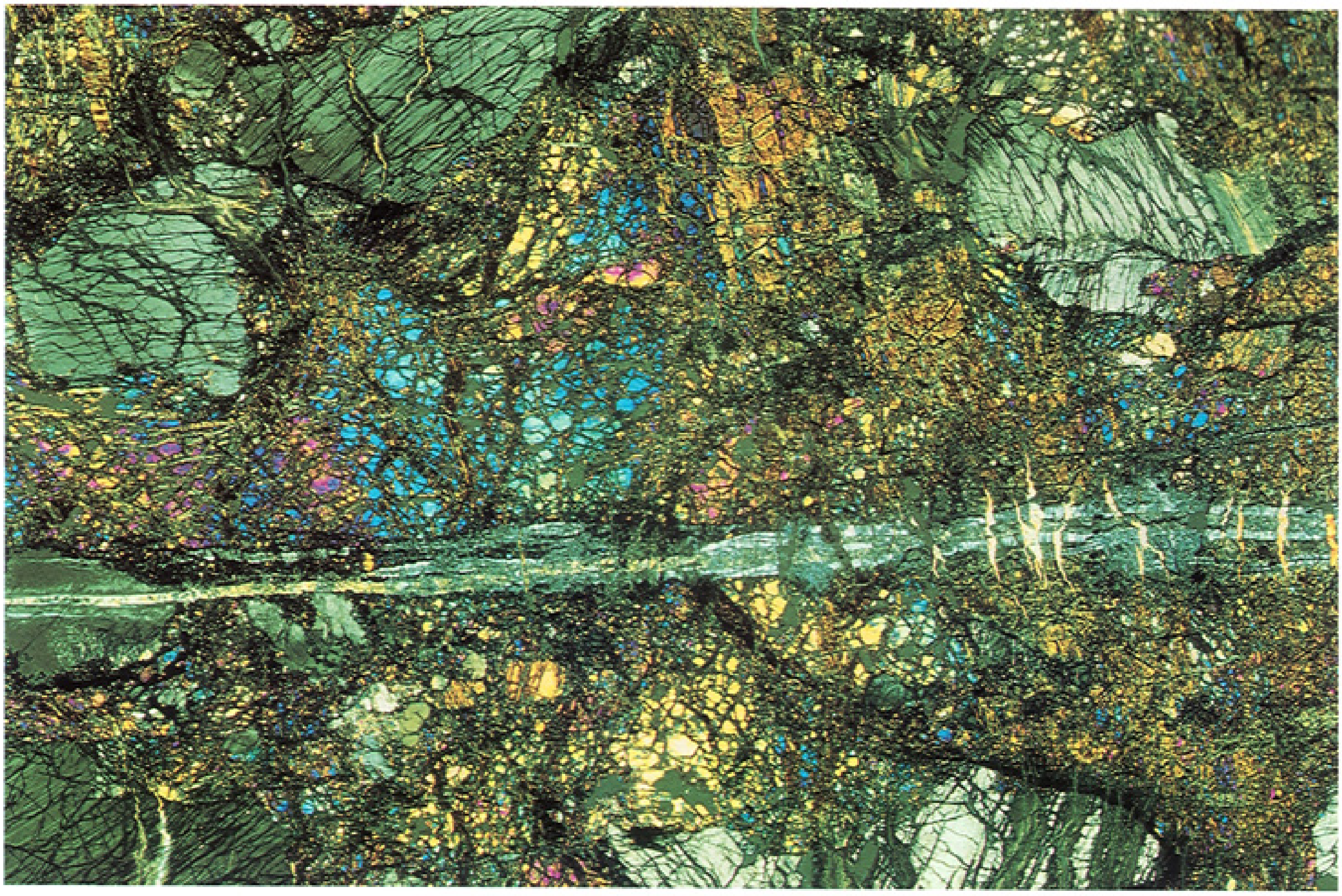

Photomicrograph of an altered mantle peridotite in polarized light. The rock was dredged from a depth of 4000 meters (13,000 feet) in the Islas Orcadas Fracture Zone, located between Antarctica and Africa at 54°S 6°E. Brightly colored grains are bits of the primary mineral olivine, the common form of the gem stone peridote, criss-crossed by veins of serpentine formed by alteration from seawater.

Contents

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About the covers:
Geologist Henry J.B. Dick has studied both dredged rocks from the ocean floor and rocks on the continents to try to understand the composition of the earth's mantle, which is 1,800 miles thick and comprises 83 percent of the earth. The cover photographs are thin sections (30 microns thick) of mantle rocks he has collected. Polarized light interacting with the rocks' crystal structure produces some interesting and dramatic coloration.

The front cover is a photomicrograph of a diabase, originally molten rock, consisting of the minerals plagioclase, olivine and a very coarse grain of pyroxene. The rock was recovered by the drillship *Glomar Challenger* in 1978 from the floor of the Philippine Sea.

The back cover is a photomicrograph of olivine gabbro, another volcanic rock. Many small brightly colored olivine grains are surrounded by the minerals plagioclase and pyroxene. The sample was dredged from a depth of 4000 meters (13,000 feet) in the Kane Fracture Zone on the Mid-Atlantic Ridge near 22°N.

Annual Report 1985
Shelley M. Lauzon, *Editor & Designer*
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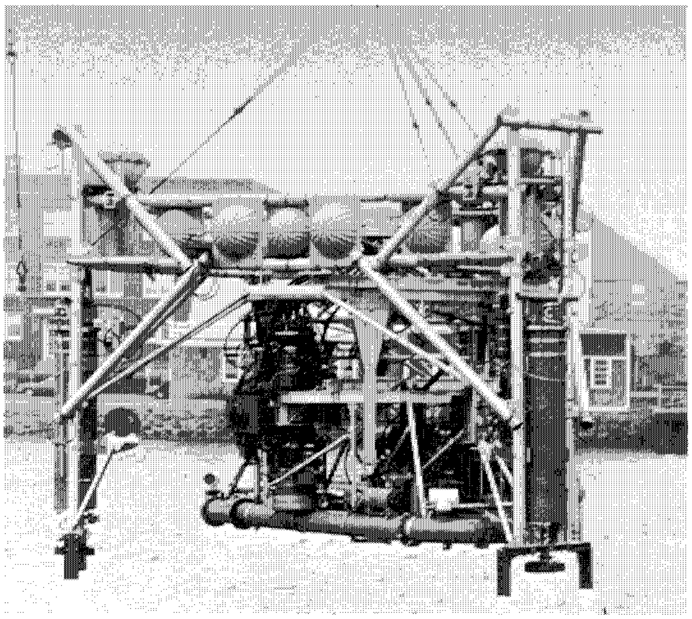
For more information about the Institution and its research and education programs, contact:
Publications and Information Office
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
617-548-1400



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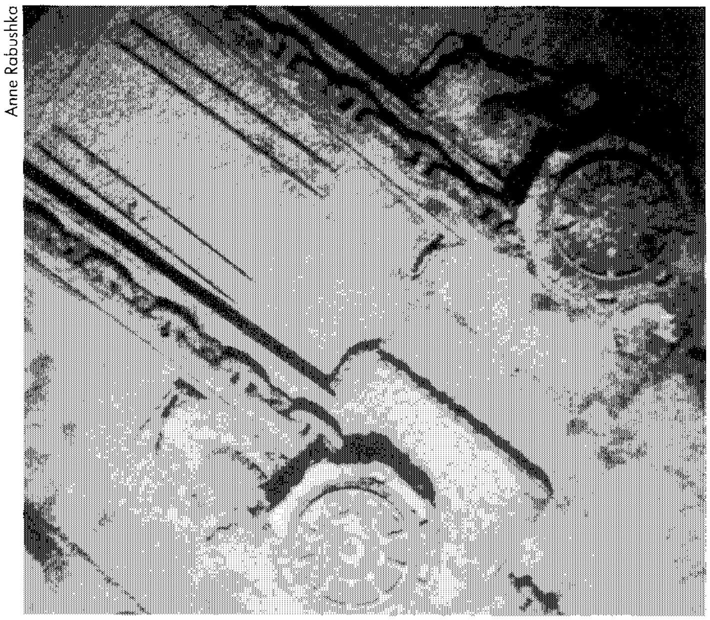
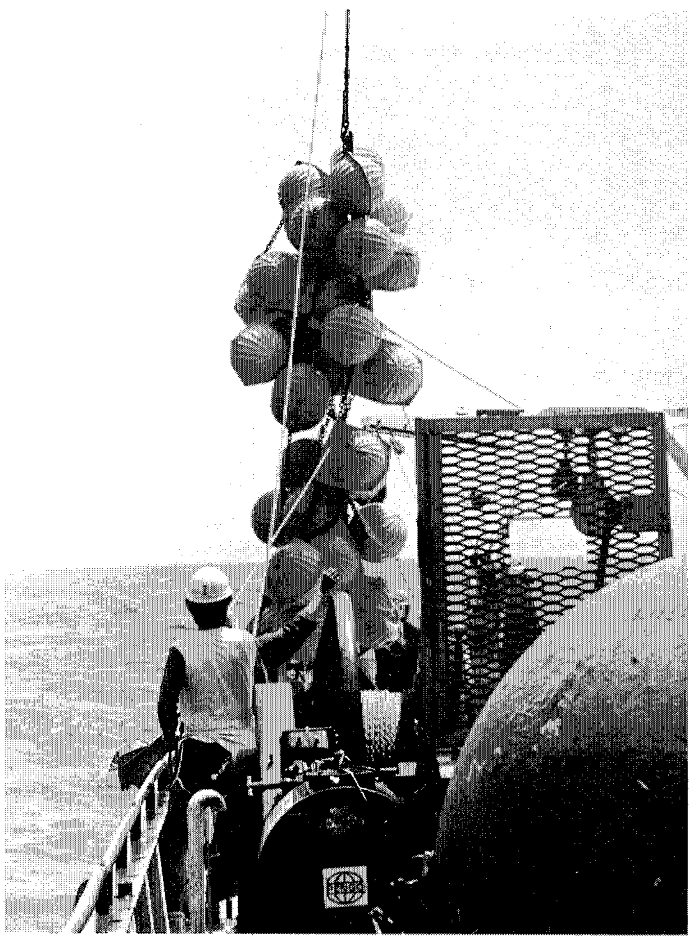


ANGUS camera system



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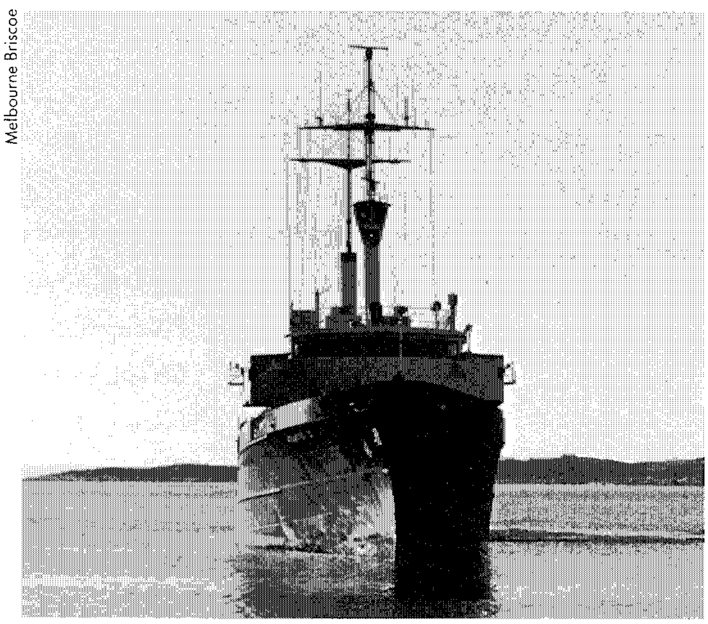


Anne Rabushka

Top left: Sea Duct, a computer-controlled deep sea flume and camera system, was designed by Institution engineers for studies of bottom currents and their effects on the terrain. Top right: Anchor chains, capstans and winches on the bow of R.M.S. TITANIC, photographed by the ANGUS camera system. Bottom left: recovery of "hard hats," used for floatation on a mooring, aboard OCEANUS. Bottom right: Bow of ATLANTIS II as it returns home following a 21-month voyage in the Pacific.

Director's Comments

Nineteen eighty-five has been an exciting year for the Woods Hole Oceanographic Institution. Major scientific discoveries have been made, some of which are summarized in this report. New insights have been provided by our staff to understand the ocean environment from salt marshes to deep-sea vents and from the present dynamics of ocean currents to the history of the ocean basins. During this year, the emerging vision of the oceans as a global system determining the earth's habitability has been given high priority by the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA). The contributions of our basic science to the U.S. Navy have been recognized by the Administration.

At the same time, we face constraints imposed by national budget deficits, and we appear to be entering a period of recurring economic crises. In this context, what emphasis can and should be given to science and especially to oceanography? What is the public view of our research? How well is it known; how significant is it judged to be?

The Institution achieved national and international attention with our involvement in finding the R.M.S. TITANIC. The summer cruise, led by Dr. Robert Ballard of the Deep Submergence Laboratory aboard the R/V KNORR, was a magnificent demonstration of new technologies developed in Woods Hole. Equally significant was the further scientific application of the ARGO video/sonar system for greatly expanded exploration of the sea floor, carried out by Dr. Ballard and his colleagues in December 1985 on the East Pacific Rise. The value of new tools and methods like ARGO is immense and is recognized within the oceanographic community. How do we take this and other scientific achievements to a larger audience?

The great questions about the oceans are not directly involved in our short-term deficit crises. Climate change, marine mineral resources, and ocean pollution are matters whose impact may be most significant in a decade or more. Yet, the knowledge we gain now is required for the longer-term response to the inherent social and economic problems facing us today. The effects of climate change driven by the oceans and the marine options for oil and for waste disposal have nationwide consequences. We must investigate these and other issues to adequately prepare for the future.

Our present concern is that the government may cease to think of science as an investment (albeit, long-term and high-risk) and begin to operate a procurement system for short-lived projects or short-term benefits. This lack of faith in such venture investments would effect all areas of science, but especially those areas where the costs are relatively high and the benefits are not immediate. Oceanography is now in the latter category. New technologies like satellite systems and computer modelling will bring significant increases to the costs of research over the next decade. The venture capital for this investment in the future should come from diverse sources, but the major shareholder is the public.

The increased costs are large in terms of our present budgets for oceanography, but small in the context of our total national Research and Development effort. We believe the benefits are critical in determining the kind of world we shall inhabit in the next few decades. To achieve these aims, we require a general recognition of the excitement as well as the benefits of these new programs, which will provide us with a global view of how the oceans function and interact with the atmosphere and the land.

The future of this Institution is closely linked to this broader acceptance of the significance of our work. We should take the lead in creating a larger audience. With the discovery of the TITANIC, we have made our voice heard. Now we must prove our case for major advances in our science.

John H. Steele
Director

Shelley Lauzon

Areas of Interest

Biology

The broad aim of biological oceanographers is to study the temporal and spatial distributions of populations of marine organisms and their interactions with each other and their environment. The work is predominantly ecological in its attempts to provide the basic information required to understand how the ocean works biologically. Among the specific research interests of Institution biologists are microbiology, biochemistry, planktonology, ichthyology, benthic biology, physiology, biogeochemistry, animal behavior, and aquaculture. Work on marine pollution includes research on the effects of PCB's and hydrocarbons and the biochemical responses of animals to these and other pollutants. The "patchy" distribution of many marine animals is under investigation as are the physiological adaptations of deep sea organisms to sparseness of food, low temperatures, high pressures, and deep sea thermal vents. Answers to questions about the food supply in the oceans are sought in studies of particles falling from the surface waters through the water column to the bottom of the sea, in studies of upwelling areas, through investigations of sulfur oxidizing organisms in the deep sea and shallow coastal ponds, and in laboratory experiments that complement field investigations. The uses of sound by marine mammals and the behavior of large marine animals followed by tagging are being studied. Other work concentrates on salt marsh ecology and conservation, nutrient cycling in coastal waters, and on aquaculture and wastewater recycling. The symbiotic relationships between marine microbes and other organisms (including wood-borers) are a new focus. Gelatinous organisms of the plankton (salps, ctenophores, and jellyfish) are being studied with new techniques that finally allow us to properly evaluate the roles of these organisms in the oceans.

Chemistry

Chemical oceanographers are concerned with the composition of the ocean environment. They seek to understand the processes that have brought seawater and sediments to their present composition and that contribute to the observed variability. They also seek understanding of the extent to which the environment may be changed by both natural and man-made phenomena operating on a variety of time scales. Input from rivers and reactions at the air-sea, seawater-sediment boundaries and seawater-volcanic rock interactions at spreading centers are under investigation as chemists consider the processes taking place at the major ocean boundaries. Some critical questions in chemical oceanography revolve around the vertical transport and transformations of particles as they fall from the surface waters to the sea floor. The photochemistry of the surface ocean and the marine atmosphere is critical to our understanding of the global sources and sinks for many gases. The genesis and composition of the oceanic crust and its interaction with seawater is important to a general understanding of the oceanic system. Studies concerning the interstitial water chemistry of deep sea sediments help us to better understand the diffusive flux of ions between sediments and the oceans. Work on the fluxes of organic carbon includes determination of the amount of organic carbon produced in surface waters, the distribution, nature, and biogeochemistry of specific organic compounds in the marine environment, and studies of processes responsible for formation and diagenesis of organic matter in sediments. While studying radioactive isotopes in the ocean, whether as a natural occurrence or as a form of pollution, chemists are also finding the known decay rates of the isotopes useful as indicators for studying rates of water circulation, the in situ rates of chemical processes in the sea, and rates of biological and chemical processes that change the composition of seawater. Stable isotopic studies in rocks can be used as geochemical and petrological indicators of large scale terrestrial mantle processes.

Geology and Geophysics

Marine geologists and geophysicists study the processes which form and affect the earth beneath the sea, as reflected in its underlying structure and composition. The sedimentary and volcanic material of the seabed is investigated by direct sampling and remote observation. Coring, dredging, or drilling techniques are commonly used to obtain samples, which are further classified in the laboratory by petrological descriptions, geochemical analyses, and measurement of physical properties. Geophysical methods include the fields of seismology, gravity, magnetism, and geothermics. The establishment of plate tectonics as the primary kinetic process creating and shaping ocean basins has focused attention at the boundaries where plates interact. At divergent plate boundaries, or mid-ocean ridges, the processes which bring up hot materials to create ocean crust and lithosphere are studied in detail. Investigations of rifted continental margins of different geological ages are important to understand how continental plates initially break apart. Finally, subduction of oceanic lithosphere beneath either continental or other oceanic lithosphere is a process which is ultimately associated with the creation of deep sea trenches and back-arc basins, accompanied by the important geological phenomena of earthquake belts and volcanic island arcs. In such geological processes, earth materials sometimes behave like viscous fluids, which can be modelled in the laboratory. Research is actively pursued on processes of particulate flux in the ocean ('marine snow'), carbonate and silicate dissolution, and other phenomena relevant to the transport of biogenic material to the sea floor. The results are essential to a better understanding of the fossil record, which in combination with studies of its oxygen isotopic variation reveal changes in climate and ocean environment over periods of thousands to millions of years. The study of the dynamics of sediment distribution on the ocean floor is important to deciphering the fossil record and interpreting sea floor morphology. Marine geologists also study near-shore and shallower regions such as continental shelves and coasts where earth, ocean, and atmosphere dynamically interact to produce complex and rapidly-changing morphology.

Ocean Engineering

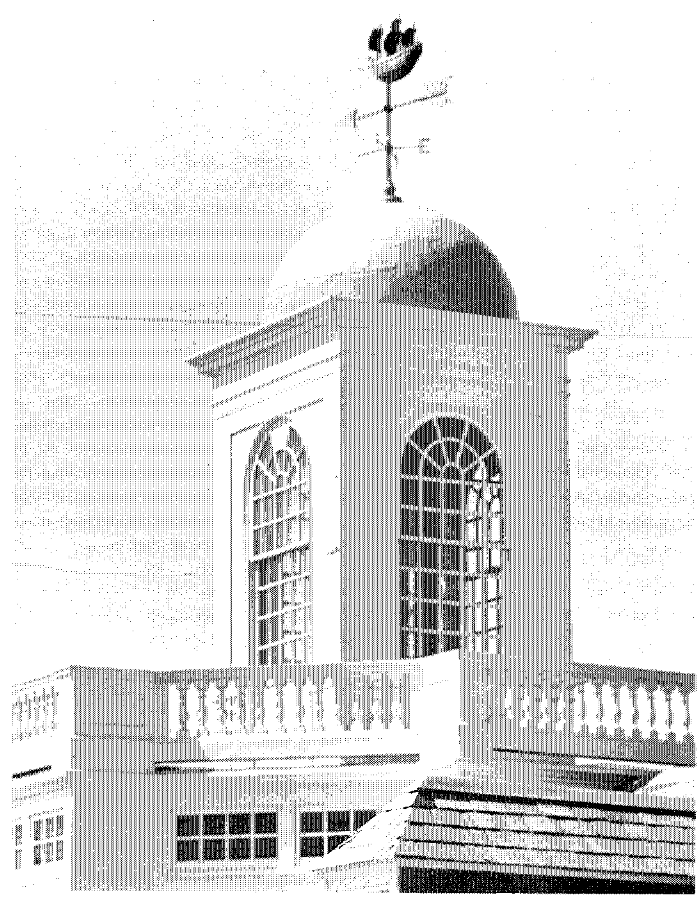
The field of ocean engineering is a complex hybrid of many of the classical engineering disciplines such as electrical, mechanical, civil, chemical, marine engineering and physics. Its purview is broad and interdisciplinary. Its objective is to bring engineering skill and scientific method to bear on research, development and exploration in the ocean. Ocean engineers conduct research and design instrumentation in almost every aspect of oceanography to answer basic scientific questions about the marine environment. Measurements span time scales of years to milliseconds and spatial scales of kilometers to millimeters. Electronic data acquisition and processing circuits and environmental sensors are designed for use in a wide variety of programs. Instrument housings and anchoring and mooring systems are designed, fabricated, and deployed at sea. Manned and unmanned deep submersible systems are engineered for search and discovery. Image enhancement and image processing algorithms are developed for use with earth orbiting satellites that remotely sense sea surface temperature, wind and height. Signal processing methods are applied to acoustic systems, satellite images, geophysical time series and data analysis. Research is conducted in hydrodynamics and turbulent processes so that mechanisms of sediment transport and energy dissipation can be described in detail and with sufficient confidence for use in predictive wind-wave and continental shelf circulation models. Ocean engineers are conducting research in Arctic acoustics, acoustic tomography, materials, microprocessor applications, robotic control of underwater vehicles, optical measurement, coastal processes, biologic processes, deep submergence engineering, estimation and detection theory, and spectral analysis, and in a wide variety of ocean observational techniques from free-drifting satellite telemetering data buoys to fast, autonomous, conductivity/temperature/depth profilers. These activities support research projects throughout the Institution. The solution to challenging problems requires creative combinations of wide ranging ocean engineering principles. Modern ocean science demands innovative instruments and measurement systems. Informed and sensible exploitation of marine resources requires engineering design and invention. National security and prosperity depend on first-rate engineering in the ocean.

Physical Oceanography

Physical oceanography is the study of the physics of the ocean. Its central goal is to describe and explain oceanic motions, which occur over a wide range of scales, from millimeters to megameters, and seconds to centuries. On a large scale, the sun heats equatorial waters and the ocean transports this heat toward the poles, so as to smooth out the climate of the planet and make large parts of the earth habitable. Variations of the temperature and salinity, the driving effects of the winds, the rotation of the earth, and the pull of the sun and the moon all contribute to these motions. There are grand persistent currents like the Gulf Stream, and there are transient waves and eddies of almost all sizes and speeds, from high frequency acoustic and surface gravity waves, to slower internal gravity waves beneath the sea surface. Large regions of the oceans are dominated by the mesoscale eddying vortical patterns of flow that display visual and dynamic similarity to atmospheric weather patterns. As in the atmosphere, relatively intense frontal systems exist. Important mixing and stirring of the ocean are accomplished by a variety of physical processes, some of great subtlety like the phenomenon of "salt fingers" whose sizes are on the centimeter scale. Important scientific questions also arise in considering the interaction of the ocean with the atmosphere. The ocean and the atmosphere drive each other in an as yet poorly understood way: exchanges of energy between the air and sea are important in determining the climate of both the atmosphere and the oceans. Physical processes in coastal regions are strongly affected by atmospheric forcing and bottom topography, and the current and wave systems in these complicated regions are of vast importance to the local climate and ecology. Physical oceanography staff members are involved in experimental, theoretical, laboratory, and numerical investigations of many parts of the system of oceanic motions. Small programs and large international projects are underway, and multidisciplinary efforts are increasing. All of these studies have the ultimate goal of understanding the structure and movement of the world's oceans, the interaction of the sea with its boundaries, and the physical role of the ocean in relation to other branches of oceanography. Physical oceanographers come to the subject with a variety of backgrounds: mathematics, physics, engineering, computers, and chemistry. The mix of interests provides a broad approach to the equally broad range of problems in the ocean.

Marine Policy & Ocean Management

The Marine Policy and Ocean Management Center (MPOM) was established in 1971 to present the opportunity for scholars to conduct interdisciplinary research on the problems and activities generated by our increasing use of the ocean. This opportunity has been focused in several ways: by support through the years to over 100 Research Fellows, trained in fields such as law, economics, anthropology, political science, engineering, mathematics, natural sciences and geography; by development of multidisciplinary projects between marine policy researchers and marine scientists; by sponsorship and participation in workshops, conferences, and classes; by publication of articles and books on vital marine policy issues; and by establishment of a permanent policy research staff at the Institution. The Marine Policy Center provides the setting for this diverse group of scholars to study, interpret and convey the information necessary for the development or modification of local, national and international ocean policy. Analyzing and evaluating appropriate policies and management strategies to deal with marine issues are tasks that often require the data and skills of both natural scientists and social scientists. Within the broad field of marine policy and the wide range of interdisciplinary research interests pursued by the Center's staff, a research program has evolved into the following thematic areas: 1) Exclusive Economic Zone (EEZ) and Law of the Sea issues, with their implications for domestic and international marine policy, offer opportunities to evaluate existing ocean legislation and administrative arrangements, and to devise improvements for future ocean policy; 2) Energy and Marine Minerals Development studies consider the domestic and international policy problems of developing potential resources contained in the oceans, such as manganese nodules, polymetallic sulfide deposits, other nonfuel minerals and hydrocarbons; 3) Coastal and Fisheries Management issues, both domestic and foreign, include assessments of the management of living marine resources, use of scientific and technical information in management of coastal zones, and various studies on fisheries management policies and planning; 4) studies of the Interaction of Science and Policy observe ocean science from the perspectives of how marine science and technology are affected by public policy, and how scientific information is used in the formulation of decisions for coastal and ocean resources policy; 5) Cooperative International Marine Affairs programs have been initiated with developing nations interested in addressing informational and policy needs stemming from the extension of their national jurisdictions over vast marine areas. The Marine Policy Center offers Postdoctoral and Senior Research Fellowships to professionals in the social sciences, law or natural sciences to apply their training to these research areas.


Shelley Lauzon

Bigelow Laboratory cupola

Reports on Research

Rather than highlight a few specific projects as we usually do in this report, we are instead giving a broad overview of current research within our scientific departments and centers. This format is particularly appropriate now for, from time to time, we need to step back to consider the whole picture, the interrelation and dovetailing of projects, consider what has been accomplished, and determine the most productive approach before setting off again on the road to discovery. By assessing our position we can increase the scope of our science and better coordinate its multi- and interdisciplinary nature. This exercise is being repeated throughout the ocean scientific community and has been a significant factor in the recent life of scientists at this institution and elsewhere.

Ocean science today is evolving rapidly. New data, ideas, models and methods are driving the disciplinary components and forging substantial links among them. At this time, compelling intellectual and technological bases for the initiation of integrated studies exist that can lead to a global perspective of the ocean and its processes. Awareness has grown of the earth as a single system with the land, air and sea exchanging energy and materials in complex feedback loops over time scales from seconds to many thousands of years. These exchanges are major factors in determining the habitability of the planet that is our home, and we must be able to take a planetary view if mankind is to be able to understand and adapt to the changing face of the restless earth. A recent report by the National Science Foundation (NSF) Advisory Committee for Ocean Sciences has laid the basis for this future science and has resulted in a major new NSF budgetary initiative in "Global Geosciences" starting in 1987.

Within this initiative two major new programs are planned, one in "Global Ocean Studies" and the other in "Ocean Lithosphere Studies." The first of these deals with the fluxes and balances of water, energy, momentum and materials in the ocean and at its boundaries, their interrelationships and their effects on marine productivity and global climate. A central element is the ocean circulation, for surface air-sea exchanges, poleward heat flux, internal ocean heat fluxes, deep and intermediate water formation processes and interannual variability are crucial components of the ocean-atmosphere system that is responsible for the maintenance and variability of the earth's climate and weather. A second major element concerns the biological and chemical cycles which drive some of the major fluxes of materials within the ocean and at its boundaries. For example, the ocean both produces and absorbs radiatively active gases such as carbon dioxide, methane and nitrous oxide. But at what rate, and are there significant long-term impacts from the burning of fossil fuels and the release of aerosols?

