GEORGE TUPPER

Heavily instrumented meteorological buoys (known as IMET buoys for Improved METeorological measurements) are loaded for Chief Scientist Bob Weller's summer 1991 R/V Oceanus *Subduction Experiment voyage. The Subduction Experiment involves studies of how surface forcing by the atmosphere in the eastern North Atlantic causes water from the mixed layer to be carried down into the interior of the ocean.*

Contents

Cover Photo: *NOBEL, the Near Ocean Bottom Explosives Launcher, is prepared for lowering on an* Atlantis II *cruise to the East Pacific Rise by, from left, Beecher Wooding, Rob Handy, Mark DeRoche, and Jim Broda.*

PHOTO BY CRAIG DICKSON

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TERRI CORBETT

A row of IMET buoys is ready for transfer to Oceanus *for the Subduction Experiment.*

TERRI CORBETT

Craig Marquette installs a tensiometer on an IMET buoy for monitoring tension on the line that bears instruments beneath the buoy.

Director's Comments

We have a challenge: to react rapidly— almost on a war footing—to global and national needs for knowledge about the environment and man's effect on it. At the same time, we must strengthen the support for science in a way that will enhance the intellectual freedom and creativity of individual researchers. WHOI has a good personnel and structural base from which to address this challenge, and we have given the subject considerable thought.

Our forte has always been the study of ocean processes and characteristics based on measurements at sea. We intend to retain this focus, and increase our capabilities for both observation and analysis. We see our role as providing the basic knowledge for wise decisions and policy making, and thus working to create an intellectual environment that enhances the somewhat chaotic, but disciplined, process of basic science. Education is an intrinsic part of our mission, and we will concentrate on the portions of the education process most closely attuned to our research focus, namely graduate and postdoctoral levels.

Our tight focus on the oceans and going to sea means that, rather than commit our limited resources to building major computational, or space, or climatic centers of expertise, we will seek to expand our ability to work continuously and in all areas of the ocean. For this reason our deep submergence capabilities, for example, are very important to us. And we will move from operating separate manned and unmanned projects to developing an integrated deep-ocean study system on board *Knorr*, which we will convert for this purpose. This plan formed the basis for our successful proposal to the Navy to operate their new research vessel AGOR-25, which should commence operations around 1997, when *Atlantis II* goes out of service.

We now have very limited abilities to work in the Arctic and at high sea states. We have argued strongly and consistently for introduction of new ship technologies like SWATH (Small Waterplane Area Twin Hull) that will enable us to conduct science in high latitudes in winter, and to work through, rather than run from, storms. The failure of the U.S. Coast Guard icebreaker *Polar Sea* to complete the 1991 Arctic expedition sharpened our concern about this deficiency, and sparked our commitment to improve.

One area in which we have made much progress recently is instrumentation. Improved access to the oceans implies a need for new data-gathering techniques and for rapid technological developments in areas as diverse as telemetry, floats, and measurement of basic physical and chemical properties. The Global Ocean Observing System, designed to help us understand environmental change, provides additional motivation for development of a new generation of unattended instruments to operate throughout the world oceans. One example—of many—is the Autonomous Benthic Explorer (ABE), a joint project of WHOI and the Japan Marine Science and Technology Center (JAMSTEC). ABE will be capable of conducting precisely repeatable observational tracks at abyssal depths for periods up to a year, allowing us for the first time to observe temporal variations in benthic activity.

FRITZ HEIDE

Craig and Cynthia Dorman board R/V Knorr *upon the ship's return from extended midlife refit. At right,* Knorr/Melville *project manager Joe Coburn welcomes Mike Palmieri, who was the ship's captain for the trip home.*

To improve the environment for instrument development we introduced career ladders for engineers and information processors to parallel our traditional research track. Additionally, we have raised over $3 million in less than a year from philanthropic sources to initiate innovative developments and to procure modern support hardware.

A second area of historical strength we wish to enhance is air-sea interaction, critical to understanding global climate processes. Boundary layer meteorology, near–surface ocean processes, and the exchange of heat, momentum, and chemicals are of interest to all of our departments. Several brilliant junior scientists in these areas joined us in 1991.

The third area where we are making a significant change is marine policy. We have had a strong program in this field for nearly 20 years, but have lacked a critical mass of resident scientific staff. In 1991 we moved the three researchers in our Marine Policy Center onto the regular scientific staff, and began searches for economists and lawyers whose scholarship and interest in oceanic issues complement the research and abilities

Director's Comments

of the rest of our science community.

A consistent theme in U.S. ocean science for the last couple of years has been "partnership," and for us that starts at a very basic and local level. We are involved in teaching "partnerships" at the village, town, regional, and state levels as a way for us to appropriately respond to the increased concern in the U.S. over the quality of science and math education at the K-12 level. With the right partnerships, we can be an incubator for marine instrumentation and biotechnology products, as demonstrated by WHOI scientists who have started their own companies. In a time of local and national economic problems, we are seen as a resource. In both education and the economic sector, we must aggressively yet carefully define how we can support legitimate societal needs without impacting our fundamental objective, to do basic research.

TOM KLEINDINST

A Massachusetts Maritime Academy honor guard greets the Russian Research Vessel Dmitri Mendeleyev *upon its November arrival at the academy pier. WHOI and the academy co-hosted a reception and tours for the* Mendeleyev *crew, who had retrieved a US Subduction Experiment mooring that went adrift in the eastern North Atlantic.*

WHOI's strength lies in its independence, both from the government and from any university. Partnerships we seek must exploit this strength, not weaken it. One advantage we have is the presence in our small village of the Marine Biological Laboratory, the National Oceanic and Atmospheric Administration's Northeast Fisheries Division, and the U.S. Geological Survey's Atlantic Branch Headquarters. We already share many common resources, such as our world-class library and our computing and networking center, and hope to expand upon such relationships as well as strengthen our common research interests. Partnerships extend into scientific interchange in regional studies, such as the Gulf of Maine and New York Bight, both bordered by several states.

More significantly, however, since our focus is on the global ocean, we value our ability to work closely on an institutional basis with our colleagues overseas. Oceanography is truly an international science, and our individual researchers historically have had very close ties with their colleagues from all nations. The multinational character of our scientific staff and students enhances those connections.

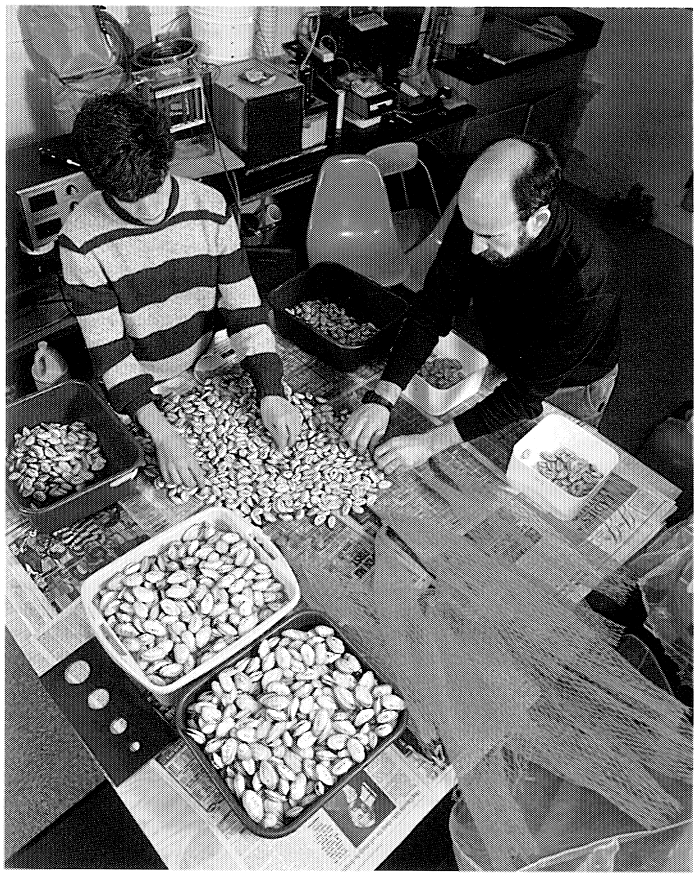
We at WHOI can, however, do more than simply encourage and passively support such natural interaction. We are able, because of our independence, to actively support both global and regional initiatives in virtually any part of the world. And because of the breadth of expertise of our scientific staff we can bring both capability and interest to bear on a very wide range of marine questions. Two of my personal interests have been our interactions with Japan and the nations of the former Soviet Union. I believe our joint agreements with JAMSTEC and the P. P. Shirshov Institute of Oceanology and others have proven beneficial to both sides.

The problems of semi-enclosed, or mediterranean, seas are drawing increasing interest. Although historically, because of our extensive borders on the Atlantic and Pacific, our attention has focused on coastal and world ocean studies, we are beginning to take a stronger interest in the research problems presented in the Red, Mediterranean, Caribbean, and Black Seas, the Arctic Ocean, and the string of seas along the Asian mainland coast. As an example of our activity in such seas, in the fall of 1991, we coordinated a five-ship multinational survey of the Black Sea, followed by an international workshop in Varna, Bulgaria, where, working with steering committees from each of the nations that border the Black Sea, we outlined a multi-year set of national and international studies of that beleaguered basin.

International activities are of particular importance to WHOI because of both the scientific value of these regional studies and the opportunities they provide for access to areas, ideas, problems, people, and facilities unavailable through our normal national procedures. As good and open as our U.S. system is, it affords only a limited number of paths for scientific inquiry and inevitably imposes administrative burdens. Opportunities for going to sea, diving, and working with our international colleagues greatly expand our options, and we plan to enhance them.

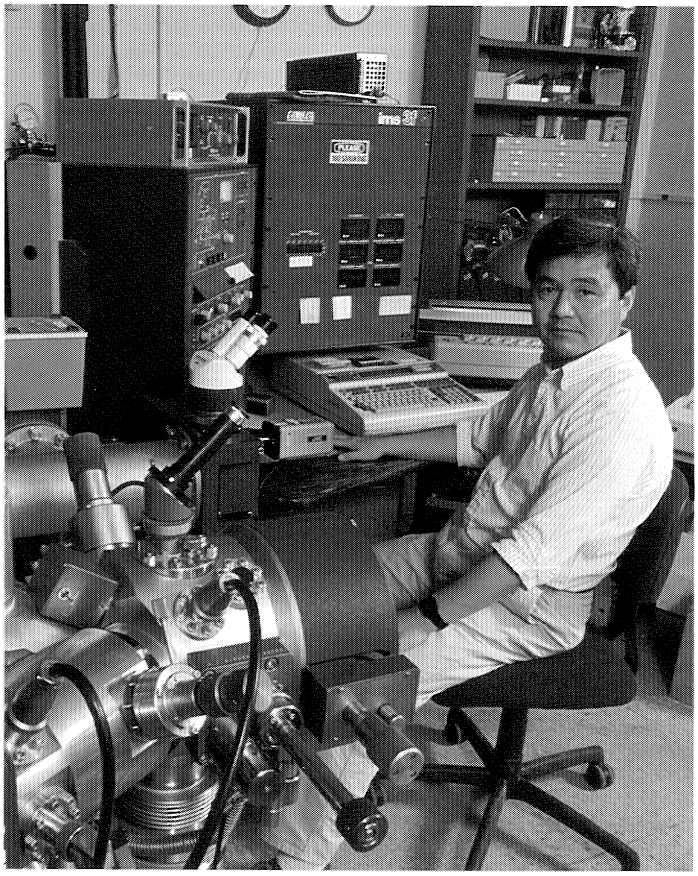
In conclusion, we at WHOI believe our basic skills and approach—to do the best ocean science, to concentrate on making measurements at sea and understanding them, and to support the national and international oceanographic communities—are a good match to both the scientific opportunities we envision, and the societal needs for our products: basic knowledge, and the next generation of skilled scientists.

Craig E. Dorman,
Director



TOM KLEINDINST

Brennon McKeon, left, and Bruce Lancaster sort shellfish collected for studies of a clam disease called hematopoietic neoplasia.



TOM KLEINDINST

Nobumichi Shimizu determines chemical and isotopic composition of rock and sediment samples with the ion microprobe facility.

TOM KLEINDINST

Liz Osborne and Al Gagnon are at work in the sample preparation laboratory of the National Ocean Sciences Accelerator Mass Spectrometry Facility.

MARY JO WHEATLEY

Rose Petrecca and Nathan Ulrich rig coring devices for ROV Jason *on a deep-water dumpsite cruise.*

TERRI CORBETT

Greg Cotter helps prepare R/V Oceanus *for a cruise.*

TOM KLEINDINST

Gary Bond, left, and Brian Way check out Sea Soar, a towed conductivity-temperature-depth measuring tool, aboard R/V Oceanus. *SOFAR floats and their listening stations are ready for sea in the background.*

Comments from the Associate Director for Research

In 1991 we continued to pursue two important areas identified in our 1990 reassessment of the Institution's science strategy. A number of significant processes need to be evaluated if we are to understand the role the ocean plays in controlling global climate change. The exchanges of heat, momentum, and chemical constituents at the air/sea interface are the core of this understanding. These areas of research constitute the major cross-departmental science initiative for the Institution. We are formulating plans for a research program at the interface of the fields of oceanography and meteorology. The plan includes physical facilities, such as a meteorological sampling tower, a visiting scholar exchange, student traineeships, and course exchanges with university meteorology departments.

The second major initiative of our science strategy is to improve the mechanism for developing advanced research instrumentation, sensors, and platforms. Over the past several years, we have recognized the need for high speed, robust sensors and instruments that can operate in the harsh, wave driven, temperature variable, salty oceanic environment. Scientists and engineers need time to prepare proof-of-concept drawings and prototype sensors and instruments to test their ideas before they submit them to a federal agency for major funding. The Institution's Keck Technology Award Program, established in 1991, provides just such a mechanism. In its first year, nine proposals were funded. They included development of an acoustic method to calculate rain rate over the ocean and planning for use of transoceanic telephone cables for seismic studies of earthquakes on the ocean floor.

In addition to these cross-departmental initiatives, 1991 advances in research ranged from using neutrally buoyant floats to track the circulation of equatorial waters and unravelling the complexities of the marine food web among small microorganisms, to drilling the deepest hole anywhere in the world's oceans into Earth's hard-rock crust. A detailed description of these studies, among several in the various science research areas, are covered in the individual department reports that follow.

These and other advances brought a healthy 7.3 percent increase in our federally sponsored research support for 1991. However, there may be an ominous funding future for scientific research in this country. There is increasing pressure to provide and interpret basic scientific information for state and federal legislators as they formulate policies in important areas, such as climate change and coastal pollution. However, the process by which the science budgets are decided in Washington appear more chaotic and less predictable each year. The costs of doing research continue to rise; at the same time science competes with other needs, including social programs, for federal dollars. Congress appears to be more concerned with the business aspects of institutions and universities, such as the indirect cost rate structures, than with how advances in science and technology can help to solve the major problems facing our society today. The government/academic research partnership now shows cracks in its foundation and it is this partnership that has been responsible for the unprecedented growth and accomplishments of basic research in this country over the past 50 years.


DAVID GRAY

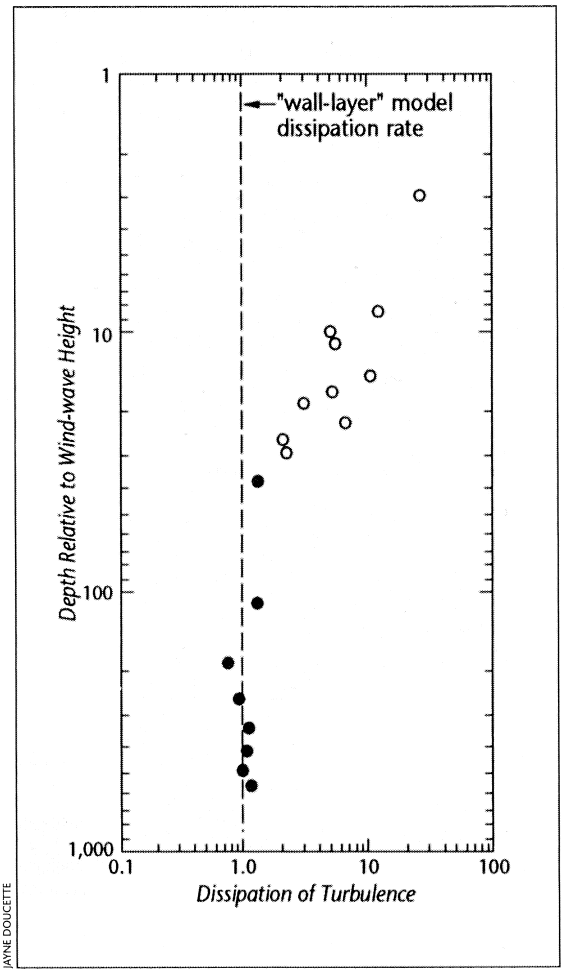
Robert Gagosian, right, speaks with Brad Butman, left, and Mike Bothner of the U.S. Geological Survey, Woods Hole Branch at the dedication of the National Ocean Sciences Accelerator Mass Spectrometry Facility.

While these changes and new forces on scientific research bring many concerns, there are also exciting opportunities. It is critical that we in the ocean sciences carefully think through the directions our efforts and resources are taking. We must be careful not to concentrate our efforts on what is popular or be overly influenced by the agendas of external agencies and organizations. We need to think carefully about the uniqueness of what we can do well in the ocean sciences and pursue these avenues with vigor.

Robert B. Gagosian,
Associate Director for Research

While it is impossible in a short space to mention all of the research in the Applied Ocean Physics and Engineering Department (AOP&E), it is possible to look at various areas of emphasis within the department.

Coastal oceanography and air-sea interaction research in AOP&E are of great importance to the environmental issues of dredge-spoil disposal, global warming, and city sewage outfall effects. Theoretical studies, which are integral to AOP&E's combined scientific and engineering goals, have resulted in new insights into the benthic boundary layer, scattering of sound in the ocean, and marine cable dynamics. Instrumentation development is an obviously important topic. Efforts along those lines have included smaller, lower-power current meters; inductive modems to telemeter ocean-sensor information to shore through ocean-bottom telephone cables; improved, modular, meteorological stations; and high-resolution acoustic tracking systems.



JAYNE DOUCETTE

A comparison of Water-Air Vertical Exchange Study measurements (open circles) and previous observations (solid circles, data from A. Soloviev) illustrates the recent finding that turbulent mixing, likely to be the result of breaking waves, plays an important role in near-surface mixing.

The development of techniques for measurement and analysis is just as important as the development of instruments, and goes hand in hand with the latter. If we can measure the ocean better with existing technology just by doing things differently, or extract more information from "routine data" by clever processing, it is clearly a significant step forward. Work in acoustic telemetering of information through the ocean, robot manipulator-arm control, and mathematical inverse theory to infer ocean structure from sound scattering fit in this category.

Other areas of research include: mooring and tow-cable dynamics, tethered and free submersible vehicles (perhaps the most glamorous tools the oceanographer uses), that help us explore regions previously inaccessible and still dangerous, and numerous other topics.

Since this short discussion cannot be inclusive, descriptions follow of three projects that are, in many ways, representative of AOP&E's efforts.

Near-Surface Mixing Beneath Waves Is Surprisingly Vigorous

Understanding turbulent mixing close to the ocean surface is central to understanding a wide range of other phenomena, such as the vertical structure of currents, the exchange of gases across the air/sea interface, the entrainment of surface pollutants, and the dynamics of the short waves imaged by remote-sensing instruments. The force exerted by the wind on the water surface generates both waves and turbulent currents. Previous observations suggest that these two kinds of motions do not interact strongly, and that the structure of the current close to the interface is equivalent to the sheared flow (velocity difference of adjacent layers) that would result from dragging a rigid plate along the surface. In such a "wall-bounded" flow (an example is the marine atmospheric surface layer), mixing is entirely due to turbulence generated by the mean shear. This model neglects wave breaking entirely, and therefore does not incorporate the well-known observation that such breaking intermittently produces large amounts of turbulence. Although individual breakers provide an extremely efficient mechanism

or transporting energy, momentum, and mass across the interface, the net transport rate depends on the frequency of breaking. The latter is poorly known, and consequently the overall importance of wave breaking in air-sea interaction has been difficult to assess.

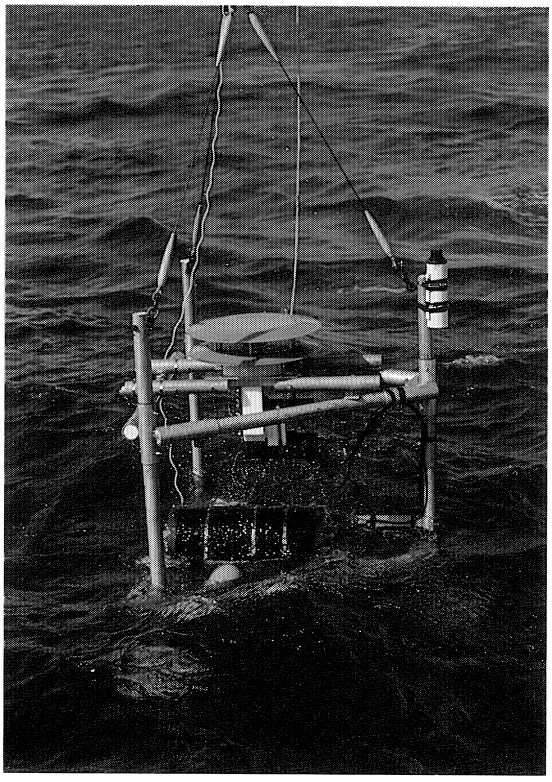
This problem was addressed in the recent Water-Air Vertical Exchange Study (WAVES) sponsored by the National Science Foundation (NSF). Gene Terray, Sandy Williams, and Yogi Agrawal (now at Quest Integrated) along with investigators from several other laboratories examined the applicability of the "wall-layer" model in a region substantially closer to the surface than previously explored. The experiment resulted in the surprising finding that close to the surface the level of turbulent mixing is several orders of magnitude greater than the analogous "wall-layer" result. Such a large deviation is likely the result of breaking waves imparting additional energy into the near-surface waters, and underscores the importance of wave breaking to near-surface mixing.

New Pump Aids Studies of Patchiness in Ocean-Bottom Plankton Populations

Associate Scientist Cheryl Ann Butman studies the effects of currents on distributions of planktonic juvenile stages ("larvae") of animals that live on or in ocean-floor sediments as adults. Because many planktonic animals have sophisticated escape reactions to flow disturbances, they are difficult to collect for population studies. For example, pumps intended to overcome the animals' escape speeds have very fast intake velocities and are limited to short sampling periods that depend on surface vessels for large amounts of power. Much longer time series are needed, however, because of patchiness in animal distributions.

Butman and Senior Engineer Ken Doherty took a different approach to plankton sampling when they were funded by NSF to develop the Moored, Automated, Serial Zooplankton Pump, the first computerized, long-term moorable plankton pump. Its design minimizes disturbances to the incoming flow, and thus to the organisms, so that a much slower intake velocity is effective, and the power requirement is considerably reduced. Rather than sampling with a nozzle, the intake on the new pump consists of two horizontal, circular plates that are hydrodynamically streamlined like airplane wings, tapering to a sharp point at the circumferential edge. Water is pumped down through a hole in the bottom plate and over mesh screening, where animals larger than the mesh size are retained and preserved for later identification. The sampling strategy is to let the natural flow carry animals between the plates without disturbing them and then to gently extract a sample of this water at the plate center. This pump can measure time series of zooplankton concentrations as deep as 1,500 meters for as long as six months in virtually any type of water flow. It allows measurements of plankton abundance and physical properties, such as flow speed and water temperature, at the same time and space scales so that conditions responsible for plankton patchiness can be evaluated.

Butman's laboratory is currently examining and classifying the first two sets of deep-sea samples taken in the fall of 1991.



CHERYL-ANN BUTMAN

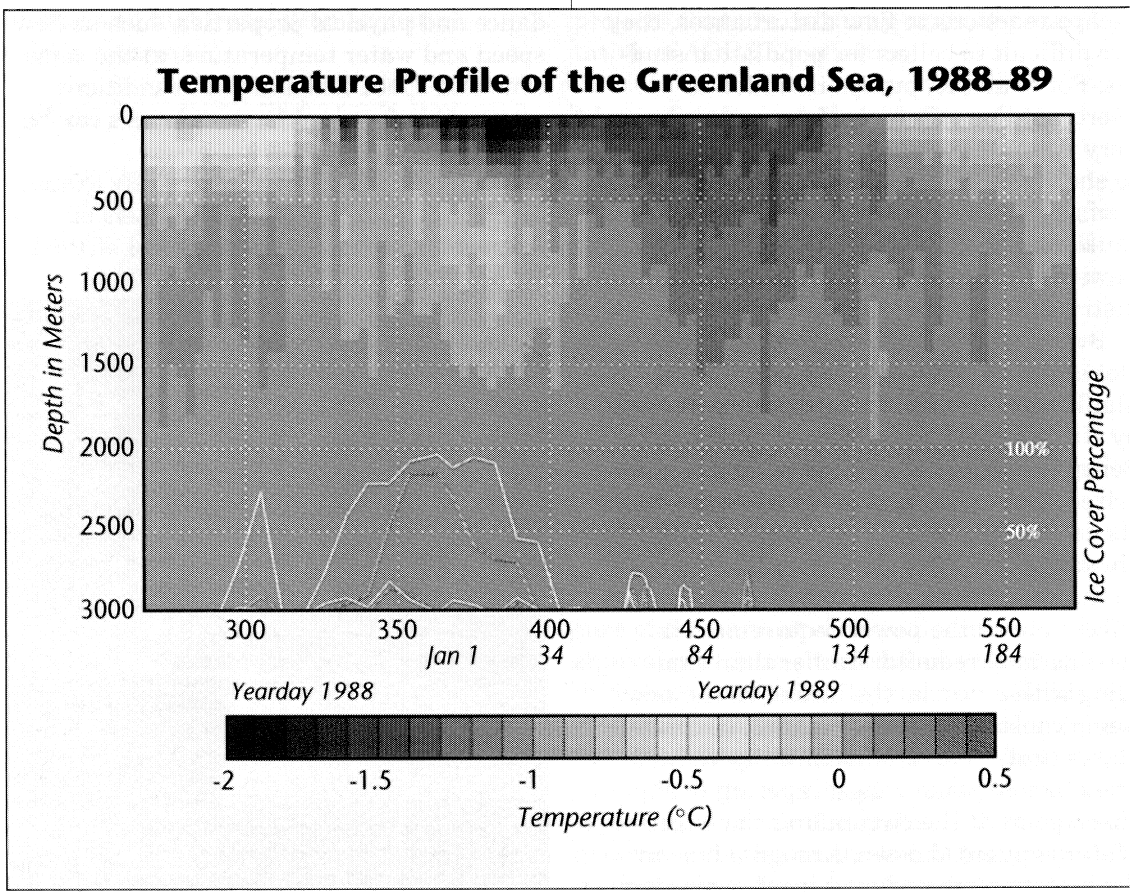
The moored, automated, serial, zooplankton pump goes over the side of R/V Edwin Link *(Harbor Branch Oceanographic Institution) at a St. Croix study site in October 1991.*

New Tomographic Studies Reveal Ocean Temperature and Arctic Ice Sheet Structures

WHOI has played a sigificant role in the development of ocean acoustic tomography, a technique that makes three-dimensional "cat-scan" images of the ocean's temperature and currents with sound. In 1991, AOP&E graduate student Richard Pawlowicz produced the first tomographic "slice" pictures of the temperature structure of the Greenland Sea using data collected during 1988-89 collaboratively by the Scripps Institution of Oceanography and WHOI.

These pictures clearly show the formation of Greenland Sea Deep Water, whereby cold, dense surface waters sink to great depths during the late Arctic winter. This process is an important part of what noted oceanographer Wally Broecker (Lamont-Doherty Geological Observatory) calls "the Great Ocean Conveyor," in which cold northern waters sink to depth and move southward, while warm mid-latitude surface waters move northward and are cooled, thus maintaining the world's climatic balance. Another important tomographic result obtained in 1991 was an actual cross section of a sheet of arctic ice in the field. Ocean ice is a very complex material, whose properties are largely unknown. By using an array of high-frequency sources and receivers, Subramaniam Rajan and his collaborators were able to map out the structure and material properties of an ice sheet in the Canadian Arctic.

The tomography work is jointly funded by NSF and the Office of Naval Research (ONR).



A tomographic time series record of temperature in the Greenland Sea shows formation of deep water over days 430 to 450.

Diversity of scientific interest and effort is a key ingredient in the success of this department's pursuit of new knowledge about the biology of the oceans. The expertise of the 27 scientific staff members ranges from bacteria to whales. The habitats and ecosystems explored extend from salt marshes to the open ocean, from the surface of the sea to the deep seafloor, and from the tropics to arctic and antarctic polar waters. The studies run the gamut from more traditional work on the systematics, distribution, abundance, physiology, biochemistry, and behavior of oceanic and coastal species to newer, fashionable research on marine pollution, molecular biological oceanography, and mathematical modeling of marine systems. A number of these research projects involve the development of new instrumentation. During 1991, this full spectrum of biological oceanographic research was addressed in 77 publications.

Diversity of funding sources is also a mark of the department with 141 proposals submitted to eight federal funding organizations and a number of private organizations as well as the Commonwealth of Massachusetts. About half of these have or will receive partial to full funding.

Many of the scientific staff were honored this year with requests to serve on editorial boards of highly regarded journals, to be visiting scholars or distinguished lecturers, or to present invited lectures. Of particular note was the announcement that Holger Jannasch was to receive the Cody Award of the Scripps Institution of Oceanography for his contributions to marine microbiology.

Brian Howes was notified by the Renew America awards program that an environmental program he heads, Falmouth Pondwatchers, was selected for an Environmental Achievement Award and accepted for listing in the 1991 Environmental Success Index.

Postdoctoral Scholar and newly appointed Assistant Scientist Mark Hahn received the prestigious New Investigator Award from the Air Force Office of Scientific Research through the Society of Environmental Toxicology and Chemistry. In addition, Judith McDowell and John Stegeman organized and cochaired the Sixth International Symposium on Responses of Marine Organisms to Pollutants held in Woods Hole. Over 200 individuals representing 14 countries attended the week-long meeting.


