The relationship of ocean and atmosphere has been a long-term interest of Institution staff. One of the many research programs conducted by the Physical Oceanography Department on this question, the Frontal Air-Sea Interaction Experiment (FASINEX), took place between January and June 1986 in the Gulf Stream vicinity near Bermuda. Electronics Engineer Jerome Dean took this photograph as R/V *Oceanus* sailed past FASINEX Buoy "D" after deployment. Shown on the buoy are the meteorological sensors for wind speed and direction, temperature, solar radiation, barometric pressure and relative humidity. A spare satellite transmitter was installed in the red cannister on the left when the system transmitter began acting erratically. The buoy also supported an array of ocean current and temperature instruments spaced along the three miles of steel wire and nylon rope to the ocean bottom. Data was recorded internally on tape every 7½ minutes around the clock during the buoy's five-month deployment.

About the covers:

Front: A fractal image, similar to ocean waves, generated on a computer from a simple mathematical formula. © 1986 Art Matrix

Back: Colorful sea stars (top photo) and fishes in the Galapagos Islands were photographed by Diving Safety Officer Terrence Rioux during a December 1985 visit to the islands. Pictured in the bottom photograph are a Pacific creolefish (at left, with white spots), a parrotfish (blue) and a wrasse (pink, partly hidden behind the parrotfish). The Institution's Marine Policy Center has worked with the Government of Ecuador to develop a marine resource management plan for the archipelago.

Annual Report 1986

Shelley M. Lauzon, *Editor & Designer*
Reynolds-DeWalt Printing, Inc., *Printer*
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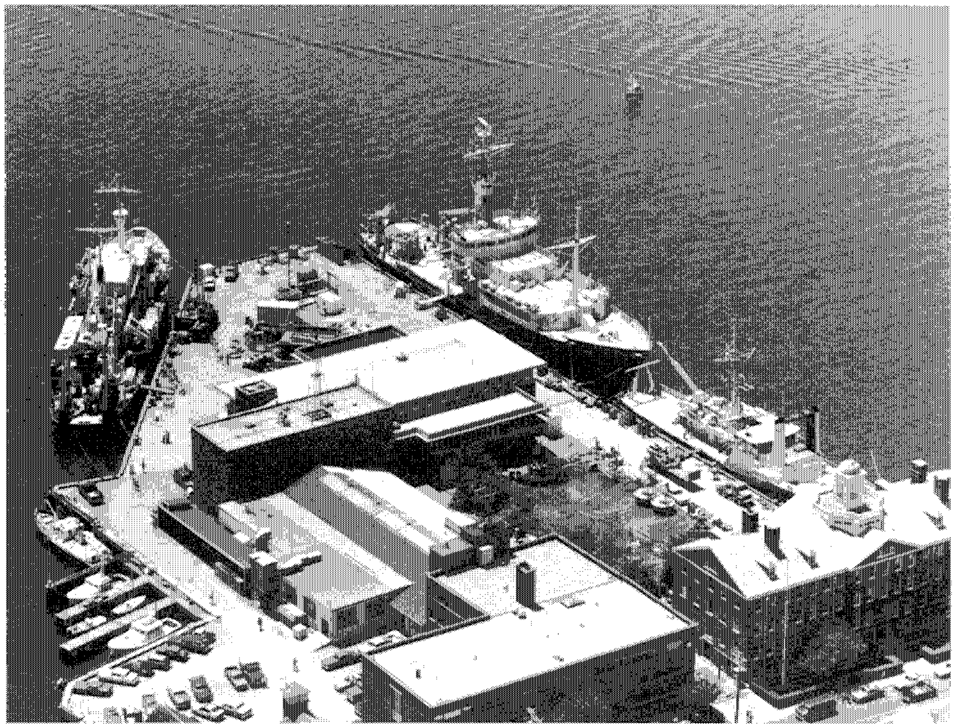
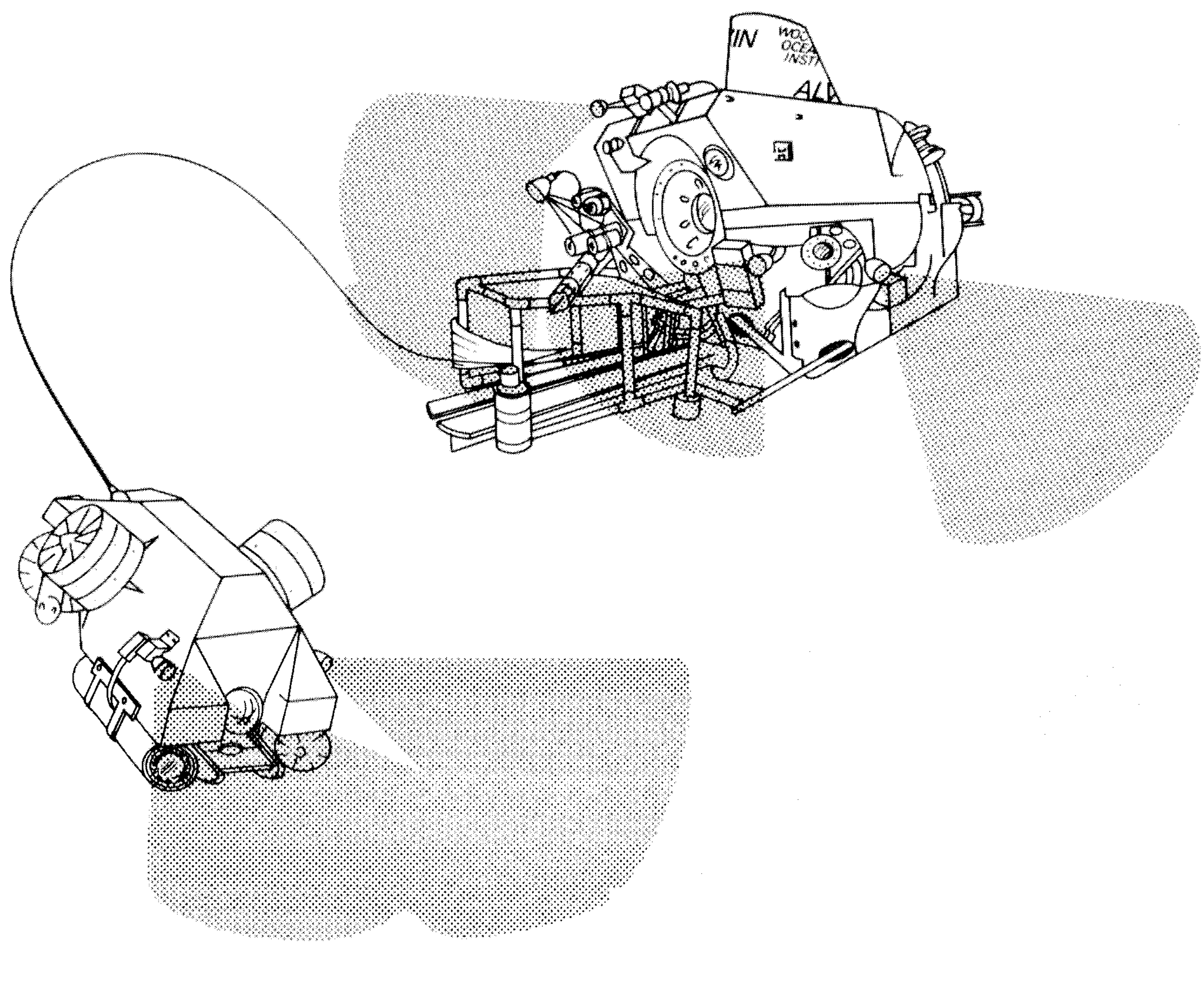


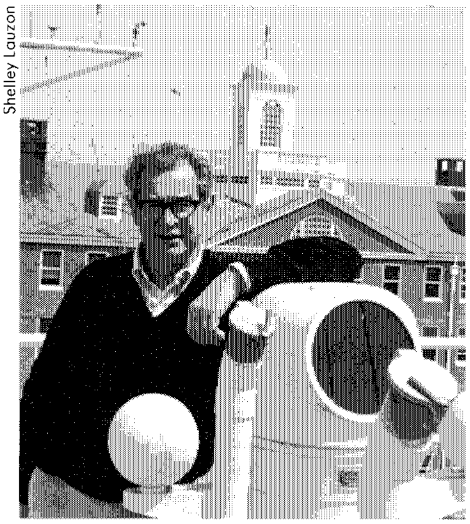
Left: Aerial view of the Institution's pier facilities, taken in July 1986. Iselin Marine Facility is at left, Bigelow Laboratory at right. R/V *Atlantis II* is at left, *Knorr* at top right and *Oceanus* at right. Bottom: Artist's sketch of DSV *Alvin* and prototype vehicle JASON JR. as they were linked for the July test cruise on R.M.S. *Titanic*.

Drawing by E. Paul Oberlander



Directors' Comments

John H. Steele



Shelley Lauzon

Last year I expressed concerns about the long-term support of basic sciences such as oceanography. Events since then make the general outlook more optimistic. We now have new programs dealing with global changes in our environment over the next decade. These programs have ocean science as a central and critical component requiring significant increases in support. How will these initiatives fare in the context of budget deficits? What should the role of the Institution be in such matters? We need to address a hierarchy of questions.

1. Why should the nation support basic research?
2. Where do the global geosciences fit into this scheme?
3. How should this Institution be involved?

Oceanography has become a significant proportion of the funding of basic science and this Institution has benefitted. In this context advances in ocean science are dependent on increases over the longer term in general support of basic research in the National Science Foundation (NSF) and other federal agencies. As an example, at the present time the Woods Hole Oceanographic Institution takes nearly twenty-five percent of the funding available for oceanography within the NSF. In turn, the geosciences as a whole receive about twenty percent of the total NSF budget.

Eric Bloch, Director of NSF, has defined three reasons to support basic research:

1. Intrinsic intellectual value
2. Make the nation's economy more competitive
3. Accomplish national missions such as defense, health

The initial response has been excellent. The President's budget for Fiscal Year 1988 states that "support for basic research is a key factor in generating sufficient new knowledge to ensure continued technological innovation." In the President's statement, there is the long-term aim of doubling the NSF budget by 1992.

Within each of the general criteria set out by Mr. Bloch, a good case can be made for oceanography. The intrinsic intellectual value of such ocean science achievements as plate tectonics is recognized, and the great potential of the new global programs is accepted as a major theme by all the agencies involved in marine research. Thus we can meet the first criterion.

Regarding the nation's economy, the second criterion, we can point to past examples of the importance of ocean studies in relation to petroleum discovery and the reserves of strategic minerals. There are many examples of future potential such as the use of the oceans in biotechnology, in waste disposal and in coastal protection. As our population increasingly comes to live near and use the Exclusive Economic Zone (seventy-five percent will live within 50 miles of the sea by the year 2000), our understanding of this coastal environment becomes crucial.

It is necessary to realize that these are national as well as local issues. The National Oceanic and Atmospheric Administration within the Department of Commerce should have a leading role, with other agencies, in developing the scientific and technical basis. Yet it is in this link between ocean science and its long-term benefits that we see significant decline in support. This issue, like our concern with the sea itself, lies at the boundary between individual economic advantage and the national welfare. We must not allow this essential element in our national agenda to be lost between the goals of particular economic gains and general benefits.

Turning to the third criterion, support for national missions, we have demonstrated the importance of our defense strategies, of new technologies and a knowledge of ocean dynamics. We can point to support from the Secretary of the Navy. The Office of Naval Research has a unique role in defining and funding basic research related to their objectives. The Navy's interest in understanding and predicting intermediate scale events in the ocean complements the larger-scale programs and our need to maintain a global presence. We are beginning to see a reversal in the trend over the last decade of declining Navy support for ocean science.

Eric Bloch selects health as a second example in this general area of government missions. In this context we have become increasingly aware that our biggest problems are not so much with individual cures as with general prevention and this is one reason why it is a national concern. There is a similar basis for putting the global programs in this category. As we change from short-term weather prediction towards longer-term capabilities to forecast climate, we are moving from the small-scale, and almost individual, interests to the larger social concerns. These concerns must necessarily be national and sometimes international in character. And so, the support of this work must rely on organizations, not merely federal, who have such general concerns as their mission.

If we wish to achieve this social context for our research, then we must create a general awareness of the importance and significance of these studies. It is apparent that the intellectual value and the coherence of our programs is a very necessary, but not a sufficient, condition for the advances that we wish to see. We need to obtain support in several constituencies. Two of these are apparent from this discussion – the federal agencies and the Congress. But beyond this and as the final arbiter, we must make the general public more aware of these issues. This Institution is unique in oceanography, and in having among its Trustees and Corporation Members diverse and influential colleagues who can guide us in this larger arena.

Areas of Interest

Departments

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 and animal behavior. Work on marine pollution includes research on the effects of 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, and nutrient cycling in coastal waters. The symbiotic relationships between marine microbes and other organisms (including wood-borers) are a recent 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 interaction at spreading centers are under investigation as chemists consider the processes taking place at major ocean boundaries. Some critical questions in chemical oceanography revolve around the vertical transport and transformations in particles as they fall from the surface waters to the bottom of the water column. 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 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.

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 is 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 this complicated region 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 undeway, 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 and to meteorology. Physical oceanographers come to the subject with a variety of backgrounds: mathematics, physics, engineering, computer science, and chemistry. The mix of interests provides a broad approach to the equally broad range of problems in the ocean.

Research Centers

Center for Marine Exploration

A Center for Marine Exploration (CME) was established in late 1986 to foster the continued development of unmanned deep ocean systems and to provide a focal point for marine scientists and others to explore the deep sea. CME, directed by Geologist Robert Ballard, has four primary goals: 1) to provide scientists with more advanced and cost-effective techniques for deep ocean exploration, furnishing the means to conduct seafloor experiments; 2) to enable engineers and technicians to create new technologies for the deep sea; 3) to provide marine archaeologists and other social scientists opportunities to utilize this technology for cultural and historic purposes; and 4) to increase public awareness of the marine environment by making scientific and technological advances and discoveries available to the public through visual means.

The capabilities and promise of unmanned robotic submersibles gained international attention with the discovery of R.M.S. *Titanic* in 1985. The ARGO and JASON JR. prototype vehicles, developed in the Institution's Deep Submergence Laboratory, were deployed and tested for the first time in the search for *Titanic* in 1985 (ARGO) and the detailed exploration of the wreck and its interior in 1986 (JASON JR.). These systems will allow many more scientists as well as the public to be able to participate in marine exploration by being able to see and experience the challenges, excitement – and setbacks, of scientific discovery.

A major focus of the Center will be the continued exploration of the 46,000-mile Mid-Ocean Ridge, the largest geological feature on earth. Research on this vast underwater mountain range has led to the accepted theory of plate tectonics and seafloor spreading, but the ridge stem remains largely unexplored and little understood. In December 1985 the Institution's ARGO system imaged an area of ridge terrain in just one week equal to all that previously viewed from manned submersibles, proving the capabilities of unmanned vehicle systems.

CME will also continue to attract skilled technicians and experts in such areas as materials science, electronics engineering, image processing, acoustics, optics, mechanical engineering, computer sciences, robotics and telecommunications to aid marine scientists in developing unmanned submersibles. The Institution's intention through CME is to add vitality to deep ocean exploration and to greatly increase the scope of exploration, which will further basic knowledge and man's ability to use the marine environment, providing a scientific and cultural window to the deep ocean.

Coastal Research Center

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 directed by Chemist John Farrington.

Coastal Research Center activities have continued to focus in four principal project areas in 1986. The first, Assimilative Capacity of the Oceans to Receive Wastes, involves a multidisciplinary team of scientists with Institution Sea Grant Program and private foundation funding who are researching the generic aspects of chemical pollution problems in Buzzards Bay and the U.S. Environmental Protection Agency (EPA) Superfund Hazardous Waste Site in New Bedford Harbor-western Buzzards Bay. The project incorporates graduate student research efforts and has already provided significant new predictive capabilities with regard to the fate and effect of organic chemical pollutants in coastal waters.

Relative Sea Level Change – the accurate assessment and prediction of relative sea level change as a result of many factors including a warming climate and the resulting consequences of human activities in coastal areas – has been the focus of a project in cooperation with the Marine Policy Center. An assessment of factors controlling relative sea level change in several large river delta areas around the world was undertaken in 1986.

Two large seawater flumes for experiments measuring turbulence, sediment resuspension and transport, and interactions with marine biota are now operational in the Coastal Research Laboratory. A major project of the past five years, the Georges' Bank Book, has gone to press and will be published in 1987.

Marine Policy Center

The Marine Policy Center, directed by Social Scientist James M. Broadus, provides a multidisciplinary setting for scholars to conduct research on problems associated with the increasing use of the world's oceans. Since its establishment in 1971, the Center has been a principal source of independent, authoritative assessment of national and international marine policy issues. Emphasis is placed on the economics of ocean space and on the role of science in governmental and industrial decision making. The accelerating pace of scientific and technical change, together with increases in the scale of effects from human activities, is reducing the "reaction time" for public policy responses to new knowledge and new developments. It becomes increasingly important, therefore, to understand the uses of marine scientific and technical information in the policy-making process and the ways in which scientific and technical progress are themselves endogenous to policy choices. A primary objective for research at the Center is to facilitate reduction of the "policy lag" so that effective policy responses to a rapidly changing world (and sometimes even more rapidly changing understanding of that world) can be achieved on a timely basis. The Center's threefold functions are: 1) *Research* through the efforts of an experienced professional staff and Research Fellows; 2) *Education* through the prestigious Marine Policy Fellowship program, institution seminars, and interaction with students; 3) *Forum for information exchange* through sponsorship of workshops and conferences. Individually and as small teams, the Marine Policy Center's staff and Fellows engage in both specialized disciplinary and broader interdisciplinary research projects. The research program concentrates on the following thematic areas: (1) Marine Science and Public Policy; (2) Development and Management of Ocean Resources; (3) Ocean Jurisdictions, Law of the Sea, and International Relations; and (4) Areawide Planning and Management. Cooperative International Marine Affairs programs have been initiated with developing nations interested in addressing information 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 research in marine affairs. Through the publication of research results, the staff and Fellows have established a solid reputation for the Center in many areas of marine policy and ocean management. Examples of some current research projects include: Economic and Legal Aspects of Marine Minerals (J. Broadus and Porter Hoagland); A Marine Reserve for the Galápagos Islands (Arthur Gaines); Valuation of Coastal Groundwater Quality (Steve Edwards); Economic Implications of Sea Level Change (Andy Solow and Steve Edwards); Federal-State Consistency in Coastal Management (Jack Archer and Tim Eichenberg); International Politics of Marine Pollution (Peter Haas and K. Ramakrishna); and Antarctica and the Law of the Sea (Chris Joyner).

Reports On Research

Derek W. Spencer

Scientific research in recent years has yielded new knowledge of the earth at an ever increasing rate. Studies of the oceans, continents, atmosphere, biosphere and cryosphere have delineated with greater clarity many of the complex interactions among the earth's components and the profound effect of these interactions, not only upon earth history and evolution, but also upon the earth's environment and resources whose qualities are critical to the welfare of mankind.

In the past, investigations in earth science have been motivated by an innate curiosity about our planet and also by the search for practical benefits to improve the quality of human life. Now, a third urgent factor has emerged. Humans are no longer simple spectators to the drama of earth evolution. They have become active participants on a world-wide scale, contributing to processes of global change that will significantly alter our habitat within a few generations.

The need for a unified global perspective of the earth system has become compelling, and the ocean and its interactions with the atmosphere and crust are the central frame of this perspective. In India and Southeast Asia, for example, the monsoon has long been recognized as controlling the success of the harvest. But the monsoon is affected by the "Southern Oscillation", flip-flops in the major atmospheric pressure cells of the Indian and South Pacific Oceans which, in turn, affect the El Niño condition in the ocean off Peru. In 1972 and 1982-1983, El Niño devastated Peruvian fisheries and was felt in many other ways. The events of the 1982-1983 El Niño have been linked to the disruption of ecosystems as far away as the Gulf of Alaska, to the triggering of storms that ravaged the west coast of North America, to the drenching of the U.S. sun belt with unusually heavy rains, and to several other extreme weather conditions throughout the world.

Shelley Lauzon

On longer time scales, the interaction of the ocean and the earth's crust have lead to major mineral and petroleum accumulations. An understanding of the processes contributing to the formation of these resources are essential for their discovery and wise exploitation.