The technology needed to pursue these programs, although existing in concept, is not all in place. Satellites that will allow us to obtain synoptic pictures of the wind forcing on the ocean's surface, of the major ocean current responses and the resulting biological growth will be essential tools. New and more efficient means of sampling the deep ocean, with real-time telemetry of data from remote subsurface locations, also need to be developed. New and more stable ships and platforms are required to allow us to obtain measurements in the stormy high latitude regions which are the birthplace of most of the waters of the deep ocean and are the sites of major exchanges of energy and momentum between the ocean and the atmosphere. Supercomputers will be essential to handle many of the difficult problems of modelling large scale regions of the ocean, and sophisticated data networking systems must be installed to speed the flow of information between instrument, computer and scientist.

The second major initiative deals with the structure, tectonics and dynamic evolution of the major features of the ocean basins and their biological and chemical consequences. With a heavy emphasis on the evolution of the transition zones between continental and oceanic crust and on mid-ocean ridge crests, where new crust is being formed, this work will be directed toward understanding the thermo-mechanical properties of the deep earth, the driving forces of oceanic plates, the mechanisms of forming and moving continents, and the short-term and long-term effects on the evolution of the environment in which we live.

These studies are also dependent on new technology. In addition to much of that already mentioned, they will make extensive use of developing capabilities of imaging the sea floor and sub-sea floor with visual, sonar and seismic tools. Research submersibles, both manned and unmanned, and long-term seafloor monitoring systems will play essential roles as will the deep ocean drilling ship.

Ocean scientists from institutions across the country will be implementing research programs directed toward the goal of developing global perspectives. The path forward is built solidly on the achievements of the past. There is a palpable excitement of major achievements throughout the community of scientists notwithstanding the "Gramm-Rudman-Hollings" budget balancing bill or other slings and arrows which are hurled to slow down progress. We may use some energy deflecting these impediments to success, but the momentum of research in these new global perspectives is impossible to halt.

Derek W. Spencer
Associate Director for Research

Richard H. Backus, Chairman

Microbial Ecology and Microplankton Studies

The metabolic activities of microbial populations were studied at two very different deep-sea sites. New kinds of thermophilic, sulfur-respiring bacteria were isolated from sediments as hot as 160°C in the Guaymas Basin spreading center at a water depth of 2000 m (about 6,000 feet). Also found at the hydrothermal vent here were mats of the aerobic, filamentous bacterium *Beggiatoa* sp. (figure 1). In contrast, samples of the bottom in 8200 m (about 25,000 feet) in the Puerto Rico Trench had the lowest bacterial numbers and activities ever measured by us in marine sediments.

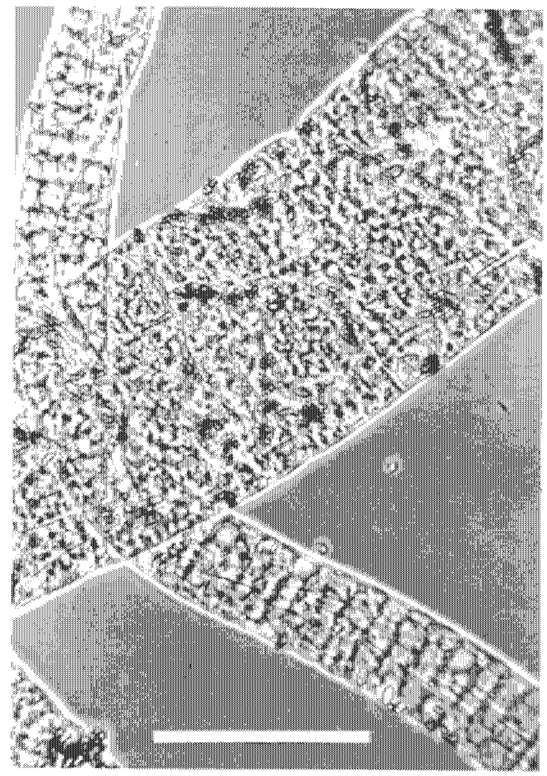
The mechanisms by which chlorophyll *a* is degraded in oxic and anoxic sediments was studied using model microbial food chains established from natural inocula. Such an approach promises to allow the isolation and determination of structure of partially and highly decomposed transformation products – goals that have eluded classical techniques.

The unique cellulose-digesting, nitrogen-fixing bacterium that lives in the gut of shipworms contributes 15-20% of the nitrogen budget of these wood-boring molluscs – the first known example of an animal/bacterium symbiosis in which nitrogen fixed by the bacterium is contributed to its host.

The systematics and taxonomy of marine and terrestrial nitrifying bacteria was reviewed. Both the relatedness of these organisms to one another and to other groups of bacteria was studied. A new genus and species of marine nitrite-oxidizer, *Nitrospira marina,* was described.

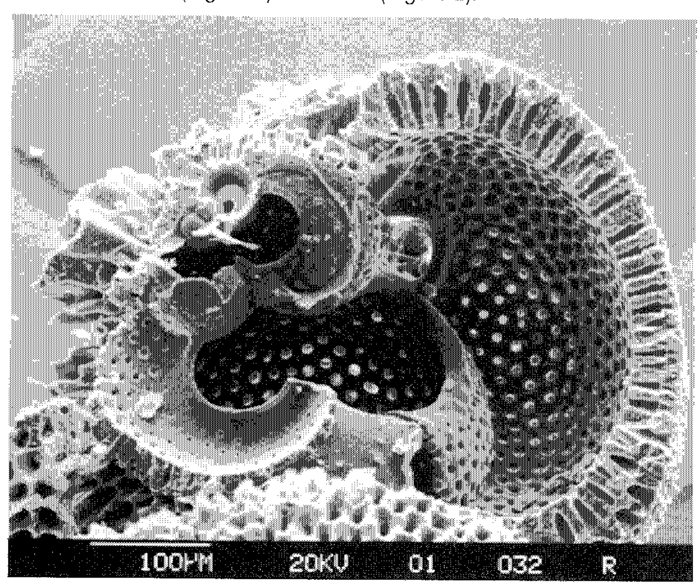
A cyanobacterium (*Synechococcus* sp.) capable of swimming was discovered in the Sargasso Sea. Since the organism lacks flagella or any other of the usual organelles that provide motility, it must be propelled by some novel mechanism. Techniques have been developed for measuring both growth and grazing rate in *Synechococcus* – because of its abundance, an important genus of phytoplankters. A novel cyanobacterium in the related genus *Synechocystis* has been isolated from the tropical Atlantic. This unicellular organism fixes nitrogen in aerobic waters warmer than 27°C, reaching concentrations as high as 10^3 cells per ml. Thus, it promises to be important in both carbon and nitrogen budgets in tropical waters.

The flow cytometer is a powerful tool recently brought into use for studying phytoplankton cells. A laser beam perceives the light-scattering and fluorescence properties of water-borne cells streaming past it, and the cells can be sorted into various classes. Now the instrument has been taken to sea and used to distinguish, and sort into culture, populations of *Synechococcus* having different fluorescences. In other collaborative studies with MIT the flow



Top: A filamentous mat-forming bacterium, *Beggiatoa* sp., from a hydrothermal vent in the Guaymas Basin. These largest of procaryotic microorganisms can oxidize hydrogen sulfide, fixing carbon dioxide. Scale bar equals 100 micrometers (Figure 1).

Bottom: scanning electron micrograph of a broken shell of the planktonic foraminifer *Globigerinoides conglobatus*. Shell thickening in this species is related to gametogenesis and will prolong the life of the shell in the sediment (Figure 2).



cytometer has been used to study the responses of *Synechococcus* sp. and other primary producers to light and nutrient level, to distinguish green algae and coccolithophorids, and to sort components of the phytoplankton in experiments measuring activity with radioactive tracers.

The high molecular-weight polysaccharides excreted by a unicellular red alga, *Porphyridium* sp., retarded oxygen exchange through the air/water interface by as much as 40-50%. Like effects might be observed at the sea surface during phytoplankton blooms.

The marine dinoflagellates are a diverse group. Some function strictly as plants, some as animals, capturing and consuming other members of the plankton. We particularly have been studying the interesting species that cause the so-called "red tides". These organisms produce potent toxins and exist as dormant cysts during a part of their life cycle. Recent studies have focussed on changes of the cell with time during encystment and the regulation of the germination of cysts, the environmental regulation of toxicity with emphasis on the physiological differences between high and low-toxicity strains, and the population dynamics of cyst-formers in shallow and deep water.

Planktonic protozoa have various modes of feeding. Some eat plants, some other unicellular animals, still others bacteria. Microflagellate protozoa fed on phytoplankton and bacteria equally well in laboratory experiments. The protozoa had high weight-specific rates of nitrogen and phosphorus regeneration, but also were efficient converters to biomass of what was ingested – up to 50-60%. Thus, to attain more than 90% of nutrient regeneration by microzooplankton requires a complex microbial food web with a hierarchy of steps.

Accumulations of the shells of certain other planktonic protozoa – the foraminifera – have been used profitably by paleoceanographers to infer climate over geologic time-scales by assuming that changes in community structure and in shell size and shape have been in response to the changing ocean. We have been doing laboratory experiments (in collaboration with the Lamont-Doherty Geological Observatory) with living foraminifera that separate the effects on shell morphology of physical factors such as temperature, salinity, and light from biological factors such as symbiosis and gametogenesis (figure 2).

Ciliate protozoans are fed upon in preference to phytoplankters of similar size by certain copepods, jellyfish, and ctenophores, and this selective consumption by such macrozooplankters is important in controlling ciliate numbers. Not all ciliates are equally susceptible to predation; naked ciliates (oligotrichs) are more consumed than the loricate forms (tintinnids). Certain naked ciliates sequester chloroplasts from the unicellular algae that they eat and appear to use these photosynthetically. These "green ciliates" can make up as much as 90% of the coastal ciliate fauna and may be important not only as grazers but as primary producers as well.

Macrozooplankton and Fish Studies

Using hydrographic and midwater fish data collected during the Warm-Core Rings Program we proposed a mechanism (in collaboration with a University of Miami scientist) that explains the concentration of organisms at ocean fronts, generally places of convergence. Plants and animals are moved horizontally by converging parcels of water, but most animals and some plants resist vertical displacement, such as by the downwelling water at the front. The result is the accumulation of living things.

Zooplankton populations in warm-core Gulf Stream rings and on Georges Bank have been studied by numerical modelling and the analysis of data collected at sea. Studies of temporal changes in ring 82-B suggest that warm-core rings are quasi-enclosed systems. Studies of meso-scale distributions and seasonal cycles of the dominant zooplankton species on Georges Bank suggest that zooplankton production in temperate seas peaks in autumn, not in spring as generally thought. Species having demersal eggs or other associations with the bottom have greatly reduced population losses that otherwise would come about by advection and diffusion off the bank. Other modelling shows that small-scale patchiness (1-100 m) of planktonic prey greatly increases predator growth rate and that small annual variations in the growth of pre-recruit fish can lead to large variations in recruitment to a fishery.

The rapidly changing conditions encountered as one proceeds from the center of a warm-core Gulf Stream ring to the Slope Water outside the ring makes the ring a good place to study diel vertical migration and other patterns of abundance in zooplankters. We have been evaluating the relative importance of extrinsic factors such as temperature, salinity, light, food, and predators as well as intrinsic factors such as physiological condition, stage of life history, and endogenous rhythms.

Studies in the Hawaiian Islands of recruitment in shore fishes (most of which have planktonic eggs and larvae) shows that most such fishes spawn at seasons when mesoscale eddies are present near the islands. Hatching and development proceed "at sea" in such an eddy, which ultimately returns the juvenile fish to its island to take up shore life. It is probable that adaptation of spawning period to ocean current pattern goes far to explain the biogeography of island fish species.

Benthic Studies

Knowledge of the community structure of the deep-sea benthos is based on amazingly few samples and is correspondingly imperfect. Recently we have taken hundreds of quantitative box-cores along the continental slope of the eastern United States for studying the effects on community structure of depth, sediment, topography, and hydrodynamic regime.

The benthos at hydrothermal vents has a low diversity compared to that at deep-sea sites in comparable depths away from the vents. This seems to fit well with the idea that the vents are ephemeral habitats of low predictability. The interaction between the benthos on the one hand and microbial activity and the flux of reduced compounds out of vents on the other was studied in the Guaymas Basin.

What are the origins of the benthic fauna of those isolated central Pacific islands that were formed by the discharge of volcanoes on the sea-floor? Examination of 210 plankton samples collected by the Scripps Institution of Oceanography between 40°N and S and 140°E and W suggests that successful immigrants are those animals having teleplanic larvae – larvae that can drift in the plankton for months until a bottom shallow enough for settling on is reached. The relationship between teleplanic larvae, the geographic distribution of bottom-living adults, and ocean currents is being further examined.

Animal Behavior and Physiology

We continued to study the fragile "jelly animals" – salps, ctenophores, medusae, and siphonophores (figure 3). Because of the difficulty of collecting and maintaining healthy animals, much study must be done in the water with the animals or in ship-board aquaria. Thus, some dives were made in the submersible *Deep Rover,* evaluating it for midwater biological research.

The first measurements of daily ration and assimilation efficiency in five species of oceanic salps were made; assimilation rates were high and capable of supporting rapid growth and reproduction. Symbiotic relationships are common in the jelly animals. Behavior experiments with hyperiid amphipods show that they are attracted by the chemical signals of their hosts. SCUBA divers on an Arctic cruise gathered data on several species of ctenophores not reported since early in the 19th century.

The pelagic molluscs called pteropods are often found in sediment traps and are of interest because of the part their shells play in the ocean's carbonate system. Experiments with pteropods and sediment traps showed that caution must be exercised in interpreting pteropod catch rates – the living animals appear to be particularly susceptible to capture by the traps.

Study of the social functions of dolphin sounds has been hindered greatly because of the inability to identify which dolphin produces a sound. We have developed a telemetry device that solves this problem and with it shown that each individual has a distinctive whistle. When a group of animals are interacting, mimicry of one individual's signature whistle by another is common, suggesting that they may be calling each other by name.

Sperm whales (figure 4) click in short, stereotyped sequences called "codas". There are both individual and group codas. We heard the same group codas from two groups in the Mediterranean Sea that were 200 miles apart – codas that were very different from those used by groups elsewhere in the Atlantic.

A review of more than 25 years of observing large whale behavior in Cape Cod waters suggests changes in the response of these animals to boats, presumably a change related to the great proliferation of whale-watching cruises in recent years. Each species observed seems to have changed its behavior in a different way.

Biochemistry

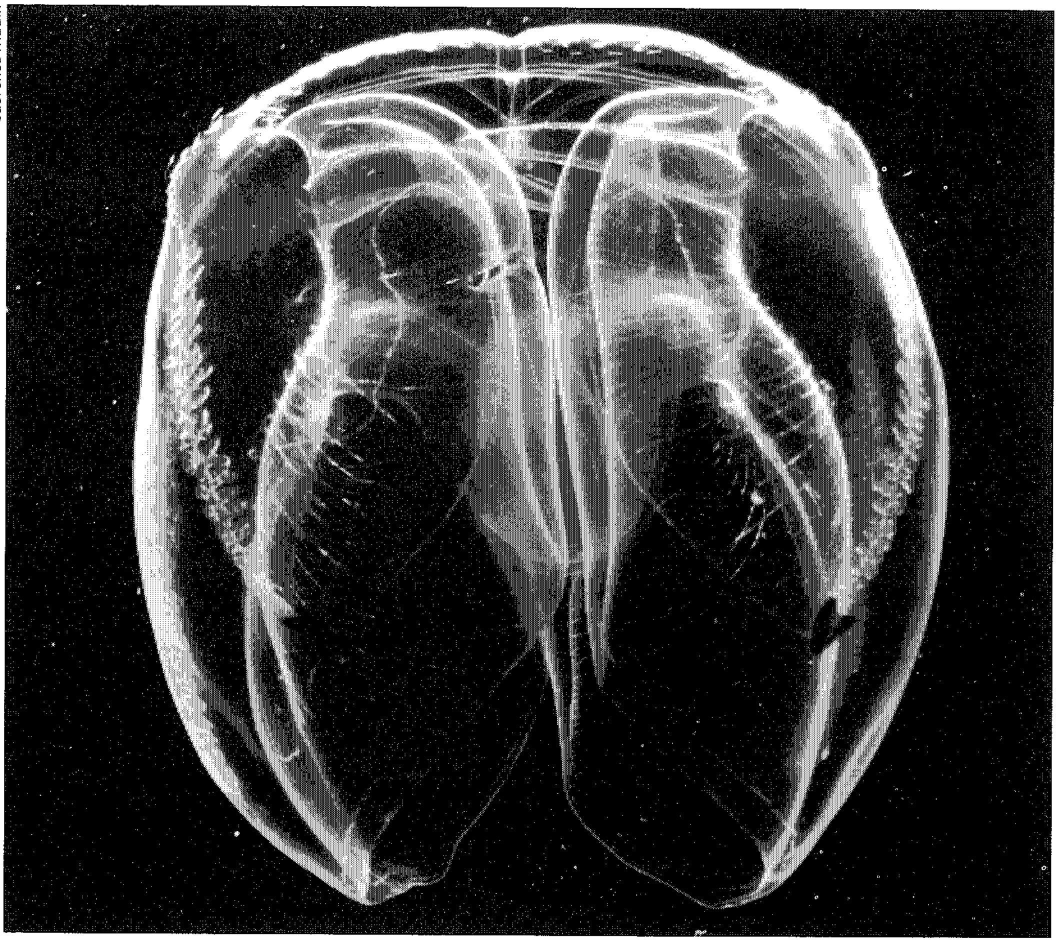
In collaboration with the Chemistry Department we studied the accumulation and biological effects of polychlorinated biphenyls (PCBs) in *Mytilus edulis,* the mussel. We wish to know if PCB uptake and accumulation has deleterious effects on metabolism, development, and reproduction and what the seasonal variability is in the biochemical parameters that influence individual PCB partitioning.

We continued to study the biochemical mechanisms of adaptation in marine animals to changes in the chemical environment. These studies centered on the enzymes called cytochromes P-450, which initiate the metabolism of chemicals – not only natural products but also carcinogens and other pollutants. The function and regulation of these enzymes are being studied with various probes, including monoclonal antibodies. We are interested not only in the evolutionary aspects of the occurrence of these enzymes in marine animals, but also in what they can tell us about man's impact on the ocean.

Biogeochemistry and Physiological Ecology

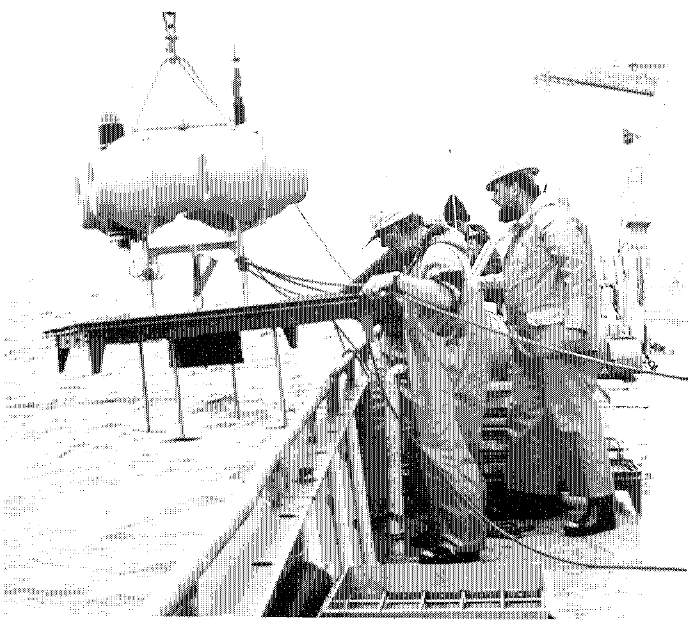
Dimethylsulfide (DMS) makes up 9/10ths of non-sulfate sulfur passing from the oceans to the atmosphere. How is DMS distributed in coastal and marine environments and how is it produced? A new mechanism of pelagic production was discovered: consumption of certain algae by zooplankton results in the release of DMS to the water. DMS also proves to be a major component of sulfur flux from salt marshes to the atmosphere. Subsurface flow is

Laurence Madin

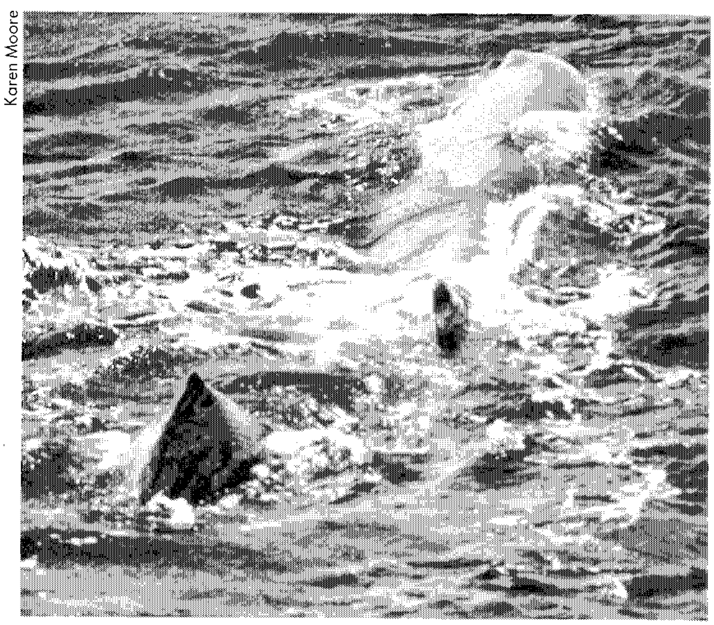


Left: Female of the ctenophore *Ocyropsis crystallina guttata*, the only ctenophore in which the sexes are separate. *Ocyropsis* spawns for a short time each evening during the course of its reproductive season (Figure 3). Bottom left: Deployment of the Free Vehicle Sediment tray, for deep-sea studies of the recolonization of benthic organisms, from OCEANUS. Bottom right: Sperm whale cow and calf (Figure 4).

Rosemarie Petrecca



Karen Moore

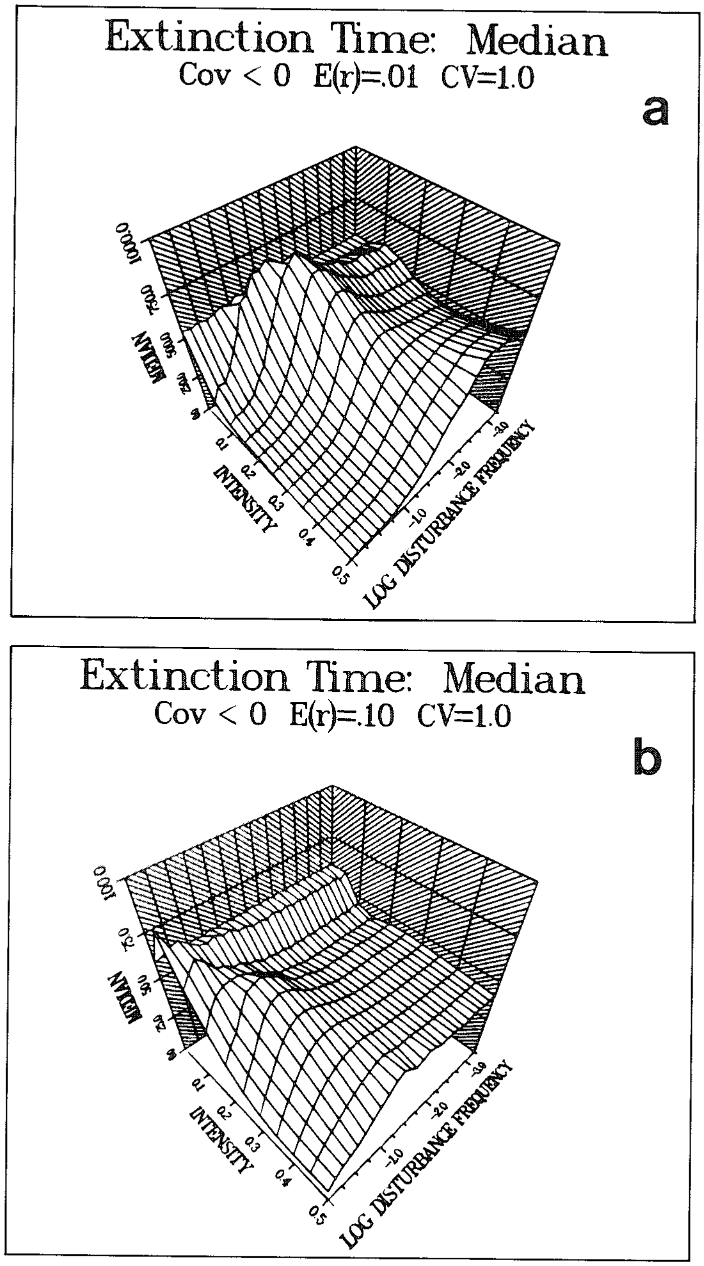


critical to all below-ground processes in saltmarshes. The flow, which is dominated by uptake by plants, also is greatly affected as the marsh sediments expand and compact with tidal flow and ebb. We extended our work in the experimental ecology of wetlands by setting up fertilized plots in a *Phragmites* marsh.

In collaboration with the Department of Ocean Engineering we have undertaken the development of an in situ chemical analyzer. This instrument will perform 120 measurements per hour of each of six chemical species and will give unprecedented resolution in the chemical mapping and profiling of dynamic hydrographic structures or, alternatively, long time series at single stations.

Population Ecology

Research in 1985 focused on demographic analysis of complex life cycles and on natural and man-induced effects on community structure. We considered two-sex population models in which nonlinearities arise from the dependence of reproduction on sex ratio, the probability of interaction between hosts and predators or parasites with stage-specific attack preferences, and the effects of disturbance on the rate of extinction in competitive systems (figure 5). We also examined the effects of toxic substances at the population level using demographic models and compared the sensitivity of deep-sea and shelf communities to disturbances due to ocean dumping.

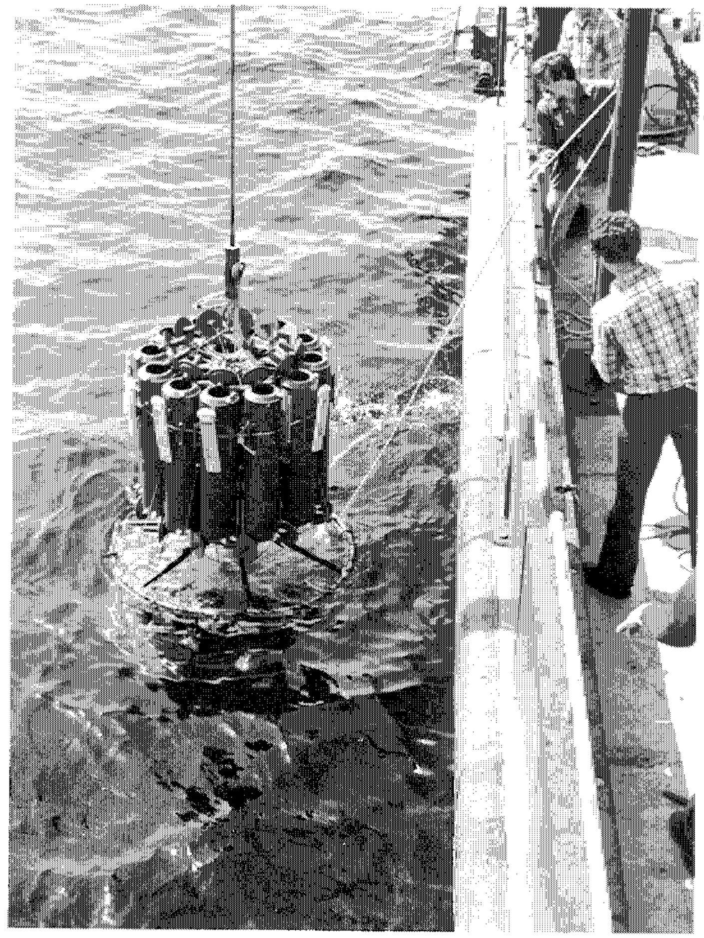


Top: The response of abiotic disturbance of two communities structured by interspecific competition but with different intrinsic rates of increase. The low rate of increase (a) describes the deep-sea case, the high rate (b) the shallow-water response. The effects of disturbance are seen at lower frequencies and intensities in the deep sea than in shallow water (Figure 5).

Chemistry Department

Robert B. Gagosian, Chairman

The central goal of chemical oceanography is to describe and explain the ocean as a chemical system. An important emphasis is placed on understanding the stability of the marine environment with respect to changes that might be brought about by natural phenomena or by human activities. The composition of seawater and ocean sediments results from a variety of complex, interacting processes operating both within the ocean and at its boundaries. These processes operate over a vary wide range of space and time scales, from centimeters and seconds to kilometers and thousands of years. Many processes are important in controlling ocean chemistry, such as evaporation and precipitation; the growth, sinking, and decomposition of marine organisms; sediment/water exchange; seawater/hot rock interactions; riverine and atmospheric material inputs to the ocean surface; and the stirring and mixing of the ocean by winds and the rotation of the earth. The application of recent advances in analytical instrumentation and chemical techniques to questions being addressed of the marine environment is leading to rapid progress on a number of fronts. Two major areas of department research in 1985 focused on chemical fluxes in the ocean and surface ocean chemical processes mediated by light.



