock
Scot P. Birdwhistell
Margaret C. Bothner
Laurie E. Christman
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Sheila A. Clifford
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Stephanie A. Page
Nancy L. Parmentier
Aaron Smith
Andrea A. Stokey
Margaret M. Sulanowska
Carly H. Tarr
Melinda M. Topham
N. Joye Wirsen
Mary Zawoysky

Geology & Geophysics Department

John W. Bailey
Pamela R. Barrows
John Billings
S. Thompson Bolmer
Katherine W. Brown
Karen L. Coluzzi
Diane E. Cook
Jennifer Crew
Jeffrey Desouza
Lori A. Dolby
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Kathryn L. Elder
Pamela V. Foster
C. Eben Franks
Susan K. Handwork
Robert E. Handy
Seth H. Hitchings
Daniel Hutton
Marleen H. Jeglinski
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Kara E. Jordan
Ernest H. Joynt III
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Karen Littlefield
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Gregory E. Moon
Anita D. Norton
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Stephen P. O'Malley
Julianne Palmieri
Anita M. Palm
May A. Reed
Ellen Roosen
Kimberly A. Sapp
Christopher Zafiriou
Lu Ping Zou

Physical Oceanography Department

Kenton M. Bradshaw
Nancy J. Brink
Maureen E. Carragher
Margaret F. Cook
Lawrence P. Costello
Gennaro H. Crescenti
Jane A. Dunworth-Baker
Penny C. Foster
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Sandipa Singh
Susan A. Tarbell
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Deborah A. Taylor
Daniel J. Torres
Toshiko T. Turner
Bryan S. Way
W. David Wellwood
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Sarah L. Zimmermann

Administrative Staff

Joseph P. Agius
Manager of Management Information Systems

Nancy E. Barry
Human Resources Administrator

Karin A. Bohr
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Assistant Purchasing Manager

Stella A. Callagee
Budget Officer

Lee A. Campbell
Information Officer

Karen E. Carmichael
Acting Accounting Operations Administrator

Jane A. Caruso
Security Officer

Susan A. Casso
Department Administrator, Marine Chemistry & Geochemistry

Tracey I. Crago
Sea Grant Communicator

Vicky Cullen
Manager of Information, Publications & Graphic Services

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Development Officer

Patricia J. Duffy
Transition Manager

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Grants Administrator I

Larry D. Flick
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Center Administrator, Marine Policy

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Grants Administrator II

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Department Administrator, Applied Ocean Physics & Engineering

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Security Officer

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JGOFS Field Program Coordinator

Robin L. Kaiser
Senior Development Officer

Judith L. Kleindinst
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Kathleen P. LaBernz
Human Resources Manager

Shelley M. Lauzon
Senior News Officer

David J. Miller
Grants Administrator II

E. Dorsey Milot
Assistant Director for Development

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Payroll Manager

Maureen F. Nunez
Controller

Nanci A. Pacheco
Staffing Administrator

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Associate Dean and Registrar

Laura O. Ranzinger
Senior Accountant I

Karen P. Rauss
Special Assistant to the Director

Claire L. Reid
Executive Assistant to Associate Director for Research

Lesley M. Reilly
Development Officer

R. David Rudden, Jr.
Assistant Controller

Marcella R. Simon
Assistant Registrar and Education Office Administrator

Clarence L. Smith
Department Administrator, Geology & Geophysics

Peggy A. Stengel
Development Officer

Jacqueline M. Suitor
Director of Development

Maurice J. Tavares
Sr. Grant Administrator

Mary Jane Tucci
Housing Coordinator

Donna Weatherston
Manager of Government Regulations

Melissa Roberts Weidman
Staff Training & Development Administrator

Leo R. Wells
Property Administrator

Mary Jo Wheatley
News Officer

Elaine M. Wilcox
Benefits Administrator

Stacey L. Yarish
Senior Accountant II

Dianna M. Zaia
Manager of Treasury Operations

Administrative Personnel

Pierrette M. Ahearn
Abbie Charlotte Alvin
Patricia Askew
Mary E. Berry
Eleanor M. Botelho
Sandra L. Botelho
John L. Broadford
Marilynn B. Brooks
Susan F. Callahan
Peggy A. Chandler
Linda L. Church
Michelle J. Cooke
Margaret M. Costello
Cheryl C. Daniels
Nancy Duggan
Joshua N. Eck
Kittie E. Elliott
Lynne M. Ellsworth
Glenn R. Enos
Barbara Ewing-DeRemer
Steven R. Ferreira
Marianne Flaherty
Gregory D. Flick
Kathleen R. Garland
Ruth E. Goldsmith
Pamela J. Goulart
Adrienne M. Gould
Patricia Halpin
Paula M. Harmon
Jane M. Harrington
Marilyn R. Hess
Stephen H. Howard
Lynn M. Ladetto
Donna L. Lamonde
Tariesa A. Lemmon
Lillian R. Lomba
Samuel J. Lomba
Jeanne Lovering
Richard C. Lovering
Linda E. Lucier
Molly M. Lumping
Carole R. Merson
Ellen M. Moriarty
Cheryl L. Newton
Sharon J. Omar
Laura L. Oxford
Maryanne F. Pearcey
Doreen M. Perito
Jeanne A. Peterson
Patricia E. Remick
Stacii L. Robbins
Michael J. Sawyer
Sandra A. Sherlock
Maria S. Silva
June E. Taft
Judith A. Thrasher
Maeve Thurston
Dacia R. Tucholke
Susan E. Vaughan
Margaret A. Vose
Margaret M. Walden
Katherine T. Walsh
Kathleen M. Warner
Susan B. West
Mary Anne White
Susan A. Wilson
Susan F. Witzell
John A. Wood, Jr.

Facilities, Services, Alvin, and Marine Operations Staff

Richard S. Chandler
Submersible Operations Coordinator

Ernest G. Charette
Assistant Facilities Manager

Gary B. Chiljean
Master, R/V Atlantis II

Joseph L. Coburn, Jr.
Marine Operations Manager

Arthur D. Colburn III
Chief Mate, R/V Atlantis II

Arthur D. Colburn, Jr.
Boat Operator, R/V Asterias

William E. Collins
Project Manager

Hugh D. Curran
Chief Engineer, R/V Atlantis II

Robertson P. Dinsmore
Marine Operations Consultant

Richard S. Edwards
Port Captain

Joel A. Fahnley
Facilities Engineer

Robert L. Flynn
Marine Personnel Coordinator

Richard E. Galat
Facilities Manager

David L. Hayden
Chief Engineer, R/V Knorr

Matthew C. Heintz
Deep Submergence Vehicle Pilot

J. Patrick Hickey
Expedition Leader and Deep Submergence Vehicle Pilot

Paul C. Howland
Master, R/V Oceanus

Tom Kleindinst

The Facilities crew put their backs to delivery of a new business computer to Challenger Annex.

