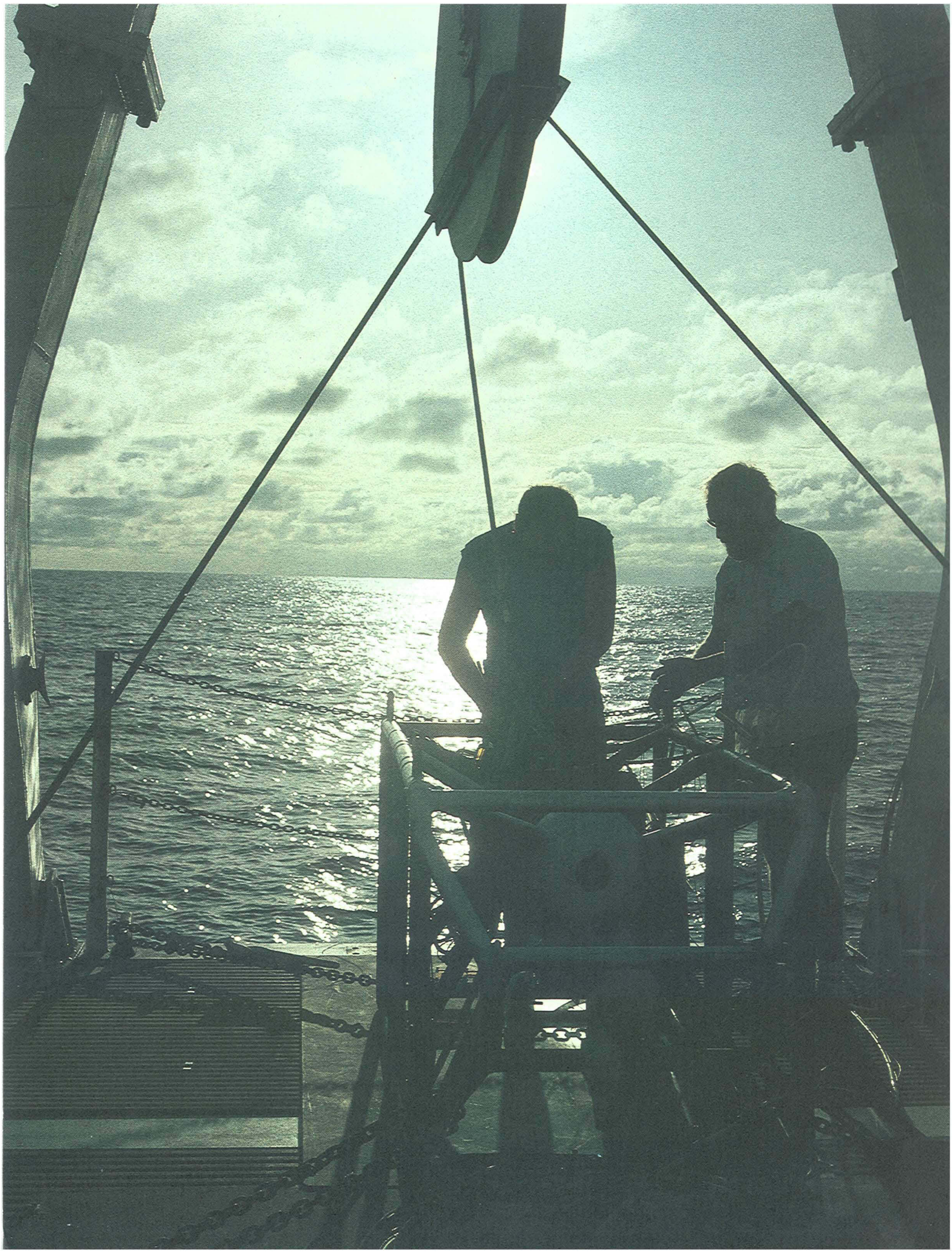

Contents

Cover Photo: A profiler known as the "Greene Bomber" (named after Charles Greene of Cornell University) is launched from the research vessel Oceanus *for experimental acoustic mapping of zooplankton distribution on Georges Bank. The acoustic mapping techniques are being developed by Tim Stanton and Peter Wiebe.*
PHOTO BY PETER WIEBE

Above: The research vessel Knorr *was working in the South Pacific for the World Ocean Circulation Experiment as 1993 began, transited the Panama Canal in April, and spent the rest of the year on Alantic Ocean studies that ranged from geological and geophysical surveys of the Mid-Atlantic Ridge to coring on the Blake/Bahama Outer Ridges.*
PHOTO BY TOM KLEINDINST

Left: Will Sellers and Bob Elder work on DSL-120's depressor aboard R/V Knorr *during a Mid-Atlantic Ridge cruise. The depressor pulled the DSL-120 to operating depth and decoupled the neutrally buoyant sonar sled from the ship's motion.*
PHOTO BY GARY JAROSLOW

1993 Annual Report
of the
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
(508) 457-2000

Editor: Vicky Cullen
Designer: Jim Canavan

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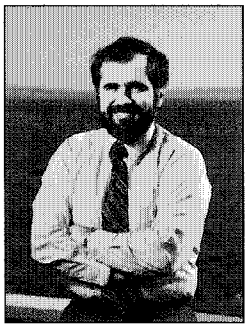
1993 was indeed a transitional year for the Institution both internally with the change in directorship and externally with the realization of a major shift in the nation's expectations of basic research.

On the national scene, federal research funding agencies have been significantly affected by both the end of the Cold War and the national budget deficit. In the past, the national strategy for basic research in the ocean sciences centered strongly on control of the seas through our nuclear submarine capability. Due mainly to the dismantling of the Soviet Union and the changing role of the United States as an economic world leader, the definition of national security has broadened significantly from one that centered on defense alone to one that now includes economic, environmental, and educational related activities.



TOM KLEINDINST

Robert B. Gagosian was named WHOI's seventh director in January 1994.

As a result, the two agencies from which we receive the majority of our funds, the National Science Foundation and the Office of Naval Research, are undergoing fundamental changes in the way they fund research. For the past 40 years, the National Science Foundation (NSF) has provided the core of the nation's basic research effort. Recently, however, NSF has felt increasing pressure to focus more on areas of national need that align themselves with the new broader definition of national security. The term "strategic research" is heard increasingly to describe those national needs with specific missions, such as manufacturing, high-performance computing, biotechnology, and global climate change. The Office of Naval Research (ONR), our second largest funding source, has eliminated the traditional separation between basic research and applied research and development. This extensive reorganization of ONR's program management structure was undertaken to enable its science and technology capabilities to be more responsive to a significantly downsized Navy, whose emphasis has shifted, because of changing warfare priorities, from deep water to the coastal zone. Similar kinds of changes have also occurred with other mission-oriented agencies, such as the National Oceanic and Atmospheric Administration, the US Geological Survey, the Department of Energy, and the Environmental Protection Agency, as their missions are redefined in this new world order.

With these changes in the federal agencies, however, come new opportunities. Taking advantage of them will require that we better understand agency priorities and work with them as partners so that both their goals and our own research objectives are accomplished.

As we assess the national needs with our own research objectives, we should keep in mind that more than 50 percent of our country's population now lives near the coast, and that the earth's population will double before the next century is half over. Since the ocean covers 71 percent of this planet, it will clearly play a pivotal role in any environmental security strategy that must account for increased human activity and growing concerns about sea-level rise, climate change, water quality, and quality of life in the coastal zones. Vigorous and well-articulated ocean sciences research will significantly help to address these issues.

The ocean sciences are still frontier sciences. They are young, relative to their "continental" cousins: biology, chemistry, physics and geology. Discoveries of the ocean's interior are still being made today. We've mapped less than one percent of the ocean floor, and just 16 years ago discovered the hydrothermal vent fields with their teeming unusual life forms amid the 300°C water in an erupting volcanic environment.

TOM KLEINDINST

Atlantis II *departs Woods Hole in early March for* Alvin *certification dives following a regular submersible refit.*

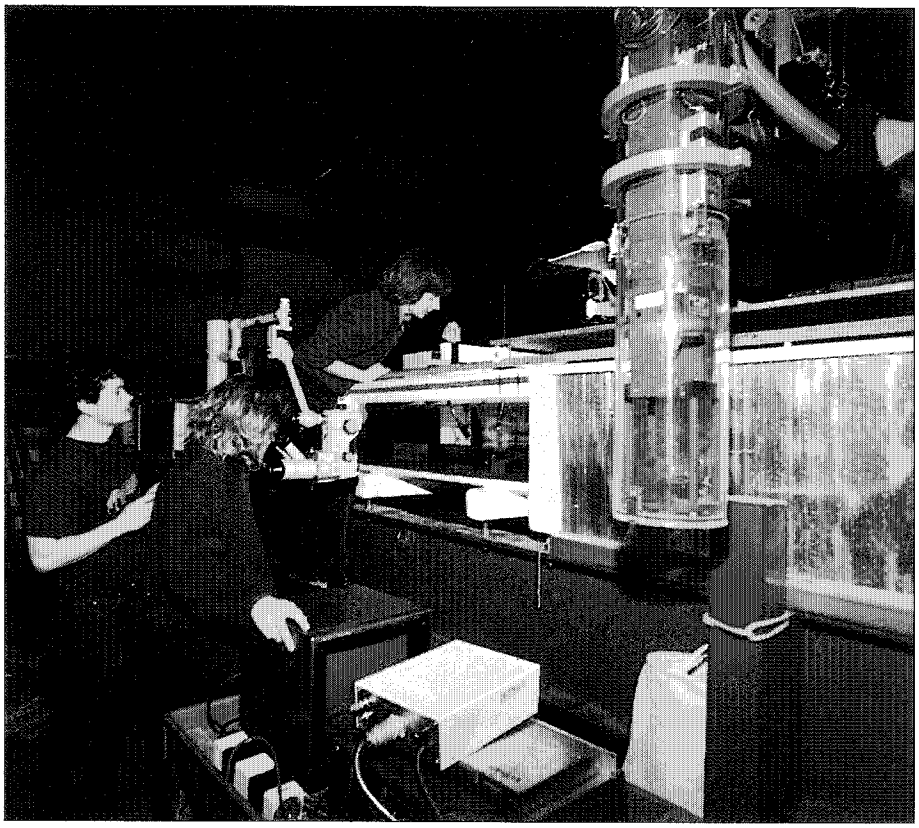
New technology allows us to undertake projects not possible a decade ago. Coupled with the observational aspects of ocean research, ocean sciences are very exciting and highly visual fields, capable of igniting enthusiasm for science both in the classroom and in general public outreach efforts. We must transmit these messages of excitement and discovery more effectively to both Congress and the media. The successful pursuit of the new definition of national security depends on it.

As the seventh Director of the Woods Hole Oceanographic Institution, my goal is

to provide a professional and personal environment where the very best researchers and students in ocean sciences and engineering will want to be. This translates into insuring a creative and innovative environment, the best marine and shore-based facilities and support services, and a critical mass of scientists and engineers from the research areas that are needed for creative synergy and interdisciplinary efforts. Past successes will not suffice. We face a number of challenges, however, in attaining this goal.

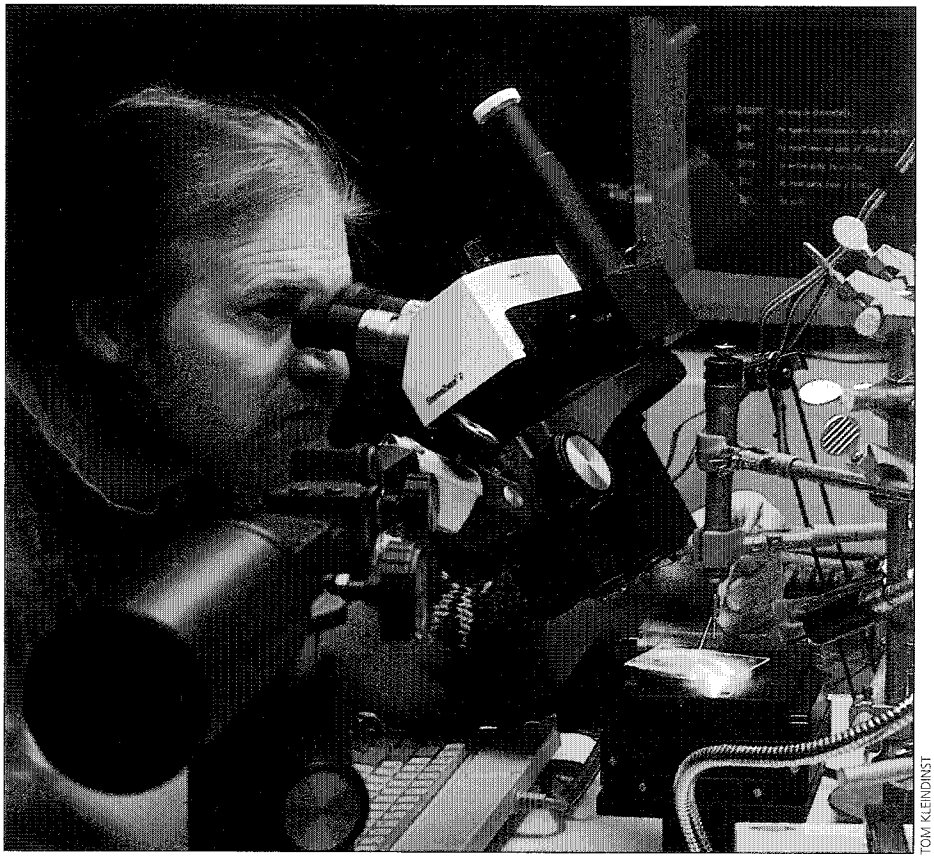
In this time of shifting federal-agency focus and fewer federal-research dollars available, the potential for our scientists and engineers to continue to succeed in their research missions is made more difficult. The Institution must meet this challenge, head-on, not only by continuing to conduct the best possible research in ocean science and engineering, but also by diversifying our federal funding base through partnerships with the mission agencies, and by more effectively communicating the importance of ocean science to the future of this planet. We need to strengthen our international collaborations and put more attention into our interactions with industry. We must also significantly increase the amount of private, unrestricted funds available to our researchers and students. These funds are essential for the Institution to continue to evolve and mature as a world-leading marine research organization and to retain its level of independence and flexibility to move in the directions its scientists and engineers believe are ripe for important advances and discoveries.

Many factors, some inherent and unique to WHOI, expertly poise us for continued success in the changing world. The Institution's high standards of excellence, its unrivaled breadth in many areas of ocean science and engineering, its interdisciplinary flexibility and lack of rigid departmental boundaries, and its commitment to transitioning knowledge to society are but a few examples of what will help us succeed. I am confident about this. And I look forward to enabling the Institution to meet the challenge.



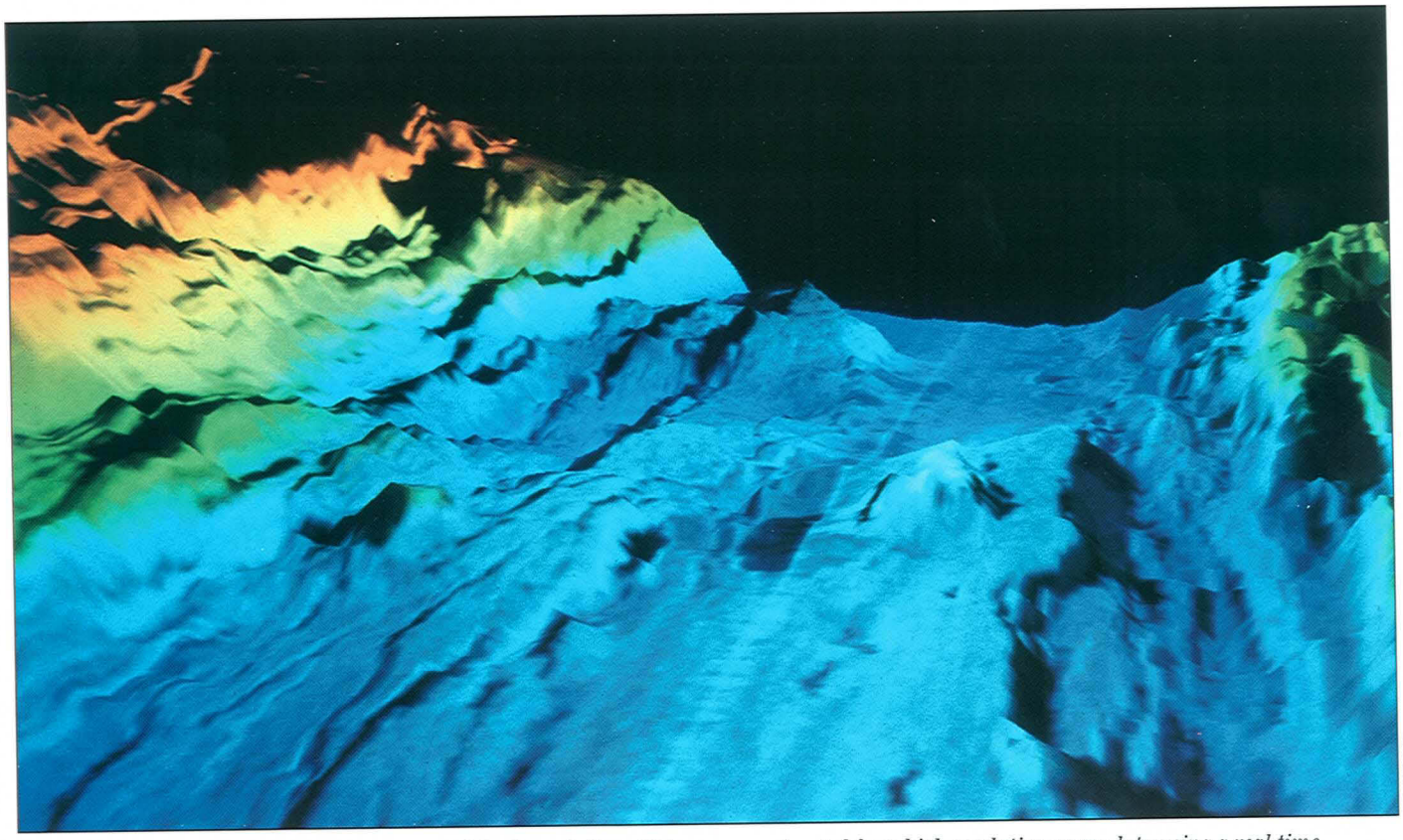
TERRI CORBETT

Jay Sisson, Lisa Garland, Cheryl Ann Butman, and Vicke Starczak (owner of the disembodied hand), conduct a flow-visualization study with a flume at the Coastal Research Laboratory.



TOM KLEINDINST

Joint Program student Chris Weidman dissects a shell for seasonal analysis.



KEN STEWART

This 3-D image of a 1-kilometer-square section of the Juan de Fuca Ridge was constructed from high-resolution sonar data using a real-time visualization package developed by WHOI's Deep Submergence Laboratory.

The Applied Ocean Physics and Engineering (AOP&E) Department, with 140 staff members and 40 graduate students, had a very productive year in 1993. Thirty-eight principal investigators led 110 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 promotion of benthic ecologist Cheryl Ann Butman to Associate Scientist with Tenure and the appointment of Walter Paul, formerly of the Martin Marietta Corporation, as Senior Engineer and Head of the Ocean Systems and Moorings Laboratory. In addition, Ben Allen, formerly of Benthos, Inc., and Mark Johnson, from the University of Auckland, were hired as Research Engineers to broaden the department's capabilities in mechanical engineering and signal processing, respectively.

A notable event in 1993 was the first AOP&E Department Retreat, which involved three days of presentations and discussions by 44 department members, 16 representatives of other WHOI science departments, and 5 from administration. Motivating factors for the retreat included: a desire to maintain the department's preeminent position in the applied ocean science and engineering community, the need to improve communication, particularly between the Scientific and Technical staffs, and a rapidly changing funding environment, especially in the Department of Defense. Working-group discussions focused on new directions in ocean instrumentation that exploit emerging technologies, innovative research that capitalizes on new instrumentation, funding for ocean engineering science and technology in the nineties, and the department's structure and role within the Institution.

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

Real-Time Remote Sensing for Underwater Exploration

It has become a truism within the marine science community that the surface of the moon is better explored than the ocean floor of our own planet—perhaps less than a tenth of one percent of this vast undersea domain has ever been seen by human eyes. The relatively opaque and inhospitable ocean medium presents formidable challenges to remote exploration, yielding a picture of the seafloor mainly through acoustic and optical means. Yet, successful and efficient subsea operations demand the capability not only to sense and model the ocean environment but to do so in real-time. If we are to more fully understand our ocean planet, to better protect our common heritage, and to avail ourselves of now-hidden resources, then remote-sensing systems offer a practical

means of projecting our human senses and capabilities into this mysterious and important realm.

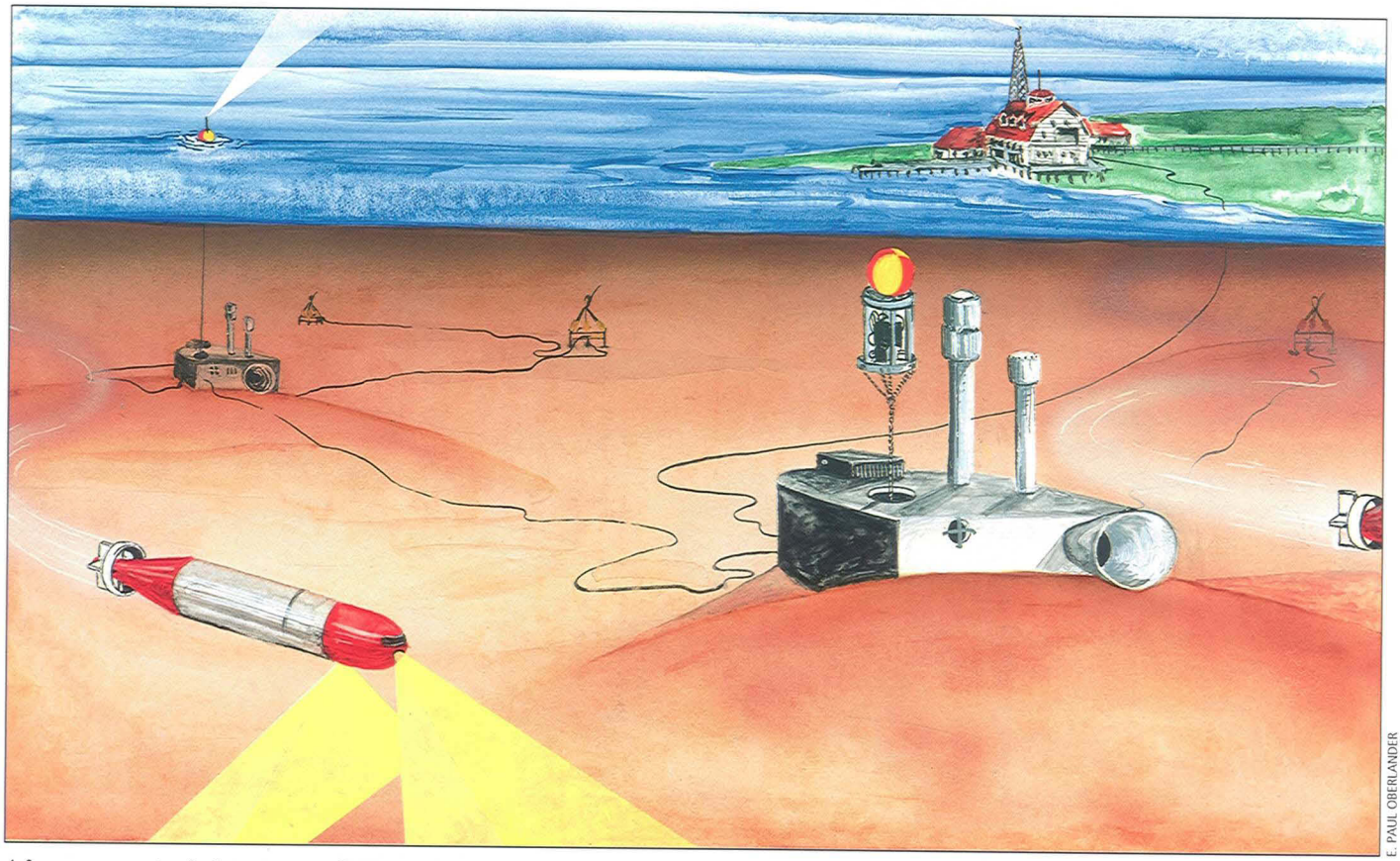
Remote-sensing images are particularly important in these endeavors since they take best advantage of our highest-bandwidth sense (about half of the human brain is devoted to visual processing). They allow a more natural interpretation of remote-sensing data, and offer the only realistic means of digesting the massive information flow now available from high-resolution devices. Today's rapidly evolving computational, graphics, and video technologies also profoundly affect underwater science and engineering. Analytically and conceptually, they extend our reach. Applied to work at sea, they give more timely and complete feedback, reducing cost and delay in post-processing tedium.

Within this context, Associate Scientist Ken Stewart and colleagues at the Deep Submergence Laboratory (DSL) are working to produce detailed, real-time images of the ocean domain. The figure shows part of a 1-kilometer-square region of the Juan de Fuca Ridge axial valley, which lies about 2,500 meters deep off the northwest US coast. It is a site of intense tectonic activity, where subterranean geothermal hot spots are associated with plate motion and volcanic formation of new crustal material. The 3-D rendering uses high-resolution sonar data acquired during a research expedition sponsored by the Office of Naval Research.

The data come from a deep-towed, phase-difference sidescan sonar, which generates high-resolution acoustic-backscatter intensity (similar to a 2-D photograph) and lower resolution bathymetry (shape). The data are combined and displayed using a real-time visualization package developed by DSL. Aboard ship or over a real-time satellite link to shore, a computer combines sonar, navigation, and attitude data to render a 3-D, color-coded view of subsea vehicles and a perspective of surrounding seafloor terrain. Alternatively, marine scientists can interactively "fly" through undersea data to acquire a more gestaltlike sense of geological and geophysical processes responsible for seafloor formation. In terms of conveying information, the composite image is, in a sense, greater than the sum of its parts.

Underwater Observatories Will Directly Link the Ocean and the Laboratory

An innovative seafloor observatory in 15 meters of water off the coast of New Jersey will soon couple the educational potential of the information superhighway with advances in transoceanic telecommunication systems and underwater robotics. With NSF and NOAA sponsorship, WHOI Oceanographic Systems Laboratory (OSL) staff are working with colleagues at the Rutgers Institute of Marine and Coastal Science and more than 30 other US scientists to develop and deploy the Long-term Ecosystem Observatory (LEO-15). Once on line, LEO-15 is



E. PAUL OBERLANDER

A few components of a long term underwater observatory. The first such observatory is expected to begin operating in June 1995.

expected to overcome the technical and financial factors that impede an important scientific commitment to making frequent observations of diverse ocean processes over long periods of time. The observatory is expected to have a 20-year life span. Plans call for a network of LEOs eventually to extend into the deep ocean.

LEO-15's Internet connection via an electro-optic cable buried in the seafloor will allow scientists anywhere in the world to obtain real-time data from observatory experiments. Using the two-way data link, they will be able to adjust the experiments based on data they are receiving. Thus traditional power-supply, data bandwidth, and wait-and-see limitations that have plagued ocean science will be essentially eliminated.

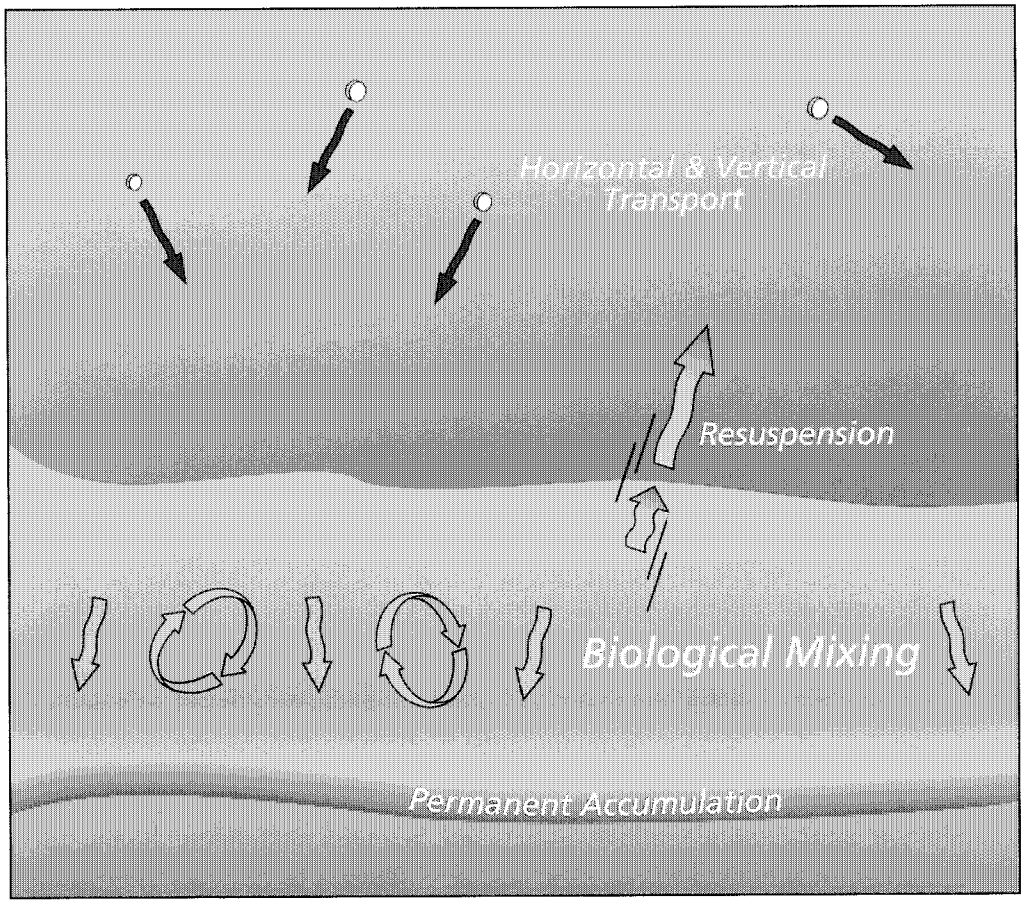
Tethered and autonomous underwater vehicles will be continuously deployed to make observations, manipulate experiments, track ocean frontal systems, and monitor episodic events as they occur. A vertical profiler will aid calibration of ocean-color satellites, and other systems will be devoted to studies of sediment transport and bottom-boundary-layer growth and decay.