Peter H. Wiebe

Launch of a CTD (conductivity/temperature/depth) profiler. The water sampling device is one of a suite of instruments used to study ocean chemistry.

Chemical Fluxes in the Ocean

Due to the important role of the biogeochemical cycles of the elements carbon, nitrogen, phosphorus, sulfur and oxygen in controlling the global environment, a concerted effort by several investigators has begun in order to better understand the flux of these materials through the ocean and across the sea/air and sediment/water interfaces. One of the main goals of these investigators is to understand the processes controlling the distribution and sedimentation of particulate material as it is transported vertically and horizontally through the water column to the surface sediments.

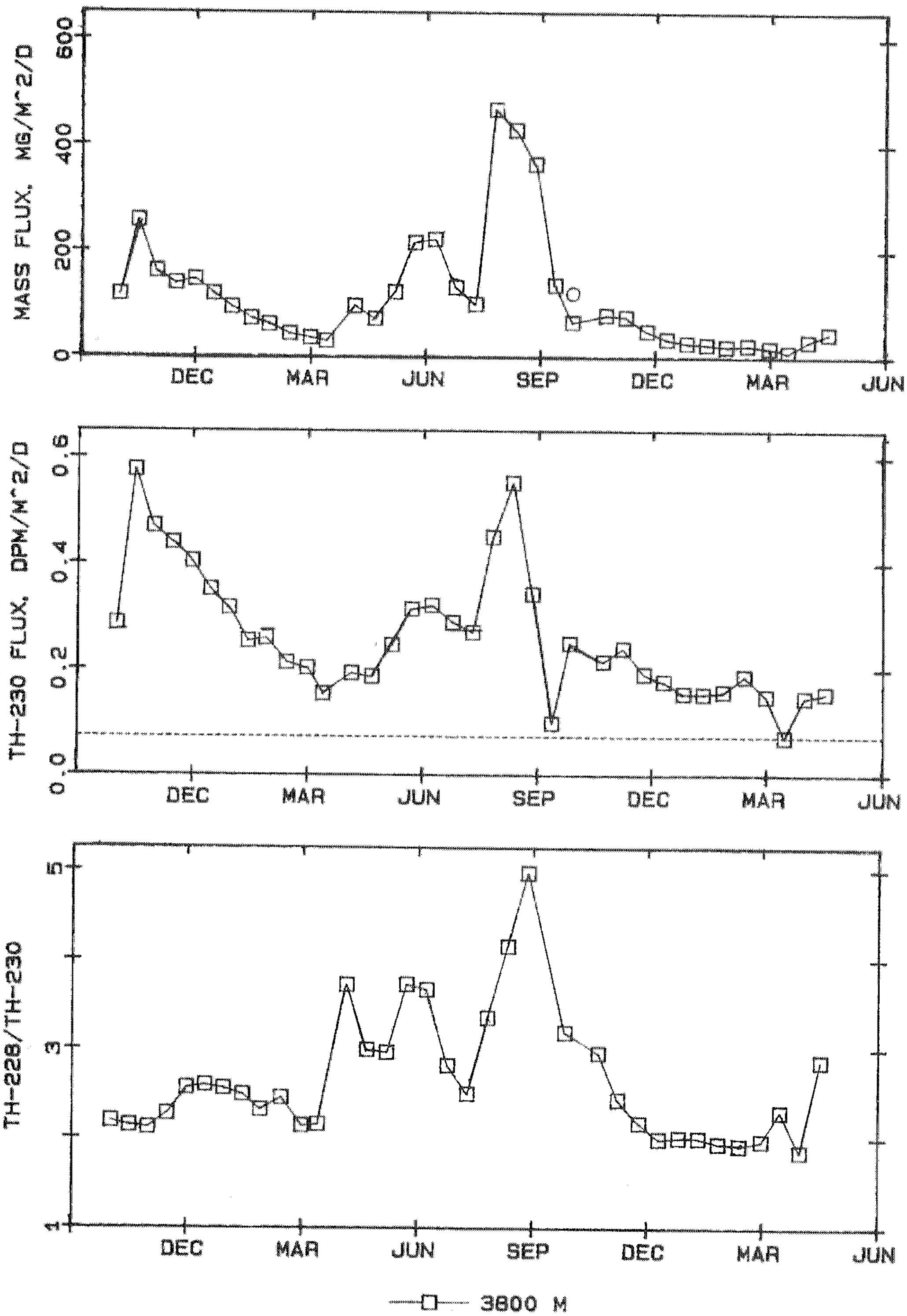
A number of natural and anthropogenic substances have been added to the ocean on a global scale and form the basis for large-scale "tracer experiments" that prove to be powerful tools in understanding these oceanic processes. For example, the natural series radioactive elements have been used by Michael Bacon and Peter Brewer to learn more about these processes. Several of the daughter radionuclides that are formed within the natural radioactive decay series, such as isotopes of lead, polonium, thorium, and protactinium, are strongly controlled in their oceanic concentrations and distributions by chemical scavenging. These daughter radionuclides are generated within the ocean by the radioactive decay of their parent radionuclides, which are dissolved in seawater. From Bacon and Brewer's studies, our knowledge of the transport of the daughter radionuclides through the ocean has been greatly enhanced. This is essentially a large-scale natural tracer experiment in which elements of interest are continually introduced to the system under study at exactly known rates.

One of the key aspects of their research has been to examine how the radionuclides are partitioned between the dissolved and particulate state. Because of radioactive decay, they are able to deduce the rate at which the radionuclides are adsorbed from solution by the particle surfaces or desorbed back into solution. A most important aspect of this research has been the capability of estimating the sinking rate of particulate matter. Using thorium isotope distributions, they were able to conclude that a thorium atom in the deep ocean generally remains in solution for approximately two years before it is taken up on the surface of one of the suspended particles. It resides there for about six months before it is released back into solution. During its residence on the particle, the thorium atom is transported vertically downward about one hundred meters. This cycle is repeated several times until the atom reaches the surface sediment where it is finally buried. This research has given us insight into chemical scavenging as a dynamic exchange process.

Bacon and Brewer's research has also interfaced in an exciting way with Institution colleagues Werner Deuser and Susumu Honjo. Deuser and Honjo have observed that the flux of particulate material reaching the deep ocean undergoes large seasonal fluctuations related to the seasonally varying productivity of the overlying surface waters. Bacon and Brewer's measurements of the radionuclide fluxes of this material show corresponding fluctuations in the rate of chemical scavenging in the deep ocean. Deuser's approach has been to use planktonic foraminifera, a group of single-celled organisms inhabiting the surface ocean, as a particulate matter flux "tracer." These organisms build a temperature record of their environment into their skeletons: the ratio of the isotopes of oxygen depends on the temperature at which the skeletons were synthesized. Their skeletons constantly rain down to the sea floor at an average rate of 100 per square meter per day, thus carrying with them a record of their lifetime ambient temperature which may then be preserved in the sediment for millions of years. Using traps moored at various depths in the water column, Deuser has intercepted many skeletons along with a great deal of other debris which settles through the water column. By measuring their oxygen isotope ratios, he has used these tiny particles as recorders in the samples of the temperature prevailing at the time the collected material left the sea surface. Moreover, by comparing the variations in their isotopic temperature record with the variations of sea surface temperatures, he has detected a delay of about one month between the temperature extremes at the surface and the arrival of their records in particle traps set at 3200 meters (approximately 10,000 feet). This delay is a good measure of the time spent by the particles in sinking from the surface to this depth. This opens up the exciting possibility of using the seasonally-pulsed rain of particles as a probe for examining the dynamics of chemical and biological processes in the ocean.

In addition to the inorganic components of seawater particulate material, several studies are currently being undertaken at WHOI to better understand the origin, flux and transformation of the organic components of seawater. The approach of Dan Repeta, John Farrington and Robert Gagosian has been to use biological source markers to delineate the processes of interest. This approach takes advantage of the unique molecular signatures of marine, terrestrial, and anthropogenic origin of various organic compound classes. Individual compounds within the various compound classes allow for the differentiation between natural continental (eg., soil or various plants), anthropogenic (eg., fossil fuel processes), and marine (eg., phytoplankton, zooplankton or bacterial) sources. By using the lipid class compounds fatty acids, hydrocarbons, fatty alcohols and steroids, these investigators have been able to ascertain that terrestrial-derived organic material appears to be more stable to transformation reactions in the water column and sediments relative to marine-derived organic material. This suggests the exciting possibility that the geographic distribution of certain biological source markers found in sediments may be a record of atmospheric and sea surface conditions at the time the material either entered or was produced in the surface ocean. In order to verify this hypothesis, the WHOI investigators have undertaken a number of studies to ascertain the mechanisms and rates of decomposition reactions as organic material is transported through the water column.

Drs. Repeta and Gagosian have also used the pigments found in phytoplankton (carotenoids) as indicators of processes affecting relatively reactive organic material after it is biologically produced. They have observed that there is a large difference between the distributions of pigments found for small and large particles at depth. This suggests that the break-up of large particles produced in the upper water column is not a significant process in the deep sea, as this material is in transit through the water column to the sediment surface. By using state of the art analytical chemical isolation and structure proof techniques, such as high pressure liquid chromatography, mass spectrometry and C-13 nuclear magnetic resonance spectroscopy, the WHOI chemists have been able to determine the reaction products and the biological processes responsible for their production. Most of these phytoplankton pigments are transformed in the guts of zooplankton in the water column; however, at the sediment surface, microbiological reactions are dominant.



Chemical Fluxes: Computer-generated graphs show strong seasonality in (A) mass flux,(B) thorium-230 flux, and (C) thorium-228/230 ratio at ocean Station P during 1982-1984. The data were obtained with a sediment trap deployed at a depth of 3800 meters by WHOI Geologist Susumu Honjo. Thorium-230 is generated throughout the water column by decay of its radioactive parent nuclide uranium-234. The observed seasonality in its flux is an indication the rate of chemical processes in the deep sea can be influenced by the variations in the flux of material leaving the sea surface. In contrast to thorium-230, the isotope thorium-228 is generated mainly in the upper ocean. The variations in isotope ratio indicate the particle flux arriving at 3800 meters depth contains varying proportions of material originating at the surface and at depth in the water column.

Surface Ocean Chemical Processes Mediated by Light

The second major area of research in the department which has recently been enhanced is concerned with chemical processes in the upper ocean mediated by light. Only recently have we begun to understand the dynamic chemical nature of the surface ocean. Thanks to the efforts of WHOI chemists Oliver Zafiriou and Neil Blough, ascertaining the chemical species responsible for these changes and determining the mechanisms and rates of their transformations is becoming much clearer. Some of the most important questions and points that have emerged from their studies concerning the processes that are initiated by the absorption of light by molecules in the surface ocean are: What are the light absorbing molecules in a given water mass? What are their sources? What are the products of their photolysis; how do these interact further with the natural system? What is the efficiency of a given process? How is the balance maintained between the production of light-sensitive compounds and their photochemical destruction?

Zafiriou's studies have focused on the inorganic photochemistry of marine systems, particularly of nitrate and nitrite. These two photochemically reactive species are very important as biologically available forms of fixed nitrogen. The WHOI chemist has found that nitrate is extremely stable to sunlight in seawater, while nitrite is lost at surface-light intensities at rates varying from 2 to 25 percent per day. This wide variation is due to poorly understood effects from other trace components in seawater such as transition metals and organic compounds.

More recent work has broken completely new ground in this area. It is known that many photochemical reactions produce free radicals, highly reactive molecules that go on to react further. For example, the photolysis of nitrite produces hydroxyl radical, a key species responsible for mediating many atmospheric reactions. In many cases, formation of free radicals may be far more significant than the disappearance of the molecules that formed them. At WHOI, a free radical (nitric oxide) was detected for the first time directly in surface seawater being exposed to sunlight. This technically difficult observation is direct evidence for the presence of a radical in a natural water system and confirms the hypothesis that such species are formed by sunlight. The radical concentration slowly rises after sunrise. Even though the radical is being formed rapidly, its concentration is low in seawater because it also reacts rapidly. One half of it is gone within about 100 seconds of its formation. Other more reactive radicals disappear much faster. For example, the hydroxyl radical which lasts about one second in the atmosphere reacts in seawater in much less than a microsecond.

Encouraged by this success, the two WHOI chemists are now attempting to develop methods to detect the superoxide radical in natural water systems. They are trying to measure superoxide because it is a key species from both the chemical and biological points of view. Chemically, it forms in the first step in the reaction of dissolved oxygen, the major oxidizing agent in surface waters. Biologically, superoxide is thought to be ubiquitous in aerobic organisms, and to be responsible for cell damage leading to such effects as aging and death. Zafiriou and Blough hypothesize that formation of superoxide radicals is ubiquitous in marine systems, and that most of it comes from photolysis of dissolved organic compounds. They are developing new methods which will have the extreme sensitivity necessary to test this hypothesis and enable them to investigate the concentrations, sources and reactions of this and other important radicals in the surface ocean.

New and exciting initiatives are being pursued on many fronts in the Chemistry Department. The application of many of the technically innovative advances that have been made recently to research problems in the marine environment will present even more challenges to our staff in the future.

David A. Ross, Chairman

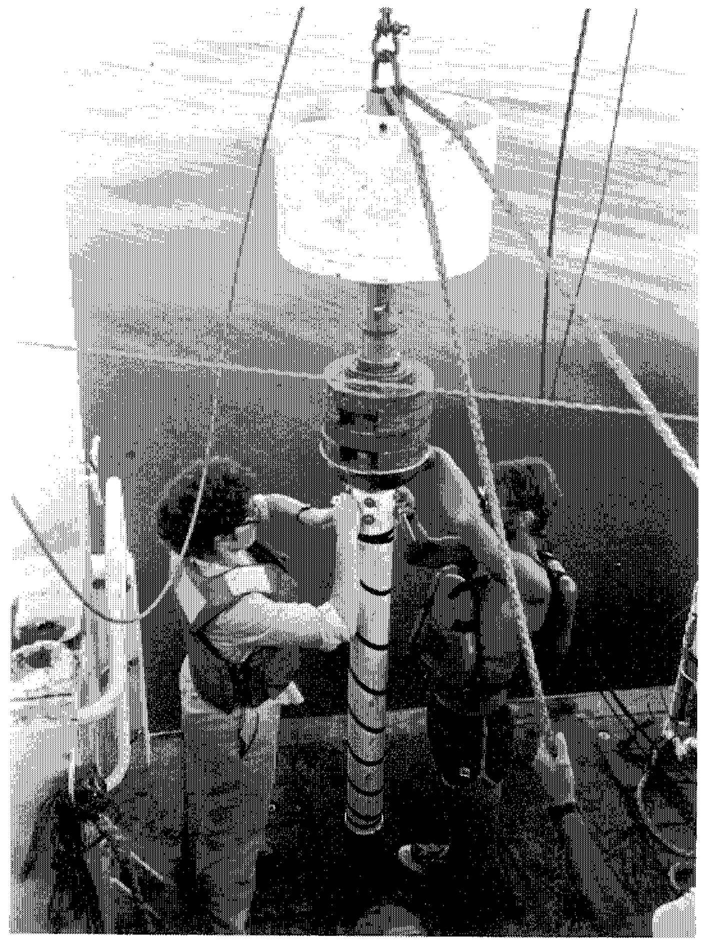
The research arena of the Marine Geology and Geophysics Department ranges from the deepest parts of the ocean basin to the continental margins and their coastal zones. These interests include the polar seas as well as the Atlantic, Pacific, and Indian Oceans. In coming years, we will also have programs in the Mediterranean, Black and Red Seas. Our studies have examined sediment input from rivers, flux of sedimentary material through the water column, sedimentary and volcanic processes on the sea floor, shallow and deep seafloor structure, paleoceanography, geophysical characteristics of the ocean crust, and evolution of the ocean basin itself. Our students play an important role in many of our research programs, as do colleagues in other departments at WHOI and at other institutions. Department scientists have led or participated in cruises aboard many research vessels including JOIDES RESOLUTION and, with ALVIN and other research submersibles, have dived in many areas of the oceans.

Evolution and Structure of Ocean Basins and Margins

One of the key objectives of research in marine geology and geophysics is to understand the evolution and structure of ocean basins and their margins. With the acceptance of plate tectonics as the driving force behind ocean basin formation and migration, marine scientists have delved further into the processes, properties, and composition of the sediments, crust and mantle beneath the oceans. An improved understanding of the fundamental physical and chemical processes governing the development of ocean basins and their bordering margins will help resolve the geological record of the continents.

The kinematic evolution of plate positions bordering the Atlantic Ocean basins has been addressed by Hans Schouten. He has qualitatively identified rifting phases since the early Jurassic breakup of Pangea by reconstructing the initial fit of the plates and their relative motions based on seafloor spreading magnetic anomalies, fracture zones, and other bathymetric markers. In another study, Schouten with Henry Dick, Kim Klitgord (USGS), and Jack Whitehead (Physical Oceanography, WHOI) used a unique combination of geophysics, petrology, and geochemistry of mid-ocean ridges and fluid dynamical laboratory experiments and models to study the upwelling of the earth's mantle under spreading ridges and the resulting magmatism that forms the oceanic crust. An integrated approach such as this can provide new insights into the behavior of shallow and deeper mantle under seafloor spreading centers, the temperature and composition of that mantle, and the segmentation of the global mid-ocean ridge system.

Brian Tucholke has worked with various colleagues to reconstruct the morphology and geologic conditions of the



John Jasper

Large diameter gravity corer is prepared for deployment.

North Atlantic Ocean basin dating from the late Triassic. With Peter Vogt, he has edited a volume on the Western Atlantic in the Geological Society of America's Decade of North American Geology series. As part of this endeavor, he has compiled a synthesis of North Atlantic paleoreconstructions that include plate positions, tectonic patterns, igneous activity, paleocoastlines, paleobathymetry, surface and deep circulation, facies, and DSDP (Deep Sea Drilling Project) drill sites on appropriate time slices. Tucholke also wrote several other chapters of this book which should serve as a standard reference work on the geology and geophysics of the North Atlantic for years to come.

A new Geologic Map of North America will also be published as part of this Decade of North American Geology project, incorporating submarine geology for the first time. For this map, Tucholke and Laurie Raymond, with the help of other scientists, have compiled: age and type of outcrop, major faults, volcanic centers, significant manganese and phosphorite and hydrothermal deposits, evaporites, and axes of submarine channels and canyons. Additionally, Tucholke and Virginia Fry have integrated seismic reflection profiles with other data to produce maps of structure contours on basement for the northwest Atlantic, presenting the principal basement features within the context of the plate-tectonic evolution of the region. Tucholke, with others, has also made an evaluation of the resource potential of the western North Atlantic.

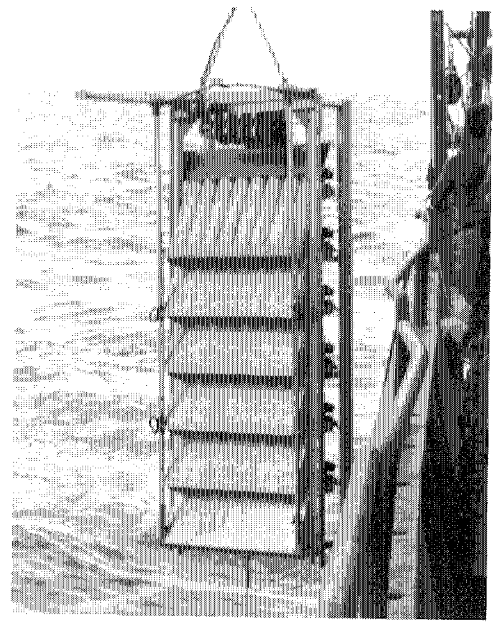
Debbie Smith has been studying the distribution and abundance of seamounts in the Pacific Ocean using quantitative statistical techniques. In this effort, she has collected a large set of data in the eastern and southern Pacific from Sea Beam swaths, wide-beam profiler records, and bathymetric maps. Smith intends to incorporate derived models into broader-based models describing large scale earth processes.

Elazar Uchupi and David Ross have completed a study of the geologic evolution of the northern Red Sea, a relatively new region of sea floor which is still undergoing tension. Ross and Uchupi with Bob White (Cambridge University) have been studying the Persian Gulf, an area dominated by continental collision tectonics, and the Gulf of Oman, a region of subduction tectonics. These marginal seas portray, on a small-scale, processes not unlike those which shape the great ocean basins. Uchupi has also been involved in the compilation of a photographic atlas of the morphological volcanic features of mid-ocean ridges. The photos in this atlas will be holotypes in mapping mid-ocean ridges using ARGO/JASON technology.

The joint WHOI-Academica Sinica (People's Republic of China) study of the oceanography and geology of the Yellow Sea has entailed three geophysical cruises in the region. Analysis of the data by John Milliman shows a complex system of buried channels that are interpreted as the remnants of river channels cut during the last low stand of sea level. In his work, Milliman has observed that recent sediment comes primarily from the modern Yellow River, the second largest in the world in terms of sediment discharge. Erosion and transportation of sediment occurs for the most part in winter storms, while the rest of the year sees strong tidal action eroding nearshore sediments.

Seismic Studies

Seismic methods are perhaps the most powerful tools available to the marine geophysicist for the investigation of the internal structure of the oceanic lithosphere. Mike Purdy has been working on the design and construction of a near-bottom towed explosive source which, in conjunction with an in situ digitally recording ocean bottom hydrophone, can carry out seismic experiments on the ocean floor instead of two miles or more above it. This technology will



David DuBois

The Deep Towed Explosive Seismic Source (DETES) makes high resolution measurements of deep ocean crustal structure. The source is towed within 100m of the ocean floor and is capable of firing up to 48 individual explosive charges on command from the research vessel. DETES was successfully used for ocean bottom refraction experiments on the Mid-Atlantic Ridge in the summer of 1985.

Altimeter data in the South Atlantic from SEASAT's descending tracks. Seamounts, fracture zones and mid-ocean ridges all form characteristic signatures in the data. Tracks end near Antarctica when sea ice interferes with the altimeter measurements.

facilitate a more precise and detailed view of the shallow crustal structure than ever before possible. Another system that he is developing comprises a hydrophone array towed 6-10 km astern of a research vessel. The broad coverage and mapping capability enabled by this tool, the Surface Towed Radio Telemetering Array (STRATA), complement high precision instruments. These two new techniques were used successfully for the first time during the summer of 1985 on the flanks of the Mid-Atlantic Ridge near latitude 23°N; the results from this new technology should aid in an eventual understanding of the physical and chemical processes that shape the outermost shell of the earth.

Purdy's research efforts in understanding how oceanic lithosphere is created focus on the monitoring of earthquake activity on mid-ocean ridges and their associated fracture zones. Arrays of fixed ocean bottom monitoring instruments yield data that defines not only the location but also the type of tectonic activity and faulting. These are the only direct observations applicable to the mechanical and thermal processes that have created two-thirds of our planet's surface.

John Ewing's research aims toward developing seismic methods for high resolution of surficial and internal structure of the ocean floor in both deep and shallow water to quantitatively relate geological and physical properties of the seabed in order to extract more information from seismic data about geology and geologic processes. His goal is twofold -- to make seismology a better sensor of subsurface geology and to determine the effect of the seabed on sound propagation.

Ralph Stephen has continued his innovative work in borehole seismology (offset vertical seismic profiling) in seafloor holes from the GLOMAR CHALLENGER and JOIDES RESOLUTION. Among Stephen's objectives are the study of seismic anisotropy and the development of synthetic seismograms with an eye toward predicting sound propagation in seafloor and continental margin environments.

A two-ship multi-channel seismic study of lithospheric flexure across seamounts, in which Tom Brocher participated, has generated results suggesting that the thickened crust beneath the Hawaiian-Emperor Seamount Chain is a deep crustal sill complex associated with the tholeitic stage of volcano building along the chain, rather than the assumed model of a surface volcanic load flexing an elastic plate.

Peter Shaw is studying the structure of the crust and uppermost mantle by applying methods of inverse theory to marine seismic refraction data. He is also working on the satellite altimeter data obtained by the SEASAT satellite which measures the shape of the sea surface, mirroring tectonic features on the seafloor. Fracture zones, seamounts, and mid-ocean ridges appear in the data, owing to the way these features perturb the gravity field. The SEASAT and GEDS satellites have provided better coverage of remote oceans than existing ship tracks which are sparse in some regions. Shaw currently is refining the relative spreading history of the South American and African plates by studying fossil fracture zone trajectories.

Remote Sensing of the Earth

A remotely sensed view of the earth is also the objective of other scientists in the department. Jim Heirtzler was involved in the recently published three-map atlas "Relief of the Surface of the Earth" -- an attractive and useful display of a global digital database of bathymetric and elevation data. The project was a cooperative effort by the U.S. Navy, Defense Mapping Agency, National Aeronautics and Space Administration (NASA), U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA). The International Oceanographic Commission is planning that its future GEBCO (General Bathymetric Chart of the Oceans) maps be done in a similar way. Heirtzler is also actively involved in the development of a magnetic field satellite called a Magnetic Field Explorer which will measure the geomagnetic field and its secular variation. The French are developing a similar satellite as part of these plans, and both national and international meetings have been held in this endeavor.

Gravity and Heat Flow Measurements

Carl Bowin and his research group utilize gravity anomalies for the study of tectonics and structure of the Earth and planetary bodies. These studies have helped elucidate the causes of observed anomalies, and the simultaneous utilization of gravity and geoid data has improved the resolution of mass anomalies. Comparison of the gravity anomalies of Venus with those for Earth have helped substantiate the core-mantle boundary mass anomalies identified for the earth.

Dick von Herzen is utilizing thermistor sensors on bottom-penetrating probes and piston cores to conduct heat flow surveys in ocean floor sediment, defining heat flow, age, and paleogeography/paleogeology of the western Mediterranian. New instrumentation developed at WHOI facilitated simultaneous drilling and temperature recording for the first time in a DSDP hole on Leg 86 in the Pacific off Japan, alleviating the shipboard scientists of the time-consuming task of alternating the drilling operations with temperature recording. Von Herzen has also compared thermal conductivity in sediments to other physical and chemical properties and developed a thermal origin model for the broad topographic swell that is the Bermuda Rise.

U.S. Coast and Geodetic Survey

Nauset Inlet, Cape Cod (MA), illustrates the complexities of nearshore geology. Extensive flood tide deltas, ebb tide deltas, rhythmic crescent bars and overwash deposits reflect the myriad processes continuously modifying our barrier beaches.

Petrology

The evolution of oceanic crust at spreading centers and fracture zones is also deduced from petrologic studies of basement volcanic rocks. William Bryan is examining the geochemistry and crystallization processes of basalts found at mid-ocean ridge spreading centers for clues to the processes associated with the separation of molten rock from deeper levels in the lithosphere or upper mantle and their subsequent upward migration and eruption on the seafloor. In particular, Bryan has compared the geochemistry of Mid-Atlantic Ridge basalts and North American and African margin basalts to identify the processes of magma genesis producing volcanic basement between these formerly adjacent continental blocks. Bryan is collaborating with Henry Dick in understanding deep melting processes and variations in deep mantle compositions along the ocean ridge system.

Peter Meyer has been studying mineralogical and chemical variations in plutonic rocks from eroded volcanic centers on oceanic islands, rift mountains associated with spreading centers, fracture zones, and continental layered intrusions to understand the size, duration, and dynamics of magma chambers in different tectonic environments. Bryan and Meyer have been involved in studying petrologic and geochemical volcanic systems in Iceland and Hawaii which are readily accessible on-land analogs to the eruptive activity at oceanic spreading centers.

Coastal Processes and Sea Level Change

David Aubrey has focused his recent work on three primary topics: estuarine processes, sea-level change and neo-tectonism, and beach processes. By combining numerical modelling with field observation, Aubrey and his colleagues from Dartmouth College and Nanjing University in China are focusing their research on the geological development and evolution of estuaries. This work has improved the understanding of estuarine circulation and sedimentation. With K.O. Emery, Aubrey has been analyzing tide-gauge records over different regions of the globe to separate the various contributions to relative sea-level change. They have found that tectonic and isostatic influences dominate over pure oceanic influences at low frequencies, suggesting that definition of a eustatic sea-level rise is difficult, if not impossible. This tide-gauge analysis clarifies aspects of neo-tectonism, isostatic adjustment, global climate research, and ocean circulation processes. Finally, Aubrey is employing improved numerical and statistical models of nearshore coastal processes to quantify shoreline evolution on time scales of interest to geologists and engineers alike.

These three areas of research have common threads, as sea level affects estuarine processes and shoreline evolution, while estuarine processes and shoreline evolution are intimately tied together. Much of this study is slated to be tested in work in progress in China, along a shoreline with minimal human activities and excellent datable materials.

Sedimentary Processes

Present-day sedimentation processes have been the focus of Kozo Takahashi's work. He has conducted seasonal flux studies of three major types of siliceous sinking particles in the subarctic Pacific and has drawn important inferences about size, number, and sinking speed of particles and has found correlations among samples related to depth, season, and preservation in surface sediments. Ian McCave has likewise addressed sediment particle size distribution and has, with others, evaluated a laser diffraction size analyzer for its effectiveness in inferring the size distribution of suspended particles. Charles Hollister, a leader in the HEBBLE project, has also deployed sediment traps to sample vertical fluxes of particulate matter on the continental slope and rise of the western North Atlantic.