Robert L. Joyce
Distribution Manager

Lewis E. Karchner
Safety Officer

Barbara J. Martineau
Marine Operations Administrator

David H. Megathlin
Chief Mate, R/V Knorr

William E. McKeon
Facilities Manager

Donald A. Moller
Marine Operations Coordinator

Theophilus Moniz III
Marine Engineer

Richard F. Morris
Chief Engineer, R/V Oceanus

David I. Olmsted
Boat Operator, R/V Asterias

Michael Palmieri, Jr.
Chief Mate, R/V Oceanus

Terrence M. Rioux
Diving Safety Officer

Lawrence A. Shumaker
Deep Submergence Vehicle Pilot

James R. Solanick
Admininstrative Staff

Carl F. Swanson
Master, R/V Knorr

Ernest C. Wegman
Port Engineer

Robert L. Williams
Deep Submergence Vehicle Pilot

Facilities, Services, *Alvin*, and Marine Operations Personnel

Jonathan C. Alberts
Steven W. Allsopp
Nadine N. Athearn
Wayne E. Bailey
Janice M. Baker
Courtenay Barber III
Mitchell G. Barros
Robert Bastarache
Janice R. Battee
Gunter H. Bauerlein
Harold A. Bean
Richard C. Bean
Lawrence T. Bearse
Linda Benway
Philip J. Bernard
John E. Bolog
Robert Bossardt
Thomas A. Bouche
Leonard A. Boutin
John R. Bracebridge
Edmund K. Brown
Frederick V. Brown
Mark Buccheri
Rene P. Buck
Frederick V. Bull
Raymond A. Burke
James J. Canavan
Socrates J. Carelo
Richard J. Carter
Leonard Cartwright
Richard A. Carvalho
David F. Casiles
Edward H. Chute
Craig A. Clarkin
John P. Clement
Charles Clemishaw
Jeffrey D. Clemishaw
C. Hovey Clifford
Debra A. Coleman
Alberto Collasius, Jr.
Alden H. Cook
John E. Cook
Arthur Costa
Janet B. Costello
Gregory Cotter
Jerome M. Cotter
John W. Cox
Jane E. Crobar
John A. Crobar
Donald A. Croft
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Judith O. Cushman
Hugh B. Dakers
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Jovinol Fernandes, Jr.
Catherine H. Ferreira
Michael J. Field
Kevin C. Fisk

Witold J. Grabiec
Patricia A. Grace
Jerry M. Graham
Edward F. Graham, Jr.
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Victoria A. Hillbrand-Marra
Marjorie M. Holland
Jane A. Hopewood
Alan J. Hopkins
Lawrence F. Jackson
Kurt S. Jilson
J. Kevin Kay
John A. Keizer
Fred W. Keller
Peter M. Kendrigan
Christopher F. Kennedy
Thomas N. Kleindinst
Eric L. Kraus
Scott R. Kutil
Dennis E. Ladino
William D. Lambert
Donald C. LeBlanc
Donald F. LeBlanc
Gregory A. LeBlanc
Paul E. LeBlanc
Jeffrey Little
Thomas J. Lively
Hélène J. Longyear
Glenn R. Loomis
William H. Lynch
Ellis H. Maris, Jr.
Colin P. Martin
J. Douglas Mayer
Joseph L. Mayes
Robert A. McCabe
Paul J. McCaffrey
Napoleon McCall, Jr.
Emily L. McClure
David McDonald
Kevin M. McGrath
Virginia McKinnon
John E. McNally
Carlos A. Medeiros
Horace M. Medeiros

Tom Kleindinst

Patricia Grace, left, and Pearl DeMello are among the WHOI switchboard operators.

David H. Megathlin
Anthony D. Mello
Mirth N. Miller
Joseph V. Mitchell
Patrick S. Mone
Anson P. Moore
Thomas W. Moore
Christopher D. Morgan
John D. Morgan
Norman E. Morrison
Paul D. Morrissey
Jose S. Mota
Jay R. Murphy
Sandra E. Murphy
Stephen Murphy
John R. Murphy, Jr.
Richard M. Nolan
Michael P. Nolin
E. Paul Oberlander
Patricia A. Odams
David W. Olds
Charles A. Olson

David A. Ouellette
Stephen G. Page
Patricia L. Pasanen
Kathleen Patterson
Sheila T. Payne
Isabel M. Penman
Charles G. Perry
Craig S. Peters
Charles J. Peters, Jr.
Jeannine M. Pires
Kathleen A. Ponti
Steven J. Poore
John Porteous
Carolann Present
Timothy W. Quinn
Douglas R. Quintiliani
William J. Reid III
Thomas D. Rennie
John P. Romiza
Lance D. Rose
Thomas A. Russo
James R. Ryder

Lewis J. Saffron
Jeanne E. Savoie
Robert W. Schreiter
Peter J. Schwamb
Timothy M. Silva
Evan L. Smith
Andrew E. Sokolowski
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William F. Sparks
Robert G. Spenle
James E. Spooner
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Jeffrey M. Stolp
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Wayne A. Sylvia
William R. Tavares, Jr.

Kevin D. Thompson
Kevin G. Threadgold
Anne Toal
Michael Toner
Philip M. Treadwell
Carlos Velez
Steven E. Velzis
Arthur W. Volstad
Herman Wagner
Stephen A. Walsh
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Harry D. Wilson
Kathleen D. Wilson
Robert J. Wilson
Bonnie L. Woodward
Carl O. Wood
Torii M. Young

1994 Retirees

Ernest E. Baker
Hugh B. Dakers
Pearl R. DeMello
William M. Dunkle
Anne S. Edwards
Robert E. Frazel
Howard A. Holland
Maxine M. Jones
Robert F. Kelley
Richard L. Koehler
Barrett H. McLaughlin
Arthur Peterson
John M. Teal
Mildred M. Teal
Suzanne B. Volkmann
Carolyn P. Winn
Ronald E. Woods

Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography/Applied Ocean Science and Engineering

Doctor of Philosophy

Andrea L. Arenovski
B.Sc., University of North Carolina, Wilmington
Special Field: *Biological Oceanography*
Dissertation: *The Distribution, Abundance and Ecology of Mixotrophic Algae in Marine and Freshwater Plankton Communities*

Molly O'Neil Baringer
B.S., Tulane University
Special Field: *Physical Oceanography*
Dissertation: *Mixing and Dynamics of the Mediterranean Outflows*

Joseph E. Bondaryk
S.B., S.M., Massachusetts Institute of Technology
Special Field: *Oceanographic Engineering*
Dissertation: *Array Processing and Forward Modeling Methods for the Analysis of Stiffened Fluid-Loaded Cylindrical Shells*

Christopher R. Bradley
B.Sc., University of New Mexico
M.S., University of Utah
Special Field: *Marine Geology and Geophysics*
Dissertation: *Very Low Frequency Seismo-Acoustic Noise Below the Sea Floor*

Edward J. Brook
B.S., Duke University
M.S., University of Montana
Special Field: *Marine Chemistry and Geochemistry*
Dissertation: *Surface Exposure Geochronology Using Cosmogenic Nuclides: Applications in Antarctic Glacial Geology*

Gail L. Christeson
B.S., Texas A&M University
Special Field: *Marine Geology and Geophysics*
Dissertation: *Seismic Constraints on Shallow Crustal Processes at the East Pacific Rise*

Daniel T. DiPerna
B.S., Lafayette College
Special Field: *Oceanographic Engineering*
Dissertation: *Sound Scattering by Cylinders of Noncircular Cross Section*

Anand Gnanadesikan
A.B., Princeton University
Special Field: *Physical Oceanography*
Dissertation: *Dynamics of Langmuir Circulation in Oceanic Surface Layers*