The growing realization of the importance of the study of the ocean and the crust beneath it has led to major initiatives of the National Science Foundation designed to accelerate our understanding of the ocean's role in the earth system. These initiatives cover two broad areas: *Global Ocean Studies* of the physical circulation and major biogeochemical cycles of the world's oceans, and *Ocean Lithosphere Studies* of the crust beneath the ocean.

In this year's Annual Report, we highlight some of the science at Woods Hole Oceanographic Institution that has been instrumental in launching these initiatives, and review some of the planning and programs that will form a major focus of our future work.

Global Ocean Circulation

Introduction

James F. Price

Physical Oceanography is undergoing a rapid change in the way in which science programs are being planned and organized. In some ways the changes could be described as a trend towards "big science" in place of the smaller, often one-man, research programs that were the norm in the 1960s and 1970s. In fact, most oceanographers were attracted into the field by both the topic and the opportunity for individual research that oceanography offered. Those opportunities still exist, of course, but there is an unmistakable and perhaps inevitable trend towards research programs that have a genuinely global scale, that demand multi-investigator and even multi-national cooperation. The global scale of these programs comes from a pressing need to understand the ocean's role in climate change, and global scale observation programs are made thinkable today by the maturation of a variety of satellite-based observational systems.

The support for these new global scale research initiatives will be organized around three national programs plannned to begin in the early 1990s. Taken together, they represent a very substantial increase in the total level of funding and research in physical oceanography. The World Ocean Circulation Experiment (WOCE) will seek to describe the general circulation of the world ocean so that changes in the circulation that accompany climate change can be recognized, monitored and modelled. The Global Ocean Flux Study (GOFS) aims to observe the oceanic transport of climatically and biologically important chemicals and materials (e.g., carbon). A third program, Coastal Ocean Dynamics and Fluxes (CODF) has goals much like WOCE and GOFS but will emphasize the continental shelf. Woods Hole Oceanographic Institution scientists will play a major role in the planning and execution of these programs. Some of the steps being taken in these directions are discussed in the following pages.

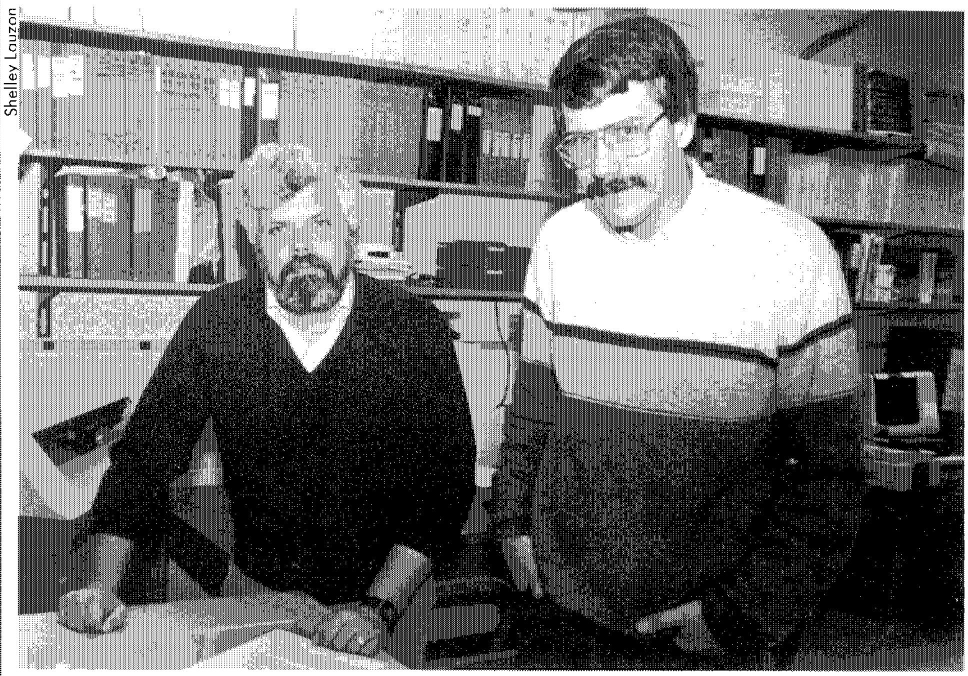
The WOCE Hydrographic Program

Terrence M. Joyce and William J. Jenkins

The primary scientific objective of the World Ocean Circulation Experiment (WOCE) is to understand the general circulation of the global ocean well enough to be able to model its present state and predict its evolution in relation to long-term changes in the climate. The large-scale circulation includes not only ocean currents which are directly observable (for example, by current meters or ship drift), but also processes of watermass formation, modification and movement which are more indirectly studied. Both are important to WOCE, and it is of value to not only determine the 'mean' circulation, but also its variability on as many time and space scales as possible.

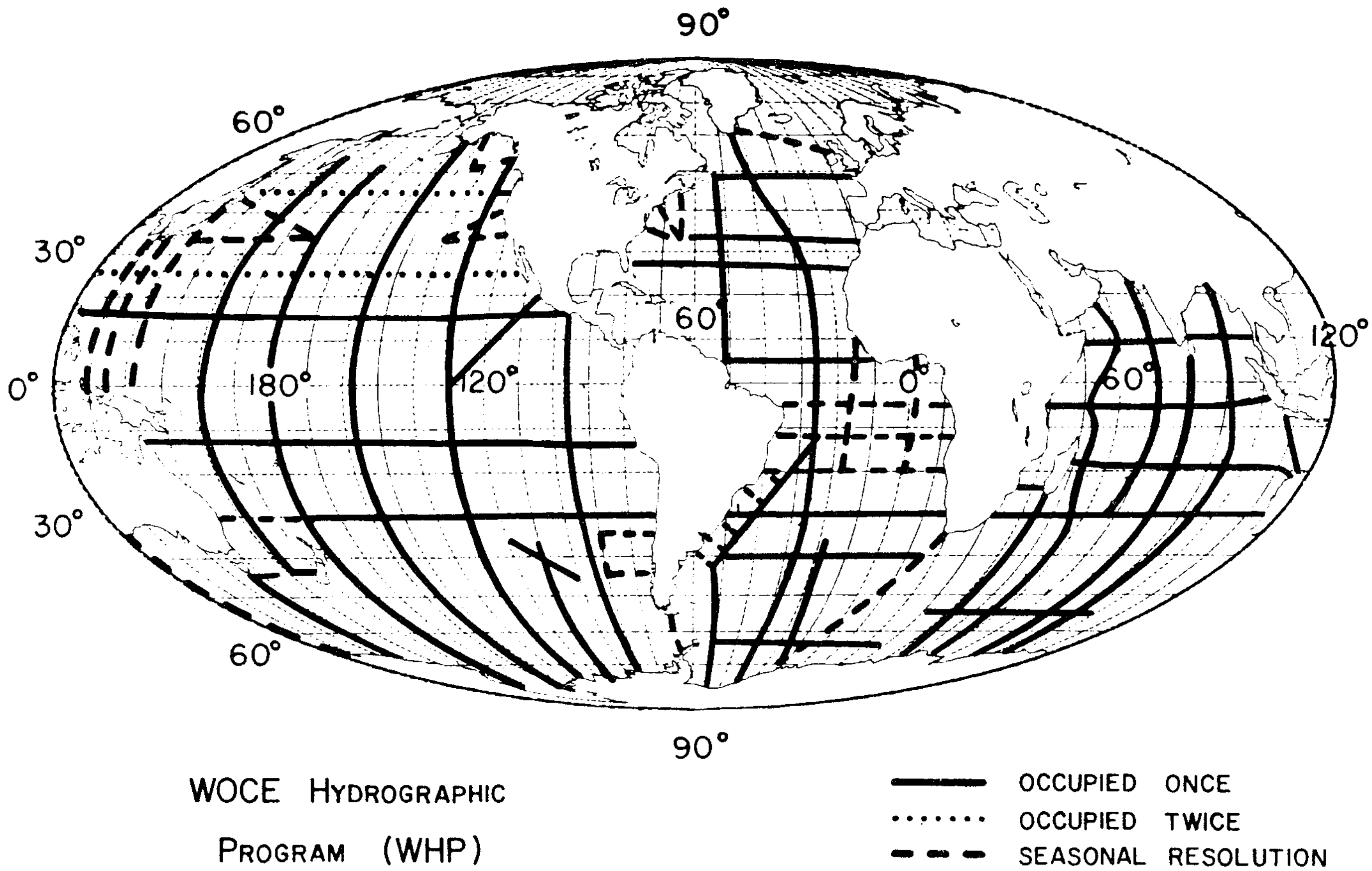
The field program to meet these objectives will be both intensive, with repeated sampling in certain critical regions, and extensive, with a global coverage. The in situ programs will take advantage of the opportunity to obtain multi-year, global observations from the next generation of ocean observing satellites. There are a number of 'tools' that will be used in WOCE to study ocean circulation, including satellites, drifters, floats, moored buoys and tide gauges. But perhaps the most venerable involves the measurement of the distributions of density, temperature, salinity and chemical tracers. From this, one infers the distribution and sources of water-masses and their flow velocities and patterns. Thus an important component will be a major effort to improve our knowledge of these distributions through the WOCE Hydrographic Program (WHP). The primary goal of the WHP is to obtain high-accuracy global hydrographic and geochemical tracer measurements.

Shelley Lauzon



Terry Joyce (left) and Bill Jenkins

Although the details remain yet to be determined, estimates have been made that some seven to eight years of ship time will be needed over the five-year intensive observation period beginning in 1990. No single oceanographic institution or nation has the resources to provide either the ships or measurement capability to undertake this program; thus, the WHP will be international with different countries, laboratories, and research vessels involved. It will be important to ensure uniformity of measurement techniques and intercalibration, if data accuracy is to be maintained. One approach may be to use a small number of dedicated



Proposed tracklines for the global survey to be undertaken as part of the WOCE Hydrographic program (WHP).

ships manned, in part, by specially trained teams of skilled and experienced oceanographers.

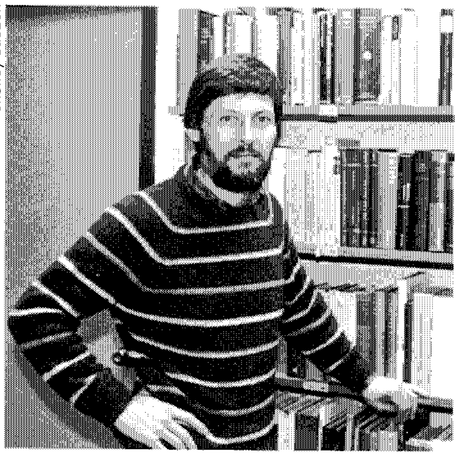
The overall scope of the WHP has been developed in a series of national and international planning meetings over the past two years. This plan is still evolving. At the present time, the proposed tracklines for the global survey are shown in Figure 1. In many cases, especially for the South Pacific and Indian Oceans, the sections will provide data where none now exists. In other cases, the sections will repeat those taken in the past so that decadal and longer time-scale changes in the circulation and tracers can be detected. Some of the sections will be repeated seasonally in regions where the general circulation is known to have strong variability. In addition, certain sites will be chosen for temporal sampling over a long period of time to extend the time series of observations beyond the five-year intensive period of WOCE. These will be important for establishing the long-term climatic change in the ocean. The primary practical objective of WOCE is to provide the scientific background for an observing system for long-term measurement of the large-scale circulation of the ocean in the future.

Except for a concerted effort to cover a single ocean basin in a short period of time (e.g., the Atlantic hydrographic survey during the International Geophysical Year(s) in the late 50's), our observations of the global circulation have been accumulated over many decades with a wide variety in the accuracy of the hydrographic measurements. New technologies and the utilization of new tracers, some of which are transient in their input to the ocean (due to man's influence) have given us new tools and an impetus to collect a global 'five-year snapshot' of the state of the ocean. This will, on the one hand, permit oceanographers to compare the present ocean with that of the past, and will also provide an accurate global baseline for detection of future changes in the ocean, some of which may be induced by man.

Deep Circulation Studies for WOCE

Nelson G. Hogg

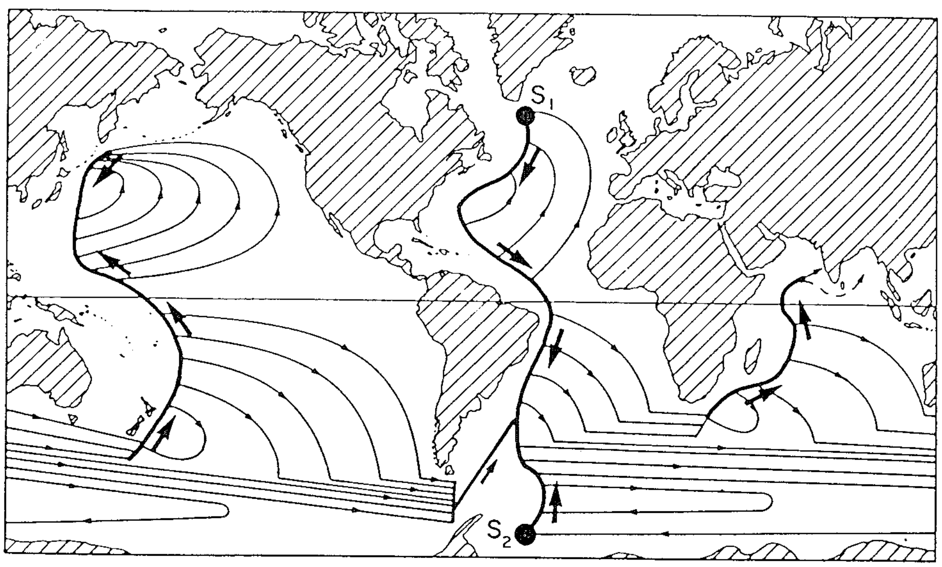
Shelley Lauzon



Top: Nelson Hogg. Bottom: Stommel's (1958) scheme for deep water circulation supplied by two polar sources (S_1 and S_2).

Our understanding of the deep circulation is largely based on the scheme put forth by Stommel (1958) nearly thirty years ago. For the deep waters of the world's oceans to remain cold in the presence of downward diffusion of heat from the thermocline, an upward advection is demanded. Continuity of mass and geostrophy then require that the interior flow is everywhere poleward, and this must be supplied by deep western boundary currents. Verification of this model has been confined to the search for the intense deep boundary currents. An abortive attempt to measure the interior meridional flows led to the discovery of the intense mid-ocean mesoscale eddy field (Crease, 1962; Swallow, 1971).

While the existence and strength of some of these deep boundary currents have been documented by direct measurement, the global picture remains fragmentary. Further work will be done during the World Ocean Circulation Experiment (WOCE) to round out this picture. It is equally important that the heat and mass transport be quantified, for these will be important constraints on inversions of hydrographic data and numerical models. Especially straightforward places to measure the deepest flows are the abyssal passages – Samoan Passage, Vema Channel, Romanche Fracture Zone – where flows are both confined and intensified. Previous work suggests that a relatively modest number of moorings and current meters are adequate to obtain reasonable transport estimates at these locations. Measurements are also needed at one location on the deep boundaries in each of the major ocean basins as well as in each of the major passages. Past measurements suggest that these abyssal flows are relatively steady. There is no reason to believe that they need to be made simultaneously although long-term observations are needed for verification. Durations of one to two years are probably sufficient. Presently, proposals are being formulated by Whitehead (4°N in the western North Atlantic), McCartney (equatorial North Atlantic and Vema Fracture Zone), and Warren and Owens (42°N in the western North Pacific).



The interior flow problem is much more difficult because mean speeds are estimated to be no more than a few millimeters per second. However, understanding of the interior circulation and how it is driven is central to WOCE objectives. Does upwelling from the deep ocean occur as a broadly distributed, quasi-uniform process as Stommel originally envisioned, or is it confined to boundaries or ridges where flows are larger as others have suggested? One can envision a large experiment focused on this problem which would require boundary current transports to be quantified at three or four locations along the western boundary of a single basin (i.e., the Brazil Basin) so that the change in boundary current flux could be related to upwelling determined by inversions of interior hydrographic and float observations. This would be a demanding experiment with long-term deployments (five years, perhaps) of a large number of current meter moorings and deep floats. Careful hydrographic work incorporating measurement of selected tracers, and perhaps including the purposeful release of some tracers, would be required. Some exploratory work with Lagrangian floats is demanded before such an ambitious basin scale field program is conducted.

Oceanic Subduction

James F. Price

Studies of the distribution of temperature and salinity in the North Atlantic begun by Woods Hole Oceanographic Institution scientists Raymond Montgomery and Columbus Iselin during the mid-1930s revealed some important clues on the structure and origin of waters in the main thermocline. One of the most graphic representations was given by Iselin (Figure 1), who showed that the temperature and salinity relationship of waters observed in a *vertical* profile through the main thermocline bore a striking resemblance to the temperature and salinity relationship found along a *horizontal* section made from north to south along the sea surface. The comparison was best when the sea surface data were taken from the late winter. The inference to be drawn is that the waters of the main thermocline are formed, in the sense of acquiring their values of temperature and salinity, at the sea surface in late winter and then conserve these properties as they flow through the thermocline of the subtropical gyre. Because the flow of denser waters from high latitudes must go underneath warmer waters at subtropical latitudes, this process of flow from the sea surface into the thermocline has been termed "subduction", in analogy with the motions of crustal plates in plate tectonics theory.

Important new evidence of this oceanic subduction has been developed within just the past few years from studies of the distribution of short-lived radio isotopes by Institution colleague William Jenkins of the Chemistry Department. Jenkins' method leads to an estimate of the elapsed time since a given water sample has been in close contact with the atmosphere. The time since contact with the atmosphere may be thought of as the age of the water. Observations of age within the thermocline of the eastern North Atlantic (Figure 2) show that waters have moved southerly since contact with the atmosphere, as would have been expected from the earlier Iselin and Montgomery studies. And, consistent with the concept of oceanic subduction, older waters are found beneath younger waters. Jenkins' data also

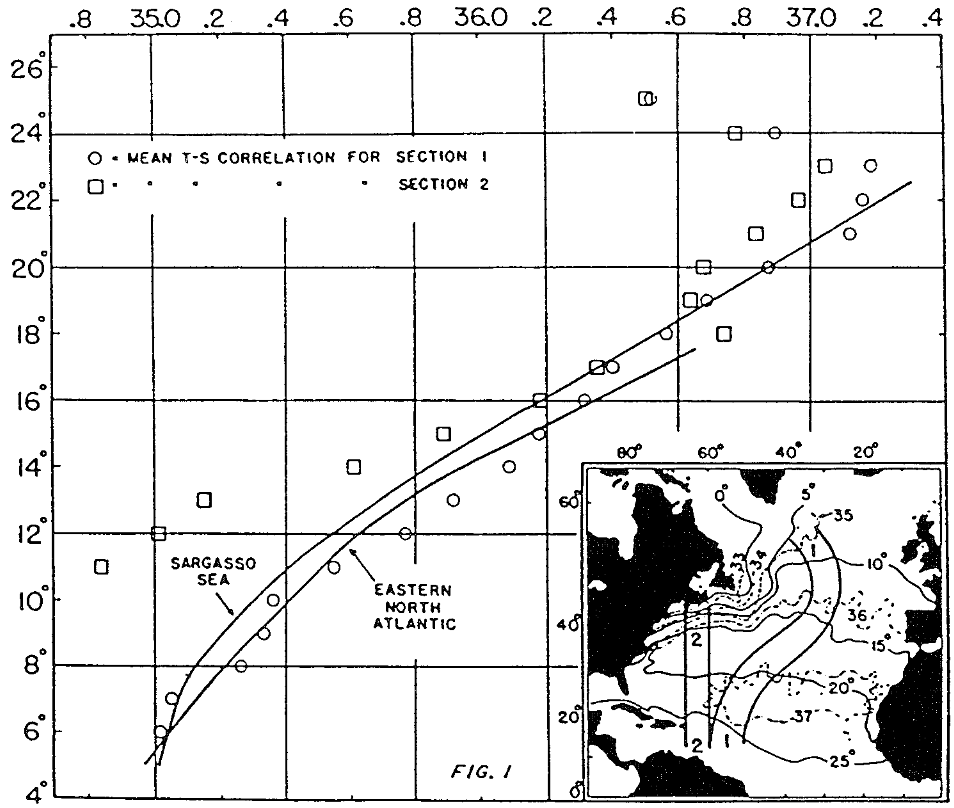
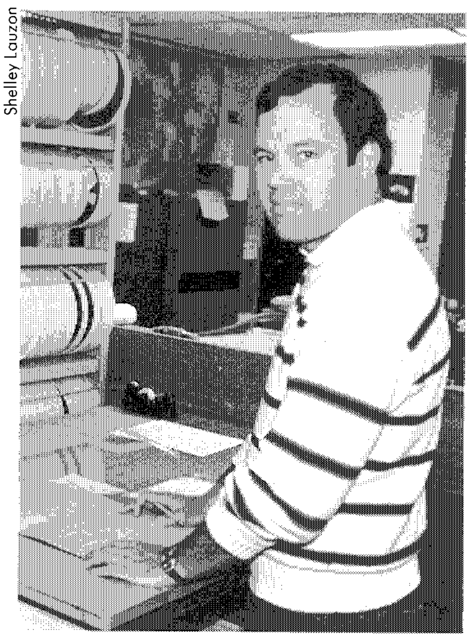


Figure 1: A temperature and salinity diagram from Iselin (1939) showing vertical profiles of temperature as a function of salinity (solid lines) and an equivalent horizontal profile along the sea surface in late winter (open symbols). Right: Jim Price.