WHOI GRAPHICS

Flowering trees frame Redfield Laboratory where a large share of WHOI biology laboratories are located

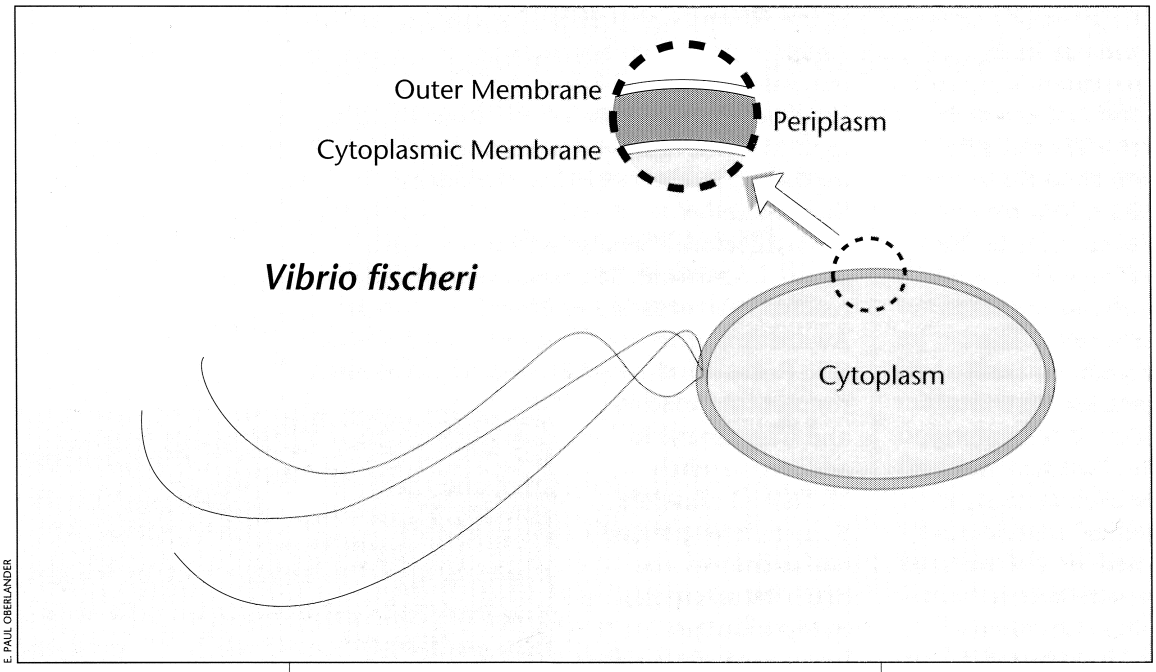
The Protein and Nucleic Acid Chemistry Center completed its second full year of operation, providing molecular biological services to investigators at WHOI, the Marine Biological Laboratory, and other research laboratories around the country. An increasing number of staff members and students are using molecular-based tools and techniques to study marine organisms, and the center is viewed as an essential element in the successful development of this area of research in the Woods Hole community.

A Nucleotide Both Turns on the Lights and Supports Growth

Microbiologist Paul Dunlap is interested in symbiosis between bacteria and marine animals, such as fish and squids, especially those in which light-emitting bacteria are housed in specialized tissues, called light organs. The bacteria produce visible light (bioluminescence) that the animal uses to help it locate food, avoid predators, and find mates. Dunlap's research focuses on the physiological and molecular-genetic mechanisms for how the symbiotic partners cooperate to benefit each other.

During recent genetic studies of how a particular nucleotide (3':5'-cyclic adenosine monophosphate, or cyclic AMP) turns on bioluminescence in *Vibrio fischeri*, a bacterium that is symbiotic with pinecone fish and certain squids, Dunlap found that this bacterium can grow on cyclic AMP, using it for energy and for new carbon-cell material. He found that *Vibrio fischeri* can also obtain from this compound the phosphorus and nitrogen necessary for growth. Before these observations, no bacterium was known to be able to grow on cyclic AMP, which is involved in gene regulation in many organisms.

Dunlap found that the ability of *Vibrio*



E. PAUL OBERLANDER

During studies of the bioluminescent bacterium Vibrio fischeri, *Paul Dunlap made the novel discovery that the organism uses the nucleotide 3':5'-cyclic adenosine monophosphate for growth. An enzyme that breaks down the nucleotide was found in* Vibrio fischeri*'s periplasm while most bacteria place this enzyme in the cytoplasm.*

fischeri to grow on cyclic AMP resulted from synthesis of an exceptionally high level of an enzyme that breaks down cyclic AMP (3':5'-cyclic AMP phosphodiesterase) and placement of this enzyme in the periplasm (the area in a bacterium between the cytoplasm and the environment), a novel cellular location for 3':5'-cyclic AMP phosphodiesterase. Other bacteria produce low levels of this phosphodiesterase and place it in the cytoplasm where it functions to control the cellular level of the nucleotide. The observations with *Vibrio fischeri* help explain how cyclic AMP, which is produced by bacteria plants, and animals, is recycled in the marine environment Cyclic AMP and othe cyclic nucleotides could therefore play previously unrecognized role in the carbon, phosphorus, and nitrogen budget of the ocean.

Dunlap speculates that cyclic AMP and the periplasmic cycli AMP phosphodiesterase are important in the symbiosis of *Vibrio fischeri* wit its animal hosts, with cyclic AMP released by the animal as a food source for *Vibrio fischeri* or as a way of preventing other kinds of bacteria from infecting the light organs, since cyclic AMP can be toxic to bacteria unable to break it down. To better understand the function of the periplasmic cyclic AMP phosphodiesterase in the ecology of cyclic nucleotides and in bioluminescent symbiosis, Dunlap's laboratory has cloned and is now analyzing the gene for this enzyme. The work is funded by the National Science Foundation.

Microbial Food Web Studies Take a New Look at Nutrient Recycling

Studies within the last several years have changed our understanding of the role of bacteria and bacteria-sized phytoplankton in the food webs of open-ocean environments. It is now firmly established that these microorganisms form a major, and often dominant, component of the biota of oceanic ecosystems, often comprising 50 percent or more of the living biomass. Clearly, there is a major role for these minute microorganisms in the energetics of oceanic plankton communities, and the production and fate of these populations has become one focal point for biological oceanographic research.

Two major objectives of David Caron's research are to identify the consumers of small phytoplankton and bacteria in the ocean, and to quantify the flow of energy through these consumer assemblages. This research program, funded by NSF, has entailed work on Georges Bank and at a study site south of Bermuda in the Sargasso Sea. Based on a series of cruises conducted over the last two years, a cleare understanding of the flow of energy at the base of oceanic food chains is emerging. These studies indicate the presence of a complex food web among small microorganisms in these environments, and a fundamental role for single-celled consumers, th protozoa, as links in the microbial food wel One implication of these results is that much of the food consumed by higher organisms in the plankton of oceanic ecosystems has first passed through several consumer populations within the microbia community.

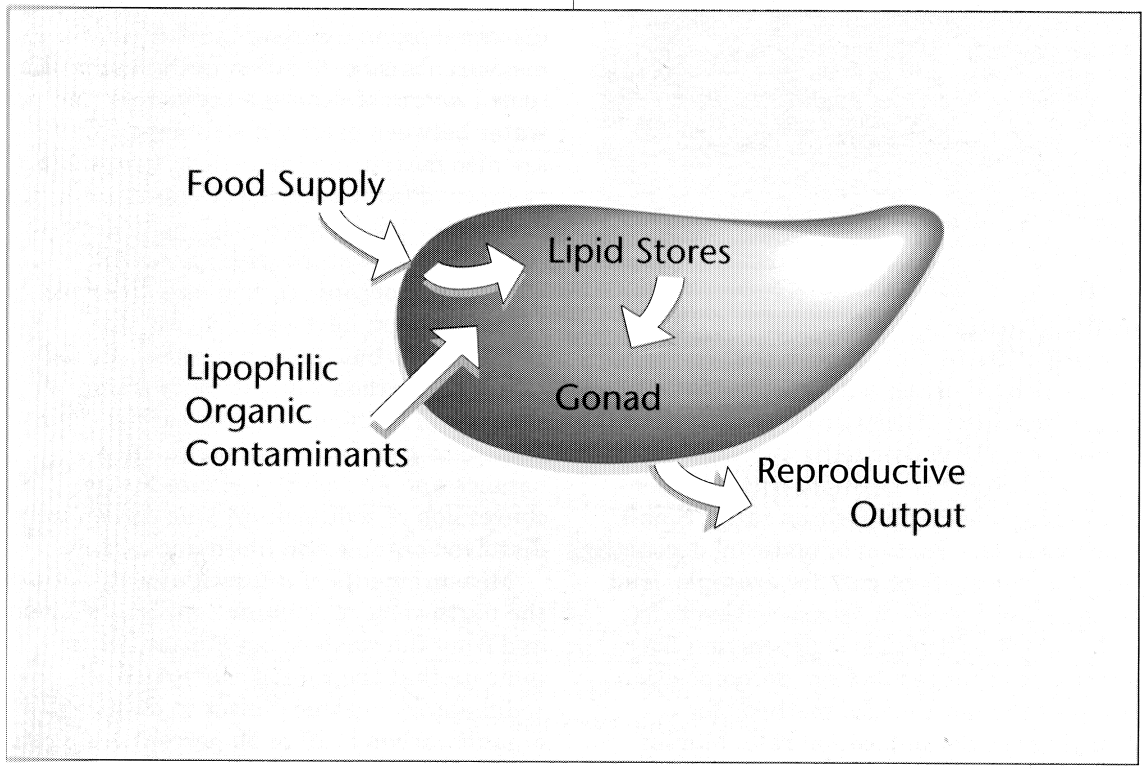
Contaminated and Uncontaminated Mussels Show Contrasting Reproductive Success

Zoologist Judith McDowell studies how marine animals adapt to perturbations in their environment, with specific emphasis on the effects of starvation, disease, and exposure to chemical contaminants. Many marine animals depend on the storage of lipids (fatty substances) as energy reserves for periods of low food supply and for reproduction. Optimization of lipid storage and mobilization of lipid reserves are critical to the reproductive and developmental success of marine animals. Understanding lipid metabolism provides insight to some of the biochemical and physiological processes that regulate adaptive responses and reproductive success.

McDowell aims to gain a better understanding of basic aspects of lipid metabolism in marine animals, the relationship of lipid accumulation and turnover to reproduction and development, the toxic action of organic contaminants such as petroleum hydrocarbons, polychlorinated biphenyls, and pesticides that are attracted to lipids (and therefore termed "lipophilic"), and the interference of such contaminants with lipid metabolism. The work, funded by the National Oceanic and Atmospheric Administration, includes examining the effects of lipophilic contaminants on the seasonal cycle of lipid accumulation and allocation to gamete production in *Mytilus edulis,* the common blue mussel.

Mussel populations from uncontaminated Cape Cod habitats accumulate lipid reserves from late fall through early winter to an early spring maximum. Lipid accumulation coincides with the onset of gamete development. Once the release of gametes commences (mid-April through early summer), lipid reserves decrease to a late summer-early fall minimum, and the seasonal cycle begins again.

McDowell's laboratory finds that exposure to lipophilic organic contaminants results in reduced lipid accumulation, impaired gamete formation, and diminished reproductive output. During the spawning period, contaminated mussels resorb gametes rather than release them. McDowell and colleagues suggest that this resorption may be a resistance strategy to help the animals survive the effects of contaminant exposure, and that understanding alterations in lipid turnover may provide insight into processes involved in both uptake of contaminants and reproductive toxicity.



The role of lipids in the reproductive cycle and the state of organic contaminants in bivalve mollusks.

The Chemistry Department was wide-ranging and successful in 1991. After a considerable effort to obtain funds, a new high-resolution, hybrid mass spectrometer, unique in the oceanographic community, was ordered to improve the speed and sensitivity of measurements for the organic geochemistry group. Also, a remote sensing group was organized to focus on modeling upper ocean biogeochemical processes using satellite observations.

Fred Sayles stepped down as department chairman at the end of the year, and is succeeded by Geoff Thompson, who also served as department chairman from 1972 to 1982. After 17 years as Executive Assistant for the department, Susan Kadar moved down the hall to the Joint Global Ocean Flux Study office, where she is coordinator of field programs. Susan Casso is the new Executive Assistant.

Another change came at the end of the year to be effected in 1992: the department will now be called the Marine Chemistry and Geochemistry Department to better reflect the research underway.

The department includes more than 20 scientists who are working on a large variety of projects, including three highlighted below for 1991.

Studies of Dissolved Organic Carbon in Sedimentary Waters Suggest It Has an Important Role in the Carbon Cycle

Bill Martin is taking a new look at the decomposition rates of biologically derived (biogenic) material on the seafloor. The fate of organic carbon cycling through the ocean is of major interest today, largely because carbon dioxide is considered a major player in global warming. Only about 1 to 10 percent of the organic carbon that falls to the seafloor is preserved in the seafloor sediments. If scientists are to interpret the historic rate of photosynthesis from sedimentary records, it is important to understand biogenic decomposition rates. Small changes in the fraction of material decomposed at the seafloor can, for example, lead to large changes in the preservation rate.

WHOI GRAPHICS

The Fye Laboratory is home base for several WHOI chemists.

Measuring the rates of production for substances that result from decomposition is one of the most useful methods for studying the decomposition rate. Martin has been testing a long-held assumption that most biogenic carbon is oxidized to carbon dioxide by bacteria living in the sediments. This carbon dioxide is converted to several chemical forms, known collectively as "dissolved inorganic carbon," and diffuses back into the deep ocean. In an NSF-funded project, Martin and Dan McCorkle of the Geology and Geophysics Department are investigating the importance of an alternative product of the decay of biogenic material: dissolved organic carbon. They have adapted recently developed methods for measuring the amount of dissolved organic carbon in seawater to measure its concentration in the interstitial (pore) waters of deep-sea sediments (the water between grains of sediment). They are also measuring the ratio of two stable isotopes of carbon, carbon 13 and carbon 12, in the dissolved organic carbon for comparison with pore-water inorganic carbon. Dissolved inorganic carbon and dissolved organic carbon have different isotopic compositons, but the two together should reflect the carbon isotopic composition of the bulk of sediment organic carbon. The scientists' goal is to construct a mass balance and an isotope balance for the conversion of sediment organic carbon to dissolved organic and inorganic carbon.

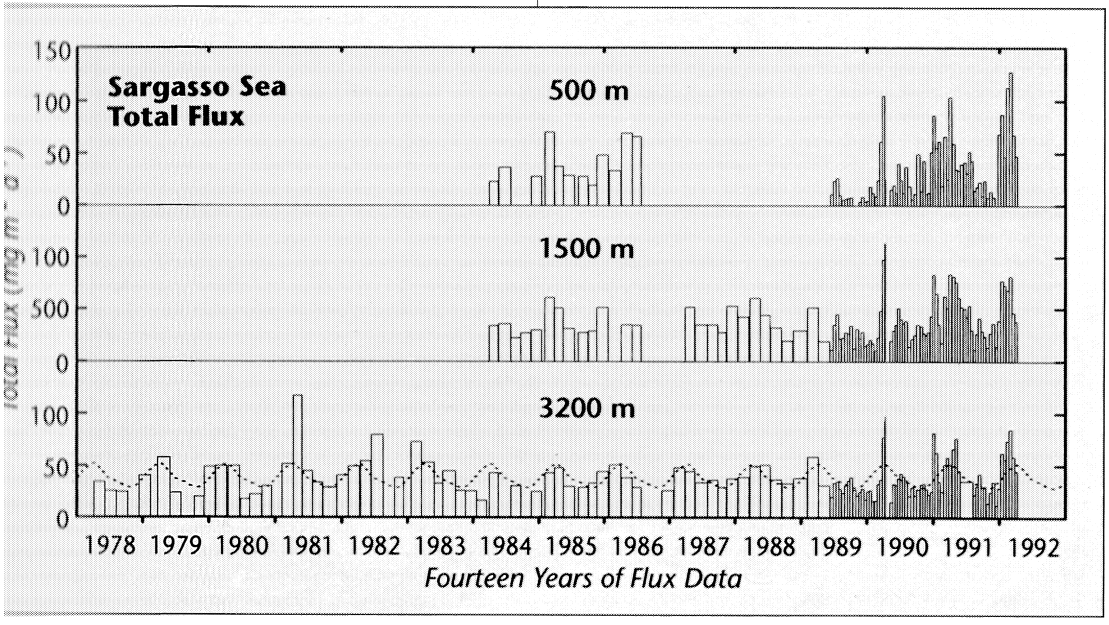
Measurements of interstitial waters from the northwestern Atlantic continental slope and from the western equatorial Pacific indicate that the rate of conversion of sedimentary organic matter to dissolved organic carbon is 10 to 50 percent of its rate

conversion to carbon dioxide. Therefore, vestigators who ignore dissolved organic rbon production risk underestimating the te of decomposition by as much as one-rd. Initial isotopic composition measure-nts indicate that dissolved organic rbon is depleted in carbon 13 relative to limentary organic matter; this is consistent with earlier studies that suggest metabolic carbon dioxide in interstitial waters is enriched in carbon 13 relative to sediment organic matter. Thus, these initial measurements indicate that dissolved organic carbon may be important in the carbon and carbon-isotope budgets of marine sediments.

urteen Years of Particle Flux Data Bring New Insights

Werner Deuser has been measuring the x of particles sinking into the deep rgasso Sea continuously for 14 years. He es sediment traps (large funnels) sus-nded at different depths in the ocean to ercept the sinking particles and store m in sample bottles programmed to ange at regular intervals. One of his jor interests is to determine the magni-le and variability of the "rain rate" of rbon to the deep ocean. When Deuser rted his NSF-supported study, that rate s thought to be rather constant. He soon covered, however, that it changes sonally and from year to year, in a ttern directly related to and closely on heels of similar changes in the amount plankton produced in the surface water. us, through the unexpectedly rapid king of particles, the deepest parts of ocean and their inhabitants are closely ked to the cycle of seasons at the sur-e. That rapid linkage also means that llutants introduced at the ocean's surface reach its deepest parts within weeks.

Most of the sinking particles are waste products and residues of life in the upper ocean. A significant fraction of the waste consists of carbon thus removed from the upper ocean and, indirectly, from the atmosphere by a process known as the "biological pump." It is thought by some to play a part in the removal of fossil-fuel carbon dioxide, the major "greenhouse gas," from the atmosphere. Just how much carbon is removed in this way worldwide, and whether or not the amount is changing, is not known, but finding out is one of the goals of global change research. By comparing the variability in his 14-year carbon flux data to the variabilities in simultaneous series of upper-ocean properties, such as sea-surface temperature or wind speed, Deuser seeks to identify one similar enough to serve as a more easily measured "proxy" for carbon flux to the deep ocean. He hopes to find one that can be measured by satellite so the biological pump can be assessed continuously and on a global scale.



Sargasso Sea total particle flux at 500, 1,500, and 3,200 meters over 14 years. The average annual cycle is indicated by the dotted line. The particle flux lags the primary production cycle by about 30 days.

Bacteria Play an Important Role in Trace-Element Geochemistry

Trace elements, substances that occur in very slight amounts, are important in the oceans as micronutrients and as tracers of oceanographic processes. Jim Moffett studies the geochemistry of manganese in the upper ocean, focusing on reactions that control its distribution by leading to uptake onto sinking particles. He is interested in the role bacteria play in removing manganese from seawater by oxidizing it into a particulate form. The resultant manganese oxides form a hard capsule around the bacteria. Nobody knows why the bacteria do this, but it appears to control manganese distributions in seawater in most marine environments studied so far. Furthermore, Moffett found that not only is this process important for manganese, but that other elements with no known biological function, such as cerium, are coprecipitated as well, and their geochemistry is also dominated by this process. Once formed, the oxides have some interesting properties. They are dissolved under reducing (low or zero oxygen) conditions, and they can be dissolved photochemically by sunlight, releasing the manganese and associated element back into solution. In this way regions of enrichment and depletion of these element are formed throughout the marine environment.

With funding from NSF and ONR, Moffett conducted studies in the equatorial Pacific in August 1991 and found it to be a anomalous environment where manganese oxidation does not occur to any significant extent. Clearly there is something unique about this region that is not conducive to manganese oxidizing bacteria. It may be related to the extremely low levels of manganese and other biologically essential elements such as iron, which may be required for bacterial growth. The levels are low because this region is so remote from continental sources of these elements. Further comparative studies of manganese behavior in remote environments and in environments where reduced oxygen reactions are important are planned with the goal of enhancing understanding of the process of microbial manganese oxidation and assessing its geochemical significance.

TERRI CORBETT

R/V Oceanus is at the WHOI pier between 1991 cruises.

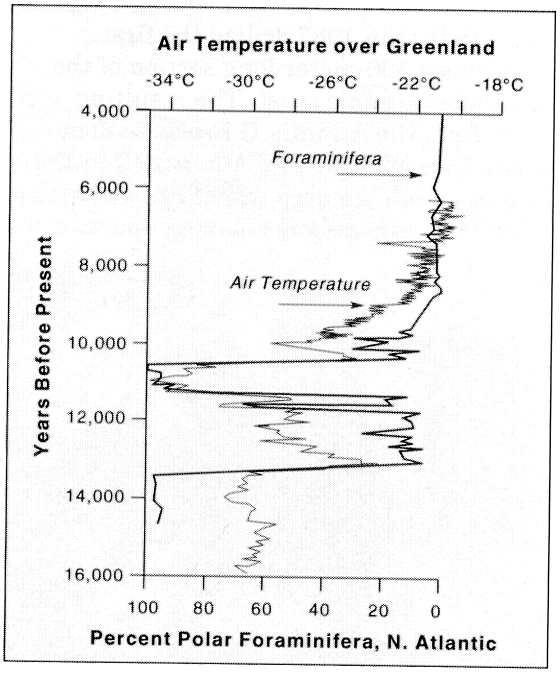
The year 1991 was an active one in the Geology and Geophysics Department. A new chairman, Mike Purdy, was appointed in January; Marine Geophysicist Bob Detrick joined the department as a Senior Scientist (leaving the University of Rhode Island), adding substantial strength to WHOI seismological research efforts; and Delia Oppo became the new Assistant Scientist in the successful paleoceanography group. Al Uchupi was awarded the prestigious Francis P. Shepard medal in Marine Geology by the Society of Economic Paleontologists and Mineralogists, and Petrologist Henry Dick was co-chief scientist on the international Ocean Drilling Program vessel *JOIDES Resolution* when in November it penetrated more than 2,000 meters below the ocean floor to drill the deepest hole anywhere in the world's oceans into Earth's hard rock crust.

Besides these highlights, 1991 was a successful year in general. The 34 members of the scientific staff working on 125 different projects generated 47 research papers and submitted 130 research proposals. As in previous years, although a wide range of funding agencies is solicited, most of the department's support, about 80 percent, came from the National Science Foundation and the Office of Naval Research.

The healthy diversity of research topics focused in paleoceanography, marine seismology, tectonics, marine geology and petrology, and geochemistry confounds any attempt at generalized description. But three landmark research efforts that achieved particular success in 1991 deserve specific explanations. These studies illustrate well how basic research in the Geology and Geophysics department has advanced understanding of such diverse processes as those that control climate change and those responsible for the creation of two-thirds of our planet's surface.

Paleoceanographers Correlate Past Sea-Surface and Atmospheric Temperature Changes

One important means of understanding humankind's impact on the planet's climate is a thorough determination of the nature and causes of substantial climate changes known to have occurred in the past, prior to human intervention. Recent NSF-funded research by paleoceanographers Scott Lehman and Lloyd Keigwin provides new insight into this issue and further emphasizes the importance of understanding the role of the oceans in the processes that control climate change. Based on a study of faunal and isotopic variations in a sediment core taken off the coast of Norway, provided by Norsk Hydro A/S, they have shown a remarkable correlation between past changes in sea-surface temperature and rapid changes in atmospheric temperatures determined from oxygen isotope ratios in Greenland ice cores. Because of unusually high sedimentation rates at the core site in the Norwegian Trench, the stratigraphic resolution in time is exceptional, permitting documentation of sea-surface temperature changes of more than 5°C in fewer than 40 years. Such massive changes in ocean temperatures, and consequently in air temperatures, occurred repeatedly during the close of the last ice age between about 13,500 and 9,000 years ago. Lehman and Keigwin conclude that these sudden shifts were driven by the impact of ice-sheet melting, and hence freshwater flux, on the thermohaline circulation of the ocean, which today effectively draws the heat of the sun from temperate latitudes towards the poles.



Correlation between air temperatures over Greenland, deduced from oxygen isotope variations in ice cores, and radiocarbon-dated changes in the proportion of polar foraminifera in a marine sediment core from the Norwegian Trench, in the northeastern corner of the North Atlantic. The larger faunal shifts correspond to sea surface temperature changes of more than 5°C and occurred within fewer than 40 years.

New Instrument Sharpens Understanding of Mid-Ocean Ridge Volcanic Processes

ELLEN PRIHODKO

Peter Mills, left, and Jim Broda set up a pierside test for NOBEL.

In great contrast to the paleoceanography results are those of a cruise in January 1991 to the East Pacific Rise that for the first time used the unique ONR-funded NOBEL (Near Ocean Bottom Explosives Launcher) sound source to carry out seismic experiments on the ocean floor. These NSF-supported experiments were designed to image with substantially better resolution than ever before possible the processes of generation of new ocean crust at a mid-ocean ridge. The interpretation of these new data by Joint Program student Gail Christeson suggests that the entire emplacement process for lava and sheeted dikes (the near-vertical supply conduits that feed magma from the mid-crustal chamber up to near the seafloor) in fast-spreading oceanic crust occurs in a 2-kilometer-wide region centered at the rise axis. In this region, the thickness of the volcanic rocks doubles due to the emplacement of lava that either overflows the sides of the axial summit caldera (a feature located on the rise axis and interpreted to be the site of the most recent lava eruptions), or travels through lateral tubes close to, but beneath, the seafloor. The depth to the top of the sheeted dikes increases from about 160 meters within the axial summit caldera to about 340 meters for the crust approximately 1 kilometer off-axis. The discovery of this rapid and substantial subsidence of the dikes, apparently a consequence of the changing thermal and density structure of the crust and upper mantle as the dikes move away from the rise axis, is a fundamental constraint on new models for how mid-ocean ridges work.

Deepest Drill Hole Provides Unprecedented View of Earth's Deepest Ocean Crust

A major effort by Petrologist Henry Dick and Geophysicist Richard Von Herzen, in cooperation with James Natland of the Scripps Institution of Oceanography, culminated in the 1991 publication of the scientific results of Ocean Drilling Program Leg 118 that in 1987 drilled the first continuous 500-meter-long section of the lowermost oceanic crust. The resulting cores from the Atlantis II Fracture Zone (named for WHOI's R/V *Atlantis II)* in the Indian Ocean, an area where two of Earth's great crustal plates are moving apart, allowed the first direct look at the deepest layer of ocean crust. Instead of the expected fossil remains of a large steady-state magma chamber, the cores revealed a layer of "crystal mush" that told a story of continuous extension and reintrusion of new batches of magma from the mantle. The mush apparently solidified periodically and then was hydrothermally altered at its deepest levels by seawater sinking through fissures and cracks and circulating along the deep shear zones that form as the rock is stretched apart between the diverging plates. Thus, at least at slow-spreading ridges, instead of the simple layer-cake view of the ocean crust as the product of crystallization of a long-lived magma chamber, there is a new model of deep crust as a semi-solid filter that magmas pass through, and are modified by, on their way to the surface. The work indicates not only that lower-ocean-crust volcanic processes are significantly different from those anticipated, but also that the processes of deformation, faulting, and alteration are important in lower-crust formation.

James Natland, left, of the Scripps Institution of Oceanography and Henry Dick show the first two pieces of 437 meters of gabbro eventually cored on JOIDES Resolution *Leg 118 (1987).*

During 1991, 39 investigators and their support staffs were working on 86 research programs in various fields of physical oceanography. The work included process studies to describe and explain the state and evolution of the ocean, coastal studies, remote sensing, instrument development, air-sea interactions, and climate studies. These programs involved observations, theory, and numerical studies as well as laboratory investigations.

Senior Scientist William Schmitz received the US Navy Meritorious Public Service Award for assisting the Navy with modeling and prediction and for helping to transfer the results of basic research to the Navy fleet. Robert Weller, Associate Scientist, received a National Aeronautics and Space Administration Certificate of Recognition for the creative development of a technical innovation that has been proposed for publication entitled "Radar Backscatter from the Ocean at Low Windspeeds."

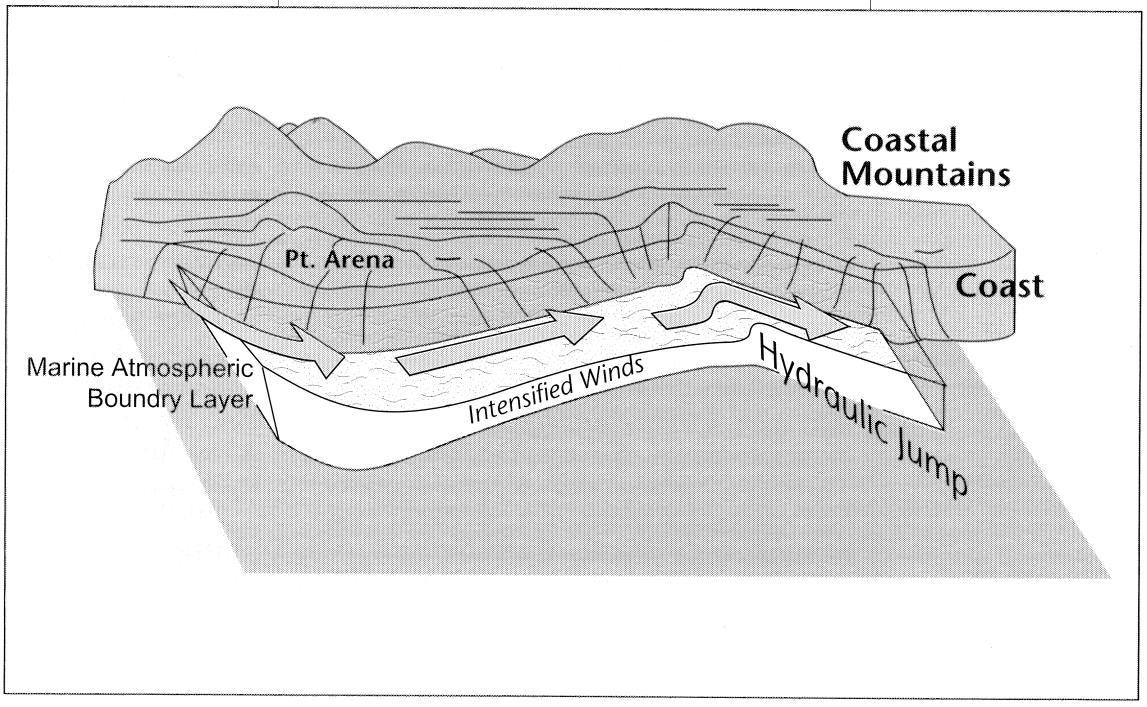
Three physical oceanography programs that reached noteworthy milestones in 1991 are highlighted below.

Mathematical Model Reproduces Supercritical Marine Layer Flow

Roger Samelson's study of supercritical marine layer flow developed and tested a theory proposed by investigators from several institutions to explain aircraft observations of the marine atmospheric boundary layer (which extends upwards several hundred meters from the sea surface) during the Coastal Ocean Dynamics Experiment off the coast of northern California in 1981-82. They suggested that strong alongshore winds cause a flow of air parallel to the coastal mountain range that reaches "supercritical" speeds, similar to the flow of water over a weir and down the spillway channel of a dam, and that bends in the coastline might then cause the persistent, intense, "small-scale" (10 to 100-kilometer) wind features (which may in turn drive small-scale ocean currents during coastal upwelling events) that were observed during the experiment.

With funding from NSF, Samelson developed a mathematical model of this supercritical flow in the marine boundary layer that included the frictional drag on the wind at the sea surface and the accelerating force exerted on the wind by the upper level atmospheric pressure field. The model successfully reproduced many aspects of the observed small-scale features, and the results suggest that the features were indeed dynamically and geographically linked to the coastal topography. The frictional drag proved to have a dramatic and previously unappreciated effect on the structure of the features—calculations that included friction showed substantially greater resemblance to the observations than those that excluded friction. Associated geographical variations in wind stress (the transfer of momentum from the wind to the sea that drives ocean currents) were as large as 50 percent over tens of kilometers.