Precious Metals Aid Mud Transport Studies

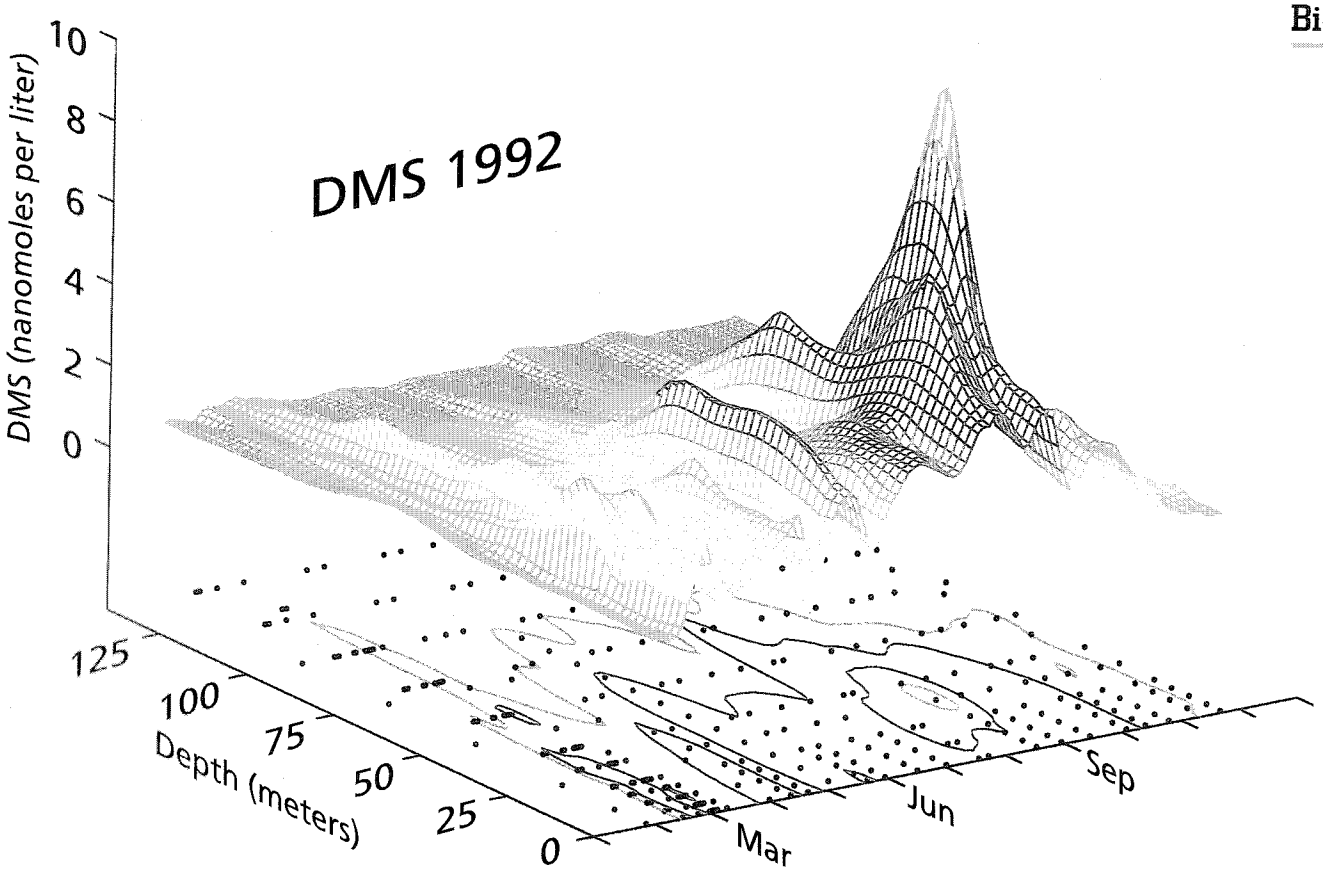
Physical and biological transport of fine particles in the coastal ocean has an important influence on the fate of many contaminants, because most contaminants are strongly bound to particle surfaces. Hence, where go the particles, so too go the pollutants. One way of learning more about particle transport is to use various "tracers" to follow particles through the environment. A tracer is defined as something that does not affect the system under study, that can be or is introduced into the environment in a known way and that is measurable at very low concentrations. Because effective models often require tracking several size classes of particles simultaneously, finding naturally occurring tracers is very difficult indeed.

Rob Wheatcroft is collaborating with Ilhan Olmez and Frank Pink of the MIT Nuclear Reactor Laboratory to develop a suite of particle tracers. Their approach, supported by the US Geological Survey (USGS), has two parts. First, they collect natural sediments from the site of interest, segregate the sediments (on the basis of size, for example) and then label each fraction with a different noble metal, such as gold or silver. The labeling process results in inert natural particles that have minute amounts of a particular element in their crystalline matrix. The second part of their technique involves spreading the labeled particles over the seafloor, allowing physical and biological processes to act for some time to redistribute the particles, and then collecting cores from the area. The researchers determine tracer concentrations in various core subsamples by using the MIT Research Reactor to bombard the samples with neutrons. All of the elements present in the sample, including the noble metals (which are the tracers), absorb some neutrons and become radioactive. Then, as they rapidly decay back to their stable states, they emit gamma rays with characteristic energies that can be counted with instruments designed to resolve concentrations of less than parts per billion.

Wheatcroft and his colleagues have used this new tracer technique to study particle-size dependent biological transport rates in Massachusetts Bay. To date they have found that fine particles penetrate the seabed substantively faster than coarse particles and that the rates change during the course of the year. These simple findings are important for models of particle transport in the coastal ocean and are being further explored with USGS colleagues.



Sediment mixing by animals can rapidly transport particles that have settled onto the seafloor deep into the seabed, sequestering them from further resuspension. Determining particle-size-dependent transport rates requires novel tracers like those described in the accompanying article.



Variability in dimethylsulfide (DMS) distribution at the Bermuda Atlantic Time Series station, the first blue-water data set showing detailed annual dynamics of DMS. The DMS profiles were measured in the water column throughout 1992. The high concentrations of DMS in shallow surface waters occur during summer when the concentration of phytoplankton biomass in the water is low.

Wide-ranging research in biological oceanography and marine biology was conducted in 1993 by 24 Biology Department scientists, 12 Technical Staff members, 5 postdoctoral scholars and investigators, 30 students, and 25 support personnel. The three research reports that follow typify the staff's diversity of interests and activities, which range from laboratory and theoretical studies to seagoing observations and experiments in all parts of the world's oceans. Studies by the staff encompass virtually all sizes and types of marine biota from the smallest viruses to the largest mammals, and habitats ranging from coastal and estuarine waters to the deep ocean. This research led to 64 scientific publications and 110 proposals submitted in 1993.

Among the year's notable achievements, Don Anderson was awarded the WHOI Stanley W. Watson Chair for Excellence in Oceanography, and Steve Bollens received an Office of Naval Research Young Investigator Award. In addition, Judith McDowell was named the new WHOI Sea Grant Director. The department was well represented in a National Science Foundation workshop in Sevastopol, Crimea, that brought together a group of American and former Soviet Union oceanographers to discuss past and future research in the Arabian Sea. Additionally, several department staff will participate in the forthcoming Joint Global Ocean Flux Study (JGOFS) expedition to the Arabian Sea.

Department scientists also continue to participate in the major Global Ocean Ecosystems Dynamics (GLOBEC) initiative supported by the National Science Foundation and the National Oceanic and Atmospheric Administration, and in the Modelling Biological-Physical Interactions program supported by the Office of Naval Research.

The effort to integrate molecular biology into basic and applied WHOI research programs continued in 1993 and included development of a postdoctoral program for young scientists interested in combining the techniques of molecular biology and biological oceanography.

Biology Laboratory Studies Greenhouse Gas That Originates In Phytoplankton

Aerosols and clouds are important in controlling the light and heat balance of the atmosphere. They appear to moderate the warming effects of such greenhouse gases as carbon dioxide and methane by reflecting light (and heat) from the sun back out to space. Although cloud droplets form around tiny particles that often begin simply as dust, they can also arise from compounds that accelerate the condensation of water vapor into liquid. By encouraging condensation, aerosols may play a role in cloud droplet nucleation, thereby influencing the reflective properties of clouds and of the earth itself. Dimethylsulfide (DMS) is one gas that, when oxidized to sulfur dioxide and methanesulfonic acid in the atmosphere,

results in the formation of aerosol precursors. The oceans are a principal contributor of DMS to the atmosphere, and since the mid 1980s John Dacey and colleagues have been investigating the dynamics of DMS in seawater, both in a coastal salt pond and, more recently, in the blue water off Bermuda.

DMS is a biologically produced gas. In the marine environment it appears to be almost exclusively the breakdown product of dimethylsulfoniopropionate (DMSP), a compound abundant in certain classes of phytoplankton. Even though the precursor is so distinct, the mode of its decomposition to form DMS is complicated. Dacey's group has discovered that most DMS is formed not by the phytoplankton themselves, but rather by processes initiated when zooplankton eat phytoplankton. When DMSP-bearing cells are eaten, there are several possible fates for the DMSP: It may decompose to DMS during feeding and digestion, it may be taken up and stored by the animals, and some intracellular DMSP is excreted into the water column, where it is decomposed by planktonic bacteria. The latter appears to be the major mechanism by which DMS is formed in the water column. Once formed, only a fraction of the DMS enters the atmosphere, while much of it is oxidized in the water column biologically or by photochemical reactions.

Following several years of laboratory work on DMS production, Dacey's group began two years ago to use the Bermuda Biological Station for Research as a base for field observations at the Bermuda Atlantic Time Series (BATS) station. For this work, which is funded by the National Science Foundation's Joint Global Ocean Flux Study, Dacey designed and built a laboratory system that collects dissolved gas from seawater samples and analyzes it automatically. As the figure on page seven indicates, findings to date demonstrate that DMS dynamics are very complex.

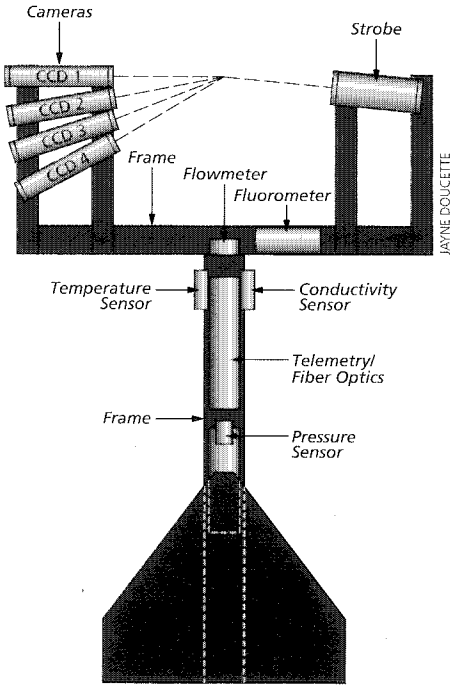
A key emphasis of future work on DMS will be to increase the capability for DMS measurements in both space and time. Since DMS concentration is controlled by a suite of biotic and abiotic processes, predicting its concentration at any given time is impossible. What happens, for example, when the wind blows? Ironically, it is exactly when conditions are most turbulent, and shipboard measurements are all but impossible, that gas exchange is likely to be proceeding at its maximum rate. Automated measurement systems for deployment on buoys or unmanned automated vehicles would fill this gap by providing measurements of DMS in both the surface ocean and the atmosphere. More field data are required to interpret the results of laboratory experiments and to evaluate the role of DMS in global change.

VPR Correlates Plankton Distribution and Hydrographic Conditions in Near Real Time

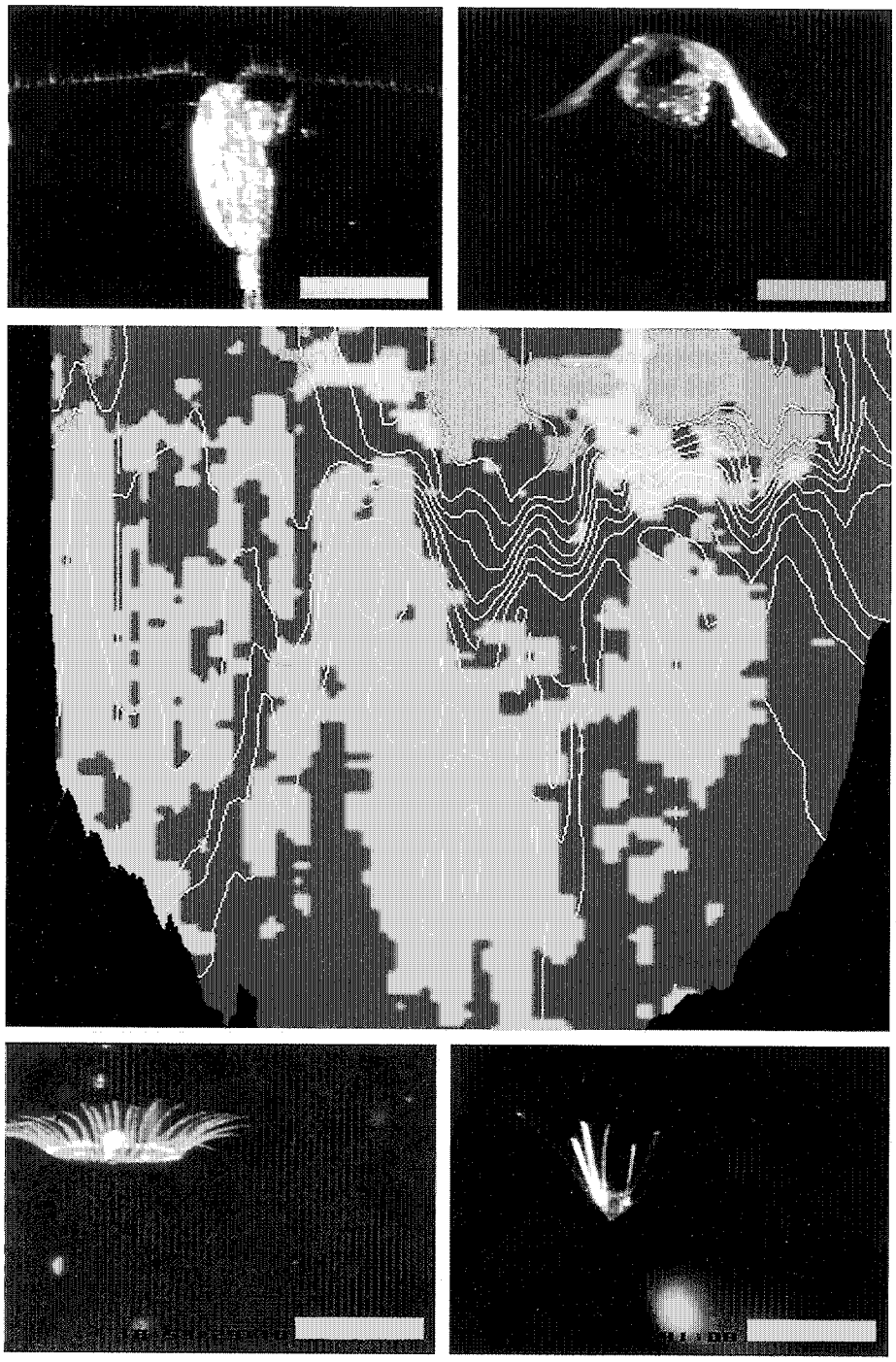
Planktonic (drifting) organisms constitute the vast bulk of living matter in the ocean, and it is the transfer of energy from sunlight through the planktonic food web that sustains most life in the sea. In addition, most species of marine biota spend critical parts of their life cycles in the plankton as larval forms. To understand the physical and biological processes that regulate marine plankton populations, it is essential to measure population distributions together with physical properties over a broad range of time and space scales. Until recently, the ability to make such measurements has been severely limited.

With funding from the National Science Foundation, Cabell Davis and Scott Gallager have recently developed the Video Plankton Recorder (VPR), a video-microscope system for imaging plankton and other particulate matter in the size range from a few microns to several centimeters. Using the VPR, the scientists have measured the abundance of plankton over a continuum of scales from microns to kilometers at towing speeds of 1 to 6 knots. Currently, with funding from the Office of Naval Research, and in collaboration with Ken Stewart and Marty Marra (WHOI Deep Submergence Laboratory) and Luc Vincent (Xerox Imaging Systems), they are developing methods to process the video in real time and automatically classify the plankton taxonomically.

The VPR has been deployed in towed configuration for mapping plankton distributions, as well as on the remotely operated vehicle *Jason* and on fixed platforms for viewing plankton swimming behaviors in two and three dimensions. In addition, a moored VPR has been



The Video Plankton Recorder system consists of four video cameras equipped with magnifying optics and synchronized at 60 fields per second to a red-filtered 80-watt xenon strobe. The four cameras are set for concentric viewing fields so that a range of up to four magnifications (5 millimeters to 10 centimeters) can be viewed simultaneously, allowing analysis over a wide plankton size range. Video, hydrographic, and biological data are telemetered to the surface via fiber-optic cable and stored, together with time code overlay, using broadcast-quality video-tape recorders. Video signals can be directed to a real-time image processor for taxonomic and size classifications.



Extensive transects (62-kilometer, 8-hour deployments at 4 knots) have been made across Georges Bank while "tow-yoing" the video plankton recorder between the surface and bottom. This sampling revealed dense aggregations of the copepod Calanus finmarchicus *(top left, yellow), the pteropod* Limacina sp. *(top right, red), the jellyfish* Obelia sp. *(bottom left, orange), and sea-star larvae (bottom right, light blue) associated with distinct water masses displaying specific physical properties. Note the close association of zooplankton with overlaid temperature contours spaced at 0.5 °C intervals ranging from 4 °C, bottom, to 8.5 °C, surface. The images are from the video camera with a 5-millimeter field of view.*

proposed for high-resolution time series measurement of vertical plankton distributions on Georges Bank. This system will telemeter data through seawater via acoustic modem to a nearby mooring fitted with a satellite transmitter. Thus, data from the moored VPR will be transmitted to WHOI in near real time.

In general, the video observations provide new insights into basic plankton ecology by allowing quantitative assessment of individuals in their natural, undisturbed state. The zooplankton aggregations observed to date have important consequences for feeding success of larval fishes on the bank and the potential impact of global climate change on food-chain relationships in the worlds' oceans.

Visualizing Plankton Distributions with High-Frequency Sound

The vastness of the oceans and the minuteness of much of their animal life are fundamental realities that constrain ocean ecologists' studies of animal distribution and abundance. Ideally, ecologists would like to be able to draw a global picture of animal populations and observe how the physical environment as well as biotic interactions regulate population size from season to season and year to year. Because conventional gear, such as nets, pumps, and water-bottle samplers, all impose space and time limits, the currently available global picture is really a composite constructed from a hundred years of uneven point-source sampling.

Use of high-frequency sound, in the range of 38 kilohertz to more than 1 megahertz, holds promise both for small-scale plankton patchiness studies and for rapid, large-scale mapping. A significant portion of the water column can be insonified several times per second at ship speeds up to 8 knots. However, in large volumes of water it is difficult to separate sound that bounced off an animal from sound that encountered particles or other things not of biological

PETER WIEBE

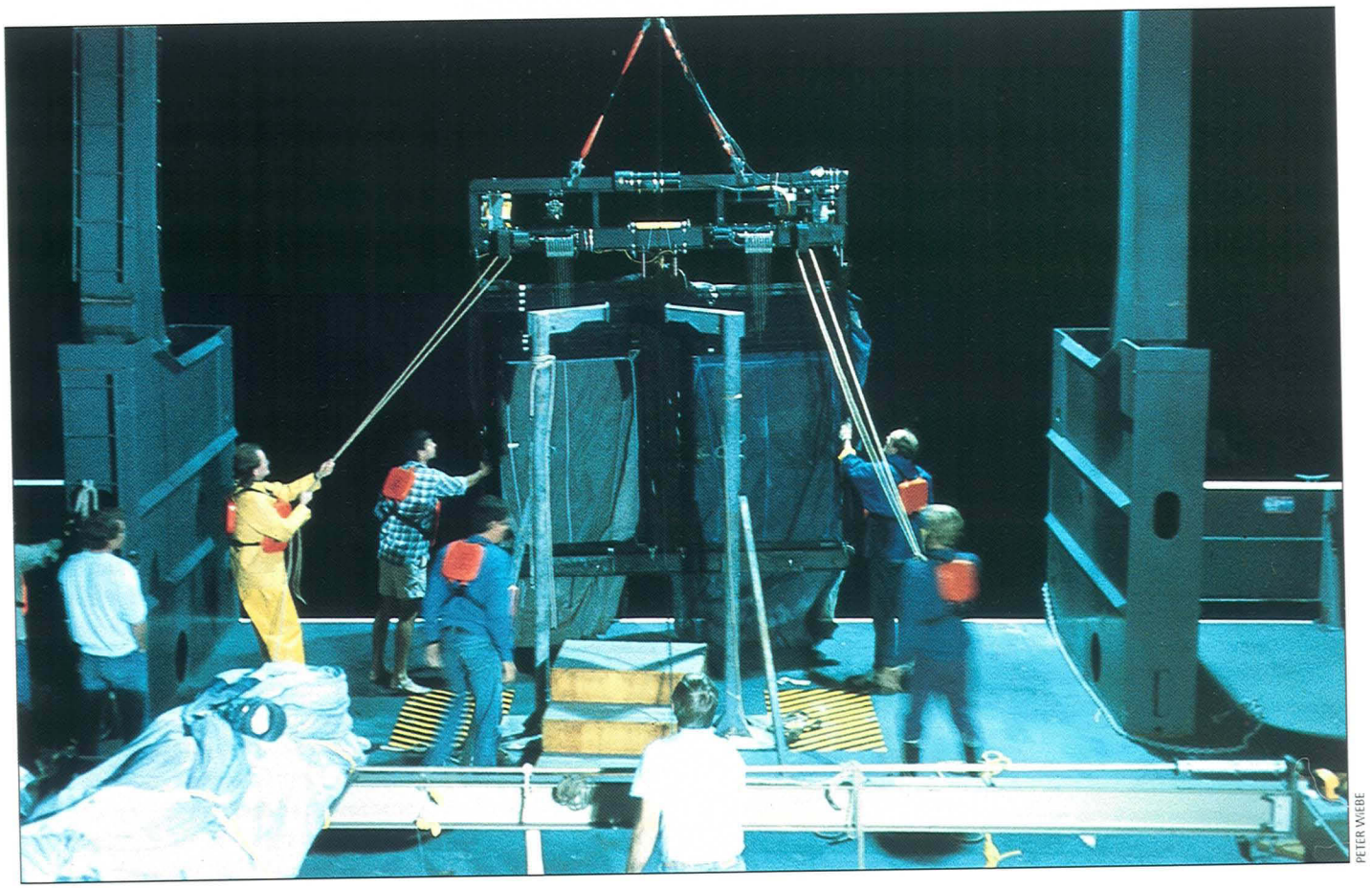
The "Greene Bomber" (named after Charles Greene of Cornell University and the fact that it was painted green) is a towed, remote sensing tool for mapping distribution of zooplankton using high frequency (420kHz) sound and physical and biooptical properties of the water.

Samples from towed nets, like the Multiple Opening-Closing Net Environmental Sensing System (MOCNESS), being launched below from RV Thomas G. Thompson, *are compared with acoustic results.*

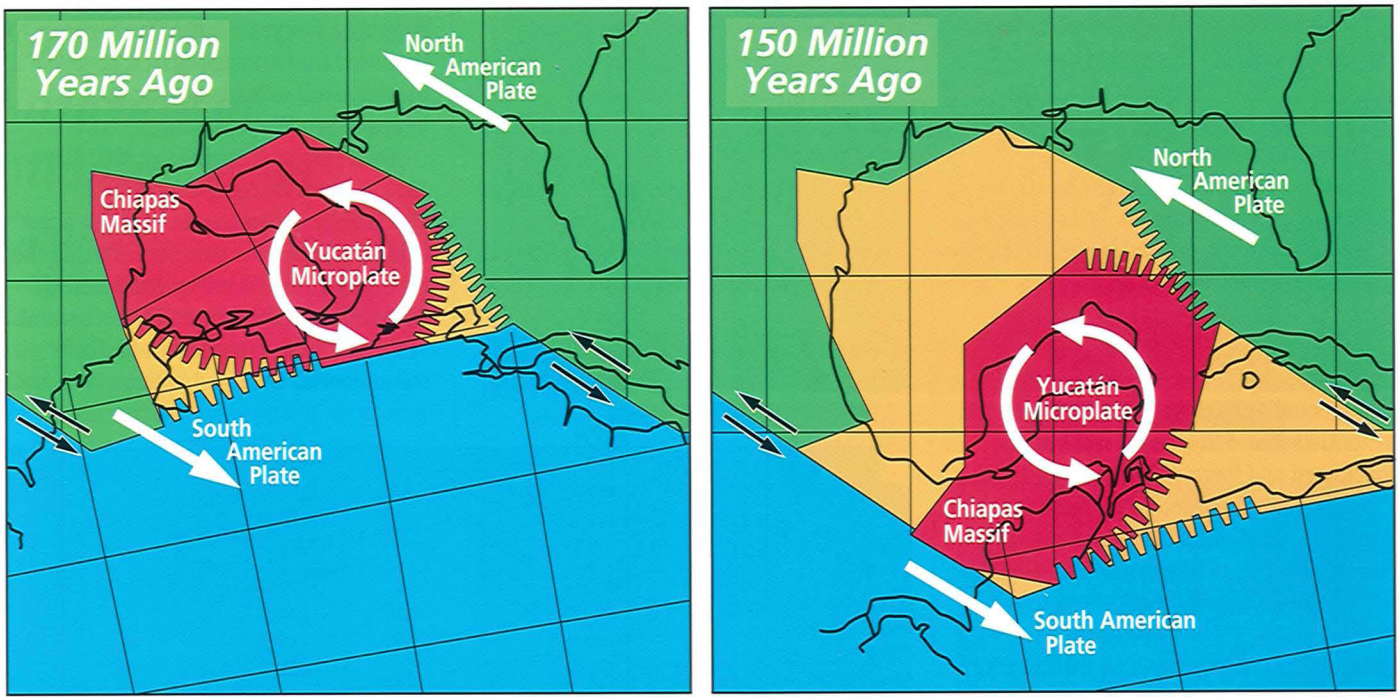
interest. Peter Wiebe, collaborating with Tim Stanton (WHOI Applied Ocean Physics and Engineering Department), and Charles Greene (Cornell University) have attacked this problem. First, they are developing new plankton-reverberation models to aid interpretation of acoustic volume backscattering in terms of real biological properties—biomass of all individuals in a given volume of water, the number of individuals present in that volume, and the number of individuals in various size classes. Concurrently they are designing and building new acoustic instruments capable of acquiring data to test the plankton-reverberation models. As part of the process, they used these tools for acoustic mapping of Georges Bank plankton distributions and used the acoustic data in combination with net-tow samples to verify the models.

A high-frequency (420 kilohertz) echo sounder mounted in a V-fin with the transducer pointed down was towed in two physically distinct areas, a well-mixed area on top of the bank and a stratified section on the bank's southern flank. The stratified area yielded four to seven times more backscatter than the well-mixed area, but, surprisingly, analysis of the net tows indicated there was no significant difference in the zooplankton biovolumes of the two regions. There were, however, significant differences in the abundance of different-sized plankton groups. This study indicates that it is possible to accurately estimate acoustic volume backscattering in both well-mixed and stratified areas and shows that species composition can strongly influence backscattering levels. The scientists are continuing to develop and calibrate their instruments for use in other areas of the world oceans.

This work was funded by the National Science Foundation, the Office of Naval Research, and NOAA.



PETER WIEBE



Opening of the Gulf of Mexico, from 170 to 150 million years ago, as a result of the counterclockwise rotation of the Yucatán microplate. The cogs show areas where the neighboring North and South American megaplates exerted edge pressure during the early opening of the Atlantic. The Gulf of Mexico basin developed simultaneously with the Yucatán basin.

The Geology and Geophysics Department's successful record of progress and accomplishment in marine earth sciences research continued in 1993. The scientific staff of 32 led more than 200 research projects, participated in more than 20 individual cruises worldwide, and generated 164 new proposals, continuing to win the ever-more-difficult battle to fund their research. However, the true measure of success lies not in logistics but in the high-quality research papers published in the peer-reviewed literature. In this, 1993 was a banner year with more than 100 separate contributions authored by the Geology and Geophysics (G&G) scientific and technical staff and students in paleoceanography, marine seismology, tectonics, marine geology, petrology, and geochemistry.

The National Ocean Sciences Accelerator Mass Spectrometry facility, housed within the G&G Department and led by Associate Scientist Glenn Jones, continued successful operations, producing high-precision, radio-carbon dates for the entire US ocean sciences community.

Dan Fornari was recruited from the Lamont-Doherty Earth Observatory of Columbia University for a joint appointment in this department and in Marine Operations. As G&G Associate Scientist with Tenure, he brings expertise in applying submersible and remotely operated vehicle technology to a wide range of mid-ocean ridge research problems; as Deep Submergence Operations Chief Scientist, he is involved with the myriad challenges associated with the planned merging of the Alvin *and* Argo/Jason *operational groups.*

Senior Scientist Al Uchupi retired after more than 30 years at WHOI, but was immediately appointed Scientist Emeritus. He remains as active and positive as ever, as evidenced by 1993 publication of his latest book, Morphology of the Rocky Members of the Solar System *(Springer-Verlag), coauthored by Scientist Emeritus K.O. Emery.*

New Kinematic Principles Explain Microplate Rotation

While the dozen or so major tectonic plates of Earth's outer skin are the best known, some most interesting, recently discovered tectonic processes involve microplates or "blocks" that are found along the boundaries of these larger plates. For example, countless small plates no larger than a few tens or hundreds of kilometers in diameter make up the western North American Plate margin. Microplates are also found in the basins behind the great volcanic island arcs of the western Pacific, where the oceanic Pacific Plate subducts beneath the continental Eurasian and Indian plates. Many of these microplates have undergone significant rotation about a vertical axis in the past and some are still rotating at rates up to 10° per million years. Another class of microplate occurs along the mid-ocean ridges where the major tectonic plates move apart. These microplates range from

100 to 1,000 kilometers across and appear to rotate as rapidly as 30° per million years.