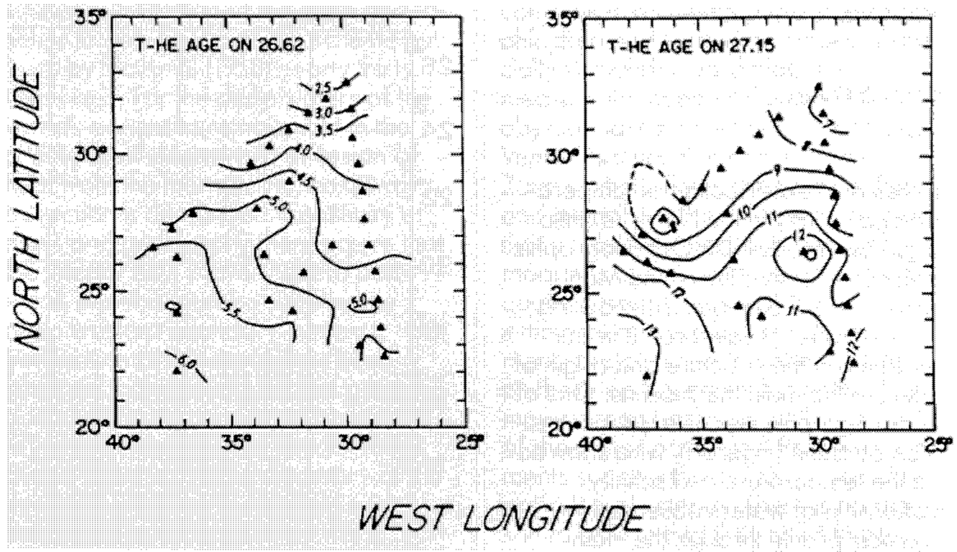


Shelley Louzon

shows the *rate* at which subduction occurs, and thus provide what is in some ways a more detailed and revealing view of the flow through the main thermocline than was ever available from observations of temperature and salinity alone. The challenge to physical oceanographers is to understand these age distributions in terms of the atmospheric forcing by wind and heat fluxes, and within the context of the large scale dynamics of the gyre.

These new observations of water age by Jenkins have been an important stimulus for planning future studies aimed at observing and modelling the subtropical gyre. Subduction provides one focus for these new studies by emphasizing the vertical component of flow within the thermocline, and also the role of surface heat fluxes which set the initial temperature and salinity at the sea surface. Measurement of these quantities requires new observational tools which are now being developed or tested at the Institution.

One such tool is a new kind of SOFAR (SOund Fixing And Ranging) float, dubbed the "Bobber" (Figure 3), which will be able to control its buoyancy to follow the vertical motion of prescribed temperature surfaces. The Bobber will make daily vertical excursions to find the depth of the prescribed temperature surfaces, and then telemeter their depths by acoustic signalling to listening stations (see the "Floats and Drifters" article by Philip Richardson in this report). The Bobber will drift passively with the horizontal flow between the isotherms, and thus provide a means to track water columns as they move horizontally and vertically through the gyre thermocline. The development of Bobber floats is being led by Douglas Webb of Webb Research (formerly of WHOI) in Falmouth, Massachusetts, and assisted by the SOFAR float group at the Woods Hole Oceanographic Institution. The first deep sea trial of Bobbers occurred in the spring of 1986 and validated the engineering design and the acoustic signalling. Further sea trials of the Bobbers, and the first scientific deployments to observe subduction, are planned for the fall of 1987. Larger and more comprehensive studies of the subtropical gyre and of subduction are now being planned as part of the World Ocean Circulation Experiment (WOCE) to begin in the early 1990s. At that time, satellite remote sensing and other kinds of new and simpler floats and drifting buoys will be working along with the Bobbers to observe the gyre-scale circulation and thermocline structure within which subduction occurs.



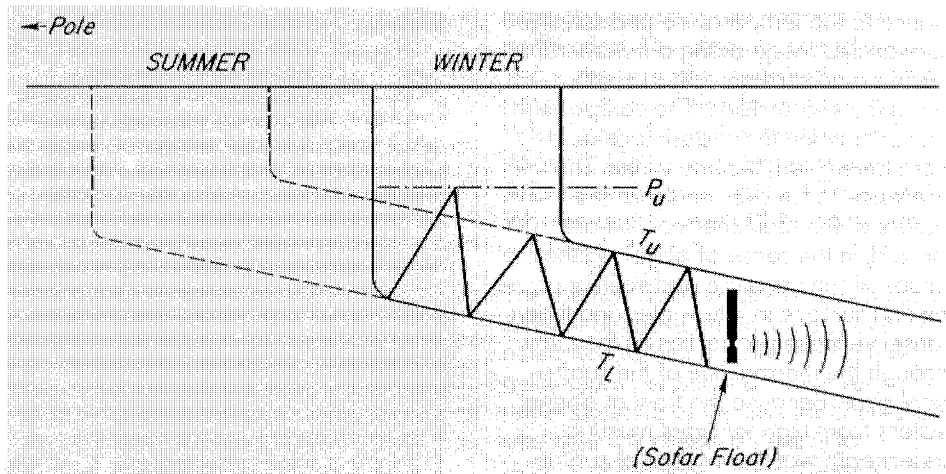


Figure 2, top: The apparent age of water (years) in the main thermocline of the eastern subtropical North Atlantic deduced by Jenkins (1986) from radio isotope data. The age increases to the south and with depth (left panel is at about 270 meters depth; right panel is at about 625 meters depth), implying the subduction of equatorward flowing water.

Figure 3, bottom: Schematic of isothermal surfaces seen in a meridional cut through the subtropical gyre. The position of winter and summer isotherms are sketched as solid and sashed lines. The track of a Bobber float is shown, with summer stratification developing after the first cycle.

Global Ocean Circulation: The Coastal Boundary

Kenneth H. Brink and Peter H. Wiebe

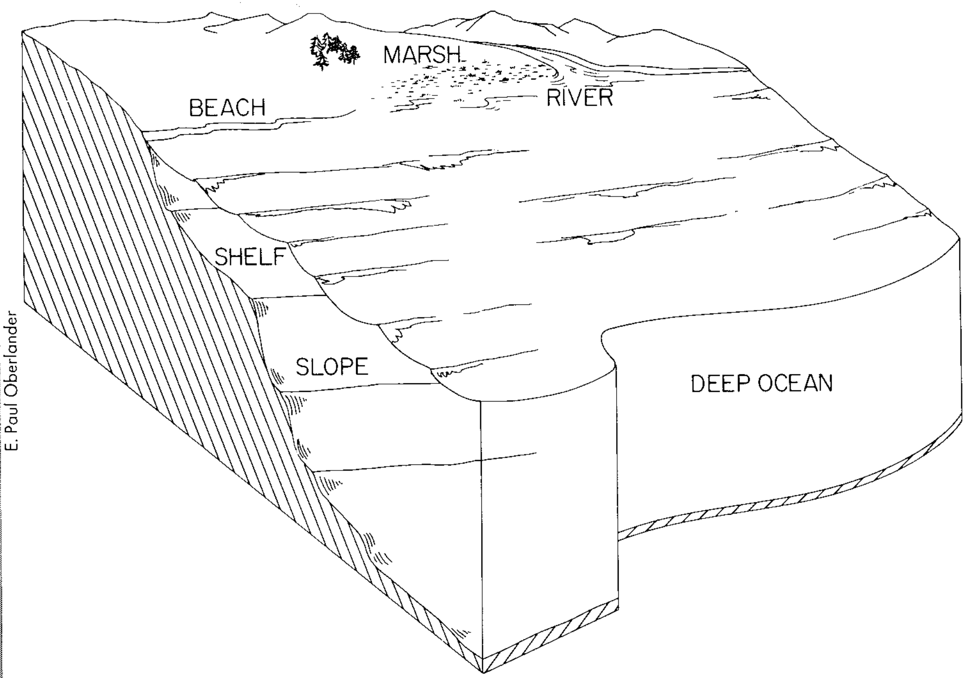
The edges of the world's oceans are the focus for numerous research programs. The amount of scientific effort in these areas is certainly disproportionately large if the area of the edge, or coastal, regions is compared to the ocean as a whole, Indeed, coastal oceanography has almost become a distinct subdiscipline.

Why all the interest? It is an area of high productivity and of intense fishing, mining and oil exploration. It has been a repository for unwanted wastes transported by rivers and streams or dumped there deliberately. It is the area where man's impact on the oceans is greatest.

Coastal oceans have a number of unique characteristics which make them different from the open (deep) ocean, and they have important influences on the global oceans. Some coastal ocean properties will be described here and some work examined which is attempting to study the nature of the interface between the coastal and open oceans.

First, we need to consider the geomorphology of the ocean's edge (Figure 1). In most places in the world, the land does not simply drop off to abyssal depths but rather goes through at least two transitional areas. The first is a gently-sloping continental shelf, typically 3-200 kilometers (approximately 2-120 miles) wide. At the outer edge of the shelf the water is generally some 50-250 meters (150-800 feet) deep, and the bottom slope abruptly becomes much steeper. This steep region, the continental slope, is generally 20-100 kilometers (12-62 miles) wide and completes the transition to the deep ocean basin, typically 2500-5000 meters (8,500 to 16,500 feet). Due to the remarkable effects of the earth's rotation, the continental slope marks a transitional zone in the nature of regional currents. Except near the Equator, little or no evidence has generally been found for shelf current patterns continuing into the deep ocean nor *vice versa*. Over the past decade, in fact, several Institution scientists have made major contributions to understanding exactly how this dynamical barrier works.

E. Paul Oberlander



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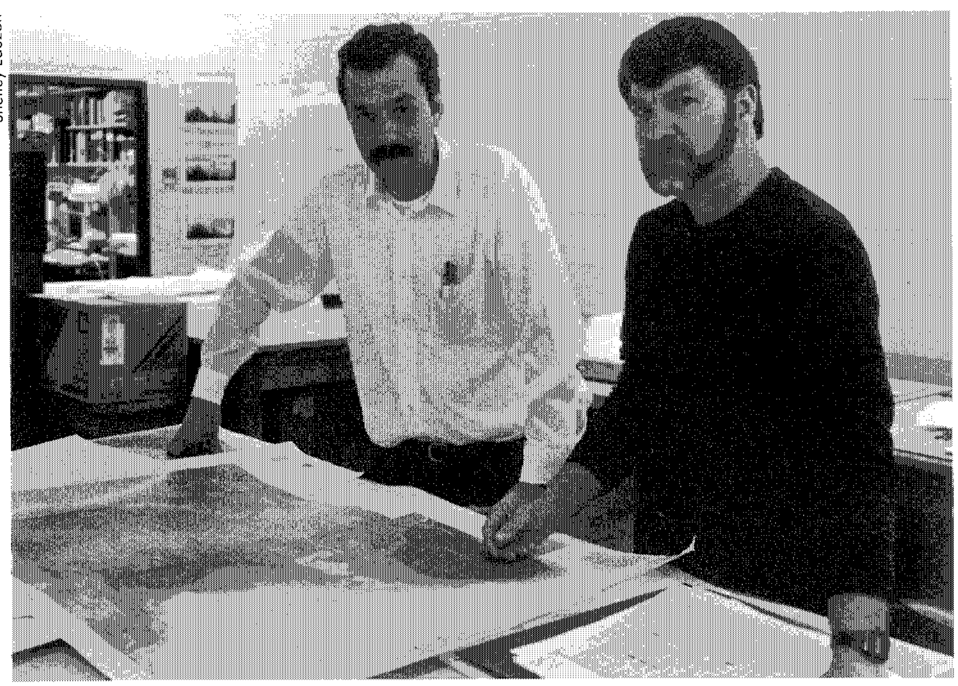


Top: Cartoon depicting the geographical regions within the continental margins (Figure 1). Bottom: Ken Brink (left) and Peter Wiebe.

If the currents over the continental shelf are distinct from those farther offshore, how then can coastal regions influence the global ocean? In order to answer this question, we must consider some of the aspects of the shelf which are different from the rest of the ocean.

Perhaps the most obvious aspect of the continental shelf is the fact that the water is shallow. The shallowness has two consequences. First, it tends to amplify tidal currents. Georges Bank,

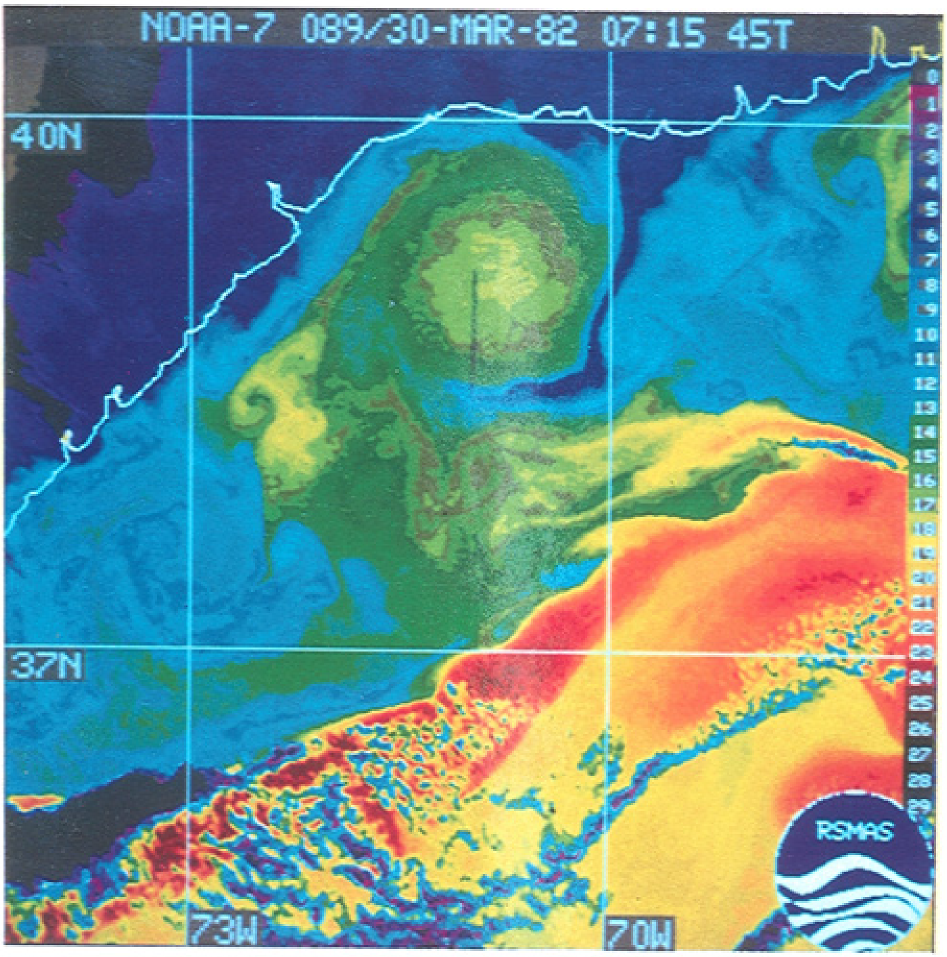


Figure 2: Satellite image of warm-core ring 82-B (circular feature in center of image just below white line marking the edge of the continental shelf) and a tongue of shelf water (dark blue water mass) being entrained by clockwise flow on the eastern edge of the ring. The data for the image were taken by the NOAA-7 advanced very high resolution radiometer on 30 March 1982 and were processed with the aid of a computer by Robert H. Evans, Otis B. Brown and James W. Brown of the University of Miami.

for example, has very strong tidal currents. These energetic periodic currents in turn lead to intense vertical mixing, and to weaker secondary circulations. The mixing brings nutrients up from depth to the surface where there is sufficient light to enable phytoplankton to exploit them. Thus, shallow water regions often have unusually high biological productivity. Second, in temperature and arctic/boreal regions, when surface cooling occurs during the winter, water over the shelf becomes much colder than in the deep ocean because the heat is spread over a lesser depth. This has important consequences in one notable area - the Weddell Sea in the Antarctic. On this large shallow shelf particularly cold, dense water is generated in the winter which is much denser than the surrounding open ocean water. As a result winter Weddell Sea water sinks off of the shelf and helps to renew the deep waters of the world's oceans.

Since the continental shelf adjoins the continental land masses, it is particularly influenced by river runoffs. The fresh water influxes, combined with the dynamical insulation of the shelf from the rest of the ocean, often allows the formation of unique, unusually fresh water masses. The salt content is often not the only distinguishing feature of the shelf waters, as other inputs peculiar to the land area, such as oxygen isotope concentrations or dissolved chemicals, can also be distinguishing features.

One of the most important processes in the coastal ocean, viewed on a global perspective, is coastal upwelling. Most of the world's ocean is unfavorable for high biological productivity because phytoplankton require light to grow and are thus generally only present in quantity in the upper 10-100 meters (30-300 feet) of the water. These phytoplankton rapidly deplete existing nutrients in the shallow photic zone, but leave untapped a reservoir of chemicals at greater depths. Biological productivity then tends to be highest in locations where upward velocities in the water column advect deep, cold high-nutrient waters into the photic zone. This upwelling process is particularly strong in regions where a coastal boundary interrupts the wind-driven offshore transport within the upper 10-50 meters (30-150 feet) of the water column. In order to make up for the resulting mass imbalance, water must come up from depth and upwelling takes place. The coastal upwelling process, which is especially well developed in the world's eastern boundary current regions which extend seaward of the western margins of the continents, explains the existence of many of the world's most productive fisheries, including those off the U.S. west coast, Peru, and Northwest and Southwest Africa.

Over the past decade, a good deal of focussed effort has gone into studying the processes, such as coastal upwelling, which are unique to the ocean's edges. Attention is now beginning to focus on those processes which can allow the "barrier" between the shelf and open ocean to be breached. It appears that the main leakage of shelf waters to the open ocean occurs in the form of narrow, near-surface (upper 100-200 meters, or 300-600 feet) tongues of shelf water which are drawn out into the open ocean. These tongues, which our current dynamical models can not treat well, fall into at least two categories. It is possible that we may some day find these two phenomena to be closely related.