Samelson plans next to study the small-scale ocean currents forced by these small-scale winds in a coastal circulation model, and to further refine the atmospheric model.

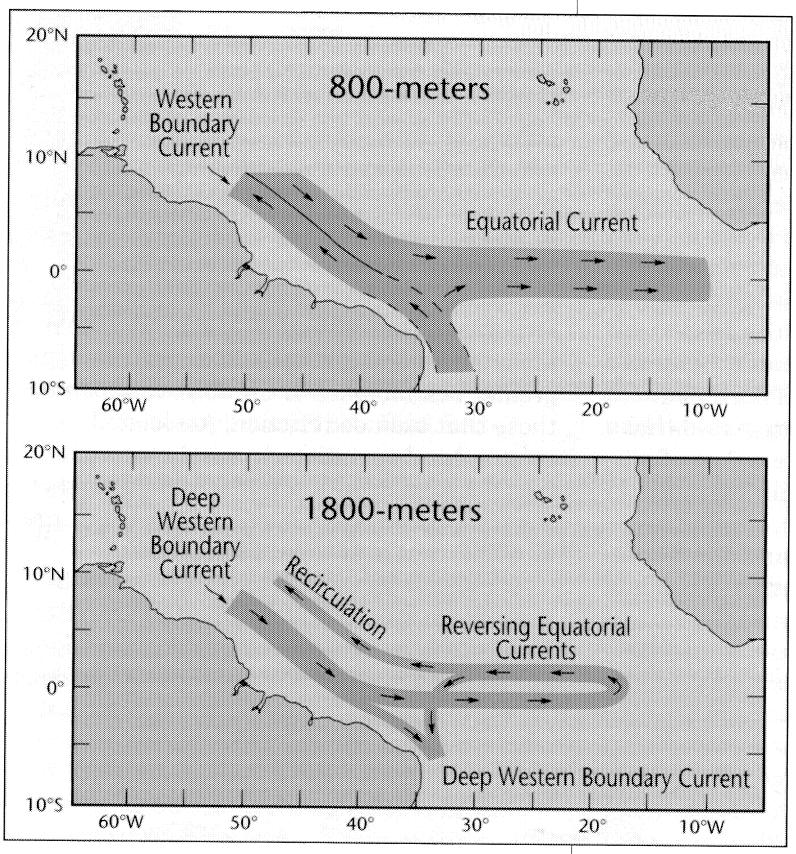


E. PAUL OBERLANDER

Off the coast of northern California, winds in the marine atmospheric boundary layer intensify south of Point Arena under supercritical flow conditions. Farther south (at the "hydraulic jump," where the marine layer thickens), the winds turn and weaken abruptly.

Float Tracking Shows Cross-Equatorial Water Flow

Phil Richardson and Bill Schmitz completed 21 months of tracking acoustic floats in equatorial Atlantic waters and found that water motions at the three depths they studied vary significantly from one another. These were the first direct measurements of cross-equatorial flow and of the connections between western boundary currents and equatorial currents. The work was funded by NSF. The cross-equatorial flow, generally northward in the upper, warmer layer and southward in the lower, colder layer, is a major part of the global conveyor belt of thermohaline circulation, which is driven by heat and salinity differences and results in a northward heat flux through the Atlantic. It is important to world climate.



Arrows chart dominant flow fields indicated by data from 21 months of tracking acoustic floats in the equatorial Atlantic. The flow at 3,300 meters was slow and no dominant pattern was seen.

The floats are ballasted to follow currents at predetermined depths. Working at several locations, the investigators released 15 floats to travel at each of three depths: 800 meters, 1,800 meters, and 3,300 meters. Once a day, the floats transmit an acoustic signal, which is recorded at several moored underwater listening stations.

Data retrieved from these stations tracked the 1,800-meter floats as they drifted swiftly southeastward, paralleling the continental slope in the deep western boundary current, which was found to be a narrow, 100-kilometer-wide jet flowing as fast as 1 knot. Roughly a third of the water transported by the jet recirculated between the jet and the Mid-Atlantic Ridge, leaving the rest to cross the equator. The float trajectories showed that at times the current turned eastward and flowed along the equator and at other times it crossed the equator and continued southward. Thus the cross-equatorial flow appeared to be linked to the direction of flow near the equator, which was eastward for the first year and westward for the second.

Because the 3,300-meter floats traveled slowly, the investigators surmise that the deep western boundary current is split vertically into two cores, one above 3,300 meters, indicated by the 1,800-meter floats, and one below, indicated by other data.

The trajectories of the 800-meter floats described a 300-kilometer-wide western boundary current travelling northwestward. Looping motions of several of these floats suggest that they were entrained in eddies that spin off a current running northward along the coast of Brazil. Six floats drifted eastward along the equator between 5°S and 6° N for roughly 18 months, and then the four still in the region reversed direction near the end of the tracking period. A float that reached the Gulf of Guinea near Africa indicates that the equatorial current extends at least 35 to 40° along the equator.

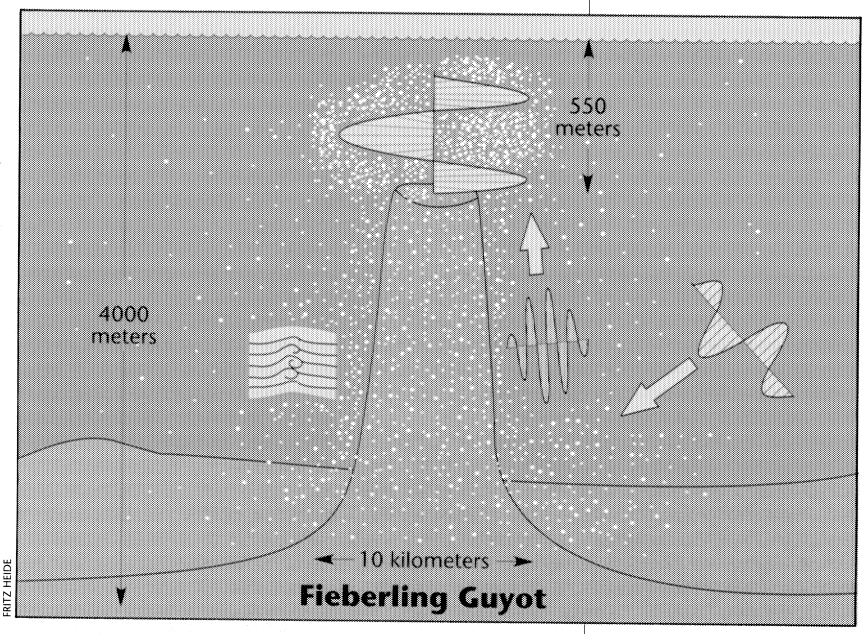
The floats are still transmitting daily signals. The next set of data will be retrieved from the listening stations in October 1992 to help further unravel the tangle of currents swirling about the equator.

Seamount Studies Indicate Ocean Boundaries Play an Important Role in Mixing Processes

The ocean's mixing rate impacts several aspects of the general circulation. Chief among them is the strength of the thermohaline circulation, in which cold, dense, polar waters sink toward the bottom, displacing lighter waters that in turn flow back toward the poles in surface currents. The mixing is partly responsible for distributing solar heat from the surface layer into the ocean interior, thereby converting the cold, deep waters into warmer, lighter waters.

The role boundaries play in oceanic mixing is only beginning to be defined. As a step toward this definition, John Toole, Raymond Schmitt, and Joint Program Student Kurt Polzin recently collaborated on a study of the flow and mixing near seamounts, structures that rise abruptly from relatively flat surroundings often to within 1,000 meters of the surface. Their ONR-funded work focused on Fieberling Guyot off the coast of California. The principle instrument utilized in the program was the High Resolution Profiler, an untethered, freely-falling probe that provides estimates of the ocean's temperature, salinity, and horizontal velocity variations with depth on vertical scales ranging from 1 meter to full-ocean depth. The instrument also yields measurements of turbulent velocity and temperature fluctuations, from which estimates of the rate of oceanic mixing are obtained. The combined data set allows investigation of the influence of larger scale motions on oceanic mixing. The Fieberling Guyot observations are notable for extending to 3,000 meters depth, nearly twice as deep as previous turbulence observations.

Ninety-seven profiles over and around Fieberling Guyot delineated remarkable flow features around the seamount. Over the summit, an intense (velocities on the order of 25 centimeters per second), small-vertical-scale (about 100 meters) disturbance was observed. At any one time, the direction of the horizontal velocity turned counterclockwise with depth in a helical pattern. With time, the whole pattern of flow direction rotated clockwise with a period of about one day. The disturbance was strongly confined over the top of Fieberling Guyot; velocities decayed to background levels within 10 to 15 kilometers of the seamount summit. Toole and colleagues speculate that this flow is a tidally forced internal wave that is trapped over Fieberling Guyot. Intense turbulence was associated with the summit flow field. The mixing rate caused by the turbulence was several orders of magnitude greater than that in the ocean interior at comparable depths. Work continues on understanding the causal relationships between the trapped wave and the turbulent mixing.



An intense disturbance with a rotating horizontal velocity vector was observed at the summit of Fieberling Guyot by researchers studying the effects of boundaries on ocean mixing. Internal waves (waves that occur in the interior of the water column with no surface signature) are shown breaking at left, and both coming in and reflecting upward at right. Intensity of turbulent mixing is indicated by weight of stippling.

Striking differences were also observed at depth between sites close to and far away from Fieberling Guyot. Twenty nautical miles away from the seamount, the internal-wave intensity was at background level at all depths down to 3,000 meters, and the ocean mixing rate was uniformly small. Adjacent to the flanks of the seamount, a pronounced enhancement of small-scale velocity fluctuations relative to the background levels was observed. The investigators believe that this signal is the result of internal waves reflecting from the sloping sides of the seamount. An enhancement of the turbulent velocity and temperature fluctuations was also observed over the flanks. The mixing rate deduced from these near-seamount measurements was nearly 100 times greater than the far-field value. These results suggest that boundary processes play an important role in deep-ocean mixing.

Coastal Research Center

Recent Coastal Research Center (CRC) activities include the primary program areas (physics, chemistry, biology, and geology), specific projects in these areas, and outreach efforts. Considerable energy has been devoted to developing and implementing research initiatives in specific thematic areas. These include geographic foci in Buzzards Bay, Georges Bank, Massachusetts Bay-Gulf of Maine, the Caribbean, and the Black Sea, partly as a result of energy and funds derived from the CRC. Recent CRC efforts to catalyze institution-wide proposals have resulted in the Massachusetts Bay Project, a four-institution research project on the physics of Massachusetts Bay; the Black Sea research initiative, which sponsored a symposium and a multi-ship cruise in 1991; and several oil spill research proposals, among others.

TOM KLEINDINST

Mytilus *heads out for coastal work. The Coastal Research Center manages the WHOI small-boat fleet.*

The Black Sea initiative builds on three decades of WHOI research in the region. The new cooperative venture began with a visit by CRC Director David Aubrey to Eastern Europe (Bulgaria, Romania, Ukraine, and Hungary) in November 1990. During this visit, overwhelming local academic and government agency interest was voiced in support of a scientific study of the western Black Sea. Following this visit, staff meetings at WHOI were convened to determine the interest of our scientists in further Black Sea research and to form an in-house steering committee to share the workload of this new initiative.

In 1991, the Black Sea research program included a five-ship, multi-nation research cruise and a successful international scientific workshop. This work will expand in 1992 and is the basis for a decade-long research program. This new CRC initiative, called the Cooperative Marine Science Program for the Black Sea, will help to coordinate national and international research efforts in this area, and international funding is being secured to ensure its viability.

David Aubrey completed five years as CRC director in 1991 and is succeeded by Robert Beardsley in this position. Beardsley is a principle contributor to the development of a research plan focusing on Georges Bank, a natural outgrowth of an earlier CRC project that resulted in the publication in 1987 by MIT Press of *Georges Bank,* a major synthesis of the scientific knowledge about that special area.

A new regional research association and a research plan were also assembled in 1991 for the Gulf of Maine.

In 1991, an ad-hoc committee of WHOI scientific staff reviewed the status of coastal research at WHOI and the increasing focus on coastal issues by state and federal agencies. Their recommendations are being incorporated into CRC operations.

Center for Marine Exploration

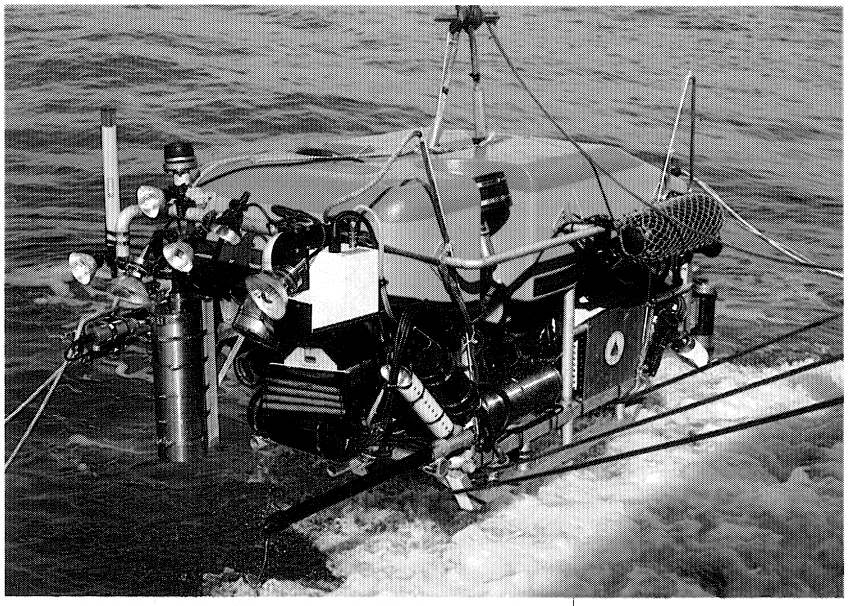
In August of 1991, the Center for Marine Exploration conducted its first major science expedition using the Institution's newly developed *Medea/Jason* robotic system. Following a short cruise for research at Deepwater Dumpsite 106 off the New York and New Jersey coasts, the system was transported to the west coast for a cruise conducted on a segment of the Mid-Ocean Ridge known as the Juan de Fuca Ridge off the coasts of Washington and British Columbia. Working at depths of 8,000 feet, a joint team of scientists and engineers from Woods Hole and the University of Washington investigated a portion of the ridge characterized by intense hydrothermal circulation. This activity manifests itself in two basic forms—low temperature hydrothermal vents surrounded by a unique community of chemosynthetic animals, and high-temperature chimneylike structures called "black smokers" where hydrothermal fluids measuring up to 400°C

result in the creation of chimneys and large accumulations of polymetallic sulfides.

Three teams of scientists and engineers working in *Jason's* shipboard control van carried out around-the-clock investigations of the volcanic, tectonic, and hydrothermal processes that create, transport, and alter newly formed oceanic crust along this active spreading center. *Jason*'s small size and high degree of maneuverability allowed investigators to position it beneath large overhanging structures that trap pools of high-temperature spring water. The temperature contrast between the fluids within the pools and surrounding bottom water create a reflecting surface resembling an upside-down reflecting pond.

Perhaps the greatest accomplishment of the expedition was when the *Jason* vehicle system was placed in closed-loop control and commanded by a shipboard computer to conduct a series of precise sampling lines above black smokers. This experiment was made possible by the deployment, for the first time, of a bottom-mounted tracking system that determined the location of *Jason* five times a second to an accuracy of less than two centimeters. With such precision and high sampling rate, *Jason's* navigational computer could easily follow the desired track coverage without the use of a human operator.

A second major accomplishment of CME in 1991 was participation in the third year of the JASON Project. Despite the sinking of its support barge, which carried more than $700,000 worth of Institution equipment, the project was able to recover and conduct its program from the Galápagos Islands on schedule. More than 400,000 students and teachers attended 20 separate down-link sites across North America where 60 "live" broadcasts were received.



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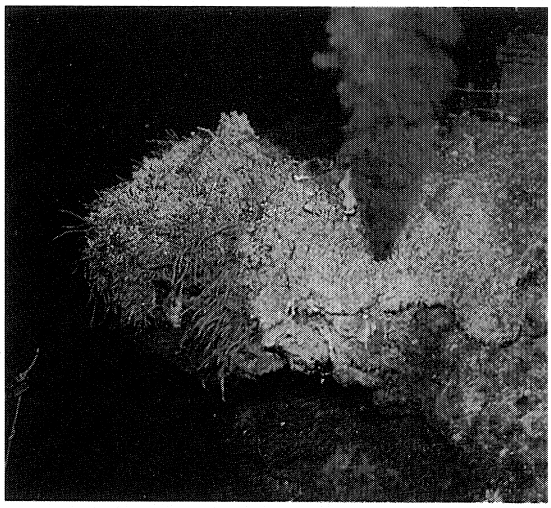


UNIVERSITY OF WASHINGTON/WHOI

The remotely operated vehicle Jason, *above, was employed for extensive exploration of the Juan de Fuca Ridge off the coasts of Washington and British Columbia. The vehicle made temperature measurements, collected samples, and took photographs, including the one at left of a "black smoker" hydrothermal vent.*

Marine Policy Center

The Marine Policy Center (MPC) adds the "human dimension" to ocean research as MPC scholars study public policy issues related to coasts and oceans. Their work fosters the integration of social sciences, such as economics and law, with WHOI's basic strengths in the ocean sciences.

The year 1991 proved to be a landmark for the Marine Policy Center. The Institution reaffirmed its commitment to marine policy research, capping an intensive review of the Center's role, performance, and future direction. The MPC scientific career ladder was brought into line with that in the science departments, and an aggressive recruiting campaign was initiated to double the size of the MPC scientific staff.

Research achievements by MPC scholars during the year provided tangible justification for this new level of commitment. MPC statistician Andrew Solow made important contributions on two front-line public policy issues, global warming and biological diversity. A critical uncertainty over global warming is the sensitivity of temperature to increases in atmospheric greenhouse gases. Attempts to estimate this from historic data have been complicated by

uncertainty about historic changes in atmospheric composition. Solow developed a new approach, based on temperature variability rather than trend, that avoids the need to reconstruct historic greenhouse forcing and that offers an alternative gauge for temperature sensitivity in climate simulation models.

To allocate scarce resources to the conservation of biological diversity, it is necessary to measure biological diversity. Previous measures either ignore the differences between species or use these differences in arbitrary and even nonsensical ways. At MPC, Solow and co-workers developed new measures that satisfy basic axioms necessary for a diversity measure. This work has led to expanded interest among economists in biological diversity and promises to provide the basis for a new bioeconomic theory to help motivate and guide conservation efforts.

WHOI GRAPHICS

Many Marine Policy Center offices are located in Crowell House.

MPC economist Yoshi Kaoru made another discovery that could improve environmental protection. Through his research on Martha's Vineyard into how the public values certain water quality improvements in coastal ponds, Kaoru found that more than half the total benefits go to non-users of these resources, who simply value the existence of clean ponds or wish to keep an option of using them in the future. This ratio of "non-use values" is larger than previously expected, and it suggests that benefit-cost assessments must attend carefully to non-use values to avoid seriously underestimating the benefits of environmental quality.

MPC researchers also contributed to improved environmental policy through involvement in an innovative technology assessment program. Electronic chart technology promises to prevent hazardous cargo spills and improve maritime safety. Development and use of the technology has been impeded by a lack of legal standards, but this gap is to be filled by newly proposed international standards. MPC Research Specialist Arthur Gaines has been coordinating a group of public and private organizations in an international program to develop and test the new technology and to evaluate and improve the draft standards. As a result of the MPC-coordinated efforts by the Intergraph Corporation and other project participants, a number of technical breakthroughs were achieved during the year.

Sea Grant Program

WHOI Sea Grant supports 12 to 15 research projects and a number of smaller "new initiative" efforts aimed at taking the first steps into promising new areas. Program thrusts address local and regional needs, such as water quality, fisheries degradation, coastal processes and erosion, and marine resources development. Sea Grant's 1991 projects included studies of

- shellfish toxicity in southern New England,
- coastal upwelling in Cape Cod Bay,
- estimating the value of marine mining for strategic minerals supply,
- continuation of water quality monitoring efforts in Falmouth's coastal ponds using local volunteers,
- creation of a directory of coastal outreach organizations on Cape Cod, and
- studying colloids and their associated metals in coastal waters.

A new lecture series called "All-Cape Coastal Science Seminars" was initiated in 1991 to provide a forum for scientists within southeastern Massachusetts to share their findings with colleagues and the general public. Topics discussed included salt marsh diking and restoration, findings from an ongoing study of marine-transported plastic, social behavior patterns of humpback whales, and the biology and conservation of terns and plovers.

The popular "Oceans Alive" series, designed for the general public, featured presentations on the fate and effects of oil in the ocean, the flushing of Boston Harbor and Massachusetts Bay, an *Alvin* pilot's view of the deep sea, sounds associated with spawning fish, New York Harbor herons, and a recollection of 40 years of marine life and changes on Cape Cod.

Dean's Comments

New, expanded roles for ocean science and oceanographic engineering education are evolving as societal concerns with global habitat change and regional and local environmental issues drive increased interest in earth and life sciences. There is growing demand for ocean science and engineering advanced degree recipients to collaborate with colleagues in the earth, life, and social sciences on pressing national and international global habitat issues. Internationally, there is increasing need for establishment of oceanographic education departments or institutions in developing countries. Simultaneously, undergraduate courses with significant ocean-science components are in greater demand in the US for both science and nonscience majors.

These demands mandate careful examination of the formal course content and seminars as well as the mentoring we offer our graduate students to prepare them for exciting and rewarding careers. We need to examine the role of the Institution in undergraduate education, perhaps expanding and strengthening our Summer Student Fellowship Program and interactions with undergraduate institutions. I look forward to continuing to address these issues in the coming year with MIT-WHOI Joint Program faculty, staff, and students, and with WHOI Trustees.

NANETTE OLDENBOURG

Dean John Farrington welcomes Joint Program student-cruise participants home from their summer voyage aboard R/V Corwith Cramer *of the Sea Education Association.*

While we evaluate our options and plan for the future, the students, faculty, and staff maintain the traditional excellence of our education programs. Some important facts, activities, and events of 1991 include:

- The MIT-WHOI Joint Program continues to attract high quality applicants for graduate studies. Applicants increased by 15 percent in 1991. Thirty-four students accepted our offers of admission and joined other Joint Program students for a fall enrollment of 135.
- For the second year, the entering MIT-WHOI Joint Program students were introduced to sea-going oceanography aboard a Sea Education Association vessel, this year SSV *Corwith Cramer*. At the suggestion of the enthusiastic 1990 participants, the cruise was expanded from seven to ten days. The introductory cruise is now a regularly scheduled event.
- We were saddened to learn of the passing this year of Professor Margaret MacVicar, MIT Dean of Students and WHOI Corporator. The world of scholarly endeavors and education, especially the arena of hands-on research experience for undergraduates, lost an innovative leader and articulate spokesperson. She was the principal architect of MIT's Undergraduate Research Opportunities Program (UROP), which offers students an opportunity to gain credit or earn stipends for

Ocean Ventures Fund Awardees for 1991

Andrea L. Arenovski
"Identification of Bacteria-Associated Growth Factor(s) Required by the Marine Mixotroph, *Chrysochromulina ericina* (Prymnesiophyceae)"

Michele D. DuRand
"Estimating Primary Productivity through Bio-Optical Properties"

Stacey Kim
"Larval Dispersal in Diffuse Plumes at Hydrothermal Vents"

Jonathan Snow
"Osmium Isotopes in the Oceanic Mantle and the Formation of the Earth's Core"

Christopher R. Weidman
"Reconstructing the Temporal Record of Bomb-Produced Radiocarbon in the Mid- and High-Latitude North Atlantic Ocean Using AMS-Dating and the Mollusc: *Arctica islandica*"

Trustee Education Committee

Lilli S. Hornig, Chair
Arnold B. Arons
Lewis M. Branscomb
Joel P. Davis
Mildred S. Dresselhaus
Evelyn E. Handler
Karen Lloyd
Henry A. Morss, Jr.
John E. Sawyer
Cecily Cannan Selby
Robert M. Solow
Keith S. Thomson

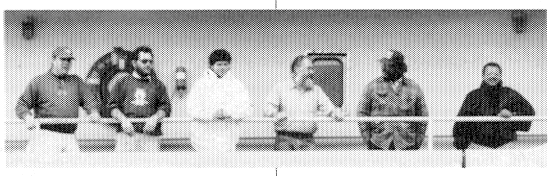
DAVID GRAY

RV Knorr *arrives in Woods Hole, welcomed by* Eagle Mar, *after a 32-month retrofit at the McDermott Shipyard in Louisiana.*

The Research Vessel *Knorr*, 34 feet longer with a new propulsion system and many other upgrades, returned to WHOI October 17, 1991, after a 32-month refit period at McDermott Shipyard in Amelia, Louisiana. Hundreds of employees, family members, and friends gathered on the dock on a cold, rainy day to greet the ship, escorted up Vineyard Sound by *Asterias*, *Eagle Mar,* and a firehose salute from Coast Guard Group Woods Hole. Colorful signal flags decorated the dock flagpole and spelled KCEJ, the ship's call letters. Another set of flags spelled out "You Are Number 1." The crowd broke into applause as Captain Michael Palmieri eased the ship to the dock. After brief remarks from Craig Dorman and *Knorr/Melville* Project Manager Joseph Coburn, Jr., the crowd was invited aboard to view the ship. Despite heavy rains several hundred toured the vessel during an afternoon open house. Access to *Knorr* was limited through the end of the year as the crew and Marine Department and Shop personnel worked to complete piping, ventilation, and airborne noise reduction systems as well as painting and final cleaning before sailing for its first scientific cruise in 1992.

CATHY HEIDE

Knorr/Melville *Project Manager Joseph Coburn, Jr., offered a few remarks upon the return of* RV Knorr.



CATHY HEIDE

Joe Mayes, Fred Bull, Patrick Mone, Steve Page, Al Dallas from McDermott Shipyard, and Mitch Barros greet family and friends from Knorr's *rail during the welcome-home ceremony in October.*

A new classification system for the Technical Staff and Departmental Research Assistant structure of the Institution was instituted January 1, affecting more than 300 of the WHOI's approximately 850 employees. There are now separately-defined career ladders for those engaged in scientific research, computer-driven operations, and engineering activities.

US/Soviet scientific collaboration was a major focus during the year as a changing world order was clearly felt in the scientific community. American and European technical experts, including Engineering Assistant Bill Lange, were invited by the Soviets in July and August to monitor the site of the sunken Soviet nuclear submarine *Komsomolets* off the coast of Norway. The sub, which sank in 1989 as the result of a fire that killed 42 of the 69 crew members, has been monitored by the Soviets since then. WHOI signed a cooperative agreement in May 1990 with the P.P. Shirshov Institute of Oceanology of the USSR Academy of Sciences that calls for "collaborative scientific programs in the fields of underwater techniques and their applications."

The risks and opportunities of US/Soviet scientific collaboration were the topics of a three-day October workshop conceived and hosted by Director Craig Dorman. Some 50 scientists from U.S. universities and private research institutions joined another 60 representatives from federal agencies, the U.S. Navy, and ocean engineering companies to discuss the future direction of collaborative research with scientists from the republics of the former Soviet Union.

An international team of scientists aboard five research vessels from three nations cooperated in a unique hydrographic and biochemical study of the Black Sea, one of the least understood bodies of water in the world. The September field program, called Hydro-Black 91, was coordinated by WHOI's Coastal Research Center and the Institute of Marine Sciences at the Middle East Technical University in Turkey to help launch a decade-long scientific focus on the Black Sea and its environmental problems by nations surrounding the basin. A scientific symposium was held September 30-October 4 in Varna, Bulgaria, to review cruise results.

WHOI received a three-year grant of $450,000 from the W.M. Keck Foundation to support the development of sophisticated

scientific instruments through a new Institution program to be called the W.M. Keck Foundation Technology Innovation Awards. The competitive annual awards are designed to encourage collaboration among scientists and engineers.

A $500,000 Science Initiative challenge grant from the Kresge Foundation will enable the Institution to maintain its leadership role in fiber-optic technology and the development of deep-sea robotic systems. Among the scientific instrumentation upgraded aboard Research Vessel *Knorr* is a new traction winch system to handle remotely operated vehicles and a 25,000-foot fiber-optic cable to transmit high-quality color images from the ocean floor for use with the *Jason / Medea* family of vehicles. The National Science Foundation provided an additional $500,000 toward scientific equipment to complete the *Knorr's* science outfitting.

Philanthropist Cecil H. Green, founder of Texas Instruments, made a $2.1 million commitment to WHOI to endow the technology innovation award program. The gift, announced in June, matches the $500,000 Kresge Foundation challenge grant.

Six research projects received $167,000 through WHOI's Technology Innovation Awards, presented for the first time in 1991. The awards were funded through the Director's Discretionary Fund, the Walter Smith Fund, and the Edwin S. Webster Foundation. The competitive awards provide seed money to researchers working on projects that are not attractive to traditional funding sources.

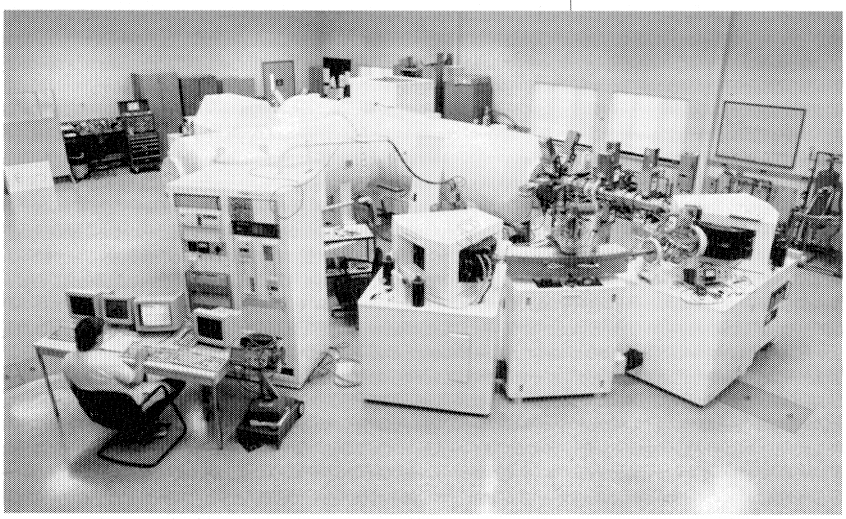
DSV *Alvin* recorded another first in April when its passengers talked from one and one-half miles beneath the surface of the Pacific Ocean to colleagues at Rutgers University in New Jersey. The occasion was the ground-breaking of the University's new Institute for Marine and Coastal Sciences, headed by former WHOI biologist and frequent *Alvin* passenger Fred Grassle.

TOM KLEINDINST

Cecil H. Green, founder of Texas Instruments, made a $2.1 million gift to endow the WHOI technology innovation award program.

Alvin recovered an unmanned U.S. Navy vehicle July 1 from the ocean floor off the coast of southern California. The CURV III (Cable-controlled Underwater Recovery Vehicle) was lost June 12 in 7,200 feet of water about 130 miles southwest of Los Angeles during a salvage operation when its cable separated. *Alvin* made four dives June 16 to 21 in the area where the vehicle was lost but did not find it. An acoustic beacon on CURV had apparently shifted frequency, requiring additional Navy equipment to determine its location. *Alvin* and *Atlantis II* completed a scientific cruise as planned and returned to the search area, locating CURV within a few hours on the first dive. *Alvin* manipulators were used to secure a lift line on the vehicle to bring it to the surface.