Recently, WHOI Senior Scientist Hans Schouten and Kim Klitgord of the US Geological Survey formulated kinematic principles to explain how rotation of microplates might be driven by edge pressure from large adjacent plates. For example, this edge-driven mechanism, as illlustrated on the previous page, explains the counterclockwise rotation of the Yucatán Block as a cogwheel between two moving racks (the North and South American plates). By envisioning certain plate boundaries as intermeshed cogs, the scientists found they could roll history backward and forward in agreement with evidence derived from measurements of the magnetism of rocks in the Chiapas Massif. They could thus view the opening of the Gulf of Mexico from 170 to 150 million years ago as a result of a 65° counterclockwise rotation of the Yucatán microplate. Schouten and Klitgord and colleagues have also tested these principles on the kinematic evolution of the Easter microplate on the East Pacific Rise between the Nazca and Pacific plates, the Juan Fernandez microplate at the junction of the Nazca, Pacific, and Antarctic plates in the southeast Pacific, the Solomon-Bismarck microplate system in the western equatorial Pacific, and the Gorda and Mathematician microplates in the northeast Pacific. Each case exhibits a sigificant edge-driven component in the computed motion of the microplates.

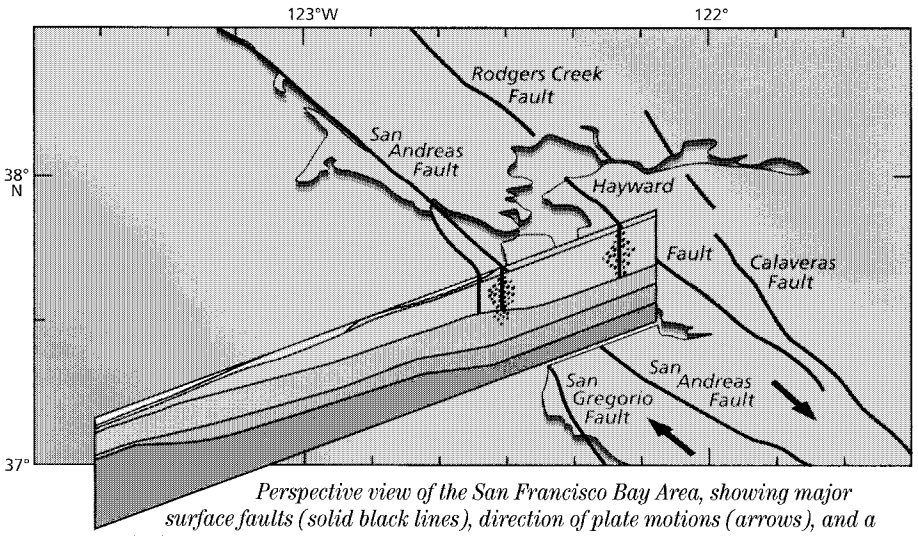
Newly Identified Fault May Link California Earthquakes

The large earthquakes that periodically rock California are no geological accident. Two of Earth's largest tectonic plates, the North American and the Pacific plates, grind slowly past one another along the San Andreas Fault. This motion is slowly altering the California landscape, bringing San Francisco and Los Angeles 35 millimeters closer together every year and releasing tectonic stress in a continual seismic chatter. Although most of the tremors are faint pops noticed only by sensitive seismographs, a few are of the loud and damaging sort, such as the 1989 Loma Prieta (Santa Cruz) and 1994 Northridge (Los Angeles) earthquakes. Understanding why earthquakes appear where they do is often difficult, since along much of the San Andreas Fault zone the physical structure of Earth's crust is poorly known.

For the past two years, Steve Holbrook and US Geological Survey (USGS) colleagues have been analyzing new seismic data in an effort to unravel the structure of the crust beneath San Francisco Bay and off the California Coast. The Pacific/North American plate boundary is particularly complicated in the San Francisco Bay area, because there the San Andreas Fault splits into several strands, including the Hayward and Calaveras faults. Damaging earthquakes occur on all of these fault strands. Therefore in the San Francisco area it is important to understand not only how each fault behaves, but also whether (and in what way) the various fault strands interact with one another.

The historic earthquake record hints that the faults may indeed be linked: At least three times in the past 160 years, large earthquakes on one side of the bay have been followed within a few years by similar tremors on the opposite side. These "paired earthquakes" may indicate that the faults are connected by other, hidden faults—so that the San Andreas, for example, can "feel" an earthquake on the Hayward Fault and may respond by slipping a few years later. One recently proposed theory suggests that just such a mystery fault extends horizontally beneath San Francisco Bay.

Data recorded during the 1991 Bay Area Seismic Imaging eXperiment (BASIX) have revealed tantalizing new evidence for such a structure. During the experiment, sound waves generated by airguns towed behind the USGS research vessel *Lee* were recorded on portable seismometers deployed both on land and on the seafloor beneath San Francisco Bay and west of the peninsula. This technique, called seismic reflection profiling, is a sort of "ground-penetrating sonar" that gives seismologists both a picture of the rock layers within the crust and an indication of those layers' composition. The BASIX results showed a strong, horizontal boundary 15 kilometers beneath San Francisco Bay, separating sedimentary rocks from a denser underlying layer. One interpretation of this structure is that it represents a fault that connects the San Andreas and Hayward faults. An alternative interpretation, however, suggests that the deeper layer represents Pacific oceanic crust caught between the faults. Continuing analysis of the BASIX data is aimed at distinguishing between these possibilities and bringing scientists one step closer to understanding the pattern of earthquakes around San Francisco.

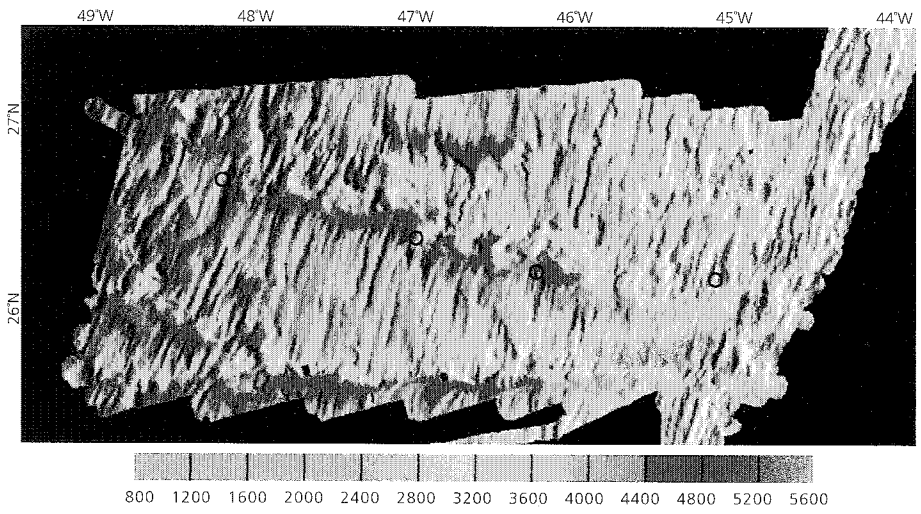


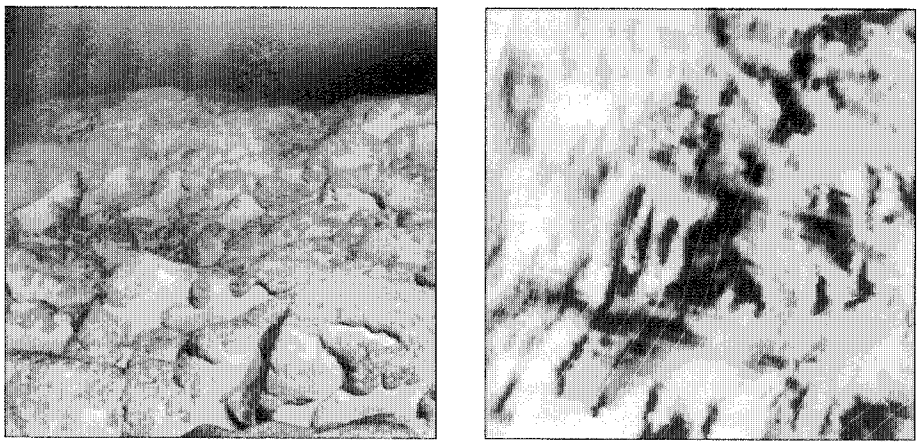
Perspective view of the San Francisco Bay Area, showing major surface faults (solid black lines), direction of plate motions (arrows), and a vertical cross-section of Earth's crust (inset). Earthquakes (dots) on the San Andreas and Hayward Faults extend into the mid crust.

Geologists Map the Fine-Scale Structure of Atlantic Ocean Crust

The great rift in the center of the Atlantic Ocean, the Mid-Atlantic Ridge axis, marks the site of separation of the North American and African plates. As the rift opens, currently at a rate of about one inch per year, magma wells up and new oceanic crust is created.

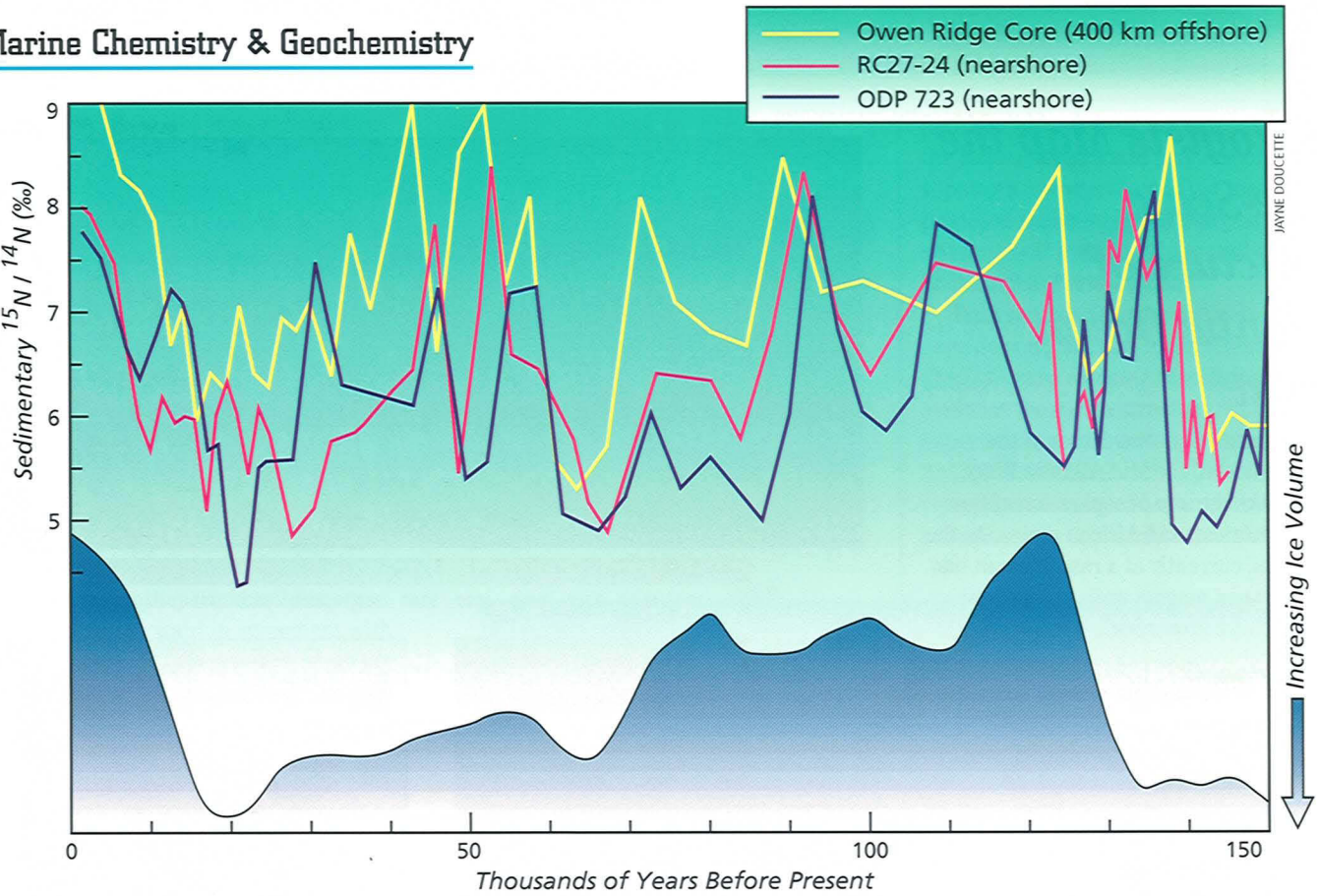
Over the past 20 years, submersibles, deep-towed sonars, and camera sleds have been used for close-up study of the volcanism and faulting associated with rifting. The older, off-axis ocean crust, however, has never been studied in comparable detail, and the evolution of this crust has been poorly known. In May and June of 1993, geologist Brian Tucholke led a party of 29 scientists and engineers aboard R/V *Knorr* to conduct ONR-sponsored fine-scale studies of ocean crust in four ridge-flank areas that range from 3 to 25 million years old. They used WHOI's sophisticated deep-towed sonars and remotely operated vehicle (ROV) *Jason* to conduct "nested surveys." This technique uses progressively higher-resolution instrumentation to map successively smaller areas in a patch of seafloor; the goal is to relate observations across scales, so that larger-scale data (which are cheaper to obtain per unit area) can be used to predict finer-scale structure. The surveys were conducted within a 200-by-400-kilometer region that had been fully mapped in 1992 using multibeam bathymetric sonar and long-range (20-kilometer swath) sidescan sonar. Initially, the detailed surveys mapped seafloor areas about 10 kilometers on a side using the DSL 120-kilohertz sonar, which provides meter-level bathymetry and backscatter imagery over swaths up to 1 kilometer wide. *Jason* was then deployed to map specific targets within the 10-kilometer boxes by collecting 200-kilohertz sidescan/bathymetric sonar; 300-kilohertz forward-scan sonar; precision pencil-beam (Mesotech) bathymetry; magnetic-field measurements; video, film, and electronic-still photography; and seafloor rock samples.





Shaded-relief map of seafloor morphology over the crest and west flank of the Mid-Atlantic Ridge at 26°N. The seafloor is illuminated from the west, and colors indicate relative depths ranging from about 2,500 meters (red) to 5,500 meters (purple). Four seafloor sites surveyed with the DSL-120 and Jason *are indicated by circles. Photo on left shows a* Jason *electronic still-camera image of a small, near-vertical fault scarp. The view is straight down; the bulbous forms are pillow lavas heavily coated with manganese encrustations and lightly dusted with light-colored sediment. On the right is a small section of a DSL-120 sidescan-sonar image, which shows trellislike patterns of crustal ridges and troughs that are the erosional remants of a once-steep scarp. The area is insonified from the right, and dark areas are the high-backscatter sides of ridges and small scarps.*

Among the real surprises of the expedition was the observation that the hard-rock basaltic crust becomes extensively eroded by mass wasting (dislodgment of rocks and sediment and their down-slope displacement under the force of gravity). Once-large, steep scarps have been heavily dissected into "trellis patterns," where weak, faulted and fissured zones have failed and avalanched down slope (see figure above).The oldest crust (25 million years old), however, is heavily coated by manganese precipitated from seawater, suggesting that there has been little tectonic activity or mass movement there for millions of years. In contrast, near-vertical fault scarps, some of which reach heights of 100 to 200 meters, are common in younger, 3 to 10 million-year-old crust, and these often have little manganese coating. Thus most of the mass wasting, together with possible off-axis faulting, appears to occur within roughly the first 10 million years after the crust is formed. Sediments raining through the overlying water column slowly cover the ocean crust, first in deep sediment ponds where they too are carried by mass wasting. Eventually, after tens of millions of years, they completely blanket the ocean floor and hide the basaltic ribs of the solid earth from our view forever.



Variations in the nitrogen 15 to nitrogen 14 ratio over the past 150,000 years at three sites in the Arabian Sea match variations in Earth's ice volume. The Owen Ridge site is about 400 kilometers offshore of Oman, and the other two sites are within 60 kilometers of the coast. Highest ice volume represents periods of extreme glaciation and cold climate.

The Department of Marine Chemistry and Geochemistry consists of 20 scientific staff, 17 technical staff, 30 graded and administrative staff, 2 visiting and 3 guest investigators, plus 4 postdoctoral and 9 graduate students in residence at Woods Hole and 8 at MIT.

The department continues to be vital, exciting, and deeply involved in a wide spectrum of projects related to global climate change, water circulation, trace metals, organic geochemistry, and sedimentary and ocean crust fluxes. Many of our projects are part of large national and international programs such as Joint Global Ocean Flux Studies (the administrative office for this program is housed in the department), World Ocean Circulation Experiment, Earth Observing System, Ridge Inter-Disciplinary Global Experiments, and the Ocean Drilling Program.

We are sorry to say that Associate Scientist Ellen Druffel and Research Associate Sheila Griffin left us this year to move to California. New additions to the Scientific Staff included two new Assistant Scientists—Jeff Seewald, an experimental geochemist, and Maureen Conte, an organic geochemist. Among the many department projects, we highlight the following three.

Sediments Record Past Changes in the Ocean's Nitrogen Cycle

Past changes in the marine nitrogen cycle may have had serious impact on important global biogeochemical cycles. This is because the supply of fixed nitrogen, available in such forms as ammonia and nitrate, regulates plant productivity in much of the ocean. Marine productivity, in turn, influences a wide range of critical processes and phenomena, including the carbon-dioxide content of the atmosphere. Until recently, though, no historic record of changes in the ocean's nitrogen cycle had been identified.

Over the past several years, with NSF funding, Mark Altabet and Roger François have found that the ratio of nitrogen 15 to nitrogen 14 ($^{15}N/^{14}N$) preserved in deep-sea sediments varies with the intensity of specific nitrogen-cycle processes. Denitrification occurs when bacteria use nitrate (NO_3^-) to oxidize organic matter in low-oxygen waters. This process constitutes the single most important removal factor for fixed nitrogen in the ocean. Because $^{14}NO_3^-$ reacts slightly faster than $^{15}NO_3^-$, residual nitrate becomes enriched in ^{15}N. The two researchers' work shows that the isotopic signature of nitrate is reflected in the phytoplankton using it and ultimately in organic matter preserved on the seafloor.

During times of reduced denitrification, sedimenting organic matter would be expected to have a lower $^{15}N/^{14}N$ ratio, and this is what Altabet and François found in sediment cores from the Arabian Sea, where one-third of the water column's denitrification occurs due to the presence of low-oxygen subsurface waters. They found significant variations in $^{15}N/^{14}N$ that are in concert with changes in Earth's climate as indicated, for example,

by the planet's ice volume. During cold glacial periods, $^{15}N/^{14}N$ is significantly lower, suggesting greatly reduced denitrification during these periods. Similar variations found at three separate sites over the last 150,000 years provide confidence in this record's regional nature. An important implication is that during glacial times the loss of fixed nitrogen decreases, and the ocean's nitrogen content, and hence productivity, increases.

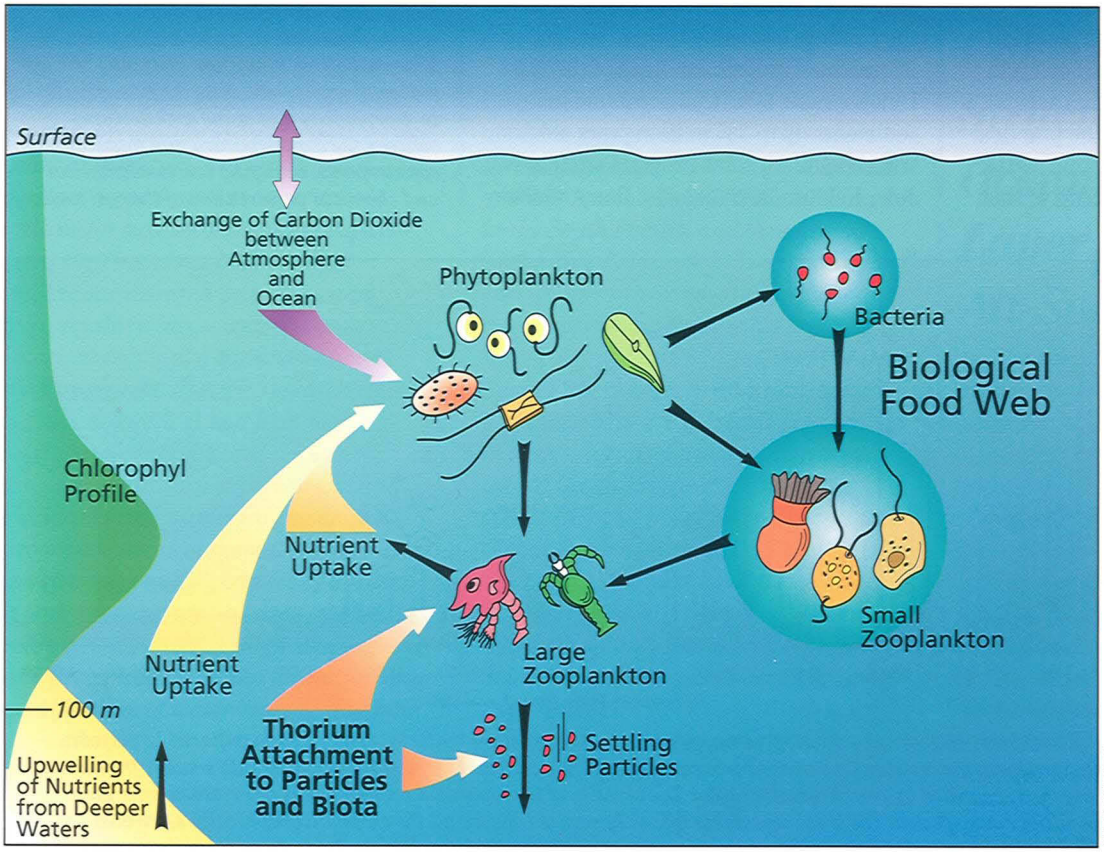
There are a number of questions for future research to answer. First, what changes in the Arabian Sea reduced denitrification? The strength of the seasonal monsoon winds is known to diminish during glacial periods. Their indirect influence on the extent and intensity of subsurface low oxygen is a likely link. Second, were there similar variations in other important denitrification regions, such as the eastern tropical Pacific? If so, even larger climate-driven perturbations in the ocean's nitrogen cycle than the work suggests to date might have occurred in the past.

Tracking Carbon in the Ocean with Natural Radioactivity

Mention of radioactivity conjures up images of human-induced disaster: mushroom clouds, a burnt-out Chernobyl reactor, leaking waste drums on the seafloor. There are, however, a wide range of *naturally* occurring radioactive elements in seawater, and they play a key role in elucidating a variety of oceanic processes. One of these is thorium 234 (^{234}Th), a naturally occurring daughter of uranium decay. Thorium's fate in seawater is determined by its chemical affinity for particle surfaces—many thorium atoms are quickly adsorbed onto any available particle surface. Since most open-ocean surface particles are biologically derived, the ^{234}Th attached to them provides a means for tracking the production and export of organic carbon and associated nutrients in the surface ocean.

Since we know from physics that 50 percent of the ^{234}Th will be lost every 24 days due to radioactive decay (this is the so-called "half-life" of ^{234}Th), any additional reduction of the thorium daughter relative to its parent can be used to determine the vertical flux of sinking particles. At any given time, the concentration of ^{234}Th is quite low, on the order of a single part per million (ppm) of a ppm of a ppm. Therefore sampling and detection methods for this trace element require extreme precision, and significant effort is devoted to refining and improving them.

As part of the international Joint Global Ocean Flux Study (JGOFS), Ken Buesseler and colleagues calculate the sinking flux of carbon from the surface of the North Atlantic and Equatorial Pacific using ^{234}Th budgets and knowledge of the relationship between organic carbon and ^{234}Th on particles. In essence, to understand the role of the ocean in modulating the ever-increasing, anthropogenic, carbon-dioxide input to the atmosphere, it is important to know not only how much carbon dioxide is taken up by marine phytoplankton, but also how much is stripped out of the surface waters. In fact, most of the carbon dioxide taken up by organic matter during photosynthesis is simply recycled. Much less than half, and as little as a few percent of the photosynthetically produced carbon, escapes the surface ocean on sinking particles to depths where it can no longer be exchanged with the atmosphere. Under sponsorship from NSF and NOAA, these investigations continue to explore the uses of ^{234}Th as a quantitative link between the atmospheric and oceanic carbon budgets.

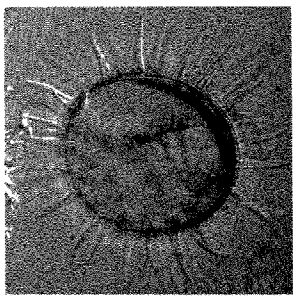


Surface ocean cycle of carbon uptake and export. Thorium-234 traces this cycle by attachment to sinking and biological particles.

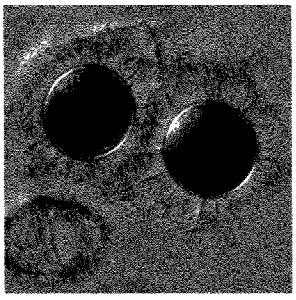
Nature's "Plastics" Preserve Organic Matter in Sediments

Organisms adopt complex yet subtle chemical variations that dictate the preservation of marine organic matter. For the most part, biological debris is eaten and degraded, either during passage through the water column or when it reaches the ocean floor. Even there, animals and bacteria graze upon it many times over to the point that, in most oceanic regimes, organic carbon eventually represents only a fraction of a percent of the sediment. Despite this efficient recycling, the tiny fraction of organic matter remaining actually comprises Earth's largest reservoir of organic carbon. Under special circumstances, organic-rich sediments can, over geological time, produce oil and gas reserves.

What is this organic matter that survives Nature's highly efficient recycling scheme? This question bears upon another all-important question concerning how and why the global carbon cycle changes through time. Scientists seeking answers are confronted with the practical problem that sedimentary organic matter is largely unrecognizable in terms of such common living-organism constituents as proteins and carbohydrates. Much of it is difficult to analyze because it is composed of very high molecular weight, chemically resistant materials that appear to be remnant, highly resistant natural products. The chemical inertness of these biologically synthesized polymeric materials (biopolymers) stems from their physical functions (protection, structural support), and their remarkable resistance invites comparisons with modern plastics. For example, some algae and higher plants synthesize biopolymers that structurally resemble polyethylene.

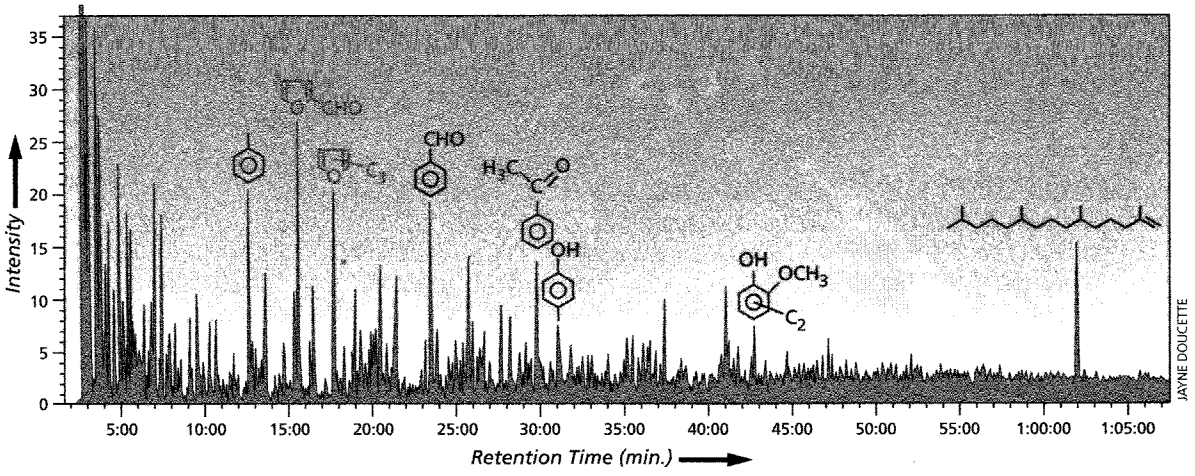


Tim Eglinton, with NSF funding, studies the chemical structures of persistent biopolymers. He uses an array of chemical and thermal dissociation methods in combination with gas chromatography and mass spectrometry to disassemble the macromolecules and then elucidate their constituent "building block" structures. He compares the chemical characteristics of resistant organic molecules in living organisms with those encountered in sediments. Recent investigations focus on the coatings of resting cysts produced by microscopic unicellular algae of the class Dinophyceae, cysts that are found in sediments up to 225 million years old. When Eglinton, Joint Program student John Kokinos, and biologist Don Anderson conducted the first rigorous chemical investigation of living dinoflagellate cyst material, they found molecular characteristics that may shed new light on plant evolution. Surprisingly, the cyst's building blocks are reminiscent of lignin, the macromolecular material that occurs in the woody tissue of land plants. However, it also displays chemical features hitherto unreported for biopolymers.

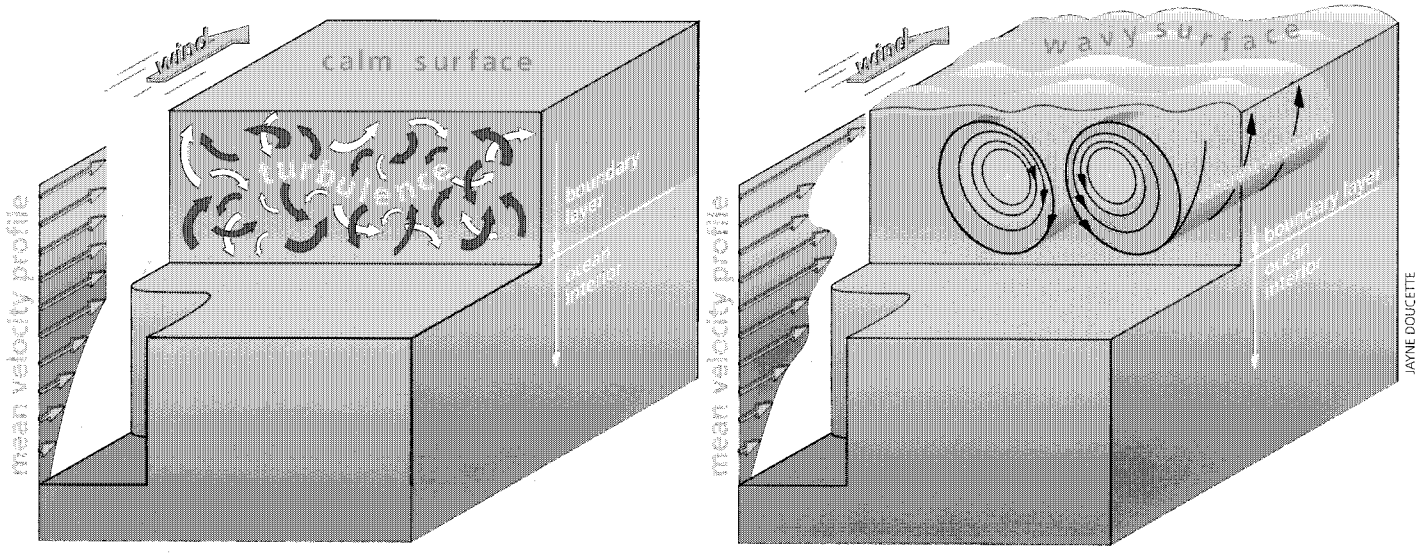


The next step will be an attempt to link modern and fossil organisms through their chemistry. Molecular characterization of these biopolymers will aid interpretation of past changes in sedimentary organic matter in terms of biological evolution, climate change, and variations in depositional environment.