The first type of tongue, commonly found south of New England and Nova Scotia, is associated with energetic eddies in the deep ocean such as warm-core rings (Figure 2). These eddies are typically 100 kilometers (62 miles) in diameter and are defined by their warm waters and by their energetic clockwise-rotating currents. Usually these eddies, which are formed between Georges Bank and the Grand Banks, drift slowly westward north of the Gulf Stream. Occasionally the rings interact with the edge of the continental shelf and they draw off long streamers of cold continental shelf waters, which either wrap around the core of the eddy or are entrained by the eastward flowing Gulf Stream. A major National Science Foundation-sponsored field program on Warm Core Rings took place in 1981 and 1982 with strong participation by Woods Hole scientists. Although the cold streamers were not the primary focus of the program, a substantial amount of information about their structure and biological significance was obtained (Figure 3). One insight

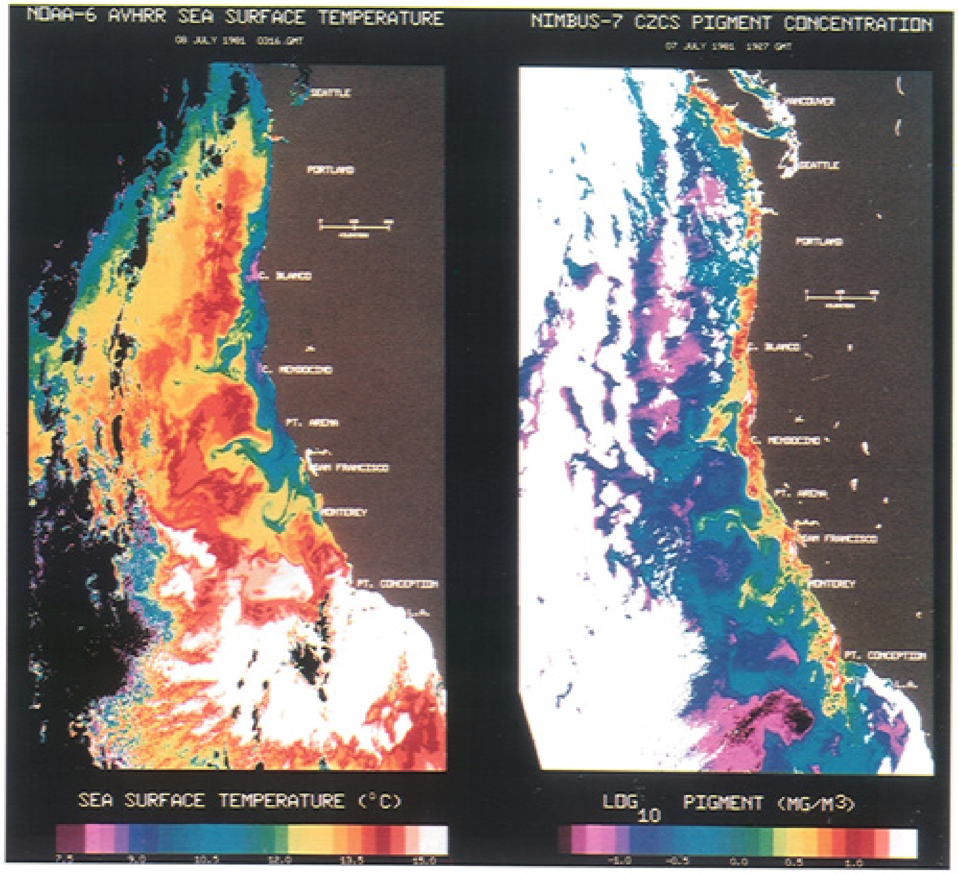


Figure 4 above: Satellite-derived estimates of sea surface temperature (left) and pigment concentrations (right) during the 1981 coastal upwelling season off the west coast of the United States. Pigment concentration is a rough measure of phytoplankton biomass in the region. Upwelling filaments are manifested as offshore-reaching tongues of cold (blue), high pigment (red or yellow) water. Photo courtesy of M. Abbott, Scripps Institution of Oceanography.

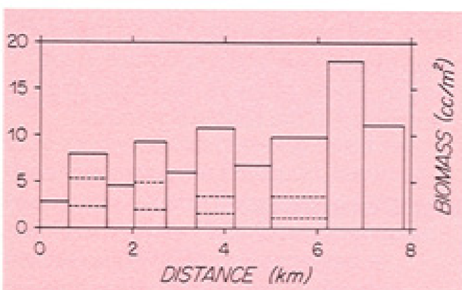
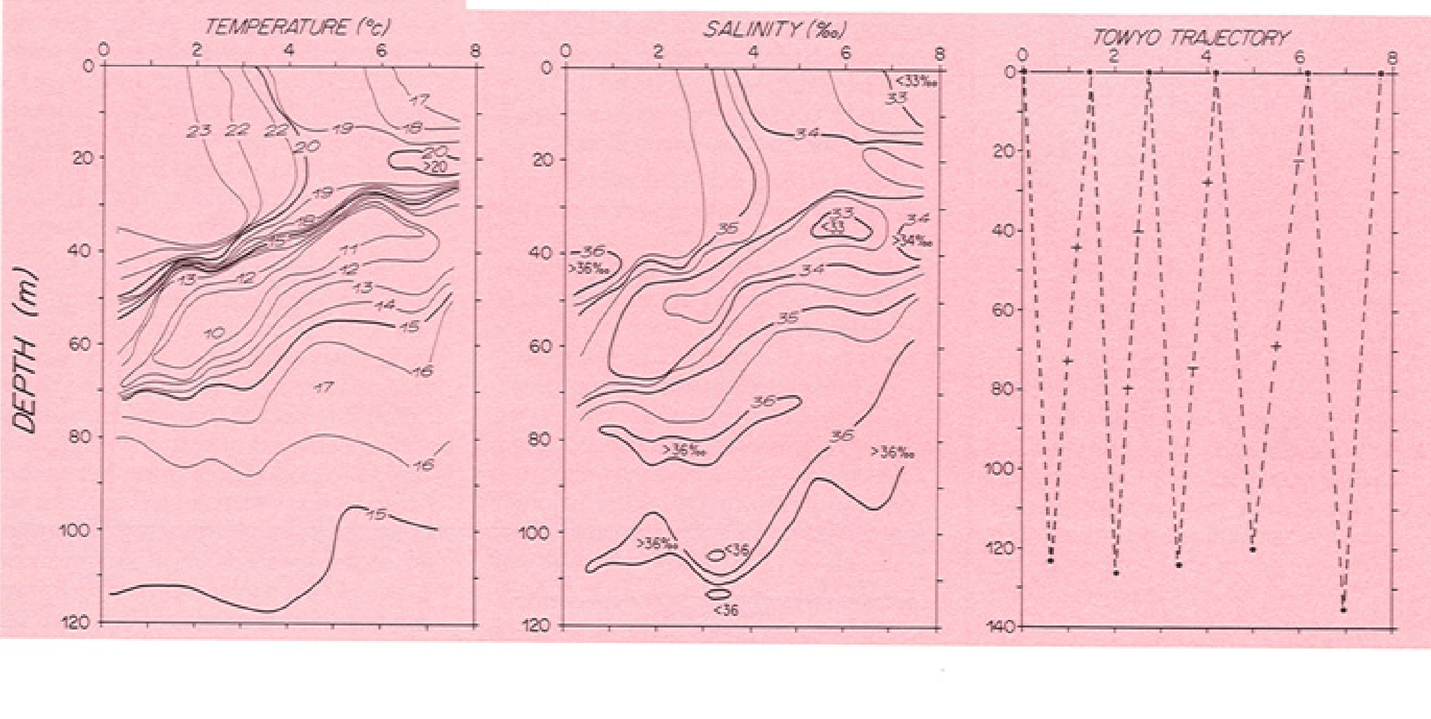


Figure 3, below: Horizontal section of temperature, salinity and zooplankton biomass taken on a daytime towyo with MOCNESS-1D in the fringe region of warm-core ring 82-H in October 1982. On the section showing the towyo trajectory, cross lines on the up-track mark the closing and opening of nets. Dashed lines on the biomass plot indicate the integrated values for the depth specific strata sampled.



gained as a result of this work was that ring-induced entrainment of shelf water into the offshore region could cause the loss of a significant fraction of fish eggs and larvae of commercially important species. This may help explain why some years of good spawning and larval development have poor recruitment of juveniles to the adult population. A follow-up program is currently envisioned for the next few years. To date, very little work has been done on estimating the effect of the streamers on the broader scale biological and physical characteristics of the upper ocean.

The second type of tongue is typified by those seen off the coast of California (Figure 4). In this case, the upwelled water, which is cold and has high nutrients and phytoplankton, is generally confined within 50-100 kilometers (30-60 miles) of the coast, except for occasional dramatic filaments which meander up to 500 kilometers (300 miles) offshore. Preliminary research suggests that the filaments, also called squirts and jets, represent a major flux of biogenic materials into the eastern Pacific ecosystem. The forces producing them are currently the subject of debate, but it seems evident that eddies in the deeper water, at a minimum, play a role in determining the filaments' paths. The Office of Naval Research is sponsoring a physical and biological study of these features with the goals of characterizing their structures and of understanding their growth and decay. The first intensive field measurements will be conducted in the spring of 1987.

We are at a very interesting stage in the study of coastal oceanography. While we have substantial knowledge about the general pattern of coastal currents, hydrographic structure, and the distribution of organisms residing there, we are only beginning to explore the intense and sporadic events which lead to fluxes of coastal water into the ocean at large. We are being called upon to think about new physical processes on scales poorly explored in the past as well as to recognize the importance of the couplings that make the coastal seas an integral part of the global ocean.

Instrumentation: An Introduction

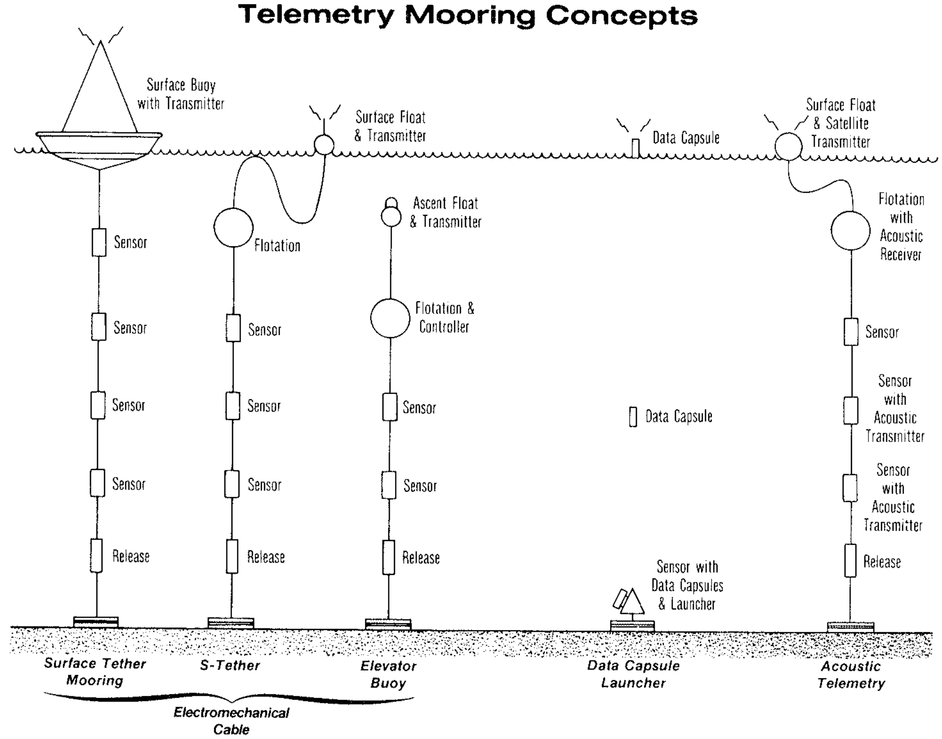
Daniel Frye

Global oceanographic measurement programs such as WOCE and GOFS (Global Ocean Flux Study) will require new scientific tools if oceanographers are going to make efficient use of the available funding resources. These new programs depend on vast arrays of instruments deployed on a global basis, many of which must be capable of operation over many years without maintenance. Due to the remoteness of large parts of the Southern Ocean, it may only be possible to visit some of these sites once during a decade-long program. As a result, currently available instrumentation - which typically requires dedicated research vessels for deployment and retrieval, has little capability for data telemetry and has limited endurance - may not meet the oceanographic needs of the 1990s due to logistical difficulties.

In addition to requirements for large-scale instrument arrays to measure the basic physical properties of the oceans, specialized instrumentation is needed to learn more about the processes which drive the global ocean circulation. These processes may act very locally or may be important only at the air-sea interface and are thus not observable using broadly-spaced arrays of standard oceanographic instrumentation. For these detailed studies, which provide the physical basis for understanding the observed circulation patterns, specialized instrumentation is being developed at the Woods Hole Oceanographic Institution and elsewhere.

Classes of new observational tools being developed for WOCE, GOFS and related programs include new satellite-based sensors and associated data processing techniques which provide global data on sea-surface temperature, surface winds, wave heights and currents. These satellite systems supply the all important link between widely-spaced in situ instruments collecting detailed information from discrete locations and the overall weather and circulation patterns. In addition to satellite-based instrumentation, data telemetry from in situ sensors is being explored as is acoustic tomography, a means of inferring the properties of the ocean's interior from sound velocity measurements made over long horizontal paths. Other technologies being developed at the Institution which have direct application in the global circulation studies are surface and subsurface drifting buoys, new meteorological and air-sea flux sensors, and new instruments for measuring vertical fine-scale structure in the ocean. Some of these new tools are described in the following pages.

Telemetry Mooring Concepts



Data Telemetry

Melbourne G. Briscoe and Daniel Frye

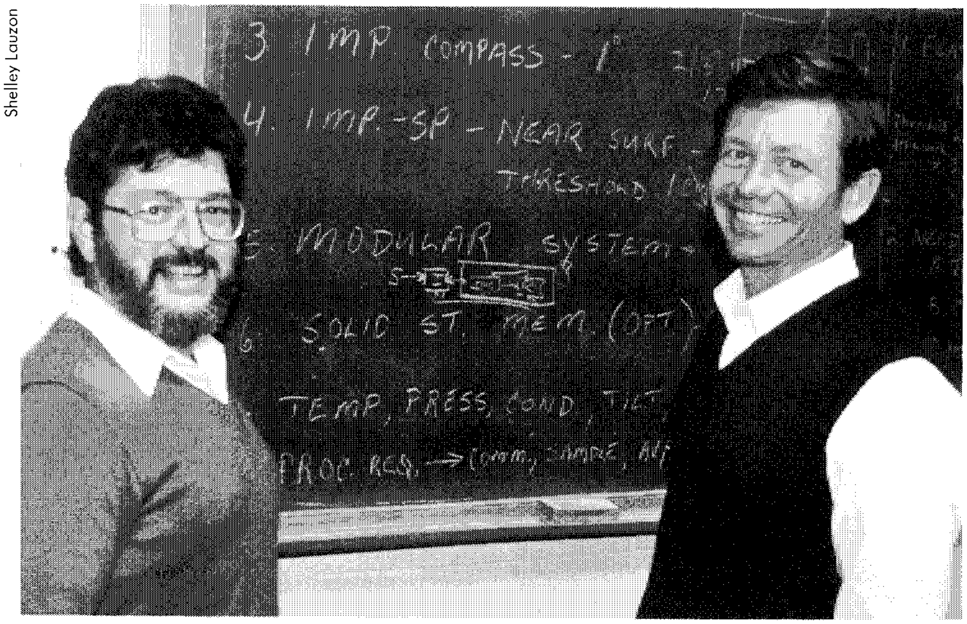
Data telemetry to and from offshore measuring devices is an exciting and potentially valuable research area in oceanography. Originally stimulated by the inability to record useful amounts of data inside an autonomous instrument, the motivations for telemetry today include the need for near real-time data, the desire to control a remote instrument, and the hope that data telemetered from logistically difficult or risky locations will permit some important research to be done in heretofore unexplored sites.

Data telemetry was invigorated in the 1970s by the appearance of reliable, low-cost links through both polar-orbiting (National Oceanic and Atmospheric Administration, or NOAA, TIROS series using the French ARGOS data collection system) and geostationary satellites (NOAA GOES series). At that time the quantity of data to be sent ashore was small, and control of the remote instrument was not needed. Today, the complexity and capability of the instruments has increased enormously, as has the need for higher data rates and remote control. The technical problems include the need to move the data from deep within the water column to a point at or near the surface from which it can be radioed ashore.

In response to this growing need for data telemetry, the Physical Oceanography and Ocean Engineering Departments at Woods Hole Oceanographic Institution (WHOI) are engaged in several major programs to develop and use reliable telemetry methods for deep-sea instruments. A major source of support is the Office of Naval Research (ONR) through the University Research Initiative Program (URIP). URIP was conceived as an innovative way for ONR to attract and fund basic research in important new directions.

The URIP at WHOI is a project to develop telemetry techniques applicable to subsurface instruments such as current meters, to combine these data with remotely-sensed information such as thermal imagery or altimeter data from satellites, and to provide inputs to advanced numerical models of ocean circulation. The telemetry component of the URIP includes the problematic in-water link from the instrument to the surface, the radio links between the surface and the shore station, and the data handling and distribution network ashore. Institution staff are working on URIP with colleagues from the Massachusetts Institute of Technology and Harvard University, as well as with some U.S. Navy laboratories and some industrial firms like the Charles Stark Draper Laboratory (CSDL) and Science Applications International Corporation (SAIC).

Shelley Lauzon



Mel Briscoe (left) and Dan Frye.

Other aggressive activities on telemetry at WHOI include the Real-Time Environmental Arctic Monitoring Program (RTeam) and the Surface Telemetry Mooring (STEM). RTEAM is another ONR developmental project whose goal is to telemeter data from sensors that are deployed under the ice in polar regions. STEM is involved with the critical mooring hardware that is required for use with surface moorings that have hardwired electrical connections between subsurface instruments and a surface buoy.

The in-water link from instrument to surface is the piece of the overall telemetry problem that is perhaps the most challenging yet has been the least addressed. Some principal obstacles include the poor reliability of electrical conductors as they pass through the surface wave zone, the problems of reverberation and attenuation when using acoustics to transmit the data, the extra power consumed by the additional telemetry components, and the higher costs and lower reliability with these technologies.

Various technical approaches for the in-water link are being pursued in our program at WHOI (Figure-pg. 16). Included are hardwired electromechanical links, a vertical acoustic data link that eliminates the need for long runs of vulnerable electrical conductors, and several methods to improve reliability or to function during high current periods by sending a tethered or expendable transmitter buoy to the surface on command or on a schedule.

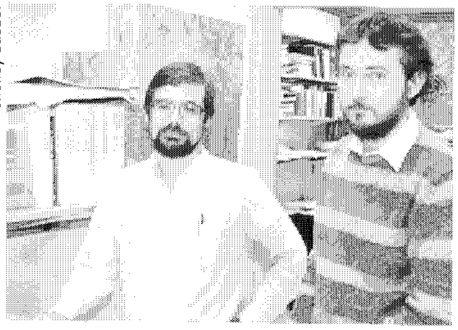
Surface-to-shore two-way radio links and the networking ashore that is required to acquire, process and then distribute the data to the ultimate users. One aspect of this project will be a test using the R/V *Oceanus* during June-August 1987 to provide a moving platform at sea. Simultaneous data transmissions of the ship's meteorological sensors and some navigational and engineering status information will be made by a high-frequency (HF) packet radio system and by a system that scatters its signals off the tiny but numerous trails of small meteors as they pass through and ionize the upper atmosphere. The meteorburst system will be a joint test with SAIC. The HF packet project is being conducted jointly with David Brooks at Texas A & M University.

We are excited by the extent of the cooperation in these telemetry programs. As with any oceanographic development project, the ultimate goal of these programs is to improve the science being done at the Institution and elsewhere.