John P. Kokinos
B.S., M.S., Stanford University
Special Field: *Biological Oceanography*
Dissertation: *Studies on the Cell Wall of Dinoflagellate Resting Cysts: Morphological Development, Ultrastructure, and Chemical Composition*

Pascal LeGrand
Engineer Diploma, École Centrale Paris, France
D.E.A., Université Pierre et Marie Curie, France
Special Field: *Physical Oceanography*
Dissertation: *What Do Paleo-Geochemical Tracers Tell Us About the Deep Ocean Circulation During the Last Ice Age?*

Cecilie Mauritzen
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Special Field: *Physical Oceanography*
Dissertation: *A Study of the Large Scale Circulation and Water Mass Formation in the Nordic Seas and Arctic Ocean*

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Special Field: *Physical Oceanography*
Dissertation: *Influence of Topography on the Dynamics of Baroclinic Ocean Eddies*

Ryszard A. Pawlowicz
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Special Field: *Oceanographic Engineering*
Dissertation: *Tomographic Observations of Deep Convection and the Thermal Evolution of the Greenland Sea Gyre 1988-1989*

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Dissertation: *Social Behaviour of Captive* Belugas Delphinapterus leucas

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B.Sc., M.Sc., Hebrew University, Israel
Special Field: *Marine Chemistry and Geochemistry*
Dissertation: *Late Quaternary Paleochemistry of the Southern Ocean: Evidence from Cadmium Variability in Sediments and Foraminifera*

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Special Field: *Biological Oceanography*
Dissertation: *Mitochondrial DNA Sequence Variation in North Atlantic Long-Finned Pilot Whales,* Globicephala melas

Knut Streitlien
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Dissertation: *Extracting Energy from Unsteady Flows through Vortex Control*

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B.A., Brown University
Special Field: *Marine Geology and Geophysics*
Dissertation: *Geophysical Studies of Plate-Boundary Earthquakes and Mid-Plate Volcanism in the Ocean Basins*

Ein-Fen Yu
B.S., Chinese Culture University, R.O.C.
M.S., National Taiwan University, R.O.C.
Special Field: *Marine Chemistry and Geochemistry*
Dissertation: *Variations in the Particulate Flux of ^{230}Th and ^{231}Pa and Paleoceanographic Applications of the ^{231}Pa/^{230}Th Ratio*

Master of Science

Max Deffenbaugh
B.S., Princeton University
Special Field: *Oceanographic Engineering*
Dissertation: *A Matched Field Processing Approach to Long Range Acoustic Navigation*

Sarah E. Herbelin
B.A., Reed College
Special Field: *Marine Chemistry and Geochemistry*
Dissertation: *Photophysics and Photochemistry of Natural Waters with Emphasis on Radical Probe Development and Application*

Helen Huang
B.S., University of Science and Technology of China
Special Field: *Oceanographic Engineering*
Dissertation: *Comparison of Neural and Control Theoretic Techniques for Nonlinear Dynamic Systems*

Anthony James Kettle
B.A., Memorial University of Newfoundland
Special Field: *Physical Oceanography*
Dissertation: *A Model of the Temporal and Spatial Distribution of Carbon Monoxide in the Mixed Layer*

Lin Li
B.S., B.E., University of Science and Technology of China
M.S., University of Science and Technology of Beijing, China
Special Field: *Marine Geology and Geophysics*
Dissertation: *Computer Modeling of a Vertical Array in a Stratified Ocean*

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Special Field: *Oceanographic Engineering*
Dissertation: *An Investigation of Shallow Water Mode Coupling Effects During Single ModeTransmission*

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Special Field: *Oceanographic Engineering*
Dissertation: *The Load/Deflection Behavior of Pretensioned Cable/Pulley Transmission Mechanisms*

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Dissertation: *Modal Analysis of Vertical Array Receptions for the Heard Island Feasibility Test*

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Dissertation: *Adaptive Estimation of Acoustic Normal Modes*

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Special Field: *Marine Geology and Geophysics*
Dissertation: *Satellite-Derived Sea Surface Temperature and Foraminiferal Production in the North Atlantic*

Ocean Engineer

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B.S.S.E., United States Naval Academy
M.S., University of Central Florida
Special Field: *Oceanographic Engineering*
Dissertation: *Six Degree of Freedom Vehicle Controller Design for the Operation of an Unmanned Underwater Vehicle in a Shallow Water Environment*

Daniel E. Leader
B.S., United States Naval Academy
Special Field: *Oceanographic Engineering*
Dissertation: *Kalman Filter Estimation of Underwater Vehicle Position and Attitude Using a Doppler Velocity Aided Inertial Motion*

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B.Sc., Duke University
Special Field: *Oceanographic Engineering*
Dissertation: *Horizontal Directional Spectrum Estimation of the Heard Island Transmissions*

Christopher J. Willy
B.S.S.E., United States Naval Academy
Special Field: *Oceanographic Engineering*
Dissertation: *Attitude Control of an Underwater Vehicle Subjected to Waves*

Master of Science and Ocean Engineer

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A.B., Harvard University
Special Field: *Oceanographic Engineering*
Dissertation: *System Identification and State Reconstruction for Autonomous Navigation of an Underwater Vehicle in an Acoustic Net*

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Massachusetts Institute of Technology

Arthur Mariano
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Salvatore Mazzola
Visiting Scientist, Massachusetts Institute of Technology

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Yale University

George Veronis
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Princeton University

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Yves Desaubies
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Bridgewater State College

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Irvington, NY

Ann L. Hollick
Washington, DC

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Bristol, RI

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Jim Luyten, right, chats with Corporation Member David Stone during a Corporation and Trustee gathering.

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In Memoriam

The Institution greatly acknowledges the service and support of those members who passed away in 1994.

John P. Chase

Frederick C. Crawford

Thomas B. Crowley

Albert L. Nickerson

Denis M. Robinson

Francis C. Ryder

Jerome B. Wiesner

Isamu Yamashita

Craig Dickson

Atlantis II spent most of 1994 in Pacific waters.

Tom Kleindinst

Chris Griner and Horace Medeiros load gear for a *Knorr* cruise.