One important result of the study of sediment flux has been the discovery that the material within deeper water layers is strongly related to surface productivity. This provides an excellent opportunity to establish a method which will estimate present and paleoproductivity, and then model future ocean environments. The PARFLUX Program, in which Susumu Honjo is involved, seeks to measure the variability of ocean flux in time and space with unprecedented precision and geographic span. Mooring experiments during 1985 were conducted in the Greenland Sea, Norwegian Basin, northeastern Pacific, Panama Basin, Black Sea, and Weddell Sea.

Glenn Jones has employed clay minerals to trace deep-sea circulation and to understand the processes of land-to-deep-sea sediment transport. Jones has been using a newly designed automated x-ray diffractometer and interactive data processing facility as well as newly developed methods to measure radiocarbon by accelerator mass spectrometer as an age-dating tool. His research has focused on the Arctic Ocean to understand the long history of Arctic ice cover and northern hemisphere glaciation.

William Curry and David Johnson aim to understand the biological and chemical evolution of the oceans. Their current research includes determining past ocean and atmospheric chemistry from the chemistry of marine microfossils; understanding the mechanism of evolutionary change in oceanic microfossils; and measuring modern and ancient ocean particulate fluxes. Lloyd Keigwin is addressing the reconstruction of past atmospheres and marine environments and, with Curry, has investigated stable isotope records in deep sea sediment as interpretive of the history of climatic and oceanographic change. Keigwin also is examining sedimentation rates from Neogene cores to resolve the details of climate history, especially with respect to duration and intensity of glaciations. This study is bridging the gap between climatology and paleoclimatology because for the first time the deep sea geological record can be linked with historical records.

Geologic Time Scales

William Berggren and Marie-Pierre Aubry have been refining the geologic time scale over the past 65 million years by integrating data from the fields of radiochronology, paleomagnetic stratigraphy, and biostratigraphy. These studies facilitate the derivation of more precise estimates of the ages of the standard subdivisions of the Cenozoic and their relative durations and have been adopted as the standard time scale for the GSA's Decade of North American Geology. Their other research efforts include: studies of Paleogene magneto- and biostratigraphic records of calcareous nannoplankton on the northwestern European margin, revealing unconformities corresponding to a major global eustatic sea level fall in the Eocene; application of benthic foraminifera to deep water petroleum exploration, resulting in the first comprehensive atlas of Cenozoic deep water benthic foraminifera; and a National Geographic Society and Smithsonian Institution sponsored search for a deep water passage between the Mediterranean Sea and Atlantic Ocean during the late Miocene and early Pliocene via geotectonic and stratigraphic studies.

David Lazarus has examined evolutionary patterns of radiolarian fossils and determined that the species *Pterocarium prismatum* broke away from its ancestor *P. charybdeum* quite rapidly between 4.3 and 4.25 million years ago, thereafter the two lineages continuing to diverge gradually from each other for the next half-million years. These findings contest the controversial punctuated equilibrium hypothesis. In other research, Lazarus has been studying siliceous microplankton fossils, the only common microfossils typically found in high latitude deep-sea sediments. A major taxonomic monograph on radiolarians and a data base of Antarctic piston core ages are being compiled to facilitate future studies of the paleoceanography of the polar oceans.

Ocean Engineering Department

Robert C. Spindel, Chairman

The Ocean Engineering Department is best described as a group of independent engineers and scientists seeking creative solutions to challenging problems in the ocean. The Department is divided into laboratories that reflect major research areas and projects.

Coastal Ocean and Fluid Dynamics Laboratory

The Coastal Ocean and Fluid Dynamics Laboratory (CODL)is dedicated to understanding and elucidating the fundamental laws of physics that control the dynamics of the ocean. William Grant and Albert Williams head a theoretical, modelling and measurement program studying aspects of the mean and turbulent flow structure and transport in both the deep sea and coastal ocean. Major focuses of the Laboratory have been the study of boundary layer flows, the interaction between waves and currents in boundary layers and particle transport. In the coastal ocean, wind stress, waves, shoaling and varying bottom types create complex currents and poorly understood transport mechanisms. Acoustic instrumentation to measure near-bottom turbulent flow, waves and currents, has been used in the Coastal Ocean Dynamics Experiment (CODE) to test predictive models. Scientists and engineers in the Laboratory are completing a measurement and analysis program designed to ascertain the effects of deep sea benthic "storms" on sediment transport and redistribution. For this program, called the High Energy Benthic Boundary Layer Experiment (HEBBLE), acoustic and laser instruments were developed to measure small-scale currents near the ocean bottom boundary layer in order to estimate Reynolds stress and flow-sediment interactions. Other instruments are being deployed to measure bubble concentrations, dissipation and turbulent mixing processes in the upper several meters of the water column. An optical instrument has been developed to measure thermohaline diffusion and microstructure near Barbados, and in this same area a video free-fall device made two dozen dives to the ocean bottom to resolve processes responsible for salinity diffusion. Experiments are being conducted in the interdisciplinary area of animal-sediment flow interactions and in estuarine processes. Hans Graber is developing numerical models to forecast global wind-wave conditions in anticipation of storm transport experiments planned for the near future. Other scientists are working on coupled boundary layer-particle transport models and continental shelf wind-driven circulation models.

Deep Submergence Laboratory

This was an exceptional year for the Deep Submergence Laboratory (DSL). In September, DSL made national headlines when, during an engineering test of its new unmanned vehicle, ARGO, the R.M.S. TITANIC was found. Robert Ballard, head of the Laboratory, was the Chief Scientist on the R/V KNORR when the superliner was located. He was also one of four ocean scientists nationwide who was awarded the first Secretary of the Navy Research Chairs. Finding the TITANIC was a vivid and dramatic example of DSL's mission and capabilities. The Laboratory is developing a family of unmanned tethered vehicles designed to enhance deep sea geologic research capabilities. ARGO is a towed system containing three low-light TV cameras, a side-scan sonar and an obstacle avoidance sonar, as well as 35 mm cameras. Under development is another remotely operated vehicle (ROV) called JASON that is designed to operate in conjunction with ARGO to provide close-in inspection and light duty manipulatory functions. These engineering development projects are supported by advanced research programs in imaging and robotics. JASON will be equipped with manipulators and thrusters robotically controlled by a high-level, supervisory control system designed by Dana Yoerger and a team of engineers. The TV and camera systems of both ARGO and JASON have benefitted from research in imagine processing and enhancement techniques conducted by Jules Jaffe. These programs insure that the data collected by the Laboratory's vehicles are optimum.

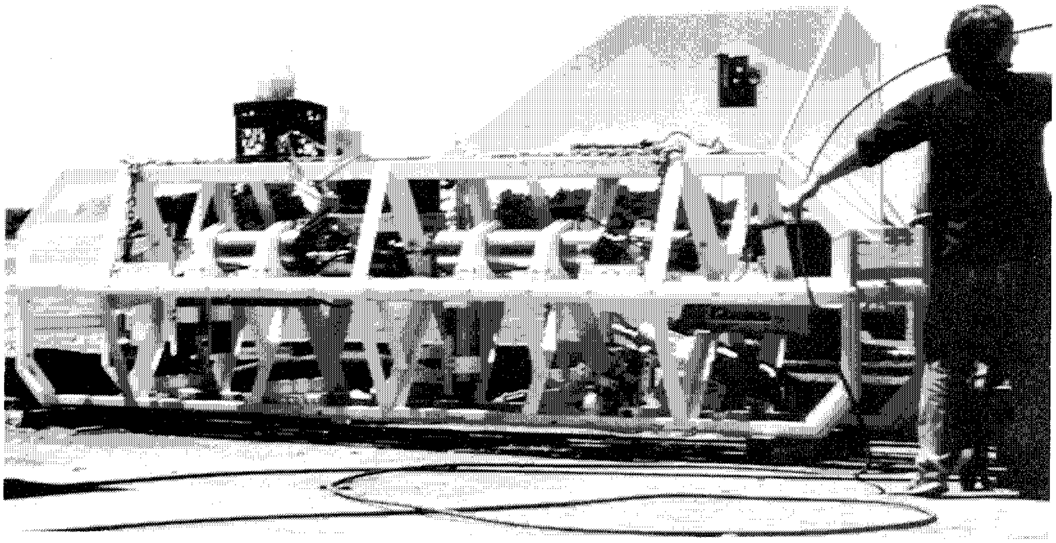
This year, DSL has conducted major seafloor investigations along the East Pacific Rise and the Guaymas Basin, and its engineers have installed imaging and lighting systems on U.S. Navy research submarines DOLPHIN and NR-l. The technological developments in DSL are offering ocean scientists new and unprecedented observational capabilities of the deep sea floor.

Ocean Acoustics Laboratory

Scientists and engineers in the Ocean Acoustics Laboratory (OAL) are conducting research that will lead to a better understanding of the mechanisms of sound transmission in the ocean. Conversely, techniques are being developed to use sound transmissions themselves to measure the physical properties of the ocean and its boundaries. Since sound is the only form of energy that can be transmitted long ranges underwater, it is an exceedingly important tool to the ocean scientist.

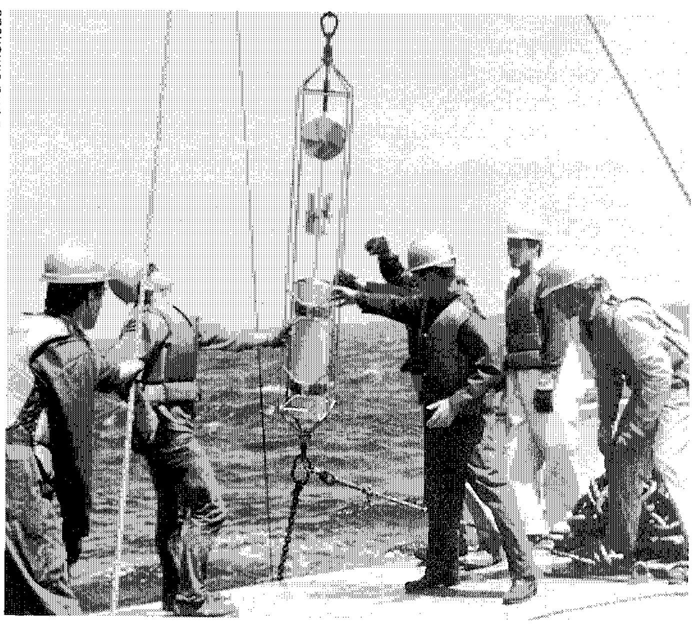
Under the direction of George Frisk, techniques are being developed to measure the physical properties of the ocean bottom using low frequency sound transmissions. An experimental method employing a single frequency moving sound source is coupled with the mathematical formalism of forward iteration and pertubative inverse techniques to determine geoacoustic models of the

William Lange



Left: The ARGO video and sonar vehicle was developed by scientists and engineers in the Deep Submergence Laboratory for deep-sea research. Bottom left: Current meter deployment from R/V WECOMA (Oregon State University) during the CODE program off California. Bottom right: Deep Submergence Vehicle ALVIN, operated by SEL.

David Simoneau



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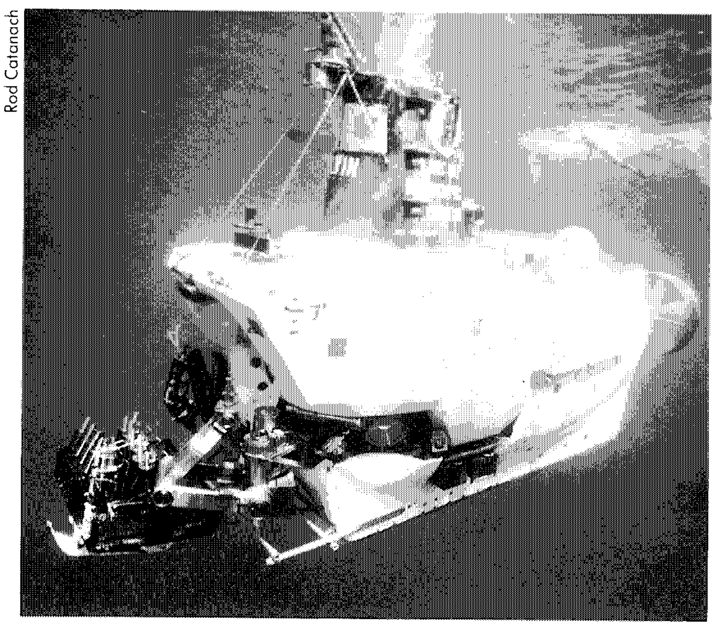
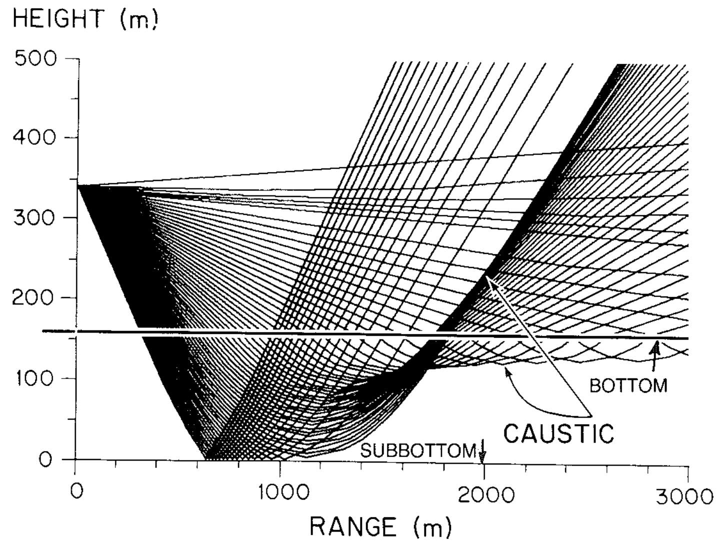
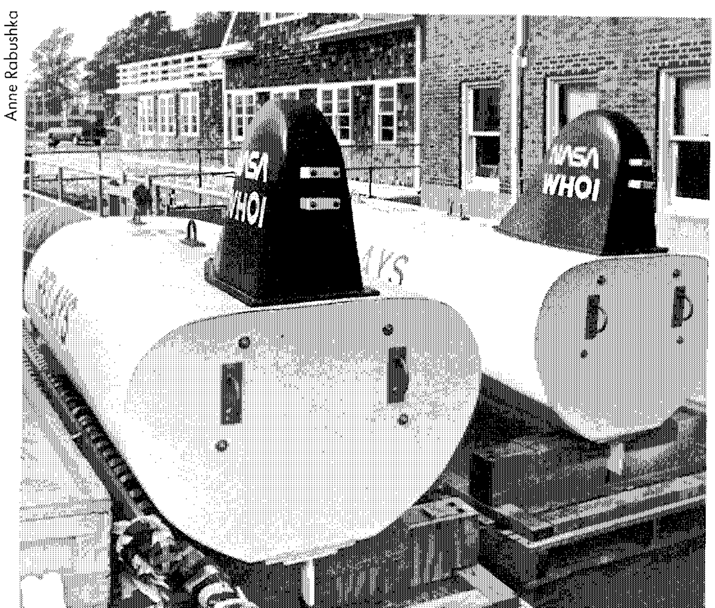




Anne Rabushka



Top: Sound ray propagation through the ocean bottom is studied in OAL. Areas of high sound intensity, known as caustics, are caused by the focusing effect of the bottom. Bottom: RELAYS free-drifting buoys, developed by MSL scientists with NASA funding, on the WHOI pier.

seabed. Frisk has conducted tests in deep water near Bermuda, and during this year with James Lynch, in the shallow waters of the Gulf of Mexico. The information obtained is an essential ingredient in understanding the propagation of sound in shallow water waveguides.

A new measurement tool called Ocean Acoustic Tomography is being developed in programs led by Robert Spindel and John Spiesberger together with a team of engineers and technicians. Ocean tomography, like its medical X-ray analog, creates a three-dimensional image of the ocean interior using remote, non-invasive observations. It promises the ocean scientist synoptic views of entire ocean basins. This year tomographic data collected using reciprocal acoustic transmissions over a 300 km (185 miles) ocean path near Bermuda, and data obtained in a tomography test in the Norwegian Sea, were inverted to obtain horizontal and vertical sound speed, temperature and current structure. A major part of the tomography program is devoted to research and engineering. Wider bandwidth and more powerful sound sources and receivers are required to increase the sensitivity and resolution of tomography. Signal processing algorithms to reduce data storage requirements and enhance system signal-to-noise are crucial. The next step in this project will be the deployment next year of a 1000 km (624 miles) array of tomographic instruments in the mid-Pacific Ocean.

Submersible Engineering Laboratory

The Submersible Engineering Laboratory (SEL) is responsible for the efficient and safe operation of one of the most unique tools and valuable resources in the ocean science community, the manned research submarine ALVIN. In the first eight months of this busy year, this Navy-owned, Woods Hole-operated facility was carried 21,700 miles on its support ship, the R/V ATLANTIS II, and made 162 dives to the seafloor. It carried scientists from universities and institutions across the nation on missions devoted to geology, geophysics, chemistry, biology, physics and engineering. It also carried sampling systems, tools, cameras, data acquisition and logging systems designed by engineers in SEL. ALVIN is presently undergoing major engineering redesign and overhaul to increase efficiency and reliability. Its main stern and side lift propellers are being replaced with six thrusters directly driven by brushless DC motors. Its battery power and hydraulic systems are being altered, and the submarine will be provided with an additional 1000 pound payload capacity. Under the supervision of Barrie Walden, head of SEL, each upgrade and addition is engineered to the highest standards of safety and reliability. When the overhaul is complete in mid-year, ALVIN will be ready for the exciting scientific challenges of the coming years.

Mooring and Structures Laboratory

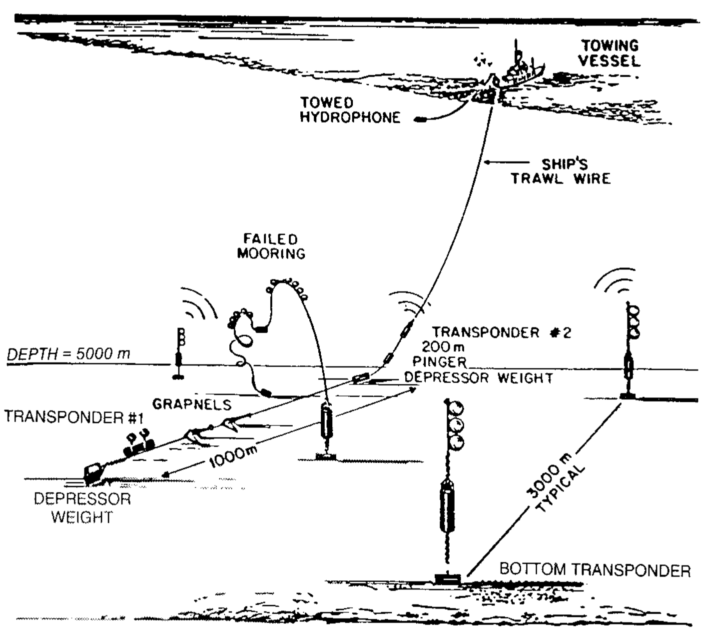
Moored and free-drifting buoys and structures are designed and fabricated in the Mooring and Structures Laboratory (MSL). The Laboratory's objective is to provide the ocean scientist with instrument platforms to meet his measurement needs. MSL designed the deep ocean, subsurface mooring system that serves as the principal tool for long-term, in situ, oceanographic measurements worldwide. Henri Berteaux, head of MSL, conducts an engineering research program to evaluate the performance of new materials for ocean use. Long-term sample testing is done at underwater test sites in the deep sea in order to improve mooring reliability and extend mooring lifetimes. New mooring methods are developed for special applications. The performance of a dual subsurface float mooring is being evaluated for use in high current regimes such as the Gulf Stream. Moorings with pop-up floats for satellite data telemetry to shore are on the drawing boards. This year a free-drifting buoy called RELAYS, with a subsurface umbilical for attachment of current, pressure and acoustic sensors, and a satellite data link to shore, was tested at sea. It is intended to be a forerunner of many such drifting systems that will provide scientists with the data needed in the measurement programs being planned for the next decade.

Information Processing and Communications Laboratory

The Information Processing and Communications Laboratory (IPCL) is the central computing and data communications complex for the entire Institution. The hardware and software engineers in IPCL are responsible for the operation of most of the Institution's major computer resources including five VAX II/780 and II/750 mainframes, a number of microVAXes, personal computers and associated peripheral devices. IPCL provides the Institution with state-of-the-art data communications between all campus locations and to off-site facilities. A CATV-based local area network (LAN) interconnects Woods Hole users, and a newly installed microwave link to the Boston area provides a 1 Megabaud connection to MIT's campus network. Additionally, a digital satellite earth station is being designed to link WHOI directly to the CRAY X-MP supercomputer at the National Center for Atmospheric Research in Boulder. This high speed connection will give scientists and engineers instant access to the extremely fast and powerful computing facilities needed for real-time numerical ocean modelling.

Advanced Engineering Laboratory

The Advanced Engineering Laboratory (AEL) is dedicated to the development of the sophisticated instruments and sensors that are needed to keep pace with the demands of modern oceanography. Recent projects have included in situ water samplers, an ocean bottom recirculating flume for sediment distribution studies, an instrument to measure ocean noise that uses fast Fourier transforms and bubble memories, a digital ocean bottom hydrophone for seismic studies, a heat probe to measure precise temperatures in the deep-sea boreholes drilled by the oceanographic drilling ship JOIDES RESOLUTION, and a drifting buoy that telemeters ocean and meteorological data to shore via a satellite radio link. Other developments include fast, autonomous profiling sensors for measuring conductivity, temperature and depth, and free ascent acoustic units to measure vertical current profiles. Under the direction of Robert Chase, AEL is a resource for the instrumentation needs of the ocean scientist at Woods Hole, at oceanographic laboratories world-wide, and in industry.



A precision dragging system developed by MSL engineers.

Physical Oceanography Department

Robert C. Beardsley, Chairman

Members of the Physical Oceanography Department were active during 1985 in a number of wide-ranging projects involving all the oceans, from the bottom to surface waters and over the continental shelves and slopes. These projects include:

I. Moored array and hydrographic programs to study several major boundary currents: the Kuroshio extension east of Japan, the structure of the northern boundary current of the Pacific, and the retroflexion and reversal of the Agulhas Current southeast of Africa.

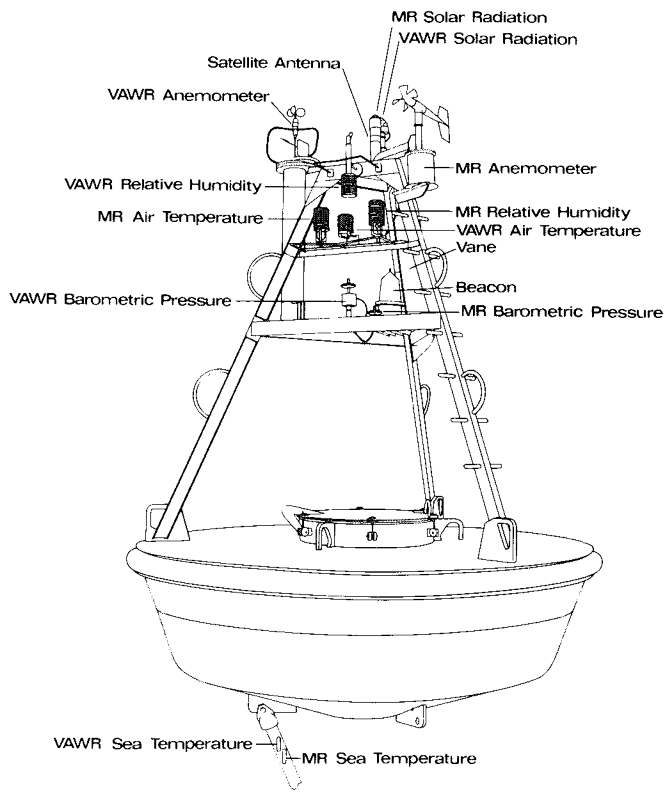
II. Remotely tracked surface drifter and neutrally buoyant SOFAR (Sound Fixing and Ranging) float studies of circulation in the upper layers and in the main thermocline of the subtropical and equatorial North Atlantic.

III. Major cooperative studies of circulation over the continental shelf and slope, involving field observations using moored current meter arrays as well as shipboard instrumentation such as CTD and doppler acoustic profilers, from the Yellow and East China Seas to California and the U.S. east coast.

IV. Fundamental studies of key oceanic processes, both experimental and theoretical, to elucidate the response of the upper ocean to wind, surface cooling and heating; of the deep Pacific to geothermal heating; to understand mixing and water mass formation processes, and to gain insight into the mechanics of various exchange processes between the atmosphere and ocean.

Given the scope of department activities and limited space in this report, two areas of work will be highlighted here: the interaction of the ocean with the atmosphere and the Gulf Stream system. Both areas involve work by many members of the department, and both have advanced to a point where new insights are beginning to emerge. The two are also, to some extent, related.

FASINEX Surface Buoy



FASINEX surface buoy instrumented with a Vector Averaging Wind Recorder (VAWR) system and a Meteorological Recorder (MR) system. Beneath the 3 m (10 feet) discus buoy is suspended a 5000 meter mooring (nearly 3 miles) with current meters at specific depths to measure ocean current velocities and temperatures.

Air-Sea Interaction

"Air-Sea Interaction" has traditionally stood for the effect of the ocean on the atmosphere, such as maintaining a benign climate in Western Europe. There is, of course, still interest in effects of this kind. However, the various ways in which the atmosphere influences the ocean has now become a prime concern of oceanographers. Some members of our department have been prominent in organizing field experiments designed to unravel details of key processes at the sea surface, while others have pioneered new conceptual models of circulation driven by surface cooling.

Melbourne Briscoe was the organizer of LOTUS (LOng-Term Upper Ocean Study), while the FASINEX (Frontal Air-Sea INteraction EXperiment) project, now in progress, is managed by Robert Weller. Both have been large cooperative projects, involving a number of investigators from several institutions. Other WHOI participants in FASINEX are Kenneth Brink, Raymond Schmitt and John Toole; Weller and James Price cooperated in LOTUS.

The questions these projects, and related theoretical studies, are attempting to answer include:

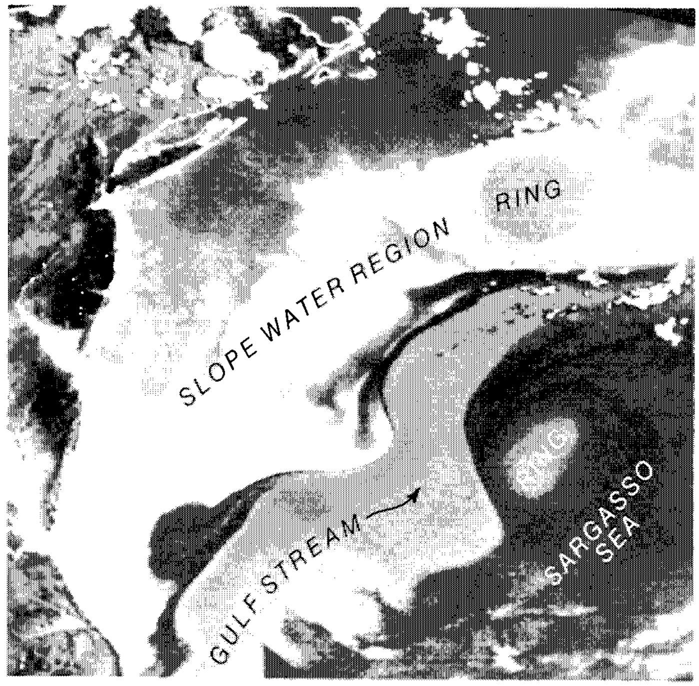
1. How precisely is the force of the wind transmitted to the water? Right at the surface small-scale breaking wavelets act as so many little paddles, leaving their moving wakes, and also offering targets to the scatterometer, a satellite radar instrument for worldwide mapping of sea surface winds. Gabriel Csanady was involved in studies of this process, in collaboration with the Jet Propulsion Laboratory (JPL). The studies are beginning to resolve the long-standing puzzle of the aerodynamic "roughness" of the sea surface and to reveal properties of turbulent flow immediately beneath the surface, in the "free surface turbulent shear layer". Expected benefits include an understanding of how the scatterometer works, improving its calibration, and better insight into heat and vapor transfer. On a slightly larger scale, the force of the wind is distributed over the surface mixed layer by eddies, the largest ones being the Langmuir circulations. Weller and Price studied these earlier; Weller is extending this work to an oceanic front as part of FASINEX.