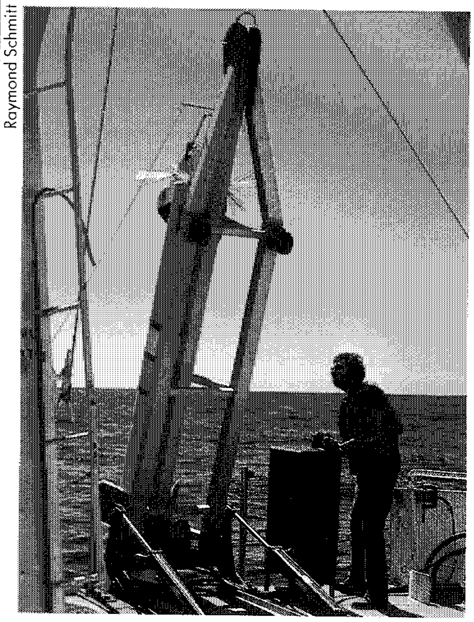
Fine- and Microstructure Observations

Raymond W. Schmitt and John M. Toole

Shelley Lauzon



Raymond Schmitt



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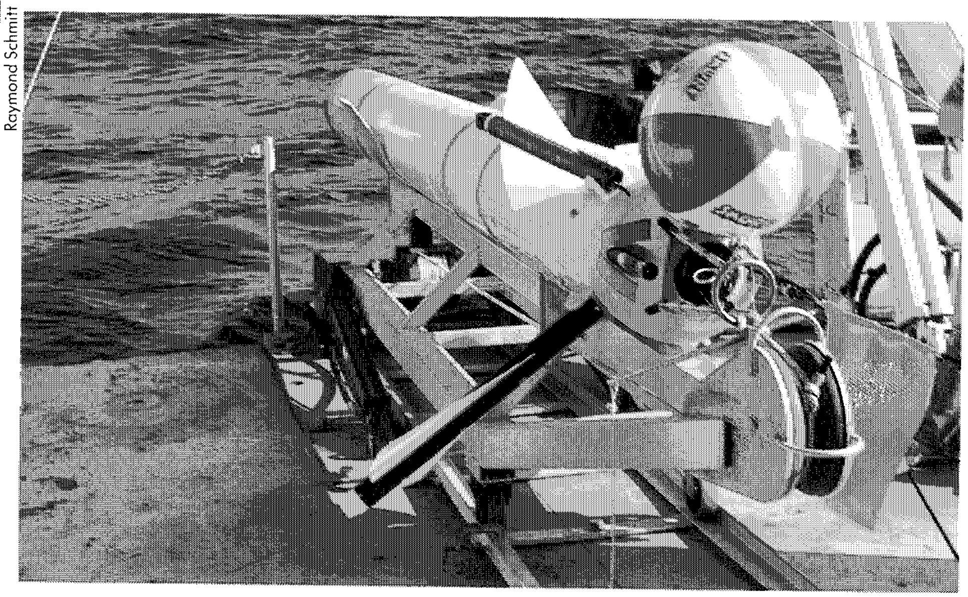


Top: Ray Schmitt (left) and John Toole. Middle: John Toole operates the launching rig as the profiler enters the water for another dive. Bottom: The Fine- and Microstructure Profiler ready for deployment from the stern of R/V *Endeavor*.

As part of the initiative to examine the global ocean circulation during the World Ocean Circulation Experiment (WOCE) and the Global Ocean Flux Study (GOFS), it is very important to refine our understanding of the small-scale processes that lead to vertical mixing in the sea. The distributions of temperature, salinity, oxygen, nutrients and other chemical tracers are crucially dependent on the vertical exchange rate. Present knowledge of the processes leading to mixing is rudimentary.

Several of the intensive experiments to be done during WOCE have the potential to greatly expand this knowledge if the appropriate instrumentation is deployed. For example, the subduction experiment (see article by James Price in this report) will study the way in which new water enters the thermocline. Two mixing processes which will affect the evolution of the subducted water are turbulence, produced by strong current shears associated with internal waves, and "salt fingers", a small-scale double-diffusive process which occurs when the vertical salinity gradient becomes sufficiently strong. Near-bottom turbulence set up by strong flows over topography and reflections of internal waves off the bottom can also produce significant mixing.

To examine these various modes of mixing, we have recently developed a sophisticated fine- and microstructure profiler with Department of Defense and Office of Naval Research support. The design of the instrument was guided by the hypothesis that turbulence at small spatial scales (about one centimeter, or one-third of an inch), which is responsible for mixing temperature, salinity and tracers and dissipating velocity differences, is driven by instabilities of finescale structures (10 meters or 33 feet,in the vertical, 1 kilometer or .62 miles in the horizontal).

The fine- and microstructure profiler is a cylinder about five meters (15 feet) long. It free-falls through the water, dropping ballast when it attains a pre-programmed depth and then returns to the surface. Data from the instrument yield vertical profiles of the ocean's horizontal velocity, temperature, salinity and density fields. Microstructure sensors for temperature, conductivity and velocity are also employed. An optical shadowgraph system may be added to provide a direct video image of the small-scale variability. Thus, from one instrument, the relationships between finescale temperature, salinity and velocity structures and turbulent mixing may be examined.

Use of the profiler to date has been very successful, and plans are being made for a series of field programs to explore the various mechanisms of mixing in the upper ocean, main thermocline and the abyss. The new instrument, with its range of measured scales, its ease of use, and the sophisticated analysis that can now be done aboard ship with small computers, is a very powerful tool for physical oceanographers. The fine-and microstructure profiler can be expected to make its most significant contributions to the process-oriented experiments during WOCE. However, the potential for exploratory work with the new instrument in other programs should not be neglected, since only an extremely small fraction of the ocean has been examined with high resolution profilers.

Meteorology

Robert A. Weller

Radiation from the sun heats the earth. Some of the heat directly enters the ocean, with more being absorbed near the equator. This uneven heating of the earth helps drive both the general circulation of the atmosphere and the large-scale currents of the world's oceans.

The ocean and atmosphere both carry heat from the equator toward the poles. Further distribution of heat occurs through convection, or the ascent of air from near the surface into the atmosphere, and through evaporation of water at the surface. If we understood all the physical processes associated with heating due to the absorption of solar radiation, with the exchange of heat between the ocean and atmosphere, with the generation of ocean currents, and with mixing of the ocean by the surface winds, we would have knowledge fundamental to explaining the dynamics and variability of the atmosphere and ocean. On a practical side, such knowledge is essential to improving our understanding of changes in climate and our ability to forecast weather.

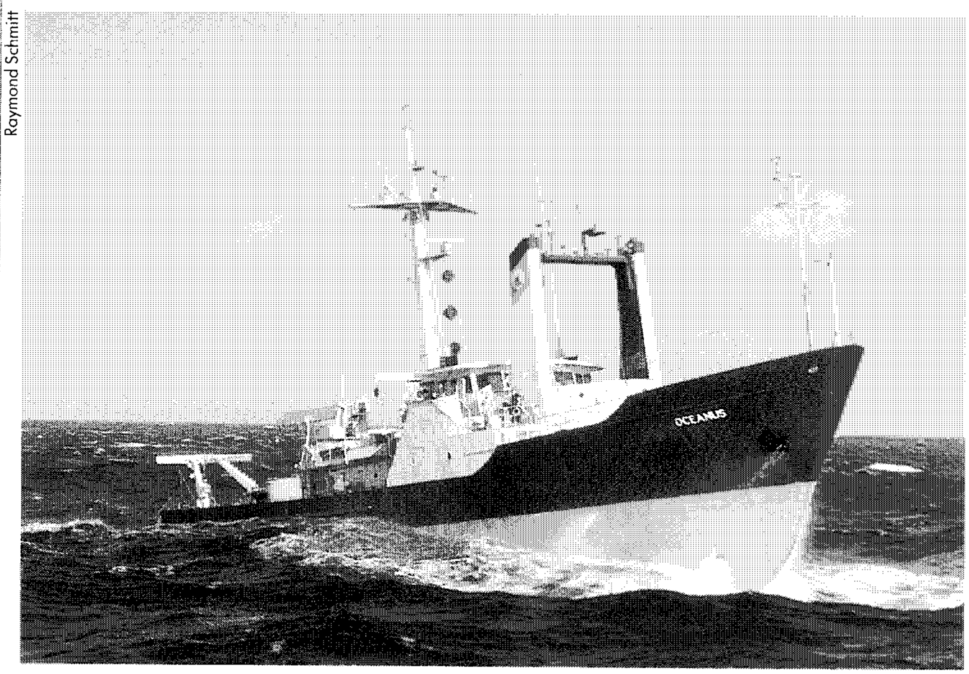
In the next decade large research initiatives such as the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean and Global Atmosphere (TOGA) program will work toward a better understanding of these processes. These programs recognize that variability in the atmosphere is linked to that in the ocean, and as a result, will focus on studies of the exchange of heat, mass and momentum between the ocean and atmosphere. Heat is exchanged by visible radiation such as sunlight, by thermal emissions or infrared radiation, by evaporation which results in cooling, and by direct processes such as conduction or convection. Mass is exchanged by rain falling into the ocean or by water evaporating from the sea surface. Momentum exchange occurs when the wind blowing over the water accelerates that fluid and thus drives a current.

One of the greatest challenges for the research programs of the next decade will be to make measurements from buoys and ships at sea with the accuracy required to achieve their scientific objectives. Accurate determination of the exchanges between the atmosphere and ocean requires good observations of wind speed and direction, air temperature, sea surface temperature, solar or shortwave radiation, infrared or longwave radiation, humidity and barometric pressure. Blowing salt spray, high waves, wind, rough seas and other effects all combine to severly test, destroy, or degrade the sensors used in the past to measure these quantities.

In preparation for these programs, Institution staff are meeting the challenge of making high quality meteorological measurements at sea. The Buoy Group has developed a surface buoy for use in such experiments and Richard A. Payne and others have devised ways to mount the sensors on our research vessels (photo) so that contamination of the measurements by the flow disturbance and heat generated by the ship is minimized. Physical Oceanography Department colleague James F. Price and David S. Hosom of our Ocean Engineering Department have, with support from the Office of Naval Research, been working on the development of an improved humidity

Nancy Pennington

Raymond Schmitt



Top: Bob Weller. Bottom: R/V *Oceanus* heads into heavy seas during the Frontal Air-Sea Interaction Experiment (FASINEX) field program in February 1986 near Bermuda. A tower with meteorological sensors was installed on the ship's bow for the experiment.

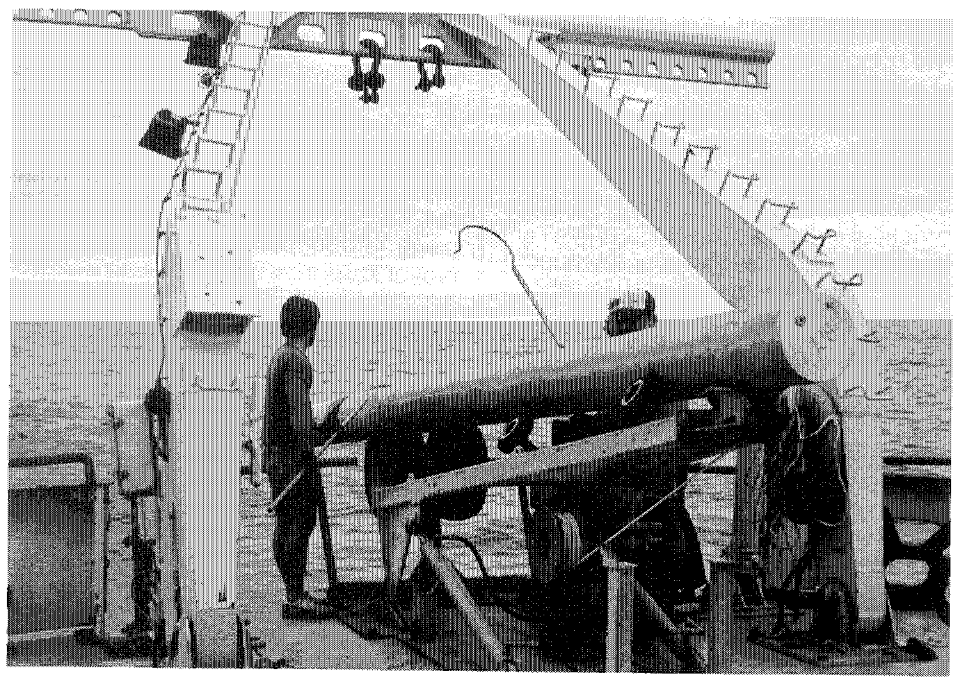
sensor, known as a chilled mirror dew-pointer, which will have the ability to clean itself, removing contaminants such as salt. Kenneth E. Prada and Donald E. Koelsch of the Ocean Engineering Department, working with William Lange of the National Center for Atmospheric Research, have developed free drifting, expendable surface floats that could be deployed on a global scale to make meteorological measurements. With Robert Pinkel from Scripps Institution of Oceanography and Thomas Dickey from the University of Southern California, I have proposed a five-year effort to the National Science Foundation to improve the meteorlogical sensors used on moored buoys and on research vessels. Parts of this project will focus on improvements to the shortwave and longwave radiation sensors, on continued improvement of humidity sensors, and on reducing measurement errors caused by the motion of the buoy or ship. Work such as this has very fundamental goals, but it is essential preparation for our participation in the field work of the 1990s, which will include large programs such as WOCE and TOGA.

SOFAR Floats

Philip L. Richardson

For the past eight years the Institution's SOFAR float group* has been using freely drifting subsurface floats to measure long-term ocean trajectories in the North Atlantic. We recently received funding from the National Science Foundation to begin participation in a World Ocean Circulation Experiment (WOCE)-related project to measure the cross equatorial flow in the tropical Atlantic from 1988 to 1992. We are also planning to participate in the main WOCE program (1990-1995) which includes deploying and tracking large numbers of subsurface floats in other areas of the world ocean.

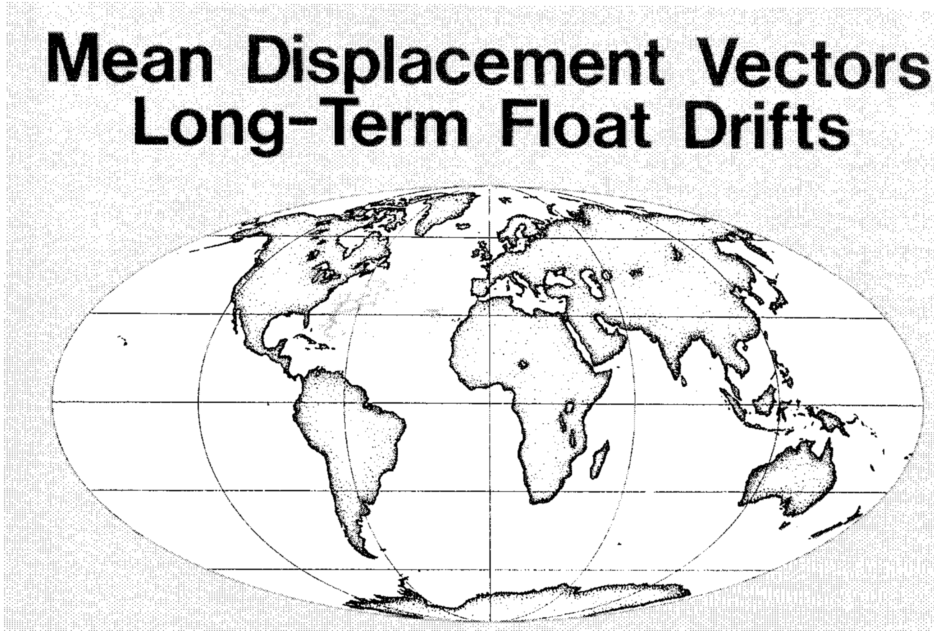
SOFAR floats are neutrally buoyant aluminum tubes that are ballasted to drift at depths from a few hundred meters to several thousand meters. The floats emit a low frequency acoustic signal (250Hz) that sounds much like a boat whistle. The sound travels horizontally through the ocean in an acoustic waveguide called the SOFAR (SOund Fixing And Ranging) channel and is received by moored undersea listening stations at ranges up to a few thousand kilometers. The floats have a lifetime of several years depending on how often they transmit. At present the listening stations can stay submerged for eighteen months, and we think we can extend this to three years in the near future, important for decreasing the costs of obtaining the data. Two recent improvements to the floats are the use of new glass floats capable of depths to 4000 meters and floats with the ability to actively seek out and cycle between preselected temperatures or depths. This makes it possible to sample and follow certain layers of water as they move through the ocean.

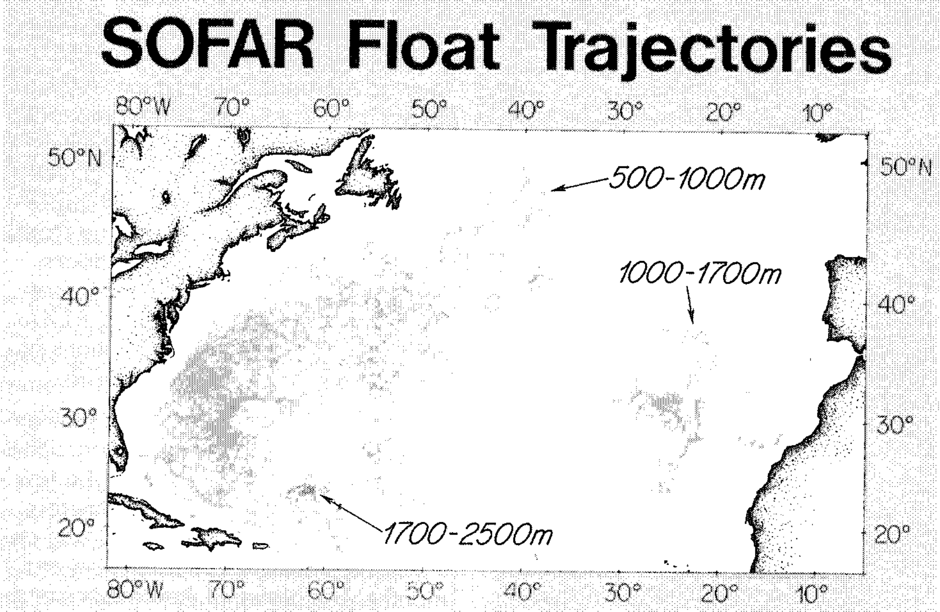


A SOFAR float ready for deployment in the western North Atlantic.

SOFAR float data are scientifically useful in many ways. Trajectories tell us how water moves on a horizontal plane in the ocean, and provide a visualization of the flow which can be very different from that inferred from moored current meters. The dispersion of groups of floats tell us how water is mixed by eddies, important for understanding how water tracers and pollutants are transported by the ocean. A velocity series of a float along its trajectory tells us about ocean velocity fluctuations.

*W. Brechner Owens, James F. Price, Philip L. Richardson and William J. Schmitz, Jr.





James Price

Top: Subsurface float measurements, nearly all in the North Atlantic (Figure 1). Bottom: Phil Richardson.

The float group has programs in three areas: the Gulf Stream and its recirculation south of New England, the northern extension of the Gulf Stream east of Newfoundland, and the Mediterranean water in the Canary Basin in the eastern North Atlantic. As part of this last experiment we have just tracked a meddy (Mediterranean eddy) continuously for two years using floats - the longest time an ocean eddy has ever been followed. Meddies are subsurface eddies approximately 100 kilometers in diameter containing very salty water which originated in the Mediterrranean Sea. The data from floats and shipboard measurements gives exciting information on the movement, life history, and decay of ocean eddies and the flux of salt and other quantities between the eddies and the surrounding waters.

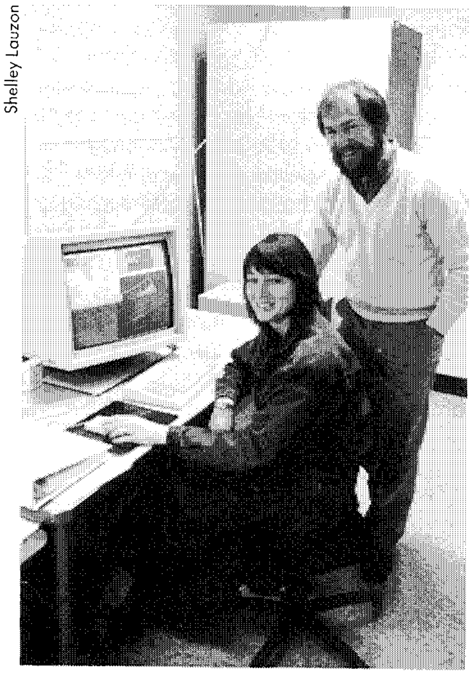
A new experiment begun in January 1987 to study the cross equatorial exchange of water between the North and South Atlantic. We are building 45 floats and will launch them in 1988 along a line across the tropical Atlantic near 8°N. The width of the Atlantic is relatively narrow there, like a strait separating the North and South Atlantic basins. Floats will be launched at 700 meters, 2000 meters and 4000 meters, most of them near the western boundary where we expect currents to be swiftest. In addition, other measurements are being planned that include CTD (conductivity/temperature/density) sections, current meter moorings and surface drifters.