The Office of Naval Research announced July 19 that WHOI had been selected by a competitive proposal process to operate



TOM KLEINDINST

The world's most sophisticated carbon-14 dating laboratory, the National Ocean Sciences Accelerator Mass Spectrometry Facility, was dedicated in June at the McLean Laboratory.

DAVID CRAY

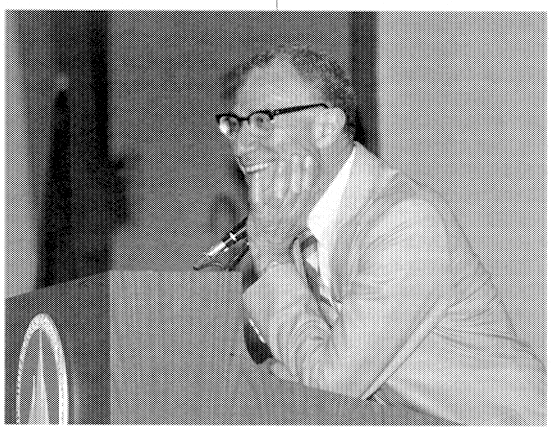
The surprise arrival of Hurricane Bob in mid-August, with its 100- mile-per-hour winds, caused major tree and limb damage but, fortunately, little structural damage to Institution facilities. Trees had to be cleared from the new James R. Shepley tennis court shown here.

AGOR-25, one of the U.S. Navy's two new research vessels for multidisciplinary worldwide research. The new vessels will be 273 feet long and will be based on the same design and specifications as the AGOR-23, Research Vessel *T.G. Thompson*, recently completed for operation by the University of Washington. AGOR-25, tentatively named *Atlantis III*, will replace the aging *Atlantis II*. Delivery is not expected until at least 1997. Scripps Institution of Oceanography was chosen to operate AGOR-24 for the University of California system.

Information Scientist David Stonehill, former director of the Information Resources Management Division of the Executive Office of the President of the United States, was named Director of the MBL/WHOI Library effective April 1.

Senior Scientist David Aubrey and Scientist Emeritus K.O. Emery dispute recent analyses of sea-level rise in their book *Sea Levels, Land Levels and Tide Gauges*, released in April. The book, published by Springer-Verlag, is the culmination of ten years of research on the impact of land movement on tide gauge records of sea level.

Honorary Trustee H. Guyford Stever was one of 20 recipients of the 1991 National Medal of Science presented September 16 by President George Bush for a lifetime of scientific achievement.



TOM KLEINDINST

Nobel Laureate and MIT Professor Robert Solow presented the 18th J. Seward Johnson Lecture in Marine Policy at the annual meeting activites in June.

Scientist Emeritus Allyn Vine received the 1991 Blakely Smith Medal from The Society of Naval Architects and Engineers November 15 for outstanding accomplishments in ocean engineering at the group's annual banquet in New York City.

Among the new faces in WHOI management is Lawrence Ladd, who was named to the redefined position of Associate Director for Institution Operations late in the year. Ladd succeeds Gary Walker, who departed November 1 for a financial position in Boston. Prior to his appointment at WHOI, Ladd had served as Dean of Administration at Tufts University since 1984.

Several hundred attended the revamped Day of Science October 11, which featured a morning program for New Associates, who were introduced to WHOI through lectures and a Carriage House luncheon with staff members. Technology and instrumentation was the theme of the main afternoon program, with lectures by Associate Director for Research Robert Gagosian, Coordinator of Industrial and International Programs David Gallo, and Associate Scientist Dana Yoerger. Walking tours of McLean Laboratory and the Clark Annex followed the lectures. The day's events concluded with a cocktail reception under a tent on the Fenno House lawn featuring poster displays on current research projects and library services.

The Information Processing and Communications Laboratory (IPCL) became a Center July 1 and is no longer part of the Applied Ocean Physics and Engineering Department. IPCL was renamed the Information Systems Center (ISC) in December, and, like the Marine Policy Center and the Coastal Research Center, reports to Associate Director for Research Robert Gagosian.

The 62nd Annual Meetings of the Trustees and Members of the Corporation were held June 14. The annual meetings included a science report by Senior Scientist John H. Steele, outgoing President of the Corporation, on "The Ocean Landscape." Trustee James M. Clark, a former chief executive officer of Hornblower-Weeks, Hemphill, Noyes, and affiliated since 1986 with Shearson Lehman Brothers, Inc. in New York City, was elected President of the Corporation. Clark's election continues his

family's more than 40-year association with the Institution.

Later that day the world's newest and most sophisticated carbon-14 dating laboratory, the National Ocean Sciences Accelerator Mass Spectrometry Facility, was dedicated at the McLean Laboratory. Keynote speaker was Robert W. Corell, Assistant Director for Geosciences at the National Science Foundation (NSF). The AMS facility was funded through a competitive $5 million NSF grant to provide high precision carbon-14 dating to the national ocean sciences research community. An estimated 4,300 seawater, ocean sediment, and other samples from around the world will be analyzed each year, 10 to 20 times more than a conventional carbon-14 dating laboratory handles. The national facility's director is Associate Scientist Glenn Jones of the Geology and Geophysics Department.

Annual meeting activities continued with the 18th J. Seward Johnson Lecture in Marine Policy. MIT Professor Robert Solow spoke on "Sustainability: An Economist's Perspective." Solow is a Nobel Laureate in Economics and a member of the Marine Policy Center's Senior Advisors Committee. A reception and dinner for more than 200 Trustees, Corporation Members, and Associates concluded the day's events.

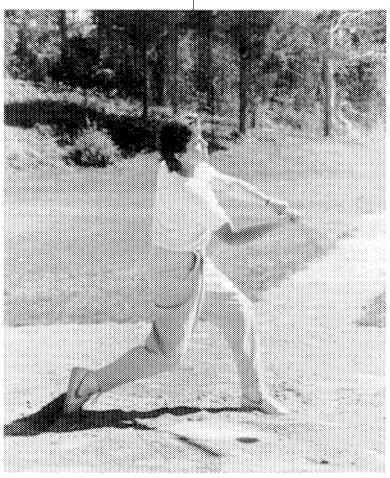
Trustees, Members of the Corporation, employees, and students numbering 400 to 500 joined McKee family members June 24 at the Institution's new recreation facilities behind Clark Laboratory to celebrate the completion of the The Joseph V. McKee, Jr., Ball Field and The James R. Shepley Tennis and Volleyball Courts. Funds for their construction were given by family and friends of the two men, who served the Institution as Trustees and Members of the Corporation and were close personal friends.

Approximately 60 people who were involved with the Institution during World War II and into the mid-1950s gathered in Woods Hole July 15 to 19 to reminisce about their experiences at a History Colloquy. Attendees came from as far as Alaska and British Columbia. Sessions were audio recorded for the Institution Archives, and many participants contributed photos, data, and other items to the Archives. Participants had a chance to visit with current staff, tour facilities, and reminisce with each other.

Hurricane Bob arrived quickly Monday morning, August 19, leaving behind a trail of incredible debris but sparing WHOI much of its wrath. Gusts reached 100 miles per hour, but luckily high tide occurred a few hours after the storm had passed over Woods Hole, and flooding of WHOI property was minimal. Structural damage was minor, but there were hundreds of downed trees and branches. The Institution closed at 11 a.m. August 19 and reopened August 21 when Woods Hole Road was partially cleared of fallen trees. The loss of electrical power for a week was among the most difficult and frustrating aftermaths of the hurricane, the first to hit the area since Hurricane Gloria in September 1985.


TERRI CORBETT

Phyllis McKee and her son Casey, along with other family members, were present for the unveiling of a memorial plaque and ceremonies at the June dedication of the new Joseph V. McKee, Jr., Ball Field located behind Clark Laboratory.


TERRI CORBETT

Lisa DiPalma was the women's champion in the home-run hitting contest, one of the highlights at the June dedication ceremony for the new Joseph V. McKee, Jr., Ball Field.

Among the many meetings held at WHOI during the year were the following.

• An international group of marine scientists, engineers, economists, and attorneys from some two dozen institutions and agencies gathered at WHOI January 7 to 10 to determine the research required to assess the potential of the deep ocean as a site for waste disposal. The 50 participants, led by Senior Scientist Derek Spencer, developed a research plan, which was reviewed by an

independent panel later in the year.

• A group of 15 Congressional staff members participated in a two and a half day seminar on Ocean Science and National Security co-sponsored with the Center for Naval Analyses, the Office of Naval Research, and the Department of Energy in February.

• The Coastal Research Center was host for a three-day workshop on the Gulf of Maine in January. Over 200 scientists from Nova Scotia, New Brunswick, Maine, New Hampshire, and Massachusetts met in Woods Hole to discuss their understanding of the physical, chemical, and biological processes that drive the gulf.

• More than 50 scientists, social scientists, and policy makers discussed preserving marine biological diversity at a February workshop hosted by the Marine Policy Center. The workshop focused on bridging different ideas on biological diversity and on using scientific information to make public policy decisions on conservation efforts.

TOM KLEINDINST

Carpentry Supervisor Buddy Baker accepts The Penzance Award as mistress of ceremonies Kathy LaBernz listens at the Third Annual Employee Recognition Celebration in October.

• The Marine Technology Society's Buoy Technology Workshop April 10 to 12 attracted about 75 researchers from the United States, Canada, and France.

• More than 130 marine educators attended the 15th annual conference of the Massachusetts Marine Educators (MME) in April. Winners of an art contest, co-sponsored by WHOI Sea Grant and MME for high school students throughout the state, were announced and their artwork displayed during the conference.

• The Marine Policy Center and the Korea Ocean Research and Development Institute co-sponsored an October conference at WHOI on "Ocean Science and Policy for Global Environmental Change."

WHOI's women's soccer team, Rogue Waves, ended their second season with a 9-8 record in the Old Colony Women's Soccer League. Cape Cod's underwater hockey teams, which include a large WHOI contingent, placed first at the Southeast Invitational Underwater Hockey Tournament March 16-17 at East Carolina University.

DAVID GRAY

From left, Paul and Mary Lou Smith, Don Hornig, and Bill Schevill participate in the 1991 History Colloquy. Coming from as far away as Alaska, some 60 people reminisced about their experiences at WHOI during World War II and into the mid-1950s.

At the Third Annual Employee Recognition Celebration in October, Acting Marine Operations Manager Richard Dimmock received special honors for his more than 42 years of service, and Mechanical Shop Supervisor Robert Weeks, who died in June, was honored posthumously for more than 40 years of service. A replica of a plaque in Bobby Weeks's memory, to be placed in the Iselin Marine Facility, was on display.

Other awards presented at the Employee Recognition celebration included the Vetlesen Award ($2,500 and a memento), which was presented to Research Specialist George Hampson for "exceptional contributions not merely above and beyond superb performance of their job and service on committees, but for true selfless dedication to the entire WHOI community over a long period of time." The Penzance Award ($5,000 discretionary account and a plaque) was presented to the Carpenter Shop, including the painters, "for sustained exceptional performance, for outstanding representation of the WHOI spirit, and for major contributions to the personal and professional lives of our staff." The first Linda Morse-Porteous Award, in memory of Senior Research Assistant Linda Morse-Porteous who died in January, was presented to Research Assistant Carol Alessi. The award honors a female technician who demonstrates leadership, dedication to and quality of work, service as a role model or mentor to junior women, and involvement in the WHOI community.

Director's Council

as of December 31, 1991

Craig E. Dorman
Director

Robert B. Gagosian
Associate Director for Research

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

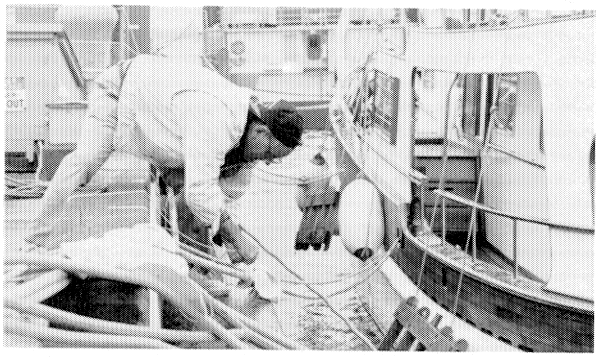
Lawrence R. Ladd
Associate Director for Institution Operations (effective 1/1/92)

Richard F. Pittenger
Associate Director for Marine Operations

Charles D. Hollister
Vice President of the Corporation

Pamela C. Hart
Executive Assistant to the Director

Karen P. Rauss
Special Assistant to the Director



TOM KLEINDINST

Dick Pittenger secures lines as Hurricane Bob advances.

Scientific & Technical Staff

as of December 31, 1991

Applied Ocean Physics & Engineering Department

Albert J. Williams 3rd
Department Chair, Senior Scientist

Lane J. Abrams
Research Engineer

John J. Atkens
Senior Engineer

Geoffrey P. Allsup
Engineer II

Richard I. Arthur, Jr.
Engineer I

Thomas C. Austin
Research Engineer

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

Henri 0. Berteaux
Principal Engineer

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
Assistant Scientist

Dezhang Chu
Research Associate

Kenneth W. Doherty
Senior Engineer

James A. Doutt
Research Associate

Timothy F. Duda
Assistant Scientist

Alan R. Duester
Engineer II

Robert L. Eastwood
Information Systems Associate II

Calvert F. Eck
Research Engineer

James B. Edson
Assistant Scientist

Robert L. Elder
Engineer II

Ned C. Forrester
Research Engineer

DAVE CRAY

Anita Norton christens the new shallow-water remotely operated vehicle (ROV) Hylas *at the Coastal Research Lab tank.* Hylas *serves as a test vehicle for deep-water ROVs.*

Dudley B. Foster
Research Associate

Alan J. Fougere
Research Engineer

Lee E. Freitag
Research Engineer

George V. Frisk
Senior Scientist

Charlotte M. Fuller
Research Associate

Nancy R. Galbraith
Information Systems Associate II

Wayne R. Geyer
Associate Scientist

Denzel E. Gleason
Research Associate

Robert G. Goldsborough
Research Engineer

Mark A. Grosenbaugh
Associate Scientist

John T. Hallinan
Research Engineer

Ole Hastrup
Visiting Investigator

Alan A. Hinton
Engineer II

Edward Hobart
Engineer II

Jonathan C. Howland
Research Engineer

James D. Irish
Research Specialist

Maxine M. Jones
Information Systems Specialist

Sean M. Kery
Engineer II

Richard L. Koehler
Senior Engineer

Donald E. Koelsch
Principal Engineer

James R. Ledwell
Associate Scientist

Steven A. Lerner
Research Engineer

Stephen P. Liberatore
Research Engineer

James F. Lynch
Associate Scientist

Martin Marra
Research Engineer

Ann Martin
Information Systems Associate II

John S. Merriam, Jr.
Engineer II

David A. Mindell
Engineer I

Robert W. Morse
Scientist Emeritus

Arthur E. Newhall
Research Associate

Kenneth R. Peal
Senior Engineer

Robert A. Pettit, Jr.
Engineer II

William J. Plant
Senior Scientist

Kenneth E. Prada
Principal Engineer

Bryce Prindle
Visiting Investigator

Michael J. Purcell
Research Engineer

Subramaniam D. Rajan
Assistant Scientist

Harold E. Rochat
Engineer II

Edward K. Scheer
Information Systems Associate II

Cynthia S. Sellers
Research Associate

Scientific & Technical Staff

BRENDAN FLANNERY

Scott Gallagher, left, Joint Program student Mercedes Pascual-Dunlap, and Cabell Davis prepare the Video Plankton Recorder for launch aboard R/V Oceanus.

Arnold G. Sharp
Senior Engineer

Robin C. Singer
Engineer II

John L. Spiesberger
Associate Scientist

Jess H. Stanbrough, Jr.
Research Specialist

Timothy K. Stanton
Associate Scientist

W. Kenneth Stewart, Jr.
Assistant Scientist

Roger P. Stokey
Research Engineer

Eugene A. Terray
Research Specialist

John H. Trowbridge
Associate Scientist

Edward H. Verry
Research Engineer

Nathan Ulrich
Assistant Scientist

Christopher von Alt
Senior Engineer

Keith von der Heydt
Senior Engineer

Barrie B. Walden
Principal Engineer, Manager, Submersible Operations

Ehud Weinstein
Adjunct Scientist

Carl J. Weidemann
Research Associate

Clifford L. Winget
Research Specialist

Warren E. Witzell, Jr.
Engineer II

Dana R. Yoerger
Associate Scientist

Biology Department

Peter H. Wiebe
Department Chair, Senior Scientist

Donald M. Anderson
Senior Scientist

Richard H. Backus
Scientist Emeritus

Francis G. Carey
Senior Scientist

David A. Caron
Associate Scientist

Hal Caswell
Senior Scientist

David J. Cooper
Visiting Investigator

James E. Craddock
Research Specialist

John W. Dacey
Associate Scientist

Cabell S. Davis III
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Edward F. DeLong
Assistant Scientist

Mark R. Dennett
Research Associate

Paul V. Dunlap
Assistant Scientist

Kurt M. Fristrup
Research Associate

Scott M. Gallager
Research Specialist

Dale D. Goehringer
Research Associate

Joel C. Goldman
Senior Scientist

George R. Hampson
Research Specialist

George R. Harbison
Senior Scientist

Brian L. Howes
Associate Scientist

Holger W. Jannasch
Senior Scientist

Dale F. Leavitt
Research Associate

Phillip S. Lobel
Associate Scientist

Laurence P. Madin
Associate Scientist

Frank J. Mather III
Scientist Emeritus

Judith E. McDowell
Senior Scientist

John J. Molongoski
Research Associate

Lauren S. Mullineaux
Assistant Scientist

Robert J. Olson
Associate Scientist

Douglas C. Prasher
Assistant Scientist

Richard J. Ridge
Research Specialist

John H. Ryther
Scientist Emeritus

Howard L. Sanders
Scientist Emeritus

William E. Schevill
Scientist Emeritus

Mary Sears
Scientist Emeritus

Roxanna M. Smolowitz
Visiting Investigator

John J. Stegeman
Senior Scientist, Stanley W. Watson Chair for Excellence in Oceanography

Diane K. Stoecker
Associate Scientist

Craig D. Taylor
Associate Scientist

John M. Teal
Senior Scientist

Peter L. Tyack
Associate Scientist

Frederica Valois
Research Specialist

John B. Waterbury
Associate Scientist

William A. Watkins
Senior Research Specialist

Stanley W. Watson
Scientist Emeritus

James R. Weinberg
Assistant Scientist

Isabelle P. Williams
Research Associate

Carl O. Wirsen, Jr.
Research Specialist

Erik R. Zettler
Research Associate

Chemistry Department

Fred L. Sayles
Department Chair, Senior Scientist

Mark A. Altabet
Associate Scientist

Michael P. Bacon
Senior Scientist

Lary A. Ball
Research Associate

Neil V. Blough
Associate Scientist

Peter G. Brewer
Senior Scientist

Kenneth O. Buesseler
Assistant Scientist

Werner G. Deuser
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Wayne H. Dickinson
Research Specialist

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Associate Scientist

Timothy I. Eglinton
Assistant Scientist

Alan P. Fleer
Research Associate

Roger H. Francois
Assistant Scientist

Nelson M. Frew
Senior Research Specialist

David M. Glover
Research Specialist

Ralf Goericke
Visiting Investigator

Catherine Goyet
Assistant Scientist

Sheila M. Griffin
Research Associate

Terence R. Hammar
Research Associate

Susan E. Humphris
Adjunct Scientist

John M. Hunt
Scientist Emeritus

William J. Jenkins
Senior Scientist, W. Van Alan Clark Chair for Excellence in Oceanography

Carl G. Johnson
Research Associate

David P. Kammer
Research Associate

Mark D. Kurz
Associate Scientist

Hugh D. Livingston
Senior Research Specialist

Dempsey E. Lott III
Research Specialist

William R. Martin
Associate Scientist

James W. Moffett
Assistant Scientist

Edward T. Peltzer III
Research Specialist

Daniel J. Repeta
Associate Scientist

David L. Schneider
Research Associate

Edward R. Sholkovitz
Senior Scientist

Stephen P. Smith
Engineer I

Derek W. Spencer
Scientist Emeritus

Geoffrey Thompson
Senior Scientist

Margaret K. Tivey
Assistant Scientist

Scientific & Technical Staff

Barbara J. Whelan
Senior Research Specialist

Oliver C. Zafiriou
Senior Scientist

Geology & Geophysics Department

G. Michael Purdy
Department Chair, Senior Scientist, W. Van Alan Clark Chair for Excellence in Oceanography

David G. Aubrey
Senior Scientist

William A. Berggren
Senior Scientist

Jerzy S. Blusztajn
Research Associate

Carl O. Bowin
Senior Scientist

James E. Broda
Research Specialist

Wilfred B. Bryan
Senior Scientist

Elizabeth T. Bunce
Scientist Emeritus

Daniel R. Burns
Visiting Investigator

Kenneth D. Burrhus
Research Specialist

Johnson R. Cann
Adjunct Scientist

Gregory J. Cohen
Engineer I

William B. Curry
Associate Scientist

Robert S. Detrick
Senior Scientist

Henry J. Dick
Senior Scientist

Kenneth O. Emery
Scientist Emeritus

John I. Ewing
Scientist Emeritus

Judith Fenwick
Research Associate

Graham S. Giese
Research Specialist

Kathryn M. Gillis
Assistant Scientist

Stanley R. Hart
Senior Scientist

W. Steven Holbrook
Assistant Scientist

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

Glenn A. Jones
Associate Scientist

Lloyd D. Keigwin, Jr.
Associate Scientist

Peter B. Keleman
Assistant Scientist

Martin C. Kleinrock
Assistant Scientist

Scott J. Lehman
Assistant Scientist

Peter C. Lemmond
Research Associate

Jian Lin
Assistant Scientist

George P. Lohmann
Associate Scientist

Steven J. Manganini
Research Specialist

Daniel McCorkle
Assistant Scientist

Ann P. McNichol
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Thomas R. McSherry
Engineer I

Peter S. Meyer
Visiting Investigator

John D. Milliman
Senior Scientist

Delia W. Oppo
Assistant Scientist

Dorinda R. Ostermann
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David A. Ross
Senior Scientist

Robert J. Schneider
Senior Research Specialist

Hans Schouten
Senior Scientist

Peter B. Shaw
Associate Scientist

Nobumichi Shimizu
Senior Scientist

Deborah K. Smith
Associate Scientist

Wayne D. Spencer
Research Associate

Ralph A. Stephen
Senior Scientist

George H. Sutton
Visiting Investigator

Stephen A. Swift
Research Associate

Kozo Takahashi
Associate Scientist

Maurice A. Tivey
Assistant Scientist

Brian E. Tucholke
Senior Scientist

Elazar Uchupi
Senior Scientist

Allyn C. Vine
Scientist Emeritus

Richard P. Von Herzen
Senior Scientist

Karl F. von Reden
Research Specialist

F. Beecher Wooding
Research Associate

Earl M. Young
Research Associate

Physical Oceanography Department

James R. Luyten
Department Chair, Senior Scientist

Frank Bahr
Research Associate

Robert C. Beardsley
Senior Scientist

Gary L. Bond
Research Associate

Amy S. Bower
Assistant Scientist

Kenneth H. Brink
Associate Scientist

Harry L. Bryden
Senior Scientist, Henry B. Bigelow Chair for Excellence in Oceanography

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Scientist Emeritus

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Research Associate

David C. Chapman
Associate Scientist

James H. Churchill
Research Specialist

Charles E. Corry
Research Specialist

Jerome P. Dean
Research Specialist

Glen G. Gawarkiewicz
Assistant Scientist

Daniel E. Frye
Research Specialist

Paul D. Fucile
Engineer I

Ruth A. Gorski Curry
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Karl R. Helfrich
Associate Scientist

Nelson Hogg
Senior Scientist

David S. Hosom
Senior Engineer

Hsiao-Ming Hsu
Research Specialist

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
Associate Scientist

TOM KLEINDINST

Jack Reece is surrounded by surface drifters, SOFAR (SOund Fixing And Ranging) floats, and SOFAR listening stations.

Scientific & Technical Staff

Richard E. Payne
Research Associate

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

Robert S. Pickart
Assistant Scientist

Albert J. Plueddemann
Assistant Scientist

Lawrence J. Pratt
Associate Scientist

James F. Price
Associate Scientist

Philip L. Richardson
Senior Scientist

Melora P. Samelson
Research Associate

Roger M. Samelson
Assistant Scientist

Raymond W. Schmitt
Associate Scientist

William J. Schmitz, Jr.
Senior Scientist

Michael A. Spall
Assistant Scientist

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

Bruce A. Warren
Senior Scientist

Robert A. Weller
Associate Scientist

John A. Whitehead
Senior Scientist

Alfred H. Woodcock
Scientist Emeritus

Christine M. Wooding
Research Associate

L. Valentine Worthington
Scientist Emeritus

Information Systems Center

Robert C. Groman
Manager, Information Systems Center, Information Systems Specialist

Raymond Ainsworth
Information Systems Associate II

Julie M. Allen
Information Systems Associate II

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
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

Edward A. Sonafrank, Jr.
Information Systems Associate II

Suzanne B. Volkmann
Information Systems Associate II

Marine Policy Center

James M. Broadus
Associate Scientist, Director, Marine Policy Center

Arthur G. Gaines, Jr.
Research Specialist

Porter Hoagland III
Research Associate

Yoshiaki Kaoru
Assistant Scientist

Andrew R. Solow
Associate Scientist

Coastal Research Center

David G. Aubrey
Director, Senior Scientist

Margaret G. Collins
Visiting Investigator

Bruce W. Tripp
Research Associate

Postdoctoral Investigators

Julio Candela
Physical Oceanography

John A. Collins
Geology & Geophysics

Gregory J. Doucette
Biology

Tetsu Hara
Applied Ocean Physics & Engineering

Graham D. Layne
Geology & Geophysics

Michael J. Moore
Biology

Richard D. Norris
Geology & Geophysics

James C. Preisig
Applied Ocean Physics & Engineering

Bo Qiu
Physical Oceanography

Gregory E. Ravizza
Geology & Geophysics

Kathleen C. Ruttenberg
Chemistry

Jeffrey S. Seewald
Chemistry

Dajun Tang
Applied Ocean Physics & Engineering

Cindy L. Van Dover
Biology

Robert A. Wheatcroft
Applied Ocean Physics & Engineering

Regular Support Staff

as of December 31, 1991

Departmental Assistants

Applied Ocean Physics & Engineering Department

Alfred T. Bouchard
John N. Bouthillette
Leonard A. Boutin
Shirley J. Bowman
Rodney M. Catanach
Charles E. Corwin
Thomas Crook
Edward A. Denton
Betsey G. Doherty
Terence G. Donoghue
Kenneth D. Fairhurst
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Matthew R. Gould
Carlton W. Grant, Jr.
Thomas P. Hurst
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Christopher S. Kinkade
Wendy W. Liberatore
Linda E. Lucier
Marguerite K. McElroy
Neil M. McPhee
George A. Meier
Laurel E. Moore
Stephen D. Murphy
Susan M. Oliver
Patrick O'Malley
Stanley G. Rosenblad
William J. Sellers
Gary N. Stanbrough
Karlen A. Wannop
Judith A. White
Susan F. Witzell
Martin C. Woodward
Jia Q. Zhang

Biology Department

Philip Alatalo
L. Susan Brown-Leger
Marjorie K. Clancy
Nancy J. Copley
Mary A. Daher
Linda H. Davis
Diana G. Franks
Elizabeth D. Garland
Terrance J. Howald
Bruce A. Keafer
David M. Kulis
Bruce A. Lancaster
Ethel F. LeFave
Jane E. Marsh
Ann E. Michaels
Zofia J. Mlodzinska
Stephen J. Molyneaux
Rosemarle F. Petrecca
Jane M. Ridge
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Lisa G. Taylor
Bruce R. Woodin
Bonnie L. Woodward

Chemistry Department

John E. Andrews III
Rebecca A. Belastock
Scot P. Birdwhistell
Lorraine Buxton
Marcia W. Davis
Peggy A. Dickinson
Anne S. Edwards
Joanne Goudreau
Mary C. Hartman
Nancy A. Hayward
Marilyn R. Hess
Timothy C. Kenna
Torvald Kohlin
John J. Lee
Molly M. Lumping
Michael 0. Mathewson
Robert K. Nelson
Julianne Palmieri
Edith H. Ross
Deborah K. Shafer
Margaret M. Sulanowski
Maren E. Tracy

Regular Support Staff

N. Joye Wirsen
Mary Zawoysky
Carla J. Zimmerman
Louping Zou

Geology & Geophysics Department

Linda M. Angeloni
John W. Bailey
Pamela R. Barrows
Stephen T. Bolmer, Jr.
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Dolores H. Chausse
Tracey I. Crago
James W. Dolan
David L. DuBois
Kathryn L. Elder
Pamela V. Foster
C. Eben Franks
Alan R. Gagnon
Cynthia T. Gallo
K.I. Faith Hampshire
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Janet M. Johnson
Carol A. Kauffman
Richard A. Krishfield
Peter B. Mills
Anita D. Norton
Elizabeth Osborne
Stephen P. O'Malley
Elizabeth Palazzo
May A. Reed
Ellen Roosen
Kimberly A. Sapp

Physical Oceanography Department

Carol A. Alessi
Karin A. Bohr
Paul R. Bouchard
Maureen E. Carragher
Margaret F. Cook
Lawrence P. Costello
Gennaro H. Crescenti
Jane A. Dunworth
Penny C. Foster
Robert E. Frazel
Barbara Gaffron
Veta M. Green
Brian J. Guest
William H. Horn
George P. Knapp III
Peter B. Landry
Mary Ann Lucas
Carol MacMurray
Anne Marie Michael
William M. Ostrom
Nancy J. Pennington
John B. Reese
Ralph D. Simoneau
Ann Spencer
Robert J. Stanley
Susan A. Tarbell
Robert D. Tavares
Deborah A. Taylor
Toshiko T. Turner
Bryan S. Way
W. David Wellwood
Scott E. Worrilow
Jeanne A. Young
Marguerite E. Zemanovic

Information Systems Center

Gail F. Caldeira
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Edward F. Dow, Jr.
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Robert G. Lowe

Marine Policy Center

Suzanne Demisch
Ellen M. Gately
Hauke L. Kite-Powell
Matthew J. LaMourie
Sarah B. Repetto

SONYA HAGOPIAN

Susan Quigley hulls strawberries for a dinner aboard Atlantis II.