Light photomicrographs of resting cysts from the dinoflagellate Lingulodinium *(formerly "*Gonyaulax*") polyedra: (top photo) living species from culture, and (bottom photo) a Miocene (about 20-million-year-old) sedimentary deposit. Note the close similarity in morphology and spine architecture between the contemporary and fossil counterparts, implying excellent physical and chemical preservation of the cyst wall.*



A pyrolysis-gas chromatography-mass spectrometry trace of the resistant material isolated from cultured L. polyedra *cysts. On pyrolysis, the resistant macromolecule comprising the cyst wall thermally dissociates into smaller fragments, which are then separated by gas chromatography. The identity of the separated compounds is determined from their corresponding mass spectra. The trace represents intensity versus time for all the chromatographically separated peaks, and indicates the chemical structures of several significant products. The phenolic products share several common features with those from lignin pyrolysis. A rather unique characteristic of the cyst material pyrolyzate is the high relative abundance of pristene, which is derived from tocopherol (vitamin E).*



Previous ideas about the structure of velocity in the oceanic boundary layer presumed the existence of small-scale turbulence and a uniform mean velocity profile (left diagram). However, recent theoretical and observational work shows that large-scale, vortical structures frequently occur in the boundary layer in addition to small-scale turbulence (right diagram). These vortices alter the mean velocity profile and affect the exchange of matter and energy between the atmosphere and the ocean.

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 millimeter and second scales. 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 three major World Ocean Circulation Experiment cruises as part of the program's Core I (Global Survey) in the South Pacific, and they are continuing fieldwork in three elements of Core III (Process Studies): the Subduction Experiment, the North Atlantic Tracer Release Experiment, and the Deep Basin 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).

One of 1993's noteworthy events was the award of WHOI's Bigelow Chair in Oceanography to Bob Weller, a Senior Scientist in the Physical Oceanography Department.

Coherent Structures in Oceanic Boundary Layer Influence Air-Sea Interaction

The ocean exchanges heat and momentum with the atmosphere in a surface boundary layer that ranges, depending on local conditions, from a few meters to a few hundred meters deep. These exchanges are important to the general circulation of the oceans, to plant and animal life within the oceans, and to Earth's weather and climate.

The boundary layer is often referred to as the "mixed layer" because within it properties such as temperature and salinity are vertically well mixed and nearly uniform. Most previous ideas about the structure of fluid velocity in the boundary layer supposed that where temperature and salinity were uniform, velocity would also be uniform. It was accepted that there

were small-scale, incoherent fluctuations in the velocity field, known as turbulence, which served to transfer momentum downwards from the sea surface. However, recent evidence indicates that in addition to turbulence on scales of millimeters to centimeters, the boundary layer is home to large, coherent vortices whose vertical scales are comparable to the boundary-layer depth.

Scientists refer to these vortices as Langmuir cells in honor of Irving Langmuir, who first hypothesized their existence in 1938. The Langmuir cells' rotation axes are roughly aligned with the wind direction. Counter-rotating cell pairs produce regions of convergence and divergence at the sea surface. Since there is a downwind component of velocity in the cells in addition to their cross-wind rotational motion, a particle released in a cell would execute a helical pattern, spiraling downwind. Theoretical work indicates that combined forcing from wind and waves forms these structures. Thus, previous boundary-layer theories that included forcing by wind, but not waves, did not account for their presence. Because Langmuir cells alter the vertical distribution of properties, understanding them is critical to understanding air-sea heat and momentum exchange.

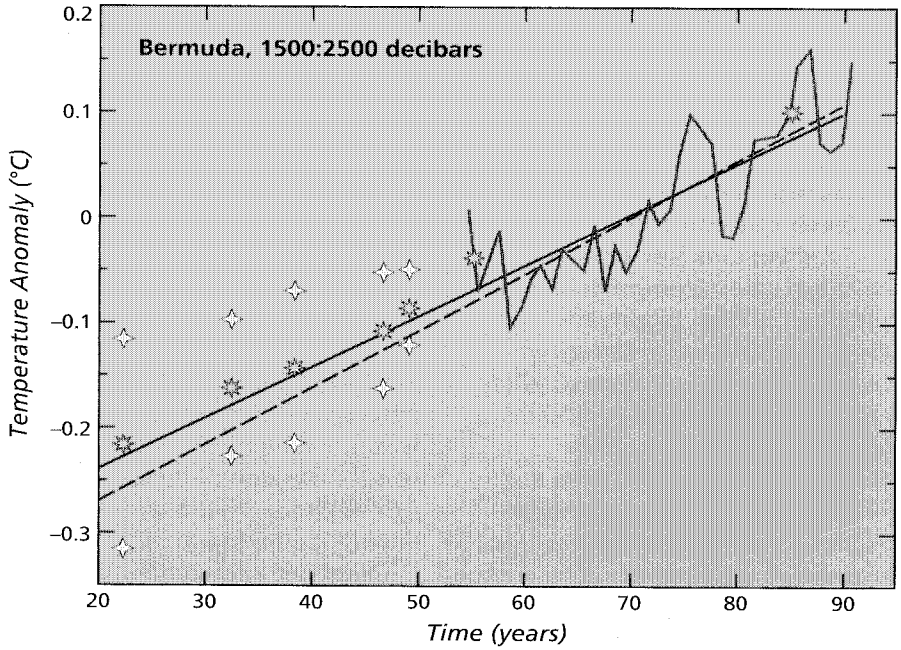
A recent field experiment funded by the Office of Naval Research provides the most compelling evidence to date for the effects of Langmuir cells on the boundary layer of the open ocean. Al Plueddemann and Bob Weller analyzed the experimental results in collaboration with investigators from the Scripps Institution of Oceanography (SIO) and the Institute of Ocean Sciences (IOS) in Canada. Two important elements distinguished this experiment from its predecessors. First, velocity measurements in the upper 100 meters of the water column were made with better vertical resolution than ever before. Second, images of horizontal velocity at the sea surface from acoustic sensors developed at SIO and IOS allowed detection of large-scale structures. This combination of observations showed that Langmuir cells produced short-term variations in boundary-layer velocity and altered the long-term mean velocity profile. Continuing work toward understanding boundary-layer processes through studies like this one will ultimately improve the ability to predict behavior of the coupled ocean-atmosphere system.

The WOCE Hydrographic Program Office

WHOI scientists are actively engaged in the World Ocean Circulation Experiment (WOCE), an eight-year international study of the general circulation of the ocean and its importance in Earth's climate system. International coordination of the WOCE Hydrographic Program (WHP) is based at WHOI under the direction of Terry Joyce.

This program's mission includes characterizing the present state of the ocean through an extensive one-time survey of all the major oceans that extends from just south of the Arctic Circle to the antarctic ice pack and features high-quality hydrographic (temperature, salinity, oxygen, and nutrient) and tracer measurements. In addition, researchers occupy certain sections repeatedly in order to characterize the representativeness of the one-time survey and to make serial observations of low-frequency variability at isolated stations. Some 100 ships are expected to occupy more than 20,000 WHP stations by 1997, surpassing all previous hydrographic programs by more than an order of magnitude. More than half this many have already been made by 18 countries, including 665 in the South Pacific by R/V *Knorr* in 1992. WHP work will also be the major focus of *Knorr's* 1995 schedule, this time in the Indian Ocean.

In addition to its overall coordination function, the WHP Office disseminates state-of-the-art measurement methodology, defines information (such as conditions under which data is taken) required by WOCE participants, assembles and performs quality control on all hydrographic data, provides progress reports to the community of WOCE scientists and national funding agencies, and transfers final data to archives for further dissemination. Principal support for WHP Office operation comes from the National



Averaged temperature measurements between the pressures of 1,500 and 2,500 decibars (roughly 1,500 to 2,500 meters) at Bermuda show a warming trend of about 0.5°C per century. Station "S" data (solid line) were augmented by historic hydrographic data taken near Bermuda (asterisks). Also shown is the sample standard deviation from a limited (usually 3 to 4) number of stations of opportunity prior to the start of Station "S." The oldest data used were taken on the 1922 Dana II *expedition, though on this and earlier cruises thermometer depth was estimated by the amount of wire out, not by a pressure measurement. The straight lines are linear fits (heavy—all available data, light—station "S" data).*

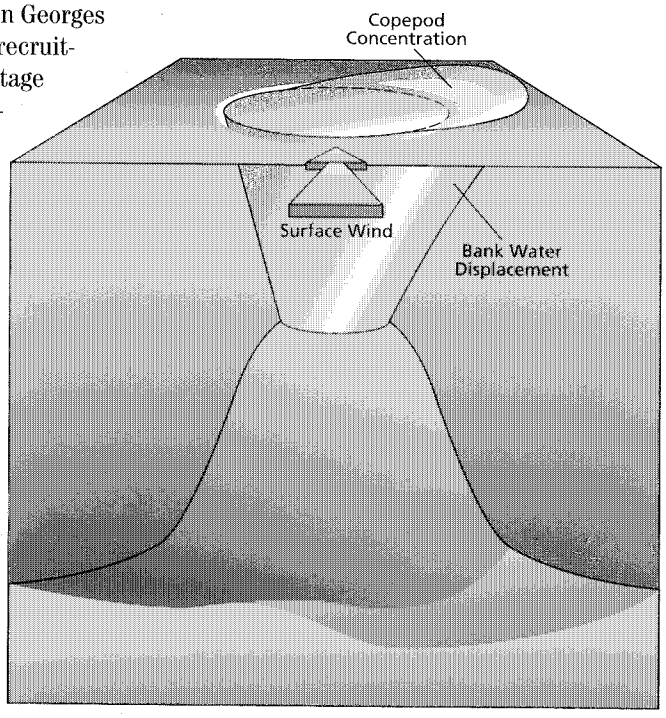
Science Foundation. Other agencies and nations support data-quality experts, whose WOCE data reviews provide assessment of data as they are submitted and valuable feedback to data submitters as problems are identified that can be solved by improved methods or better documentation.

WHP is receiving data from a time-series measurement program begun in 1954 near Bermuda at station "S," and Terry Joyce has added historic hydrographic data that extends to Denmark's 1922 *Dana II* expedition to provide a broad temporal (though limited spatial) picture of long-term hydrographic change in the subtropical gyre of the North Atlantic. (Data from WHOI's 1932, 1938, and 1946 *Atlantis* cruises are also incorporated.) Analyzing these data, Joyce found that the deep water layer from 1,500 to 2,500 decibars (roughly 1,500 to 2,500 meters) warmed at a rate of 0.5°C per century from 1922 to 1990, when WOCE began. However, shallower levels at Bermuda show no consistent trend over the same time period. Though WOCE researchers do not yet know the reasons for this long-term trend at Bermuda, it is clearly a manifestation of long-period changes in ocean climate, whose understanding is WOCE's primary goal. WHP measurements will provide a 1990 to 1997 "snapshot" of the world ocean circulation, but models developed as a result of WOCE promise to bring understanding, perhaps even forecasting, of changes like that at Bermuda station "S," but on a global scale.

Modeling Links Physical Processes and Larval Fish Survival Rates

As part of an effort to understand the potential effects of climate change on oceanic ecosystems, physical oceanographer Glen Gawarkiewicz and biologist Cabell Davis are investigating the physics of wind-driven transport off submarine banks and subsequent effects on cod and haddock population dynamics. Their goals are to understand the complex factors that regulate interannual variability in Georges Bank cod and haddock recruitment (first year larval-stage survival), and to investigate how climate changes might affect recruitment.

Previous work by Cabell Davis suggests that winters with calm winds result in an abundance of the copepods on which larval cod and haddock feed. Therefore, the larval-fish survival rate may be higher in these calm winters. By understanding how submarine-bank currents are affected by wind forcing, the scientists can quantify year-to-year changes in the salinity and temperature of bank water and examine the effect of wind-driven changes on copepod and fish population structure.



The distribution of bank waters (aqua) over the bank surface after 20 days of strong wind forcing. The initial distribution of bank water before wind forcing began was bounded by the dashed line. The depth-integrated abundance of copepods after 20 days are shown in yellow. The copepods initially were concentrated at the center of the bank with a decrease towards the edge of the bank but are carried off the bank with the bank water.

The numerical models they employ incorporate both the physics of flow over the bank and the biological populations' food-chain interactions and life-stage dynamics. Determining wind-driven movement of water off the south flank of Georges Bank involves understanding the effects of wind-forcing on density-driven flows. The persistent currents in this area orient along the bathymetry and are primarily driven by density differences between the low-salinity bank water and more saline slope water just offshore of the bank. The research shows that the combined forces of wind blowing over the bank and Earth's rotation cause near-surface water to be carried off the bank and into the slope water, to the right of the wind-stress direction. When the wind ceases, the density structure readjusts very rapidly (over about 18 hours) and the currents again flow along the bathymetry, with a large pool of near-surface bank water isolated offshore.

The response to wind forcing is asymmetrical in that bank water is driven off the bank on the side to the right of the wind direction, but slope water is carried onto the bank on the side to the left of the wind direction. Further biological modelling (with Joint Program student Craig Lewis) shows that this asymmetry affects the distribution of phytoplankton and copepods over the bank, with substantially reduced abundances on the side of the bank to the left of the wind direction.

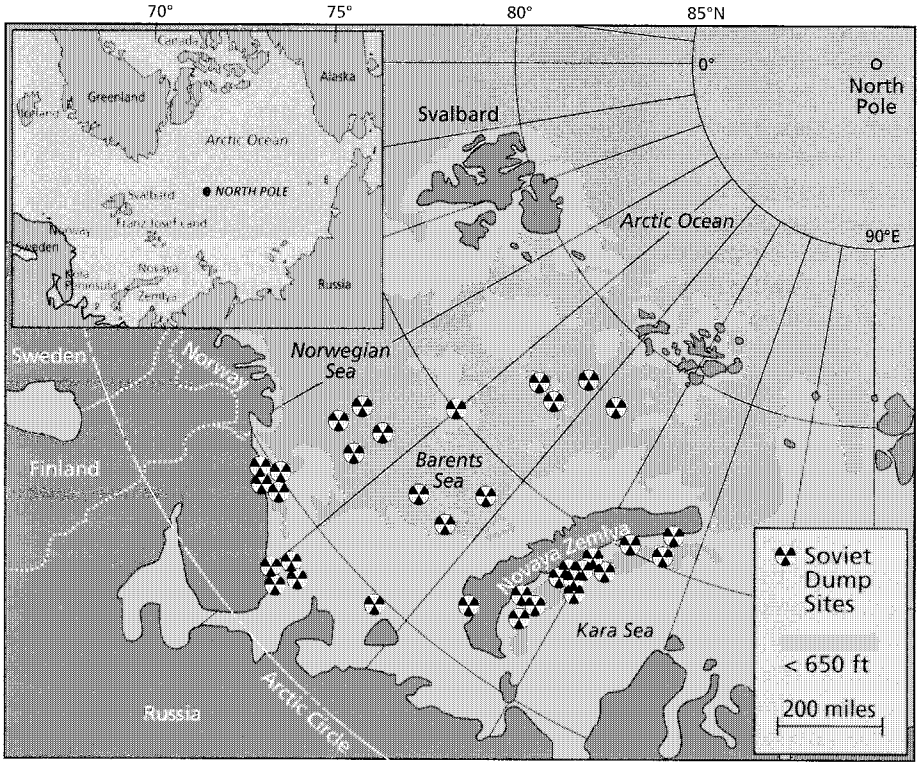
Future work will involve using actual wind fields recorded in various years to determine wind-driven losses from winters of varying storm strength and frequency, and to incorporate more realistic biological interactions into the physical model. The winter of 1993-94, with its record number of winter storms, will be a good one to test!

This work was supported by the GLOBEC (Global Ocean Ecosystem) Initiative jointly supported by the National Science Foundation and the National Oceanic and Atmospheric Administration.

Marine Policy Center

At the Marine Policy Center (MPC), scholars engage in social scientific research to help optimize the management of coastal and marine resources. Their work fosters integration of economics, statistics, policy analysis, law, and technology development with WHOI's basic strengths in the ocean sciences. In 1993, the center made important contributions in areas of public policy concern that include species extinction, recognition of regional and global threats to environmental security, the trend toward increasing military compliance with national and international marine environmental law, and the development of new technologies and international standards for maritime transportation and safety.

Protection of endangered species and the preservation of biological diversity continue to be prominent research and public-policy topics attracting national and international attention. The extinction of rare species is particularly difficult to ascertain, because the rate of sightings prior to extinction is typically constant for chronically small but stable populations. In 1993, MPC statistician Andrew Solow introduced two new methods for inferring extinction from sighting data for such populations, as well as a separate test that is more suitable for declining populations with an elevated risk of extinction. In addition to the applicability of Solow's test to the protection of endangered species, it has surprising relevance for certain problems arising in software reliability.



Approximate locations of nuclear dumpsites used secretly by the Soviet and Russian governments between 1959 and 1992. The radioactivity introduced into this area is estimated to equal roughly twice the amount dumped in the oceans by all other countries combined. Scholars at the WHOI Marine Policy Center argue that uncertainty as to the long-term environmental consequences within the region, coupled with Russia's lack of appropriate technology for managing its backlog of nuclear wastes, constitutes an urgent problem of international environmental security.

A broad range of technical and policy issues is addressed in *The Oceans and Environmental Security: Shared US and Russian Perspectives*, edited by MPC Director James Broadus and MPC Senior Fellow Raphael Vartanov, Head of the Oceans and Environment Section of the Institute for World Economy and International Relations of the Russian Academy of Sciences. Forthcoming in 1994 from Island Press, this multiauthored work promises to be the first in the emerging field of environmental security to offer a concrete working definition, supported by in-depth case studies illustrating how phenomena as diverse as radioactive waste dumping, overfishing of high-seas straddling stocks, and conflicting management philosophies for Antarctica and the Southern Ocean all may threaten to undermine assurances of national well-being or the common interests of the international community. The book's shared US-Russian approach is of particular value, in light of the two countries' positions as the world's foremost maritime presences: They conduct most of the naval operations with potential for degrading the marine environment, control most of the world's maritime shipping capacity, govern the planet's two longest coastlines, and manage the two largest coastal state zones of jurisdiction.

During 1993, the Center's research staff was joined by US Naval Reserve lawyer James Kraska, the first recipient of MPC's Policy Research Fellowship in Naval Oceanography and National Security, sponsored by the Office of Naval Research. Kraska explored the implications of evolving national and international marine environmental law for the Navy's conduct of oceanographic research, given the eroding tradition of special treatment for military facilities and operations and the effort by navies toward greater environmental compliance. A primary focus of Kraska's research was the deployment of expendable marine instruments, which collect data about the water column for use in naval operations, oceanographic and scientific research, commercial ocean industry, and the promotion of safe navigation. Tens of thousands of such devices, having completed data-collection cycles lasting anywhere from several minutes to several years, lie inactive on the ocean floor. International agreements that ban or limit dumping and other modes of pollution appear not to extend to the deployment of such instruments on the high seas. Still, careful consideration is

warranted for the legal status of these deployments under both domestic law and the Law of the Sea Convention, which enters into force in November 1994.

In 1993, the Center also expanded its research into policy questions related to maritime transportation safety and infrastructure. Much of the new work on marine transportation builds on MPC's ongoing research into industrial activity in marine electronic instrumentation. In March, Research Specialist Arthur Gaines and colleagues on the Center's US ECDIS Test Bed Project provided the International Maritime Organization with a detailed evaluation of proposed international performance standards for Electronic Chart and DIsplay Systems (ECDIS), a computer-based technology that is beginning to replace paper charts as the basis of marine navigation. MPC's primary recommendation, that the draft standard was unnecessarily restrictive of technological alternatives, has been affirmed by subsequent developments in the field. MPC Research Associate Hauke Kite-Powell provided support to a National Research Council Marine Board committee investigating the future of NOAA's nautical charting efforts, and MPC Postdoctoral Fellow Di Jin and Kite-Powell prepared a model of optimal risk sharing in marine transportation that can be used to develop liability regimes for hazardous-materials transport. The Marine Policy Center expects to continue to broaden its research activities in maritime transportation.

TERRI CORBETT

Sebastien Morel and Brendan Zinn carry benthic chambers toward the water for Nantucket Harbor Project work. In the background, George Hampson talks with Steve O'Malley.

Coastal Research Center

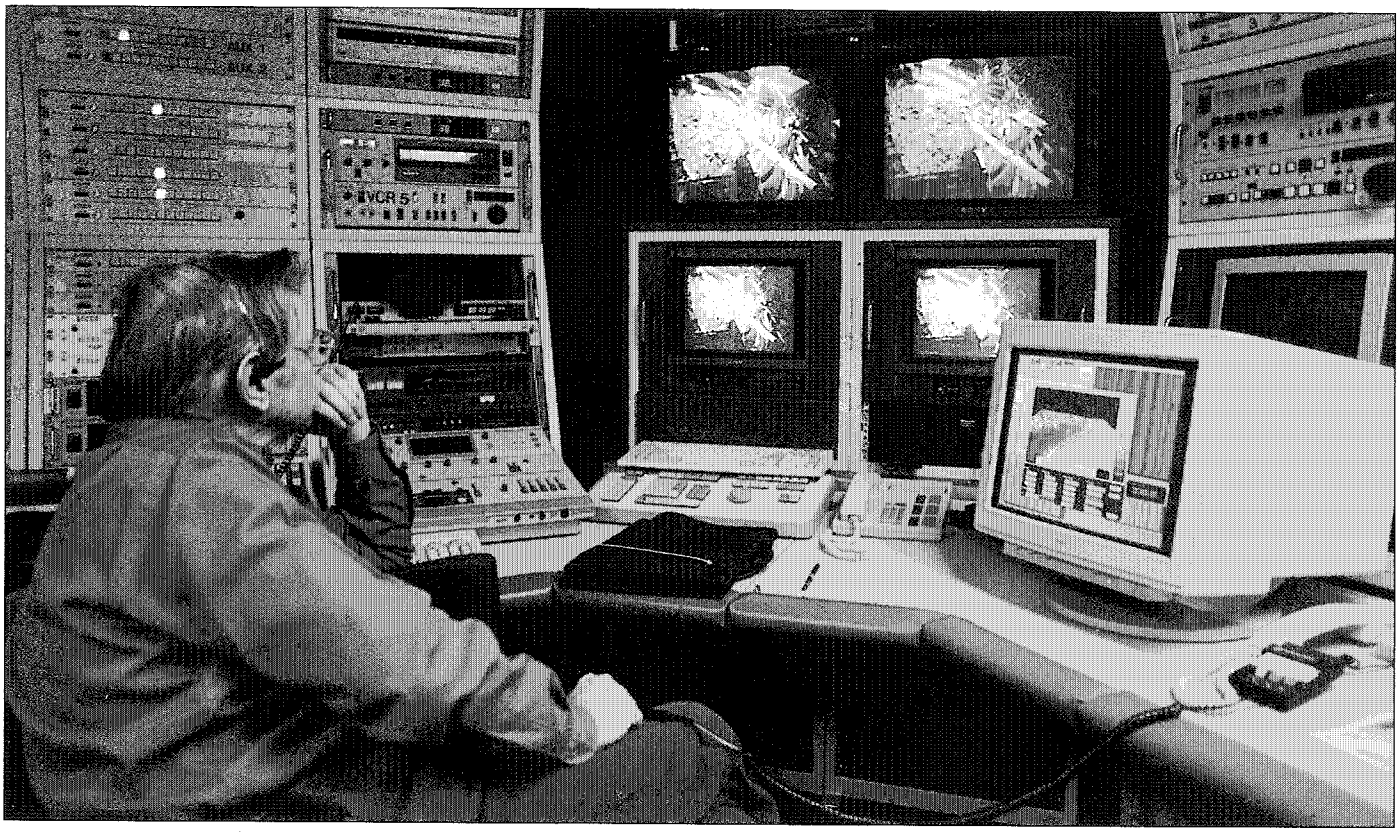
The mission of the Coastal Research Center (CRC) is to encourage and initiate interdisciplinary research on fundamental coastal ocean processes, to communicate the research results to the scientific, resource management, and policy communities as well as to the general public, and to develop the intellectual and technical infrastructure necessary to support advanced research on coastal ocean processes. Foundation and other private funding secured for CRC activities provides a unique source of support for innovative research, rapid response to coastal events, and cost-sharing to leverage other funding sources.

In 1993, CRC received a $900,000 challenge grant from the Andrew W. Mellon Foundation to be spent over the next six years. During the lifetime of this grant, WHOI intends to raise funds to permanently endow coastal research at this level. Continuing CRC support has also been provided by Mobil Corp. and Exxon Corp.

In 1993, CRC supported small projects on sediment transport and nutrient cycling during the Mississippi River flood, investigation of new chemical tracer methodology in the Gulf of Maine, a retrospective assessment of the past two decades of salt-marsh research in Great Sippiwissett Marsh, and partial support of innovative coastal measurement techniques. In addition, CRC committed to cost share in WHOI Sea Grant proposals related to coastal processes, and to partial support of a new postdoctoral scholar in environmental biogeochemistry and a student thesis research project. CRC staff also compiled and shared with the research community a list of instruments available for loan from WHOI laboratories, and a database of Gulf of Maine research vessels available for charter was created in response to Georges Bank and Gulf of Maine research needs.

CRC's 1993 Gulf of Maine activities included coordination of a WHOI planning response to the NSF-NOAA Global Ocean Ecosystems Dynamics (GLOBEC) Northwest Atlantic/George's Bank program. The center will provide continuing support when GLOBEC fieldwork begins in 1994. As the WHOI link to the Regional Association for Research of the Gulf of Maine (RARGOM), CRC sponsored participation in several activities including a coastal modeling workshop and a data management workshop.

The International Mussel Watch coastal monitoring program is based at



TERRI CORBETT

Microbiologist Holger Jannasch, in the WHOI "Black Room," views live images being relayed by satellite from the cameras of the remotely operated vehicle Jason *being flown above hydrothermal vents on the ocean floor in the Sea of Cortez nearly 4,000 miles away during the 1993 JASON Project.*

CRC. In 1993, the initial phase of this program, focusing on field sampling and analysis of tissue samples for chlorinated hydrocarbon biocides, was completed. A total of 370 samples were collected at 125 stations along the Atlantic and Pacific coastlines of Central and South America. Results from chemical analyses of these samples, done by collaborating laboratories in Texas and Monaco, will provide a unique overview of coastal contamination in this area. The International Mussel Watch now moves to the second sampling phase, in the Asia-Pacific region, while continuing to provide some technical support to its network of Latin American scientists.

CRC regional outreach in 1993 included:

- serving in an advisory capacity to the Waquoit Bay National Estuarine Research Reserve, the Buzzards Bay Action Committee, and the Barnstable County Coastal Resources Committee;
- cosponsoring, with WHOI Sea Grant, a forum on salt-marsh loss due to construction of structures intended to protect coastal properties from erosion;
- participating in a variety of ways in the public discussion concerning the new Boston ocean sewer outfall; and
- collaborating with WHOI Sea Grant and the US Geological Survey to initiate "Coastal Briefs," network electronic publication of a series of summary papers on coastal topics of general interest.

Center for Marine Exploration

In 1993 the Center for Marine Exploration completed *Argo/Jason* system development and conducted a major expedition to the Sea of Cortez that fully utilized the system's capability.

When *Argo/Jason* development began in 1982, the goal was to develop a remotely operated vehicle system that would revolutionize the way scientists explored the deep seafloor. Using a fiber-optic cable, they would be able to carry out their work to a depth of 6,000 meters without having to actually make the daily journey to the ocean floor.

In the past, a submersible dive, to 3,800 meters, the average depth of the ocean, took two hours each way, with less than four hours actually spent working on the bottom and only one or two miles explored. In contrast, the remotely operated *Argo/Jason* system was designed to remain on the bottom for long periods rather than returning to the surface each day, greatly increasing the amount of work that could be carried out on an expedition.

Another objective was to operate *Jason* but to permit scientists to participate in the expedition from their home laboratories. This objective was achieved in March 1993 during a cruise to Guaymas Basin within the Sea of Cortez. Using advanced telecommunications technology, the images and data collected by *Jason* and displayed in its control center aboard ship were also transmitted to a similar control center at Woods Hole, where scientists could supervise experiments and review the data being collected by *Jason* in real time. Their colleagues at other institutions in the US, Bermuda, Canada, and Great Britain also participated in the expedition using similar satellite downlink sites. In addition,

through a pilot project coordinated by Andrew Maffei of the WHOI Information Systems Center, *Jason* data was placed on Internet, permitting scientists, students, and teachers around the world to monitor the research program being carried out aboard ship. At several of the sites, individuals were able to assume control of *Jason* through the satellite link and drive around a series of active hydrothermal vents in over 2,500 meters of water.

Guaymas Basin images were transmitted to 28 JASON Project sites between March 1 and 13, 1993. Nearly 10,000 southeastern Massachusetts students and teachers participated at the Bridgewater State College (BSC) site sponsored jointly by BSC and WHOI. The Institution loaned equipment and provided technical assistance as well as staff support. Senior Scientist Robert Ballard hosted the JASON Project broadcasts, and nearly a dozen Deep Submergence Laboratory staff and other scientists and engineers participated in the expedition.

LUCIANO MARTIN

Sea Grant volunteers gather in Falmouth, Massachusetts, to stencil the message "Don't Dump" on storm drains. To date, the annual event has covered more than 300 storm drains. WHOI Sea Grant staff members Tracey Crago (with sheaf of papers) and Sheri DeRosa (striped shorts) organized the group.