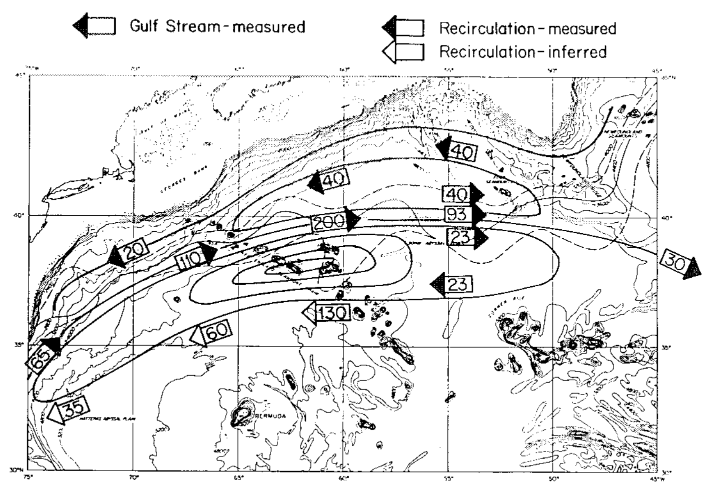
2. What motions are generated in the surface mixed layer, and layers immediately below, by wind and by wind-stress changes as the air passes over an oceanic front, and how does this affect the front? Brink and Weller are addressing these questions as part of FASINEX.

3. How intense is the downward mixing of heat and momentum, and how far does it reach, at and near an oceanic front? Schmitt and Toole are examining these questions, by a study of "fine" and "micro"-scale motions. A related project is C-SALT (Caribbean - Sheets And Layers Transects), a study of the strong thermohaline "staircase". Schmitt, in collaboration with investigators from other institutions, is testing the hypothesis that salt fingering plays a significant role in the maintenance of a "steppy" thermocline as well as in vertical exchange.

Gulf Stream Studies

On a somewhat larger scale, effects of surface cooling on a warm core ring were studied by Terrence Joyce and Schmitt. Warm core rings are found between the Gulf Stream and the continental shelf. Because they carry warm water from the Sargasso Sea into cooler surroundings, very large heat losses are experienced by these rings, mainly during the winter months. The strong cooling transforms warm, surface waters into denser waters, which can then be mixed back into the North Atlantic thermocline by





Top: Satellite image of the Gulf Stream, with rings spinning off north and south. The ring to the north of the Stream is a Warm Core Ring, and that to the south a Cold Core Ring (Figure 1). Cape Cod is visible at top center, Long Island at top left, Delaware Bay at left center and Chesapeake Bay just below at bottom left.

Bottom: Gulf Stream circulation (Figure 2). The substantial deep recirculation both north and south of the Stream in tight gyres is a new insight.

the Gulf Stream. Some parcels of such modified water have been found as isolated lenses in the thermocline, forming eddies with their own distinct water mass characteristics. This pathway for the renewal of thermocline waters was unrecognized before the Warm Core Rings program.

Warm core rings float in "slope water", the formation of which is also due largely to atmospheric effects: the slope water "pycnostad", or homogeneous layer, is generated during winter cold air outbreaks. This was documented in the course of the MASAR experiment (Mid-Atlantic Slope And Rise) in which Csanady participated. Among its other effects, the formation of the slope water pycnostad results in the upward mixing of nutrients from the nutrient-maximum layer located at some 250 m depth in slope water.

Surface cooling might also affect the large scale circulation of the ocean in previously unsuspected ways. This recognition has emerged from theoretical work of Henry Stommel, Joseph Pedlosky and James Luyten, who pioneered ocean circulation models of a newly recognized phenomenon called "subduction" of surface waters and of (negative-) buoyancy driven ocean circulation. A recent result was conceptual understanding of circulation in the "subpolar gyre" of the North Atlantic, including specifically the factors that govern the path and transport of the North Atlantic Current. Luyten and Stommel are at present developing models of another effect of heat loss, the reduction of the high vorticity in the Gulf Stream, to match the low values encountered downstream in the interior of the subtropical gyre.

This modeling work connects the two areas of research mentioned in this report. The Gulf Stream system has been a topic of intense study on several occasions in the past and it has not lost its fascination. In a fundamental way, we still do not understand what governs the behavior of boundary currents on the western edge of an ocean. The theme of present field studies is that a combination of new and old methods of observations throws new light on this old problem. The most prominent new method is instrumentation carried on satellites. Infrared images of large areas of the ocean are now routinely available and provide the "big picture" of features with pronounced temperature contrasts, such as the Gulf Stream or its spun-off warm and cold core rings. Infrared images have been exploited by Joyce in connection with warm core ring studies (Figure 1) and by Nicholas Fofonoff in a detailed study of Gulf Stream meanders. Remote sensing of near-surface currents by acoustic-Doppler techniques has permitted Joyce and co-investigators to map ocean currents in conjunction with satellite and more conventional hydrographic measurements. Fofonoff combined satellite images with information from drogue, SOFAR float and current meter studies to reveal the evolution of meanders and documented spectacular instances of near-discontinuous motion. Intensive studies of this kind have the promise of yielding quantitative detail on the unstable motions of a western boundary current and perhaps lead to an understanding of this key oceanic dissipative process.

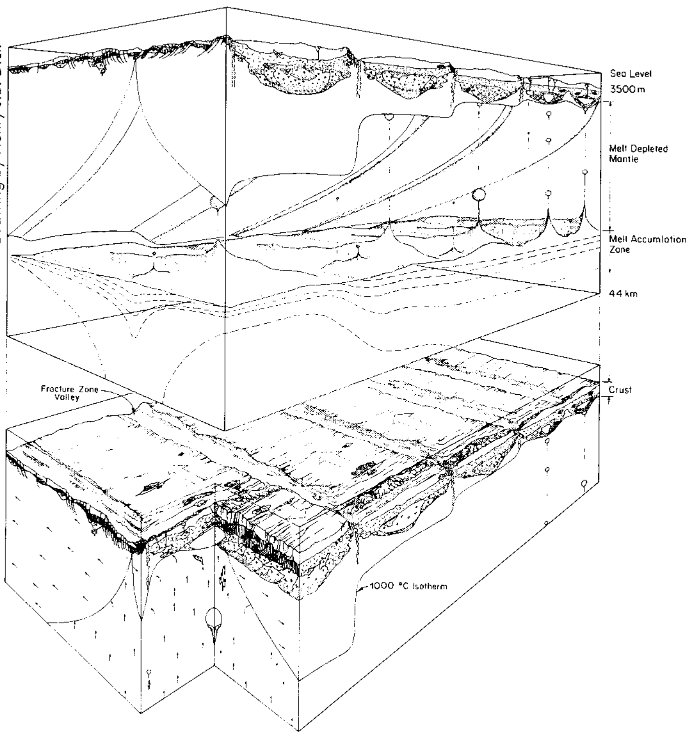
Harry Bryden, Nelson Hogg, W. Brechner Owens, and Philip Richardson have carried out current meter, drogue, SOFAR float and hydrographic studies on the mean circulation along the Gulf Stream system between Cape Hatteras and the Grand Banks. A recent synthesis of this work is shown in Figure 2, illustrating total (depth and width integrated) transports in this region of the North Atlantic. The center feature, maximum Gulf Stream transport of about 200×10^6 m^3 s^{-1}, is more or less according to earlier evidence. However, the substantial deep recirculation both north and south of the Stream, in very tight elongated gyres is a new insight (tentative at present to some extent: open arrows in Figure 2 are inferences).

One of the controversial questions in recent years has been whether the Gulf Stream continues past the Grand Banks as the North Atlantic Current, and if so, how much water crosses in this manner from the subtropical into the subpolar gyre. Recent work by William Schmitz (together with earlier work of Bruce Warren) has resolved this question: the Gulf Stream and the North Atlantic Current are undoubtedly connected, the cross-gyre transport having a magnitude of order 20×10^6 m^3 s^{-1}.

At the other end of the Gulf Stream system, at its equatorial origins off the coast of Brazil, Richardson has carried out a definitive study of surface circulation based on ship-drift and other data. Together with earlier work of William Metcalf and John Bruce this study demonstrates that equatorial surface waters make their way along the coast of Guana into the Caribbean, (and eventually into the Gulf of Mexico) at the rate of some 10×10^6 m^3 s^{-1}. Csanady has carried out theoretical studies of how such a boundary current is affected by vorticity constraints, and how those constraints help control the rate of warm surface water formation in the region of equatorial upwelling. The formation and poleward transport of this warm water mass (via the Gulf Stream system) is an important element of the global thermodynamic cycle executed by the ocean. This is air-sea interaction again, on the largest scale, connecting to other work described above.

Center for Analysis of Marine Systems

Peter H. Wiebe, Director



Drawing by Henry J.B. Dick

Model for the formation of ocean crust along mid-ocean ridges utilizing new observations on the nature of the oceanic mantle and on the segmentation of ocean ridges and a basic principle of fluid dynamics called Rayleigh-Taylor gravitational instability. The model was developed by Petrologist Henry Dick in cooperation with Geophysicist Hans Schouten and Physical Oceanographer Jack Whitehead.

In this model, magma formed by partial melting of the earth's mantle segregates at depth beneath the mid-ocean ridges prior to ascending at regularly spaced points to form new crust, consisting of a series of volcanoes along the rift valley of an ocean ridge. The melting of the mantle to form basaltic lava occurs due to compression of hot mantle peridotite as it moves toward the surface, where the ocean crust and lithosphere is pulled apart during seafloor spreading.

Examples of mantle peridotite, now badly altered by seawater, and of basaltic lava and its crystallization products can be seen on the cover of this report.

Research about how our planet works has traditionally taken place in different disciplines with distinct divisions and in separate institutions. We have, for example, laboratories for terrestrial ecology, for atmospheric science, and for oceanography. Recent advances in science, however, have made us realize that we have to think of the earth as a single system and consider global issues, such as the interactions between land, sea and air.

Some problems, like what do we do with low-level toxic waste, are immediate. Shall we bury, dump, burn or recycle our excess waste materials? Other problems are longer term and involve the cycling of elements such as carbon and nitrogen between the earth, air and water. How do these cycles affect our climate? What changes will occur as we utilize increasing quantities of fossil fuels? And still other problems involve far greater time scales and focus on issues such as the distribution of fresh water and its flux between ice, land and sea.

At WHOI, a focal point for interdisciplinary studies is the Center for Analysis of Marine Systems (CAMS). CAMS brings together investigators from a variety of disciplines both within the Institution's five scientific departments and from research organizations throughout the world for theoretical studies and computer modelling of problems which cannot be studied in the field or are best suited to computer analysis. Private donations from foundations and individuals since the Center's founding in 1980 have supported computer time, honoraria for guest lecturers, seminar support and research projects ranging in length from six to eighteen months. Time at CAMS is temporary; when the research project is completed, investigators return to their respective departments at WHOI or to other institutions from which they are on leave. CAMS serves primarily as a catalyst, a "think tank" environment where research ideas are nurtured both intellectually and financially to the point where traditional funding support, such as the National Science Foundation or Office of Naval Research, can be obtained to continue the project. Offices are located on the second floor of Fenno House on the Institution's Quissett Campus.

The Center's strength is interdisciplinary collaboration. Physicists work with biologists, geologists with chemists to combine theory, observation and computer modelling in a unique way. For many scientists it is their first experience working with others outside their discipline. Field work isn't necessary, as access to the fastest and most powerful computers, the "supercomputers", enables CAMS scientists to look at tremendous quantities of data already on hand that have not been fully analyzed or utilized. Data analysis, not data collection, is the priority. New insights have been gained by the freedom CAMS support provides to investigate new and non-traditional areas of research. More than 25 scientific papers and technical reports have been generated, numerous seminars held, and new research directions explored.

Projects have focused on studies of pollutants in the ocean and the paths they travel, fisheries ecology, geodynamics (the movement of the earth's crust), and the warming of the earth's atmosphere from excess carbon dioxide - the "greenhouse effect." CAMS provides researchers with a new awareness of the many factors involved in a problem, which can in turn lead to new research directions to help solve that problem or to at least better understand it. Marine pollution, for example, involves biology, chemistry, physics and geology. How are biological populations affected? What chemical reactions take place? How far will it spread, and how will bottom topography affect its movement? Interdisciplinary collaboration is vital to fully understand the problem. CAMS has brought together investigators in each of these fields to look at data they may never have seen, to ask questions, and to discuss established theories and propose new ones. The result: a better understanding of the problem from a total perspective rather than a single aspect.

One CAMS project has already proven useful to the oceanographic community. The Living Atlas, formally known as the CAMS Interactive Atlas Package, was developed by physical oceanographers with CAMS support. Scientists can archive and display salinity, temperature, depth and other oceanographic factors in any global projection. In addition, the Institution's massive CTD (conductivity/temperature/depth) data base can be readily accessed, data useful to scientists investigating the ocean's role in atmospheric warming.

A recent "breakthrough" supported by CAMS occurred in geodynamics. WHOI scientists Henry J.B. Dick, a geologist, Hans Schouten, a geophysicist, and John A. Whitehead, Jr., a physicist, were all separately investigating aspects of the earth's crust. Dick is interested in the composition of the mantle, Schouten in sea floor spreading and magnetic anomalies, and Whitehead in fluid dynamics. A CAMS lecture brought the trio together. Schouten believed fracture zones along the mid-ocean ridge developed in an evenly spaced pattern but didn't know what caused the spacing, while Dick was trying to find out where magma beneath these fracture zones went, since rocks he dredged from the fracture zones contained minimal traces of magma despite the fact his chemical analyses indicated magma was formed in the rocks. Whitehead wasn't looking at the mid-ocean ridge system at all; he was using a fluid dynamics principle to study salt dome formation in Texas and Louisiana. Following a CAMS geodynamics lecture and ensuing discussions, Whitehead applied that principle, which states that a heavy fluid over a lighter fluid causes a gravitational instability (known technically as a Rayleigh-Taylor instability), to the movement of magma beneath the earth's crust, and it worked. The new model for magma flow which resulted suggests the instability forces magma out of the mantle, but not straight out as generally believed. Instead, the magma moves both vertically and laterally, flowing into the evenly-spaced pockets along the ridge Schouten had found and explaining why Dick's rock samples didn't contain magma. The CAMS-supported scientists were the first to apply this principle to the mid-ocean ridge and have published two papers on their findings with a third in preparation.

Collaboration can also result in very practical applications. Variations in yearly populations of many fish stocks led biologists, physicists and fisheries managers to CAMS, where they reviewed the scientific literature on the subject. Gaps in research, particularly on juvenile fish, quickly emerged, and physical factors such as the Gulf Stream rings were found to play a much greater role in species survival than previously believed. The result: new research programs in learning how to catch juvenile fish and in new equipment to catch them, and the development of computer models of long-term fluctuations in fish stocks which will aid fisheries managers to stabilize catches.

In these and other projects, CAMS provided the means for the first intellectual approach to the unravelling of problems which have not yet been verified by experimentation, or problems whose solutions could be found in the synthesis of data. Computer modelling pointed to the directions scientists must take in acquiring the data necessary for solution or verification.

Coastal Research Center

John W. Farrington, Director

The objective of the Coastal Research Center (CRC) is to conduct research contributing to an ever-expanding base of knowledge and improved understanding of the coastal ocean, its physics, chemistry, biology and geology, which in turn will provide a basis for wise management of coastal resources. Interaction of multidisciplinary groups of scientists at the Institution is encouraged, and the Center supports multiorganizational and multinational efforts as appropriate. CRC, founded in 1980, is fortunate to receive private foundation suppport to catalyze and sustain several projects through grants from the Andrew W. Mellon Foundation, the Richard King Mellon Foundation and the Mobil Foundation, Inc. Principal research efforts during 1985 focused on the following projects.

Assimilative Capacity-Buzzards Bay Project

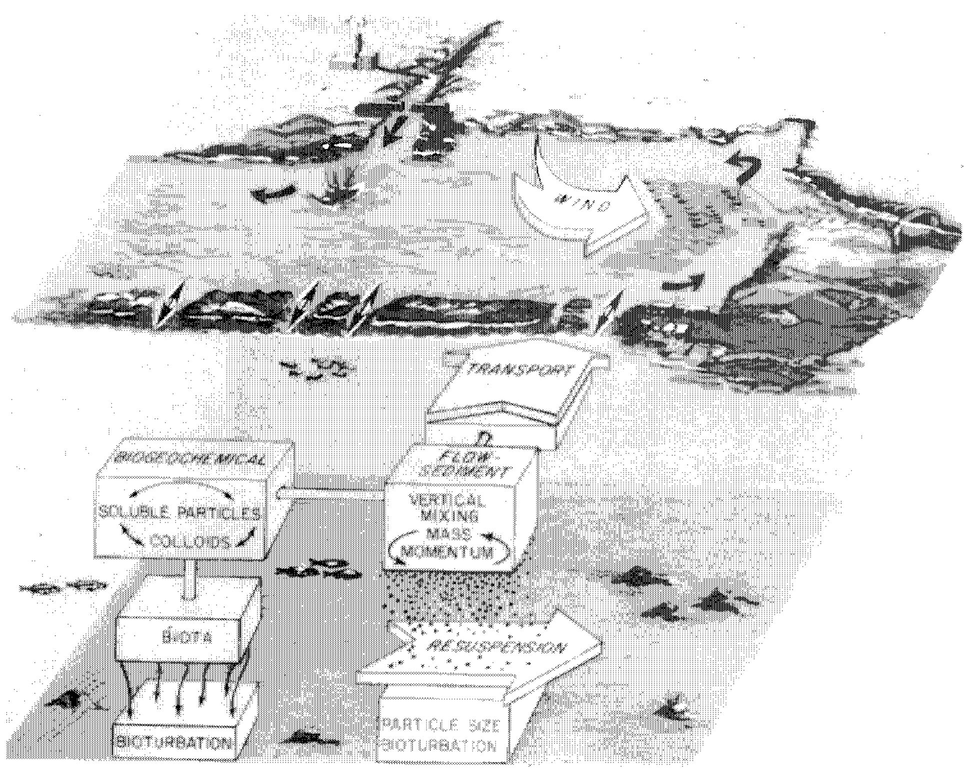
The present and future role of the coastal ocean for receiving and assimilating wastes from man's activities has undergone reassessment in the past five years. It is now recognized that the oceans cannot be excluded arbitrarily from consideration of waste disposal options to the detriment of air and land.

CRC research efforts in this area during 1985 focused primarily on a jointly funded CRC-Institution Sea Grant project in Buzzards Bay, Massachusetts. The western portion of Buzzards Bay in the Acushnet River Estuary - New Bedford Harbor area is heavily contaminated with the industrial chemicals PCBs (polychlorinated biphenyls) to the extent the area has been designated an Environmental Protection Agency (EPA) Superfund hazardous waste site. Earlier work by Institution scientists had contributed to defining the magnitude of the problems and outlining potential solutions.

The multidisciplinary focus of the CRC-Sea Grant project is outlined schematically below. Research activities are concerned with fluid processes responsible for mixing, diffusing, resuspending and controlling transport of particulate matter throughout the ecosystem, biogeochemical processes acting on chemical pollutants such as sorption, desorption between dissolved and particulate phases, bioavailability to organisms, and influences of biological processes such as bioturbation by bottom living organisms on stability of sediment to resuspension. Biological problems under investigation include effects at the cellular, organismal and population levels of biological organization.

CRC conducted a very active field program in 1985, with numerous instrumented tripod deployments to study circulation in Buzzards Bay, storm wave interactions with sediment in resuspension events, and other physical dynamics measurements by scientists and engineers led by William

Schematic diagram illustrating the multidisciplinary research focus of the Buzzards Bay Project.



Grant and Albert Williams of the Institution's Ocean Engineering Department and Robert Beardsley of the Physical Oceanography Department in collaboration with Bradford Butman of the U.S. Geological Survey's Atlantic Marine Geology Branch in Woods Hole.

Cages of the common blue mussel *Mytilus edulis* were transplanted from clean areas in Sandwich, Massachusetts, to sites in Buzzards Bay and Vineyard Sound to assess bioavailability of chemical pollutants in the bay and factors controlling concentrations of pollutant chemicals in marine organisms. The scientists also assessed numerous sublethal physiological, histopathological and biochemical responses of organisms to gradients of chemical pollution stress in a joint effort involving the laboratories of John Farrington of the Chemistry Department and Judith Capuzzo of the Biology Department.

Additional scientists are conducting research on other important aspects of Buzzards Bay ecosystems. While these projects contribute to a base of knowledge necessary for wise management of Buzzards Bay, an important area of the Massachusetts coast, the driving force of our research is to gain knowledge of generic value and applicable in many ways to the world's coastal areas. One aspect of CRC commitments in this regard is the involvement of numerous guest scientists from other countries in these research efforts, both in a mutual learning mode and in training and education.

Interactions of Sea Level Change and River Flow Modification

Sea level changes due to climatic and tectonic factors occur to varying degrees in the world's coastal areas. Interactions of transgressing sea level with changes in water flow and sediment transport by major rivers as a result of flood control and soil erosion management can result in substantial changes in coastal geomorphology, altered coastal/estuarine circulation patterns, salinity changes and ecosystem community and population adjustments to the preceding. The extent, severity and rates of these changes and consequences in the delta areas of some of the world's major rivers is the subject of a CRC-sponsored research project initiated in 1985 with joint CRC-EPA funding by John Milliman and David Aubrey of the Geology and Geophysics Department and James Broadus and Maynard Silva of the Marine Policy and Ocean Management Center.

Experimental Flume

The 20-meter (approximately 65-foot) flume was completed in January 1985 in the Coastal Research Laboratory on the Quissett Campus. Designed by a team of WHOI engineers under the direction of William Grant, this unique flume can accommodate several different types of experiments, such as the interactions of turbulence and the flux chemicals from sediments to the overlying waters, and animal-sediment-flow regime interactions in controlling sediment resuspension and in controlling larval settlement and growth in benthic animal communities. Initial experiments calibrating the flow regime and establishing requirements for maintaining larval populations were conducted in 1985.

Georges Bank Book

The initial phase of the Georges Bank project was to summarize existing knowledge of this important area of the world's oceans by preparation of a book and atlas. Much useful knowledge has been accumulated by many scientists employed by numerous organizations over the past several decades. However, there was a need for a comprehensive, carefully authored and edited scholarly work on Georges Bank which would be useful to scientists, industries, government officials and the general public.

Senior Scientist Richard Backus of the Biology Department undertook the task of general editor. He is advised by an editorial board consisting of Robert Beardsley of the Physical Oceanography Department, Bradford Butman of the U.S. Geological Survey, and Marvin Grosslein of the National Marine Fisheries Service. Richard Price, formerly a geographer in the Marine Policy and Ocean Management Center during the formative and critical stages of writing the book, is the cartographic editor.

The Georges Bank book has gone to press after final editing during 1985 and will be published in late 1986 by MIT Press. The book has been a substantial undertaking; 57 chapters deal with physical and biological sciences, resoures and public policy, and 110 authors and coauthors from the Woods Hole scientific institutions and organizations elsewhere have contributed to the chapters and ten vignettes. The undertaking has been well worth the effort given the importance of Georges Bank resources to the people of the United States, Canada and many other countries.

New ideas have emerged from the numerous small gatherings of authors during the writing of this book. Among these were the need for expanded ecological research related to fisheries. CRC, in cooperation with the Institution's Center for Analysis of Marine Systems, has taken that idea onboard and initiated joint research ventures with the National Marine Fisheries Service's Northeast Fisheries Center in Woods Hole which we plan to nurture and expand in the coming years, drawing on the talent and expertise of scientists at both laboratories.

James M. Broadus III, Director

In the two decades since the founding of the Marine Policy and Ocean Management Center (MPOM), many changes have occurred in methods of study, use and understanding of the ocean. The Marine Policy Center's research areas are responsive to these changing circumstances, and within this flexible construct, the Center's research program has evolved into five study areas.

Law of the Sea and Exclusive Economic Zone Issues

The implications for domestic and international marine policy in Law of the Sea and Exclusive Economic Zone (EEZ) issues offer opportunities to evaluate existing ocean legislation and administrative arrangements and to devise improvements for future ocean policy. In light of the U.S. declaration of its Exclusive Economic Zone and Law of the Sea discussions, projects for 1985 have included preparation by Research Specialist Maynard Silva of a comprehensive bibliography on marine protected areas of the world and a publication on marine protected areas in Latin America. Research Fellow Dean Cycon chaired a workshop on "Piracy at Sea" which brought an international group of experts to Woods Hole to discuss the resurgence of the worldwide problem of piracy. A text on the issues raised at the workshop is being prepared and will examine the international control regime that has evolved to accommodate the problem, that regime's placement in the Law of the Sea Convention, and the persistence of piracy as an international problem. Cycon, a lawyer, is also continuing his work on the development of administrative regimes and laws to regulate the search for and recovery of underwater archaeological sites and objects. Senior Fellow Michael Morris prepared a book manuscript that focuses on EEZ practices among the Southern Cone states of South America, with particular attention to the Strait of Magellan. A seminar series was presented by MPOM on domestic and international shipping issues, covering shipping policies of the developed and developing countries, trends in technological development, and an update on maritime boundary delimitations. Speakers were featured from MPOM, the University of Rhode Island and the Massachusetts Institute of Technology. Research in this study area is continuing or proposed on implications and definition of specific boundaries (e.g., width of the territorial sea), exploration, exploitation and management of the U.S. EEZ, implementation of EEZs by other coastal nations, and the use and protection of marine resources.

Energy and Marine Minerals Development Studies

MPOM studies of energy and marine mineral's development consider the domestic and international policy problems of developing potential ocean resources, such as hydrocarbons, manganese nodules, polymetallic sulfide deposits, and other nonfuel minerals. Marine polymetallic sulfides (MPS) have been the target of several long-term studies at MPOM. Economist James Broadus has been coordinating efforts by political scientists, an international lawyer, a geochemist and others to consider the economic and legal/political factors affecting the potential development of polymetallic sulfide deposits. The discovery of

Crowell House in the village of Woods Hole is the home of the Marine Policy and Ocean Management Center.

these deposits at oceanic crustal spreading centers is of great scientific interest, but their true economic importance is subject to serious question. Another study is taking the lessons learned about MPS and applying that information to other potential marine deposits in the U.S. EEZ. This research effort, headed by Broadus with Research Associate Porter Hoagland, is attempting to describe the location and to characterize the estimated volumes of deposits known to exist within the EEZ and to assess the economic conditions facing their development as in the case of MPS. Partial results from both these studies were presented by Broadus in testimony before the U.S. Congressional Subcommittee on Oceanography. Other projects in this research area include a study by Research Fellow Tim Eichenberg of state and federal conflicts over energy development on the outer continental shelf, and initiation of a discussion series on EEZ hard minerals which brings together representatives from the offshore hard minerals industry, the coastal states and environmental interest groups to propose management mechanisms for development of U.S. marine hard mineral resources.

Coastal and Fisheries Management Studies

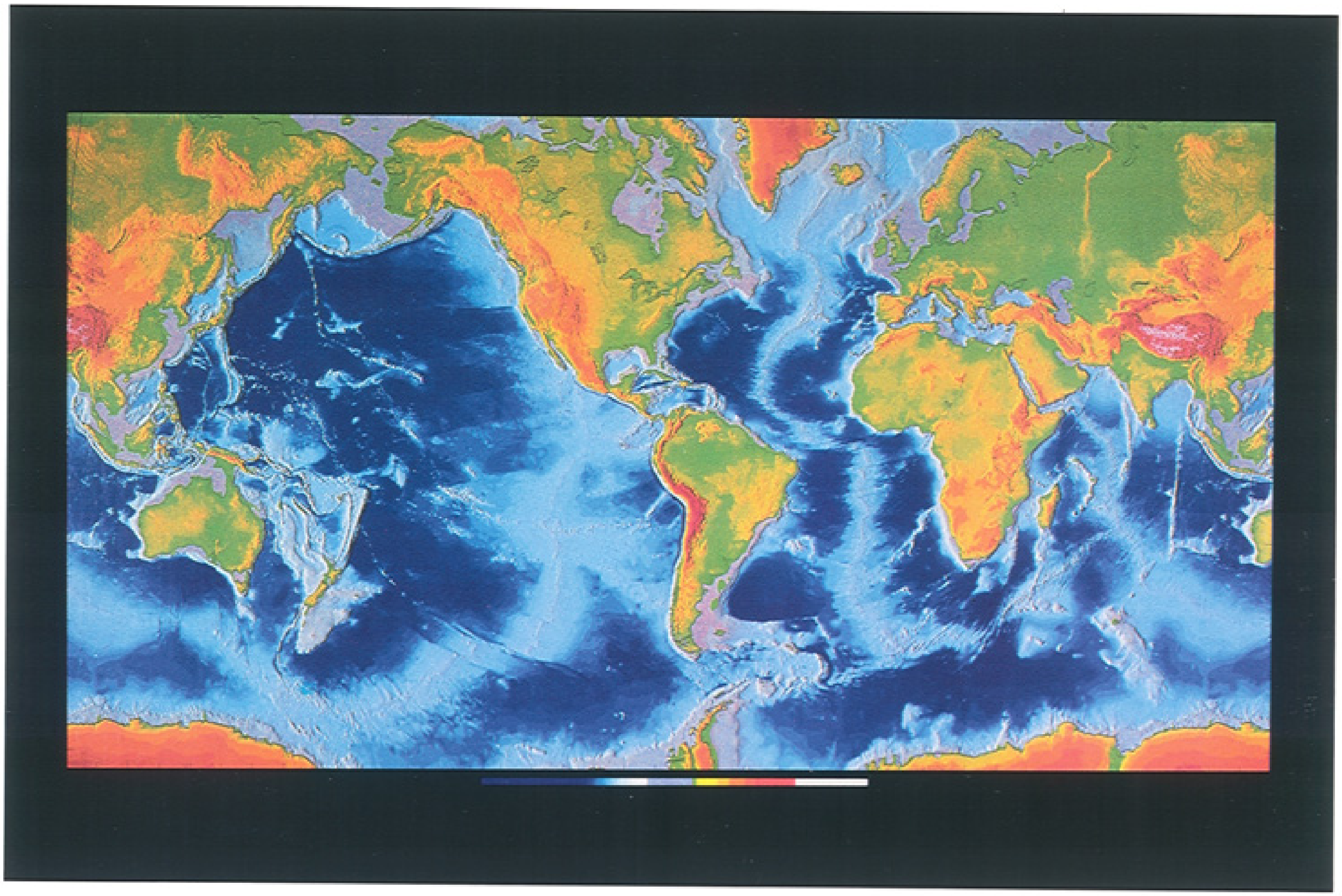
The coastal zone has been a major focus of the Center's research. Research Fellow Steven Edwards has estimated economic benefits of protecting water quality in coastal ponds and published an economics primer for coastal zone management. Other coastal zone studies have concentrated on the legal/political/social aspects. Maynard Silva and former MPOM Fellow Mark Meo examined institutional responses to sea level rise (using coastal wetlands loss in Louisiana as a metaphor for policy analysis) and planning for sea level rise by reviewing institutional responses previously adopted to deal with coastal phenomena resembling sea level rise, such as storms, subsidence, and erosion. Assessments of the management of marine resources have included Silva's recent workshop and text in preparation on intergovernmental relations and ocean resources in the 1980s; an analysis by Research Fellow Kem Lowry on state roles in U.S. marine management; various fisheries studies from the perspectives of fisheries management in the EEZ, the processes of producing management plans through regional fisheries management councils (analyzed by anthropologist Estellie Smith and economist James Wilson), and how scientific and technical information is used by the New England Fishery Management Council in policy decisions, a project headed by Silva with contributions by three former MPOM Fellows. The Center has also sponsored a workshop on Cape Cod's inland wetlands and a seminar series on the development of Cape Cod and related planning issues.