Coastal Research Center

Frank J. Gable
Olimpia L. McCall

Administrative Staff

Kendall B. Bohr
Assistant Purchasing Manager

Stella A. Callagee
Education Office Administrator

Lee Anne Campbell
Information Officer

Karen E. Carmichael
Information Systems Associate I

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Safety Officer

Susan A. Casso
Executive Assistant/ Chemistry

Lisa A. Clark
Assistant Editor/Oceanus

Vicky Cullen
Manager of Publications & Graphic Services

Patricia J. Duffy
Accounting Operations Manager

Kim B. Fahnley
Executive Assistant, Marine Policy Center

Larry D. Flick
Executive Assistant, Deep Submergence Laboratory

David G. Gallo
Coordinator of Industrial & International Programs

Robin C. Good
Development Officer

Sonya Hagopian
Media Coordinator

Carolyn S. Hampton
Information Systems Associate

Frederic R. Heide
Assistant Manager of Graphic Services

Ann C. Henry.
Executive Assistant, Applied Ocean Physics & Engineering Department

Hartley Hoskins
Coordinator, Ocean Industries Program

Susan Kadar
JGOFS Field Program Coordinator

Victoria A. Kaharl
Science Writer

Robin L. Kaiser
Senior Development Officer

Judith L. Kleindinst
Executive Assistant/ Biology

Kathleen P. LaBernz
Assistant Personnel Manager

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Senior News Officer

Virginia A. LeFavor
General Accounting Administrator

David J. Miller
Assistant Sponsored Programs Administrator

Elizabeth D. Milot
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Mozart P. Moniz
Purchasing Manager

Laura A. Murphy
Payroll Administrator

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Conference Coordinator

Sallie K. Riggs
Director of Communications

R. David Rudden, Jr.
Assistant Controller

C.L. Roy Smith
Executive Assistant/ Geology & Geophysics

George A. Smith
Controller

Jacqueline M. Suitor
Director of Development

Martha E. Tarafa
Executive Assistant to the Associate Director

Maurice J. Tavares
Sponsored Programs Administrator

Mary Jane Tucci
Housing Coordinator

Melissa R. Weidman
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Mary Jo Wheatley
Media Coordinator

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Benefits Administrator
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Dianna M. Zaia
Financial Analyst

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Patricia Askew
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Eleanor M. Botelho
Sandra L. Botelho
Marilynn Brooks
Leonard Cartwright
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Linda L. Church
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Terri C. Corbett
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Cheryl C. Daniels
Dale V. DePonte
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Kathleen M. Eimer
Lynne M. Ellsworth
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Barbara Ewing-Deremer
Nancy E. Farrell
Steven R. Ferreira
Susan P. Ferreira
Kathryn M. Fitzpatrick
Kathy S. Frisbee
Ruth E. Goldsmith
Pam J. Goulart
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Richard C. Lovering
Lori Mahoney
Virginia McKinnon
Gretchen McManamin
Gail McPhee
Carole R. Merson
Sandra E. Murphy
Cheryl L. Newton


SONYA HAGOPIAN

Chris Haney sports a smile following his first dive in Alvin *to Fieberling Guyot in the Pacific Ocean. Tim Conners is at left.*


TOM KLEINDINST

Facilities and Services personnel, left to right, Jay Murphy, Robert Greene, Jeff Clemishaw, Lewis Saffron, and Napoleon McCall arrange the fifth floor conference room for a meeting.

E. Paul Oberlander
Sharon J. Omar
Laura L. Oxford
Kathleen Patterson
Maryanne F. Pearcy
Doreen M. Perito
Clara Y. Pires
Jeannine M. Pires
John Porteous
John M. Powers
Sandra A. Sherlock
Jeanne Silva
Timothy M. Silva
Peggy A. Stengel
Mildred M. Teal
Judith A. Thrasher
Alice I. Tricca
Margaret M. Walden
Adrianne Wallace
Leo R. Wells
John A. Wood, Jr.
Marcella R. Youngman

Facilities, Library, Services, *Alvin*, Marine Operations Staff

Socrates J. Carelo
Information Systems Associate II
Ernest G. Charette
Assistant Facllities Manager
Richard S. Chandler
Submersible Operations Coordinator
Gary B. Chiljean
Master, R/V Atlantis II
Joseph L. Coburn Jr.
Marine Operations Manager
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DSV Pilot, R/V Atlantis II
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Research Associate, Data Library
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Port Captain
Joel A. Fahnley
Facilities Engineer
Richard E. Galat
Facilities Engineer
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DSV Pilot, R/V Atlantis II
Charles F. Hall
Chief Engineer, R/V Atlantis II
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Pilot, DSV Alvin
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Traffic Manager
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Manager of Marine Employment
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Marine Operations Coordinator
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Chief Engineer, R/V Atantis II
David I. Olmsted
Boat Operator, R/V Asterias
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Master, R/V Oceanus
Michael G. Raymond
Assistant Project Manager
Terrence M. Rloux
Diving Officer
Eric W. Spencer
Safety Officer
Carl F. Swanson
Master, R/V Oceanus
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Port Engineer
Carolyn P. Winn
Research Librarian
W. Davld Yowell
Boat Operator, R/V Eagle Mar

Regular Support Staff

Facilities, Library, Services, *Alvin*, & Marine Operations Personnel

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Nadine N. Athearn
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Janice M. Baker
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Charles Clemishaw
Jeffrey D. Clemishaw
C. Hovey Clifford
James E. Coddington
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Alden H. Cook
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Gregory Cotter
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Donald F. LeBlanc
Paul E. LeBlanc
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Jose S. Mota
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John R. Murphy, Jr.
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Margaret A. Rioux
John P. Romiza
Lewis J. Saffron
Albert Santiago, Sr.
Michael J. Sawyer
Robert W. Schreiter
Peter J. Schwamb
Ernest G. Smith II
Steven P. Solbo
Robert G. Spenle
Mark L. St. Pierre
Carlotta S. Squire
Margaret P. Stern
Harold W. Swanson
William R. Tavares, Jr.
Kevin D. Thompson
Michael Toner
Carlos Velez
Robert Wichterman
John C. Williams
Ronald E. Woods

SHELLEY LAUZON

Volunteers for the Earth Day beach clean-up at Trunk River included, from left, George Hampson, Bruce Lancaster, Fred Keller, Rick Galat, and Ernie Charette.

Marine Personnel

Wayne A. Bailey
Courtenay Barber III
Jonathan W. Barros
Mitchell G. Barros
Robert Bastarache
Gunter H. Bauerlein
Harold A. Bean
Richard C. Bean
Lawrence T. Bearse
Edward R. Broderick
John H. Brzezinski
Frederick E. Bull, Jr.
Christopher H. Clark
Harry F. Clinton
Arthur D. Colburn III
Alberto Collasius, Jr.
Lawrence P. Costello
Jerome M. Cotter
Steven M. Cross
Hugh B. Dakers
Sallye A. Davis
Mark C. DeRoche
Craig D. Dickson
Derek F. Dineen
Willian J. Dunn, Jr.
Richard Edwards, Jr.
Kevin C. Fisk
Edward F. Graham, Jr.
Thomas Green
Christopher M. Griner
John F. Gumbleton
James A. Haley
Cecile S. Hall
Peter Hall
William S. Hartnett III
David L. Hayden
Perry Hodell
Alan J. Hopkins
Dennis M. Hunt
Kurt S. Jilson
John K. Kay
Jeffrey Little
John T. Lobo
J. Douglas Mayer
Joseph L. Mayes
William McBride
David H. Megathlin
Mirth N. Miller
Patrick S. Mone
John D. Morgan
Richard F. Morris
Paul D. Morrissey
Richard M. Nolan
Michael P. Nolin
David A. Ouellette
Patrick J. Paddack
Patricia L. Pasanen
Charles G. Perry
Craig S. Peters
Brett M. Price
Susan Quigley
Eric Selberg
Richard F. Simpkin
Ernest G. Smith, Jr.
L. Evan Smith
Harry H. Stanton
Jeffrey M. Stolp
John K. Sweet, Jr.
Wayne A. Sylvia
Philip M. Treadwell
Herman Wagner
Kelly Walinski
Brandy R. Walker
Parrish M. Wall
Stephen A. Walsh
Kathleen D. Wilson
Carl 0. Wood

1991 Retirees

Margaret S. Dimmock
Richard H. Dimmock
Robertson P. Dinsmore
Leon J. Fitzgerald
Nick P. Fofonoff
Nancy H. Green
George D. Grice, Jr.
John A. Keizer
Jonathan Leiby
Rudolf Scheltema
Marvel C. Stalcup
John H. Steele

1991 Degree Recipients

Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography/Oceanographic Engineering

Doctor of Philosophy

Esther C. Brady
B.S., University of Massachusetts, Amherst
Special Field: *Physical Oceanography*
Dissertation: *On the Role of the Tropical Instability Waves in the Dynamics of the Pacific Equatorial Undercurrent*

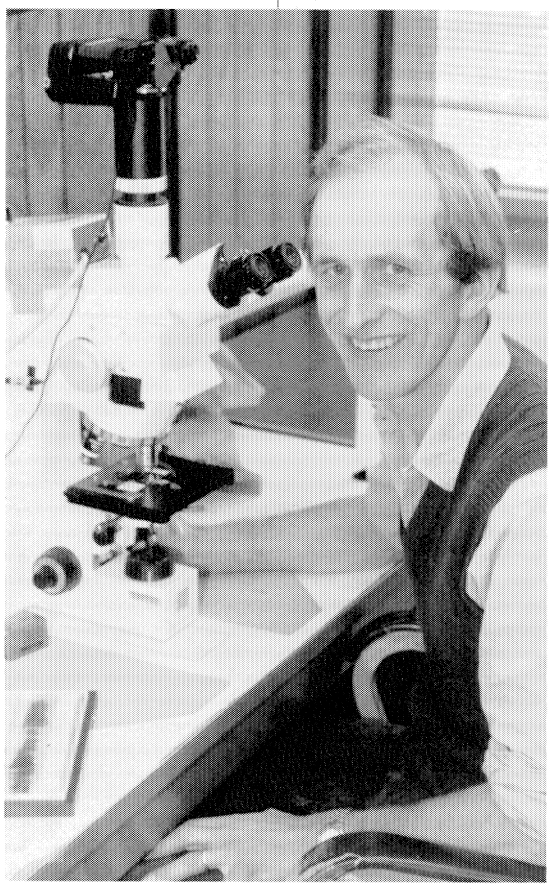
Debra C. Colodner
B.S., Yale University
Special Field: *Chemical Oceanography*
Dissertation: *The Marine Geochemistry of Rhenium, Iridium and Platinum*

Matthew J. Cordery
B.S., University of Chicago
Special Field: *Marine Geology and Geophysics*
Dissertation: *Mantle Convection, Melt Migration and the Generation of Basalts at Mid-Ocean Ridges*

Scott C. Doney
B.A., University of California, San Diego
Special Field: *Chemical Oceanography*
Dissertation: *A Study of North Atlantic Ventilation Using Transient Tracers*

J. Robert Fricke
B.S., Vanderbilt University
M.S., Vanderbilt University
Special Field: *Oceanographic Engineering*
Dissertation: *Acoustic Scattering from Elastic Ice: A Finite Difference Solution*

Gregory C. Johnson
B.S., Bates College
Special Field: *Physical Oceanography*
Dissertation: *Near-Equatorial Deep Circulation in the Indian and Pacific Oceans*



TERRI CORBETT

Michael Moore was one of the 1991 graduates of the MIT/WHOI Joint Program.

Michael J. Moore
B.A., Cambridge University
M.A., Cambridge University
Special Field: *Biological Oceanography*
Dissertation: *Vacuolation, Proliferation and Neoplasia in the Liver of Boston Harbor Winter Flounder,* Pseudopleuronectes americanus

Kirby S. Olson
B.S., Eckerd College
Special Field: *Biological Oceanography*
Dissertation: *Developmental Changes in the Structure and Function of Lobster Hemocyanin*

Markku J. Santala
B.S.C.E., University of Massachusetts
Special Field: *Oceanographic Engineering*
Dissertation: *Surface-Referenced Current Meter Measurements*

Rebecca R. Schudlich
B.S., University of Michigan
M.S., University of Michigan
Special Field: *Physical Oceanography*
Dissertation: *Upper Ocean Dynamics during the LOTUS and TROPIC HEAT Experiments*

Niall C. Slowey
B.S., Tufts University
M.S., University of North Carolina
Special Field: *Marine Geology and Geophysics*
Dissertation: *The Modern and Glacial Thermoclines along the Bahama Banks*

Dajun Tang
B.S., University of Science and Technology, PRC
M.S., Institute of Acoustics, Academia Sinica, PRC
Special Field: *Oceanographic Engineering*
Dissertation: *Acoustic Wave Scattering from a Random Ocean Bottom*

LuAnne Thompson
B.S., University of California, Davis
M.A., Harvard University
Special Field: *Physical Oceanography*
Dissertation: *Flow over Finite Isolated Topography*

Jan C. Zemba
B.S.M.E., University of California, Irvine
M.S.M.E., University of California, Irvine
Special Field: *Physical Oceanography*
Dissertation: *The Structure and Transport of the Brazil Current between 27 and 36 degrees South*

Doctor of Science

D. Andrew Trivett
Diploma/Engineering, Dalhousie University
B. Eng., Technical University of Nova Scotia
Special Field: *Oceanographic Engineering*
Dissertation: *Diffuse Flow from Hydrothermal Vents*

Ocean Engineer

Timothy E. Lindstrom
B.S.E.E., Rochester Institute of Technology
Special Field: *Oceanographic Engineering*
Dissertation: *Predictions and Observations of Seafloor Infrasonic Noise Generated by Sea Surface Orbital Motion*

Master of Science

Karen G. Bemis
B.A., Rice University
Special Field: *Marine Geology and Geophysics*
Dissertation: *Geothermal Heat Flux and Hydrothermal Plumes on the Juan de Fuca Ridge*

John R. Buck
S.B., S.B., Massachusetts Institute of Technology
Special Field: *Oceanographic Engineering*
Dissertation: *Implementation and Evaluation of a Dual-Sensor Time-Adaptive EM Algorithm for Signal Enhancement*

Lawrence F. Galvin
B.S., U.S. Naval Academy
Special Field: *Oceanographic Engineering*
Dissertation: *Human Factors Engineering in Sonar Visual Displays*

Alison M. MacDonald
B.A., Bryn Mawr College
Special Field: *Physical Oceanography*
Dissertation: *Mass, Heat, Oxygen and Nutrient Fluxes at 30 Degrees South and their Implications for the Pacific-Indian Through Flow and the Global Heat Budget*

James D. McLaren
B.Sc., Dalhousie University
Special Field: *Physical Oceanography*
Dissertation: *Evolution of Gaussian Vortices in Vertical Shear on the Beta-Plane*

Lynn A. Oschmann
B.A., Bryn Mawr College
Special Field: *Marine Geology and Geophysics*
Dissertation: *Global Isotopic Signatures of Oceanic Island Basalts*

Elise A. Ralph
B.A., University of Chicago
Special Field: *Physical Oceanography*
Dissertation: *Prediction of Ring Formation using Inverse Scattering*

Thomas J. Woodford
B.S.E.E., University of Virginia, Charlottesville
Special Field: *Oceanographic Engineering*
Dissertation: *Propulsion Optimization for ABE, an Autonomous Underwater Vehicle (AUV)*

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M.S., Academia Sinica
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Dissertation: *A Model of the Equatorial Deep Jets and the Role of the Horizontal Coriolis Parameter*

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Aboard Atlantis II, *Lauren Mullineau, Bob Grieve, and Carla Curran discuss a sample retrieved with* Alvin.

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TOM KLEINDINST

Kathy Gillis explains the work in her laboratory to those attending the Congressional Seminar.

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TERRI CORBETT

The Geophysical Fluid Dynamics study program occupies Walsh Cottage each summer. This group of 1990 participants takes advantage of a sunny afternoon for discussions on the porch.

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Marine Policy and Ocean Management 1991-1992

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TOM KLEINDINST

From left, Tom Austin, Ed Denton, Martin Woodward, and Rich Arthur work on the Tethered Remotely Operated Vehicle.

CRAIG DICKSON

DSV Alvin *is brought aboard* Atlantis II *during a series of September dives off the Washington-Oregon coast.*

1991 Voyage Statistics

Atlantis II & DSV *Alvin*

Total Nautical Miles for 1991 - 44,026 • Total ALVIN dives - 152 • Total Days at Sea - 261

Voyage	Cruise Period	Principal Objective, Area of Operation	Ports of Call	Chief Scientist
125-XIX	7 Jan - 4 Feb	East Pacific Rise, geophysical measurements of seismic velocity in oceanic crust in support of ODP (non-*Alvin*)	San Diego	M. Purdy
125-XX	18 Feb - 24 Feb	California Coast, biological studies in vicinity of a whale skeleton, 6 dives	San Diego	C.Smith (Hawaii)
125-XXI	28 Feb - 5 Mar	Transit to Guaymas, Mexico	Guaymas, Mexico	- - -
125-XXII	6 Mar - 15 Mar	Sea of Cortez, chemosynthetic microbiology at hydrothermal vent sites, 8 dives	Guaymas, Mexico	H.Jannasch
125-XXIII	15 Mar - 23 Mar	Sea of Cortez, continuation of Leg XXII, 5 dives	Acapulco, Mexico	H.Jannasch R.Lutz (Rutgers)
125-XXIV	28 Mar - 27 Apr	East Pacific Rise, volcanological and geochemical studies at hydrothermal vents in support of ODP, 25 dives	Acapulco, Mexico	R.Haymon (UCSB) D.Fornari (Lamont)
125-XXV	2 May - 2 Jun	East Pacific Rise, geological studies of spreading centers of the Siqueiros transform feature, 18 dives	San Diego	D.Fornari (Lamont)
125-XXVI	15 Jun - 19 Jun	California coast, salvage ops ROV CURV-III, 3 dives	San Diego	NAVSEA
125-XXVII	20 Jun - 30 Jun	California coast, salvage ops ROV CURV-III, 1 dive Fieberling Guyot, biological studies at abrupt topographical features, 6 dives	San Diego	NAVSEA L.Mullineaux
125-XXVIIIA	30 Jun -2 Jul	California coast, salvage ops ROV CURV-III, 1 dive	Monterey	B.Walden
125-XXVIIIB	2 Jul - 6 Jul	Transit to Astoria	Astoria, Oregon	- - -
125-XXIX	9 Jul - 31 Jul	Juan de Fuca Ridge, geological and geochemical studies at active hydrothermal vents, 20 dives	Seattle, Wash.	J.Delaney (Washington) A.Schultz (Washington)
125-XXX	5 Aug - 13 Aug	Juan de Fuca Ridge, biological studies at hydrothermal vents, 5 dives	Astoria, Oregon	R.Lutz (Rutgers)
125-XXXI	18 Aug - 6 Sept	Juan de Fuca Ridge, chemical studies of hydrothermal vents, 16 dives	Astoria, Oregon	R.Embley (NOAA)
125-XXXII	10 Sept - 27 Sept	Juan de Fuca Ridge, geological and geochemical studies at active hydrothermal vents, 15 dives	Seattle, Wash.	J.Delaney (Washington) A.Schultz (Washington) K.Becker (Miami) R.Gallotta (ONT)
125-XXXIII	3 Oct - 14 Oct	Juan de Fuca Ridge, chemical studies of hydrothermal vents, 9 dives	Astoria, Oregon	D.Stakes (So.Carolina) K.Becker (Miami)
125-XXXIV	16 Oct - 21 Oct	Transit to San Diego	San Diego	- - -
125-XXXV	25 Nov - 21 Dec	East Pacific Rise, biological studies at hydrothermal vents, 14 dives	San Diego	L.Mullineaux C.Van Dover

R/V *Knorr*

Returned to Woods Hole on October 17 after a 32-month refit period at McDermott Shipyard in Amelia, Louisiana.

MARGARET BOWLES

Employees, students, family members, and friends gathered on a cold and rainy October 17 to greet R/V Knorr.

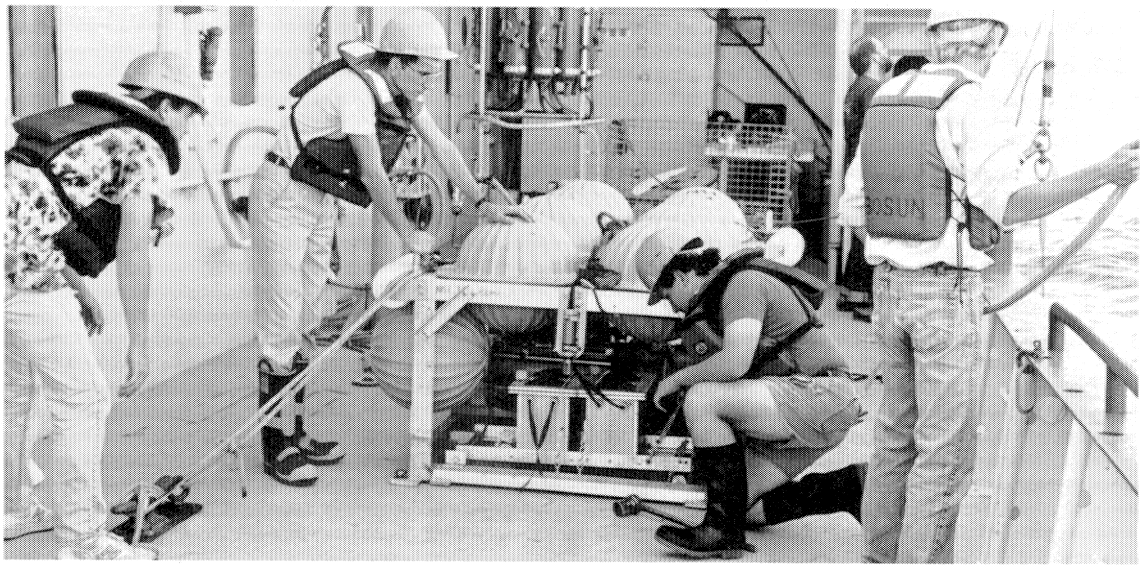
TOM KLEINDINST

Oceanus *bosun Richard Simpkin signals the crane operator.*

R/V *Oceanus*

Total Nautical Miles for 1991 - 26,063 • Total Days at Sea - 209

Voyage	Cruise Period	Principal Objective, Area of Operation	Ports of Call	Chief Scientist
230	7 Jan - 12 Jan	Mid-Atlantic Bight, acoustics experiments	Woods Hole	G.Frisk
231	14 Jan - 15 Jan	Massachusetts Bay, mooring recovery	Woods Hole	W.Strahle (USGS)
232	22 Jan - 26 Jan	Mid-Atlantic Bight, acoustics experiments	Woods Hole	G.Frisk
233	28 Jan - 30 Jan	Gulf Stream, search for mooring	Woods Hole	J.Kemp
234	31 Jan - 1 Feb	Massachusetts Bay, mooring deployment	Woods Hole	W.Strahle (USGS)
235	5 Feb - 8 Feb	Mid-Atlantic Bight, acoustics experiments	Woods Hole	G.Frisk
236	19 Feb - 23 Feb	Mid-Atlantic Bight, acoustics experiments	Woods Hole	G.Frisk
237-I	2 Mar - 10 Mar	Western North Atlantic, acoustics experiments	San Juan	P.Worcester (Scripps)
237-II	12 Mar - 30 Mar	Western North Atlantic, acoustics experiments	Woods Hole	P.Worcester (Scripps)
238	3 Apr - 7 Apr	Mid-Atlantic Bight, acoustics experiments	Woods Hole	M.Purdy
239	22 Apr - 24 Apr	Western North Atlantic	Woods Hole	- - -
240-I	26 Apr - 3 May	Transit to Azores	Ponta Delgada	- - -
240-II	5 May - 3 Jun	Eastern North Atlantic, Subduction Experiment surveys	Funchal, Madiera	J.Luyten
240-III	17 Jun - 5 Jul	Eastern North Atlantic, Subduction Experiment mooring deployment	Ponta Delgada	R.Weller
240-IV	10 Jul - 23 Jul	Western North Atlantic, SYNOP Experiment mooring recovery	Woods Hole	S.Worrilow
241-I	29 Jul - 6 Aug	Western North Atlantic, study of the microbial ecology of oceanic plankton and benthic communities	St.George, Bermuda	D.Caron
241-II	7 Aug - 12 Aug	Western North Atlantic, study of the microbial ecology of oceanic plankton and benthic communities	St.George, Bermuda	D.Caron
241-III	13 Aug - 22 Aug	Western North Atlantic, study of the microbial ecology of oceanic plankton and benthic communities	Woods Hole	D.Caron
242	28 Aug - 30 Aug	Western North Atlantic, engineering test of video plankton recorder	Woods Hole	C.Davis
243-I	10 Sept - 10 Sept	Western North Atlantic, study of relationship between high-resolution remote sensors and surface processes, including surface films	Woods Hole	E.Bock
243-II	11 Sept - 26 Sept	Western North Atlantic, study of relationship between high-resolution remote sensors and surface processes, including surface films	Woods Hole	E.Bock
244	1 Oct - 12 Oct	Western North Atlantic, engineering tests of WOCE Tracers Experiment chemical injection instruments	Woods Hole	J.Ledwell
245	18 Oct - 26 Oct	DWDS-106, box-core sediment sampling	Woods Hole	A.Cantillo (NOAA)
246	12 Nov - 16 Nov	Western North Atlantic, JGOFS instrumentation tests	Woods Hole	J.Bishop (Lamont)
247-I	2 Dec - 3 Dec	Georges Bank, engineering test of video plankton recorder	Woods Hole	C.Davis
247-II	5 Dec - 6 Dec	Georges Bank, engineering test of video plankton recorder	Woods Hole	C.Davis
248	18 Dec - 18 Dec	NSF inspection	Woods Hole	- - -



CRAIG MARQUETTE

Chris Kinkade, Jim Ledwell, Sean Kery, and Jeff Stolp prepare to launch Ledwell's tracer injection sled on an R/V Oceanus *test cruise.*

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Chairman of the Board Guy Nichols spoke at the June dedication of the National Ocean Sciences Accelerator Mass Spectrometry Facility at McLean Laboratory.

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Charles Dana, left, and Charles Hollister applaud Cecil Green at the June Associates dinner.

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In Memoriam

The Institution gratefully acknowledges the service and support of those members who passed away in 1991:

Alan C. Bemis

Albert E. Parr

Roger Revelle

Publications

Compiled by Maureen O'Donnell, Office of the Research Librarian

1991 publications of record as of February 1, 1992. Entries are listed by department. Institution contribution number appears at the end of each entry. 1990 publications not listed in the 1990 Annual Report are listed here.

Applied Ocean Physics & Engineering Department

Boden, Linda, James B. Bowlin and John L. Spiesberger.
Time domain analysis of normal mode, parabolic, and ray solutions of the wave equation. *J.Acoust.Soc.Am.*, 90(2),Pt.1:954-958, (1991) 7728.

Bowlin, James B.
Generating eigenray tubes from two solutions of the wave equation. *J.Acoust.Soc.Am.*, 89(6):2663-2669, (1991) 7536.

Bradley, Albert M.
The role of the microcontroller in ocean research instruments. *Oceanus*, 34(1):53-60, (1991).

Brink, K. H., R. C. Beardsley, P. P. Niiler, M. Abbott, A. Huyer, S. Ramp, T. Stanton and D. Stuart.
Statistical properties of near-surface flow in the California coastal transition zone. *J.Geophys.Res.*, 96(C8):14693-14706, (1991).

Brown, Neil.
The history of salinometers and CTD sensor systems. *Oceanus*, 34(1):61-66, (1991).

Catipovic, Josko and Lee E. Freitag.
Spatial diversity processing for underwater acoustic telemetry. *IEEE J.Ocean.Eng.*, 16(1):86-97, (1991) 7718.

DiPerna, Daniel T. and Timothy K. Stanton.
Fresnel zone effects in the scattering of sound by cylinders of various lengths. *J.Acoust.Soc.Am.*, 90(6):3348-3355, (1991) 7498.

Edson, J. B., C. W. Fairall, P. G. Mestayer and S. E. Larsen.
A study of the inertial-dissipation method for computing air-sea fluxes. *J.Geophys.Res.*, 96(C6):10689-10711, (1991).

Freitag, Lee E., J. Stevens Merriam, Daniel E. Frye and Josko A. Catipovic.
A long-term deep-water acoustic telemetry experiment. *Oceans '91*, 1:254-260, (1991).

Geyer, W. Rockwell.
Time-dependent, two-layer flow over a sill. In: *The Physical Oceanography of Sea Straits*. L. J. Pratt, ed. NATO Advanced Study Institute Series. Series C. Mathematical and Physical Sciences: V. 318. Kluwer Academic Publishers, Dordrecht :421-432, (1990).

Geyer, W. Rockwell, Robert C. Beardsley, Julio Candela, Belmiro M. Castro, Richard V. Legeckis, Steven J. Lentz, Richard Limeburner, Luis B. Miranda and John H. Trowbridge.
The physical oceanography of the Amazon outflow. *Oceanography*, 4(1):8-14, (1991) 7623.

Geyer, W. Rockwell and Richard Signell.
Measurements and modeling of the spatial structure of nonlinear tidal flow around a headland. In: *Tidal Hydrodynamics*. Bruce B. Parker, ed. Proceedings of the International Conference on Tidal Hydrodynamics. John Wiley and Sons, Inc., Publishers, New York :403-418, (1991) 7279.

Greene, Charles H., Timothy K. Stanton, Peter H. Wiebe and Sam McClatchie.
Acoustic estimates of Antarctic krill. *Nature(Lond)*, 349(6305):110, (1991) 7497.

Grosenbaugh, M. A., D. R. Yoerger, F. S. Hover and M. S. Triantafyllou.
Drag forces and flow-induced vibrations of a long vertical tow cable - Part II: Unsteady towing conditions. *J.Offshore Mech.Arctic Eng.*, 113:199-204, (1991) 7484.

Gross, Thomas F. and A. J. Williams 3rd
Characterization of deep sea storms. *Mar.Geol.*, 99(3-4):281-301, (1991) 7582.

Hosom, D. S., R. A. Weller and A. A. Hinton.
A sea water battery for upper ocean buoy systems. In: *MTS '91 an Ocean Cooperative: Industry, Government and Academia*. Proceedings of MTS '91. New Orleans, November 10-14, 1991. Sponsored by the Marine Technology Society. Marine Technology Society, Washington, DC 1:32-36, (1991).

Hosom, D. S., R. A. Weller, K. E. Prada and R. P. Trask.
A three meter discus buoy with IMET meteorological sensors. In: *MTS '91 an Ocean Cooperative: Industry, Government and Academia*. Proceedings of MTS '91. New Orleans, November 10-14, 1991. Sponsored by Marine Technology Society. Marine Technology Society, Washington, DC 1:206-210, (1991) 7817.

Ledwell, James R. and Andrew J. Watson.
The Santa Monica Basin Tracer Experiment: A study of diapycnal and isopycnal mixing. *J.Geophys.Res.*, 96(C5):8695-8718, (1991).

Ledwell, James R., Andrew J. Watson, Kenneth W. Doherty and William M. Berelson.
Integrating samplers for the deep sea. *J.Geophys.Res.*, 96(C5):8727-8732, (1991).

Lentz, Steven J. and John H. Trowbridge.
The bottom boundary layer over the Northern California Shelf. *J.Phys.Oceanogr*, 21(8):1186-1201, (1991) 7445.

Lynch, J. F. and Y. C. Agrawal.
A model-dependent method for inverting vertical profiles of scattering to obtain particle size spectra in boundary layers. *Mar.Geol.*, 99:387-401, (1991) 6653.

Lynch, James F., Thomas F. Gross, Blair Brumley and Richard A. Filyo.
Sediment concentration profiling in HEBBLE using a 1-MHz acoustic backscatter system. *Mar.Geol.*, 99:361-385, (1991) 6756.