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. It is part of the National Sea Grant College Program of the National Oceanic and Atmospheric Administration (NOAA), a network of 30 individual programs located in each of the coastal and Great Lakes states to foster cooperation among government, academic institutions, and industry. WHOI Sea Grant-supported projects provide linkages between basic and applied research and communication between the scientific community and groups that utilize marine environment and resource information.

In 1993 WHOI Sea Grant supported 15 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. Some examples of currently funded projects include:

- a study of public perception of flood risks in coastal areas,
- development of an ecosystem-based, water-quality management plan for Nantucket Harbor,
- the use of protozoan prey for feeding winter-flounder larvae during their early developmental stages, and
- development of a novel assay system using cultured cells for analysis of chemical contamination of marine resources.

Sea Grant supports three ongoing research projects in Massachusetts and Cape Cod bays concerning the Boston Harbor Outfall Project. They focus on red-tide bloom dynamics, the effect changing nitrogen inputs or changing sewage treatment strategies will have on coastal-water nitrogen budgets and food-chain dynamics, and the rate of vertical mixing across the thermocline in Massachusetts Bay.

Communication and outreach activities include:

- the expansion of "Shorewatch", a cable television series presented on 22 Massachusetts stations and one California station, reaching over one million potential viewers;
- organizing beach cleanups, storm-drain painting projects, and guided beach and coastal walks;
- completion of a database cataloging hundreds of reference materials; and
- distribution of an activity booklet that presents facts and illustrations on various topics in oceanography and field guides to coastal ecosystems.

"All-Cape Coastal Science Seminar" topics included salt marshes and rising seas, coastal dune management, and coastal-bank erosion. The popular "Oceans Alive" lecture series, designed for the general public, featured presentations on marine education, high-school science-fair projects, clam farming on Cape Cod, marine biotoxins and red tides, the geology of Cape Cod, and songs and poetry of the sea.

25th Anniversary of the


L. BARRY HEATHERINGTON

This was a year of celebration for the WHOI Education Programs in honor of the 25th anniversary of the MIT-WHOI Joint Program in Oceanography and Applied Ocean Sciences and Engineering. On May 8, 1968, the late Paul M. Fye, WHOI President and Director, and MIT President Howard W. Johnson signed a one and one-half page Memorandum of Understanding that launched the MIT-WHOI Joint Program. In essence, it was an agreement that each institution would do its best to make the program a success. Twenty-five years later the spirit of


L. BARRY HEATHERINGTON

cooperation continues at both institutions, and the high quality of the alumni/ae and current students is evident. A total of 388 degrees have been awarded to 364 graduates, and 145 students were enrolled in the 1993-94 academic year. Graduates' accomplishments attest to the wisdom and foresight of those who launched the Joint Program.

Considering that the recipients of Joint Program degrees are now distributed worldwide, we were very pleased that 85 alumni and alumnae, almost 25 percent of the degree recipients, attended the October 1 to 3, 1993, celebration weekend at MIT and WHOI. More than 250 faculty, staff, trustees, current students, and alumni/ae attended a cocktail reception and dinner at the Museum of Science in Boston that MIT Joint Program Director Sallie Chisholm and I hosted jointly. Greetings from MIT were extended by Provost Mark Wrighton and from WHOI by Acting Director Bob Gagosian. Among those attending were former MIT President and original memorandum signator Howard Johnson, Chairman of the WHOI Board of Trustees Guy Nichols and WHOI Trustees Education Committee Chair Lilli Hornig. The 1966 Trustees Education Committee that recommended establishment of the Joint Program was represented by Honorary WHOI Trustee Arnold Arons along with current Education Committee member Cecily Selby, whose husband, James S. "Spike" Coles was also a member of the 1966 Committee.

A Saturday morning symposium entitled "Alumni/ae Perspectives on the Field of Oceanography and Oceanographic Engineering" was held at MIT and chaired by 1977 graduate Susan Humphris. It was followed by a luncheon at the MIT Faculty Club and an address on "Environmental Stewardship and Sustainable Development" by the Honorable D. James Baker, Under Secretary for Oceans and Atmosphere, US Department of Commerce and Administrator of the National Oceanic and Atmospheric Administration.

Following one of the Joint Program student mottos, "We Commute," the participants then travelled the familiar roads between Cambridge and Woods Hole by bus and auto for a late Saturday afternoon Alumni/ae Association formation meeting at WHOI. Retiring WHOI Geologist and Senior Scientist Elazar Uchupi received a special tribute from 1979 alumnus Jamie Austin on behalf of students Uchupi has taught and mentored over the years.

We were especially pleased to have Honorary WHOI Trustee Ruth Fye attend a special presentation of Ruth and Paul Fye Awards for Excellence in Research, which recognize the best student papers. The Fye award was established upon Paul Fye's retirement as WHOI President and Director to honor his role as a principal force in the Joint Program's establishment and the couple's dedication to the Joint Program. The WHOI Educational Council voted to present five Ruth and Paul Fye Awards for the 25th anniversary celebration, one in each of the Joint Program curricula areas. They are Carol Arnosti (chemical oceanography), Marjorie Friedrichs (physical oceanography), Erik Hauri (geology and geophysics), Ee Lin Lim (biological oceanogra-


JOINT PROGRAM ALUMNI/AE

phy), and John Van Gurley (applied ocean sciences and engineering).

Festivities then moved to a large tent, where a clambake attracted 265 alumni/ae, faculty, staff, students, and guests. The closing event of the weekend was a Sunday morning brunch where alumni/ae shared experiences with current students. The 25th anniversary celebration had attributes of the most important aspects of the Joint Program: lively intellectual exchange and debate, informal gatherings to share experiences, and a touch of formality at the appropriate times.

JOINT PROGRAM ALUMNI/AE

JOINT PROGRAM ALUMNI/AE

Facing page: (top photo) Bob and Susan Gagosian with former MIT President Howard Johnson at the Museum of Science dinner. (middle) Arnold and Jean Arons at the Museum of Science. (bottom) Peter and Gail Dahl and Rob Fricke's daughter clown with clambake lobsters.
This page: (top photo) Ruth and Paul Fye award winner Ee Lin Lim, left, poses with Ruth Fye, Penny Chisholm, and John Farrington. (left) Doug Biggs, left, and Ken MacDonald at the Saturday morning symposium at MIT. (below) Cindy Van Dover and Sarah Little. (bottom) Bob Young, Brian Tucholke, Rick Burroughs, and Wilf Gardner at the clambake.

JOINT PROGRAM ALUMNI/AE

JOINT PROGRAM ALUMNI/AE

Current Joint Program

The MIT-WHOI Joint Program continues to attract excellent applicants. There were 192 applicants for the 1993-94 entering class, an increase of 14 percent over the previous year and up 34 percent over four years. We offered admission to 40 applicants and a commendable 83 percent accepted. The alumni/ae ranks grew with the awarding of 26 degrees, which are listed on page 41 (note that two people remained in the program, and one person received 2 degrees).

During the summer, WHOI Director and 1972 Joint Program graduate Craig Dorman said goodbye to WHOI for the second time in his life. Dorman was very supportive of the graduate students, the MIT-WHOI Joint Program, and all WHOI education programs. During his term as Director, the quality of student life in Woods Hole improved significantly with the 1989 completion of new Oyster Pond Road housing and the completion of the student lounge in Clark South. In addition, Dorman inaugurated the introductory cruise for new Joint Program graduate students. These cruises (1993's was the fourth), aboard Sea Education Association vessels SSV *Corwith Cramer* or SSV *Westward*, continue to be a rousing success as they introduce incoming students to one another and to oceanography at sea. It is difficult to capture in words the genuine interest that Craig and his wife Cynthia brought to the students and the warmth of the student response, but I hope the following vignette captures this spirit:

Craig relished telling incoming students that life in the Joint Program had improved since the time over 20 years ago when he, Cynthia, and their family camped in a tent for summer housing. Few opportunities passed in student gatherings without Craig recounting some version or other of this story. It was appropriate, then, that late one evening a few days before Craig and Cynthia departed, several students (demonstrating the continuing ingenuity of Joint Program students for having fun) sneaked onto the lawn in front of the Director's house and set up tents to camp for the night. In the morning, Craig's surprise was complete. Now Craig has another Joint Program story to tell!

Postdoctoral Scholar Program

Active for over 30 years, this program's excellence was recognized by a challenge grant from the Henry L. and Grace Doherty Foundation, Inc., and the Devonshire Associates, under the leadership of WHOI Trustee Weston "Dusty" Howland, substantially increased their annual Postdoctoral Program support. These gifts will allow us to increase the postdoctoral award period from one year to eighteen months, beginning with the 1994 awards.

The 1993 Postdoctoral Scholar applicant pool was of the usual high quality. The 10 award recipients (see list on page 43) bring outstanding qualifications to the Institution and enrich the intellectual vitality and expertise of the Woods Hole scientific community.

Geophysical Fluid Dynamics Summer Study Institute

Each summer for the past 35 years, this program has gathered an eclectic and stimulating group of scholars from around the world for a series of seminars and informal discussions at WHOI. This year 10 fellows and 40 other participants from 15 countries carried on the tradition, focusing on "Geometric Methods in Fluid Dynamics" under the leadership of Rick Salmon of the Scripps Institution of Oceanography.

Summer Student Fellowship Program

Twenty-five undergraduates from twenty-four colleges and universities, most between their junior and senior year, participated in the thirty-fifth summer student fellow year. This program of individual research projects introduces the students to hands-on research and to the breadth of oceanographic and ocean-engineering research through special seminars by WHOI Scientific and Technical Staff. Much appreciated support from endowments and continuing annual gifts by private supporters provided funding for 15 fellowships. This year we received a three-year grant from the National Science Foundation Research Experience for Undergraduates Program renewing their support of the Summer Student Fellowship Program. Along with support for 10 fellows in 1993, 1994, and 1995, we also received support for special "Ethics in Science" Summer Student Fellows seminars and discussion sessions intended to enhance understanding of the importance of responsible conduct of research. Two undergraduate *Minority Trainees* participated in the undergraduate summer activities, joining a distinguished group of 38 previous minority trainees who have come to WHOI since 1978 for undergraduate research experience.

Degree Statistics

		1993	1968-93
WHOI	PhD	0	3
MIT/WHOI	PhD	17	263
MIT/WHOI	ScD	2	28
MIT/WHOI	Engineer	4	*44
MIT/WHOI	SM	6	*50
		29*	388
Total Degree Recipients		28	**376
Total Graduates		26	365

*Some receive more than one degree
**11 with interim degrees

High School Science Teacher Fellowships.

A new feature of the NSF grant is support for four high school teachers to experience laboratory research at WHOI. The teachers chosen for the 1993 summer fellowships, their general research topics, and their advisors are listed below. This effort is part of a more than 20-year WHOI effort to support *K-12 science, mathematics, and technology* education locally, regionally, and nationally. Another example is continuing involvement in the JASON Foundation for Education telepresence programs led by Senior Scientist Robert Ballard. This year the Institution co-sponsored the Southeastern Massachusetts downlink site for the program from Baja California and the Sea of Cortez with Bridgewater State College. Transfer of the downlink site and co-sponsorship with Bridgewater State College brings the strengths of both WHOI and Bridgewater State to interactions with teachers and students in the classroom curriculum portion of the program.

We also continue our work with the Woods Hole Science and Technology Education Partnership and its involvement with the Massachusetts statewide systemic change in K-12 science and math education known as project PALMS (Partnerships to Advance Learning in Mathematics and Science). WHOI is cooperating in a five-year NSF Grant awarded to the University of Massachusetts, Dartmouth, for "The Buzzards Bay Rim" project designed to enhance the sciences for elementary grade teachers in the Southeastern Massachusetts region.

In addition WHOI continues to support Falmouth public schools and Falmouth Academy science fairs. I am particularly pleased to report that this year the Falmouth Academy Science Fair first-place prize has been named the "A. Lawrence Peirson III Prize" in honor of Associate Dean and Registrar Jake Peirson's long-standing dedication to both WHOI and Falmouth Academy.

It is an honor and pleasure to be associated with such a fine group of students, postdoctoral scholars, alumni/ae, faculty and staff.

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

High School Science Teacher Fellowships

George Hussey – Falmouth High School, Chemistry & Earth Sciences Teacher. *WHOI Advisor:* William Curry, Geology & Geophysics Department. *Topic:* Paleoceanography

Valerie Bell – Nauset Regional High School, Biology Teacher. *WHOI Advisor:* Larry Madin, Biology Department. *Topic:* Biology of Open-Ocean Organisms

George Goodfellow – New Bedford High School, Chemistry Teacher. *WHOI Advisor:* Robert Schneider, Geology & Geophysics Department. *Topic:* Accelerator Mass Spectrometer Measurements in Relation to Global Climate Change

Pam Sterling – Plymouth South High School, Science and English Special Needs Teacher. *WHOI Advisors:* Judith McDowell and George Hampson, Biology Department. *Topic:* Coastal Pollution/Ecology

The search for a new Director began when Craig Dorman announced May 18 that he would step down August 1 as the Institution's sixth Director after serving more than four and a half years in the post.

Senior Associate Director and Director of Research Robert Gagosian was named Acting Director effective August 1, and Senior Scientist Fred Sayles of the Marine Chemistry and Geochemistry Department became Acting Associate Director of Research effective September 1.

An eight-member Director search committee, half from the scientific staff and half representing the Trustees and Corporation, was formed in June. It was chaired by MIT Professor and Nobel Laureate Robert Solow. An extensive search and interview process eventually focused on one of our own, and Bob Gagosian was named Director at the Trustees' January 1994 meeting.

TERRI CORBETT

A padlock and key were among the farewell gifts presented to the Dormans.

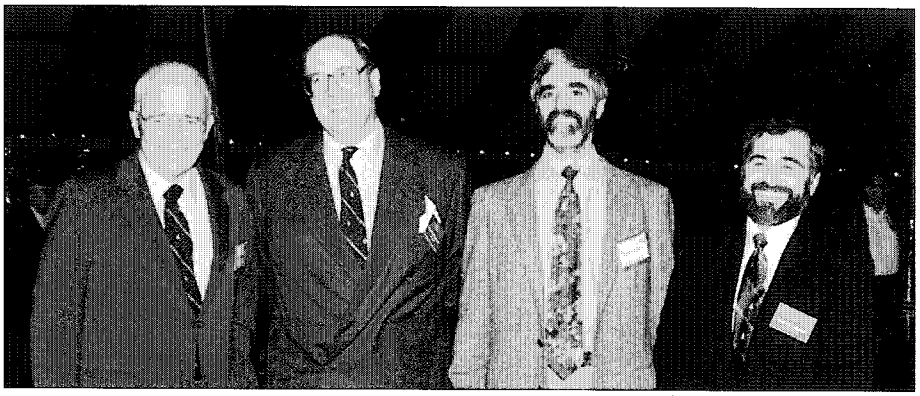
Several hundred members of the WHOI community gathered on the Iselin Mall July 23 to wish Craig and Cynthia Dorman well and to thank them for their contributions to the Institution. The many presentations included a framed pastel watercolor of the Meteor House view toward Little Harbor by local artist Jan Selman, a photo album, and a lifetime Associates membership. Cynthia received a 101-recipe cookbook from the WHOI community in appreciation of her culinary skills, and Craig was presented a drawing and description of a new aplacophoran (unusual, spiky mollusc) species, *Falcidens dormani*, named for him by biologists Rudolf and Amélie Scheltema.

Transferring WHOI technology to the public sector is the goal of the Quissett Development Corporation (QDC) and Office of Commercial Affairs (OCA), established in February by Director Dorman. QDC's purpose is to form partnerships with commercial entities and return unrestricted income to WHOI. QDC can issue license agreements with companies to manufacture a product developed at WHOI, seek venture capital, and help establish spinoff companies. Associate Director for Institution Operations Lawrence Ladd is President of QDC, and Facilities Manager William McKeon is Vice President and General Manager. OCA, headed by McKeon, is intended to identify and protect the Institution's intellectual property, such as computer software, inventions, and processes. OCA also deals with patents, copyrights, and trademarks.

DAVE GRAY

The farewell party for Craig and Cynthia Dorman drew a large crowd to the Iselin Mall in July.

A Continuous Improvement Council (CIC) chaired by Larry Ladd was formed early in the year to focus on ways to improve the quality and cost effectiveness of the Institution's support processes. CIC is charged with creating a support climate that "is flexible, collaborative and responsive to the changes and needs of



DAVE GRAY

From left, Guy Nichols, John Bockstoce, Ernie Charette, and Bob Gagosian were speakers at the gala Capital Campaign Kickoff in October.

the ocean sciences and education community." In March, CIC named travel and procurement process improvement teams. An immediate result of their early June recommendations was a change in the travel-authorization process.

CIC chartered an Improvement Implementation Team (IIT) in July to "recommend fundamental improvements in business services quickly with no increase in overhead." The II Team was also asked to recommend ways the Institution could take advantage of new business hardware and software systems that will replace ROSS, the Institution's current administrative and financial system. All sectors of the Institution were engaged during 1993 in extensive discussions and careful analysis of requirements for the new system.

A new ad hoc Task Force on Total Compensation met for the first time in April following several months of planning. The group was asked to analyze and evaluate the Institution's current total compensation package, with a focus on benefits, and to submit recommendations to the Director by July 1, 1994.

TOM KLEINDINST

Charles Adams displays the Cecil Green Award for outstanding contributions to oceanography he received during June annual meeting activities. Associates President Charles Dana applauds.

Trustees and Corporation Members voted in January to honor the late physical oceanographer Henry M. Stommel by establishing and striking a medal to be awarded to individuals who have made "fundamental and enduring contributions to observing and understanding ocean processes." In October the selection committee announced the first recipient of the Henry Stommel Medal in Oceanography, British oceanographer John Swallow, who received the medal in February 1994.

At the June annual meetings of the Trustees and Corporation, members decided to have two Joint Meetings (spring and fall), and the Trustees will gather for a third time in winter. Charles Adams, former chairman of the WHOI Board of Trustees and former chairman of the board of Raytheon Company, received the Cecil Green Award for outstanding contributions to oceanography June 18 during annual meeting activities. The award, a crystal engraved with the WHOI logo and a plaque, was presented by Associates President Charles Dana, who noted Adams's long relationship with and many contributions to WHOI.

Honorary Trustee and Member of the Corporation John Sawyer was presented the first Chairman's Award October 15 during the Fall Joint Meeting of the Trustees and Corporation "for his extraordinary dedication, enthusiasm, wisdom, stewardship, and sustained generosity of spirit which have marked his 20 years of service" to the Institution.

Honorary Trustee and Corporation Member Jerome Wiesner, president emeritus of MIT, received the National Academy of Sciences Public Welfare Medal "for his devoted and successful efforts in science policy, education, and nuclear disarmament and world peace." Corporation Member Frank Press, a two-term president of the National Academy of Sciences, was awarded The Japan Prize for his work in advancing scientific understanding of earthquakes and for encouraging international cooperation in reducing damage caused by natural disasters. The award is Japan's highest honor for achievement in science and technology.

New occupants for two of the Institution's permanently endowed chairs were officially announced at the Trustee and Corporation meetings June 18. Physical oceanographer Robert Weller was awarded the Henry Bryant Bigelow Chair for Excellence in Oceanography for his research in air-sea interaction, and biologist Donald Anderson was named to the Stanley W. Watson Chair for Excellence in Oceanography for his red-tide research. The recipients' commitment to long-term development of science at the Institution and a record of scientific excellence and potential are among the award criteria. The five-year chair awards provide up to six months of salary support annually.

Senior Scientist Robert Ballard received two honorary Doctor of Science degrees in spring commencement exercises, one from Bridgewater State College, where he gave the commencement address, and the other from Lehigh University. Senior Scientist Holger Jannasch was elected a Fellow of the American Academy of Microbiology. Research Associate Bruce Tripp received the 1993 Buzzards Bay Guardian Award from the Coalition for Buzzards Bay "for outstanding service in the stewardship of this magnificent estuary."

TOM KLEINDINST

Senior Research Specialist Hugh Livingston, center, with glasses, was one of the convenors of the first international conference on radioactivity and environmental security in the oceans, held in Woods Hole in June 1993.

After 15 years at the helm, Senior Scientist David A. Ross stepped down as Director of the WHOI Sea Grant program August 1. He was succeeded by Senior Scientist Judith E. McDowell. Ross was honored for his contributions at a Bell House gathering.

The Institution's first Manager of Government Regulations, Donna Weatherston, began her new duties September 20. Weatherston will manage the Institution's compliance with federal regulations and established WHOI financial policies, including coordinating

TOM KLEINDINST

John Sawyer, seated, was presented the first Chairman's Award at the fall Trustees and Corporation meeting for his extraordinary service to the Institution.

all government audit activity.

Patricia Pasanen of the Marine Department received her master's license in September, making her the first woman at WHOI to achieve a captain's rank.

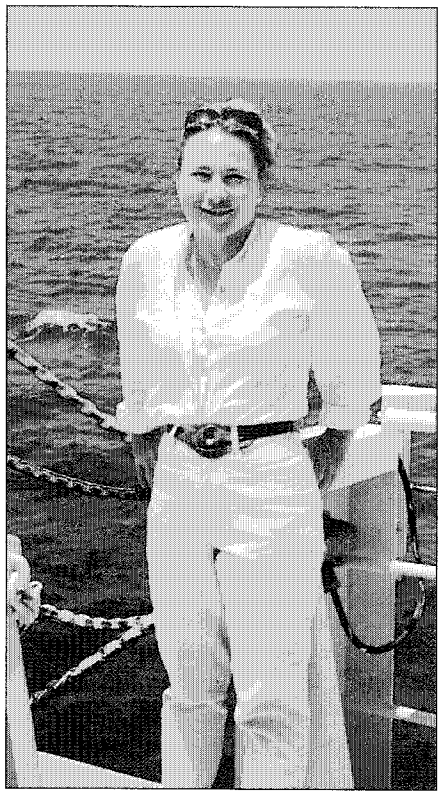
Ellen Gately of the Marine Policy Center received the first annual Educational Scholarship from the Women's Committee. The $300 award was provided by an anonymous donor and is intended to supplement the WHOI Employee Education Assistance Program.

The National Ocean Sciences Accelerator Mass Spectrometry (AMS) facility at WHOI set a record when it demonstrated the highest level of precision achieved to date under normal operating conditions by any of the seven AMS facilities in the world. The world's first "routine" high-precision radiocarbon analyses were conducted on 13 water samples collected in the Canadian Basin. The findings were reported by AMS Director Glenn A. Jones at the Sixth International AMS Conference in October in Australia.

Nearly 120 representatives from 10 nations gathered in Woods Hole in June to attend the first international conference on "Radioactivity and Environmental Security in the Oceans: New Research and Policy Priorities in the Arctic and North Atlantic." Twenty-four Russians, members of the Russian Academy of Sciences and other scientists and government officials, were among those attending, the largest contingent of Russians to participate in an international conference on the subject. Institution scientists participated in a month-long cruise in July aboard the Russian research vessel *Keldysh* to continue monitoring the sunken Russian nuclear submarine *Komsomolets* off Norway.

"Cigarette Smoke and Radon" by Falmouth High School junior Margaret Bothner was awarded the overall prize, a $1,500 college scholarship from WHOI, at the 15th annual science fair March 13 at Falmouth High School. The Institution also sponsored a $500 college scholarship, two subscriptions to *Oceanus* magazine, and a cruise aboard the coastal vessel *Asterias* to winners at the Falmouth Academy Science Fair March 19.

Several hundred attended the annual summer picnic August 14. Pony rides, face painting, games, and music were enjoyed under sunny skies on the Joseph V. McKee, Jr., Ball Field. The holiday party December 18 at MBL's Swope Center attracted more than 175.



CARL SWANSON

In 1993, marine crew member Patricia Pasanen, shown here aboard Atlantis II, *became the first WHOI woman to earn a master's license.*

The Institution continued its 20-year tradition of donating proceeds from the summer use of the Dyer's Dock parking lot to local organizations. This year $1,000 was awarded to the Woods Hole Foundation and $1,200 to the Falmouth Public Schools. The lot is made available to the Woods Hole Business Association nights and weekends during the summer months, with the proceeds after expenses returned to WHOI.

As part of the expanding information superhighway, WHOI created its own Gopher Internet server to provide access to information throughout the world. Numerous groups within the Institution are using the Gopher server to share information electronically.

Volunteers working in various capacities throughout the Institution contributed more than 2,800 hours of their time to WHOI between October 1992 and October 1993. Each was presented a token of appreciation at the annual Volunteer Luncheon October 13 in Clark 507. The Volunteer Program has been in place since 1985.

Some 75 attended the International Committee's reception November 16 at Carriage House. Guests included international visitors and their WHOI sponsors, students, community helpers, and English tutors. Other International Committee activities during the year included a tax-preparation workshop, a Director's reception, and bi-weekly café gatherings.

"Climate Change: A View from the Ocean" was the theme of the annual Associates Day of Science September 17. Some 225 attended the afternoon lectures in Clark 507 and the reception under a tent on the Fenno House lawn, where displays and poster sessions on climate change research and other topics attracted considerable interest.

More than 600 employees, students, Trustees and Corporation Members, volunteers, and other guests attended the official opening of the Institution's $50 million Capital Campaign October 14. The atmosphere was festive as the crowd enjoyed a buffet and dancing under a tent on the Joseph V. McKee, Jr., Ball Field. Chairman of the Board Guy Nichols, Campaign Chairman John Bockstoce, Acting Director Robert Gagosian, and Assistant Facilities Manager and member of the Employee Capital Campaign Committee Ernest Charette were among the speakers at a brief program announcing that $22 million, more than 40 percent, of the campaign goal had been committed. Special donations from members of the Trustee Capital Campaign Committee supported the celebration. The campaign, which will run through 1996, is the largest ever undertaken by WHOI. A 14-member Employee Capital Campaign Committee was formed in late summer to involve the staff in the campaign.

The Trustees and Members of the Corporation continue to work hard at raising matching dollars for two major challenge grants. The largest, a $3.5 million Penzance Foundation Challenge, will endow support for Assistant Scientists. The grant is to be matched in $700,000 increments over five years. The first segment was completed

successfully in 1993. A two-for-one challenge from the Henry L. and Grace Doherty Charitable Foundation, Inc. will create WHOI's first ever endowed postdoctoral scholarship. Half of the total $1.2 million has been raised.

Deep Submergence Vehicle *Alvin* completed a five-month overhaul in February and was certified to dive March 16. After several months in lay-up status, Research Vessel *Atlantis II* returned to service in March with *Alvin* dives off Bermuda, followed by geological studies on the Mid-Atlantic Ridge and exploration of a new hydrothermal vent field near the Azores. The vessels departed Woods Hole July 29 for an extended voyage in the Pacific Ocean.

Research Vessel *Knorr* returned home August 11 after a 17-month absence. The ship departed Woods Hole March 22, 1992, and traveled some 58,000 miles, working mostly in the South Pacific for the World Ocean Circulation Experiment (WOCE). *Knorr* spent the remainder of 1993 working in the North Atlantic, with a year-end port call at Jacksonville, FL, for scheduled maintenance and the installation of a Sea Beam mapping system.

Research Vessel *Oceanus* departed Woods Hole November 1 for Atlantic Drydock in Jacksonville, FL, to begin a scheduled mid-life overhaul. An expanded pilot house and additional laboratory space are among the upgrades included in the $3 million project.

The 65-foot motor yacht *Eagle Mar*, donated to WHOI in July 1990 by Edward W. Scripps II, was sold late in the year to a Wisconsin firm for use as a charter vessel.

In August, representatives of the Naval Sea Systems Command briefed WHOI staff on plans for *AGOR-25*, a new 274-foot ship expected to be delivered to Woods Hole in 1997. (AGOR stands for Auxiliary General Purpose Oceanographic Research Vessel. The ship has not yet been named.) An unexpected budget cut late in the year deleted funds for the ship, but Congress later restored its funding.

In accordance with a plan for fleet replacement that includes the recent *Knorr* upgrade and acquisition of *AGOR-25*, the Institution announced plans to sell the 30-year-old *Atlantis II* and use the proceeds to convert *Knorr to* a deep-submergence platform. Base asking price for *Atlantis II* is $1.75 million.

A bit of Institution history disappeared when the attic water tanks in Bigelow Laboratory were removed during the fall to make room for badly needed office space. The gravity-fed concrete tanks had been in use since the building was constructed in 1930 and helped supply water to the Redfield wet lab. A new pump was installed to provide water to Redfield.

One of the largest events of the year, the Employee Recognition Celebration, attracted 450 employees and retirees September 20 to a tent on the Fenno House lawn. The fifth annual such event honored 49 employees with more than 10, 20, 30, and 40 years of accrued service. The 10-year service recipients received a pin, those with 20 years of service received a Seth Thomas schooner desk clock, and the 30-year honorees had a choice of a Nichols & Stone WHOI armchair or rocker. The two 40-year service recipients, William Dunkle, Jr., and Paul Howland, were presented lifetime Associates memberships, engraved pewter bowls, and personal

TOM KLEINDINST

Activities planned around the Associates 1993 June dinner included a visit to the Exhibit Center.

gifts. They join 420 long-service employees who have been honored in the past four years.

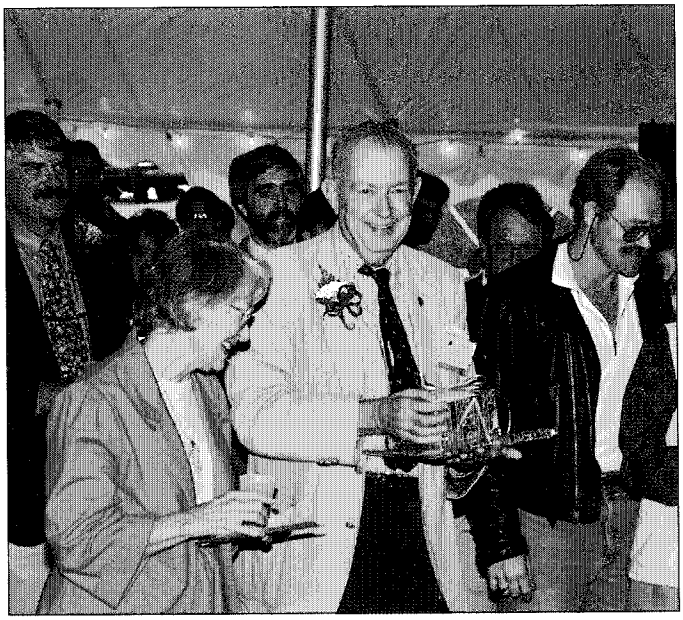
A highlight of the festivities was presentation of plaques and checks to the 1993 Vetlesen, Penzance, and Linda Morse-Porteous awards recipients. Food Services Coordinator Sheila T. Payne received this year's Vetlesen Award "for exceptional contributions not merely above and beyond superb performance of their jobs and service on committees, but for true selfless dedication of a major portion of themselves to the entire WHOI community over a long period of time."