The Interaction of Science and Policy

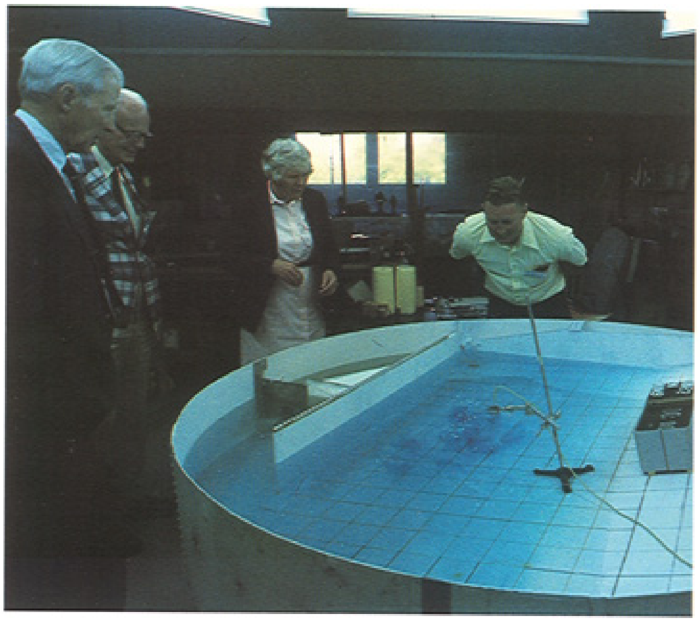
Center staff are working with colleagues in the Institution's Geology and Geophysics Department and Coastal Research Center (CRC) to predict certain types of economic impacts from sea level rise. This multidisciplinary study will combine scientific scenarios with socioeconomic appraisals to estimate losses that could be expected from the combined effects of sediment diversion and rising sea levels in major river delta systems of the world. Investigators from the Geology and Geophysics Department and CRC are characterizing the physical effects that might be expected from the combination of sea level rise and reductions in sediment loads associated with upstream water projects; the MPOM team of Broadus, Silva and Edwards will then estimate the socioeconomic consequences implied by various scientific scenarios.

Cooperative International Marine Affairs Programs

Informational and policy needs in developing nations, resulting from the extension of national jurisdictions over vast marine areas in newly established 200-mile EEZs, are being addressed in a number of cooperative international marine affairs programs. In 1985 Kem Lowry assisted the Government of Sri Lanka in the preparation of a coastal resources management plan. Another project has been underway since 1983 with the Government of Ecuador to develop a marine management scheme for that nation's Galapagos Islands. This project headed by James Broadus has focused on major areas: consultation and study of comparative experiences in coastal zone management, estimation of the nature and demand for tourism in the islands and implications for tourism regulation, the future management status of the Galapagos archipelago marine area, and improved application of scientific and technical information in Ecuadorian coastal and marine area management. In September, the Government of Ecuador drafted an Executive Decree to establish the Galapagos marine area as a Marine Biological Reserve. The boundaries proposed for the Reserve are exactly those described by MPOM's 1984 report to the government, and the contributions of Institution personnel are noted in the preamble of the draft decree. In addition, MPOM is proposing to assist the Government of Ecuador in organizing an international conference to address the issue of the future status of the Galapagos waters.



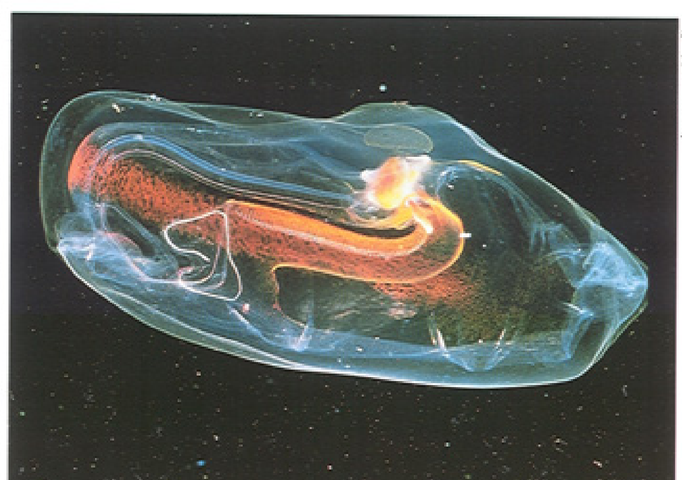
Above: Computer-generated relief map of the surface of the earth, edited by Geophysicist James Heirtzler; reds indicate height, blues depth, with color intensity varying with elevation. Left: A CTD (conductivity/temperature/depth) profiler is deployed from *Knorr*.



Shelley Lauzon

©Suki Coughlin

Thomas Kleindinst

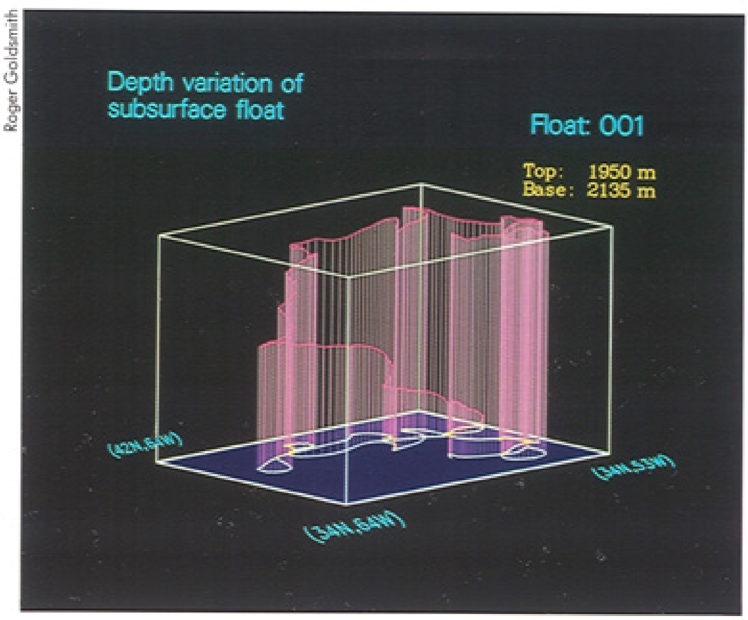


Laurence Madin

Top left: Physicist Jack Whitehead explains an experiment underway in his rotating table to Coastal Research Laboratory visitors. Top right: A box corer is prepared for deployment from *Knorr* during a HEBBLE cruise. Bottom left: McLean Laboratory's atrium with Japanese garden. Bottom right: Jellyfish *Pegea socia*, studied by Biologist Larry Madin.

Shelley Lauzon

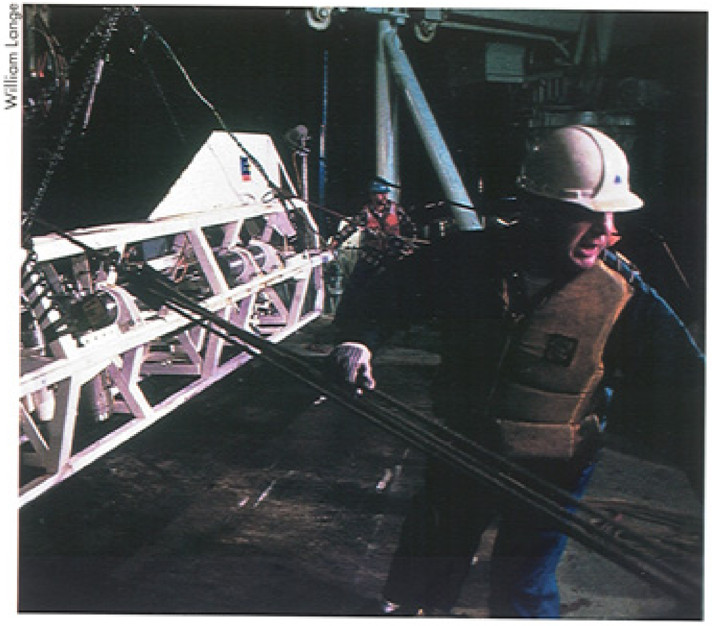
Roger Goldsmith



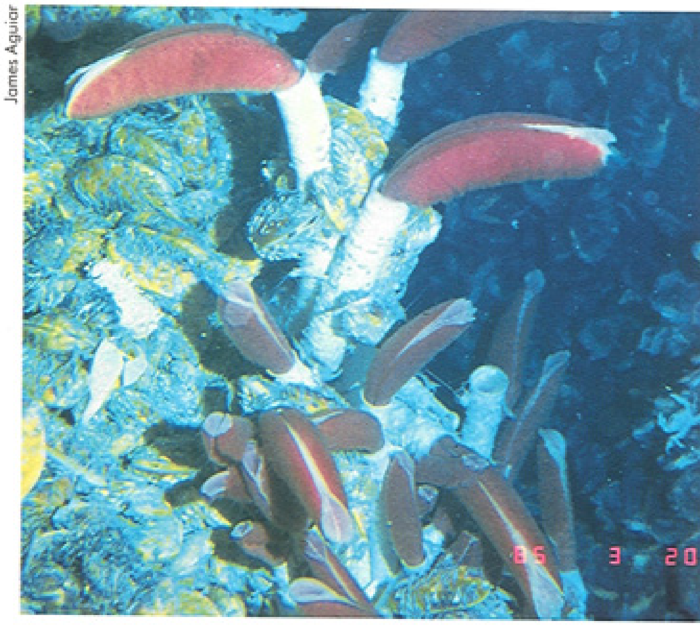
Keith Bradley

Top: *Knorr* (left) and *Oceanus* at the Institution pier between cruises. Bottom left: Computer graphic, generated by the Information Processing and Communications Laboratory, of the path of a subsurface float. Bottom right: Surface buoy with meteorological instruments is loaded aboard *Oceanus* for air-sea interaction studies near Bermuda.

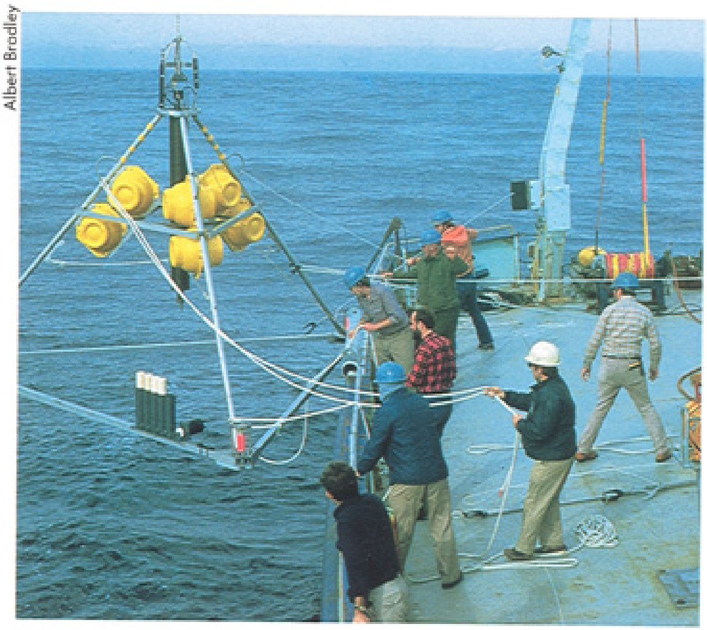
William Lange



James Aguiar



Albert Bradley



Anne Rabushka

Top left: Night launch of the ARGO video/sonar sled during the R.M.S. *Titanic* search aboard *Knorr*. Top right: Tube worms and mussels in the Guaymas Basin, Gulf of California. Bottom left: POPUP tripod, a bottom-mounted current profiler, is deployed from *Knorr*. Bottom right: *Asterias* heads for Eel Pond after a day's work; *Oceanus* at the pier.

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

Doctor of Philosophy

CHING-SANG CHIU
B.S. Northeastern University
Special Field: Oceanographic Engineering
Dissertation: *Estimation of Planetary Wave Parameters from the Data of the 1981 Ocean Acoustic Tomography Experiment*

JEREMY S. COLLIE
B.Sc. University of York, United Kingdom
Special Field: Biological Oceanography
Dissertation: *Feeding Habits of the Yellowtail Flounder and Production of its Invertebrate Prey on Georges Bank*

EDWIN L. FERGUSON, JR.
B.S. Massachusetts Institute of Technology
Special Field: Biological Oceanography
Dissertation: *Genetic Analysis of the Vulval Cell Lineages of the Nematode Caenorhabditis elegans*

MELINDA M. HALL
B.A. Duke University
Special Field: Physical Oceanography
Dissertation: *Horizontal and Vertical Structure of Velocity, Potential Vorticity, and Energy in the Gulf Stream*

STEPHEN E. LOHRENZ
B.A. University of Oregon
Special Field: Biological Oceanography
Dissertation: *Primary Production of Particulate Protein Amino Acids: Algal Protein Metabolism and its Relationship to the Composition of Particulate Organic Matter*

WILLIAM R. MARTIN
A.B. Brown University
B.S. University of Washington
Special Field: Chemical Oceanography
Dissertation: *Transport of Trace Metals in Nearshore Sediments*

ANNE E. MCELROY
Sc.B. Brown University
Special Field: Biological Oceanography
Dissertation: *Benz(a)anthracene in Benthic Marine Environments: Bioavailability, Metabolism, and Physiological Effects on the Polychaete Nereis virens*

RICHARD S. MERCIER
B.A.Sc. University of Waterloo, Canada
Special Field: Oceanographic Engineering
Dissertation: *The Reactive Transport of Suspended Particles: Mechanisms and Modeling*

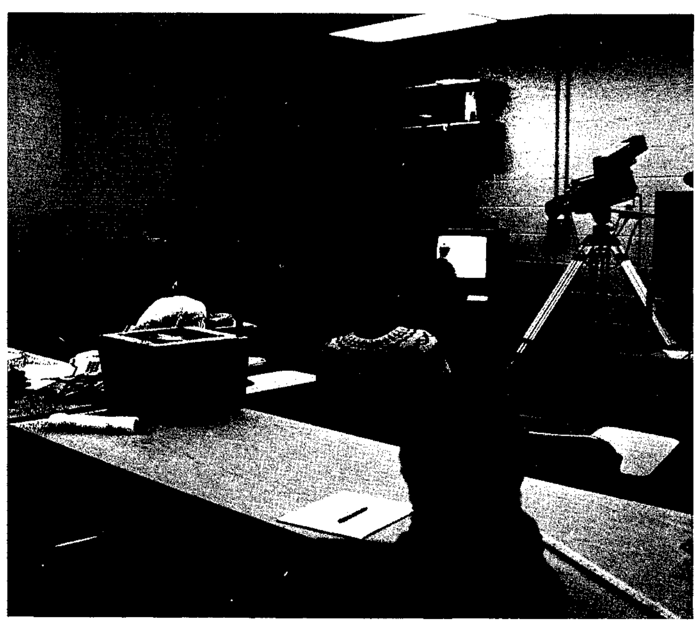
STEPHANIE L. PFIRMAN
B.A. Colgate University
Special Field: Marine Geology
Dissertation: *Modern Sedimentation in the Northern Barents Sea: Input, Dispersal and Deposition of Suspended Sediments from Glacial Meltwater*

SUBRAMANIAM D. RAJAN
B.E. College of Engineering, India
Special Field: Oceanographic Engineering
Dissertation: *An Inverse Method for Obtaining the Attenuation Profile and Small Variations in the Sound Speed and Density Profiles of the Ocean Bottom*

DANIEL VAULOT
Eng. Ecole Polytechnique, France
Eng. Ecole National du Genie Rural des Eaux et des Forets, France
Special Field: Oceanographic Engineering
Dissertation: *Cell Cycle Controls in Marine Phytoplankton*

Top, from left: Dean Charles Hollister discusses a research project with Joint Program students John Collins and Douglas Toomey. Bottom: Students in the new video classroom in Clark Laboratory. Microwave transmission linking WHOI and MIT began in the fall.


Shelley Lauzon


Anne Rabushka

Dean's Comments

Charles D. Hollister, Dean

The notion that science is losing its popular appeal among college students seems to be a hot topic. According to a recent survey, the percentage of freshmen science majors plunged 33% nationwide between 1974 and 1984. The total number of incoming freshmen declined 38% over the same period. Educators are decrying the lack of well qualified undergraduates and the growing number of better qualified foreign college graduates.

Our young people seem increasingly anxious for the guaranteed security of traditionally lucrative careers, such as law, medicine or business. Whatever happened to the students who wonder how the world works and with the courage to risk following their own curiosity?

The WHOI/MIT Joint Program in Oceanography/Oceanographic Engineering reflects the national trends of falling applicant numbers. However, we have seen a healthy increase in the number of women applicants. Eighteen students entered the Joint Program in 1985; 11 students were graduated, bringing our alumni total to 179. The incoming students were chosen from a total 114 applicants, our smallest pool in recent history. Among the matriculants were five naval officers, and four students received fellowships from the U.S. Navy and the National Science Foundation.

This class was the first to benefit from a new microwave link which brought us the "television classroom." No longer do students and faculty have to commute the 77 miles each way from one campus to the other for a course. Classes transmitted via microwave to video monitors at both campuses allow students and faculty to not only hear and see each other, but to talk to each other. The TV classroom idea was only a dream in 1981, when serious planning started. The three men most responsible for making it a reality were Physical Oceanographer Joseph Pedlosky and Engineer Hartley Hoskins of WHOI and Arthur Baggeroer, Professor of Ocean Engineering at MIT.

Once the complicated task of finding a clear transmission path devoid of obstructions (such as hills and buildings) was finally accomplished, microwave dishes were hoisted in Cambridge, Woods Hole and midway in Kingston. But the unexpected erection of a new high-rise, the Westin Hotel, in Boston's Back Bay forced us to move the antenna atop MIT's Green Building to another corner of the rooftop and actually hang it slightly over the side to skirt the Westin. By late July, microwave service started. Except for an interruption during hurricane season in the fall, the system has run smoothly.

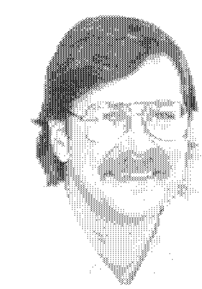
In 1985, five new chairs, one within each department, were created with J. Seward Johnson endowment. Mr. Johnson endowed research focusing on the Atlantic salmon at the Matamek Research Station in Quebec, Canada, which was operated by the Institution's Biology Department. When Matamek closed in 1984, the endowment income was channeled into WHOI's education programs according to Mr. Johnson's wishes. The following year, on recommendation of the Board of Trustees, it was used to create five new chairs. The chairs were awarded to staff members who, as teachers and scientists, have made outstanding contributions to the Joint Program. Recipients were: John M. Teal, Biology; Edward R. Sholkovitz, Chemistry; Brian E. Tucholke, Geology and Geophysics; George V. Frisk, Ocean Engineering; and Michael S. McCartney, Physical Oceanography.

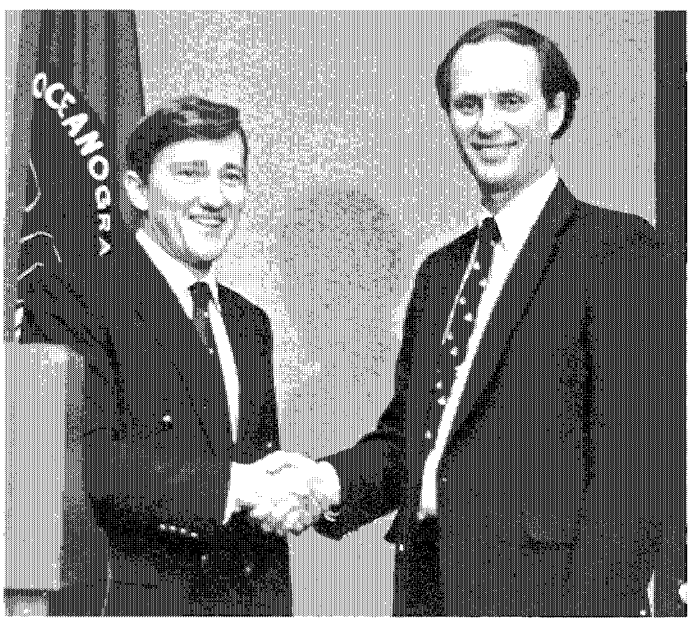
Each J. Seward Johnson Chair in Oceanography provides six months annual salary for three consecutive years, with a single possible renewal for three more years. Chairholders will serve as departmental ombudsmen for the Joint Program, advising students, coordinating course work, directing applicant recruitment and overseeing teaching in general. The endowed positions allow the recipients to "bank" up to two months annual salary support for sabbatical leave.

J. Seward Johnson Chair Recipients

Left: Senior Scientist John Teal. Middle left: Associate Scientist Edward Sholkovitz. Middle right: Associate Scientist Brian Tucholke. Bottom left: Associate Scientist George Frisk. Bottom right: Associate Scientist Michael McCartney.

Photos by Anne Rabushka





Top: Assistant Scientist Cheryl Ann Butman (far right) explains her research programs at the Coastal Research Laboratory during New Associates Day 24 May. Bottom: Secretary of the Navy John Lehman (left) and Senior Scientist Robert Ballard following the presentation of the first Secretary of the Navy Research Chair in Oceanography 1 July.

The Winter 1984/85 issue of *Oceanus* magazine, dedicated to the topic of the U.S. Exclusive Economic Zone (EEZ), was supported by a $20,000 grant from the Alfred P. Sloan Foundation. The issue reached President Ronald Reagan's desk; White House sources said the President was interested in the introduction's appeal for an oceanography exploration program on the level of NASA's Apollo program and flattered by the analogy of his EEZ action to that of Thomas Jefferson's Louisiana Purchase.

"Black Women in Science and Technology" was the theme of February's Black History Month events, cosponsored by the Institution, Marine Biological Laboratory, National Marine Fisheries Service and the U.S. Geological Survey. Keynote speaker for the annual celebration was Dr. Reatha Clark King, President of Metropolitan State University in Minneapolis/St. Paul, who spoke on "The Joys, Pains and Myths Surrounding the Black Woman Scientist."

A delegation of Institution scientists from various departments and marine operations personnel spent 2-13 February in Hawaii testing the design and feasibility of the SWATH (Small Waterplane Area Twin Hull) Vessel *Kaimalino* for oceanographic research. The U.S. Navy-owned ship was built in 1973 and is one of nine SWATHS in operation in the world. The SWATH is being considered as a design for new ships in the U.S. academic research fleet.

"Marine Science and Biomedical Applications" was the topic of a workshop 21-23 February in Woods Hole sponsored by the Institution, Marine Biological Laboratory and the Howard Hughes Medical Institute. Some 35 universities and research institutions participated in the program, organized by Associate Scientist Judith M. Capuzzo of the Biology Department and Senior Scientist Robert B. Gagosian of the Chemistry Department.

Falmouth High School freshman Tracy Goldsmith, daughter of Research Associate Roger Goldsmith of the Ocean Engineering Department, was the recipient of the Institution's $1,000 college scholarship as the overall winner of the 1985 Falmouth Community Science Fair 9 March. Her project focused on tree rings as historical records of Cape Cod precipitation.

A six-week series in March and April on "Planning on Cape Cod", sponsored by the Marine Policy and Ocean Management Center and the Sea Grant program, focused on urban planning, rapid growth in rural areas, state-federal issues in coastal zone policy, and planning and conservation commissions.

"CO_2, Climate and the Oceans" was the topic of a lecture by Senior Scientist Peter G. Brewer of the Chemistry Department at the New York Associates Dinner 28 March at the Lotus Club, attended by 68. More than 150 attended the Boston dinner 4 April at the Museum of Science.

The first woman to walk in space, Astronaut Kathryn Sullivan, visited friends at the Institution 24 April during a brief stop on Cape Cod. Sullivan worked with WHOI scientists James R. Heirtzler, Wilfred B. Bryan and Robert D. Ballard in 1974 aboard *Knorr* during Project FAMOUS (French-American Mid-Ocean Undersea Study) and holds a doctoral degree in geology from Dalhousie University in Nova Scotia. She presented the Institution with a photo montage of her flight aboard the shuttle Challenger.

A $20,000 gift from the EDO Corporation in memory of former EDO and WHOI Chairman of the Board Noel B. McLean will support a Summer Student Fellowship in even numbered years, beginning in 1986. Any excess funds from the endowment of the Noel B. McLean Summer Student Fellowship will be used toward additional fellowships.

Fourteen MIT/WHOI Joint Graduate Program students received their degrees 3 June in commencement exercises at MIT. The WHOI Education Office hosted a reception for the graduates and their guests 31 May at Fenno House. The total number of graduates is now 179.

"Piracy at Sea: The Modern Challenge" was the topic of a workshop 25-26 April organized by Marine Policy and Ocean Management Center Research Fellow Dean E. Cycon. The sixteen panel members included representatives of the International Maritime Bureau, U.S. Navy, United Nations, and shipping and enforcement nations. Approximately 35 attended the conference in Clark 507, including local, national and international media.

Some 130 scientists from the U.S. and Great Britain gathered in Woods Hole 28-30 April for the CAMS-sponsored "Melt and the Mantle" workshop hosted by Associate Scientist Henry J.B. Dick of the Geology and Geophysics Department. Participants related geophysics and geochemistry to the origin of magma in the earth and the changes new knowledge in these fields has made in our understanding of the earth.

Sixty-five Associates and guests learned about Institution activities and facilities during New Associates Day 24 May.

Atlantis II was outfitted in January with the final components of the Sea Beam echo sounding system for swath mapping of the ocean floor. *Atlantis II* and *Alvin* spent much of the year working at hydrothermal vents near the Galapagos Islands and along the East Pacific Rise.

Alvin set another record in 1985, successfully completing 100 of a scheduled 101 dives during the first six months of the year. Operational problems forced a cancellation.

After three months at the pier for scheduled maintenance, *Knorr* headed for sea 1 April for a month-long study of bioluminescence and optical variability in the western North Atlantic.

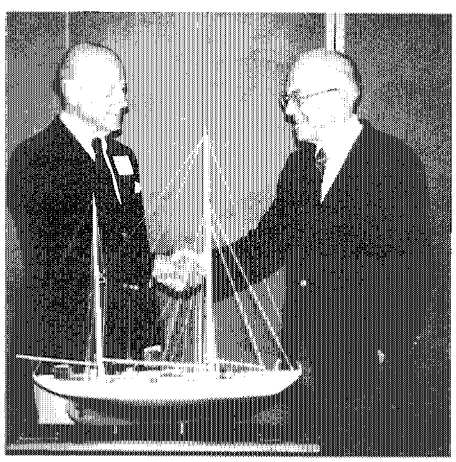
More than 150 friends and colleagues attended a testimonial dinner 13 June in Clark 507 for retiring Chairman of the Board Charles F. Adams, who served in the post since 1973. Adams was presented a model of *Atlantis*, built by Justin Camarata of Mystic Seaport. Earlier in the day forty-five Trustees, Honorary Trustees and Trustees-Elect attended a meeting prior to the Annual Meeting.