R/V *Atlantis II* & DSV *Alvin*

Total Nautical Miles in 1994 – 19,991 • Total Alvin dives – 181 • Total days at sea – 266

Voyage	Cruise period	Cruise objective, Area of operation	Ports of Call	Chief Scientist
131-IX	5 Jan - 28 Jan	East Pacific Rise–9°N, investigation of the geological and geophysical processes of abyssal hill formation, 17 dives	Acapulco	K. Macdonald (UC,SB)
131-X	1 Feb - 3 Mar	Costa Rica, study of the distribution, temperature and chemistry of fluid vents associated with the sub-duction of the ocean crust below Costa Rica, 22 dives	Acapulco	E. Silver (UC,SB)
131-XI	8 Mar - 6 Apr	East Pacific Rise–9°N, long-term study of the evolution of the hydrothermal, biological and geological processes at vents located at the site of 1991 volcanic eruptions, 27 dives	Manzanillo	K.Von Damm (UNH)
131-XII	11 Apr - 26 Apr	East Pacific Rise–9°N, near-bottom gravity measurements and a study of the chemosynthetic microbial population at hydrothermal vent sites, 12 dives	Manzanillo	D. Fornari, H. Jannasch
131-XIII	28 Apr - 2 May	Transit to San Diego	San Diego	—
131-XIV	7 Jun - 8 Jun	California coast, U.S. Navy INSURV inspection of *Alvin* and engineering tests, 2 dives	San Diego	B. Walden
131-XV	9 Jun - 13 Jun	Transit to Oregon	Newport	—
131-XVI	16 Jun - 9 Jul	Juan de Fuca Ridge, long-term study of chemical and geological changes at hydrothermal vent sites, 20 dives	Astoria	R. Embley (NOAA/PMEL)
131-XVII	14 Jul - 30 Jul	Juan de Fuca Ridge, long-term study of genetic variations of deep-sea organisms, 13 dives	Astoria	R. Lutz (Rutgers)
131-XVIII	3 Aug - 10 Aug	Juan de Fuca Ridge, radioisotopic studies of hydrothermal vent systems, development testing of instrumentatation, 6 dives	Astoria	D. Kadko (U. Miami)
131-XIX	15 Aug - 31 Aug	California coast, long-term biological study of benthic boundary layer communities, 10 dives	San Diego	K. Smith (Scripps)
131-XX	10 Sept - 11 Sept	California coast, rock drill tests, 1 dive	San Diego	R. Batiza (U. Hawaii)
131-XXI	12 Sept - 12 Sept	California coast, engineering tests, 1 dive	San Diego	R. Chandler
131-XXII	13 Sept - 26 Sept	California coast, long-term biological study of benthic boundary layer communities, 10 dives	San Diego	K. Smith (Scripps)
131-XXIII	30 Sept - 10 Oct	Guaymas Basin, long-term study of genetic variations of deep-sea organisms, 4 dives	Mazatlan	R. Vrijenhoek (Rutgers)
131-XXIV	14 Oct - 1 Nov	East Pacific Rise–9°N, long-term study of the evolution of the hydrothermal, biological, and geological processes at vents located at the site of 1991 volcanic eruptions, 15 dives	Manzanillo	R. Lutz (Rutgers)
131-XXV	6 Nov - 5 Dec	East Pacific Rise–9°N, biological studies of the interaction of organisms and the environment during colonization of new hydrothermal vent systems, 21 dives	Balboa	L. Mullineaux
131-XXVI	6 Dec - 15 Dec	Transit of Panama Canal to Woods Hole	Woods Hole	—

R/V *Oceanus**

Total Nautical Miles in 1994 – 860 • Total days at sea – 4

Voyage	Cruise period	Cruise objective, Area of operation	Ports of Call	Chief Scientist
264-II	11 Jun - 14 Jun	Transit from shipyard	Woods Hole	—
* Vessel out of service in 1994 for refit and lay-up.				

R/V *Knorr*

Total Nautical Miles in 1994 – 36,963 • Total days at sea – 238

Voyage	Cruise period	Cruise objective, Area of operation	Ports of Call	Chief Scientist
141-II	2 Feb - 5 Feb	Transit from shipyard in Jacksonville, Fl.	Woods Hole	—
142-I	19 Feb - 26 Feb	Transit to Barbados, biological sampling	Bridgetown	R. Anderson (Bigelow)
142-II	27 Feb - 28 Mar	Equatorial Atlantic, study of dissolution of calcium carbonate at the seafloor	Recife	W. Martin
142-III	3 Apr - 21 May	South Atlantic, Deep Basin Experiment of the WOCE Hydrographic Program	Salvador	W. Smethie (LDEO)
142-IV	28 May - 13 Jun	South Atlantic, Deep Basin Experiment current meter mooring recovery	Bridgetown	J. Whitehead
142-V	21 Jun - 21 Jul	Mid-Atlantic Ridge, side-scan and camera surveys of hydrothermal vent fields	Woods Hole	M. Kleinrock
143	27 Jul - 29 Jul	New York Bight, acoustic array tests	Woods Hole	M. Forbes (NUWC)
144	3 Aug - 8 Aug	Transit to/from shipyard in Newport	Woods Hole	—
145-I	17 Aug - 31 Aug	Transit to Mediterranean	Augusta, Sicily	P. Lemmond (NUWC)
145-II	4 Sept - 17 Sept	Adriatic Sea, SHAREM experiment	Catania, Sicily	M. Forbes
145-III	22 Sept - 20 Oct	Transit of Suez Canal to Australia	Fremantle	—
145-IV	19 Nov - 23 Nov	Indian Ocean, Sea Beam seatrials	Fremantle	B. Walden
145-V *	1 Dec - 19 Jan	Indian and Antarctic Oceans, hydrographic survey for WOCE Hydrographic Program, lines I8S and I9S	Fremantle	M. McCartney
*At sea on December 31				

Tom Kleindinst

R/V *Knorr* departs Woods Hole on a 1994 research voyage.

1994 publications of record as of Feb. 1, 1995. Entries are listed by department. Institution contribution number appears at the end of each entry. 1992 and 1993 publications not listed in prior Annual Reports are listed here. *Compiled by Maureen O'Donnell, Library.*

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Mary Sears, right, and Mary Swallow, both long-time editors of *Deep-Sea Research,* met at the reception following presentation of the Stommel Medal to Mary Swallow's husband, John.

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John and Mary Swallow, far right, met with Joint Program students as part of the Stommel Medal festivities.

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Steve Page, aboard *Oceanus*, confers with Theo Moniz ashore following the ship's return to Woods Hole in June. Theo's son Daniel is at right.

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Table 1
Types of Revenue
(Exclusive of Vessels)