The Penzance Award went to the Facilities Services Group, Frederick Brown, Jeffrey Clemishaw, Robert Greene, Napoleon McCall, Jr., Jay Murphy, Lewis Saffron, and Carlos Velez, for "sustained exceptional performance, for outstanding representation of the WHOI spirit and for major contributions to the personal and professional lives of our staff."

Research Associate Dale Goehringer of the Biology Department received the Linda Morse-Porteous Award, presented on behalf of the Women's Committee to a female technician on the technical or graded staff who has consistently demonstrated leadership, dedication to and quality of work, service as a role model and/or mentor to junior women, and involvement in the WHOI community.

TOM KLEINDINST

Dale Goehringer received the 1993 Linda Morse-Porteous Award. Judy Kleindinst is at left.

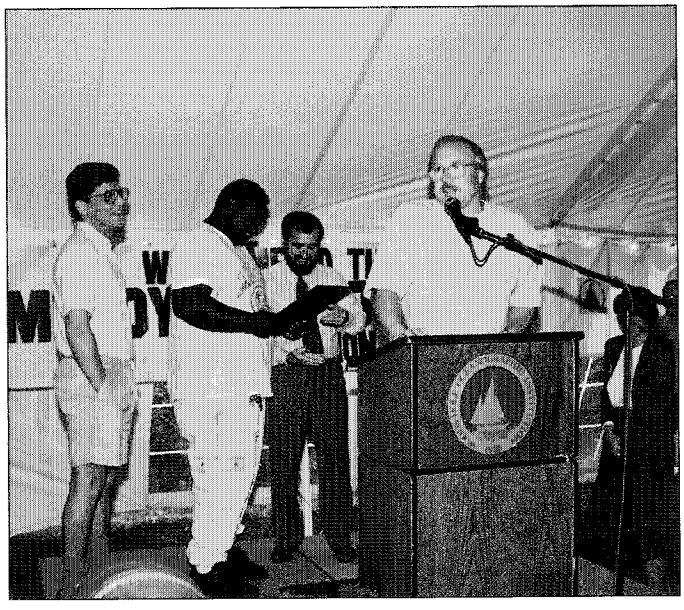


TOM KLEINDINST

Bill Dunkle, wearing boutonniere, was honored for 40 years of service to WHOI at the 1993 Employee Recognition Ceremony.

TOM KLEINDINST

Sheila Payne was the 1993 Vetlesen Award winner. She gets a hug from Susan Tarbell.



TOM KLEINDINST

The 1993 Penzance Award went to the Facilities Services Group. Jay Murphy is at the microphone. Napoleon McCall shows the award plaque to Bob Gagosian, and Carlos Velez is at left.

As of December 31, 1993

Robert B. Gagosian
Acting Director
(Director as of 1/7/94)

Fred L. Sayles
Acting Associate Director for Research

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

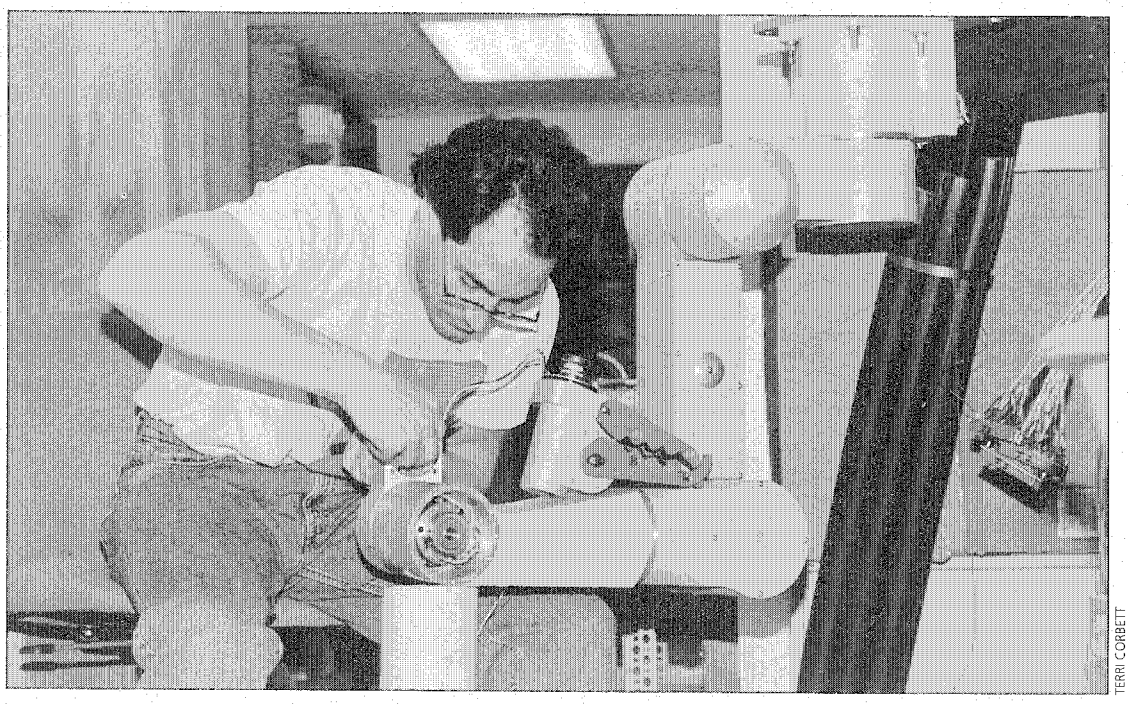
Lawrence R. Ladd
Associate Director for Institution Operations

Richard F. Pittenger
Associate Director for Marine Operations

Charles D. Hollister
Vice President

Pamela C. Hart
Executive Assistant to the Director

Karen P. Rauss
Special Assistant to the Director



TERRI CORBETT

Nathan Ulrich installs a new gripper on ROV Jason's *manipulator.*

Scientific and Technical Staff

As of December 31, 1993

Applied Ocean Physics and 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
Research Engineer

Robert D. Ballard
Senior Scientist and Director, Center for Marine Exploration

Alessandro Bocconcelli
Engineer II

Erik J. Bock
Assistant Scientist

Paul R. Boutin
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
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Calvert F. Eck
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Ned C. Forrester
Research Engineer

Dudley B. Foster
Research Associate

Lee E. Freitag
Research Engineer

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Denzel E. Gleason
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Research Engineer

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Associate Scientist

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Ole Hastrup
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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

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Research Engineer

Sean M. Kery
Engineer II

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Research Engineer

Stephen P. Liberatore
Research Engineer

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Research Engineer

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Walter H. Paul
Senior Engineer

Kenneth R. Peal
Senior Engineer

Robert A. Petitt, Jr.
Engineer II

Daniel F. Potter
Engineer II

Kenneth E. Prada
Principal Engineer

Bryce Prindle
Visiting Investigator

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Research Engineer

Subramaniam D. Rajan
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Cynthia J. Sellers
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Arnold G. Sharp
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Robin C. Singer
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Roger P. Stokey
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Dajun Tang
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Nathan Ulrich
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Christopher von Alt
Senior Engineer

Keith von der Heydt
Senior Engineer

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Principal Engineer and Manager, Submersible Operations

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Ehud Weinstein
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Jia Q. Zhang
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Richard H. Backus
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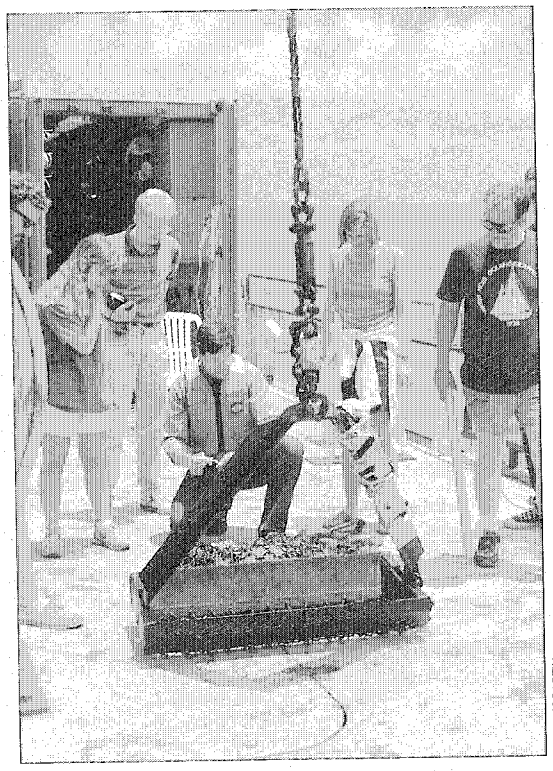
Stephen M. Bollens
Assistant Scientist

Ann C. Bucklin
Visiting Investigator

Francis G. Carey
Senior Scientist



JAVIER ESCARTIN

Brian Tucholke (chief scientist) prepares to unload a dredge aboard R/V Knorr *as, from left, Laura Magde, Johan Robertsson (Rice University), Evelyn Price, and Will Sellers observe.*

David A. Caron
Associate Scientist

Hal Caswell
Senior Scientist

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

Paul V. Dunlap
Associate Scientist

Kurt M. Fristrup
Research Specialist

Scott M. Gallager
Assistant Scientist

Ronald W. Gilmer
Visiting Investigator

Dale Goehringer
Research Associate

Charles S. Greene
Visiting Investigator

Mark E. Hahn
Assistant Scientist

George R. Hampson
Research Specialist

George R. Harbison
Senior Scientist

Brian L. Howes
Associate Scientist

Holger W. Jannasch
Senior Scientist

Sibel I. Karchner
Visiting Investigator

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Research Associate

Dale F. Leavitt
Research Associate

Philip S. Lobel
Associate Scientist

Laurence P. Madin
Associate Scientist

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Michael J. Moore
Visiting Investigator

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Associate Scientist

Robert J. Olson
Associate Scientist

Andrew J. Read
Visiting Investigator

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Scientist Emeritus

Howard L. Sanders
Scientist Emeritus

William E. Schevill
Scientist Emeritus

Rudolf S. Scheltema
Scientist Emeritus

Mary Sears
Scientist Emeritus

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Associate Scientist

John M. Teal
Senior Scientist

Peter L. Tyack
Associate Scientist

Frederica Valois
Research Specialist

John W. Waterbury
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Ken O. Buesseler
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Michael D. Degrandpre
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Werner G. Deuser
Senior Scientist

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Research Specialist

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Lorraine Eglinton
Research Associate

Timothy I. Eglinton
Associate Scientist

Alan P. Fleer
Research Associate

Roger François
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Senior Research Specialist

David M. Glover
Research Specialist

Catherine Goyet
Assistant Scientist

Terence R. Hammar
Research Associate

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
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Dempsey E. Lott III
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William R. Martin
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James W. Moffett
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Brian Schroeder
Research Associate

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Research Specialist

Wilfred B. Bryan
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Susumu Honjo
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Assistant Scientist

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Delia W. Oppo
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Hans Schouten
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Nobumichi Shimizu
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Elazar Uchupi
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Earl M. Young
Research Associate

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Research Associate

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Assistant Scientist

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Charles E. Corry
Research Specialist

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Senior Research Specialist

Daniel E. Frye
Research Specialist

Nick P. Fofonoff
Scientist Emeritus

Paul D. Fucile
Engineer II

Nancy R. Galbraith
Information Systems Associate II

TOM KLEINDINST

Visiting scientist Sara Spencer, left, Summer Student Fellow Wanda Robertson, and WHOI Associate Scientist Debbie Smith discuss how volcanoes are formed at the axis of the Mid-Atlantic Ridge.

Scientific and Technical Staff

Glen G. Gawarkiewicz
Assistant Scientist

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

Craig D. Marquette
Engineer II

Michael S. McCartney
Associate Scientist

William G. Metcalf
Scientist Emeritus

Robert C. Millard, Jr.
Research Specialist

Ellyn T. Montgomery
Information Systems Associate II

W. Brechner Owens
Senior Scientist

Richard E. Payne
Research Associate

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

Robert S. Pickart
Assistant Scientist

Albert J. Plueddemann
Associate Scientist

Lawrence J. Pratt
Associate Scientist

James F. Price
Associate Scientist

Philip L. Richardson
Senior Scientist

Melora P. Samelson
Research Associate

Roger M. Samelson
Associate Scientist

Raymond W. Schmitt
Associate Scientist

William J. Schmitz, Jr.
Senior Scientist and W. Van Alan Clark Chair for Excellence in Oceanography

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

William S. von Arx
Scientist Emeritus

Marine Policy Center

James M. Broadus
Senior Scientist and Director, Marine Policy Center

Arthur G. Gaines, Jr.
Research Specialist

Porter Hoagland III
Research Associate

Di Jin
Assistant Scientist

Yoshiaki Kaoru
Associate Scientist

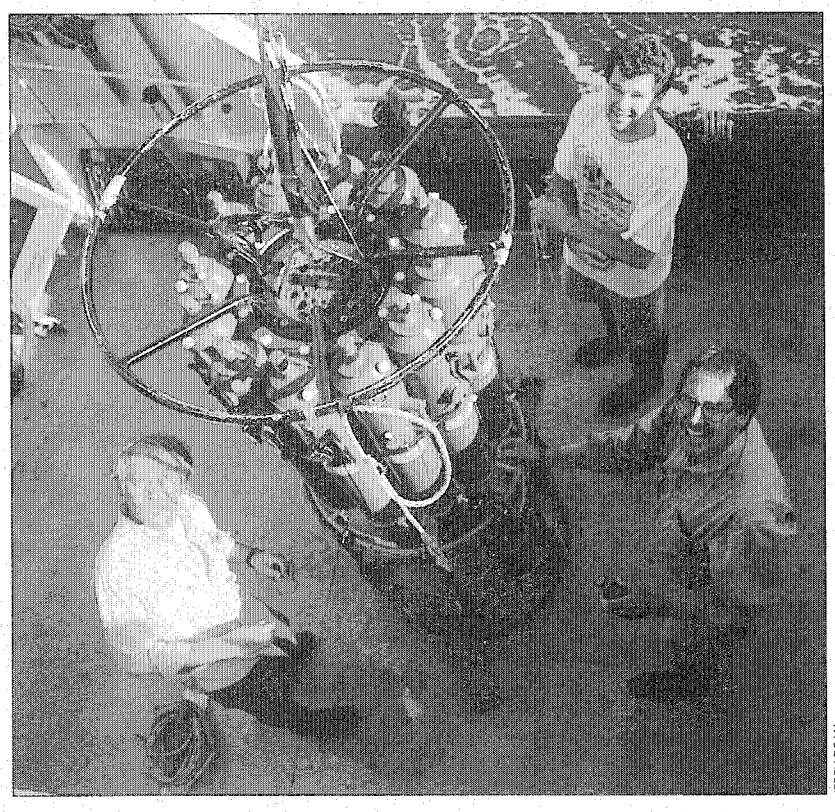
Information Systems Center

Robert C. Groman
Manager, Information Systems Center

Raymond Ainsworth
Information Systems Associate II

Julie M. Allen
Information Systems Associate II

Brian D. Betterton
Information Systems Associate II



JERRY DEAN

Clockwise from left aboard R/V Oceanus, *Dempsey Lott, Jim Luyten, and Josh Curtice report that all the bottles fired. Luyten was named WHOI Associate Director for Research on February 1, 1994.*

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

L. Valentine Worthington
Scientist Emeritus

Hauke L. Kite-Powell
Research Associate

Andrew R. Solow
Associate Scientist

John H. Steele
Scientist Emeritus

Coastal Research Center

Robert C. Beardsley
Center Director and Senior Scientist

Bruce W. Tripp
Research Associate

Cynthia L. Chandler
Information Systems Associate I

Roger A. Goldsmith
Information Systems Specialist

Christine L. Hammond
Information Systems Associate II

John Krauspe
Information Systems Associate II

William S. Little, Jr.
Information Systems Specialist

Andrew R. Maffei
Information Systems Specialist

Elizabeth Owens
Information Systems Associate I

Michael E. Pare
Information Systems Associate II

George H. Power
Information Systems Specialist

Laura T. Praderio
Information Systems Associate I

Warren J. Sass
Information Systems Associate II

William C. Scully
Information Systems Associate II

E. Allan Sonafrank, Jr.
Information Systems Associate II

Suzanne B. Volkmann
Information Systems Associate II

Graphic Services

William N. Lange
Research Associate

Postdoctoral Investigators

Steven P. Anderson
Physical Oceanography

Wei-Jun Cai
Marine Chemistry & Geochemistry

Miguel A. Goni
Marine Chemistry & Geochemistry

Gail C. Kineke
Applied Ocean Physics and Engineering

Birgit A. Klein
Physical Oceanography

James C. Preisig
Applied Ocean Physics and Engineering

Peter J. Saccocia
Geology and Geophysics

David Schneider
Geology and Geophysics

Jia Wang
Applied Ocean Physics and Engineering

David S. White
Biology

Susan E. Wijffels
Physical Oceanography

Zoran Zvonar
Applied Ocean Physics and Engineering

As of December 31, 1993

Applied Ocean Physics and Engineering Department

Alfred T. Bouchard
Paul R. Bouchard
John N. Bouthillette
Shirley J. Bowman
Rodney M. Catanach
Charles E. Corwin
Thomas Crook
Edward A. Denton
Betsey G. Doherty
Terence G. Donoghue
Laurel E. Duda
Kenneth D. Fairhurst
Janet J. Fredericks
Stephen R. Gegg
Allan G. Gordon
Matthew R. Gould
Beven V. Grant
Carlton W. Grant, Jr.
Thomas P. Hurst
Joanna F. Ireland
John N. Kemp
Wendy W. Liberatore
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Neil M. McPhee
George A. Meier
Stephen D. Murphy
Susan M. Oliver
Patrick O'Malley
Stanley G. Rosenblad
Christina E. Saffron
David S. Schroeder
William J. Sellers
John D. Sisson
Gary N. Stanbrough
Cindy L. Sullivan
Nancy Y. Trowbridge
Karlen A. Wannop
Judith A. White
Martin C. Woodward

Biology Department

Philip Alatalo
Susan Brown-Leger
Catherine M. Cetta
Marjorie K. Clancy
Nancy J. Copley
Tracey I. Crago
Mary A. Daher
Linda H. Davis
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Sheri D. Derosa
Diana G. Franks
Andrew P. Girard
Beth E. Goff
Andrew M. Grant
Judith L. Harbison
Linda Hare
Erich F. Horgan
Terrance J. Howald
Michael R. Howarth
David M. Kulis
Bruce A. Lancaster
Mary C. Landsteiner
Ethel F. Lefave
Jane E. Marsh
Susan W. Mills
Zofia J. Mlodzinska
Stephen J. Molyneaux
Karen E. Moore
Jane M. Ridge
Daniel W. Smith
Alicia M. Soderberg
Trevor R. Spradlin
Armando F. Tamse
Lisa G. Taylor
Christopher M. Tebeau
Bonnie L. Woodward

Marine Chemistry & Geochemistry Department

Robert J. Adams
Steven S. Andrews
John E. Andrews III
Rebecca A. Belastock
Scot P. Birdwhistell
Carla J. Bold
Margaret C. Bothner
Sam A. Brodsky
Sigalit Caron
Howard M. Chen
Laurie E. Christman
Misha E. Clark
William R. Clarke
Sheila A. Clifford

TERRI CORBETT

Butch Grant, right, and John Kemp work on the Fiber-Optic Survey System winch.

Joshua M. Curtice
Marcia W. Davis
Meghan Delaney
Shawna R. DiPetta
Joanne C. Donoghue
Anne S. Edwards
Joanne E. Goudreau
Mary C. Hartman
Nancy A. Hayward
Joyce E. Irvine
Timothy C. Kenna
Peter B. Landry
Molly M. Lumping
Robert K. Nelson
Stephanie A. Page
Julianne Palmieri
Nancy L. Parmentier
Aaron Smith
Margaret M. Sulanowska
Colm Sweeney
Maren E. Tracy
N. Joye Wirsen
Mary Zawoysky

Geology & Geophysics Department

John W. Bailey
Pamela R. Barrows
John Billings
S. Thompson Bolmer
Katherine W. Brown
Peter R. Cadden
Dolores H. Chausse
Karen L. Coluzzi
Diane E. Cook
Jennifer Crew
Jeffrey DeSouza
David L. DuBois
Kathryn L. Elder
Kristina L. Faul
Pamela V. Foster
C. Eben Franks
Robert E. Handy
Yuan Huang
Daniel Hutton
Janet M. Johnson
Ernest H. Joynt III
Carol A. Kauffman
James G. Kirklin
Richard A. Krishfield
Karen Littlefield
Peter B. Mills
Gregory E. Moon
Anita D. Norton
Susan A. O'Connor-Lough
Stephen P. O'Malley
Anita M. Palm
May A. Reed
E.B. Roark
Aaron J. Roe
Ellen Roosen
Kimberly A. Sapp
Christopher Zafiriou
Lu Ping Zou

Physical Oceanography Department

Karin A. Bohr
Kenton M. Bradshaw
Nancy J. Brink
Maureen E. Carragher
Margaret F. Cook
Lawrence P. Costello
Gennaro H. Crescenti
Jane A. Dunworth
Penny C. Foster
Robert E. Frazel
Marjorie A. Friedrichs
Barbara Gaffron
Helen E. Gordon
Veta M. Green
Brian J. Guest
William H. Horn
George P. Knapp
Mary A. Lucas
Theresa K. McKee
Anne M. Michael
William M. Ostrom
Julie S. Pallant
John B. Reese
Ralph D. Simoneau
Sandipa Singh
Robert J. Stanley
Susan A. Tarbell
Robert D. Tavares
Deborah A. Taylor
Daniel J. Torres
Toshiko T. Turner

Regular Support Staff

Bryan S. Way
W. David Wellwood
Scott E. Worrilow
Jeanne A. Young
Marguerite E. Zemanovic
Sarah L. Zimmerman

Marine Policy Center

Matthew J. LaMourie
Mary E. Schumacher

Coastal Research Center

Olimpia L. McCall

Information Systems Center

Gail F. Caldeira
Bruce R. Cole
Aganoris Collins
Eric Cunningham
Peter J. Cvitan
Lisa M. DiPalma
Edward F. Dow, Jr.
Annda W. Flynn
Channing N. Hilliard, Jr.
Deborah K. Shafer

Administrative Staff

Joseph P. Agius
Manager, Management Information Systems

Susan S. Berteaux
Information Systems Associate I

Kendall B. Bohr
Assistant Purchasing Manager

Stella A. Callagee
Assistant Registrar and Education Office Administrator

Lee A. Campbell
Information Officer

Karen E. Carmichael
Information Systems Associate I

Jane A. Caruso
Security Officer

Susan A. Casso
Department Administrator, Marine Chemistry & Geochemistry

Lisa A. Clark
Assistant Editor, Oceanus

Vicky Cullen
Manager of Publications & Graphic Services and Editor, Oceanus

Amy L. Donner
Development Officer

Patricia J. Duffy
Accounting Operations Manager

William M. Dunkle, Jr.
Research Associate

Larry D. Flick
Center Administrator, Applied Ocean Physics and Engineering

David G. Gallo
Director, Corporate Research & Technology Program

Ellen M. Gately
Center Administrator Marine Policy Center

Carolyn S. Hampton
Information Systems Associate II

Frederic R. Heide
Assistant Manager of Graphic Services

Ann C. Henry
Department Administrator, Applied Ocean Physics and Engineering

Nancy A. Hickey
Staffing Coordinator

Colleen D. Hurter
Information Systems Associate II

Charles S. Innis, Jr.
Security Officer

Susan Kadar
JGOFS Field Program Coordinator

Victoria A. Kaharl
Science Writer

Robin L. Kaiser
Senior Development Officer

Judith L. Kleindinst
Department Administrator, Biology

Kathleen P. LaBerriz
Assistant Human Resources Manager

Shelley M. Lauzon
Senior News Officer

David J. Miller
Assistant Sponsored Programs Administrator

E. Dorsey Milot
Senior Development Officer

Mozart P. Moniz
Purchasing Manager

Laura A. Murphy
Payroll Administrator

A. Lawrence Peirson III
Associate Dean and Registrar

Laura O. Ranzinger
Senior Accountant I

Clarie L. Reid
Department Administrator, Physical Oceanography

Lesley M. Reilly
Conference Coordinator

Margaret A. Rioux
Information Systems Associate I

R. David Rudden, Jr.
Assistant Controller

Marcella R. Simon
Benefits Representative

Clarence L. Smith
Department Administrator, Geology & Geophysics

Peggy A. Stengel
Development Officer

David L. Stonehill
Director, WHOI/MBL Library

Jacqueline M. Suitor
Director of Development

Martha E. Tarafa
Executive Assistant to the Associate Director for Research

Maurice J. Tavares
Sponsored Programs 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

Barbara Wickenden
Human Resources Manager

Elaine M. Wilcox
Benefits Administrator

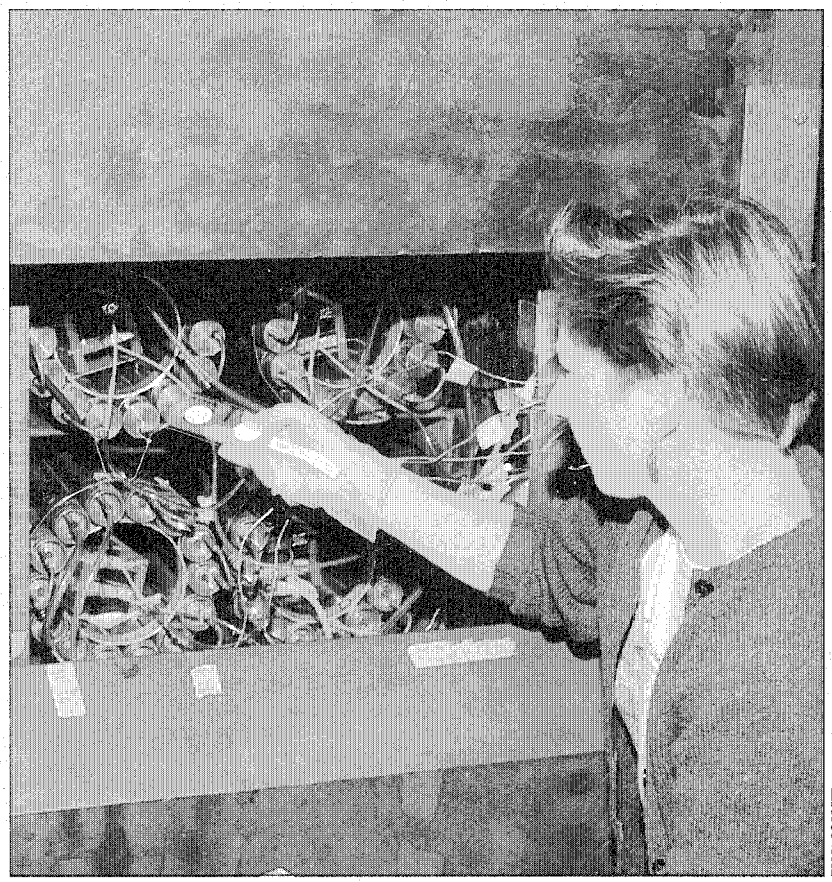
Carolyn P. Winn
Research Librarian

Stacey L. Yarish
Senior Accountant II

Dianna M. Zaia
Financial Analyst

Administrative Personnel

Pierrette M. Ahearn
Steven W. Allsopp
Patricia Askew
Nancy E. Barry
Janice R. Battee
Mary E. Berry
Eleanor M. Botelho
Sandra L. Botelho
Marilynn Brooks
Susan F. Callahan
James J. Canavan
Leonard Cartwright
Peggy A. Chandler
Linda L. Church
John E. Cook
Michelle J. Cooke
Terri C. Corbett
Margaret M. Costello
Joseph J. Curran
Cheryl C. Daniels



TERRI CORBETT

Mary Hartman prepares samples for cesium content analysis in a beta counter.

Helen M. Desmond
Jayne H. Doucette
Nancy Duggan
Kittie E. Elliott
Lynne M. Ellsworth
Glenn R. Enos
Barbara Ewing-Deremer
Steven R. Ferreira
Susan P. Ferreira
Kathryn M. Fitzpatrick
Justine M. Gardner-Smith
Virginia M. Garms
Ruth E. Goldsmith
Pam J. Goulart
David L. Gray
Monika Grinnell
Susan K. Handwork
Beverley A. Harper
Jane M. Harrington
Marilyn R. Hess
Mark V. Hickey
Jane A. Hopewood
Joan B. Hulburt
Abbie Jackson
Thomas N. Kleindinst
Lynn M. Ladetto
Donna L. Lamonde
Tariesa A. Lemmon
Ellen Levy
Lillian R. Lomba
Samuel J. Lomba
Helene J. Longyear
Richard C. Lovering
Robert G. Lowe
Lori Mahoney
Virginia McKinnon
Gretchen McManamin
Gail McPhee
Carole R. Merson
Sandra E. Murphy
Cheryl L. Newton
E. Paul Oberlander
Sharon J. Omar
Laura L. Oxford
Maureen E. O'Donnell
Mary E. Parker
Kathleen Patterson
Alora K. Paul
Maryanne F. Pearcey
Doreen M. Perito
Jeanne A. Peterson
Clara Y. Pires
Jeannine M. Pires
John Porteous
Lisa M. Raymond
Patricia E. Remick
Stacii L. Robbins
Sandra A. Sherlock
Jeanne Silva
Timothy M. Silva
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June E. Taft
Mildred M. Teal
Judith A. Thrasher
Maeve Thurston
Dacia R. Tucholke
Susan E. Vaughan
Margaret A. Vose
Margaret M. Walden
Katherine T. Walsh
Kathleen M. Warner
Mary A. White
Susan A. Wilson
Susan F. Witzell
John A. Wood, Jr.