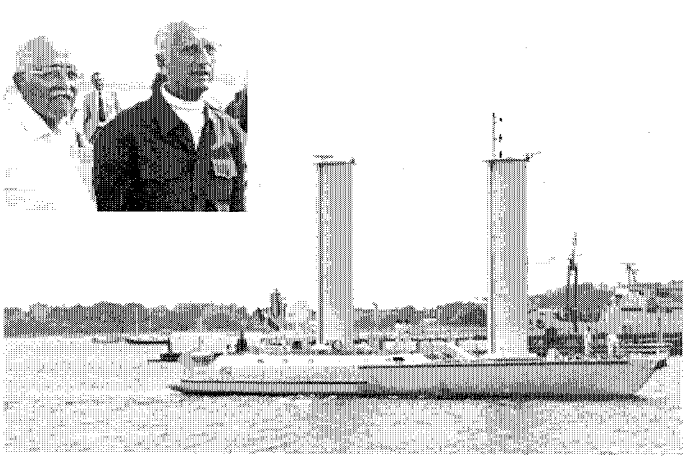
The 56th Annual Meetings of the Trustees and Members of the Corporation were held 14 June in Clark Laboratory. Sixty-five Trustees and Corporation Members attended. Guy W. Nichols, former Chief Executive Officer and Chairman of the Board of the New England Electric System, was elected Chairman of the Board to succeed Charles Adams. Nichols was elected a Member of the Corporation in 1976 and a Trustee in 1981. Senior Scientist Henry M. Stommel of the Physical Oceanography Department presented the science report on "A Delicate Equilibrium: The Ocean Circulation." Later in the day Associate Scientist John B. Waterbury of the Biology Department presented the Associates Lecture on "A Boring Mollusc with an Exciting Bacterium: A Symbiosis that Permits Shipworms to Eat Wood," attended by more than 200 Associates and WHOI staff. Open Houses followed at the Coastal Research Laboratory and McLean Laboratory. Some 300 Trustees, Corporation Members and Associates gathered under a tent on the Fenno House grounds for the annual Woods Hole dinner, completing the day's events.

Jacques Cousteau and his new experimental windship, *Alcyone*, visited the Institution 22-23 June at the invitation of President Paul M. Fye. A brief news conference was held upon arrival, followed by a reception on the Iselin Mall. Despite poor weather, an estimated 7,000 came to the Institution pier the following day to view the ship before it departed for Norfolk, Virginia. The Institution was *Alcyone's* only New England port call during her maiden voyage.

A series of seminars on "Shipping: A Forgotten Industry" were offered by the Marine Policy and Ocean Management Center during June and July, with speakers from WHOI, MIT and URI. The seminars focused on the use of the ocean as a highway and examined changes in the shipping industry.

The first Secretary of the Navy Research Chair in Oceanography was awarded 1 July to Senior Scientist Robert D. Ballard of the Ocean Engineering Department. The four-year, $800,000 award was presented by Secretary of the Navy John Lehman during brief ceremonies in Clark 507. Lehman said the new academic research chairs "indicate the Navy's intention to maintain clear, strong and long-term support for basic research not linked to any task or application." Following the ceremony, the Secretary met with the five naval officers who entered the MIT/WHOI Joint Grad-





Top: Willard Scott of NBC's "Today" show during a live broadcast 1 November at New York's South Street Seaport featuring *Atlantis II* and *Alvin*. Middle: Retiring Chairman of the Board Charles F. Adams (left) and new Chairman Guy W. Nichols. Bottom: Jacques Cousteau and Paul Fye (insert) watch the arrival of Cousteau's new windship *Alcyone* 22 June in Woods Hole.

uate Program in June. Included in the group is Kristine Holdereid, the first woman to graduate first in class from the U.S. Naval Academy.

Physical Oceanography Department Chairman Nicholas P. Fofonoff was honored 30 January for his service as Department Chairman since November 1981. Senior Scientist Robert C. Beardsley was named his successor.

Senior Scientist Richard P. von Herzen stepped down 1 April as Geology and Geophysics Department Chairman after two and one-half years to devote more time to his research activities. Senior Scientist David A. Ross, Coordinator of the Sea Grant program and Director of the Marine Policy and Ocean Management Center (MPOM), was named to the post. President of the Corporation and former Director Paul M. Fye was named Acting Director of MPOM to succeed Ross, who held the post since 1980.

Associate Scientist Hal Caswell of the Biology Department, Senior Scientist John I. Ewing of the Geology and Geophysics Department and Director John H. Steele were elected Fellows of the American Association for the Advancement of Science.

Senior Scientist Joseph Pedlosky of the Physical Oceanography Department was one of 60 members elected to the National Academy of Sciences for "distinguished and continuing achievement in original research."

Senior Scientist Richard H. Backus succeeded John M. Teal as Chairman of the Biology Department 1 December. Teal had held the position since February 1982; Backus had served in the post from 1970 to 1973.

The sunken luxury liner R.M.S. *Titanic* was discovered 1 September by Senior Scientist Robert D. Ballard and colleagues in the Deep Submergence Laboratory aboard *Knorr* during deep water engineering tests of the new sonar and video camera vehicle ARGO. A joint French-American expedition began in June aboard the French research vessel *Suroit* headed by scientists from the French Institute for Research and Exploration of the Sea (IFREMER), who were testing their new sonar system SAR. Several IFREMER scientists, along with representatives of the U.S. Navy and the National Geographic Society, were members of the science party aboard *Knorr* for the ARGO tests. *Knorr* returned home 9 September to a triumphant welcome by hundreds of family members, friends and colleagues as well as several hundred media representatives from around the world. A brief news conference followed in Redfield Auditorium, after which media were invited aboard the *Knorr*. An open house for community residents was held 10 September, with an estimated 2,000 visiting the ship to see ARGO and the 35mm camera sled ANGUS. The major news conference on the discovery was held 11 September at National Geographic Society in Washington, where more than 250 international media representatives filled Grosvenor Auditorium for the nearly 90-minute presentation by Dr. Ballard. News coverage of the discovery was intense through the remainder of the year, with increased interest in Institution research activities.

Ninety Associates enjoyed the annual Whale Watch 6 September aboard the *Dolphin* fleet out of Provincetown.

Two hundred scientists from around the world gathered in Woods Hole 8-11 September for the Second International Conference on Endotoxins and their detection with the Limulus Amoebocyte Lysate test. Senior Scientist Stanley W. Watson of the Biology Department hosted the group.

"Beach Nourishment: Its Future for the Massachusetts Coast" was the topic of a 10 October workshop sponsored by the WHOI Sea Grant program and Massachusetts Coastal Zone Management. Forty-five attended the session in Clark 507. The Sea Grant program also sponsored a 23-25 October conference on "Eelgrass: The Plant, the Community and the Possible Decline" attended by 40 representatives of marine laboratories from North Carolina to New Hampshire.

Nearly 400 Associates and guests attended the Day of Science 11 October, with illustrated morning lectures in Clark 507 followed by luncheon under a tent on the Iselin Mall and tours of *Knorr*. The day concluded with afternoon lectures in Redfield Auditorium.

A port call 31 October - 2 November at the South Street Seaport in New York City was *Atlantis II* and *Alvin's* first visit to that city. NBC's "Today" show broadcast weather spots featuring *AII* Captain Reuben R. Baker, Jr., *Alvin* Chief Pilot Ralph M. Hollis, and a nine-inch Galapagos clam shell and a science interview with Biologist J. Frederick Grassle live from the ship during their 1 November program. A brief news conference and media tours and filming aboard ship followed. More than 100 invited guests enjoyed luncheon and 200 an evening reception aboard ship. An estimated 500 Associates and members of the South Street Seaport Museum visited the ship during an Open House 2 November prior to sailing for Woods Hole, where the ship arrived 4 November to complete a 21-month voyage to the Pacific. *Atlantis II* sailed 29,700 miles in 500 days and *Alvin* made 337 dives during Voyage #112, which began 24 January 1984 in Woods Hole.

Director John H. Steele was sworn in as committee chairman of the Massachusetts Center for Excellence in Marine Science, which encompasses marine facilities in southeastern Massachusetts, during a 12 November visit by state Secretary for Economic Affairs Evelyn Murphy.

A small group of Institution representatives attended the 26 November night launch of the space shuttle *Atlantis* at the Kennedy Space Center, Cape Canaveral, Florida, on its first scientific mission. A piece of the mast of its namesake, WHOI's Research Vessel *Atlantis*, was carried into orbit as a memento. The newest of NASA's four space shuttles made its maiden voyage 3-9 October on a classified mission for the Department of Defense. The shuttles are named for great ships of discovery.

Thirty-year service awards were presented 13 December to Executive Assistant to the Director Charles S. Innis, Jr. and Senior Scientist Howard L. Sanders of the Biology Department. Those retiring in 1985 were also honored in ceremonies in Clark 507.

Among the many visitors to the Institution in 1985 were more than 100 members of the Massachusetts Shellfish Officers Association, which held its annual meeting 21 March in Redfield Auditorium cosponsored by the Sea Grant program. The Massachusetts Marine Educators gathered 23 March for their annual meeting, with more than 150 attending lectures and tours. Dallas Peck, Director of the U.S. Geological Survey (USGS), and William Cannon, Associate Chief Geologist at USGS, met with members of the Directorate1 April to discuss common research interests. Dr. Leo Young, Director of Research and Laboratory Management for the Department of Defense, attended the Staff Council meeting 29 April and visited various laboratories.

Four members of the Marine Subcommittee of the British House of Lords Select Committee on Science and Technology visited 28-29 May to discuss research programs and trends in marine research. Two groups from the Naval War College visited Woods Hole 29-31 May, and a third 3 September. The Board of Ocean Science Policy (BOSP) of the National Academy of Sciences met at the Carriage House 17-19 June; Director John H. Steele and President Paul M. Fye are members of BOSP. The Institution hosted the Naval Research Advisory Committee (NRAC) 8-19 July at Fenno and Carriage Houses for their Summer Study session, with eighty civilians from across the nation participating in the two-week session. Fifty attended the Ocean Industry Program's Ocean Dynamics and Engineering Section meeting 17-20 September in Clark 507. Twenty-seven senior cadets from the U.S. Coast Guard Academy heard about Institution research programs and toured *Atlantis II* during a 6 November visit. Four members of a Congressional delegation interested in research and development also visited 6 November, hosted by Associate Director for Research Derek W. Spencer. Several scientific delegations from the People's Republic of China and many individuals from other nations visited during the year.

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Geology & Geophysics Department

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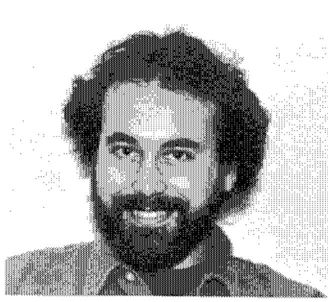
Shelley Lauzon

Shelley Lauzon

Shelley Lauzon

Anne Rabushka



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Adjunct Full Professor, Brown University; Professor, University of Stockholm
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James E. Broda, Research Associate
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+Loren Shure, Assistant Scientist
Wayne D. Spencer, Research Associate
Ralph A. Stephen, Associate Scientist
Kozo Takahashi, Assistant Scientist
Brian E. Tucholke, Associate Scientist
Adjunct Senior Research Scientist, Lamont-Doherty Geological Observatory
Elazar Uchupi, Senior Scientist
Allyn C. Vine, Scientist Emeritus
Richard P. von Herzen, Senior Scientist
Warren E. Witzell, Sr., Hydroacoustics Engineer
Frank B. Wooding, Research Associate

Ocean Engineering Department

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Paul M. Dragos, Research Associate
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Ned C. Forrester, Research Engineer
George V. Frisk, Associate Scientist
Roger A. Goldsmith, Software Applications Analyst
Hans C. Graber, Assistant Scientist
William D. Grant, Associate Scientist
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Stewart E. Harris, Electrical Engineer
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Jules S. Jaffe, Assistant Scientist
Maxine M. Jones, Research Associate
Sean M. Kery, Ocean Engineer
Richard L. Koehler, Electrical Engineer
Donald E. Koelsch, Electronics Engineer
Stephen P. Liberatore, Research Associate
William S. Little, Jr., Manager-Information Processing and Communications Laboratory
James F. Lynch, Assistant Scientist
Andrew R. Maffei, Research Associate
Roger H. Maloof, Research Engineer
William M. Marquet, Instrumentation Engineer, Senior Research Specialist, Manager-Deep Submergence Engineering Section
Edward C. Mellinger, Research Associate
Robert W. Morse, Scientist Emeritus
+Richard T. Nowak, Acoustics Engineer
Michael E. Pare, Research Associate

* Deceased, February 23, 1985
** Deceased, March 10, 1985

Kenneth R. Peal, Electronics Engineer
George H. Power, Computer Analyst
Kenneth E. Prada, Electronics Engineer, Senior Research Specialist, Manager Engineering Technologies
Warren J. Sass, Research Associate
Edward K. Scheer, Research Associate
Arnold G. Sharp, Mechanical Engineer
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Barrie B. Walden, Manager-Submersible Operations
Robert G. Walden, Electronics Engineer, Senior Research Specialist, Manager-Ocean Structures, Moorings & Materials Section
Ehud Weinstein, Associate Scientist
Senior Lecturer, Department of Electronic Communications, Control and Computer Systems, Faculty of Engineering, Tel Aviv University
Albert J. Williams 3rd, Associate Scientist
Valentine P. Wilson, Research Associate
Clifford L. Winget, Electromechanical Engineer
Dana R. Yoerger, Assistant Scientist
Earl M. Young, Jr., Research Associate

Physical Oceanography Department

Robert C. Beardsley, Department Chairman, Senior Scientist
Alvin L. Bradshaw, Applied Physicist
Kenneth H. Brink, Associate Scientist
Melbourne G. Briscoe, Associate Scientist
Harry L. Bryden, Associate Scientist
Dean F. Bumpus, Scientist Emeritus
David C. Chapman, Assistant Scientist
James H. Churchill, Research Associate
Gabriel T. Csanady, Senior Scientist
Associate, Great Lakes Institute, University of Toronto
Jerome P. Dean, Electronics Engineer
Gifford C. Ewing, Scientist Emeritus
Nicholas P. Fofonoff, Senior Scientist
Paul D. Fucile, Ocean Engineer
Frederick C. Fuglister, Scientist Emeritus
Dale B. Haidvogel, Adjunct Scientist
Associate, Division of Applied Sciences Harvard University
Nelson G. Hogg, Senior Scientist
Terrence M. Joyce, Associate Scientist
Richard Limeburner, Research Associate
Kelly G. Luetkemeyer, Research Associate
James R. Luyten, Associate Scientist
Michael S. McCartney, Associate Scientist
James R. McCullough, Instrument Engineer
Robert E. McDevitt, Research Associate
William G. Metcalf, Scientist Emeritus
Robert C. Millard, Jr., Physical Oceanographer
David L. Musgrave, Assistant Scientist
W. Brechner Owens, Associate Scientist
Richard E. Payne, Research Associate
Joseph Pedlosky, Senior Scientist, Henry L. Doherty Oceanographer
Lawrence J. Pratt, Assistant Scientist
James F. Price, Associate Scientist
+ Peter B. Rhines, Senior Scientist
Philip L. Richardson, Associate Scientist
Karl E. Schleicher, Oceanographic Engineer
Raymond W. Schmitt, Associate Scientist
William J. Schmitz, Jr., Senior Scientist
Marvel C. Stalcup, Physical Oceanographer
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John M. Toole, Assistant Scientist
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James R. Valdes, Research Associate
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Robert A. Weller, Associate Scientist
John A. Whitehead, Jr., Associate Scientist
Geoffrey G. Whitney, Jr., Research Associate
Alfred H. Woodcock, Scientist Emeritus, *nonresident Research Affiliate, Department of Oceanography, University of Hawaii*
Mary E. Woodgate-Jones, Research Associate
Valentine Worthington, Scientist Emeritus

Marine Policy & Ocean Management

Paul M. Fye, Acting Director, Marine Policy and Ocean Management
James M. Broadus III, Social Scientist
Porter R. Hoagland III, Research Associate
Maynard E. Silva, Political Scientist

Postdoctoral Investigators

Mark A. Altabet (Chemistry)
Vernon L. Asper (Geology & Geophysics)
Cheryl A. Butman (Ocean Engineering)
Ching-Sang Chiu (Ocean Engineering)
John R. Ertel (Chemistry)
Brian L. Howes (Biology)
Barbara J. Kamicker (Biology)
Katherine A. Kelly (Physical Oceanography)
Subramaniam D. Rajan, (Ocean Engineering)
Stephen A. Swift (Geology & Geophysics)
Saran Twombley (Biology)
Spahr C. Webb (Geology & Geophysics)

+ Leave of Absence

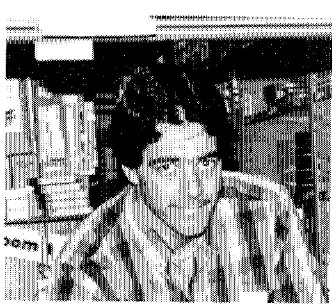
Regular Support Staff

Anne Rabushka

Anne Rabushka

Anne Rabushka

Anne Rabushka



Top to bottom: Steve Bolmer, Mary Jane Tucci, Jack Keizer, Steve Ferreira.

+Leave of Absence
*Deceased, August 16, 1985

Departmental Assistants

Biology Department

Philip Alatalo
+Valerie A. Barber
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Catherine M. Cetta
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Marcia W. Pratt
Edith H. Ross
Deborah K. Shafer
Margaret M. Sulanowski
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Martha E. Tarafa

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Paul J. Andrew
Pamela R. Barrows
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Julia E. Cole
Maura Connor
Christine A. Coughanowr
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Martin F. Bowen
Sharon L. Callahan
Rodney M. Catanach
Philip H. Chase, Jr.
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Aganoris Collins
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Karin A. Bohr
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John H. Thomson
Toshiko T. Turner
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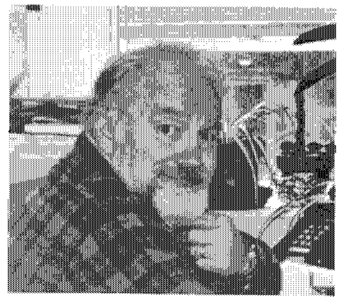
Scott E. Worrilow
A. Cleo Zani
Marguerite E. Zemanovic

+ Leave of Absence
* Deceased, October 1, 1985
** Deceased, May 28, 1985
*** Deceased, November 22, 1985

Marine Policy & Ocean Management

Judith Fenwick
Ellen M. Gately
Rosamund C. Ladner
Ethel F. LeFave


Anne Rabushka


Anne Rabushka

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Patricia M. DeBoer	Financial Analyst/Auditor
Paul Dudley Hart	Development Director
Eric H. Frank, Jr.	Systems & Procedures Manager
Arthur G. Gaines, Jr.	Marine Science Advisor
Gordon K. Glass	Executive Assistant/Ocean Engineering
Jane T. Hanrahan	Personnel Administrator
Beverley A. Harper	Programmer/Analyst
Hartley Hoskins	Coordinator, Ocean Industries Program
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Susan Kadar	Executive Assistant/Chemistry
Victoria A. Kaharl	Science Writer/Assistant to the Dean
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Gary B. Walker	Controller
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Mary Nan Weiss	Executive Assistant/Associates Program
Barbara Wickenden	Personnel Manager

Top left: Paul Ryan. Top right: Ellen Gately. Far right: Charles Innis. Right: Barbara Vallesio.


Anne Rabushka


Anne Rabushka

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N. Joye Wirsen
Jeanne A. Young
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James F. Aguiar, Jr.	Pilot, DSV ALVIN
Reuben R. Baker, Jr.	Master, R/V ATLANTIS II
John P. Bizzozero	Chief Engineer, R/V ATLANTIS II
Edward L. Bland, Jr.	Research Associate, ALVIN Operations
Richard J. Bowen	Master, R/V KNORR
Richard S. Chandler	Manager, Shipboard Scientific Support Group
Ernest G. Charette	Assistant Facilities Manager
Arthur D. Colburn, Jr.	Boat Operator, ASTERIAS
Don C. Collasius	Pilot, DSV ALVIN
Vicky Cullen	Manager, Graphic Services
Richard H. Dimmock	Port Engineer
Robertson P. Dinsmore	Consultant for Marine Operations and Planning
John D. Donnelly	Manager, Marine Operations
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Jonathan Leiby	Naval Architect
Barbara J. Martineau	Executive Assistant/Marine Operations Department
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**Paul R. Mercado	Chief Engineer, R/V OCEANUS
Donald A. Moller	Marine Operations Coordinator
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Terrence M. Rioux	Diving Safety Officer
William J. Sellers	Pilot, DSV ALVIN
Eric W. Spencer	Safety Officer
Ernest C. Wegman	Chief Engineer, R/V OCEANUS
Carolyn P. Winn	Research Librarian

* Deceased, June 24, 1985
** Deceased March 22, 1985

Anne Rabushka

Right: Sally Davis secures a line on ATLANTIS II. Bottom: J.P. Kamataris talks to the KNORR bridge.

Shelley Louzon

Facilities Personnel

Edward F. Acton
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Percy L. Kennedy, Sr.
Jay R. Murphy
Sebastian Rezendes III
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Kittie E. Elliott
Carole R. Merson
Stephen G. Page
Judith A. White

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Kirk J. McGeorge
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David M. Sanders
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Paul D. Tibbetts

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Mitchell G. Barros
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+Harry H. Stanton
John K. Sweet, Jr.
George B. Tanguay
Herman Wagner
Franklin S. Weldon
Stephen T. Wessling
Linda G. Wilson

+ Leave of Absence
* Deceased, June 3, 1985

EMPLOYEES RETIRING DURING 1985

William F. Freund, Jr.
Arthur T. Henderson
Roderique A. LaRochelle
Jack N. Lindon
Eben A. Sage
Leon W. Schuyler
Emilio Soto
Robert G. Walden
Bernard L. Zentz

Anne Rabushka

Anne Rabushka

Top: Donna Carson typesetting copy at Graphic Services. Bottom: Charles Olson makes glass disks for chemical experiments.

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Stanford University
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Messiah College, University of Hawaii
John A. Barth
University of Colorado
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Dartmouth College
Sara L. Bennett
Colorado State University
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Yale University
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Bowling Green State University
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Massachusetts Institute of Technology
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United States Naval Academy, University of Maryland
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Winona State University
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University of California, Berkeley
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Queens University, Canada Dalhousie University, Canada
John R. Fricke
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Ichiro Fukumori
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Mt. Holyoke College, University of Delaware
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University of Delaware

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Stanford University
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Florida Institute of Technology, University of Rhode Island
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Stevens Institute of Technology
Rebecca R. Schudlich
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Peter N. Schweitzer
University of Maryland
University of Kansas
Glen T. Shen
Massachusetts Institute of Technology
Robert M. Sherrell
Oberlin College


Rod Catanach

ALVIN Pilot Don Collasius enjoys a quiet moment aboard ATLANTIS II.

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University of Michigan
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Wesleyan University, University of North Carolina
Niall C. Slowey
Tufts University, University of North Carolina
Wendy M. Smith
Rensselaer Polytechnic Institute
Elisabeth A. Snowberger
Washington University
Kevin G. Speer
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Southern Methodist University, University of Virginia
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Joanne M. Willey
University of Pennsylvania
University of Pennsylvania, School of Nursing
Anthony J. Withnell
Indiana University

Tamara M. Wood
Union College
Robert A. Zackin
Brown University

Postdoctoral Scholars 1985-1986

John L. Bullister
Scripps Institution of Oceanography
Blair H. Brumley
Cornell University
Wayne R. Geyer
University of Washington
David M. Glover
University of Alaska
Charles H. Greene
University of Washington
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Massachusetts Institute of Technology
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University of Kiel
Deborah K. Smith
Scripps Institution of Oceanography
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University of Connecticut

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Herman Medwin
Naval Postgraduate School
David J. Thomson
Bell Laboratories, New Jersey
Miriam Kastner
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Institute for Marine & Coastal Studies, University of Southern California, Los Angeles
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Geology and Geophysics Department, Woods Hole Oceanographic Institution
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Department of Political Science University of California, Santa Barbara
J. Phil Clarner
Biology Department, Woods Hole Oceanographic Institution
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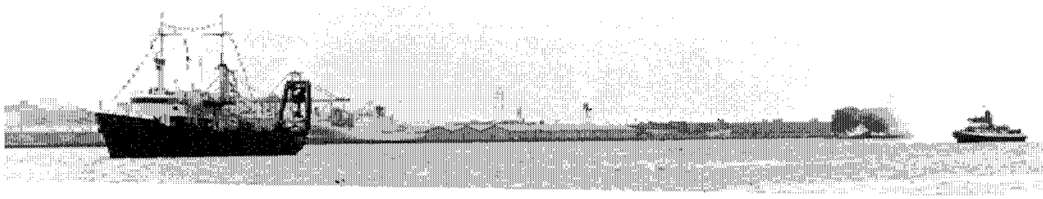
DSV *Alvin* and R/V *Atlantis II*

Total Nautical Miles for 1985 - 13,800 miles
Total Days at Sea - 240 days
Total Dives - 162 dives

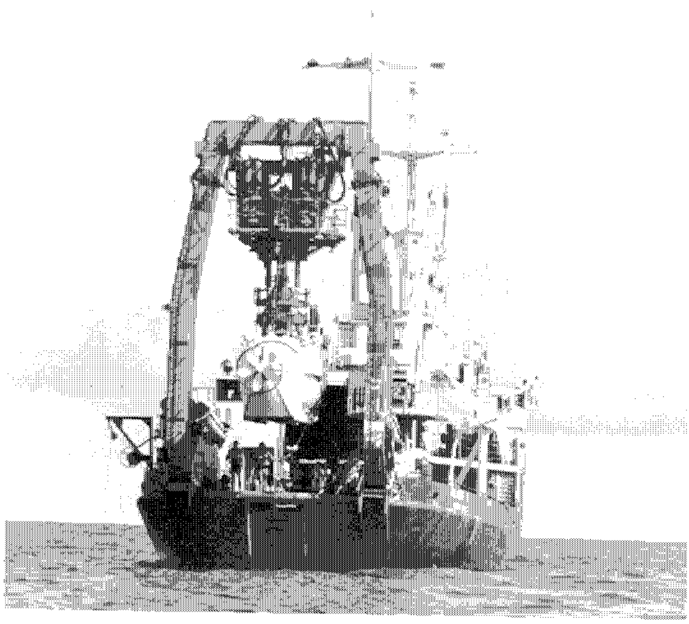
Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
112-XIX	13 Jan-21 Jan	Seven *Alvin* dives in the California Borderland Basins to study deep-sea benthic boundary layer fauna	San Diego, California	Carney (Moss Landing)
112-XX	2 Feb-6 Feb	Studies of fauna and dynamics of large, biogenic sediment mounds on the level floor of the Santa Catalina Basin; three *Alvin* dives	San Diego, California	Smith (Univ. of Washington)
112-XXI	10 Feb-24 Feb	Tests of the newly installed SEA BEAM echo sounding system	Puntarenas, Costa Rica	Tyce (URI)
112-XXII	26 Feb-23 Mar	Nineteen *Alvin* dives to study the ecology and physiology of hydrothermal vent communities at the Galapagos Rift	Balboa, Panama	Hessler (SIO)
112-XXIII	28 Mar-6 Apr	In situ examination of the benthic boundary layer in the Pacific Panama Basin; six *Alvin* dives	Puntarenas, Costa Rica	Honjo
112-XXIV	11 Apr-8 May	Geological investigations of the Galapagos propagating rift system; twenty *Alvin* dives	Acapulco, Mexico	Hey (SIO)
112-XXV	13 May-1 Jun	Investigations of the early stages of seamount evolution, development of craters and calderas and summit plateaus on young seamounts; fifteen *Alvin* dives for petrochemical and magmatic sampling	Acapulco, Mexico	Fornari (LDGO)
112-XXVI	5 Jun-28 Jun	Observation and sampling of the detailed structural anatomy of the plate boundary on the East Pacific Rise in the vicinity of the Clipperton Transform Fault; twenty *Alvin* dives	Manzanillo, Mexico	Fox (URI)
112-XXVII	5 Jul-16 Jul	Ten *Alvin* dives for tests of AMUVS (Advanced Maneuverable Underwater Viewing System), measurements of biological colonization rates, micropaleontology studies, descriptions of megafauna, and reconnaissance of future dive sites in the Guaymas Basin	Guaymas, Mexico	Ballard Grassle
112-XXVIII	24 Jul-8 Aug	Fourteen *Alvin* dives for biological and geochemical studies of hot vents in the Guaymas Basin of the Gulf of California	Guaymas, Mexico	Grassle
112-XXIX	12 Aug-27 Aug	Continuation of biological and geochemical studies of Guaymas Basin hydrothermal vent systems; fifteen *Alvin* dives	Guaymas, Mexico	Edmond (MIT)
112-XXX	31 Aug-17 Sep	Fourteen *Alvin* dives for sampling and observation of biological and chemical processes on submarine volcanos in the vicinity of the Larson Seamounts and East Pacific Rise	Acapulco, Mexico	Edmond (MIT)

ATLANTIS II is greeted with a fireboat welcome upon her first visit to New York City October 31. Bottom left: Completion of another dive as ALVIN is recovered on ATLANTIS II. Bottom right: All the ships were home for the holidays.