Lynch, James F., Subramaniam D. Rajan and George V. Frisk.
A comparison of broadband and narrow-band modal inversions for bottom geoacoustic properties at a site near Corpus Christi, Texas. *J.Acoust.Soc.Am.*, 89(2):648-665, (1991) 7359.

Mullineaux, L. S. and C. A. Butman.
Initial contact, exploration and attachment of barnacle (*Balanus amphitrite*) cyprids settling in flow. *Mar.Biol.*, 110:93-103, (1991) 7419.

Park, Melora M., Robin C. Singer, Albert J. Plueddemann and Robert A. Weller.
High-speed real-time data acquisition for vector measuring current meters. *IEEE J.Ocean.Eng.*, 16(4):360-367, (1991) 7550.

Pawlik, Joseph R., Cheryl Ann Butman and Victoria R. Starczak.
Hydrodynamic facilitation of gregarious settlement of a reef-building tube worm. *Science(WashDC)*, 251:421-424, (1991) 7466.

Plant, William J.
Comment on 'Wind wave directionality effects on the radar imaging of ocean swell' by F. J. Ocampo-Torres and I. S. Robinson. *J.Geophys.Res.*, 96(10):18527-18529, (1991) 7659.

Plant, William J.
The variance of the normalized radar cross section of the sea. *J.Geophys.Res.*, 96(C11):20643-20654, (1991) 7682.

Plant, William J.
Comment on the full-wave controversy. *J.Geophys.Res.*, 96(C9):17105-17106, (1991) 7702.

Rajan, Subramaniam D. and George V. Frisk.
The effect of seasonal temperature fluctuations in the water column on sediment compressional wave speed profiles in shallow water. In: *Ocean Variability and Acoustic Propagation*. J. Potter and A. Warn-Varnas, eds. Kluwer Academic Publishers, Dordrecht :69-80, (1991) 7405.

Rajan, Subramaniam D. and Cinthia S. Howitt.
Determination of the sediment shear speed profiles from phase and group velocity dispersion data of SH wave. In: *Shear Waves in Marine Sediments*. J. M. Hovem, et al., eds. Kluwer Academic Publishers, Dordrecht :529-536, (1991) 7542.

Rajan, Subramaniam D., James F. Lynch and George V. Frisk.
On the determination of modal attenuation coefficients and compressional wave attenuation profiles in a range-dependent environment in Nantucket Sound. *IEEE J.Ocean.Eng.*, 17(1):118-128, (1992) 7782.

Santala, Markku J. and Albert J. Williams 3rd
Estimates of directional spectra from the Surface Acoustic Shear Sensor (SASS). *Oceans '90*, :41-45, (1990) 7434.

Signell, R. P., R. C. Beardsley, H. C. Graber and A. Capotondi.
Effect of wave-current interaction on wind-driven circulation in narrow, shallow embayments. *J.Geophys.Res.*, 95(C6):9671-9678, (1990) 7066.

Spiesberger, John L. and Kurt Metzger.
Basin-scale tomography: A new tool for studying weather and climate. *J.Geophys.Res.*, 96(C3):4869-4889, (1991) 7366.

Spiesberger, John L. and Kurt Metzger.
New estimates of sound speed in water. *J.Acoust.Soc.Am.*, 89(4):1697-1700, (1991) 7402.

Spiesberger, John L. and Kurt Metzger.
A new algorithm for sound speed in seawater. *J.Acoust.Soc.Am.*, 89(6):2677-2688, (1991) 7537.

Stanton, T. K. and D. V. Holliday.
Using sonar to examine the ocean food chain. *J.Acoust.Soc.Am.*, 89(1):465-466, (1991).

Stanton, Timothy.
Sound scattering by zooplankton. *Rapp.P.-v.Reun.Int.Explor.Mer*,189:353-362, (1990).

Stewart, W. Kenneth.
Multisensor visualization for underwater archaeology. *IEEE Comp.Graph.Appl.*, March:13-18, (1991) 7606.

Stewart, W. Kenneth.
Visualization resources and strategies for remote subsea exploration. In: *Scientific Visualization of Physical Phenomena*. N. M. Patrikalakis, ed. Springer-Verlag Tokyo, Tokyo :85-109, (1991) 7620.

Stewart, W. Kenneth.
High-resolution optical and acoustic remote sensing for underwater exploration. *Oceanus*, 34(1):10-22, (1991) 7664.

Stewart, W. Kenneth.
Remote-sensing issues for intelligent underwater systems. In: *Proceedings of the 1991 IEEE Computer Society Conference on Computer Vision and Pattern Recognition*. Lahaina, Maui, Hawaii, June 3-6, 1991. IEEE Computer Society Press, Los Alamitos :230-235, (1991) 7665.

Tang, Dajun and George V. Frisk.
Plane-wave reflection from a random fluid half-space. *J.Acoust.Soc.Amer.*, 90(5):2751-2756, (1991) 7251.

Triantafyllou, Michael S. and Mark A. Grosenbaugh.
Robust control for underwater vehicle Systems with time delays. *IEEE J.Ocean.Eng.*, 16(1):146-151, (1991) 7485.

Trivett, D. Andrew, Eugene A. Terray and Albert J. Williams 3rd
Error analysis of an acoustic current meter. *IEEE J.Ocean.Eng.*,16(4):329-337, (1991) 7626.

Trowbridge, J. H. and S. J. Lentz.
Asymmetric behavior of an oceanic boundary layer above a sloping bottom. *J.Phys.Oceanogr*, 21(8):1171-1185, (1991) 7456.

Villaret, Catherine and J. H. Trowbridge.
Effects of stratification by suspended sediments on turbulent shear flows. *J.Geophys.Res.*, 96(C6):10659-10680, (1991) 7544.

Wanninkhof, Rik, James R. Ledwell and Andrew J. Watson.
Analysis of sulfur hexafluoride in seawater. *J.Geophys.Res.*, 96(C5):8733-8740, (1991).

Watson, Andrew J., James R. Ledwell and Stewart C. Sutherland.
The Santa Monica Basin Tracer Experiment: Comparison of release methods and performance of perfluorodecalin and sulfur hexafluoride. *J.Geophys.Res.*, 96(C5):8719-8725, (1991).

Weller, Robert A., David S. Hosom, Kenneth E. Prada and Gennaro H. Crescenti.
Improved meteorological instruments and data acquisition systems for buoys and ships. In: *7th Symposium on Meteorological Observations and Instrumentation. Special Sessions on Laser Atmospheric Studies*. 71st AMS Annual Meeting, January 14-18, 1991, New Orleans, LA. American Meteorological Society, Boston :129-133, (1991).

Williams, Albert J., 3rd.
Ocean engineering. *Oceanus*, 34(1):4-5, (1991).

Williams, Albert J., 3rd. and Thomas Gross.
In situ processing of boundary layer flow measurements for data compression. *Oceans '91*, 2:973-975, (1991) 7742.

Yoerger, Dana R.
Robotic undersea technology. *Oceanus*, 34(1):32-37, (1991).

Yoerger, Dana R., Hagen Schempf and David M. DiPietro.
Design and performance evaluation of an actively compliant underwater manipulator for full-ocean depth. *J.Robot.Syst.* (Special issue on Underwater Robotics), 8(3):371-392, (1991) 7594.

Biology Department

Berninger, Ulrike-G., David A. Caron, Robert W. Sanders and Bland J. Finlay.
Heterotrophic flagellates of planktonic communities, their characteristics and methods of study. In: *Biology of Free-living Heterotrophic Flagellates*. David J. Patterson and Jacob Larsen, eds. Systematics Association Special Volume No. 45. Clarendon Press, Oxford :39-56, (1991) 7766.

Borlakoglu, J. T., J. J. Stegeman and R. R. Dils.
Induction of hepatic cytochrome P-450IA1 in pigeons treated *in vivo* with aroclor 1254, a commercial mixture of polychlorinated biphenyls (PCBS). *Comp.Biochem.Physiol.*, 99C(3):279-286, (1991).

Bricelj, V. M., J. H. Lee, A. D. Cembella and D. M. Anderson.
Uptake kinetics of paralytic shellfish toxins from the dinoflagellate *Alexandrium fundyens* in the mussel *Mytilus edulis*. *Mar.Ecol.Prog.Ser.*, 63:177-188, (1990) 7217.

Caldwell, Melba C., David K. Caldwell and Peter L. Tyack.
Review of the signature-whistle hypothesis for the Atlantic Bottlenose Dolphin. In: *The Bottlenose Dolphin: Recent Progress in Research*. S. Leatherwood and R. Reeves, eds. Academic Press, San Diego :199-234, (1990) 7156.

Caron, David A.
Growth of two species of bacterivorous microflagellates in batch and continuous culture, and implications for their planktonic existence. *Mar.Microb.Food Webs*, 4(2):143-159, (1990) 7014.

Caron, David A.
Heterotrophic flagellates associated with sedimenting detritus. In: *The Biology of Free-Living Heterotrophic Flagellates*. David J. Patterson and Jacob Larson, eds. Clarendon Press, Oxford :77-92, (1991) 7558.

Caron, David A.
Evolving role of protozoa in aquatic nutrient cycles. In: *Protozoa and Their Role in Marine Processes*. P. C. Reid, et al., eds. NATO ASI Series, Vol. G 25. Springer-Verlag, Berlin :387-415, (1991).

Caron, David A., Ee Lin Lim, Geraldine Miceli, John B. Waterbury and Frederica W. Valois.
Grazing and utilization of chroococcoid cyanobacteria and heterotrophic bacteria by protozoa in laboratory cultures and a coastal plankton community. *Mar.Ecol.Prog.Ser.*, 76:205-217, (1991) 7705.

Caswell, Hal and Joel E. Cohen.
Communities in patchy environments: A model of disturbance, competition, and heterogeneity. In: *Ecological Heterogeneity*. Jurek Kolasa and Steward T. A. Pickett, eds. Springer-Verlag New York, Inc., New York :97-121, (1991) 7214.

Caswell, Hal and Joel E. Cohen.
Disturbance, interspecific interaction and diversity in metapopulations. *Biol.J.Linn.Soc.*, 42:193-218, (1991) 7325.

Conway, Noellette and Judith McDowell Capuzzo.
Incorporation and utilization of bacterial lipids in the *Solemya velum* symbiosis. *Mar.Biol.*, 108:277-291, (1991) 7356.

Davis, Cabell S., Glenn R. Flierl, P. H. Wiebe and P. J. S. Franks.
Micropatchiness, turbulence and recruitment in plankton. *J.Mar.Res.*, 49(1):109-151, (1991) 7613.

DeLong, E. F.
Molecular systematics, microbial ecology and single cell analysis. In: *Particle Analysis in Oceanography*. S. Demers, ed. NATO Advanced Study Institute Symposium Volume G27. Springer-Verlag Berlin Heidelberg :237-257, (1991) 7564.

Distel, D. L., E. F. DeLong and J. B. Waterbury.
Phylogenetic characterization and in situ localization of the bacterial symbiont of shipworms (Teredinidae: Bivalvia) using 16S rRNA sequence analysis and oligodeoxynucleotide probe hybridization. *Appl.Envir.Microbiol.*, 57(8):2376-2382, (1991) 7602.

Doucette, G. J. and P. J. Harrison.
Aspects of iron and nitrogen nutrition in the red tide dinoflagellate *Gymnodinium sanguineum*. I. Effects of iron depletion and nitrogen source on biochemical composition. *Mar.Biol.*, 110:165-173, (1991) 7638.

Doucette, G. J. and P. J. Harrison.
Aspects of iron and nitrogen nutrition in the red tide dinoflagellate *Gymnodinium sanguineum*. II. Effects of iron depletion and nitrogen source on iron and nitrogen uptake. *Mar.Biol.*, 110:175-182, (1991) 7639.

Doucette, Gregory J., Allan D. Cembella and Gregory L. Boyer.
Cyst formation in the red tide dinoflagellate *Alexandrium tamarense* (Dinophyceae): Effects of iron stress. *J.Phycol.*, 25:721-731, (1989) 7149.

Doucette, Gregory J. and Paul J. Harrison.
Some effects of iron and nitrogen stress on the red tide dinoflagellate *Gymnodinium sanguineum*. *Mar.Ecol.Prog.Ser.*, 62:293-306, (1990).

Dunlap, Paul V.
Organization and regulation of bacterial luminescence genes. *Photochem.Photobiol.*, 54(6):1157-1170, (1991) 7801.

Dunlap, Paul V. and E. P. Greenberg.
Role of intercellular chemical communication in the *Vibrio fischeri*-Monocentrid fish symbiosis. In: *Microbial Cell-Cell Interactions*. Martin Dworkin, ed. American Society for Microbiology, Washington, DC :219-253, (1991) 7524.

Publications

Goksoyr, Anders, Tommy Andersson, Donald R. Buhler, John J. Stegeman, David E. Williams and Lars Forlin.
Immunochemical cross-reactivity of β-naphthoflavone-inducible cytochrome P450 (P450IA) in liver microsomes from different fish species and rat. *Fish Physiol.Biochem.*, 9(1):1-13, (1991).

Goldman, J. C. and M. R. Dennett.
Ammonium regeneration and carbon utilization by marine bacteria grown on mixed substrates. *Mar.Biol.*, 109:369-378, (1991) 7287.

Graneli, Edna, Bo Sundstrom, Lars Edler and Donald M. Anderson.
Toxic Marine Phytoplankton. Edna Graneli, Bo Sundstrom, Lars Edler and Donald M. Anderson, eds. Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton. June 26-30, 1989, Lund, Sweden, Elsevier Science Publ. Co. 554 pages, (1990).

Gray, Elizabeth Snowberger, Bruce R. Woodin and John J. Stegeman.
Sex differences in hepatic monooxygenases in winter flounder (*Pseudopleuronectes americanus*) and scup (*Stenotomus chrysops*) and regulation of P450 forms by estradiol. *J.Exper.Zool.*, 259:330-342, (1991) 7423.

Greene, Charles H., Timothy K. Stanton, Peter H. Wiebe and Sam McClatchie.
Acoustic estimates of Antarctic krill. *Nature(Lond)*, 349(6305):110, (1991) 7497.

Hacker, Sally D. and Laurence P. Madin.
Why habitat architecture and color are important to shrimps living in pelagic *Sargassum*: The use of camouflage and plant-part mimicry. *Mar.Ecol.Prog.Ser.*, 70:143-155, (1991) 7530.

Hahn, Mark E. and Thomas A. Gasiewicz.
Determination of individual porphyrins in rodent urine using high-performance liquid chromatography following clean-up by anion-exchange chromatography. *J.Chromatogr.*, 563:363-368, (1991).

Hahn, Mark E. and John J. Stegeman.
The role of biotransformation in the toxicity of marine pollutants. In: *Pour l'Avenir du Beluga*. (For the Future of the Beluga.) Jacques Prescott and Michel Gauquelin, eds. Proceedings of the International Forum for the Future of the Beluga, Presses de l'Universite du Quebec, Quebec :185-198, (1990) 7552.

Holland, Heinrich D., George I. Smith, Holger W. Jannasch, Andrew G. Dickson, Zheng Miangping and Ding Tiping.
Lake Zabuye and the climatic history of the Tibetian Plateau. *Geowissenschaf.*, 2:37-44, (1991) 7543.

Kitchell, Judith P., Saraswathy V. Nochur, Judith K. Marquis, Dennis A. Bazylinski and Holger W. Jannasch.
Microbial oxidation of sulfur in dibenzothiophene. *Resour.Conserv.Recycl.*, 5:255-263, (1991) 7513.

Kurr, Margit, Robert Huber, Helmut Konig, Hoger W. Jannasch, Hans Fricke, Antonio Trincone, Jakob K. Kristjansson and Karl O. Stetter.
Methanopyrus kandleri, gen. and sp. nov. represents a novel group of hyperthermophilic methanogens, growing at 100°C. *Arch.Microbiol.*, 156:239-247, (1991) 7615.

Lobel, Phillip S.
Mating strategies of coastal marine fishes. *Oceanus*, 34(3):19-26, (1991).

Madin, Katherine A. C. and Laurence P. Madin.
Sex (and asex) in the jellies. *Oceanus*, 34(3):27-35, (1991).

Monosson, Emily and John J. Stegeman.
Cytochrome P450E (P450IA) induction and inhibition in winter flounder by 3,3',4,4'-tetrachlorobiphenyl: Comparison of response in fish from Georges Bank and Narragansett Bay. *Environ.Toxicol.Chem.*, 10:765-774, (1991) 7357.

Mullineaux, Lauren S., Peter H. Wiebe and Edward T. Baker.
Hydrothermal vent plumes: Larval highways in the deep sea? *Oceanus*, 34(3):64-68, (1991).

Mullineaux, L. S. and C. A. Butman.
Initial contact, exploration and attachment of barnacle (*Balanus amphitrite*) cyprids settling in flow. *Mar.Biol.*, 110:93-103, (1991) 7419.

Nakamura, Yasuo, Tatsushi Umemori, Masataka Watanabe, David M. Kulis and Donald M. Anderson.
Encystment of *Chattonella antiqua* in laboratory cultures. *J.Oceanogr.Soc.Japan*, 46:35-43, (1990) 7216.

O'Kane, Dennis J., Bonnie Woodward, John Lee and Douglas C. Prasher.
Borrowed proteins in bacterial bioluminescence. *Proc.Nat.Acad.Sci.USA*, 88:1100-1104, (1991) 7540.

Ozkaynak, Engin, David C. Rueger, Eric A. Drier, Clare Corbett, Richard J. Ridge, T. Kuber Sampath and Hermann Oppermann.
OP-1 cDNA encodes an osteogenic protein in the TGF-β family. *EMBO J.*, 9(7):2085-2093, (1990).

Pascual, Mercedes and Hal Caswell.
The dynamics of a size-classified benthic population with reproductive subsidy. *Theor.Popul.Biol.*, 39(2):129-147, (1991) 7300.

Pawlik, Joseph R., Cheryl Ann Butman and Victoria R. Starczak.
Hydrodynamic facilitation of gregarious settlement of a reef-building tube worm. *Science(WashDC)*, 251:421-251, (1991) 7466.

Pley, Ursula, Jutta Schipka, Agata Gambacorta, Holger W. Jannasch, Hans Fricke, Reinhard Rachel and Karl O. Stetter.
Pyrodictium abyssi sp. nov. represents a novel heterotrophic marine archaeal hyperthermophile growing at 110°C. *System.Appl.Microbiol.*, 14:245-253, (1991) 7593.

Prasher, D. C., D. O'Kane, J. Lee and B. Woodward.
The lumazine protein gene in *Photobacterium phosphoreum* is linked to the *lux* operon. *Nucl.Acids Res.*, 18(21):6450, (1990) 7538.

Purcell, Jennifer E. and Laurence P. Madin.
Diel patterns of migration, feeding, and spawning by salps in the subarctic Pacific. *Nature(Lond)*, 73:211-217, (1991) 7351.

Sampath, T. Kuber, John E. Coughlin, Robert M. Whetstone, David Banach, Clare Corbett, Richard J. Ridge, Engin Ozkaynak, Hermann Opperman and David C. Rueger.
Bovine osteogenic protein is composed of dimers of OP-1 and BMP-2A, two members of the transforming growth factor-β superfamily. *J.Biol.Chem.*, 265(22):13198-13205, (1990).

Sanders, Robert W., Karen G. Porter and David A. Caron.
Relationship between phototrophy and phagotrophy in the mixotrophic chrysophyte *Poterioochromonas malhamensis*. *Microb.Ecol.*,19:97-109, (1990) 7274.

Sayigh, Laela S., Peter L. Tyack, Randall S. Wells and Michael D. Scott.
Signature whistles of free-ranging bottlenose dolphins *Tursiops truncatus*: Stability and mother-offspring comparisons. *Behav.Ecol.Sociobiol.*, 26:247-260, (1990) 7127.

Scheltema, Amelie H., John Buckland-Nicks and Fu-Shiang Chia.
Chaetoderma argenteum Heath, a northeastern Pacific aplacophoran mollusc redescribed (Chaetodermomorpha: Chaetodermtidae). *Veliger*, 34(2):204-213, (1991) 7512.

Scheltema, Amelie H. and Alan M. Kuzirian.
Helicoradomenia juani gen. et sp. nov., a Pacific hydrothermal vent Aplacophora (Mollusca:Neomeniaomorpha). *Veliger*, 34(2):195-203, (1991) 7465.

Schmidt, Thomas M., Edward F. DeLong and Norman R. Pace.
Analysis of a marine picoplankton community by 16S rRNA gene cloning and sequencing. *J.Bacteriol.*, 173(14):4371-4378, (1991).

Schwinghamer, P., D. M. Anderson and D. M. Kulis.
Separation and concentration of living dinoflagellate resting cysts from marine sediments via density-gradient centrifugation. *Limnol.Oceanogr.*, 36(3):588-592, (1991) 7272.

Silva, J. F., J. Raventos and H. Caswell.
Fire and fire exclusion effects on the growth and survival of two savannah grasses. *Acta Oecol.*, 11(6):783-800, (1990) 7383.

Smolowitz, R. M., M. E. Hahn and J. J. Stegeman.
Immunohistochemical localization of cytochrome P450IA1 induced by 3,3',4,4'-tetrachlorobiphenyl and by 2,3,7,8-tetrachlorodibenzofuran in liver and extrahepatic tissues of the teleost *Stenotomus chrysops* (scup). *Drug Metab.Dispos.*, 19(1):113-123, (1991) 7390.

Stegeman, John J. and John J. Lech.
Cytochrome P450 monooxygenase systems in aquatic species: Carcinogen metabolism and biomarkers for carcinogen and pollutant exposure. *Environ.Health Perspect.*, 90:101-109, (1990) 7178.

Stegeman, John J., Roxanna M. Smolowitz and Mark E. Hahn.
Immunohistochemical localization of environmentally induced cytochrome P450IA1 in multiple organs of the marine teleost *Stenotomus chrysops* (scup). *Toxicol.Appl.Pharmacol.*, 110:486-504, (1991) 7662.

Publications

Stoecker, Diane K.
Mixotrophy in marine planktonic ciliates: Physiological and ecological aspects of plastid-retention by oligotrichs. In: *Protozoa and Their Role in Marine Processes*. P. C. Reid, et al., eds. NATO ASI Series, Vol. G 25. Springer-Verlag Berlin Heidelberg, Berlin :161-179, (1991) 6853.

Swanberg, Neil R. and David A. Caron.
Patterns of sarcodine feeding in epipelagic oceanic plankton. *J.Plankton Res.*, 13(2):287-312, (1991) 7589.

Tay, K. L., K. G. Doe, S. J. Wade, J. D. A. Vaughan, R. E. Berrigan and M. J. Moore.
Biological effects of contaminants in Halifax Harbour sediment. *Can.Tech.Rept.Fish.Aquat.Sci.*, 1(1774):383-426, (1991).

Twombly, Saran and Hal Caswell.
Demographic analysis of tropical zooplankton populations. *Verh.Int.Ver.Limnol.*, 24:1183-1187, (1991) 7176.

Tyack, Peter.
Use of a telemetry device to identify which dolphin produces a sound. In: *Dolphin Societies: Discoveries and Puzzles*. Karen Pryor and Kenneth S. Norris, eds. University of California Press, Berkeley, Los Angeles and Oxford :319-344, (1991) 6362.

Tyack, Peter L. and Cheri A. Recchia.
A datalogger to identify vocalizing dolphins. *J.Acoust.Soc.Am.*, 90(3):1668-1671, (1991) 7586.

Valiela, Ivan, Joseph Costa, Kenneth Foreman, John M. Teal, Brian Howes and David Aubrey.
Transport of groundwater-borne nutrients from watersheds and their effects on coastal waters. *Biogeochem.*, 10:177-197, (1991) 7418.

Van Dover, Cindy Lee.
Diving the Soviet *Mir* submersibles. *Oceanus*, 34(2):8-13, (1991).

Walls, Mari, Hal Caswell and Matti Ketola.
Demographic costs of *Chaoborus*-induced defences in *Daphnia pulex*: A sensitivity analysis. *Oecologia*, 87:43-50, (1991) 7177.

Watkins, William A. and Peter Tyack.
Reaction of sperm whales (*Physeter catodon*) to tagging with implanted sonar transponder and radio tags. *Mar.Mammal Sci.*, 7(4):409-413, (1991) 6735.

Weiskel, Peter K. and Brian L. Howes.
Quantifying dissolved nitrogen flux through a coastal watershed. *Water Resour.Res.*, 27(11):2929-2939, (1991) 7506.

Chemistry Department

Altabet, Mark A., Werner G. Deuser, Susumu Honjo and Christian Steinen.
Seasonal and depth-related changes in the source of sinking particles in the North Atlantic. *Nature(Lond)*, 354(6349):136-139, (1991) 7648.

Bacon, Michael P.
Kinetics of chemical scavenging deduced from natural tracer distributions. *Appl.Geochem.*, 3(1):73, (1988).

Buesseler, K. O., H. D. Livingston and S. A. Casso.
Ruthenium-106 in the Black Sea. In: *Black Sea Oceanography*. E. Izdar and J. W. Murray, eds. NATO advanced Workshop, Cesme, Turkey, October 1989. Kluwer Academic Publishers, Dordrecht :229-243, (1991) 7509.

Buesseler, Ken O.
Do upper ocean sediment traps provide an accurate record of particle flux? *Nature(Lond)*, 353(6343):420-423, (1991) 7652.

Buesseler, Ken O., Hugh D. Livingston and Susan A. Casso.
Mixing between oxic and anoxic waters of the Black Sea as traced by Chernobyl cesium isotopes. *Deep-Sea Res.*, 38(Suppl.2):S725-S745, (1991) 7376.

Druffel, Ellen R. M., Peter M. Williams, Ken Robertson, Sheila Griffin, A. J. T. Jull, Douglas Donahue, Lawrence Toolin and T. W. Linick.
Radiocarbon in dissolved organic and inorganic carbon from the central North Pacific. *Radiocarbon*, 31(3):523-532, (1989) 6993.

Druffle, Ellen R. M. and Peter M. Williams.
Radiocarbon in seawater and organisms from the Pacific coast of Baja California. *Radiocarbon*, 33(3):291-296, (1991) 7845.

Fabry, Victoria J. and Werner G. Deuser.
Aragonite and magnesian calcite fluxes to the deep Sargasso Sea. *Deep-Sea Res.*, 38(6):713-728, (1991) 7493.

Fasham, M. J. R., K. Denman and P. G. Brewer.
The Joint Global Ocean Flux Study: Goals and objectives. In: *Global Environmental Change*. Robert W. Corell and Patricia A. Anderson, eds. Proceedings - NATO Advanced Research Work Shop on the Science of Global Environmental Change. Lucca, Italy May 31- June 2 1990, NATO ASI Series, Springer-Verlag, Berlin :245-256, (1991).

Fleer, Alan P.
Updated determination of particulate and dissolved Thorium-234. In: *Marine Particles: Analysis and Characterization*. American Geophysical Union Monograph 63. American Geophysical Union, Washington, DC :227-228, (1991).

Francois, Roger.
Marine sedimentary humic substances: Structure, genesis, and properties. *Rev.Aquat.Sci.*, 3(1):41-80, (1990).

Francois, Roger and Michael P. Bacon.
Variations in terrigenous input to the deep equatorial Atlantic during the last 24,000 years. *Science(WashDC)*, 251:1473-1476, (1991) 7486.

German, C. R., A. P. Fleer, M. P. Bacon and J. M. Edmond.
Hydrothermal scavenging at the Mid-Atlantic Ridge: Radionuclide distributions. *Earth Planet.Sci.Lett.*, 105:170-181, (1991) 7651.

Griffin, Sheila and Ellen R. M. Druffel.
Sources of carbon to deep-sea corals. *Radiocarbon*, 31(3):533-543, (1989) 6992.

Hannington, Mark, Peter Herzig, Steven Scott, Geoff Thompson and Peter Rona.
Comparative mineralogy and geochemistry of gold-bearing sulfide deposits on the mid-ocean ridges. *Mar.Geol.*, 101:217-248, (1991) 7735.

Hunt, John M.
Generation of gas and oil from coal and other terrestrial organic matter. In: *Coal and Terrestrial Organic Matter as a Source Rock for Petroleum*. W. G. Dow and P. K. Mukhopadhyay, eds. *Org.Geochem.* Special Publication 17(6):673-680, (1991) 7478.

Hunt, John M., M. D. Lewan and R. J-C. Hennet.
Modeling oil generation with time-temperature index graphs based on the Arrhenius equation. *Am.Assoc.Petrol.Geol.Bull.*, 75(4):795-807, (1991) 7318.

Jenkins, W. J.
Determination of isopycnal diffusivity in the Sargasso Sea. *J.Phys.Oceanogr*, 21(7):1058-1061, (1991) 7515.

King, Linda L. and Daniel J. Repeta.
Novel pyropheophorbide steryl esters in Black Sea sediments. *Geochim.Cosmochim.Acta*, 55:2067-2074, (1991) 7715.

Kurz, Mark D. and David P. Kammer.
Isotopic evolution of Mauna Loa volcano. *Earth Planet.Sci.Lett.*, 103:257-269, (1991) 7399.

Linn, L. J., M. L. Delaney and E. R. M. Druffel.
Trace metals in contemporary and seventeenth-century Galapagos coral: Records of seasonal and annual variations. *Geochim.Cosmochim.Acta*, 54:387-394, (1990) 7285.

Livingston, Hugh D. and Stella J. Livingston.
Good morning, Comrades! *Oceanus*, 34(2):72-80, (1991).

Martin, W. R., M. Bender, M. Leinen and J. Orchardo.
Benthic organic carbon degradation and biogenic silica dissolution in the central equatorial Pacific. *Deep-Sea Res.*, 38(12):1481-1516, (1991) 7614.

McCaffrey, Mark A., John W. Farrington and Daniel J. Repeta.
The organic geochemistry of Peru margin surface sediments: II. Paleoenvironmental implications of hydrocarbon and alcohol profiles. *Geochim.Cosmochim.Acta*, 55:483-498, (1991) 7374.

Moran, S. B. and R. M. Moore.
The potential source of dissolved aluminum from resuspended sediments to the North Atlantic deep water. *Geochim. Cosmoc him.Acta*, 55:2745-2751, (1991).

Murnane, Richard J., Jorge L. Sarmiento and Michael P. Bacon.
Thorium isotopes, particle cycling models, and inverse calculations of model rate constants. *J.Geophys.Res.*, 95(C9):16195-16206, (1990).

Olmez, Ilhan, Edward R. Sholkovitz, Diane Hermann and Robert P. Eganhouse.
Rare earth elements in sediments off Southern California: A new anthropogenic indicator. *Environ.Sci.Technol.*, 25(2):310-316, (1991) 7264.

Percival, C. Mark, Leroy O. Olson, Richard H. Bennett, Frederick L. Sayles and Armand J. Silva.
Applications to subseabed disposal: (ISHTE)- A model experiment. *Mar. Geotechnol.*, 8:285-371, (1989).

Publications

Purdy, Caroline B., Ellen R. M. Druffel and Hugh D. Livingston.
Anomalous levels of ^{90}Sr and $^{239,240}Pu$ in Florida corals: Evidence of coastal processes. *Geochim. Cosmochim. Acta*, 53:1401-1410, (1989) 6907.

Repeta, Daniel J.
Analysis of carotenoids and chlorophylls in suspended particulate matter, sediment trap samples, and surface sediments. In: *Marine Particles: Analysis and Characterization*. American Geophysical Union Monograph 63. American Geophysical Union, Washington, DC :125-128, (1991).