Facilities, Services, Alvin, and Marine Operations Staff

Richard S. Chandler
Submersible Operations Manager

Ernest G. Charette
Assistant Facilities Manager

Gary B. Chiljean
Master, R/V Atlantis II

Joseph L. Coburn, Jr.
Marine Operations Manager

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

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

Robertson P. Dinsmore
Marine Operations Consultant

Richard S. Edwards
Port Captain

William A. Eident
Chief Engineer, R/V Oceanus

TOM KLEINDINST

Machine Shop Supervisor Don LeBlanc checks a lathe in the R/V Atlantis II *machine shop.*

Joel A. Fahnley
Facilities Engineer

Richard E. Galat
Facilities Engineer

Robert J. Grieve
Chief Pilot/DSV Alvin

David L. Hayden
Chief Engineer, R/V Knorr

J. Patrick Hickey
Expedition Leader/ DSV Alvin

Hartley Hoskins
Research Associate

Paul C. Howland
Master, R/V Oceanus

Robert L. Joyce
Distribution Manager

Lewis E. Karchner
Safety Officer

Larry W. Lindvall
Owner's Representative, R/V Oceanus

Barbara J. Martineau
Marine Operations Administrator

William E. McKeon
Facilities Manager

Barrett H. McLaughlin
Chief Engineer, RV Knorr

Joseph M. Milner
Coordinator of Marine Crew Staffing

Donald A. Moller
Marine Operations Coordinator

Theophilus Moniz III
Marine Engineer

Richard F. Morris
Chief Engineer, RV Atlantis II

David I. Olmsted
Boat Operator, R/V Asterias

Terrence M. Rioux
Diving Safety Officer

Carl F. Swanson
Master, RV Knorr

Ernest C. Wegman
Port Engineer

Facilities, Services, Alvin, and Marine Operations Personnel

Nadine N. Athearn
Helen L. Ayres
Ernest E. Baker
Janice M. Baker
Linda Benway
Robert Bossardt
Thomas A. Bouche
Daryl R. Boudreau
Leonard A. Boutin
Jonn R. Bracebridge
Frederick A. Brauneis
John L. Broadford
Edmund K. Brown
Frederick V. Brown
Mark Buccheri
Socrates J. Carelo
Richard J. Carter
Edward H. Chute
John P. Clement
Charles Clemishaw
Jeffrey D. Clemishaw
Charles H. Clifford
Debra A. Coleman
Alden H. Cook
Arthur Costa
Gregory Cotter
Jane E. Crobar
John A. Crobar
Donald A. Croft
William B. Cruwys
Judith O. Cushman
Pearl R. DeMello

Regular Support Staff

TERRI CORBETT

Mary Ann Daher compares marine mammal sounds using a sound spectrograph from Bill Watkins's digital marine animal sound database.

James H. Dufur, Jr.
James M. Dunn
Daniel B. Dwyer
Anthony Ferreira
Catherine H. Ferreira
Michael J. Field
Patricia A. Grace
Robert J. Greene
Barry V. Hamilton
K.I. Faith Hampshire
William H. Handley
Patrick J. Harrington
Matthew C. Heintz
Robert W. Hendricks
Marjorie M. Holland
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Christopher F. Kennedy
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William D. Lambert
Donald C. LeBlanc
Donald F. LeBlanc
Paul E. LeBlanc
Peter D. Marenna
Robert A. McCabe
Paul J. McCaffrey
Napoleon McCall, Jr.
David McDonald
Carlos A. Medeiros
Joseph V. Mitchell
Thomas W. Moore
Norman E. Morrison
Jose S. Mota
Jay R. Murphy
Stephen Murphy
John R. Murphy, Jr.
Patricia A. Odams
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Stephen G. Page
Sheila T. Payne
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Arthur Peterson
Steven J. Poore
Thomas D. Rennie
John P. Romiza
Lewis J. Saffron
Michael J. Sawyer
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Daryl L. Schuchman
Peter J. Schwamb
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Steven P. Solbo
Robert G. Spenle
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Harold W. Swanson
William R. Tavares, Jr.
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Michael Toner
Carlos Velez
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Mitchell G. Barros
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Richard A. Carvalho
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Albert Collasius, Jr.
Jerome M. Cotter
John W. Cox
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Sallye A. Davis
Mark C. DeRoche
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Jovinol Fernandes, Jr.
Kevin C. Fisk
Jerry M. Graham
Edward F. Graham, Jr.
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John F. Gumbleton
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Alan J. Hopkins
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Herman Wagner
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Carl O. Wood
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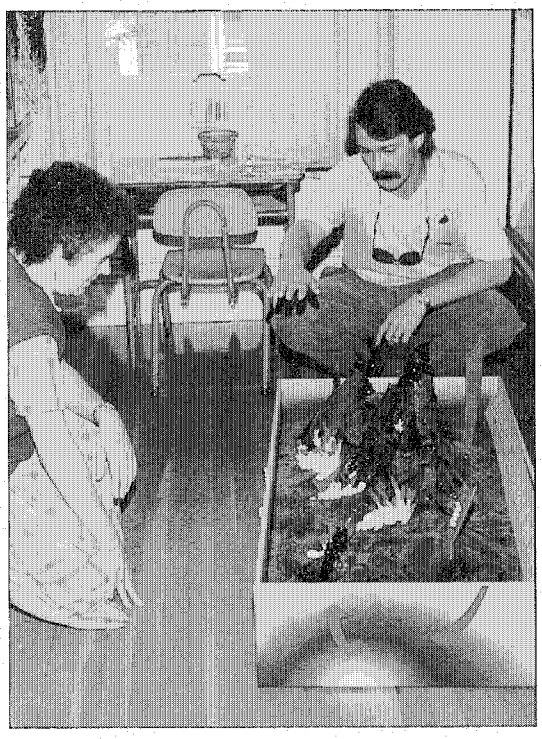
Charles F. Hall
William H. Horn
Virginia A. LeFavor
Robert G. Lowe
Harry H. Stanton
John C. Williams
Elazar Uchupi



DAVE GRAY

Information Officer Lee Anne Campbell and Illustrator Paul Oberlander discuss a new hydrothermal-vent display for the Exhibit Center.

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

Doctor of Philosophy

Carol Arnosti
B.A,. Lawrence University
Special Field: *Chemical Oceanography*
Dissertation: *Structural Characterization and Bacterial Degradation of Marine Carbohydrates*

Antonietta Capotondi
Laurea , University of Pisa
Special Field: *Physical Oceanography*
Dissertation: *Assimilation of Altimeter Data in a Quasi-Geostrophic Model of the Gulf Stream System: A Dynamical Perspective*

David B. Chester
B.S., Southampton University
S.M., MIT/WHOI Joint Program in Oceanography
Special Field: *Physical Oceanography*
Dissertation: *A Tomographic View of the Gulf Stream Southern Recirculation Gyre at 38° North, 55° West*

Mary Carla Curran
B.S., University of South Carolina, Columbia
B.Sc., Victoria University
Special Field: *Biological Oceanography*
Dissertation: *The Behavioral Physiology of Labroid Fishes*

Thomas Ehrendorfer
Magister, University of Vienna
Special Field: *Marine Geology and Geophysics*
Dissertation: *Late Cretaceous (Maestrichtian) Calcareous Nannoplankton Biogeography with Emphasis on Events Immediately Preceding the Cretaceous/Paleocene Boundary*

Francis Felizardo
B.S., M.S., University of the Philippines
Special Field: *Oceanographic Engineering*
Dissertation: *Ambient Noise and Surface Wave Dissipation in the Ocean*

Carl T. Friedrichs
B.A., Amherst College
Special Field: *Marine Geology and Geophysics*
Dissertation: *Hydrodynamics and Morphodynamics of Shallow Tidal Channels and Intertidal Flats*

Linda L. King
B.S., Mary Washington University
Special Field: *Chemical Oceanography*
Dissertation: *Chlorophyll Diagenesis in the Water Column and Sediments of the Black Sea*

Eric Lamarre
B.E., McGill University
Special Field: *Oceanographic Engineering*
Dissertation: *An Experimental Study of Air Entrainment by Breaking Waves*

Kathleen M. Ledyard
B.S., Columbia University
Special Field: *Chemical Oceanography*
Dissertation: *Marine Microbial Production of Dimethylsulfide from Dissolved Dimethylsulfoniopropionate*

Kazuhiko Ohta
B.S., Kyoto University
S.M., Massachusetts Institute of Technology
Special Field: *Oceanographic Engineering*
Dissertation: *Analysis of Modal Evolution Caused by a Weakly Range-Dependent Seabed in Shallow Water and its Application to Inversion for Geoacoustic Properties*

Christopher A. Scholin
B.A., University of California, Santa Barbara
M.A., Duke University
Special Field: *Biological Oceanography*
Dissertation: *Analysis of Toxic and Non-Toxic Alexandrium (Dinophyceae) Species Using Ribosomal RNA Gene Sequences*

Paul V.R. Snelgrove
B.Sc., Memorial University of Newfoundland
M.Sc., McGill University
Special Field: *Biological Oceanography*
Dissertation: *The Importance of Fine-Scale Flow Processes and Food Availability in the Maintenance of Soft-Sediment Communities*

Jonathan E. Snow
B.A., B.A., Indiana University
M.S., University of Rochester
Special Field: *Marine Geology and Geophysics*
Dissertation: *The Isotope Geochemistry of Abyssal Peridotites and Related Rocks*

Liping Wang
B.S., Zhengshang University
M.S., Academia Sinica
Special Field: *Physical Oceanography*
Dissertation: *The Dynamic Role of Ridges in a Beta-plane Channel*

Nathalie A. Waser
Maitrise, D.E.A., Pierre and Marie Curie University
Special Field: *Chemical Oceanography*
Dissertation: *Cosmogenic ^{32}P and ^{33}P in the Atmosphere and Oligotrophic Ocean and Applications to the Study of Phosphorus Cycling*

Susan E. Wijffels
B.Sc., Flinders University
Special Field: *Physical Oceanography*
Dissertation: *Exchanges between Hemispheres and Gyres: A Direct Approach to the Mean Circulation of the Equatorial Pacific*

Doctor of Science

Ramnarayan Gopalkrishnan
B.S., India Institute of Technology
Special Field: *Oceanographic Engineering*
Dissertation: *Vortex-Induced Forces on Oscillating Bluff Cylinders*

Franz S. Hover
B.Sc., Ohio Northern University
S.M., MIT/WHOI Joint Program
Special Field: *Oceanographic Engineering*
Dissertation: *Methods for Positioning Deeply-Towed Underwater Cables*

Master of Science

James R. Gunson
B.Sc., University of Western Australia Honors, Flinders University
Special Field: *Physical Oceanography*
Dissertation: *Time-Dependent Assimilation of CTD Data to an Open Ocean Rossby Wave Model*

Young-Gyu Park
B.S., M.S., Seoul National University
Special Field: *Physical Oceanography*
Dissertation: *Turbulent Mixing in Stratified Fluids –Layer Formation and Energetics*

Dennis M. Wojcik
B.S.E.E., Marquette University
Special Field: *Oceanographic Engineering*
Dissertation: *Passive Localization of Underwater Acoustic Beacons*

Carole A. Womeldorf
A.B., Sc.B., Brown University
Special Field: *Oceanographic Engineering*
Dissertation: *Dispersion of Fine-Particles by Wave-Induced Mass Transport Near a Circular Island*

Master of Science in Oceanographic Engineering & Master of Science in Mechanical Engineering

Robert W. Keefe
B.S., United States Naval Academy
Special Field: *Oceanographic Engineering*
Dissertation: *Design of a Controllable Pitch Underwater Thruster System*

Master of Science in Electrical Engineering

James M. Njeru
B.S., B.S.E.E., Lafayette College
S.M., MIT/WHOI Joint Program
Special Field: *Oceanographic Engineering*
Dissertation: *A Tomographic Ocean Sound Speed Profile from a Long Vertical Acoustic Array*

Ocean Engineer

Stephen G. Bowen
B.S., United States Naval Academy
Special Field: *Oceanographic Engineering*
Dissertation: *Forward Scattering of a Pulsed Continuous Wave Signal through Laminar and Turbulent Thermal Plumes*

Matthew L. Johnson
B.S., University of New Mexico
Special Field: *Oceanographic Engineering*
Dissertation: *Orientation Dependence of the Acoustic Backscatter for Elongated Zooplankton*

Douglas S. Ray
B.S., United States Naval Academy
Special Field: *Oceanographic Engineering*
Dissertation: *Acoustic Travel Time Perturbations Due to an Internal Tide and Internal Wave Field in the Barents Sea*

MIT/WHOI Joint Graduate Program 1993-1994 Fall Term

Robert P. Ackert, Jr.
University of Maine, Orono
University of Maine, Orono, M.S.

Jess F. Adkins
Haverford College

J. Ewann Agenbroad
University of Washington

Einat Aharonov
Tel-Aviv University, Israel

Susan E. Alderman
Mt. Holyoke College

Lihini I. Aluwihare
Mt. Holyoke College

Keith D. Alverson
Princeton University

Linda A. Amaral Zettler
Brown University

Jamie M. Anderson
University of California, San Diego
MIT/WHOI Joint Program, S.M.

Andrea L. Arenovski
University of North Carolina, Wilmington

Jay A. Austin
California Polytechnic Institute

Katherine A. Barbeau
Long Island University

John F. Barimo
Virginia Commonwealth University

Molly O. Baringer
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University of California, Davis, M.S.

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Marine Policy and Ocean Management 1993-1994

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Raphael Vartanov
Russian Academy of Sciences

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University of Washington

Sergey Alexander Cherkis
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Rachel Collin
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Ben Motten
SUNY, Brockport

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Stevens Institute

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Bill Curry, right, and WHOI Trustee George Argyros discuss a core related to Curry's paleoclimate work.

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Massachusetts Institute of Technology, Cambridge, MA

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In Memoriam

The Institution gratefully acknowledges the service and support of those members who passed away in 1993:

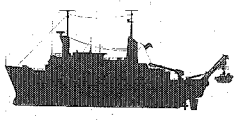
Henry A. Morss, Jr.

Robert W. Pierce

Arthur J. Santry, Jr.

Robert R. Schrock

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



Total Nautical Miles in 1993 – 21,297 • Total Alvin Dives – 136 • Total Days at Sea – 232

Voyage	*Cruise period*	*Cruise objective, Area of operation*	*Ports of Call*	*Chief Scientist*
128	26 Feb	Local waters, NSF Inspection	Woods Hole	–
129-I	4 Mar - 15 Mar	Bermuda, *Alvin* certification, 7 dives	St. George, Bermuda	B. Walden
129-II	16 Mar - 18 Mar	Bermuda, biological sampling on the slope of the Bermuda Plateau, 2 dives	St. George, Bermuda	D. Calder (Royal Ontario Museum)
129-III	19 Mar - 6 Apr	Mid-Atlantic Ridge-24°N, geological studies of a major fault zone, 7 dives	St. George, Bermuda	J. Karson (Duke)
129-IV	18 Apr - 23 Apr	Bermuda, engineering test dives, 6 dives	St. George, Bermuda	B. Walden
129-V	23 Apr - 23 May	Mid-Atlantic Ridge-26°N, geothermal and geoelectrical studies at a hydrothermal vent site, 21 dives	Ponta Delgada	R. Von Herzen
129-VI	27 May - 4 June	Mid-Atlantic Ridge-37°N, preliminary investigation at a newly discovered hydrothermal vent site, 7 dives	Ponta Delgada	C. Langmuir (Lamont)
129-VII	5 June - 3 July	Mid-Atlantic Ridge-29°N, 26°N, 23°N, biological studies at hydrothermal vent sites, 17 dives	Woods Hole	C. Van Dover H. Jannasch S. Chamberlain (Syracuse)
130	9 July - 23 July	New York Bight, biological and sediment sampling at the long-term ecological observatory DWDS-106, 14 dives	Woods Hole	F. Grassle (Rutgers)
131-I	29 July - 21 Aug	Transit to the Pacific following 1 engineering dive	Astoria	–
131-II	28 Aug - 8 Sept	Juan de Fuca Ridge, study of the geomorphology of headless submarine canyons, 10 dives	Astoria	D. Orange (MBARI)
131-III	9 Sept - 23 Sept	Juan de Fuca Ridge, hydrogeological and chemistry studies, 13 dives	Astoria	B. Carson (Lehigh)
131-IV	25 Sept - 4 Oct	Juan de Fuca Ridge, continuation of Leg III and borehole instrumentation recovery, 6 dives	Astoria	K. Becker (U.Miami) B. Carson (Lehigh)
131-V	9 Oct - 25 Oct	Juan de Fuca Ridge, geological and geochemical sampling at sites of recent volcanic activity, 12 dives	Astoria	J. Delaney (U.Wash.) R. Embley (NOAA)
131-VI	27 Oct - 31 Oct	Transit to San Diego	San Diego	–
131-VII	4 Dec - 5 Dec	California Coast, engineering tests, 1 dive	San Diego	D. Foster
131-VIII	9 Dec - 31 Dec	East Pacific Rise-9°N, study of the temporal changes in the biology and associated geological features at newly-formed hydrothermal vents, 12 dives	Acapulco	R. Lutz (Rutgers)

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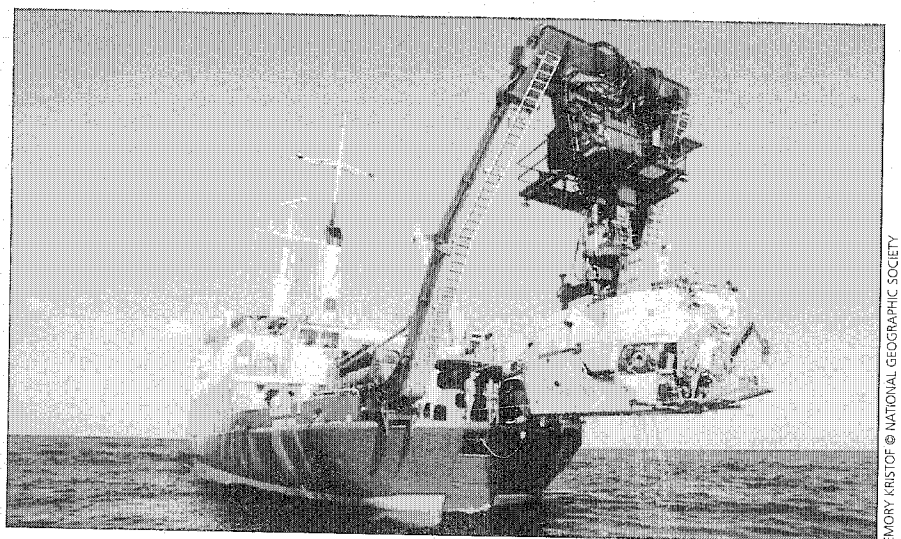

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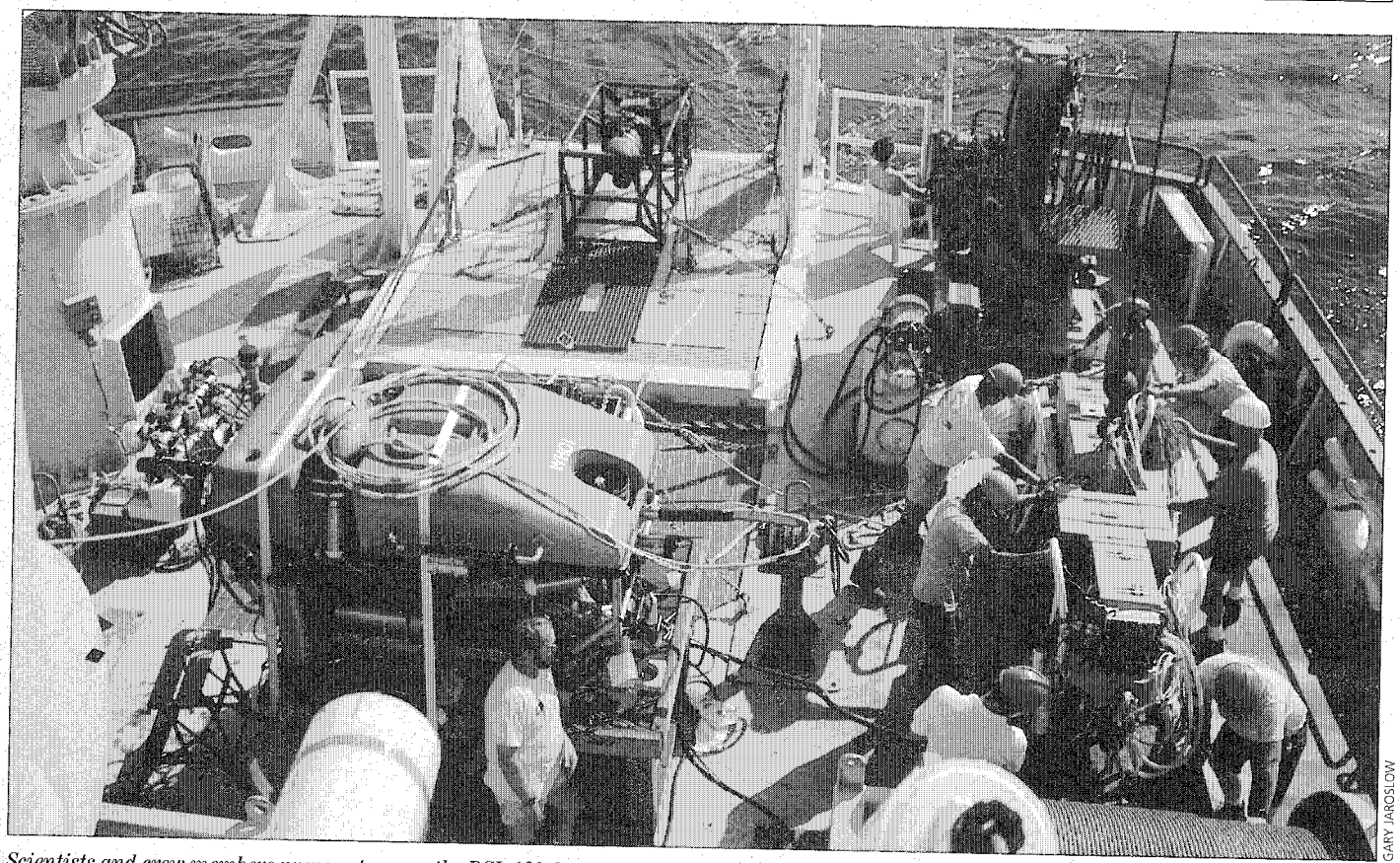
On left, Craig Dickson, kneeling, and Paul McCaffrey are ready to attach Alvin's *lifting apparatus. At right, the sub is lifted from the water following a dive.*

R/V *Knorr*

Total Nautical Miles in 1993 – 30,648 • Total Days at Sea – 240

Voyage	*Cruise period*	*Cruise objective, Area of operation*	*Ports of Call*	*Chief Scientist*
138-X *	4 Dec - 22 Jan	South Pacific, hydrographic survey for WOCE Hydrographic Program, line P17	Punta Arenas	J. Swift (Scripps)
138-XI	28 Jan - 17 Feb	South Pacific, studies of chemistry of magmas that have erupted along the Chile Ridge	Punta Arenas	E. Klein (Duke) J. Karsten (U. Hawaii)
138-XII	23 Feb - 13 Apr	South and Central Pacific, hydrographic survey for WOCE Hydrographic Program, line P19C	Panama Canal	L. Talley (Scripps)
138-XIII	16 Apr - 21 Apr	Transit to Atlantic	Jacksonville	–
138-XIV	9 May - 10 June	Mid-Atlantic Ridge-26°N, fine-scale geological and geophysical surveys	Ponta Delgada	B. Tucholke
138-XV	13 June - 30 June	Eastern Atlantic, recovery of Subduction Experiment mooring array	St. George, Bermuda	R. Trask
138-XVI	7 July - 2 Aug	Mid-Atlantic Ridge-26°N, study of the physics governing the interaction of low-frequency acoustic energy and the seafloor	St. George, Bermuda	W. Hodgkiss (Scripps)
138-XVII	4 Aug - 11 Aug	Mid-Atlantic Continental Shelf, acoustic surveys	Woods Hole	J. Gettrust (NRL)
139	17 Aug	Local waters, USN INSURV inspection	Woods Hole	–
140-I	25 Sept - 27 Oct	Carolina Continental Rise, side-scan surveys of breached diapirs	Jacksonville	F. Spiess (Scripps) C. Paull (U.N.Carolina)
140-II	1 Nov - 18 Nov	Blake/Bahama Outer Ridges, piston coring for studies of climate and global change	Woods Hole	L. Keigwin
141-I	8 Dec - 21 Dec	Sargasso Sea, deploy mooring array for low-frequency near-surface acoustic backscatter experiment	Jacksonville	H. Deferrari (U.Miami)

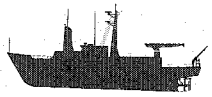
* At sea on January 1



GARY JAROSLOW

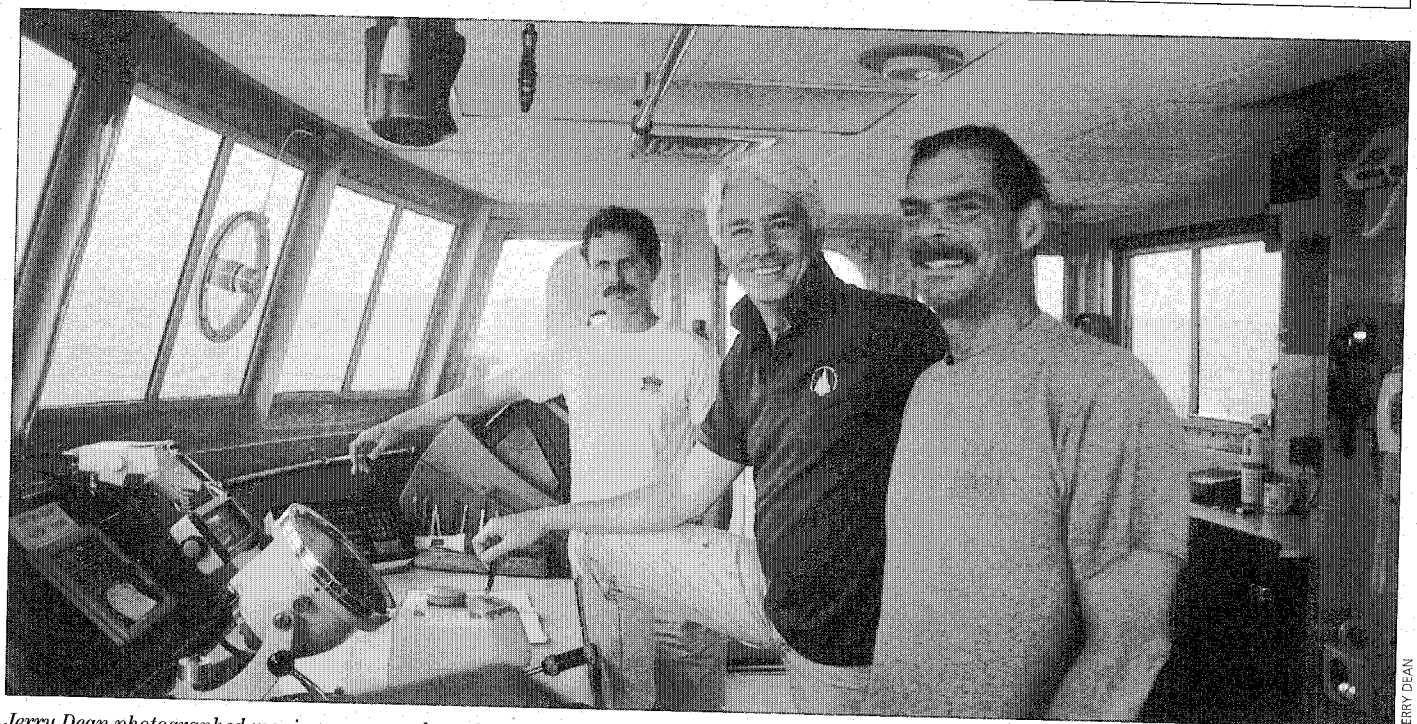
Scientists and crew members prepare to move the DSL-120 deep-towed sonar system aboard R/V Knorr *during the May-June Mid-Atlantic Ridge cruise. ROV* Jason *rests center deck, and DSL-120's depressor is beneath the A-frame.*

R/V *Oceanus*



Total Nautical Miles in 1993 – 24,953 • Total Days at Sea – 181

Voyage	*Cruise period*	*Cruise objective, Area of operation*	*Ports of Call*	*Chief Scientist*
255	10 Feb	Local Waters, sea trials	Woods Hole	–
256-I	11 Mar -24 Mar	Bermuda, studies of the chemistry of nitrification of the water column and of carbon monoxide and manganese cycles	St. George, Bermuda	O. Zafiriou
256-II	26 Mar - 4 Apr	Bermuda, biological sampling of salps	Woods Hole	L. Madin
257	8 Apr - 13 Apr	Continental Shelf, carbon dioxide studies and instrument tests	Woods Hole	D. Repeta
258-I	19 Apr - 27 Apr	North Atlantic, biological sampling in the Gulf Stream	Ponta Delgada	A. Bucklin (UNH)
258-II	30 Apr - 13 May	Eastern North Atlantic, deploy sound-source moorings for AMUSE experiment	Funchal	A. Bower
258-III	18 May - 17 June	Eastern North Atlantic, Subduction Experiment hydrographic surveys and water sampling	Ponta Delgada	J. Luyten
258-IV	20 June - 1 July	North Atlantic, biological sampling in the Gulf Stream	Woods Hole	R. Scheltema
259-I	7 July - 26 July	Western North Atlantic, hydrographic surveys and mooring deployment for studies of circulation patterns of the Labrador Current	St. John's, Newfoundland	T. Rossby (URI)
259-II	30 July - 10 Aug	Western North Atlantic, continuation of Leg I	St. John's, Newfoundland	R. Watts (URI) A. Clark (Bedford I.O.)
259 -III	12 Aug - 16 Aug	North Atlantic, biological sampling in the Gulf Stream	Woods Hole	R. Scheltema
260	21 Aug - 12 Sept	N. J. Coast, side-scan surveys and bottom sampling	Woods Hole	J. Austin, (U. Texas)
261	16 Sept - 22 Sept	Continental Shelf, study of shallow-water, low-frequency acoustic-wave propagation	Woods Hole	T. Yamamoto (U. Miami)
262	27 Sept - 6 Oct	Continental Shelf, acoustic-backscatter experiment with live marine organisms	Woods Hole	T. Stanton
263	8 Oct - 10 Oct	Continental Shelf, instrument tests	Woods Hole	F. Sayles
264	1 Nov - 4 Nov	Transit to shipyard	Jacksonville	–



JERRY DEAN

Jerry Dean photographed marine crew members, from left, Gardner Doherty, Jeff Stolp, and Kevin Kay on the Oceanus *bridge during the ship's May-June Subduction Experiment cruise.*

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TOM KLEINDINST

Maureen O'Donnell of the library staff is charged with compiling the publications list for the annual report each year.