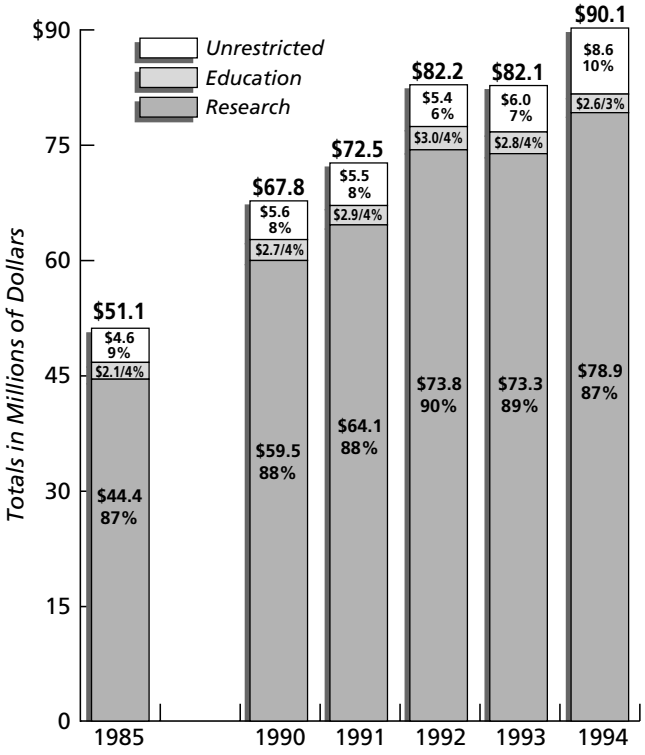


Table 2
Sources of Research Funding

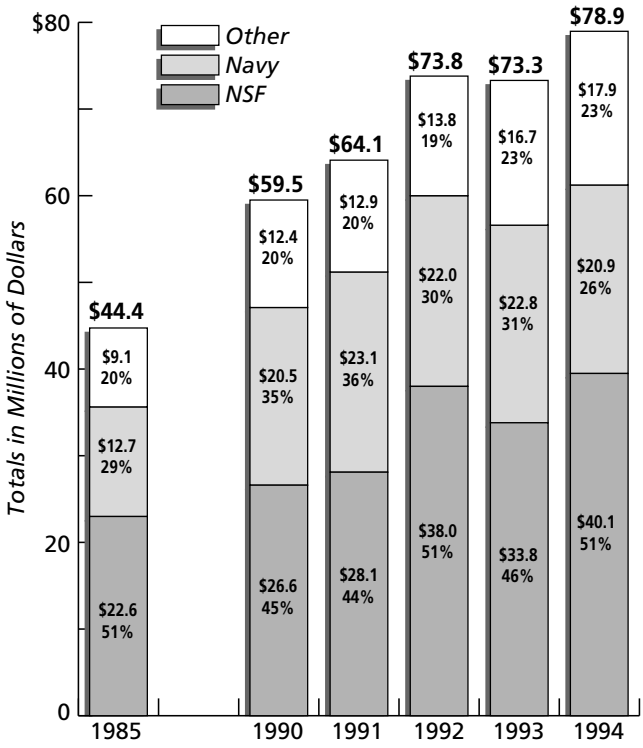


Table 3
Gifts and Grants from Private Sources

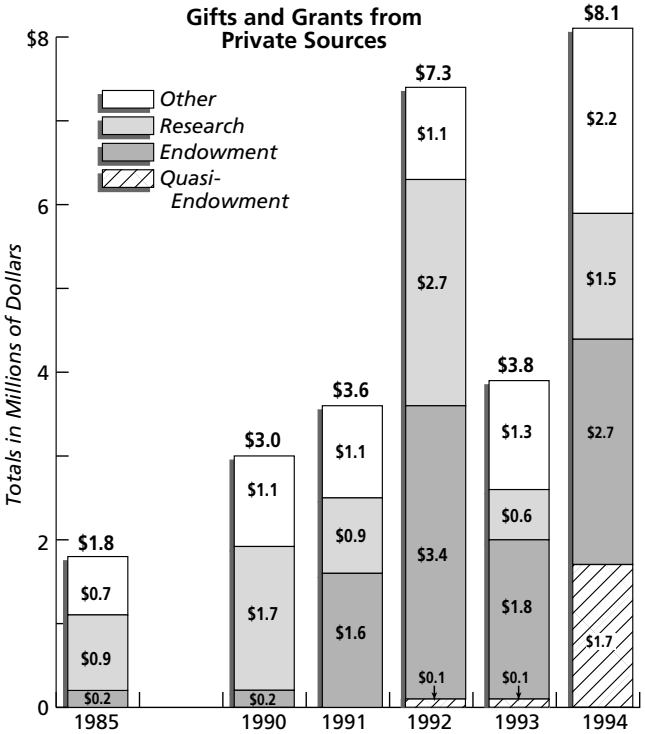
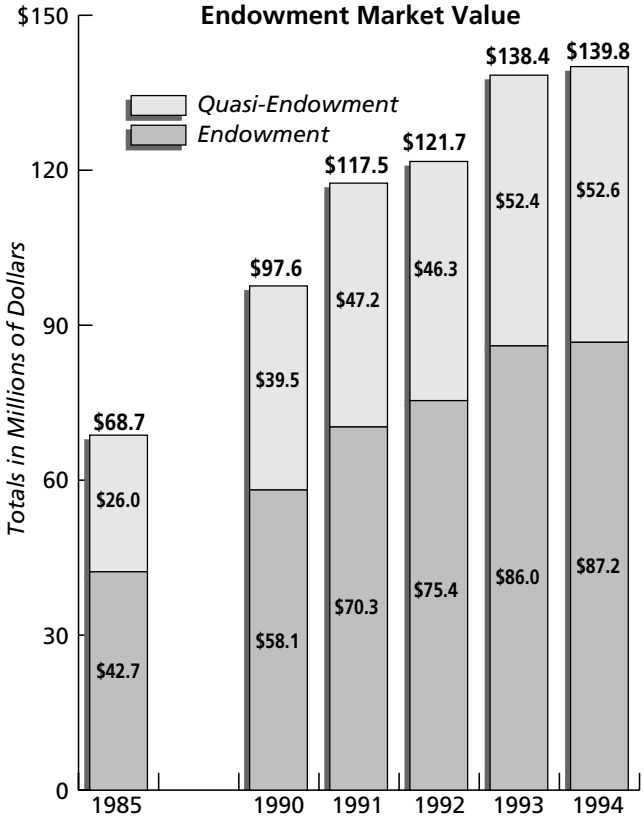


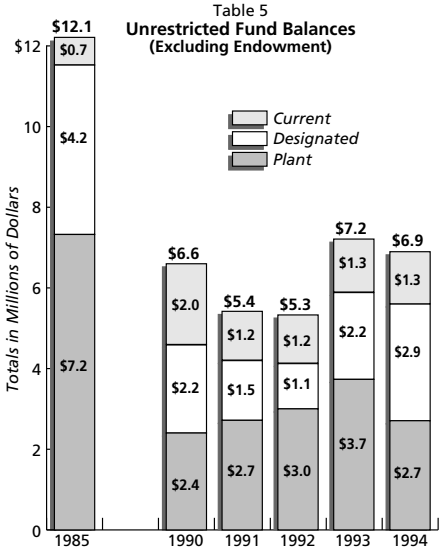
Table 4
Endowment Market Value



The Institution's 1994 financial results were, for the most part, very positive. On the plus side, the unrestricted fund showed a surplus, even after transferring funds to augment reserves for future contingencies. The endowment market value grew modestly, and private fundraising efforts were extremely successful, adding over $8 million in gifts and grants in 1994. Government sponsored research grew 9.3% over 1993 levels due in large part to a one-time grant from the Advanced Research Project Agency which accounted for $4.1 million in revenue in 1994. The trend in government funding is expected to decline in the near future, and WHOI management has begun a strategic planning process in order to be able to anticipate and respond to the changing funding environment, and to be better positioned to take advantage of alternative funding sources. In late 1994, the government and the Institution reached a resolution of all outstanding audit issues from 1987-1992, thus relieving the Institution from the financial uncertainty associated with those years remaining open. On a less positive note, overhead recovery was less than actual expenses, and the unrestricted plant fund balance declined due to large budgeted capital expenditures.

Overhead expenditures were more than 3% under budget in 1994, but the labor base over which those costs were allocated was 6% under budget. The declining labor base resulted in the Institution's overhead recovery being less than actual costs. This 1994 underrecovery combined with a similar underrecovery in 1993 are offset by amounts collected in prior years which were in excess of government approved expenses. At the end of 1994, WHOI and the government agreed in principle to offset the amounts owed to each other without affecting the overhead rates in future years, and without negatively impacting WHOI's cash flow in 1994. This agreement closes all remaining issues between WHOI and the government for the years 1987 through 1992. Going forward, there are no financial uncertainties regarding government audit issues.