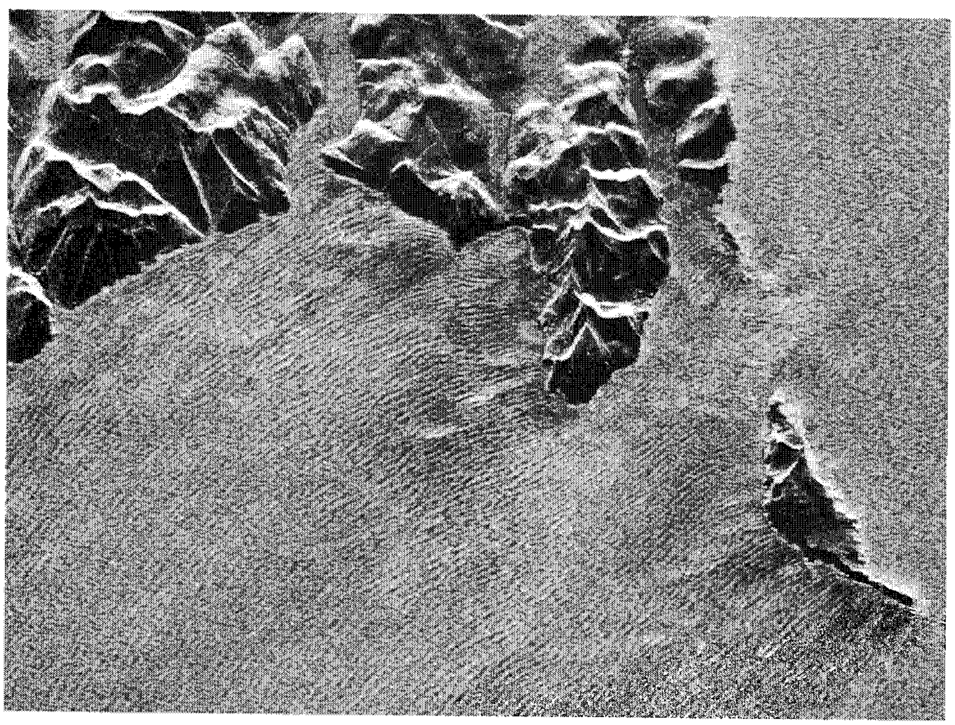
Virtually all of the long-term subsurface float measurements that have been made are in the North Atlantic (Figure 1). We plan to expand our participation in WOCE by launching and tracking floats in other oceans. We hope that after WOCE is completed, other areas of the world will have as much float data as does the western North Atlantic today and that our understanding of ocean circulation will have improved proportionately.

The View from Space: A New Global Perspective for Oceanography

Hans C. Graber and Kathryn A. Kelly

Shelley Lauzon





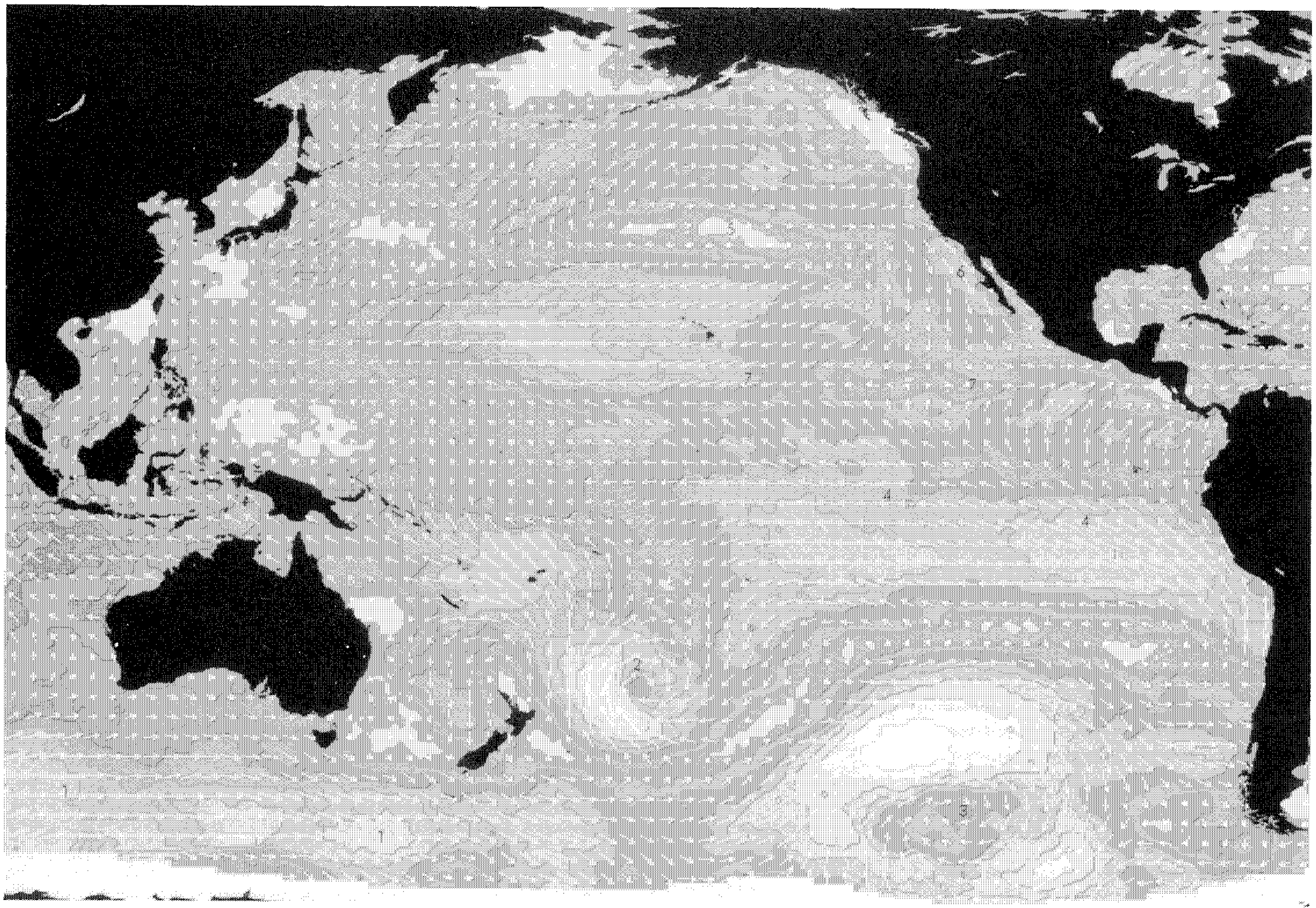
Top: Kathy Kelly and Hans Graber. Bottom: A synthetic aperture radar (SAR) image from SEASAT showing wave structure around the Faroe Islands in the North Atlantic. Diffraction and refraction of surface waves due to the islands is clearly evident. (Photo courtesy of DFULR/GSOC)

Observing the ocean from space emphasizes, more than perhaps any other perspective, its global nature and its sensitivity to changes in wind and current speed, waves, temperature and fluxes. Scientists are paying increasing attention to this global view and are realizing the importance of viewing the atmosphere and oceans as a complete system, focusing more on global processes and their interaction with synoptic-scale processes using long-term observations.

Both research and operational satellites have demonstrated an ability to measure on a global scale variables crucial to our understanding of the relationship between the atmosphere and ocean. Present satellite-based remote sensing techniques, passive measurements of the natural radiation emitted by ocean or ice surface in the visible, infrared and microwave spectral bands and active microwave radar methods, are capable of measuring oceanic surface winds, wave heights, sea surface temperature, ocean color, sea surface topography, and sea ice distributions.

To prepare for the increasing importance and usage of satellite data, we started a major new initiative in 1986 to develop the techniques and equipment for archiving, displaying and analyzing satellite data. This effort is part of the University Research Initiative Program (URIP), funded by the Office of Naval Research, and is a joint project with Harvard University and the Massachusetts Institute of Technology (MIT). The program focuses on improving our observational tools and techniques as well as developing comprehensive numerical models of ocean processes which can assimilate large and diverse data from satellite sensors and in situ instruments. With several new satellite missions projected to start in 1989 and subsequent years, we need to develop methodologies to transform and condense the vast influx of data into useful maps depicting wind and wind stress vector fields, contours of surface wave heights and surface geostrophic currents. Crucial to this endeavor is the education of students and researchers about how these instruments work, their advantages and limitations, the information contained in the data, and how to analyze and combine it with other data and with models. The new data which is likely to be most important to oceanography will come from the next generation of active radars, especially the NSCAT and ERS-1 scatterometers, the altimeters on TOPEX/ Poseidon and ERS-1, and variations of the synthetic aperture radar (SAR).

Surface winds and wind stress play an important role for most oceanographic processes over spatial scales of a few kilometers to thousands of kilometers (one kilometer equals .62 miles) and on time scales of several hours to several months. The National Aeronautics and Space Administration (NASA) provided funds to model the surface wind stress and sea state off the West Coast of North America using scatterometer data. As members of the Science Definition Team (SDT) for the NASA-scatterometer (NSCAT) our responsibilities are to provide advice and guidance to the project on issues crucial to the success of the proposed investigations. During the pre-launch period we will investigate how the wind stress on the oceans is affected by the surface wave field and develop a methodology to construct optimal surface wind and wind stress maps. This research is necessary for the successful achieve-



ment of our post-launch science objectives in predicting surface gravity waves using scatterometer wind measurements and in studying wind-driven coastal currents in the eastern North Pacific.

To educate students both in the classroom and in the laboratory we and colleague Jules Jaffe are teaching a two-semester course, entitled Physics and Principles of Remote Sensing, in the MIT/WHOI Joint Graduate Program. The first semester introduces students to the basic principles of remote sensing of the oceans, with lectures conducted over the microwave link to MIT. The propagation of electromagnetic waves and their interaction with rough surfaces, atmospheric and ocean scattering and absorption, orbital dynamics and geometric distortion are the basic topics, followed by a more detailed examination of instruments using active or passive microwave and visible or infrared radiation. The second semester is research-oriented, with each student analyzing a specific set of satellite data to determine its characteristics and probable errors and the spatial and temporal scales of the information, with the goal of obtaining quantitative information unavailable or impractical to obtain from other types of data.

The enormous volume of data from satellites necessitates specialized computing equipment for storage, processing and analysis. Satellite data analysis relies heavily on graphical displays of the data because there are simply too many measurements to examine in any other way. The volume of data is typically 10 to 100 times that of conventional oceanographic measurements, and the computations to reduce the data to a usable form or to obtain simple quantitative information are correspondingly large. As part of URIP and NSCAT projects we have acquired the basic building blocks for a network of workstations dedicated to satellite data analysis: two SUN Microsystems color workstations with computation speeds about five times greater than that available on our shared computing system. Both the Harvard and MIT satellite groups have selected the same brand of computer to facilitate software development and the sharing of data products. With better networking capabilities we project an improved flow of information between institutions and between researchers using various techniques to understand the ocean.

A NASA map showing the Pacific Ocean segment of a global wind field map for September 6 to 8, 1978. The arrows point in the direction the winds blow, with longer arrows indicating greater wind speeds. For emphasis, the wind speed is contoured and color coded. Light winds (less than nine miles per hour) are dark grays and strong winds (greater than 31 mph) are lighter grays. The continents are black and the Antarctic pack ice is white. Graber and Kelly have received funding to compute winds over the Pacific and to generate wind stress maps for NSCAT, the next generation scatterometer. Software development on the SUN workstations is by Christopher E. Dunn of the Ocean Engineering Department.

Global Ocean Flux: An Overview

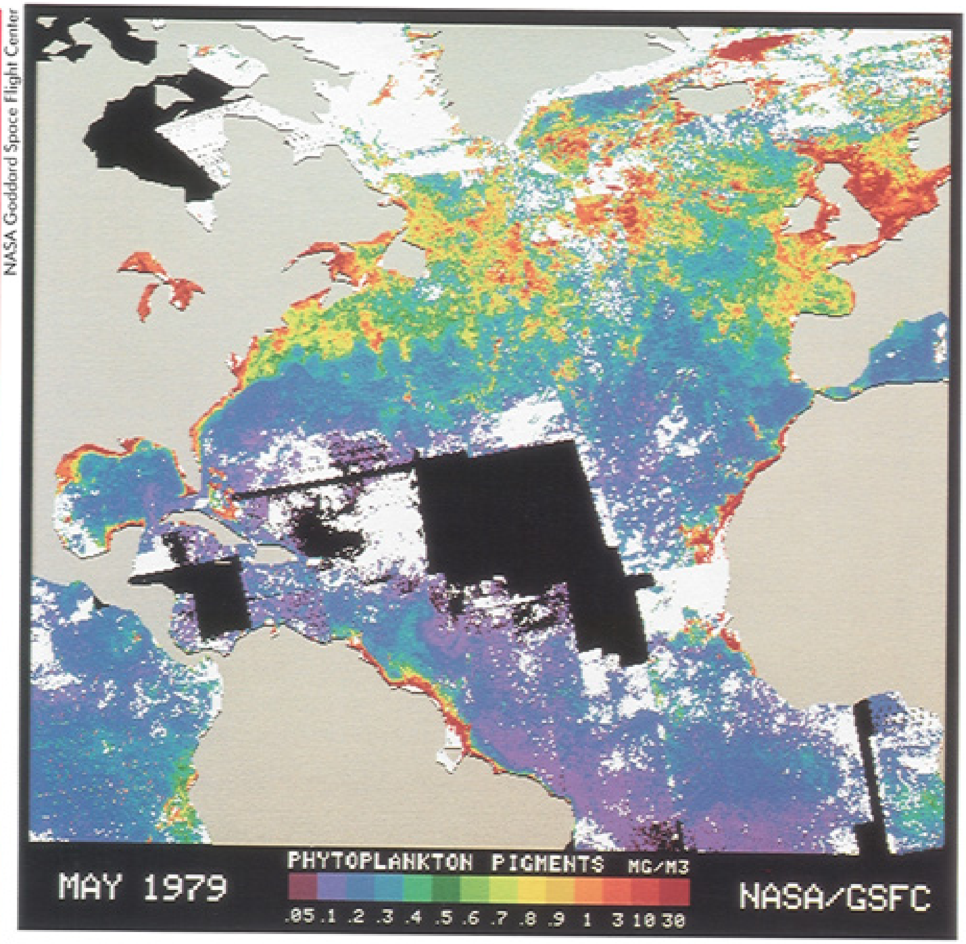
Peter G. Brewer and Michael P. Bacon

The Global Ocean Flux Study (GOFS) is one of the principal components of a major federal initiative known as the Global Geosciences Program, which consists of separate but related research efforts that treat the earth as an integrated system of global oceanic and atmospheric circulations and as a delicate and dynamic balance of biogeochemical fluxes that sustain life on our planet. The overall goals of GOFS are (1) to identify and quantify the physical, chemical and biological processes controlling biogeochemical cycling in the ocean and their interaction with the global atmosphere, and (2) to understand the processes governing the production and fate of biogenic materials in the sea well enough to predict their influences on, and responses to, global scale perturbations. There is a clear need for launching such a program now because of growing concerns over the impact of biogeochemical and climatic changes on global habitability.

Conception of a Global Ocean Flux Study occurred in early 1984 at a meeting convened in Washington by Institution Director John H. Steele under the auspices of the Board of Ocean Science and Policy of the National Research Council. That meeting was followed later in the year by a large workshop attended by sixty-five prominent marine scientists, eleven of them from the Woods Hole Oceanographic Institution, to review the conceptual and technological advances that would make GOFS feasible and to develop a blueprint for the program. Since then planning for the U.S. segment of GOFS has proceeded under the guidance of a steering committee, chaired by Peter Brewer of the Institution's Chemistry Department, with support from the National Science Foundation and the National Aeronautics and Space Administration.

GOFS planners have identified three key strategies that need to be worked out to meet the aims of the program. The first is the use of satellites to sense ocean color and from this to estimate distributions of the phytoplankton from

NASA Goddard Space Flight Center



Shelley Lauzon

Top: A satellite ocean color image showing the distribution of phytoplankton pigments in the North Atlantic Ocean. Regions of high pigment concentrations are colored yellow and red and reflect periods of enhanced phytoplankton production. A pronounced band, rich in phytoplankton, is evident across the entire North Atlantic; it is the spring "bloom" seen for the first time as a coherent feature across the entire basin. Localized regions of high productivity are also evident in the North Sea, along the ice edge, the coastal upwelling zones along the coasts of northwest Africa and South America. White indicates cloud cover, black no measurement. This image, produced from data collected during May 1979 using the Coastal Zone Color Scanner (CZCS) aboard the NASA Nimbus-7 satellite, is the first time and space composite of phytoplankton distributions and abundances for an entire ocean basin. Bottom: Mike Bacon (left) and Peter Brewer.

which the biogenic fluxes are derived. Only with satellites is it possible to obtain global pictures with adequate detail and at adequate frequency. An example of the kind of picture that can be obtained is shown in the figure accompanying this article. The second key element of GOFS strategy is the correlation of the satellite images with direct observations of upper ocean chemistry and biology from ships and instrumented buoys. It is foreseen that this second requirement will stimulate a number of advances in oceanographic instrumentation that will allow serial observations and sampling to be carried out from unmanned platforms that can be left unattended for long periods of time. The third strategy is the measurement of the rain rate of biogenic debris to the ocean floor and its relationship to the sediment accumulation flux. Sediment traps for measuring these fluxes directly have been an extraordinary development in recent years, largely spearheaded by Susumu Honjo of the Institution's Geology and Geophysics Department. The traps are now capable of recording the flux of particles to the ocean floor with two-week resolution over a year-long deployment period and of returning samples for sophisticated analyses.

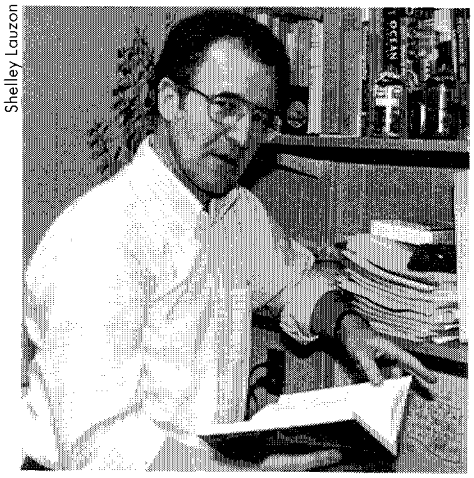
These strategies will be superimposed on the necessary physical template of ocean heating, cooling, mixing and transport processes that will be provided by programs such as the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean Global Atmosphere (TOGA). Implicit in all of this is the ultimate objective of being able to predict the global distribution of ocean fluxes and their variations over time from remotely sensed properties of the sea surface. This is a major intellectual challenge that will require the continual development and testing of sophisticated ocean models.

Considerable progress toward making GOFS a reality was achieved in 1986. Planning for GOFS has reached the stage where a coherent U.S. program is nearing final form, and the first Joint Global Ocean Flux Study (JGOFS) meeting has just been held in Paris to establish mechanisms for the international cooperation that will be essential for an undertaking of this magnitude. The first GOFS cruises are scheduled to begin in 1989.

The Ocean Lithosphere and Ridge Crest: An Introduction

David A. Ross

Shelley Lauzon



One of the more exciting discoveries of past decades was the detection of the essentially world-encircling mid-ocean ridges. The importance of these features started to become evident with the acceptance of the concept of plate tectonics. The ocean ridges, or spreading centers, are now known to be part of an extremely complex system where energy from deep within the earth moves upward through the lithosphere into the overlying ocean. In doing so, it profoundly influences not only the geology and geophysics of the region but also the chemistry of seawater, produces a unique bottom fauna and may even be reflected in some physical oceanographic processes.

For the geologist and geophysicist, understanding the ridge crest and lithosphere is critical to learning about the formation and evolution of the ocean basin. It is at the ocean ridges where the initial processes occur that eventually determine the structure and geophysical characteristics of about three-fourths of the ocean floor. Through seafloor spreading the material formed and imprinted at these ridges will slowly move outward, eventually forming the underlying crust of the ocean basin and ultimately being consumed at zones of subduction.

By studying the processes occurring at the ocean ridges, we will be able to understand and even predict much about the characteristics of the remaining parts of the ocean. Unfortunately, understanding the processes operating at the ridge is not a simple matter; it is a complex environment with rapid changes. Some of the processes can be studied by now conventional techniques such as submersibles, deep-towed instruments or accurate measurements of seafloor topography. However, these observations and measurements need to be augmented by new technologies that allow more direct observation. These techniques will involve long-term observations and experiments, perhaps with the use of ocean bottom stations that could monitor microearthquakes and changes in hydrothermal circulation. Other possibilities include the ARGO/JASON system for detailed observation and sampling, advanced mapping techniques, seismic tomography, borehole seismology and hard rock drilling. These observations will allow some conjecture about the convective processes operating under the ridge and the presence, movement and shape of magma bodies.