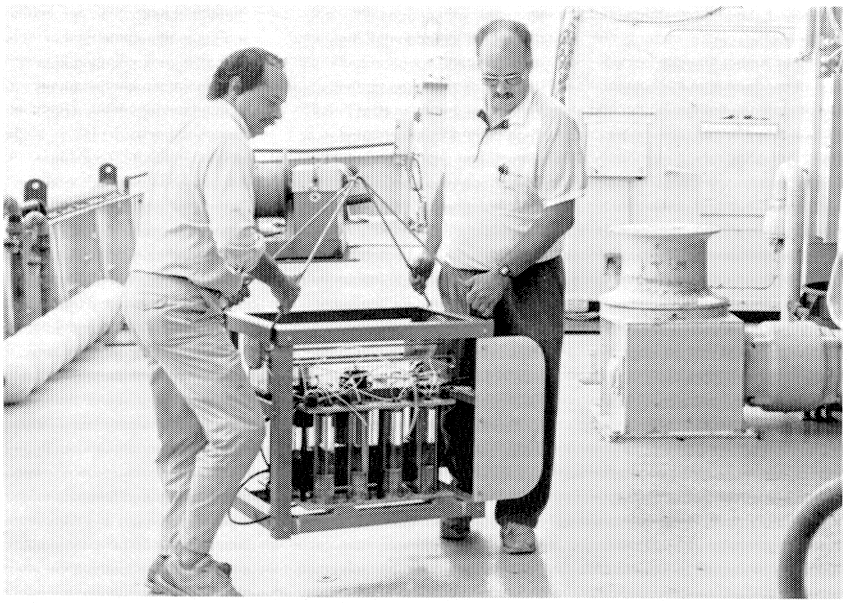
Sayles, F. L. and W. H. Dickinson.
The seep meter: A benthic chamber for the sampling and analysis of low velocity hydrothermal vents. *Deep-Sea Res.*, 38(1):129-141, (1991) 7229.

Sayles, F. L. and W. H. Dickinson.
The ROLAI^{2}D Lander: A benthic lander for the study of exchange across the sediment-water interface. *Deep-Sea Res.*, 38(5):505-529, (1991) 7409.

Seewald, Jeffrey S. and William E. Seyfried.
Experimental determination of portlandite solubility in H_2O and acetate solutions at 100-350°C and 500 bars: Constraints on calcium hydroxide and calcium acetate complex stability. *Geochim. Cosmochim. Acta*, 55:659-669, (1991).

Shaw, Timothy J. and Roger Francois.
A fast and sensitive ICP-MS assay for the determination of ^{230}Th in marine sediments. *Geochim. Cosmochim. Acta*, 55:2075-2078, (1991) 7685.

Sholkovitz, E. R. and D. L. Schneider.
Cerium redox cycles and rare earth elements in the Sargasso Sea. *Geochim. Cosmochim. Acta*, 55:2737-2743, (1991) 7571.



CRAIG MARQUETTE

Ken Doherty, left, and Craig Taylor work with the Sample Incubation Device aboard R/V Oceanus.

Sholkovitz, Edward.
Filtration techniques for river and coastal waters with emphasis on trace metals in anoxic waters. In: *Marine Particles: Analysis and Characterization.* American Geophysical Union Monograph 63. American Geophysical Union, Washington, DC :295-301, (1991).

Thompson, Geoffrey.
Metamorphic and hydrothermal processes: Basalt-seawater interactions. In: *Oceanic Basalts*. P. A. Floyd, ed. Blackie and Sons, Ltd., Glasgow and London :148-173, (1991) 7753.

Tivey, Margaret K.
Hydrothermal vent systems. *Oceanus*, 34(4):68-74, (1991).

Trull, T. W., M. D. Kurz and W. J. Jenkins.
Diffusion of cosmogenic ^3He in olivine and quartz: Implications for surface exposure dating. *Earth Planet.Sci.Lett.*, 103:241-256, (1991) 7489.

Whelan, Jean, Robert Carangelo, Peter R. Solomon and Wallace G. Dow.
TG/plus - a pyrolysis method for following maturation of oil and gas generation zones using T_{max} of methane. *Adv.Org.Geochem.*, 16(4-6):1187-1201, (1990) 7237.

Zafiriou, Oliver C. and Brian Dister.
Photochemical free radical production rates: Gulf of Maine and Woods Hole - Miami transect. *J.Geophys.Res.*, 96(C3):4939-4945, (1991) 7421.

Geology & Geophysics Department

Altabet, Mark A., Werner G. Deuser, Susumu Honjo and Christian Steinen.
Seasonal and depth-related changes in the source of sinking particles in the North Atlantic. *Nature(Lond)*, 354(6349):136-139, (1991) 7648.

Blundy, Johnathan D. and Nobumichi Shimizu.
Trace element evidence for plagioclase recycling in calc-alkaline magmas. *Earth Planet.Sci.Lett.*, 102:178-197, (1991).

Bowin, Carl.
The Earth's gravity field and plate tectonics. *Tectonophysics*, 187:69-89, (1991).

Bryan, Wilfred B.
Exploring Pacific seafloor ashore: Megadan Province, USSR. *Oceanus*, 34(2):48-61, (1991).

Bryan, Wilfred B.
From pillow lava to sheet flow. *Oceanus*, 34(4):42-50, (1991).

Chapman, David C., Graham S. Giese, Margaret Goud Collins, Rolu Encarnacion and Gil Jacinto.
Evidence of internal swash associated with Sulu Sea solitary waves? *Cont.Shelf Res.*, 11(7):591-599, (1991) 7482.

Chen, C.-Y., F. A. Frey, M. O. Garcia, G. B. Dalyrumple and S. R. Hart.
The tholeiite to alkalic basalt transition at Haleakala Volcano, Maui, Hawaii. *Contrib.Mineral Petrol.*, 106:183-200, (1991).

Dougherty, Martin E. and Ralph A. Stephen.
Seismo/acoustic propagation through rough seafloors. *J.Acoust.Soc.Am.*, 90(5):2637-2651, (1991) 7838.

Emery, K. O. and D. A. Ross.
Past and future evolution of marine geology. In: *From Shoreline to Abyss: Contributions in Marine Geology in Honor of Frances Parker Shepard.* Robert H. Osborne, ed. SEPM, Tulsa. Society for Sedimentary Geology Special Publication No. 46 :11-14, (1991) 7174.

Frey, Fred A., N. Shimizu, A. Leinbach, M. Obata and E. Takazawa.
Compositional variations within the lower layered zone of the Horoman Peridotite, Hokkaido, Japan: Constraints on models for melt-solid segregation. *J.Petrol.* (Special Lherzolites Issue), :211-227, (1991).

Galbreath, K. C., C. K. Shearer, J. J. Papike and N. Shimizu.
Inter- and intra-group compositional variations in Apollo 15 pyroclastic green glass: An electron- and ion-microprobe study. *Geochim.Cosmochim.Acta*, 54:2565-2575, (1990).

Gillis, K. M. and P. T. Robinson.
Multistage alteration in the extrusive sequence of the Troodos ophiolite, Cyprus. In: *Ophiolites: Oceanic Crustal Analogues*. J. Malpas, E. M. Moores, A. Panayiotou and C. Xenophonots, eds. Proceedings of the Symposium Troodos '87. Cyprus Geological Survey Department, Cyprus :655-664, (1990).

Goff, John A. and Martin A. Kleinrock.
Quantitative comparison of bathymetric survey systems. *Geophys.Res.Lett.*, 18(7):1253-1256, (1991) 7704.

Hart, S. R. and M. R. Reid.
Rb/Cs fractionation: A link between granulite metamorphism and the S-process. *Geochim.Cosmochim.Acta*, 55:2379-2383, (1991).

Hattori, Keiko, Louis J. Cabri and Stanley R. Hart.
Osmium isotope ratios of PGM grains associated with the Freetown Layered Complex, Sierra Leone, and their origin. *Contrib.Mineral Petrol.*, 109:10-18, (1991).

Hattori, Keiko and Stanley R. Hart.
Osmium-isotope ratios of platinum-group minerals associated with ultramafic intrusions: Os-isotopic evolution of the oceanic mantle. *Earth Planet.Sci.Lett.*, 107:499-514, (1991).

Publications

Hodell, David A., Jason H. Curtis, Glenn A. Jones, Antonia Higuera-Gundy, Mark Brenner, Michael W. Binford and Kathleen T. Dorsey.
Reconstruction of Caribbean climate change over the past 10,500 years. *Nature(Lond)*, 352(6338):790-793, (1991).

Holbrook, W. Steven, R. D. Catchings and Craig M. Jarchow.
Origin of deep crustal reflections: Implications of coincident seismic refraction and reflection data in Nevada. *Geology(Boulder)*, 19:175-179, (1991).

Honjo, Susumu.
Calcareous Nannoplankton Biocoenosis: Sediment Trap Studies in the Equatorial Atlantic, Central Pacific, and Panama Basin. by John C. Steinmetz. Ocean Biocoenosis Series No. 1. Sususmu Honjo, ed. Woods Hole Oceanographic Institution, Woods Hole. 85 pp, (1991) 6270.

Jones, G. A., A. P. McNichol, K. F. Von Reiden and R. J. Schneider.
National ocean sciences AMS facility at Woods Hole Oceanographic Institution. *Nucl.Inst.Methods Phys.Res.Sect.B*, B52:278-284, (1990).

Jones, Glenn A.
A stop-start ocean conveyer. *Nature(Lond)*, 349(6308):364-365, (1991).

Jones, Glenn A.
Spatial and temporal distribution of Laurentide and Fennoscandian meltwater during the last deglaciation. *Norsk Geol.Tidsskr.*, 71:145-148, (1991).

Kleinrock, M.
Overview of sidescan sonar systems and processing. *Oceans '91*, 1:77-83S, (1991).

Kleinrock, M.
Geological comparison of seafloor survey instrumentation. *Oceans '91*, 3:1131-1139, (1991).

Kleinrock, Martin C.
Capabilities of some systems used to survey the deep-sea floor. In: *CRC Handbook of Geophysical Exploration at Sea*. 2nd. ed. Richard A. Geyer, ed. CRC Press, Boca Raton :36-86, (1991) 7854.

Lawver, Lawrence A., Bruno Della Vedova and Richard P. Von Herzen.
Heat flow in the Jane Basin, northwest Weddell Sea. *J.Geophys.Res.*, 96(B2):2019-2038, (1991).

Lin, Jian.
The segmented Mid-Atlantic Ridge. *Oceanus*, 34(4):11-18, (1991).

Lohmann, G. P. and P. N. Schweitzer.
On eigenshape analysis. In: *Proceedings of the Michigan Morphometrics Workshop*. F. James Rohlf and Fred L. Bookstein, eds. University of Michigan, Ann Arbor, May 16-28, 1988. Special Publication No. 2, University of Michigan Museum of Zoology, Ann Arbor :147-166, (1990) 7048.

Lowell, Robert P. and Ralph A. Stephen.
Heat-flow and lateral seismic-velocity heterogeneities near Deep-Sea Drilling Project-Ocean Drilling Program Site 504. *Geology(Boulder)*, 19:1141-1144, (1991).

MacFarlane, Andrew W. and Nobumichi Shimizu.
SIMS measurements of $\delta^{34}S$ in sulfide minerals from adjacent vein and stratabound ores. *Geochim.Cosmochim.Acta*, 35:525-541, (1991).

McCorkle, Daniel C. and Gary P. Klinkhammer.
Porewater cadmium geochemistry and the porewater cadmium: $\delta^{13}C$ relationship. *Geochim.Cosmochim.Acta*, 55:161-168, (1991) 7388.

McNichol, Ann P., Ellen R. M. Druffel and Cindy Lee.
Carbon cycling in coastal sediments: 2. An investigation of the sources of ΣCO_2 to pore water using carbon isotopes. In: *Organic Substances and Sediment in Water, Vol. 2, Processes and Analytical*. R. A. Baker, ed. Lewis Publishers, Chelsea :249-272, (1991) 7413.

Moore, Rory O., John J. Gurney, William L. Griffen and Nobu Shimizu.
Ultra-high pressure garnet inclusions in Monastery diamonds: Trace element abundance patterns and conditions of origin. *Eur.J.Mineral.*, 3:213-230, (1991).

Muller, R. Dietmar, David T. Sandwell, Brian E. Tucholke, John G. Sclater and Peter R. Shaw.
Depth to basement and geoid expression of the Kane Fracture Zone: A comparison. *Mar.Geophys.Res.*, 13:105-129, (1991) 7625.

Phipps Morgan, Jason and Martin C. Kleinrock.
Transform zone migration: Implications of bookshelf faulting at oceanic and Icelandic propagating rifts. *Tectonics*, 10(5):920-935, (1991) 7133.

Reed, Thomas B. and Brian E. Tucholke.
Geologic visualization of the Kane Fracture Zone: Interactive processing of sidescan and bathymetric data. *Oceans '91*, 2:1152-1158, (1991).

Reiter, Edmund C., M. Nafi Toksoz, Timothy H. Keho and G. M. Purdy.
Imaging with deep water multiples. *Geophysics*, 56(7):1081-1086, (1991) 7314.

Robinson, P. T., H. J. B. Dick and R. P. Von Herzen.
Metamorphism and alteration in oceanic layer 3: Hole 735B. *Proc.Ocean Drill.Prog., Sci.Res.*, 118:541-552, (1991).

Salters, Vincent J. M. and Stanley R. Hart.
The mantle sources of ocean ridges, islands and arcs: The Hf-isotope connection. *Earth Planet.Sci.Lett.*, 104:364-380, (1991).

Schweitzer, Peter N. and G. P. Lohmann.
Ontogeny and habitat of modern menardiiform planktonic foraminifera. *J.Foramin.Res.*, 21(4):332-345, (1991) 7557.

Shaw, Peter R.
Isolation of source and receiver statics and scale factors in waveform inversion of marine refraction data. *Geophys.Res.Lett.*, 18(8):1429-1432, (1991) 7776.

Shimizu, Nobumichi and Ikuo Kushiro.
The mobility of Mg, Ca, and Si in diopside-jadeite liquids at high pressures. In: *Physical Chemistry of Magmas*. L. L. Perchuk and I. Kushiro, eds. Advanced Physics and Geochemistry Vol. 9. Springer-Verlag, New York :192-212, (1991).

Speer, Paul E., David G. Aubrey and Carl T. Friedrichs.
Nonlinear hydrodynamics of shallow tidal inlet/bay systems. In: *Tidal Hydrodynamics*. Bruce B. Parker, ed. John Wiley and Sons, Inc., Publishers, New York :321-339, (1991).

Staudigel, H. and K. Gillis.
The timing of hydrothermal vent alteration in the Troodos ophiolite. In: *Ophiolites: Oceanic Crustal Analogues*. J. Malpas, E. M. Moores, A. Panayiotou and C. Xenophonots, eds. Proceedings of the Symposium Troodos '87. Cyprus Geological Survey Department, Cyprus :665-672, (1990).

Steinmetz, John C.
Calcareous Nannoplankton Biocoenosis: Sediment Trap Studies in the Equatorial Atlantic, Central Pacific, and Panama Basin. by John C. Steinmetz. Ocean Biocoenosis Series No. 1. Susumu Honjo, ed. Woods Hole Oceanographic Institution, Woods Hole, 85p, (1991).

Stephen, Ralph A.
Finite difference modeling of shear waves. In: *Shear Waves in Marine Sediments*. J. M. Hoven, et al, eds. Proceeding of the NATO Symposium on Shear Waves in Marine Sediments. La Spezia, October 1990. Kluwer Academic Publishers, Dordrecht :471-478, (1991) 7631.

Takahashi, Kozo.
Silicoflagellates and Actiniscus: Vertical Fluxes at Pacific and Atlantic Sediment Trap Stations. by Kozo Takahashi. Ocean Biocoenosis Series No. 2. Susumu Honjo, ed. Woods Hole Oceanographic Institution, Woods Hole. 35 pp., (1991) 5876.

Takahashi, Kozo.
Radiolaria: Flux, Ecology, and Taxonomy in the Pacific and Atlantic. by Kozo Takahashi. Ocean Biocoenosis Series No. 3. Susumu Honjo, ed. Woods Hole Oceanographic Institution, Woods Hole. 303 pp., (1991).

Tivey, Maurice A. and H. Paul Johnson.
The magnetic structure of Axial Seamount, Juan de Fuca Ridge. *J.Geophys.Res.*, 95(B8):12735-12750, (1990) 7277.

Tucholke, Brian E.
Comment and reply on 'North Atlantic fracture-zone distribution and patterns shown by multibeam sonar'. Comment. *Geology(Boulder)*, 18:911-912, (1990).

Tucholke, Brian E., Ken C. Macdonald and Paul J. Fox.
ONR seafloor natural laboratories on slow- and fast-spreading mid-ocean ridges. *EOS*, 72(25):268-270, (1991) 7624.

Tucholke, Brian E., Ken C. Macdonald and Paul J. Fox.
ONR seafloor natural laboratories on the Mid-Atlantic Ridge and East Pacific Rise. *Ridge Events*, 2(1):15-18, (1991).

Uchupi, Elazar and K. O. Emery.
Genetic global geomorphology: A prospectus. In: *From Shoreline to Abyss: Contributions in Marine Geology in Honor of Francis Parker Shepard*. Robert H. Osborne, ed. SEPM, Tulsa. Society for Sedimentary Geology Special Publication No. 46 :273-290, (1991) 7186.

Uchupi, Elazar and K. O. Emery.
Pangaean divergent margins: Historical perspective. *Mar.Geol.*, 102(1/4):1-28, (1991) 7414.

Publications

Von Herzen, R. P. and J. H. Scott.
Thermal modeling for Hole 735B. *Proc.Ocean Drill.Prog.,Sci.Res.*, 118:349-356, (1991) 7338.

Von Herzen, Richard P., Paul T. Robinson, Andrew C. Adamson, Keir Becker, Sherman H. Bloomer, Mathilde Cannat, Henry J. B. Dick, Rolf F. K. Emmermann, Gunilla Gard, David Goldberg, Rejean Hebert and Jan G. H. Hertogen.
Proceedings of the Ocean Drilling Program. Volume 118, Scientific Results. Fracture Zone Drilling on the Southwest Indian Ridge. Sondra K. Stewart, Volume ed. Ocean Drilling Program, Texas A and M University, College Station. 597 pp., (1991).

Wilcock, William S. D. and J. A. Whitehead.
The Rayleigh-Taylor instability of an embedded layer of low-viscosity fluid. *J.Geophys.Res.*, 96(B7):12193-12200, (1991) 7612.

Physical Oceanography Department

Allen, J. S., R. M. Samelson and P. A. Newberger.
Chaos in a model of forced quasi-geostrophic flow over topography: An application of Melnikov's method. *J.Fluid Mech.*, 226:511-547, (1991) 7343.

Bower, Amy S.
A simple kinematic mechanism for mixing fluid parcels across a meandering jet. *J.Phys.Oceanogr*, 21(1):173-180, (1991) 7245.

Brink, K. H., R. C. Beardsley, P. P. Niiler, M. Abbott, A. Huyer, S. Ramp, T. Stanton and D. Stuart.
Statistical properties of near-surface flow in the California coastal transition zone. *J.Geophys.Res.*, 96(C8):14693-14706, (1991).

Brink, K. H. and T. J. Cowles.
The Coastal Transition Zone Program. *J.Geophys.Res.*, 96(C8):14637-14647, (1991).

Brink, Kenneth M., John M. Bane, Thomas M. Church, Christopher W. Fairall, Gerald L. Geernaert, Donn S. Gorsline, Robert T. Guza, Douglas E. Hammond, George A. Knauer, Christopher S. Martens, John D. Milliman and Charles A. Nittrouer.
Coastal Ocean Processes (CoOP): Results of an Interdisciplinary Workshop. Report of the Coastal Processes Workshop, July 9-11,1990, University of California, San Diego. Prepared by the CoOP Interim Steering Committee. 51 pages., (1990) 7584.

Brooks, David A. and Melbourne G. Briscoe.
Tests of long-range ocean data telemetry using frequency-agile HF packet-switching protocols. *J.Atmos.Ocean.Tech.*, 8(6):856-868, (1991) 7568.

Bryden, Harry L. and Thomas H. Kinder.
Steady two-layer exchange through the Strait of Gibraltar. *Deep-Sea Res.*, 38(Suppl.1):S445-S463, (1991) 7194.

Bryden, Harry L. and Thomas H. Kinder.
Recent progress in strait dynamics. *Rev.Geophys.*, Suppl.:617-631, (1991) 7596.

Bryden, Harry L., Dean H. Roemmich and John A. Church.
Ocean heat transport across 24°N in the Pacific. *Deep-Sea Res.*, 38(3):297-324, (1991) 6570.

Chapman, David C., Graham S. Giese, Margaret Goud Collins, Rolu Encarnacion and Gil Jacinto.
Evidence of internal swash associated with Sulu Sea solitary waves? *Cont.Shelf Res.*, 11(7):591-599, (1991) 7482.

Churchill, J. and Peter C. Cornillon.
Water discharged from the Gulf Stream north of Cape Hatteras. *J.Geophys.Res.*, 96(C12):22227-22243, (1991) 7553.

Churchill, James H. and Peter C. Cornillon.
Gulf Stream water on the shelf and upper slope north of Cape Hatteras. *Cont.Shelf Res.*, 11(5):409-431, (1991) 7294.

CoOP Interim Steering Comm.:, Kenneth Brink, John Bane, et al.
Interdisciplinary coastal ocean research is goal of new program. *EOS*, 72(14):153, 158, (1991).

Crescenti, Gennaro H., David S. Hosom and James F. Price.
Development of an intelligent chilled mirror dew point sensor. In: *7th Symposium on Meteorological Observations and Instrumentation. Special Sessions on Laser Atmospheric Studies.* 71st AMS Annual Meeting, January 14-18, 1991, New Orleans, LA. American Meteorological Society, Boston :297-302, (1991).

Crescenti, Gennaro H. and Richard E. Payne.
Evolution of two types of thin film capacitive relative humidity sensors for use on buoys and ships. In: *7th Symposium on Meteorological Observations and Instrumentation. Special Sessions on Laser Atmospheric Studies.* 71st AMS Annual Meeting, January 14-18, 1991, New Orleans, LA. American Meteorological Society, Boston :125-133, (1991).

Freitag, Lee E., J. Stevens Merriam, Daniel E. Frye and Josko A. Catipovic.
A long-term deep-water acoustic telemetry experiment. *Oceans '91*,1:254-260, (1991).

Friehe, Carl A. and Henry M. Stommel.
Andrew F. Bunker: Pioneering in air-sea interaction research 1946-79. *Bull.Am.Meteorol.Soc.*, 72(1):44-49, (1991) 7403.

Frye, Daniel E., W. Brechner Owens and James R. Valdes.
Ocean data telemetry: New methods for real-time ocean observation. *Oceanus*, 34(1):46-60, (1991).

Frye, Daniel E. and W. Brechner Owens.
Recent developments in ocean data telemetry at Woods Hole Oceanographic Institution. *IEEE J.Ocean.Eng.*, 16(4):350-359, (1991) 7700.

Gawarkiewicz, Glen, Robert K. McCarthy, Kenneth Barton, Ann K. Masse and Thomas M. Church.
A Gulf Stream-derived pycnocline intrusion on the Middle Atlantic Bight shelf. *J.Geophys.Res.*, 95(C12):22305-22313, (1990).

Gawarkiewicz, Glenn and David C. Chapman.
Formation and maintenance of shelfbreak fronts in an unstratified flow. *J.Phys.Oceanogr*, 21(8):1225-1239, (1991) 7595.

Geyer, W. Rockwell, Robert C. Beardsley, Julio Candela, Belmiro M. Castro, Richard V. Legeckis, Steven J. Lentz, Richard Limeburner, Luis B. Miranda and John H. Trowbridge.
The physical oceanography of the Amazon outflow. *Oceanography*, 4(1):8-14, (1991) 7623.

Hall, Melinda M.
Energetics of the Kuroshio Extension at 35°N, 152°E. *J.Phys.Oceanogr*, 21(7):958-975, (1991) 7360.

Helfrich, Karl R. and Thomas M. Battisti.
Experiments on baroclinic vortex shedding from hydrothermal plumes. *J.Geophys.Res.*, 96(C7):12511-12518, (1991) 7438.

Hogg, Nelson.
Mooring motion corrections revisited. *J.Atmos.Ocean.Tech.*, 8(2):289-295, (1991) 7534.

Hosom, D. S., R. A. Weller, A. A. Hinton and B. M. L. Rao.
Sea water battery for long lived upper ocean systems. *Oceans '91*, 3:1673-1676, (1991) 7707.

Hosom, D. S., R. A. Weller, K. E. Prada and R. P. Trask.
A three meter discus buoy with IMET meteorological sensors. In: *MTS '91 an Ocean Cooperative: Industry, Government and Academia.* Proceedings of MTS '91. New Orleans, November 10-14, 1991. Sponsored by Marine Technology Society. Marine Technology Society, Washington, DC 1:206-210, (1991) 7817.

Hosom, D. S., R. A. Weller and A. A. Hinton.
A sea water battery for upper ocean buoy systems. In: *MTS '91 An Ocean Cooperative: Industry, Government and Academia.* Proceedings of MTS '91. New Orleans, November 10-14, 1991. Sponsored by the Marine Technology Society. Marine Technology Society, Washington, DC 1:32-36, (1991).

Hosom, David S., Gennaro H. Crescenti, Clifford L. Winget, Sumner Weisman, Donald P. Doucet and James F. Price.
An intelligent chilled mirror humidity instrument. *J.Atmos.Ocean.Technol.*, 8(4):585-596, (1991) 7439.

Huang, Rui Xin.
On the three-dimensional structure of the wind-driven circulation in the North Atlantic. *Dyn.Atmos.Oceans*, 15:117-159, (1989) 6970.

Huang, Rui Xin.
A note on combining wind and buoyancy forcing in a simple one-layer oceanic model. *Dyn.Atmos.Oceans*, 15:535-540, (1991) 7316.

Huang, Rui Xin.
The three-dimensional structure of wind-driven gyres: Ventilation and subduction. *Rev.Geophys.*, Suppl.:590-609, (1991) 7590.

Johnson, Gregory C., Bruce A. Warren and Donald B. Olson.
A deep boundary current in the Arabian Basin. *Deep-Sea Res.*, 38(6):653-661, (1991) 7382.

Johnson, Gregory C., Bruce A. Warren and Donald B. Olson.
Flow of bottom water in the Somali Basin. *Deep-Sea Res.*, 38(6):637-652, (1991) 7396.

Publications

Joyce, Terrence M.
Review of U. S. contributions to warm-core rings. *Rev.Geophys.*, Suppl.:610-616, (1991) 7562.

Joyce, Terrence M.
Thermohaline catastrophe in a simple four-box model of the ocean climate. *J.Geophys.Res.*, 96(C11):20393-20402, (1991) 7724.

Kelly, Kathryn A.
The meandering Gulf Stream as seen by the Geosat altimeter: Surface transport, position, and velocity variance from 73° to 46°W. *J.Geophys.Res.*, 96(C9):16721-16738, (1991) 7355.

Kelly, Kathryn A.
Satellite remote sensing in Japanese oceanography. *Sci.Infor.Bull.*, 16(1):129-133, (1991).

Kelly, Kathryn A., Terrence M. Joyce, David M. Schubert and Michael J. Caruso.
The mean sea surface height and geoid along the Geosat subtrack from Bermuda to Cape Cod. *J.Geophys.Res.*, 96(C7):12699-12709, (1991) 7547.

Kessler, William S.
Can reflected extra-equatorial Rossby waves drive ENSO? *J.Phys.Oceanogr*, 21(3):444-452, (1991) 7436.

Kundu, Pijush K. and Robert C. Beardsley.
Evidence of a critical Richardson number in moored measurements during the upwelling season off northern California. *J.Geophys.Res.*, 96(C3):4855-4868, (1991) 7597.

Kundu, Pujush K., Robert C. Beardsley and Adriana Huyer.
Observed interaction between low and high frequency motions off the coasts of Peru and California. *J.Phys.Oceanogr*, 20(9):1333-1348, (1990).

Lentz, Steven J. and John H. Trowbridge.
The bottom boundary layer over the Northern California Shelf. *J.Phys.Oceanogr*, 21(8):1186-1201, (1991) 7445.

Luyten, James R. and Henry M. Stommel.
Comparison of M_2 tidal currents observed by some deep moored current meters with those of the Schwiderski and Laplace models. *Deep-Sea Res.*, 38(Suppl.1):S573-S589, (1991) 7067.

MacWhorter, M. A. and R. A. Weller.
Error in measurements of incoming shortwave radiation made from ships and buoys. *J.Atmos.Ocean.Technol.*, 8(1):108-117, (1991) 7322.

Mangum, L. J., S.P. Hayes, J. M. Toole, Z. Wang, S. Pu and D. Hu.
Thermohaline structure and zonal pressure gradient in the western equatorial Pacific. *J.Geophys.Res.*, 95(C5):7279-7288, (1990).

McCartney, M. S., S. L. Bennett and M. E. Woodgate-Jones.
Eastward flow through the Mid-Atlantic Ridge at 11°N and its influence on the abyss of the eastern basin. *J.Phys.Oceanogr*, 21(8):1089-1121, (1991) 5858.

McCartney, M. S. and M. E. Woodgate-Jones.
A deep-reaching anticyclonic eddy in the subtropical gyre of the eastern South Atlantic. *Deep-Sea Res.*, 3(Suppl.1):5411-5443, (1991) 7182.

Park, Melora M., Robin C. Singer, Albert J. Plueddemann and Robert A. Weller.
High-speed real-time data acquisition for vector measuring current meters. *IEEE J.Ocean.Eng.*, 16(4):360-367, (1991) 7550.

Pedlosky, J. and P. Klein.
The nonlinear dynamics of slightly supercritical baroclinic jets. *J.Atmos.Sci.*, 48(10):1276-1286, (1991) 7551A.

Pedlosky, Joseph.
The link between western boundary currents and the Equatorial Undercurrent. *J.Phys.Oceanogr*, 21(10):1553-1558, (1991) 7535.

Pedlosky, Joseph and Paul Robbins.
The role of finite mixed-layer thickness in the structure of the ventilated thermocline. *J.Phys.Oceanogr*, 21(7):1018-1031, (1991) 7585.

Pedlosky, Joseph and R. M. Samelson.
Radiation-induced baroclinic instability. *Geophys. Astrophys.Fluid Dyn.*, 58:243-262, (1991) 7408.

Pickart, Robert S. and D. Randolph Watts.
Deep Western Boundary Current variability at Cape Hatteras. *J.Mar.Res.*, 48:765-791, (1990).

Plueddemann, A. and Robert Pinkel.
Biasing of the covariance-based spectral mean estimator in the presence of band-limited noise. *J.Atmos.Ocean.Tech.*, 8(1):172-178, (1991).

Pratt, L. J., J. Earles, P. Cornillon and J.-F. Cayula.
The nonlinear behavior of varicose disturbances in a simple model of the Gulf Stream. *Deep-Sea Res.*, 38(Suppl.1):S591-S622, (1991) 7221.

Pratt, L. J. and P. A. Lundberg.
Hydraulics of rotating strait and sill flow. *Ann.Rev.Fluid Mech.*, 23:81-106, (1991) 7435.