Table 5
Unrestricted Fund Balances
(Excluding Endowment)



Capital spending in 1994 was $3.6 million, a significant increase over 1993 spending of $1.8 million, resulting in a decrease in the unrestricted plant fund. The increase in spending is mainly attributable to the budgeted acquisition of the hardware and software associated with the new administrative computing system. Funds for capital expenditures are provided from depreciation recovery, thus the reduction in the unrestricted plant fund will be short-lived as the depreciation recovery from assets purchased in 1994 will replenish the plant fund beginning in 1995.

Sponsored research continues to be the primary source of revenue for the Institution, representing 86.2% of the total revenue in 1994, compared to 82.2% in 1993 and 81.6% in 1992. (See Tables 1 and 2 for an overview of the sources of revenue to the Institution.) Unrestricted revenue increased to 9.4% of total revenue in 1994, compared to 6.8% in 1993 and 5.9% in 1992. This trend reflects WHOI management's efforts to increase flexibility by reducing reliance on government sponsored research.

In 1994, gifts and grants from private sources (excluding pledges) were $6.0 million, in addition to which gifts-in-kind valued by the Institution at $2.1 million were received, for a total of $8.1 million, compared to $3.8 million in 1993 and $7.3 million in 1992. (See table 3.) Outstanding pledges at the end of 1994 were $2.6 million, compared to $2.1 million at the end of 1993 and $4.7 million at the end of 1992. Due to strong support from our many friends and supporters, our net fundraising achievement since the inception of the capital campaign (1990 – 1994) has been $33.9 million.

In addition to the unrestricted plant fund balance, there are two other sources of expendable fund balances; the unrestricted current fund balance and the designated current fund balance. (See Table 5.) While the unrestricted plant fund balance declined as noted previously, the designated and unrestricted current funds grew. The unrestricted current fund grew from $1,297,879 to $1,332,596 and the designated current fund grew from $2,169,409 to $2,948,279.

In summary, 1994 was a very important year for the Institution, as resolution of all outstanding government audit issues was achieved without a significant negative impact on our financial statements. In addition, the capital campaign continued to reflect tremendous financial support for the Institution and its scientists. While the government sponsored research funding outlook is in a state of flux, the Institution is taking whatever steps are necessary to ensure that we are in the best position to take advantage of funding opportunities as they become available. To this end, WHOI is looking to broaden our base of funding sources, while maintaining the level of excellence in Ocean Science Research and Education for which the Institution is known.

You are invited to review the Institution's audited financial statements and accompanying notes presented on the following four pages.

Lawrence R. Ladd
Associate Director for Institution Operations
April 11, 1995

Statement of Current Fund
Revenues, Expenses and Transfers
For the years ended December 31, 1994 and 1993

	1994	1993
Revenues:		
Sponsored research:		
Government	$71,998,821	$65,885,079
Nongovernment	6,883,351	7,425,830
	78,882,172	73,310,909
Oceanus overhaul	1,331,328	–
Knorr/Melville refit	–	6,979,565
Education funds availed of	2,656,456	2,805,946
Total restricted	82,869,956	83,096,420
Unrestricted:		
Fees	626,565	503,212
Endowment income	1,253,555	1,163,633
Gifts	3,230,513	1,173,263
Tuition	2,489,657	2,148,452
Rental income	592,477	524,367
Oceanus subscriptions	101,047	207,402
Investment income	147,047	171,946
Other	161,753	122,794
Total unrestricted	8,602,614	6,015,069
Total revenues	91,472,570	89,111,489
Expenses:		
Sponsored research:		
Salaries and fringe benefits	22,432,290	21,775,137
Material and equipment	11,743,498	8,891,221
Ships and submersibles	9,362,787	12,013,533
General and administrative	8,996,714	6,880,789
Laboratory overhead	7,966,267	8,051,949
Subcontracts	5,200,398	4,307,078
Other	13,180,218	11,391,202
	78,882,172	73,310,909
Oceanus overhaul	1,331,328	–
Knorr/Melville refit	–	6,979,565
	1,331,328	6,979,565
Education:		
Faculty expense	1,786,319	1,615,483
Student expense	1,127,173	1,238,131
Postdoctoral programs	334,006	444,106
Other	548,723	493,721
	3,796,221	3,791,441
Unsponsored research	769,741	862,026
External affairs	1,986,169	2,101,819
Other activities	2,137,208	907,149
	4,893,118	3,870,994
Total expenses	88,902,839	87,952,909
Net increase before transfers	2,569,731	1,158,580
Transfers - (to) from:		
Designated reserves	(781,370)	(1,065,255)
Other	–	(34,751)
Endowment fund	(1,753,644)	–
Total	(2,535,014)	(1,100,006)
Net increase - unrestricted current funds	$ 34,717	$ 58,574

The accompanying notes are an integral part of the financial statements.

Balance Sheets
December 31, 1994 and 1993

	1994	1993
Assets		
Current fund (Note A):		
Cash and cash equivalents	$ 7,301,137	$ 13,158,072
Accrued interest and dividends	1,119,351	602,048
Reimbursable costs and fees:		
Billed	3,685,844	2,864,459
Unbilled	1,902,002	2,231,680
Other receivables	768,505	604,001
Inventories	598,348	602,716
Deferred charges and prepaid expenses	1,210,733	969,257
Deferred fixed rate variances	474,346	1,485,525
Due from (to) other funds	2,677,475	(236,131)
	19,737,741	22,281,627
Endowment fund (Notes A and B):		
Investments, at market	133,702,747	123,302,653
Cash and cash equivalents	10,033,155	18,664,950
Due to other funds	(3,907,403)	(3,579,795)
	139,828,499	138,387,808
Plant fund (Note A):		
Land, buildings, and improvements	41,591,075	40,907,076
Vessels and dock facilities	8,911,543	7,399,976
Laboratory and other equipment	8,918,901	6,669,997
Work in process	408,171	8,838
	59,829,690	54,985,887
Less: accumulated depreciation	(30,302,689)	(27,968,837)
	29,527,001	27,017,050
Due from other funds	1,229,928	3,815,926
	30,756,929	30,832,976
Total all funds	$190,323,169	$191,502,411
Liabilities and Fund Balances		
Current fund:		
Liabilities:		
Accounts payable and other liabilities	$ 4,315,387	$ 8,363,703
Accrued payroll and related liabilities	4,778,649	4,418,140
	9,094,036	12,781,843
Contingencies (Note H)		
Fund balances:		
Restricted - unexpended:		
Sponsored research	3,393,202	3,917,909
Education program	2,469,628	2,114,587
Other	500,000	–
Designated	2,948,279	2,169,409
Unrestricted	1,332,596	1,297,879
	10,643,705	9,499,784
	19,737,741	22,281,627
Endowment fund:		
Endowment:		
Income restricted	83,209,294	83,229,253
Income unrestricted	3,860,903	2,681,556
Pooled income fund	113,337	80,094
Quasi-endowment:		
Income designated	21,061,864	21,331,363
Income unrestricted	31,583,101	31,065,542
	139,828,499	138,387,808
Plant fund:		
Invested in plant	27,980,201	27,017,050
Unexpended:		
Restricted	108,434	90,773
Unrestricted	2,668,294	3,725,153
	30,756,929	30,832,976
Total all funds	$190,323,169	$191,502,411

The accompanying notes are an integral part of the financial statements.