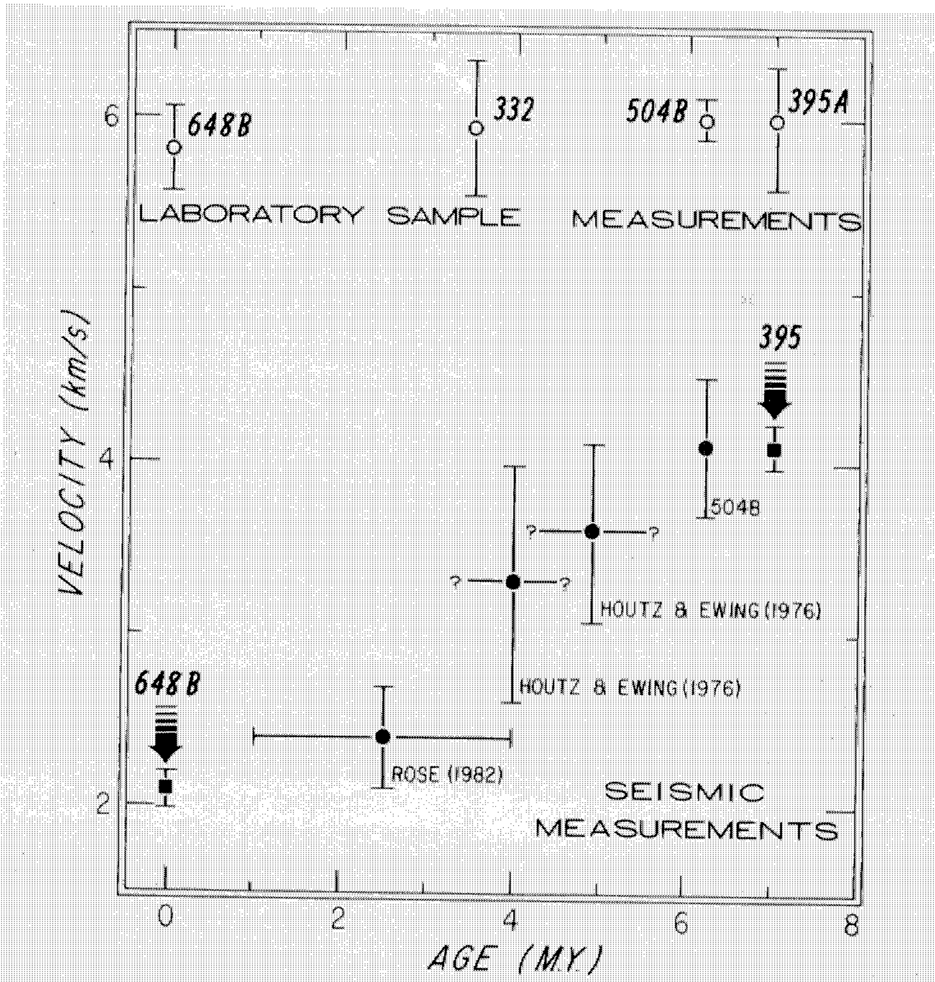
Further advances in understanding ocean ridge processes await a combination of scientific skills and techniques. These will involve a variety of earth scientists bringing their knowledge to bear on ocean ridge and lithospheric processes. Such an effort is underway in a program called Geodynamics. Described on the following pages are some of the new techniques and results.

Ocean Bottom Seismology

G. Michael Purdy

Anne Rabushka

Top: Mike Purdy. Bottom: Compilation of young shallow igneous crust velocities from laboratory sample measurements (open circles) at the 'classic' drill sites on the Mid-Atlantic Ridge (648B, 332 and 395A) and flanks of the Galapagos spreading center (504B). Solid dots are refraction velocity measurements: the bold arrows indicate the two DETES-DOBH measurements. The refraction velocities double over the first few million years and are one-third the laboratory sample values at zero age.



Progress in understanding the creation and evolution of the oceanic lithosphere is limited by the lack of knowledge concerning deep earth processes. Important advances are being made in the development of models of mid-ocean ridges (see the Geodynamics article by Dick, Schouten and Whitehead in this report), but they are poorly constrained by simple observations of seafloor morphology, variations in the geochemistry of the extruded basaltic rocks, interpretations of the geomagnetic field and inferences from presumed fossil sections of oceanic crust preserved on land (ophiolites).

A clear need exists for direct observations of the deep earth that will determine thermal structure, physical properties and chemical constitution with sufficient precision that definitive multi-component models can be supported or discounted. This need has fueled considerable progress in the development of seismological techniques for imaging the boundaries within the oceanic lithosphere and for mapping the lateral and vertical variations in velocity structure. Seismology is, in fact, one of the very few available geophysical techniques that provides direct observations of the earth's interior. Our efforts at the Institution have focused on the use of fixed ocean bottom monitoring instruments to record seismic energy that has propagated through the earth's crust and upper mantle from both natural (earthquake) and man made (explosive) sources. The many objectives of this research are closely related but the brevity of this report requires their arbitrary separation into the three themes described below.

One of our long-term efforts is simply to determine the constitution and evolution of the oceanic crust itself. In the past year or so exciting progress has been made towards this objective. Ironically one of the sections of oceanic crust about which the least is known is the uppermost several hundred meters (one meter equals 3.28 feet) of the volcanic section. The rough surface of this random pile of heavily faulted extrusive pillow lavas that constitutes the uppermost surface of the crust scatters and diffracts seismic energy. The very large vertical velocity gradients (three to four kilometers/second per kilometer of depth) that exist in the uppermost sections refract the laterally propagating energy so rapidly that it has proven impossible to satisfactorily determine the seismic structure using conventional methods.

The development of the first effective low-frequency deep-towed seismic source by our group at Woods Hole has radically changed this situation. This new source allows us, for the first time, to conduct a complete seismic experiment on the ocean floor in water depths as great as 5000 to 5500 meters (16,500 to 18,000 feet). By using both fixed ocean bottom receiver and ocean bottom sources we are able to carry out precise on-bottom experiments and produce direct and well-constrained observations of the uppermost few hundred meters of an approximately one kilometer (approximately one-half mile) area of the ocean floor. An important point is that these on-bottom refraction experiments, the first of which were conducted on the Mid-Atlantic Ridge in the summer of 1985 from the R/V *Knorr*, allow structural determinations to be made on a lateral scale consistent with the seafloor structures observed with submersibles, photography and side-scan sonar.

Our first experiments have already produced some intriguing results, shown in Figure 1, but which are by no means yet fully understood. This figure combines data from laboratory sound velocity measurements on basalts recovered by drilling with other less well-constrained refraction velocity measurements and with the results of three of our new on-bottom experiments (denoted by the bold arrows). These velocity measurements of the uppermost oceanic crust, plotted against age in millions of years, show that the velocity at near zero age on the scale of refraction measurements (100 meters, or 330 feet) is one-third that measured in the laboratory at the scale of centimeters (2.54 centimeters equals one inch). While on a small scale no age dependency of velocity is discernible during the first eight million years, on the seismic scale the velocity approximately doubles. No completely satisfactory explanation exists for these dramatic effects, but if we seek one only in terms of large scale porosity changes, then the inference is that at zero age the uppermost crust has a porosity of many tens of percent and this porosity decreases by approximately fifteen percent during the first several million years of crustal formation. A reasonable mechanism to explain such a huge change in porosity is yet to be found.

A second longstanding research theme within our group has been the study of the structure of active plate boundaries, the emphasis of which has shifted in recent years from fracture zones to mid-ocean ridges. Our explosive seismic refraction experiments on the Mid-Atlantic Ridge have shown the structurally segmented nature of the mid-ocean ridge system, proving that this segmentation, first recognized by Institution colleagues from bathymetric and geomagnetic data, is indeed a fundamental property of the accretion process and most probably defines the extent of the individual volcanic centers that feed the system with new material. These observations, along with those previously mentioned that prove substantial changes of structure with age,

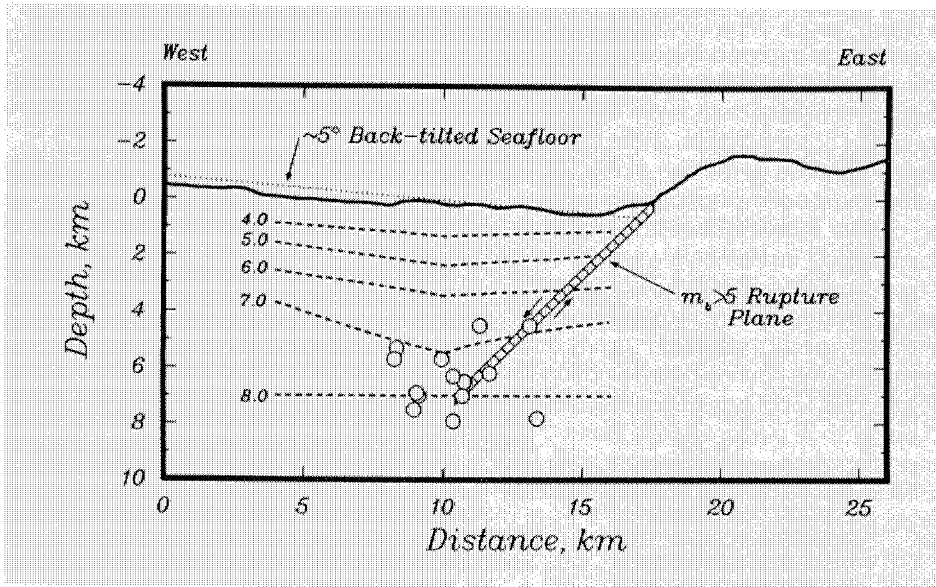


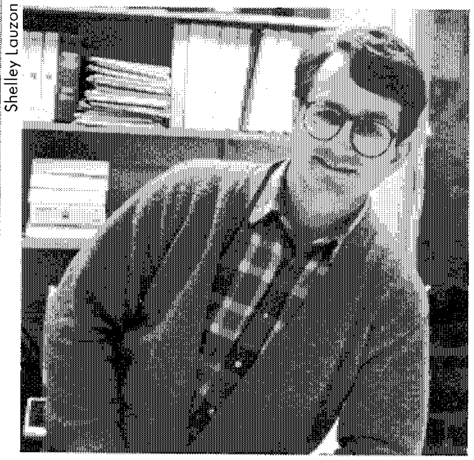
Figure 2: A profile across the median valley of the Mid-Atlantic Ridge near latitude 23°N showing the interrelationships between seafloor topography, the inferred rupture plane of a globally recorded earthquake, microearthquake foci (open circles) and the two-dimensional velocity structure of the crust. Velocity contours are annotated in kilometers per second. (This figure is from Joint Program student Douglas Toomey's Ph.D. thesis.)

make clear that mid-ocean ridge systems are strongly heterogeneous in three dimensions. However, seismic experiments are typically carried out along single profiles and are most often only interpreted in two dimensions. This inadequacy in techniques has led us to the development and adaptation of experiments and formal travel time inversion methods that produce structural images in three dimensions. This approach, commonly described as tomography, will be applied to the study of a magma chamber beneath the East Pacific Rise during a National Science Foundation-funded cruise in January 1988 (Figure 2). We are hoping that this experiment, to be conducted in cooperation with Sean Solomon of MIT, will produce a complete image of the crustal accretion process, defining for the first time the shape of the magma body beneath the rise crest and perhaps even something of its internal structure. If successful, this type of three-dimensional imaging experiment will revolutionize our ability to map earth structures beneath the oceans. Several more steps are needed before we can be completely confident of this, however. Not only do we need to prove our ability to collect the data with sufficient accuracy, but more computer modelling efforts are required to quantify exactly the resolving power and uncertainties of the resulting structural images.

The third area of ocean bottom seismology that has seen major progress in recent years is the study of mid-ocean ridge microearthquake activity. This rich source of data on the faulting mechanisms associated with crustal accretion has long been underutilized simply because of the use of inadequate and poorly positioned monitoring arrays. However, we can now deploy 10-12 instruments within a tectonic framework that is sufficiently well understood to ensure that the majority of activity occurs within our array, thus permitting the routine determination of depths and locations of earthquakes to better than a kilometer. In these endeavors we will cooperate with colleagues from MIT and have recently, through the work of MIT/WHOI Joint Program student Douglas Toomey, made major progress in unravelling the mysteries of the Mid-Atlantic Ridge. Earthquake data alone can be disappointing in its ability to improve understanding, but when brought together with other geophysical parameters, can result in significant leaps in comprehension. A prime example is given in Figure 3, from Toomey's Ph.D. thesis, showing an east-west cross-section of the Mid-Atlantic Ridge median valley near latitude 23°N. This shows how, for the first time, a specific relationship can be suggested between the topography of the valley itself, the inferred fault plane of a large globally recorded earthquake, and the microearthquake epicenters. The understanding of these relationships is the key to learning how a mid-ocean ridge operates.

Borehole Seismology

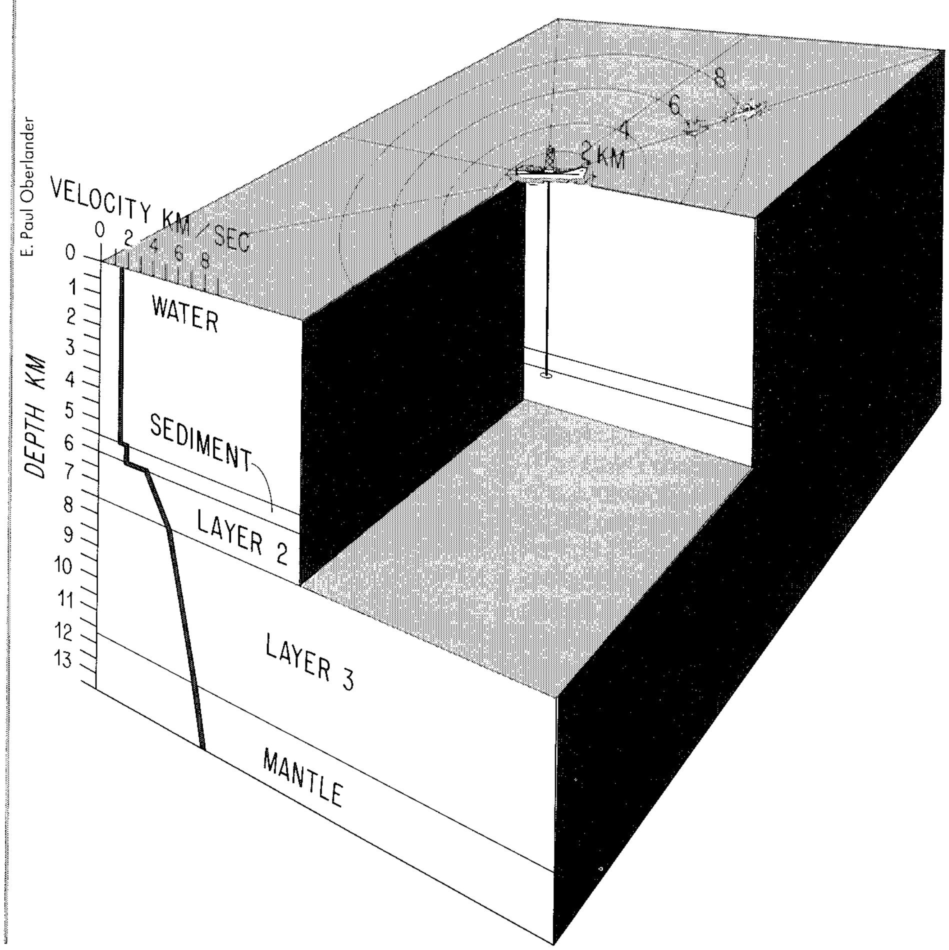
Ralph A. Stephen



Shelley Lauzon

Top: Ralph Stephen. Bottom, Figure 1: Schematic diagram of an oblique seismic experiment (OSE) over oceanic crust. In an oblique seismic experiment, a three-component borehole seisometer is clamped in the open hole at a fixed depth and shots are fired at the surface at a number of azimuths out to ranges of twelve kilometers (7.5 miles) or more.

Since the model of vertical velocity gradients replaced that of thick homogeneous layers for oceanic crustal structure in the mid-1970s, the trend in marine seismology has been towards more detailed seismic analysis of fine-scale structure. This trend has been motivated by a desire to understand oceanic crustal processes such as crustal formation, hydrothermal circulation and geochemical alteration, and by a desire to correlate field observations of ophiolites, well logging results and deep-sea core and dredge sample analyses with the gross in situ structure of oceanic crust. A number of intermediate issues have arisen. These include questions of scale, structural refinement, lateral variability, anisotropy and porosity. It is important to keep these issues in mind when addressing both the fundamental geological and geophysical processes and the seismic data interpretation.



E. Paul Oberlander

The scales involved in the study of oceanic crustal structure range from detailed, even microscopic, analysis of hand sample specimens (less than 1.0 millimeter) to seismic refraction experiments over tens of kilometers. Scale must be considered when comparing results of different techniques and even in the same experiment, structures of different scales may affect different observations. For example, in the interpretation of a seismic refraction line, travel times reflect the structure along the whole ray path (approximately tens of kilometers) but the amplitude of a particular arrival is sensitive to finer scale topography and lateral variability in the region of the source and receiver (about hundreds of meters).

The importance of structural refinement in interpreting oceanic crustal structure has recently been emphasized. Areas that would have been collectively referred to as "normal" oceanic crust twenty years ago are presently divided into ridge, trench, fracture zone and "normal" oceanic crust. With the postulated "zero offset" fracture zones "anomalous" structure may occur every ten kilometers (six miles) and the meaning of "normal" oceanic crust in a seismic refraction context becomes nebulous.

Lateral variability is an issue on all length scales. It is frequently ignored because it is easier to conceive of purely depth dependent variations. In some techniques, such as seismology, the theoretical problem is considerably simplified by assuming lateral homogeneity. If lateral heterogeneity occurs over distances which are large compared to a seismic wavelength (approximately 500 meters, or 1500 feet), the effect is to merely bend ray paths. However, if the heterogeneity occurs over distances on the order of a wavelength, anomalous amplitudes and attenuation due to scattering will occur. If the variation occurs over distances much less than a wavelength the medium can be represented by composite elastic properties. The most obvious violation of lateral homogeneity in the deep sea environment occurs at the top of igneous basement, the basalt-sediment or water interface, which is frequently assumed flat although it is notoriously rough on all length scales from millimeters to kilometers.

Anisotropy is frequently avoided because of its complexity. In a seismic context, general anisotropy requires twenty-one elastic constants to express the elastic behavior at every point in a medium (which is not homogeneous) instead of only two elastic constants which are required to interpret an isotropic structure. It is not surprising that seismologists prefer to disregard anisotropy if possible, but structural geologists, sedimentologists and petrologists regard anisotropy as a fundamental property of oceanic crustal rocks.

Porosity of oceanic crust is the most important unknown parameter in oceanic crustal studies. (In this discussion porosity refers to all void space in a rock and includes fissures, cracks and inclusions.) It affects all crustal measurements and processes. In correlating petrology to crustal structure by velocity analysis some assumption about porosity is essential. It is clearly important in upper oceanic crust (approximately 500 meters, or 1650 feet) where porosity typically reaches twenty percent, but the depth at which it is negligible is unknown. Some heat flow arguments require hydrothermal circulation and significant permeability and porosity throughout the crust. The problem is further complicated by the aspect ratio distribution of the voids which have a strong effect on both the permeability and seismic velocity.