Pratt, L. J. and J. Pedlosky.
Linear and nonlinear barotropic instability of geostrophic shear layers. *J.Fluid Mech.*, 224:49-76, (1991) 7446.

Pratt, Lawrence J.
Geostrophic versus critical control in straits. *J.Phys.Oceanogr*, 21(5):728-732, (1991) 7517.

Qiu, Bo, Kathryn A. Kelly and Terrence M. Joyce.
Mean flow and variability in the Kuroshio Extension from Geosat altimetry data. *J.Geophys.Res.*, 96(C10):18491-18507, (1991) 7649.

Ramp, Steven R., Paul F. Jessen, Kenneth H. Brink, Pearn P. Niiler, Francis L. Daggett and Jeffrey S. Best.
The physical structure of cold filaments near Point Arena, California, during June 1987. *J.Geophys.Res.*, 96(C8):14859-14883, (1991).

Richardson, P. L., M. S. McCartney and C. Maillard.
A search for meddies in historical data. *Dyn.Atmos.Oceans*,15:241-265, (1991) 7309.

Richardson, Philip L.
SOFAR floats give a new view of ocean eddies. *Oceanus*, 34(1):23-31, (1991).

Samelson, R. M. and B. Shrayer.
Currents forced by stochastic winds with meridionally-varying amplitude. *J.Geophys.Res.*, 96(C10):18425-18429, (1991) 7583.

Schmitz, William J., Jr. and James R. Luyten.
Spectral time scales for mid-latitude eddies. *J.Mar.Res.*, 49:75-107, (1991) 7389.

Schmitz, William J., Jr. and Philip L. Richardson.
On the sources of the Florida Current. *Deep-Sea Res.*, 38(Suppl.1):S379-S409, (1991) 7020.

Siegel, David A. and Albert J. Plueddemann.
The motion of a solid sphere in an oscillating flow: An evaluation of remotely sensed Doppler velocity estimates in the sea. *J.Atmos.Ocean.Tech.*, 8(2):296-304, (1991) 7354.

Signell, R. P., R. C. Beardsley, H. C. Graber and A. Capotondi.
Effect of wave-current interaction on wind-driven circulation in narrow, shallow embayments. *J.Geophys.Res.*, 95(C6):9671-9678, (1990) 7066.

Spall, Michael A.
A diagnostic study of the wind- and buoyancy-driven North Atlantic circulation. *J.Geophys.Res.*, 96(C10):18509-18518, (1991) 7689.

Spall, Michael A. and William R. Holland.
A nested equation model for oceanic applications. *J.Phys.Oceanogr*, 21(2):205-220, (1991).

Speer, Kevin G. and Michael S. McCartney.
Tracing Lower North Atlantic Deep Water across the equator. *J.Geophys.Res.*, 96(C11):20443-20448, (1991).

Stern, Melvin E. and J. A. Whitehead.
Separation of a boundary jet in a rotating fluid. *J.Fluid Mech*, 217:41-69, (1990).

Stommel, Henry M.
Douglas Chester Webb: A profile. *Oceanus*, 34(1):104-108, (1991).

Strub, P. Ted, P. Michael Kosro, Adriana Huyer, C. James, L. J. Walstad, R. L. Smith, J. A. Barth, R. R. Hood, M. R. Abbott, K. H. Brink, T. L. Hayward and P. P. Niiler.
The nature of the cold filaments in the California Current system. *J.Geophys.Res.*, 96(C8):14743-14768, (1991).

Trowbridge, J. H. and S. J. Lentz.
Asymmetric behavior of an oceanic boundary layer above a sloping bottom. *J.Phys.Oceanogr*, 21(8):1171-1185, (1991) 7456.

Warren, Bruce A. and Kevin G. Speer.
Deep circulation in the eastern South Atlantic Ocean. *Deep-Sea Res.*, 38(Suppl.1):S281-S322, (1991) 6984.

Weller, R. and R. Samelson.
Upper ocean variability associated with fronts. In: *Ocean Variability and Acoustic Propagation*. J. Potter and A. Warn Varnas, eds. Kluwer Academic Publishers, Dordrecht :463-478, (1991).

Weller, R. A., M. A. Donelan, M. G. Briscoe and N. E. Huang.
Riding the crest: A tale of two wave experiments. *Bull.Am.Meteor.Soc.*, 72(2):163-183, (1991) 7380.

Weller, R. A., D. L. Rudnick, C. C. Eriksen, K. L. Polzin, N. S. Oakey, J. W. Toole, R. W. Schmitt and R. T. Pollard. Forced ocean response during the Frontal Air-Sea Interaction Experiment (FASINEX). *J.Geophys.Res.*, 96(C5):8611-8638, (1991) 7490.

Weller, Robert A. Overview of the Frontal Air-Sea Interaction Experiment (FASINEX):A study of air-sea interaction in a region of strong oceanic gradients. *J.Geophys.Res.*, 96(C5):8501-8516, (1991) 7417.

Weller, Robert A., David S. Hosom, Kenneth E. Prada and Gennaro H. Crescenti. Improved meteorological instruments and data acquisition systems for buoys and ships. In: *7th Symposium on Meteorological Observations and Instrumentation. Special Sessions on Laser Atmospheric Studies*. 71st AMS Annual Meeting, January 14-18, 1991, New Orleans, LA. American Meteorological Society, Boston :129-133, (1991).

Welsh, Elizabeth B., Nelson G. Hogg and Ross M. Hendry. The relationship of low-frequency deep variability near the HEBBLE site to Gulf Stream fluctuations. *Mar.Geol.*, 99:303-317, (1991) 6591.

Whitehead, J. A. and Karl R. Helfrich. Instability of flow with temperature-dependent viscosity: A model of magma dynamics. *J.Geophys.Res.*, 96(B3):4145-4155, (1991) 7431.

Whitehead, J. A. and Karl R. Helfrich. Magma waves and diapiric dynamics. In: *Magma Transport and Storage*. M. P. Ryan, ed. John Wiley and Sons, Ltd., New York :53-76, (1990).

Wilcock, William S. D. and J. A. Whitehead. The Rayleigh-Taylor instability of an embedded layer of low-viscosity fluid. *J.Geophys.Res.*, 96(B7):12193-12200, (1991) 7612.

Coastal Research Center

Edwards, Steven F. and Frank J. Gable. Estimating the value of beach recreation from property values: An exploration with comparisons to nourishment costs. *Ocean Shoreline Mgmt.*, 15:37-55, (1991) 6967.

Emery, K. O. and David G. Aubrey. *Sea Levels, Land Levels, and Tide Guages*. by K. O. Emery and David G. Aubrey. Springer-Verlag New York, Inc, New York. 237 pp., (1991).

Gable, F. Caribbean coastal and marine tourism - coping with climate change and its associated effects. In: *Proceedings of the 1990 Congress on Coastal and Marine Tourism*. Marc L. Miller and Jan Auyong, eds. May 25-31, 1990, Honolulu, Hawaii. National Coastal Resource Research and Development Institute, Newport 1:248-258, (1990) 7369.

Gable, F. J. and D. G. Aubrey. Potential coastal effects of climate change in the Caribbean. In: *Proceedings of the Second North American Conference on Preparing for Climate Change: A Cooperative Approach*. J. C. Topping, ed. Washington, DC, December 6-8, 1988. The Climate Institute, Washington, DC :417-421, (1989) 6964.

Gable, Frank. Contemporary climate change and its related effects on global shoreline. In: *Coastal Zone '89*. Orville T. Magoon, Hugh Converse, Dallas Miner, L. Thomas Tobin and Delores Clark, eds. Proc. Sixth Symposium on Coastal and Ocean Management. Charleston, SC, July 11-14, 1989. American Society of Civil Engineers, New York 2:1370-1383, (1989) 6966.

Gable, Frank and David Aubrey. Changing climate and the Pacific. *Oceanus*, 32(4):71-73, (1989).

Gable, Frank J., J. H. Gentile and D. G. Aubrey. Global climatic issues in the coastal wider Caribbean region. *Envir.Conserv.*, 17(1):51-60, (1990) 7180.

Speer, Paul E., David G. Aubrey and Carl T. Friedrichs. Nonlinear hydrodynamics of shallow tidal inlet/bay systems. In: *Tidal Hydrodynamics*. Bruce B. Parker, ed. John Wiley and Sons, Inc., Publishers, New York :321-339, (1991).

Valiela, Ivan, Joseph Costa, Kenneth Foreman, John M. Teal, Brian Howes and David Aubrey. Transport of groundwater-borne nutrients from watersheds and their effects on coastal waters. *Biogeochem.*, 10:177-197, (1991) 7418.

Marine Policy Center

Agardy, Tundi. Pacific sea turtles threatened. *Oceanus*, 32(4):80-81, (1990).

Brigham, Lawson. Advanced marine technology for the Soviet Arctic. *Oceanus*, 34(1):74-75, (1991).

Brigham, Lawson W. *The Soviet Maritime Arctic*. Lawson W. Brigham, ed. Naval Institute Press, Annapolis. 336 pp., (1991) 7609.

Broadus, James M. Marine electronic instrumentation: An industrial perspective. *Oceanus*, 34(1):102-103, (1991).

Broadus, James M. and Raphael V. Vartanov. The oceans and environmental security. *Oceanus*, 34(2):14-19, (1991).

Eiswerth, Mark E. Integrated environmental management and land-based pollution in the East Asian Seas. *Trop.Coast.Area Mgmt.*, 5(3):6-8, (1990) 7637.

Gornitz, V. and A. Solow. Observations of long-term tide-gauge records for indications of accelerated sea level rise. In: *Greenhouse-Gas-Induced Climatic Change: A Critical Appraisal of Simulations and Observations*. M. E. Schlesinger, ed. Elsevier Science Publishers B. V., Amsterdam :347-367, (1991) 7328.

Hoagland, Porter, III and Hauke L. Kite-Powell. European advanced marine electronic instrumentation: A U.S. perspective. *Mar.Policy*, 15(6):431-454, (1991) 7785.

Joyner, Christopher C. Ice-covered regions in international law. *Nat.Resour.J.*, 31:213-242, (1991) 7170.

Joyner, Christopher C. and Scot Frew. Plastic pollution in the marine environment. *Ocean Dev.Int.Law*, 22:33-69, (1991) 7577.

Nelson, Robert H. Guiding the ocean search process: Applying public land experience to the design of leasing and permitting systems for ocean mining and ocean shipwrecks. *Ocean Dev.Int.Law*, 20:577-600, (1990).

Solow, Andrew. On the statistical comparison of climate model output and climate data. In: *Greenhouse-Gas-Induced Climatic Change: A Critical Appraisal of Simulations and Observations*. M. E. Schlesinger, ed. Elsevier Science Publishers B. V., Amsterdam :505-510, (1991) 7327.

Solow, Andrew R. Geostatistical cross-validation: A cautionary note. *Math.Geol.*, 22(6):637-639, (1990) 7267.

Solow, Andrew R. The nonparametric analysis of point process data: The freezing history of Lake Konstanz. *J.Clim.*, 4:116-119, (1991) 7461.

Solow, Andrew R. and James M. Broadus. Global warming: Quo vadis? *Fletcher For.World Aff.*, 14(2):262-269, (1990) 7738.

Steele, John H. Marine functional diversity. *Bioscience*, 41(7):470-474, (1991) 7684.

Steele, John H. Marine ecosystem dynamics: Comparison of scales. *Ecol.Res.*, 6:175-183, (1991).

Administration

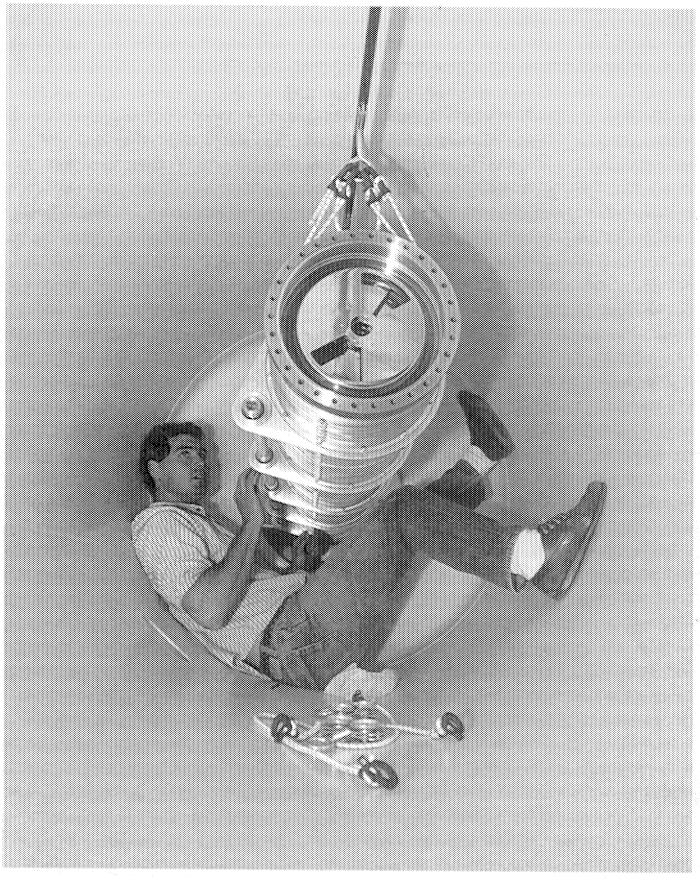
Clark, Lisa. Reproductive adaptations in marine organisms. *Oceanus*, 34(3):6-10, (1991).

Cullen, Vicky. An open door: Soviet-American cooperation in marine science. *Oceanus*, 34(2):5-7, (1991).

Cullen, Vicky. On mid-ocean ridges. *Oceanus*, 34(4):5-6, (1991).

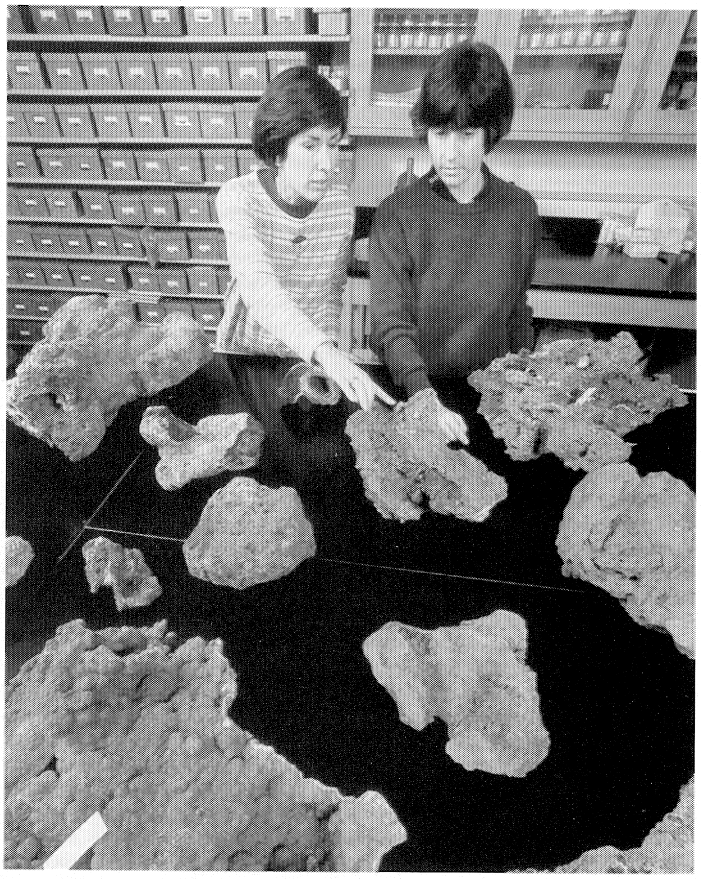
Putnam, Susan S. Depositing 'grey literature' in the U. S. technical information system - Who is responsible?. In: *Breaking the Barriers to the Free Flow of Information*. Elizabeth Fuseler McDowell and Stephen Wilst, eds. 16th International Association of Marine Science Libraries and Information Centers Conference. October 2-5, 1990, Seattle. IAMSLIC series :153-163, (1991) 7871.

Rioux, Margaret A. Promises, pitfalls, and proposals: Automating small public library cataloging in a consortium. *Pub.Libr.*, 30(4):226-231, (1991).



TOM KLEINDINST

Rob Naughler of US-AMS installs equipment in the high-energy end of the National Ocean Sciences Accelerator Mass Spectrometry Facility.



TOM KLEINDINST

Margaret Sulanowska, left, and Margaret Tivey work with some of the Institution's seafloor rock samples.

LISA POOLE

Stein Kaartvedt, left, and Peter Wiebe arrange a Multiple Opening-Closing Net Environmental Sensor System (MOCNESS) for lowering from Atlantis II.

Financial Statements

The Institution had another successful and stable financial year, with strong revenue growth from government, the endowment, and gifts from its many friends and supporters.

In 1991, total revenues increased by 7.0% to $83,142,969 from $77,711,259, a change of $5,431,710. This increase was the result of growth in government sponsored research (exclusive of the *Knorr/Melville* refit) of 7.8%, to $56,461,106 from $52,392,315. Nongovernmental research increased by 7.0%, to $7,622,201 from $7,125,979. Government and nongovernment research combined represented 77.1% of the Institution's total revenue.

For government research, the National Science Foundation sponsorship increased by 5.6% or $1,495,830 and United States Navy research funding (exclusive of the *Knorr/Melville* refit) increased by 12.6% or $2,593,397. Other government funding decreased moderately at 0.4% or $20,436. Unrestricted income also declined slightly, by 0.3% or $15,175 because of reductions in the fund balances earning interest income. The backlog at year end of sponsored research excluding the vessel refit increased $3,065,494 to $35,160,309.

Reflecting the increases in revenue, total expenses increased by 9.6% or $7,401,785, to $84,644,161 from $77,242,376. Costs of sponsored research, excluding the *Knorr/Melville* refit, increased by 7.7% or $4,565,013. Education expenses increased 11.1% due to increasing faculty costs while other expenses increased 39.2%, principally unsponsored research costs in support of unfunded scientific staff and the write-off of an outstanding receivable of $671,837 due from the JASON Foundation for Education.

In order to strengthen our reserves, record the 1991 expenses of the capital campaign, and write off the JASON Foundation receivable, transfers and write-offs have resulted in a reduction in the unrestricted current funds balance of $869,257, leaving the balance of unrestricted current funds at $1,195,787 as of December 31, 1991.

In 1991, gifts and grants from private sources increased by $558,407, to $3,580,754 from $3,022,347 (18.5%), reflecting the initial success of the capital campaign.

The market value of the endowment, including new gifts of $1,632,434 (compared to $233,859 in 1990), increased by $19,877,113 to $117,522,574 from $97,645,461, an increase of 20.4%.

Capital expenditures totaled $2,172,321, compared to $8,259,173 in 1990. Funds for capital expenditures were provided from depreciation recovery.

The number of employees at year end increased by 45 to 929.

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

Lawrence R. Ladd,
Associate Director for
Institution Operations

Kenneth S. Safe, Jr.,
Treasurer

R. David Rudden, Jr.,
Acting Controller

DAVID GRAY

Quissett Campus view shows the new Joseph V. McKee, Jr., Ball Field located behind Clark Laboratory.

Financial Statements

Statements of Current Fund

Revenues, Expenses and Transfers
for the years ended December 31, 1991 and 1990

Revenues

	1991	1990
Sponsored Research:		
Government	$56,461,106	$52,392,315
Nongovernment	7,622,201	7,125,979
	64,083,307	59,518,294
Knorr/Melville refit	10,693,042	9,960,627
Education funds availed of	2,830,835	2,681,378
Total restricted	77,607,184	72,160,299
Unrestricted:		
Fees	463,530	392,672
Endowment income	1,224,916	1,423,222
Gifts	884,439	995,015
Tuition	1,748,693	1,307,704
Investment income	292,147	530,104
Oceanus subscriptions	351,462	347,834
Other	570,598	554,409
Total unrestricted	5,535,785	5,550,960
Total revenues	**83,142,969**	**77,711,259**

Expenses

Sponsored research:		
Salaries and fringe benefits	20,180,151	17,820,188
Ships and submersibles	7,575,185	6,746,322
Material and equipment	9,056,008	8,670,267
Subcontracts	2,854,788	3,939,599
Laboratory overhead	7,994,335	6,729,737
General and administrative	6,735,345	6,103,788
Other	9,687,495	9,508,393
	64,083,307	59,518,294
Knorr/Melville refit	10,693,042	9,960,627
Education:		
Faculty expense	1,656,837	1,469,065
Student expense	1,157,913	1,087,691
Postdoctoral programs	452,161	435,616
Other	438,270	342,858
	3,705,181	3,335,230
Unsponsored research	2,280,721	2,274,444
External affairs	1,963,706	1,641,675
Other activities	1,918,204	512,106
Total Expenses	**84,644,161**	**77,242,376**
Net increase/(decrease) before transefers	(1,501,192)	468,883
Transfers - (to) from:		
Designated reserves	631,935	(344,580)
Plant fund	–	(100,000)
Total	**631,935**	**(444,580)**
Net increase/(decrease) unrestricted current funds	**$(869,257)**	**$24,303**

Balance Sheets

December 31, 1991 and 1990

Assets

	1991	1990
Current fund (Note A):		
Cash	$2,418,653	$14,991,921
Short-term investments, at cost which approximates market	7,036,117	4,441,454
Accrued interest and dividends	851,002	856,489
Reimbursable costs and fees:		
Billed	2,122,501	2,708,514
Unbilled	2,407,318	1,161,620
Other receivables	624,939	502,310
Inventories	572,477	519,676
Deferred charges and prepaid expenses	993,667	423,800
Deferred fixed rate variances	515,591	2,234,452
Due to other funds	(2,498,208)	(2,703,219)
	15,044,057	**25,137,017**
Endowment fund (Notes A and B):		
Investments, at market	110,858,023	84,256,241
Cash and cash equivalents	6,706,253	12,951,220
Due to/from current fund	(249,991)	263,400
	117,314,285	97,470,861
Annuity investments, at market	208,289	174,600
	117,522,574	**97,645,461**
Plant fund (Note A):		
Land, buildings, and improvements	38,192,039	36,540,455
Vessels and dock facilities	7,403,251	7,403,251
Laboratory and other equipment	6,658,785	6,011,146
Work in process	258,250	399,366
	52,512,325	50,354,218
Less: accumulated depreciation	(24,102,012)	(21,398,715)
	28,410,313	28,955,503
Due from current fund	2,748,199	2,439,819
	31,158,512	**31,395,322**
Total all funds	**$163,725,143**	**$154,177,800**

Liabilities and Fund Balances

	1991	1990
Current fund:		
Liabilities:		
Accounts payable and other liabilities	$3,691,060	$2,153,566
Accrued payroll and related liabilities	4,329,432	3,917,359
	8,020,492	6,070,925
Contingency (Note H):		
Fund balances:		
Restricted - unexpended:		
Sponsored research	833,347	11,217,590
Education program	3,497,098	3,605,440
Designated	1,497,333	2,178,018
Unrestricted	1,195,787	2,065,044
	7,023,565	19,066,092
	15,044,057	**25,137,017**
Endowment fund:		
Endowment:		
Income restricted	68,645,664	56,792,656
Income unrestricted	1,391,866	1,144,312
Pooled income fund	47,061	–
Quasi-endowment:		
Income designated	17,902,844	14,678,694
Income unrestricted	29,326,850	24,855,199
Total endowment	117,314,285	97,470,861
Annuity	208,289	174,600
	117,522,574	**97,645,461**
Plant fund:		
Invested in plant	28,410,313	28,955,503
Unexpended:		
Restricted	77,003	60,594
Unrestricted	2,671,196	2,379,225
	31,158,512	**31,395,322**
Total all funds	**$163,725,143**	**$154,177,800**

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

Statement of Changes in Fund Balances

for the year ended December 31, 1991

	Current Funds				Endowment	Plant Fund		Total all Funds	
	Restricted	Designated	Unrestricted	Total	Fund	Invested in Plant	Unexpended	1991	1990
Increases:									
Gifts, grants and contracts:									
Government	$57,570,609			$57,570,609				$57,570,609	$62,981,935
Non-government	6,020,090		$878,342	6,898,432	$1,632,434		$25,001	8,555,867	8,490,033
Endowment and similar funds	3,283,664		1,224,916	4,508,580				4,508,580	5,206,906
Net increase (decrease) in realized and unrealized appreciation				–	17,706,346			17,706,346	(4,895,210)
Supplemental retirement plan				–	536,805			536,805	562,058
Other	241,499		3,432,526	3,674,025	1,528			3,675,553	3,430,431
Total increases	67,115,862		5,535,784	72,651,646	19,877,113		25,001	92,553,760	75,776,153
Decreases:									
Expenditures	(77,607,184)		(7,036,976)	(84,644,160)				(84,644,160)	(77,242,376)
Depreciation (Note A)				–		$(2,717,511)	2,455,700	(261,811)	(261,814)
Plant asset additions				–		2,172,321	(2,172,321)	–	–
Other	(50,013)			(50,013)				(50,013)	(912)
Total (decreases) increases	(77,657,197)		(7,036,976)	(84,694,173		(545,190)	283,379	(84,955,984)	(77,505,102)
Net change before transfers	(10,541,335)		(1,501,192)	(12,042,527)	19,877,113	(545,190)	308,380	7,597,776	(1,728,949)
Transfers – additions/(deductions):									
Current revenues to:									
Designated reserves		$(631,935)	631,935	–				–	–
Other transfers	48,750	(48,750)		–				–	–
Total transfers	48,750	(680,685)	631,935	–				–	–
Change in fund balances for year	(10,492,585)	(680,685)	(869,257)	(12,042,527)	19,877,113	(545,190)	308,380	7,597,776	(1,728,949)
Fund balances, December 31, 1990	14,823,030	2,178,018	2,065,044	19,066,092	97,645,461	28,955,503	2,439,819	148,106,875	149,835,824
Fund balance, December 31, 1991	**$4,330,445**	**$1,497,333**	**$1,195,787**	**$7,023,565**	**$117,522,574**	**$28,410,313**	**$2,748,199**	**$155,704,651**	**$148,106,875**

Report of Independent Accountants

To the Board of Trustees of
Woods Hole Oceanographic Institution:

We have audited the accompanying balance sheet of Woods Hole Oceanographic Institution as of December 31, 1991 and the related statements of changes in fund balances, and of current fund revenues, expenses and transfers for the year then ended. We previously audited and reported upon the financial statements of the Institution for the year ended December 31, 1990; totals for that year are shown for comparative purposes. These financial statements are the responsibility of the Institution's management. Our responsibility is to express an opinion on these financial statements based on our audit.

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

In our opinion, the financial statements referred to above present fairly, in all material respects, the financial position of Woods Hole Oceanographic Institution as of December 31, 1991, the changes in its fund balances, and its current fund revenues, expenses and transfers for the year then ended, in conformity with generally accepted accounting principles.

Boston, Massachusetts
May 29, 1992

Coopers & Lybrand

Notes to Financial Statements

A. Summary of Significant Accounting Policies:

Fund Accounting

The accompanying financial statements have been prepared on the accrual basis. 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

Included in cash at December 31, 1991 and 1990 is $1,992,033 and $14,750,553, 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 from the federal government.

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 equipment. Depreciation expense on plant assets purchased by the Institution amounting to $2,455,700 in 1991 and $2,084,713 in 1990, 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 $261,814 in each year) 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, 1990 presentation have been reclassified to conform with the December 31, 1991 presentation.

B. Endowment Fund Investments:

The cost and market value of investments held at December 31, 1991 and 1990 are as follows:

	1991		1990	
	Cost	Market	Cost	Market
U.S. Government and govenment agencies	$18,974,031	$ 19,933,552	$18,002,572	$18,317,663
Convertible bonds	1,055,625	911,050	1,209,755	936,325
Corporate bonds	8,955,901	9,599,251	8,988,293	9,075,881
Other bonds	1,880,635	2,008,279	824,143	829,007
Common stock	62,709,600	75,644,347	51,538,959	52,460,264
Other	3,156,552	2,761,544	2,578,019	2,637,101
Total investments	**$96,732,344**	**$110,858,023**	**$83,141,741**	**$84,256,241**

C. Investment Units:

The value of an investment unit at December 31, 1991 and 1990 was $2.1866 and $1.8532,respectively. The investment income per unit for 1991 and 1990 was $.0874 and $.1016, respectively.

	1991	1990
Unit value, beginning of year	$1.8532	$1.9471
Unit value, end of year	2.1866	1.8532
Net change for the year	.3334	(.0939)
Investment income per unit for the year	.0874	.1016
Total return per unit	**$ .4208**	**$ .0077**

D. Endowment Income:

Endowment income consisted of the following:

	1991	1990
Interest and dividends	$4,961,440	$5,668,281
Investment management costs	(452,860)	(461,375)
Net endowment income	**$4,508,580**	**$5,206,906**

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 of the Institution. 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 1991:

Service cost	$ 3,364,976
Interest cost	4,693,488
Actual return on plan assets	(16,551,732)
Net amortization and deferral	10,332,051
Net pension expense	**$1,838,783**

Below is a reconciliation of the combined funded status of the plans at December 31, 1991:

Accumulated benefit obligations:	
Vested benefits	$47,448,611
Nonvested benefits	2,717,706
Total accumulated benefit obligation	**50,166,317**
Projected benefit obligation	72,259,907
Market value of plan assets (primarily invested in common stocks and fixed income securities)	87,920,176
Plan assets in excess of the projected benefit obligation	(15,660,269)
Unrecognized net transition asset	5,177,247
Unrecognized prior service costs	(599,280)
Unrecognized net loss	11,082,302
Accrued pension cost	**$ -**

The market value of plan assets listed above contains $85,181,313 of plan assets held in the Woods Hole Oceanographic Retirement Trust at December 31, 1991. In addition, the Institution has designated, as quasi endowment, approximately $2,737,863 to fund certain supplemental benefits at December 31, 1991.

The discount rate and rate of increase in future compensation used to determine the projected benefit obligation as of December 31, 1991 were 7.25% and 7.06%, respectively. The expected return on plan assets was 8.25%.

F. Postretirement Health Care 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. The cost of retiree health care is recognized as an expense when paid. These costs amounted to $397,800 in 1991 and $344,700 in 1990.

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 contracted with a shipyard in 1989 to perform certain refit and modification work on the R/V Knorr and R/V Melville. The project was funded by the United States Navy. During 1991, the shipyard assessed a claim of approximately $11,000,000 against Woods Hole Oceanographic Institution. The claim related to alleged delays and disruptions encountered in performing work on the R/V Knorr. In 1992, a similar claim was asserted related to work performed on the R/V Melville which amounted to approximately $8,000,000. In addition, the Institution has asserted various counterclaims against the shipyard and other subcontractors aggregating approximately $6,000,000.

As stipulated in the original contract between the shipyard and the Institution, these matters have been presented to the American Arbitration Association for a binding resolution. The Institution is vigorously defending itself against these claims and believes them to be substantially without merit. In addition, the Institution is evaluating sources of additional funding should this be required. The Institution's ultimate liability, if any, is not determinable at this time. However, the Institution believes that if there is an award of damages through the arbitration process, it would not have a materially adverse impact on the financial condition of the Institution.

All funds expended by the Institution in connection with government grants and contracts are subject to audit by the federal government. In the opinion of management, any cost disallowances resulting from these audits will not have a material impact on the financial condition of the Institution.