Shelley Lauzon

Rod Catanach



Shelley Lauzon

112-XXXI	22 Sep-17 Oct	Investigations of the geological, geophysical, and geochemical processes of sulfide deposits on the Galapagos Ridge; eighteen *Alvin* dives	Balboa, Panama (NOAA)	Embley
112-XXXIIA	22 Oct-28 Oct	Transit through Panama Canal	Little Creek, Virginia	
112-XXXIIB	29 Oct-31 Oct	One DSV *Alvin* engineering test dive	New York, New York	Akens
112-XXXIII	3 Nov-4 Nov	Transit to Woods Hole after courtesy port call at New York City's South Street Seaport Museum	Woods Hole	Walden
113-I	12 Nov-13 Nov	To shipyard	Brooklyn, New York	
113-II	19 Dec-20 Dec	From shipyard	Woods Hole	

R/V Knorr

Total Nautical Miles for 1985 - 18,709 miles
Total Days at Sea - 179 days

Voyage	*Cruise Period*	*Principal Objective, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
112	1 Apr-27 Apr	Studies of bioluminescence, short-term behavior of oceanic mixed layers, and optical variability in the western North Atlantic	Woods Hole	Marra (LDGO)
113	4 May-8 May	Structural stability tests and evaluation of the Sea-Air Exchange Program (SEAREX) sampling tower	Woods Hole	Chisholm (URI)
114	13 May-14 May 17 May-18 May	To shipyard From shipyard	East Boston Woods Hole	
115-I	17 Jun-7 Jul	Deployment of ocean bottom hydrophones, seismometers, and explosive sound sources in the vicinity of 25°N, 45°W	San Juan, Puerto Rico	Purdy
115-II	11 Jul-10 Aug	Recovery of equipment set out on Leg I; seismic experiments using prototype deep explosive sources and digital ocean bottom hydrophones and the newly designed Surface Towed Radio Telemetry Array (STRATA)	Ponta Delgada, Azores	Purdy
115-III	15 Aug-9 Sep	Deep water engineering tests of the ARGO instrument system; lowerings in the vicinity of 42°N, 50°W located the R.M.S. *Titanic*	Woods Hole	Ballard
116	17 Sep-24 Sep	Deployment of moorings, photography, coring, and station work for the High Energy Benthic Boundary Layer Experiment (HEBBLE) at the Nova Scotian Continental Rise	Woods Hole	Hollister
117-I	25 Sep-26 Sep	Transit to safe harbor during Hurricane Gloria	East Boston	
117-II	28 Sep-28 Sep	Return	Woods Hole	
118-I	19 Oct-27 Oct	Transit	Bridgetown, Barbados	
118-II	28 Oct-12 Nov	Examination and surveys of the strong thermohaline staircase layering in the tropical North Atlantic for the Caribbean Sheets and Layers Transects (C-SALT) Experiment	Bridgetown, Barbados	Schmitt
118-III	16 Nov-2 Dec	Continuation of thermohaline finestructure studies for the C-SALT Experiment	San Juan, Puerto Rico	Schmitt
118-IV	5 Dec-17 Dec	Microbiology and physiology studies in the deep sea	Woods Hole	Jannasch

R/V Oceanus

Total Nautical Miles for 1985 - 21,700 miles
Total Days at Sea - 210 days

Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
162	28 Jan-4 Feb	Studies of time and space variability of oceanic carbon dioxide	Woods Hole	Brewer
163	13 Feb-3 Mar	Investigations of nutrient coupling, nitrogen uptake, and production of phytoplankton off Chesapeake Bay	Woods Hole	Malone (Univ. of Maryland)

164-I	7 Mar-12 Mar	Tests of the Surface Towed Radio Telemetry Array (STRATA)	St. George's, Bermuda	Purdy
164-II	13 Mar-19 Mar	Continuation of chemistry studies of time and space variability of oceanic carbon dioxide	Woods Hole	Bacon
165-I	23 Mar-4 Apr	Life histories, feeding behavior, and morphology studies of gelatinous zooplankton using diving, mid-water trawls, and plankton tows	Charleston, South Carolina	Harbison
165-II	7 Apr-20 Apr	Continuation of biological studies of gelatinous zooplankton	Woods Hole	Harbison
166	25 Apr-8 May	Studies of biological processes on the Continental Slope south of Cape Cod and Georges Bank to assess the impact of exploratory drilling activities on benthic communities	Woods Hole	Hampson
167	14 May-24 May	Continuation of studies assessing drilling activities on benthic communities on the Continental Slope off the New Jersey and Delaware coasts	Woods Hole	Petrecca
168	21 Jun-28 Jun	Continuation of chemistry studies of time and space variability of oceanic carbon dioxide	Woods Hole	Brewer
169	2 Jul-8 Jul	Continuation of studies assessing drilling activities on benthic communities on the Continental Slope south of Cape Cod and Georges Bank	Woods Hole	Hampson
170	15 Jul-26 Jul	Diving and plankton net tows for observation and collection of gelatinous zooplankton, microzooplankton, and marine snow in the Gulf Stream	Woods Hole	Madin
171	1 Aug-13 Aug	Continuation of studies assessing drilling activities on benthic communities on the Continental Slope off the New Jersey and Delaware coasts	Woods Hole	Petrecca
172	16 Aug-22 Aug	Continuation of chemistry studies of time and space variability of oceanic carbon dioxide	Woods Hole	Bacon
173-I	31 Aug-21 Sep	Deployment and recovery of Autonomous Listening Station (ALS) moorings and launch of Sound Fixing and Ranging (SOFAR) floats	Las Palmas, Canary Islands	Valdes
173-II	18 Oct-16 Nov	Investigations of recently discovered Mediterranean salt lenses to determine their importance, evolution, and stability	Ponta Delgada, Azores	Armi (SIO)
173-III	19 Nov-27 Nov	Transit	St. George's, Bermuda	
173-IV	2 Dec-10 Dec	Continuation of chemistry studies of time and space variability of oceanic carbon dioxide	Woods Hole	Bacon

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*Deceased 5 July 1985

Shelley Lauzon

Terry Hammar works on a sampling device in the Coastal Research Laboratory.

In Memoriam

The Institution gratefully acknowledges the service and support of Trustee Lawrason Riggs III who died in 1985.

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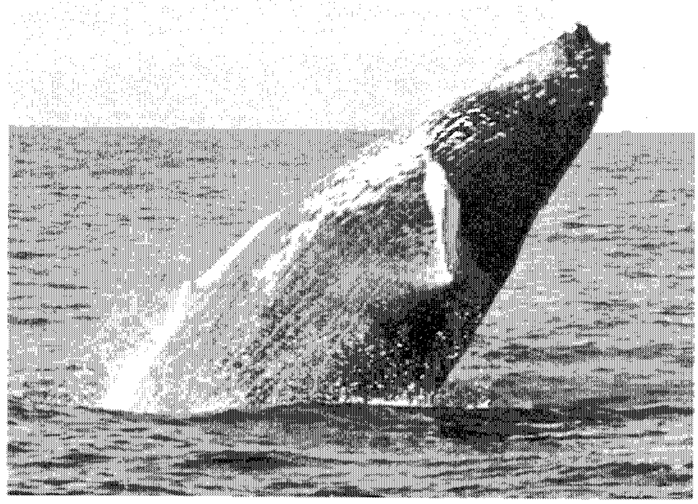
A humpback whale plays off Provincetown, Massachusetts.

Anne Rabushka



Highlights:

The Institution's total operating revenue increased 4% in 1985 to $51,052,546 compared with a 6% increase and total revenues of $48,997,255 in 1984. Excess current unrestricted funds of $1,500,000 were transferred to Unexpended Plant Funds and $500,000 to a newly created Director's Innovative Fund.

Funding for Sponsored Programs increased 4% in 1985 as compared to 1984. Government sponsored research increased 2% from $37,690,000 in 1984 to $38,551,000 in 1985. The modest increase reflects the uncertainties associated with the Federal budget deficit. Non-Government research increased 18% from $4,904,000 in 1984 to $5,800,000 in 1985, due primarily to funds received from the Howard Hughes Medical Institute for upgrading the Environmental Systems Laboratory for research on Aplysia.

	1985	*1984*	*Increase (Decrease)*
National Science Foundation	$22,618,000	$20,936,000	8.0%
Office of Naval Research	12,741,000	13,058,000	(2.4%)
Department of Energy	672,000	533,000	26.1%
National Oceanic & Atmospheric Administration	1,416,000	1,389,000	1.9%
Other Government	1,104,000	1,775,000	(37.8%)
Restricted Endowment Income	502,000	723,000	(30.6%)
Other Restricted Gifts, Grants, and Contracts	5,298,000	4,180,000	26.7%
	$44,351,000	$42,594,000	4.1%

Capital expenditures, including year-end work in process, were $1,349,000, a 3% increase over 1984 expenditures of $1,306,000. Included in 1985 expenditures was $668,000 for upgrading Chemistry facilities in the Redfield Laboratory. Additional funds were expended for acquisition of computer resources, shop equipment and general renovations. Funds for capital improvements were derived from Depreciation Recovery and use of other Institution Unrestricted Income.

Other statistics of interest are:	*1985*	*1984*	*Increase (Decrease)*
Full-time Equivalent Employees	795	810	(1.9%)
Total Compensation (including Overtime and Benefits)	$27,257,000	$25,780,000	5.7%
Endowment Income (net)	3,658,000	3,221,000	13.6%
Additions to Endowment Principal	172,000	57,000	301.8%
Endowment Principal (year-end at market value)	68,659,000	56,441,000	21.6%
Sponsored Programs Backlog	23,191,000	22,499,000	3.1%

Gifts and grants from private sources including the 1,500 WHOI Associates totaled $1,776,000 in 1985 of which $1,250,700 was restricted and $525,300 was unrestricted as follows:

Addition to Endowment Principal	$172,500
WHOI/MIT Data Communications Link	100,000
Marine Policy & Ocean Management	400,000
Benthonic Foraminifera Studies	60,000
Education Program	151,200
Coastal Research Programs	113,000
Sperm Whale Underwater Behavior Studies	25,000
Ocean Engineering Research Laboratory	100,000
Whale Bioacoustics	102,000
Other Research Programs	27,000
Unrestricted	525,300
	$1,776,000

Funds availed of in support of the Education Program were derived principally from endowment income received in 1985 totaling $1,836,000. In addition to other funds restricted for education, unrestricted funds of $478,000 were availed of for the Education Program. Funds of $993,000 for student tuition and stipend support were provided either directly by charges to Research Grants and Contracts or indirectly through the General and Administrative overhead rate.

Your attention is invited to the Financial Statements and the notes accompanying them, audited by Coopers & Lybrand.

Joseph Kiebala, Jr.
Assistant Director for Finance & Administration
Kenneth S. Safe, Jr.
Treasurer
Gary B. Walker
Controller

Balance Sheets December 31, 1985 and 1984

ASSETS	1985	1984
Current Fund Assets (Note A):		
Cash	$ (400,913)	$ (297,484)
Short-term investments, at cost which approximates market	18,751,964	13,479,552
Accrued interest and dividends	801,934	199,040
Reimbursable costs and fees:		
Billed	544,569	949,552
Unbilled	582,666	227,153
Other receivables	327,245	333,558
Inventories	369,264	442,522
Deferred charges and prepaid expenses	56,476	210,272
Deferred fixed rate variances	(1,485,523)	(565,568)
Due to/from other funds	(7,101,406)	(5,974,165)
	12,446,276	**9,004,432**
Endowment and Similar Fund Assets (Notes A and B):		
Investments, at market:		
Bonds	22,644,406	18,417,993
Stocks	41,080,060	32,461,532
Other	1,030,789	595,013
Total investments (cost $51,019,826 in 1985 and $43,796,201 in 1984)	64,755,255	51,474,538
Cash and cash equivalents	4,008,126	4,956,614
Due to/from current fund	(104,408)	10,200
	68,658,973	**56,441,352**
Annuity Fund Assets (Note A):		
Investments, at market (cost $72,469 in 1985 and $69,614 in 1984)	125,020	100,580
Cash	2,173	1,727
	127,193	**102;307**
Plant Fund Assets:		
Land, buildings, and improvements	23,522,041	22,502,765
Vessels and dock facilities	7,425,434	7,430,092
Laboratory and other equipment	3,308,223	2,984,951
Work in progress	119,357	151,560
	34,375,055	33,069,368
Less accumulated depreciation	13,064,204	11,749,854
	21,310,851	21,319,514
Due from current fund	7,205,814	5,963,965
	28,516,665	**27,283,479**
	$109,749,107	**$ 92,831,570**

LIABILITIES AND FUND BALANCES	1985	1984
Current Fund Liabilities and Balances:		
Accounts payable, other accrued expenses and deferred revenues	$ 1,372,156	$ 1,866,436
Accrued payroll related liabilities	2,022,777	1,846,677
Unexpended balances restricted for:		
Sponsored Research	3,548,519	807,021
Education Program	589,632	425,409
Total restricted balances	4,138,151	1,232,430
Unrestricted balances designated for:		
Director's innovative fund	500,000	–
Income and salary stabilization	3,513,304	3,213,784
Ocean industry program	218,994	298,543
Unrestricted current fund	680,894	546,562
Total unrestricted balances	4,913,192	4,058,889
	12,446,276	**9,004,432**
Endowment and Similar Fund Liabilities and Balances:		
Endowment:		
Income restricted	41,872,777	34,375,632
Income unrestricted	823,704	660,710
Term Endowment	–	3,630,173
Quasi-endowment:		
Income restricted	9,944,212	8,195,972
Income unrestricted	16,018,280	9,578,865
	68,658,973	**56,441,352**
Annuity Fund Liabilities and Balance:		
Annuities payable	21,339	22,351
Fund balance	105,854	79,956
	127,193	**102,307**
Plant Fund Balances:		
Invested in plant	21,310,851	21,319,514
Unexpended, unrestricted	7,205,814	5,963,965
	28,516,665	**27,283,479**
	$109,749,107	**$ 92,831,570**

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

Anne Rabushka

Current meters await preparation in the Buoy Lab.

Statement of Current Fund Revenues and Expenses for the years ended December 31, 1985 and 1984

Revenues	1985	1984
Sponsored Research:		
Government	$38,551,142	$37,690,433
Nongovernment	5,799,530	4,904,224
	44,350,672	42,594,657
Education funds availed of	2,052,140	1,868,849
Total restricted	46,402,812	44,463,506
Unrestricted:		
Fees	658,685	486,229
Endowment and similar fund income	898,559	791,357
Gifts	525,320	827,868
Tuition	849,566	788,101
Investment income	1,191,524	1,141,562
Oceanus subscriptions	238,308	246,871
Other	287,772	251,761
Total unrestricted	4,649,734	4,533,749
Total revenues	**51,052,546**	**48,997,255**
Expenses		
Sponsored research:		
Salaries and fringe benefits	13,671,989	12,822,261
Ships and submersibles	7,830,485	7,923,030
Materials and equipment	6,454,005	6,265,839
Subcontracts	1,164,526	1,016,392
Laboratory overhead	3,948,449	3,460,402
Other	6,590,036	6,612,020
General and administrative	4,691,182	4,494,713
	44,350,672	42,594,657
Education:		
Faculty expense	575,731	522,052
Student expense	1,038,298	1,000,533
Postdoctoral programs	426,282	338,302
Other	239,631	227,270
General and administrative	250,483	231,340
	2,530,425	2,319,497
Unsponsored research	567,183	632,486
Oceanus magazine	323,250	303,102
Other activities	705,961	588,210
General and administrative	155,322	184,144
	1,751,716	1,707,942
Total expenses	**48,632,813**	**46,622,096**
Net increase – unrestricted current fund	**$ 2,419,733**	**$ 2,375,159**
Designated for:		
Director's innovative fund	$ 500,000	$ –
Income and salary stabilization	299,520	263,786
Ocean industry program	(79,549)	25,366
Unrestricted current fund	134,332	26,007
Innovative research fund	–	60,000
Education fund	36,430	–
Endowment fund	29,000	–
Plant fund, unexpended	1,500,000	2,000,000
Total	**$ 2,419,733**	**$ 2,375,159**

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

Report of the Certified Public Accountants

To the Board of Trustees of Woods Hole Oceanographic Institution:

We have examined the balance sheets of Woods Hole Oceanographic Institution as of December 31, 1985, and 1984, and the related statements of changes in fund balances, and of current fund revenues and expenses for the years then ended. Our examinations were made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the financial statements referred to above present fairly the financial position of Woods Hole Oceanographic Institution as of December 31, 1985, and 1984, the changes in its fund balances, and its current fund revenues and expenses for the years then ended, in conformity with generally accepted accounting principles applied on a consistent basis.

Coopers & Lybrand

Boston, Massachusetts
March 28, 1986

Statement of Changes in Fund Balances for the years ended December 31, 1985 and 1984

	Current Fund			Endowment and Similar Funds	Annuity Fund	Plant Fund		Total Funds
1985	Restricted	Unrestricted	Total			Invested In Plant	Unexpended	
Increases:								
Gifts, grants and contracts:								
Government	$40,683,899		$40,683,899					$ 40,683,899
Nongovernment	5,778,286	$ 525,320	6,303,606	$ 172,467				6,476,073
Endowment and similar funds investment income (Note D)	2,759,043	898,559	3,657,602					3,657,602
Net increase in realized and unrealized appreciation				12,015,371				12,015,371
Other	52,077	3,225,855	3,277,932		$ 25,898			3,303,830
Total increases	49,273,305	4,649,734	53,923,039	12,187,838	25,898			66,136,775
Decreases:								
Expenditures	(46,402,812)	(2,230,001)	(48,632,813)					(48,632,813)
Depreciation (Note A)						$(1,352,500)	$1,090,686	(261,814)
Other	(419)	–	(419)				(5,000)	(5,419)
Total decreases	(46,403,231)	(2,230,001)	(48,633,232)			(1,352,500)	1,085,686	(48,900,046)
Net change before transfers	2,870,074	2,419,733	5,289,807	12,187,838	25,898	(1,352,500)	1,085,686	17,236,729
Transfers – additions (deductions):								
Current revenues to plant fund	–	(1,500,000)	(1,500,000)				1,500,000	–
Current revenues to endowment	(783)	(29,000)	(29,783)	29,783				–
Ocean Industry Program revenues to education	36,430	(36,430)	–					–
Plant asset additions						1,343,837	(1,343,837)	–
Total transfers	35,647	(1,565,430)	(1,529,783)	29,783		1,343,837	156,163	–
Change in fund balance for the year	2,905,721	854,303	3,760,024	12,217,621	25,898	(8,663)	1,241,849	17,236,729
Fund balance, December 31, 1984	1,232,430	4,058,889	5,291,319	56,441,352	79,956	21,319,514	5,963,965	89,096,106
Fund balance, December 31, 1985	**$ 4,138,151**	**$4,913,192**	**$ 9,051,343**	**$68,658,973**	**$105,854**	**$21,310,851**	**$7,205,814**	**$106,332,835**
1984								
Increases:								
Gifts, grants and contracts:								
Government	$37,175,769		$37,175,769					$37,175,769
Nongovernment	3,841,643	$ 827,868	4,669,511	$ 56,200			$ 35,120	4,760,831
Endowment and similar funds investment income (Note D)	2,429,846	791,357	3,221,203					3,221,203
Net increase in realized and unrealized appreciation				(1,089,117)				(1,089,117)
Other	91,906	2,914,524	3,006,430		$(1,291)			3,005,139
Total increases	43,539,164	4,533,749	48,072,913	(1,032,917)	(1,291)		35,120	47,073,825
Decreases:								
Expenditures	(44,463,506)	(2,158,590)	(46,622,096)					(46,622,096)
Depreciation (Note A)						$(1,248,974)	987,160	(261,814)
Total decreases	(44,463,506)	(2,158,590)	(46,622,096)			(1,248,974)	987,160	(46,883,910)
Net change before transfers	(924,342)	2,375,159	1,450,817	(1,032,917)	(1,291)	(1,248,974)	1,022,280	189,915
Transfers – additions (deductions):								
Current revenues to plant fund		(2,000,000)	(2,000,000)				2,000,000	–
Current revenues to endowment	(777)		(777)	777				–
Current revenues to innovative research fund	60,000	(60,000)	–					–
Plant asset additions						1,305,578	(1,305,578)	–
Total transfers	59,223	(2,060,000)	(2,000,777)	777		1,305,578	694,422	–
Change in fund balance for the year	(865,119)	315,159	(549,960)	(1,032,140)	(1,291)	56,604	1,716,702	189,915
Fund balance, December 31, 1983	2,097,549	3,743,730	5,841,279	57,473,492	81,247	21,262,910	4,247,263	88,906,191
Fund balance, December 31, 1984	**$ 1,232,430**	**$4,058,889**	**$ 5,291,319**	**$56,441,352**	**$79,956**	**$21,319,514**	**$5,963,965**	**$89,096,106**

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

Notes to Financial Statements

A. Summary of Significant Accounting Policies:

Fund Accounting
In order to comply with the internal designations and external restrictions placed on the use of the resources available to the Institution, the accounts are maintained in accordance with the principles of fund accounting. This procedure classifies resources into various funds in accordance with their specified activities or objectives.

Investments
Investments in securities are stated 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. Investments for which a readily determinable market value cannot be established are stated at cost.

Income, net of investment expenses, is distributed on the unit method. Unrestricted investment income is recognized as revenue when received and restricted investment income is recognized as revenue when it is expended for its stated purpose. Realized and unrealized gains and losses are attributed to the principal balance of the funds involved.

During 1985, the Institution changed its method of accounting for endowment and similar investment income from the cash basis to the accrual basis. The effect of such change was not material.

Contracts and Grants
Revenues associated with contracts and grants are recognized as related costs are incurred. Beginning with fiscal 1978, the Institution has negotiated with the government fixed rates for the recovery of certain indirect costs. Such recoveries are subject to carryforward provisions that provide for an adjustment to be included in the negotiation of future fixed rates.

Gifts
Gifts are recorded in the applicable funds when received. 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 of $1 until such time as the value becomes known. Unrestricted gifts are recognized as revenue when received and restricted gifts are recognized as revenue as they are expended for their stated purposes.

Plant
Plant assets are stated at cost. Depreciation is provided at annual rates of 2% to 8 1/2% on buildings, 3 1/3% on Atlantis II and 5% to 33 1/3% on equipment. Depreciation expense on Institution-purchased plant assets amounting to $1,090,686 in 1985 and $987,160 in 1984 has been charged to operating expenses. Depreciation on certain government funded facilities (Atlantis II, 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.

Annuity Funds
On the date of receipt of annuity fund gifts, the actuarially computed value of the future payments to annuitants is recorded as a liability and any excess amount of the gift is credited to the fund balance. The actuarial values of the liabilities are recomputed annually.

B. Endowment and Similar Fund Investments:

The cost and market value of investments held at December 31, 1985, and 1984, are as follows:

	December 31, 1985 Cost	December 31, 1985 Market	December 31, 1984 Cost	December 31, 1984 Market
Government and government agencies	$13,766,881	$15,143,553	$15,191,373	$15,949,425
Convertible bonds	945,900	1,021,125	268,125	287,000
Corporate bonds	6,096,258	6,479,728	2,162,592	2,181,568
Convertible preferred stocks	–	–	295,715	222,000
Common stocks	29,213,055	41,080,060	25,297,331	32,239,532
Venture capital	897,732	897,732	481,065	481,065
Other	100,000	133,057	100,000	113,948
Total investments	**$51,019,826**	**$64,755,255**	**$43,796,201**	**$51,474,538**

C. Pooled Investment Units:

The value of an investment unit at December 31, 1985, and 1984, was $1.5343 and $1.2652 respectively. The investment income per unit for 1985 and 1984 was $.0819 and $.0723 respectively.

	1985	1984
Unit value beginning of year	$1.2652	$1.2896
Unit value end of year	1.5343	1.2652
Net change for the year	.2691	(.0244)
Investment income per unit for the year	.0819	.0723
Total return per unit	$.3510	$.0479

D. Endowment and Similar Fund Income:

Income of endowment and similar funds consisted of the following:

	1985	1984
Dividends	$1,127,993	$995,476
Interest	2,861,294	2,534,382
	3,989,287	3,529,858
Investment management costs	(331,685)	(308,655)
Net investment income	$3,657,602	$3,221,203

E. Retirement Plan:

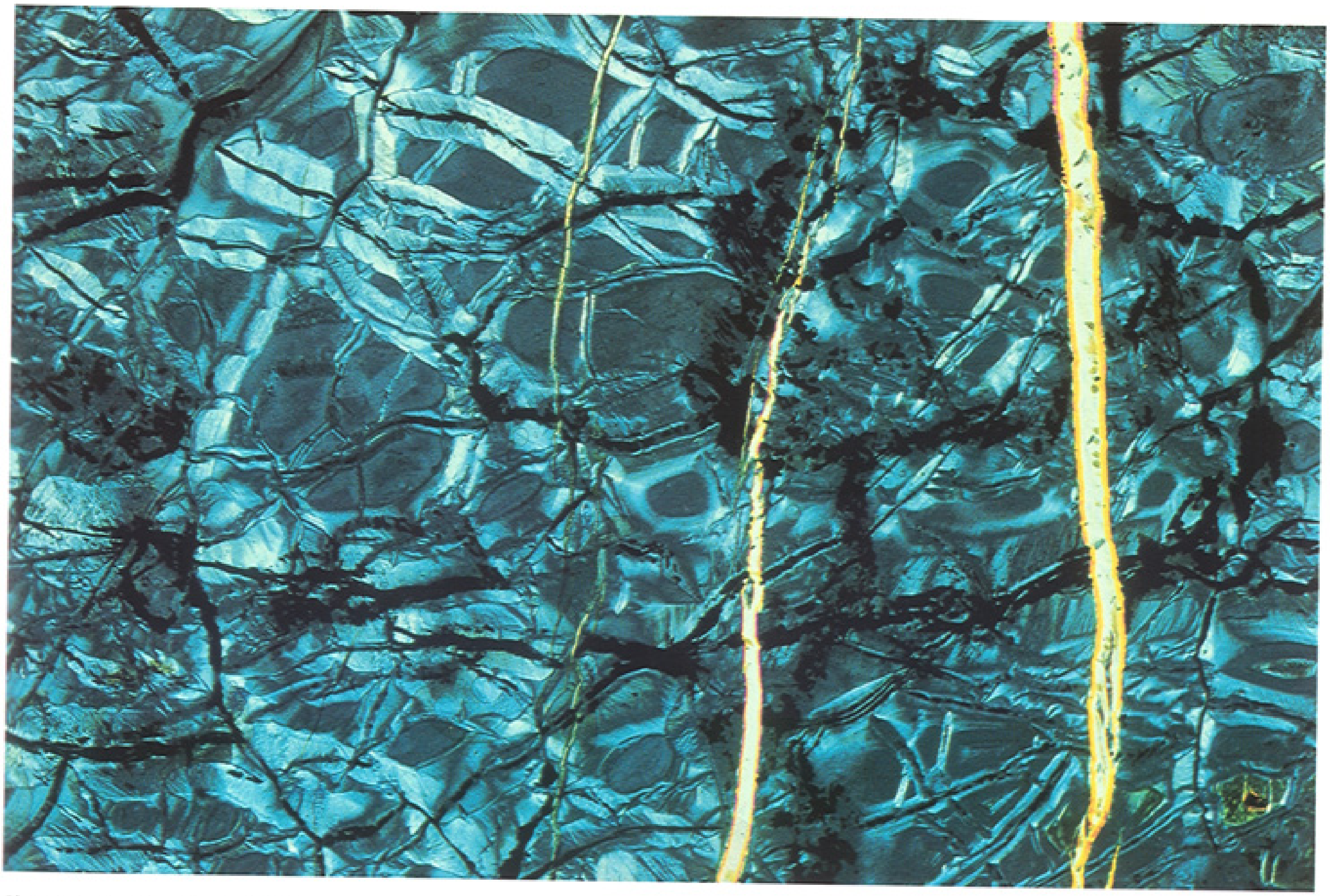
The Institution has a noncontributory defined benefit trusteed retirement plan covering substantially all full-time employees. The Institution's policy is to fund pension cost accrued which includes amortization of prior service costs over a 30-year period. Retirement plan costs charged to operating expense amounted to $2,329,000 in 1985 and $2,310,000 in 1984, including $221,000 and $190,700, respectively, relating to expenses of the retirement trust. As of January 1, 1985 (the most recent valuation date) the comparison of accumulated plan benefits and plan net assets is as follows:

	January 1 1985	1984
Actuarial present value of accumulated plan benefits:		
Vested	$23,978,594	$21,570,874
Nonvested	1,292,780	1,161,858
Total actuarial present value of accumulated plan benefits	$25,271,374	$22,732,732
Net assets available for plan benefits	**$35,726,839**	**$31,286,294**

The assumed rate of return used in determining the actuarial present value of accumulated plan benefits was six and one-half percent compounded annually.

F. Post-Retirement 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 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 tptaled $119,300 in 1985 and $103,779 in 1984.



Photomicrograph of a serpentinite formed by the reaction of seawater with a mantle peridotite from the Islas Orcadas Fracture Zone in the South Atlantic. The rock was dredged from a depth of 4000 meters (13,000 feet). Seafloor spreading along the Southwest Indian Ridge most likely brought this rock to the surface from a depth of 60 to 100 km (36 to 62 miles).