Statement of Changes in Fund Balances

For the year ended December 31, 1994

	Current Funds				Endowment	Plant Fund		Total All Funds	
	Restricted	Designated	Unrestricted	Total	Fund	Invested in Plant	Unexpended	1994	1993
Increases:									
Gifts, grants and contracts:									
Government	$71,644,793			$71,644,793				$ 71,644,793	$ 66,294,964
Nongovernment	7,452,523		$3,230,513	10,683,036	$ 2,678,133		$ 24,724	13,385,893	9,142,879
Endowment and similar funds	4,027,380		1,253,555	5,280,935				5,280,935	3,998,028
Net increase (decrease) in realized and unrealized appreciation					(1,611,767)			(1,611,767)	15,093,690
Supplemental retirement reserve					215,216			215,216	261,016
Other	80,980		4,118,546	4,199,526				4,199,526	3,785,389
Total increases	83,205,676		8,602,614	91,808,290	1,281,582		24,724	93,114,596	98,575,966
Decreases:									
Expenditures	(82,869,956)		(6,032,883)	(88,902,839)				(88,902,839)	(87,952,909)
Depreciation						$(2,591,513)	2,490,742	(100,771)	(114,189)
Plant asset additions						3,554,664	(3,554,664)		
Other	(7,886)			(7,886)	(1,594,535)			(1,602,421)	(634,952)
Total (decrease) increase	(82,877,842)		(6,032,883)	(88,910,725)	(1,594,535)	963,151	(1,063,922)	(90,606,031)	(88,702,050)
Net change before transfers	327,834		2,569,731	2,897,565	(312,953)	963,151	(1,039,198)	2,508,565	9,873,916
Transfers - additions (deductions):									
Current revenues to:									
Designated reserves		$ 781,370	(781,370)						
Endowment			(1,753,644)	(1,753,644)	1,753,644				
Other transfers	2,500	(2,500)							
Total transfers	2,500	778,870	(2,535,014)	(1,753,644)	1,753,644	-	-	-	-
Change in fund balances for year	330,334	778,870	34,717	1,143,921	1,440,691	963,151	(1,039,198)	2,508,565	9,873,916
Fund balance, December 31, 1993	6,032,496	2,169,409	1,297,879	9,499,784	138,387,808	27,017,050	3,815,926	178,720,568	168,846,652
Fund balance, December 31, 1994	$ 6,362,830	$2,948,279	$1,332,596	$10,643,705	$139,828,499	$27,980,201	$2,776,728	$181,229,133	$178,720,568

The accompanying notes are an integral part of the financial statements.

Report of Independent Accountants

To the Board of Trustees of
Woods Hole Oceanographic Institution:

We have audited the accompanying balance sheet of Woods Hole Oceanographic Institution as of December 31, 1994 and the related statements of changes in fund balances, and of current fund revenues, expenses and transfers for the year then ended. We previously audited and reported upon the financial statements of the Institution for the year ended December 31, 1993; totals for that year are shown for comparative purposes. These financial statements are the responsibility of the Institution's management. Our responsibility is to express an opinion on these financial statements based on our audit.

We conducted our audit in accordance with generally accepted auditing standards. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis for our opinion.

In our opinion, the financial statements referred to above present fairly, in all material respects, the financial position of Woods Hole Oceanographic Institution as of December 31, 1994, the changes in its fund balances, and its current fund revenues, expenses and transfers for the year then ended, in conformity with generally accepted accounting principles.

Boston, Massachusetts
March 27, 1995

Coopers & Lybrand L.L.P.

Notes to Financial Statements

A. Summary of Significant Accounting Policies:

Fund Accounting

The accompanying financial statements have been prepared on the accrual basis of accounting. In order to comply with the internal designations and external restrictions placed on the use of the resources available to the Institution, the accounts are maintained in accordance with the principles of fund accounting. This procedure classifies resources into various funds in accordance with their specified activities or objectives.

Cash and Cash Equivalents

Cash and cash equivalents consist of cash, money market accounts and overnight repurchase agreements which are stated at cost which approximates market value.

Included in cash at December 31, 1994 and 1993 is $2,447,884 and $2,812,274, respectively, representing advances received from the United States Navy. Such amounts are restricted in use to certain vessel refit and other research programs. Interest earned on unspent funds reverts to the federal government.

Investments

Investment securities held by the endowment fund are carried at market value determined as follows: securities traded on a national securities exchange are valued at the last reported sales price on the last business day of the year; securities traded in the over-the-counter market and listed securities for which no sales prices were reported on that day are valued at closing bid prices. Purchases and sales of investment securities are recorded on a trade date basis. Realized gains and losses are computed on a specific identification method.

Investment income, net of investment expenses, is distributed on the unit method. Unrestricted investment income is recognized as revenue when earned and restricted investment income is recognized as revenue when it is expended for its stated purpose. Realized and unrealized gains and losses are recognized on a specific fund basis.

Contracts and Grants

Revenues earned on contracts and grants for research are recognized as related costs are incurred. The Institution has negotiated with the federal government fixed rates for the recovery of certain indirect costs. Such recoveries are subject to carryforward provisions that provide for adjustments to be included in the negotiation of future fixed rates. The deferred fixed rate variance account represents the cumulative amount owed to or due from the federal government.

Endowment Income Utilization

Investment of the Institution's endowment fund is based on a total return policy. The Institution distributes to current and plant funds an amount of investment income earned by each of the funds proportionate share of investments in the endowment fund (interest and dividends) based on a percentage of the prior years' endowment market values. During periods when investment income exceeds the distribution such excess income is added to a stabilization account. Conversely, when investment income is less than the distribution such deficit is funded by accumulated excess income or accumulated net realized and unrealized gains of the stabilization account.

Gifts

Unrestricted gifts are recognized as revenue when received and restricted gifts are recognized as revenue as they are expended for their stated purposes.

Noncash gifts are generally recorded at market value on the date of gift, although certain noncash gifts for which a readily determinable market value cannot be established are recorded at a nominal value until such time as the value becomes known.

Plant

Plant assets are stated at cost. Depreciation is provided on a straight-line basis at annual rates of 2% to 12 1/2% on buildings and improvements, 3 1/2% on vessels and dock facilities and 20% to 33 1/3% on laboratory and other equipment. Depreciation expense on plant assets purchased by the Institution in the amounts of $2,490,742 and $2,494,463 in 1994 and 1993, respectively, has been charged to operating expenses. Depreciation on certain government funded facilities (Atlantis II, the Laboratory for Marine Science and the dock facility) amounting to $100,771 and $114,189 in 1994 and 1993, respectively, is accounted for as a direct reduction of the plant asset and invested in plant fund. Title to the research vessel Atlantis II is contingent upon its continued use for oceanographic research.

The Institution consolidates available cash from the plant fund with other cash in the current fund for investment purposes.