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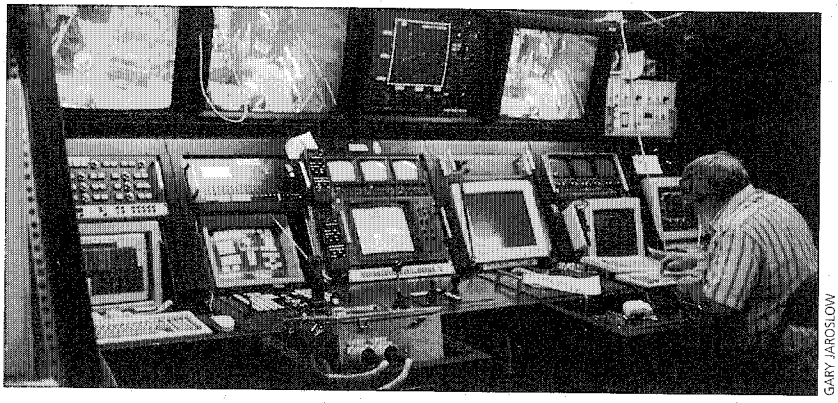

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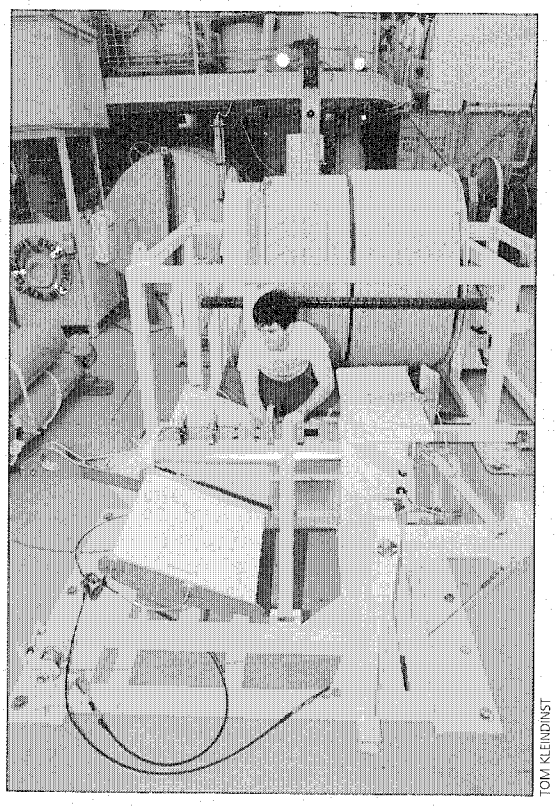

TOM KLEINDINST

Paul Fucile attaches connectors to a sea cable for Sea Soar, an undulating profiling platform, for a cruise aboard R/V Oceanus.

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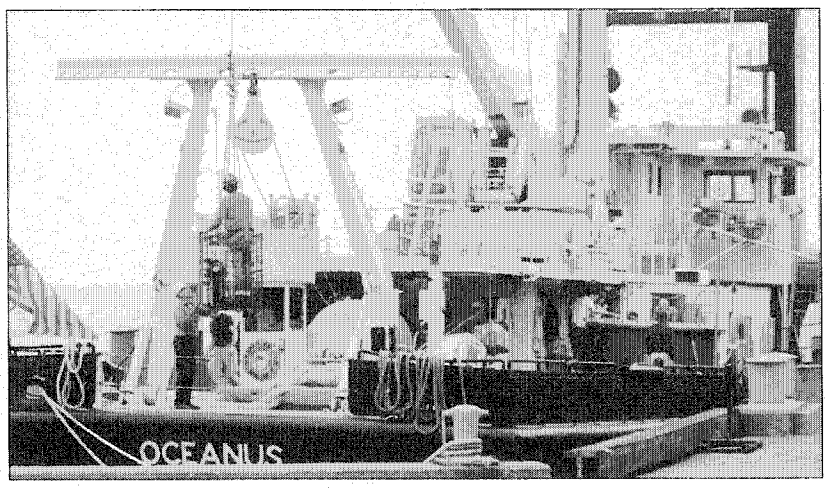

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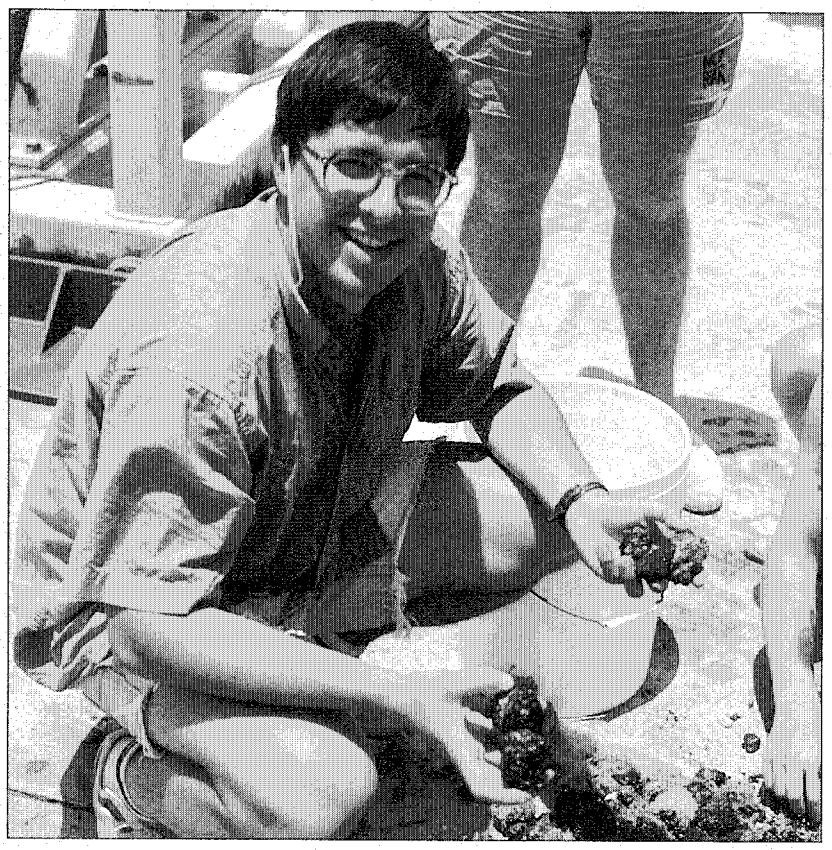

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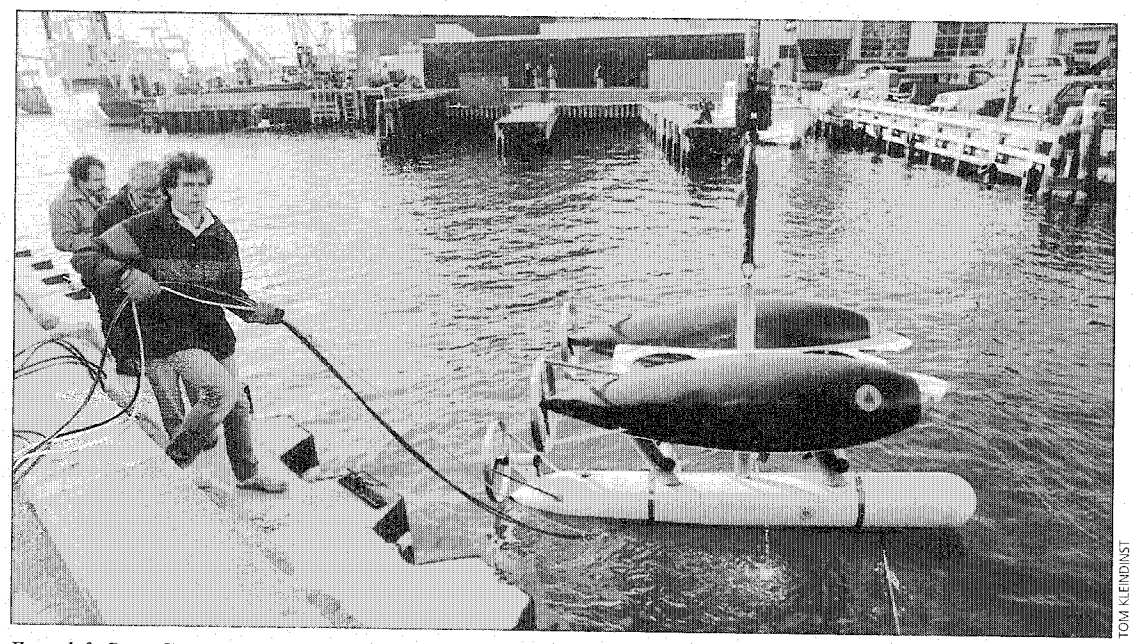

TOM KLEINDINST

From left, Dana Yoerger, Ed Verry, and Rod Catanach handle the autonomous underwater vehicle ABE during dockside trials in Woods Hole.

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Table 1
Types of Revenue
(Exclusive of Knorr-Melville Refit)

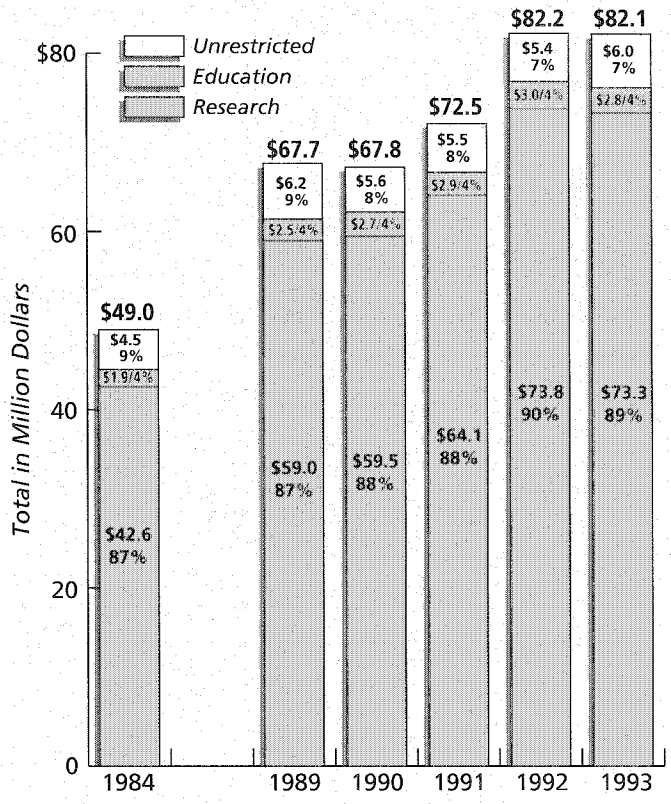


Table 2
Sources of Research Funding

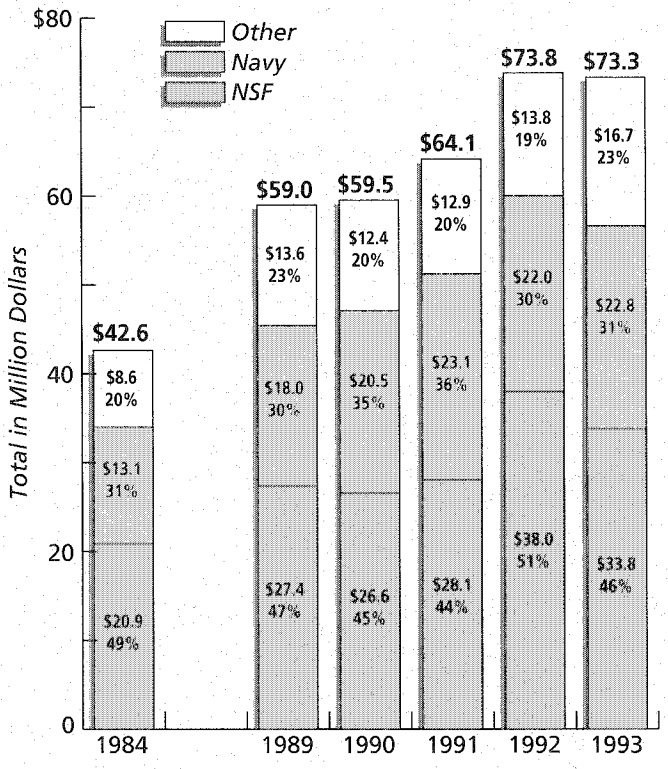


Table 3
Gifts and Grants from Private Sources

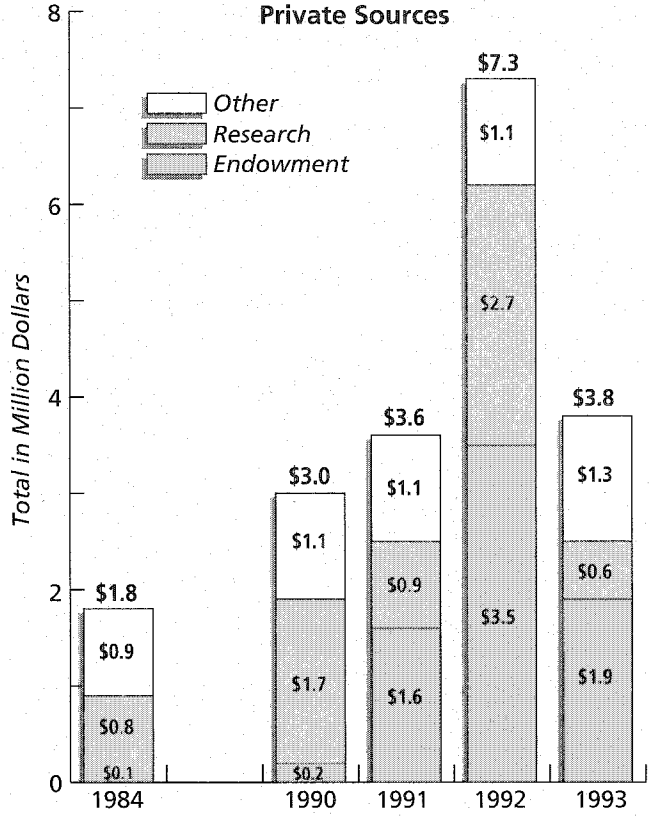
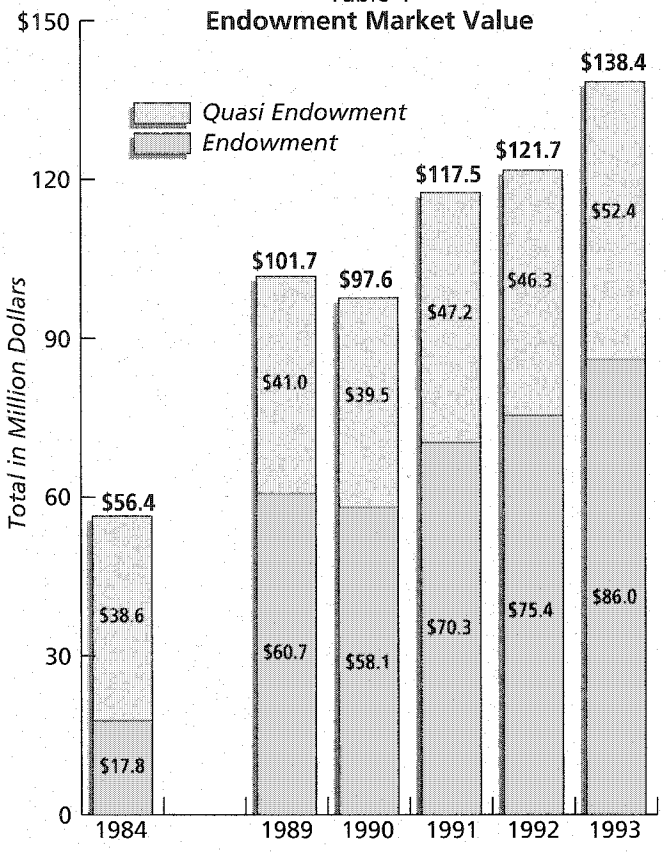


Table 4
Endowment Market Value

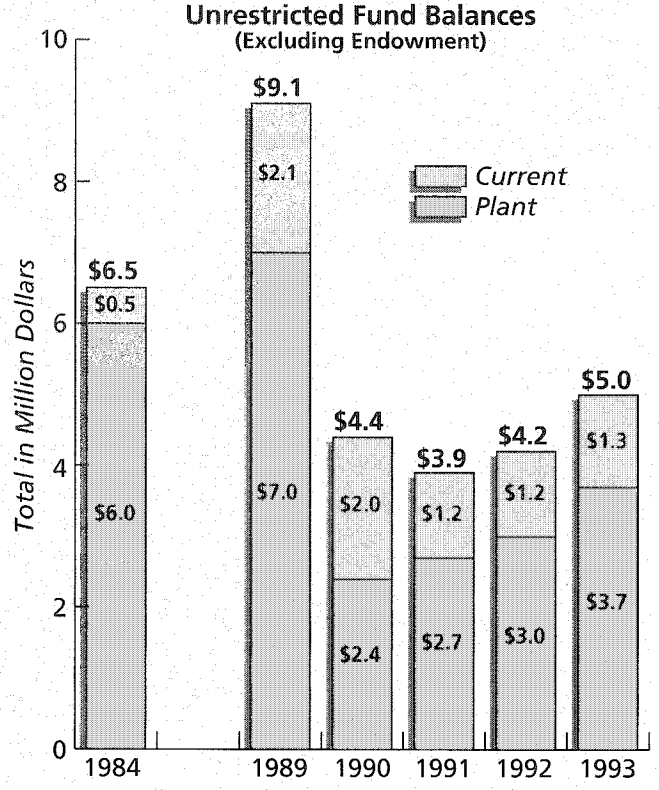


The Institution's 1993 financial results showed a surplus while also allowing transfers to bolster reserves for future contingencies. The endowment market value has continued its steady growth and our unrestricted fund balances increased for the second year in a row. Exclusive of the Knorr/Melville refit, government-sponsored research declined modestly. Revenues from private fundraising showed a short-term reduction as well.

Institution revenues were reduced by 1.4% in 1993 to $89.1 million. Sponsored research continues to be the primary source of income, representing 82.3% of the Institution's total revenue compared to 81.6% in 1992 and 77.1% in 1991. (See Tables 1 and 2 for an overview of the sources of revenue to the Institution.) Unrestricted income increased by 12.5% over 1992. Unrestricted revenues exceeded the 1993 budget by 14.0% while unrestricted expenses were under budget by 15.7%. Overhead expenditures were also under budget for 1993. The Institution's managers paid close attention to their budgets and are to be commended for producing excellent results.

Fundraising for the Institution slowed in 1993 as a result of the search for a new director and trustee attention given to other important matters. In 1993, gifts and grants from private sources (excluding pledges) were $3.8 million, compared to $7.3 million in 1992, $3.6 in 1991 and $3.0 million in 1990. (See Table 3.) Outstanding pledges at the end of 1993 were $2.1 million, compared to $4.7 million at the end of 1992 and $3.1 million at the end of 1991.

Table 5
Unrestricted Fund Balances
(Excluding Endowment)



In spite of lower achievement in 1993, overall the Institution's fundraising initiatives are improving substantially the fiscal base of the Institution. Our net achievement (cash and pledges) over the past three years (1991 through 1993) has been $20.9 million. Our fundraising expenses have been 13.4% of fundraising achievement.

The market value of the endowment, including new gifts, increased by 13.7% to $138.4 million. As a result of generous support from our many friends and benefactors, new gifts of $1.6 million were added to the endowment in 1993, compared to $3.5 million in 1992, $1.6 million in 1991 and $0.2 million in 1990. (See Table 4.) The total return on the endowment under professional management was 16.1%. Of that total return, $4.0 million (income) and $1.7 million (appreciation) supported operations while $13.4 million (appreciation) has been reinvested in the endowment.

Capital expenditures in 1993 were $1.8 million, a decrease of 18.1% from $2.2 million in 1992. Funds for capital expenditures are provided from depreciation recovery.

The two primary sources of expendable fund balances are the Unrestricted Current Funds Balance and the Unrestricted Plant Fund Balance. After substantial declines in 1990 and 1991, those fund balances grew in 1993 for the second year in a row. (See Table 5.) The Unrestricted Current Fund increased from $1,239,000 to $1,298,000 and the Unrestricted Plant Fund increased from $3,005,000 to $3,725,000. The two fund balances combined increased from $4,245,000 to $5,023,000.

In summary, on the plus side the Institution's budget was balanced while allowing enhancements of reserves. Revenues were sufficient and overhead and unrestricted expenditures were under budget. The endowment and unrestricted fund balances have all increased. On the negative side, our research funding has leveled off and overhead recovery may be insufficient to cover true costs. Thus, the major uncertainty facing the Institution is the nature and extent of Federal financial support for the kind of scientific research in which WHOI has traditionally excelled, including the issue of overhead reimbursement rates.

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 28, 1994

STATEMENTS OF CURRENT FUND

Revenues, Expenses, and Transfers
for the years ended December 31, 1993 and 1992

Revenues

	1993	1992
Sponsored research:		
Government	$65,885,079	$66,654,520
Nongovernment	7,425,830	7,155,906
	73,310,909	73,810,426
Knorr/Melville refit	6,979,565	8,238,152
Education funds availed of	2,805,946	3,023,691
Total restricted	83,096,420	85,072,269
Unrestricted:		
Fees	503,212	449,074
Endowment income	1,163,633	1,106,438
Gifts	1,173,263	929,126
Tuition	2,148,452	1,809,280
Rental income	524,367	501,700
Oceanus subscriptions	207,402	262,245
Investment income	171,946	231,148
Other	122,794	58,056
Total unrestricted	6,015,069	5,347,067
Total revenues	89,111,489	90,419,336

Expenses

Sponsored research:		
Salaries and fringe benefits	21,775,137	22,788,260
Ships and submersibles	12,013,533	10,482,377
Material and equipment	8,891,221	9,090,725
Laboratory overhead	8,051,949	8,986,363
General and administrative	6,880,789	7,922,360
Subcontracts	4,307,078	2,393,772
Other	11,391,202	12,146,569
	73,310,909	73,810,426
Knorr/Melville refit	6,979,565	8,238,152
Education:		
Faculty expense	1,615,483	1,569,591
Student expense	1,238,131	1,430,450
Postdoctoral programs	444,106	419,453
Other	493,721	508,837
	3,791,441	3,928,331
Unsponsored research	862,026	1,801,843
External affairs	2,101,819	1,935,823
Other activities	907,149	3,924,930
Total expenses	87,952,909	93,639,505
Net increase/(decrease) before transfers	1,158,580	(3,220,169)
Transfers - (to) from:		
Designated reserves	(1,065,255)	354,115
Other	(34,751)	-
Endowment fund	-	2,909,572
Total	(1,100,006)	3,263,687
Net increase-unrestricted current funds	$ 58,574	$ 43,518

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

BALANCE SHEETS

December 31, 1993 and 1992

Assets

	1993	1992
Current fund (Note A):		
Cash and cash equivalents	$ 13,158,072	$ 19,335,773
Accrued interest and dividends	602,048	906,717
Reimbursable costs and fees:		
Billed	2,864,459	3,097,833
Unbilled	2,231,680	1,746,005
Other receivables	604,001	995,073
Inventories	602,716	627,480
Deferred charges and prepaid expenses	969,257	891,254
Deferred fixed rate variances	1,485,525	(795,324)
Due (to) from other funds	(236,131)	194,332
	22,281,627	26,999,143
Endowment fund (Notes A and B):		
Investments, at market	123,302,653	106,732,763
Cash and cash equivalents	18,664,950	18,246,005
Due to other funds	(3,579,795)	(3,281,920)
	138,387,808	121,696,848
Plant fund (Note A):		
Land, buildings, and improvements	40,907,076	39,654,127
Vessels and dock facilities	7,399,976	7,399,444
Laboratory and other equipment	6,669,997	6,667,094
Work in process	8,838	120,148
	54,985,887	53,840,813
Less: accumulated depreciation	(27,968,837)	(26,006,227)
	27,017,050	27,834,586
Due from other funds	3,815,926	3,087,588
	30,832,976	30,922,174
Total all funds	$191,502,411	$179,618,165

Liabilities and Fund Balances

	1993	1992
Current fund:		
Liabilities:		
Accounts payable & other liabilities	$ 8,363,703	$ 6,254,252
Accrued payroll & related liabilities	4,418,140	4,517,261
	12,781,843	10,771,513
Contingency (Note I)		
Fund balances:		
Restricted - unexpended:		
Sponsored research	3,917,909	10,965,992
Education program	2,114,587	2,919,445
Designated	2,169,409	1,102,888
Unrestricted	1,297,879	1,239,305
	9,499,784	16,227,630
	22,281,627	26,999,143
Endowment fund:		
Endowment:		
Income restricted	83,229,253	73,352,087
Income unrestricted	2,681,556	2,000,802
Pooled income fund	80,094	46,794
Quasi-endowment:		
Income designated	21,331,363	18,834,025
Income unrestricted	31,065,542	27,463,140
	138,387,808	121,696,848
Plant fund:		
Invested in plant	27,017,050	27,834,586
Unexpended:		
Restricted	90,773	82,286
Unrestricted	3,725,153	3,005,302
	30,832,976	30,922,174
Total all funds	$191,502,411	$179,618,165

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

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, 1993 and 1992 is $2,640,873 and $8,173,953, 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 the funds. Conversely, when investment income is less the distribution such deficit is funded by accumulated excess income or accumulated net realized and unrealized gains of the respective funds.

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 amounted to $2,494,463 and $2,501,059, 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 $114,189 and $261,814 in 1993 and 1992, 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.

Reclassification

Certain amounts in the December 31, 1992 financial statements have been reclassified to conform with the December 31, 1993 presentation.

B. Endowment Fund Investments:

The cost and market value of investments held at December 31, 1993 and 1992 are as follows:

	1993		1992	
	Cost	Market	Cost	Market
U.S. Government and government agencies	$ 13,152,282	$ 13,602,220	$14,661,169	$ 14,818,296
Convertible bonds	-	-	504,312	489,937
Corporate bonds	10,587,481	10,965,298	10,988,953	11,369,752
Other bonds	12,068,502	12,549,104	881,946	920,972
Common stock	63,030,762	83,034,443	63,610,607	75,975,133
Other	3,818,044	3,151,588	2,909,062	3,158,673
Total investments	$102,657,071	$123,302,653	$93,556,049	$106,732,763

C. Investment Units:

The value of an investment unit at December 31, 1993 and 1992 was $2.5085 and $2.2491, respectively. The investment income per unit for 1993 and 1992 was $.0644 and $.0785, respectively.

	1993	1992
Unit value, beginning of year	$2.2491	$2.1866
Unit value, end of year	2.5085	2.2491
Net change for the year	.2594	.0625
Investment income per unit for the year	.0644	.0785
Total return per unit	$ .3238	$ .1410

D. Endowment Income:

Endowment income consisted of the following:

	1993	1992
Interest and dividends	$3,998,028	$4,687,677
Investment management costs	(489,085)	(485,239)
Net endowment income	$3,508,943	$4,202,438

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 pension cost accrued.

Combined net periodic pension cost for the two plans consisted of the following for 1993:

Service cost	$ 2,550,986
Interest cost	5,447,101
Actual return on plan assets	(14,596,216)
Net amortization and deferral	6,945,129
Net pension expense	$ 347,000

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Interest cost	5,447,101
Actual return on plan assets	(14,596,216)
Net amortization and deferral	6,945,129
Net pension expense	$ 347,000

Below is a reconciliation of the combined funded status of the plans at December 31, 1993:

Actuarial present value of obligation:	
Vested benefit obligations	$(56,008,322)
Nonvested benefits	(3,066,103)
Accumulated benefit obligation	$(59,074,425)
Projected benefit obligation	$(76,153,905)
Fair value of plan assets (primarily invested in common stocks and fixed income securities)	105,689,615
Plan assets in excess of the projected benefit obligation	$ 29,535,710
Unrecognized net transition asset	$ (4,141,021)
Unrecognized prior service costs	485,542
Unrecognized net gain	(25,880,231)
Prepaid pension cost	$ –

The fair value of plan assets listed above includes $101,235,635 of plan assets held in the Woods Hole Oceanographic Retirement Trust at December 31, 1993. In addition, the Institution has designated, as quasi endowment, $4,453,980 to fund certain supplemental benefits at December 31, 1993.

The discount rate and rate of increase in future compensation used to determine the projected benefit obligation as of December 31, 1993 were 7.75% and 5.0%, respectively. The expected return on plan assets was 8.75%.

F. Other Post Retirement 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 1993:

Service cost	$ 588,507
Interest cost	1,426,217
Net amortization and deferral	745,276
Net periodic postretirement benefit cost	$2,760,000

The Institution has a Voluntary Employees' Beneficiary Association Trust (the "Trust") that will be used to partially fund health care benefits for future retirees. In general, the Institution intends to contribute to the trust an amount equal to the annual expense of the plan. During the year ended December 31, 1993 the Institution paid $485,000 in retiree health benefits on behalf of the Trust. The following table sets forth the funded status of the Plan as of December 31, 1993:

Financial status of plan:	
Accumulated postretirement benefit obligation:	
Retirees	$(8,640,805)
Fully eligible, active plan participants	(5,470,036)
Other active plan participants	(6,411,787)
Total obligation	(20,522,628)
Plan assets at fair value	–
Unrecognized net transition obligation	16,217,437
Unrecognized net loss	2,030,191
Accrued postretirement benefit liability	$(2,275,000)

The assumed discount rate is 7.75 percent. The expected long- term rate of return on plan assets used in determining the net periodic postretirement benefits costs was 8.25 percent in 1993. The rate of increase in the per capita costs of covered health care benefits is assumed to be 9.0 percent in 1994, decreasing gradually to 5.5 percent by the year 1996 and remaining at that level thereafter.

If the health care cost trend rate assumptions were increased by 1 percent, the accumulated postretirement benefit obligation, as of December 31, 1993 would be increased by approximately $3.55 million; the effect of this change on the sum of the service cost and interest cost components of net periodic postretirement benefit cost for 1993 would be an increase of approximately $204,000.

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 1992. In these reports, the DCAA has proposed the disallowance of certain of these cost recoveries. The ultimate resolution of the DCAA claims is not certain, however, the Institution believes that it has meritorious defenses to these claims and intends to vigorously defend itself. The Institution believes that the ultimate resolution of these matters will not have material impact on its financial position.