B. Endowment Fund Investments:

The cost and market value of investments held at December 31, 1994 and 1993 are as follows:

	1994		1993	
	Cost	Market	Cost	Market
U.S. Government and government agencies	$ 11,340,797	$ 10,578,329	$ 13,152,282	$ 13,602,220
Corporate bonds	9,875,143	9,304,581	10,587,481	10,965,298
Other bonds	13,488,439	12,894,410	12,068,502	12,549,104
Common stock	80,648,097	97,707,523	63,030,762	83,034,443
Other	3,980,188	3,217,904	3,818,044	3,151,588
Total investments	$119,332,664	$133,702,747	$102,657,071	$123,302,653

C. Investment Units:

The value of an investment unit at December 31, 1994 and 1993 was $2.4524 and $2.5085, respectively. The investment income per unit for 1994 and 1993 was $.0684 and $.0644, respectively.

	1994	1993
Unit value, beginning of year	$2.5085	$2.2491
Unit value, end of year	2.4524	2.5085
Net change for the year	(.0561)	.2594
Investment income per unit for the year	.0684	.0644
Total return per unit	$ .0123	$ .3238

D. Endowment Income:

Endowment income consisted of the following:

	1994	1993
Interest and dividends	$4,309,024	$3,998,028
Investment management costs	(423,783)	(489,085)
Net endowment income	$3,885,241	$3,508,943

E. Retirement Plans:

The Institution maintains a noncontributory defined benefit pension plan covering substantially all employees of the Institution. The Institution also maintains a supplemental benefit plan covering certain employees. Pension benefits are earned based on years of service and compensation received. The Institution's policy is to fund at least the minimum required by the Employee Retirement Income Security Act of 1974.

Combined net periodic pension cost for the two plans consisted of the following for 1994:

Service cost	$2,814,552
Interest cost	5,691,186
Actual return on plan assets	(1,154,131)
Net amortization and deferral	(7,206,119)
Net pension expense	$ 145,488

Below is a reconciliation of the combined funded status of the plans at December 31, 1994:

Actuarial present value of obligation:	
Vested benefit obligations	$(58,816,475)
Nonvested benefits	(3,307,326)
Accumulated benefit obligation	$(62,123,801)
Projected benefit obligation	$(79,781,880)
Fair value of plan assets (primarily invested in common stocks and fixed income securities)	104,188,976
Plan assets in excess of the projected benefit obligation	24,407,096
Unrecognized net transition asset	(3,622,908)
Unrecognized prior service costs	428,673
Unrecognized net gain	(20,142,986)
Prepaid pension cost	$ 1,069,875

The fair value of plan assets listed above includes $99,621,976 of plan assets held in the Woods Hole Oceanographic Retirement Trust at December 31, 1994. In addition, the Institution has designated, as quasi-endowment, $4,567,000 to fund certain supplemental benefits at December 31, 1994.

The discount rate and rate of increase in future compensation used to determine the projected benefit obligation as of December 31, 1994 were 7.75% and 5.0%, respectively. The expected return on plan assets was 8.75%.

F. Other Postretirement Benefits:

In addition to providing pension benefits, the Institution provides certain health care benefits for retired employees and their spouses. Substantially all of the Institution's employees may become eligible for the benefits if they reach normal retirement age (as defined) or elect early retirement with certain time in service limitations.

In December 1990, the Financial Accounting Standards Board issued Statement of Financial Accounting Standards No. 106, "Employers' Accounting for Postretirement Benefits Other than Pensions" ("SFAS 106"). SFAS 106 requires companies to accrue the cost of postretirement health care within the employees' active service periods. In 1993, the Institution adopted SFAS 106. SFAS 106 allows either immediate recognition of the obligation for postretirement benefits or the delayed recognition method. The Institution elected the delayed recognition method and will recognize the accumulated postretirement benefit obligation over 20 years.

Net periodic postretirement benefit cost consisted of the following for 1994:

Service cost	$ 682,855
Interest cost	1,561,441
Actual return on plan assets	(96,067)
Amortization of transition obligation	853,549
Other amortization and deferrals	56,830
Net periodic postretirement benefit cost	$3,058,608

The Institution has a Voluntary Employees' Beneficiary Association Trust (the "Trust") that will be used to partially fund health care benefits for future retirees. The Institution intends to contribute to the Trust an amount equal to the annual expense of the Plan. During the year ended December 31, 1994 the Institution paid $563,000 in retiree health benefits on behalf of the Trust. The following table sets forth the funded status of the Plan as of December 31, 1994:

Financial status of plan:	
Accumulated postretirement benefit obligation:	
Retirees	$ (8,232,716)
Fully eligible, active plan participants	(5,900,096)
Other active plan participants	(7,585,423)
Total obligation	(21,718,235)
Plan assets at fair value	4,918,517
Unrecognized net transition obligation	15,363,888
Unrecognized net loss	1,962,218
Accrued postretirement benefit asset	$ 526,388

The assumed discount rate is 7.75%. The expected long-term rate of return on plan assets used in determining the net periodic postretirement benefit cost was 8.25% in 1994. The rate of increase in the per capita costs of covered health care benefits is assumed to be 7.0% in 1995, decreasing gradually to 5.5% by the year 1996 and remaining at that level thereafter.

If the health care cost trend rate assumptions were increased by 1%, the accumulated postretirement benefit obligation, as of December 31, 1994 would be increased by approximately $4,050,500; the effect of this change on the sum of the service cost and interest cost components of net periodic postretirement benefit cost for 1994 would be an increase of approximately $534,000.

G. Tax Status:

The Institution is exempt from federal income tax as an organization described in Section 501(c)(3) of the Internal Revenue Code of 1954 as it is organized and operated exclusively for education and scientific purposes.

H. Contingencies:

The Institution receives funding or reimbursement from federal government agencies for sponsored research under government grants and contracts. These grants and contracts provide for reimbursement of indirect costs based on rates negotiated with the Office of Naval Research (ONR), the Institution's cognizant agency. The Institution's indirect cost reimbursements have been based on fixed rates with carryforward of under or over recoveries. The Defense Contract Audit Agency (DCAA) is responsible for auditing both direct and indirect charges to grants and contracts on behalf of the ONR. The DCAA has issued audit reports on completed audits of direct and indirect cost recoveries from the government for the years 1987 to 1993. In these reports, the DCAA has proposed the disallowance of certain of these cost recoveries. As of 1994, the Institution and ONR have reached a resolution on the settlement of years 1987 to 1992. In the settlement each party agrees to consolidate actual 1987-1992 and estimated 1993-1994 carryforward amounts and liquidate the net carryforward balances as part of the 1995 fixed rates. In addition the 1995 fixes rates will include the unallowable costs from years 1987-1992. Currently the years 1993 and 1994 remain open subject to final negotiation. The Institution believes that the ultimate resolution of these matters will not have a material impact on its financial position.

I. Implementation of SFAS No. 116 and 117:

Effective December 31, 1995, the Institution will be required to implement SFAS No. 116 "Accounting for Contributions Received and Contributions Made," and SFAS No. 117 "Financial Statements of Not-for-Profit Organizations." The most significant provisions of SFAS No. 116 are the recognition of promises (pledges) and the lapse of certain external restrictions, recognition of contributed services as well as recognition and capitalization of collections in the financial statements. SFAS No. 117 requires a change in the display of the financial statements from those based on fund accounting to a display based on the concept of "net assets." The impact of these pronouncements has not been determined, but are not expected to have a material impact on the fund balances of the Institution.