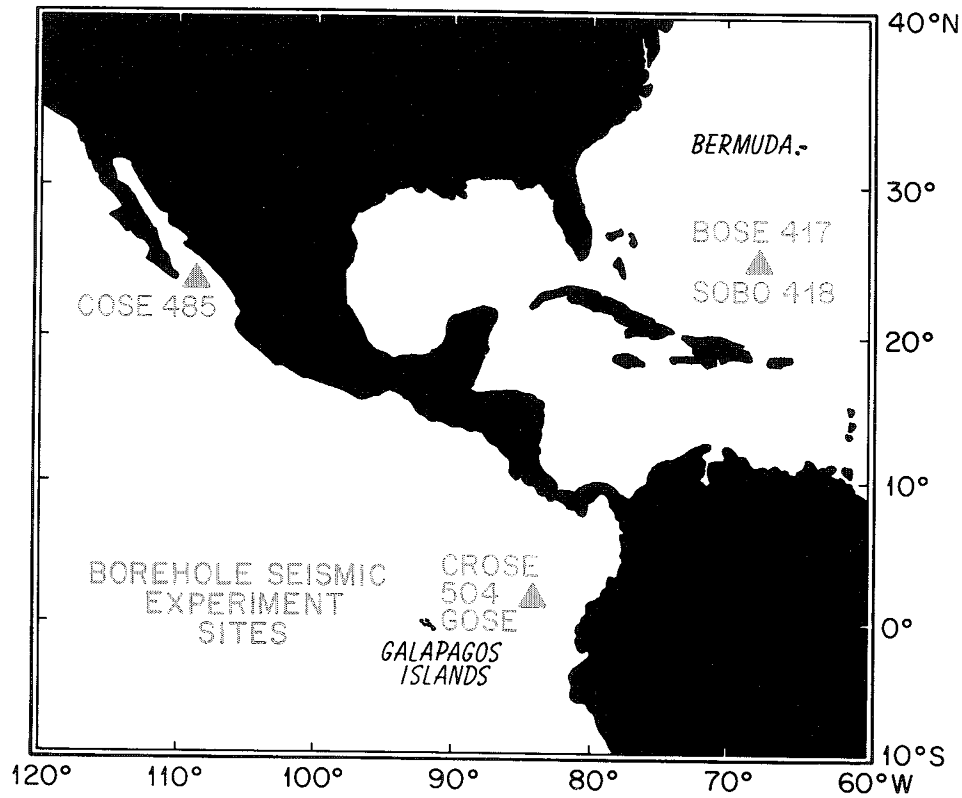


Figure 2: The locations of the three borehole seismic experiments conducted to date.

These five issues are significant because each includes many unanswered questions, some of which can only be solved by innovative data collection, analysis and interpretation techniques. Borehole seismic experiments provide insights into these problems.

Borehole receiver experiments, or oblique seismic experiments (OSE), which use clamped borehole geophones as receivers, have a number of advantages over conventional seismic refraction techniques which use ocean bottom seismometers, ocean bottom hydrophones or sonobuoys:

1. Conventional techniques do not obtain the same degree of lateral resolution as the OSE.
2. The OSE does not rely on the presence of reflecting or refracting horizons in order to obtain a velocity determination.
3. Conventional refraction experiments cannot detect low velocity zones. The OSE can.
4. Travel times in the OSE are less sensitive to the basement topography correction than travel times in conventional refraction experiments.

5. Proper attenuation measurements in oceanic crust can be made with the OSE by comparing amplitudes.
6. When the receiver is clamped to the rock wall of the borehole it has better coupling than an ocean bottom receiver which has fallen more or less randomly into the seabed.

The large-scale simplicity of oceanic crustal structure models, mostly defined by seismic refraction experiments, led early investigators to sweeping, general models of plate tectonics, seafloor spreading, and internal composition and petrology. On the scale of tens to hundreds of kilometers, the approximations of lateral homogeneity and isotropy seemed perfectly valid in the sense that it was not necessary to invoke lateral heterogeneity or anisotropy to explain the seismic observations. Over the past decade there has been a trend, largely a result of our deep sea drilling capability and detailed studies of ophiolites, towards smaller scale observations and processes (e.g., hydrothermal circulation, geochemical processes, shallow crustal structure). Although there is some evidence that seismic structure remains simple down to the kilometer scale, there is overwhelming evidence that on the scale of hundreds of meters and less the structure becomes significantly more complicated. In order to study this structure seismically, more innovative field techniques and data reduction and interpretation procedures must be developed. Direct observation by camera systems, diving submersibles and drilling reveals the basement interface as rough on length scales from millimeters to kilometers with significant lateral changes in structure and preferred orientations. At normal seismic frequencies the processes of mode-conversion and scattering from the lateral heterogeneities and the effects of anisotropy become significant.

Borehole seismic experiments have improved our knowledge of upper oceanic crust by providing accurate in situ velocities at seismic frequencies, measures of lateral heterogeneity on the scale of kilometers, and evidence for seismic anisotropy due to preferred fracture orientation.

Characterizing Seafloor Topography

Deborah K. Smith and Peter R. Shaw

Topographic features of the seafloor are the surface expression of processes occurring within the earth's interior. If it were possible to drain the ocean basins so that the topography could be observed directly, spatial and temporal relationships between features would reveal much about the processes controlling oceanic vulcanism and plate evolution. Except for brief excursions to the ocean bottom in manned submersibles, however, the seafloor remains hidden from view, and its topography must be inferred from data collected by remote sensing instruments on satellites and deployed from surface ships. In fact, the ocean is such an effective barrier in concealing the bottom that small-scale topographic relief found on the surface of some of the other planets is better known than that found on our planet's seafloor.

Maps of seafloor topography constructed from bathymetric data collected by conventional wide-beam echosounders in the 1950s and 1960s (Figure 1) were an integral part in the development of the ideas which led to the theory of plate tectonics. Once this theory was advanced, oceanic surveys focused mainly on features relating to large-scale tectonic processes such as mid-ocean ridges, subduction zones, hot spot traces, and major fracture zones. Such studies have dramatically increased our understanding of seafloor processes.

It is convenient to divide seafloor topography into two categories: the relief created at or very near mid-ocean ridges, and that generated away from the ridge. Along the ridge axis oceanic crust is accreted, and the newly formed lithosphere is faulted to form abyssal hill topography elongated in a direction parallel to the ridge. Transform faults divide the ridge and its associated topography into segments juxtaposing lithosphere of different ages. These faults propagate outwards from the ridge as fracture zone scars which run parallel to the local spreading direction. The regular fault-block topography created at the ridge can be altered in various ways. For example, oceanic vulcanism which gives rise to the numerous isolated seamounts observed both near and away from the ridge, and the oceanic vulcanism which forms large hot-spot traces such as Hawaii, overprint and mask the pre-existing topography. In addition, sediments begin to accumulate and smooth and subdue the topographic relief as the lithosphere moves away from the spreading center.

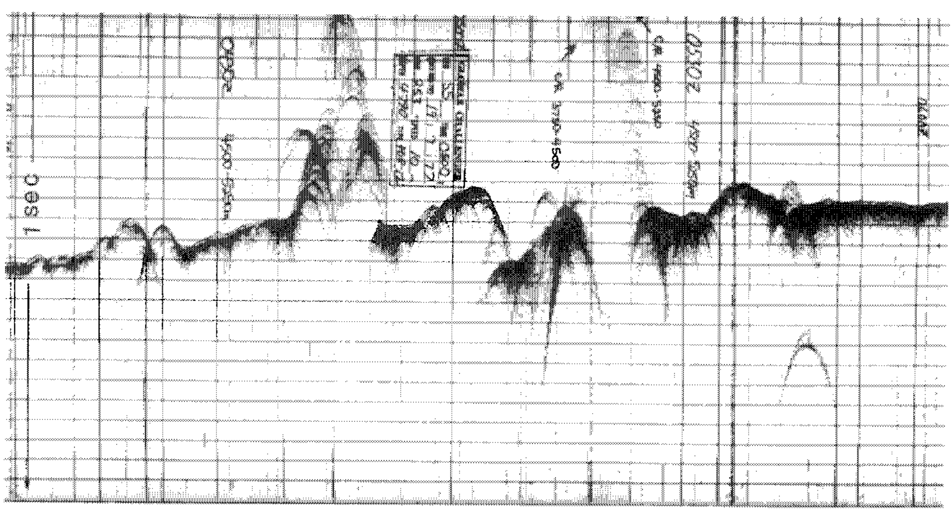
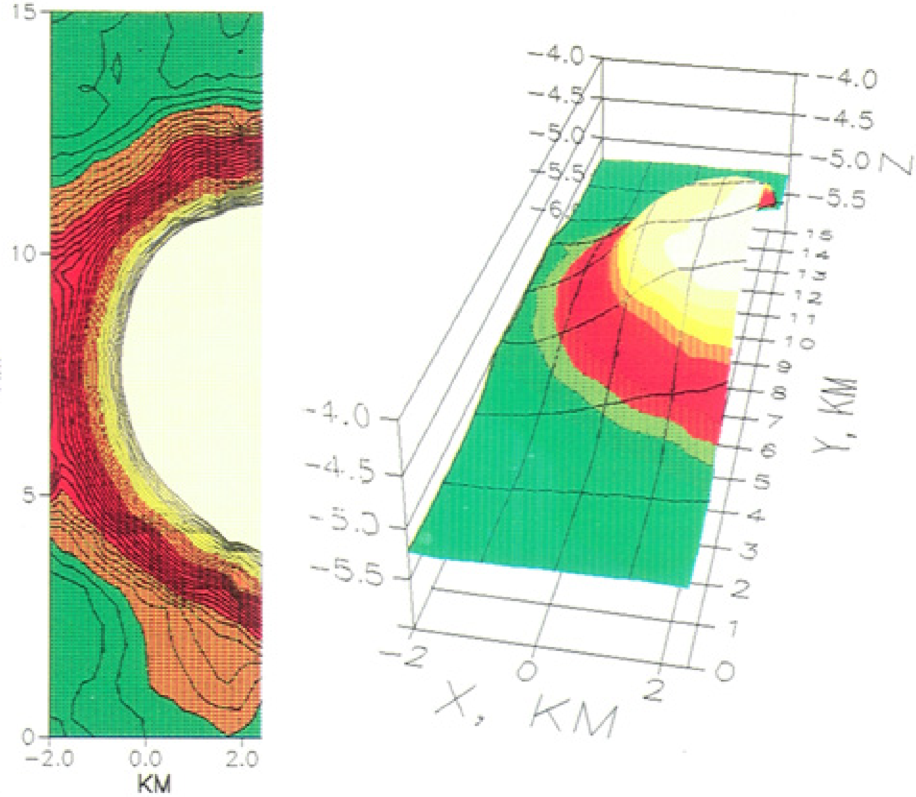
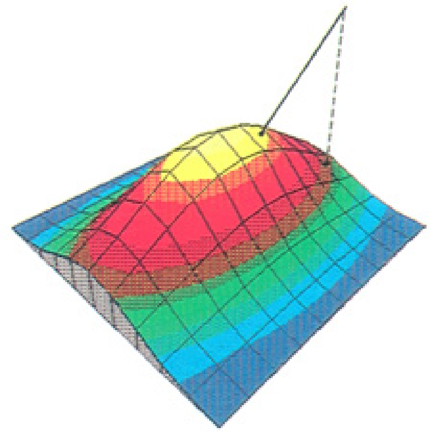


Figure 1: Wide-beam profile record collected on Deep Sea Drilling Project Leg 55 between San Diego and Honolulu. The vertical scale is 750 meters from top to bottom. Notice the two seamounts recorded on the echogram.





Fine-scale studies of seafloor topography became possible with the development of multi-beam and side-scanning sonar systems such as Sea Beam, GLORIA and SeaMarc II (Figure 2). These systems provide a high resolution areal view of the seafloor, and have revealed many details not apparent on the one-dimensional wide-beam profiles. Sea Beam swath data, for example, collected over the mid-ocean ridges have substantially clarified our views of crustal accretion and the formation of oceanic lithosphere. Sea Beam surveys of the mid-ocean ridges have shown that ridge-crest segments are not necessarily continuous between transform faults as once thought, but that the ridge axis is offset by many different types of discontinuities (e.g., overlapping spreading centers and propagating rifts).

Recent studies have focused on statistical modelling of seafloor topography, and methods have been developed which use multi-beam digital data to estimate properties of seafloor topography such as roughness, abyssal hill elongation directions, and asymmetry in the shape of abyssal hills. One such method involves the use of topographic slopes for characterizing seafloor properties. Normal vectors to small patches of seafloor are computed in a region and compiled into two-dimensional histograms (Figure 3). Parameters estimated from these slope histograms are found to vary geographically, and variations can be correlated to geologic variables such as spreading rate and age of the lithosphere. Simple statistical models of seafloor morphology based on the data are widely applicable. They can be used to predict topography in poorly surveyed portions of the oceans, and they provide important information on dynamic earth processes.

Shelley Lauzon

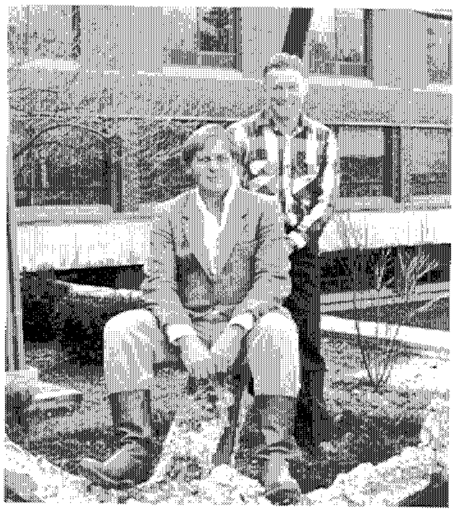
Figure 2 (top left): Sea Beam swath collected in the northeastern Pacific across a small seamount is shown in a plan view (left) and a three-dimensional view (right). Notice how much more information is available from the multi-beam swath when compared to the wide-beam profile in Figure 1. Figure 3 (top right): Example of how normal vectors to the topography are calculated for small patches of seafloor. Bottom: Peter Shaw and Deborah Smith.

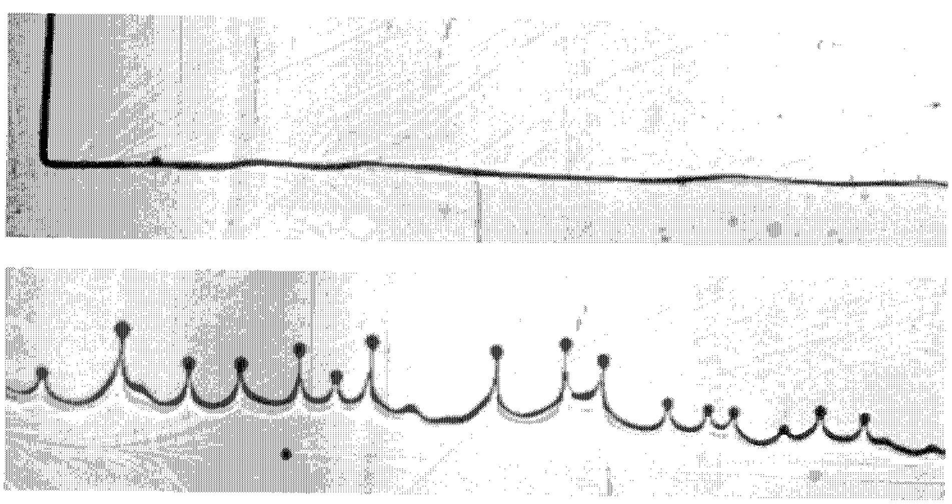
Geodynamics and Ocean Ridges

Henry J.B. Dick, Hans Schouten and John A. Whitehead, Jr.

Shelley Lauzon

Anne Rabushka





Top: Henry Dick. Middle: Hans Schouten (seated) and Jack Whitehead. Bottom, Figure 1: Rayleigh-Taylor instability of a horizontal line of water/glycerine mixture in a bath of denser pure glycerine. In the top photo the line has been formed by moving an injector from right to left. In the bottom photo the line has developed numerous protrusions. The spacing of the protrusions is a function of the diameter of the original line and the viscosities of the two fluids.

Geodynamics is the study of geology from a dynamic viewpoint, with an emphasis on understanding mechanism and process rather than on simple observation. The Institution's Geodynamics Program is investigating the formation of the ocean lithosphere, the product of the separation of the earth's great tectonic plates and the upwelling and melting of the mantle between them at the ocean ridges.

Due to the length of the geologic time scale (seafloor spreading occurs at about the same speed as the growth of your thumbnail), marine geologists are fundamentally limited by not observing this process in motion. The data they collect effectively represents an instantaneous snapshot of a dynamic earth. Marine geophysicists, petrologists and geochemists have worked inductively, trying to infer the general principles and mechanisms which underly the formation of the lithosphere from these observations. The discipline of fluid dynamics, however, is concerned with dynamic transient equilibria and disequilibria, as opposed to the stable equilibrium processes to which earth scientists mainly appeal. Such a mode of thinking is particularly helpful in understanding geologic processes occurring at ocean ridges.

We have capitalized on the Institution's unique strength in fluid dynamics in the Physical Oceanography Department and its expertise in igneous petrology and geophysics to create a synergistic approach to analysis of the ocean crust. An exciting result has been a series of papers in which we have been able to present a three-dimensional model for the segregation of magma from the mantle and the formation of the ocean crust. Until recently, this was viewed as a simple two-dimensional process, with melt segregating from the mantle ascending beneath ocean ridges, rising uniformly upwards to feed a continuous magma chamber in the overlying crust, and erupting to the surface as lava. Since the ocean ridges are undergoing continuous extension, this was believed to create a simple layer cake crust, with coarse plutonic rocks crystallized from the magma chambers overlying the mantle at depth and an intermediate level of sheeted dikes which provided conduits for magmas to erupt to form a thin layer on the sea floor.

Our new model is based on application of a simple fluid dynamic principle to explain a series of new observations on the nature of rocks dredged from the ocean ridges, on the regularity with which ocean ridges are segmented by periodically spaced fracture zones and lows along their length, and on new evidence for a dramatic thinning of the crust at these locations.

We were initially stimulated by the need to explain some startling conclusions from an extensive study by Dick, an igneous petrologist, of abyssal peridotites from oceanic fracture zones. These rocks are believed to be the residues of the mantle melting beneath ocean ridges which produces the effusive basaltic lavas erupted there. Along the extremely slow spreading ocean ridge system that surrounds Antarctica, which we have been systematically exploring for the last ten years, thousands of square kilometers of the sea floor in the vicinity of the fracture zones are paved largely with such peridotites, covered over by only occasional basalt flows. Since the peridotites have undergone a high degree of melting, and the melt was not trapped in the peridotite, the peridotites should not be exposed at all.

Rather, they should be covered by a thick layer of basaltic magma squeezed out of the peridotite during melting. Since the areal extent of exposed peridotite is far too large to explain as the result of any known

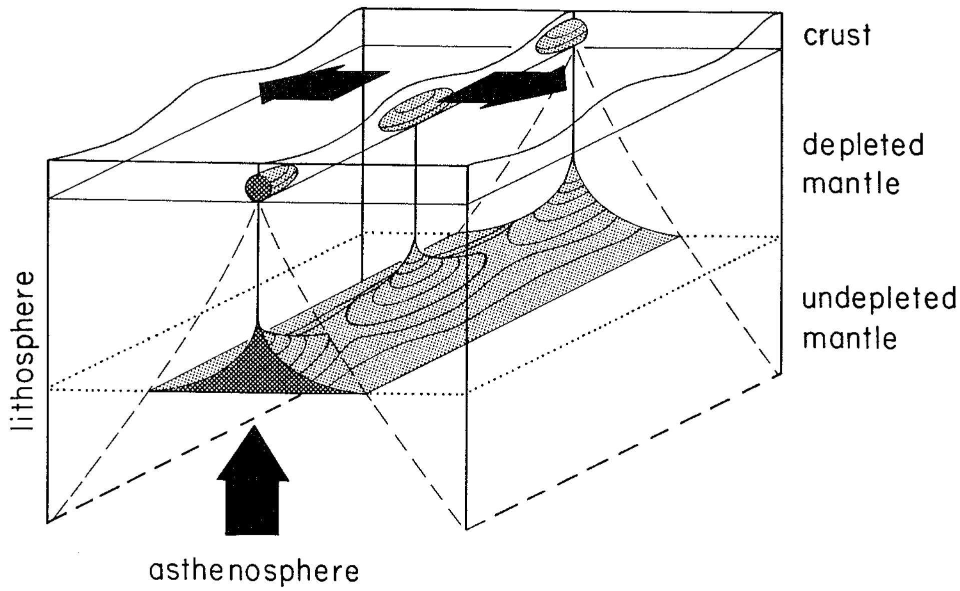


Figure 2: A sketch of a possible three-dimensional flow beneath spreading centers. As mantle material rises above a certain level it passes through a zone in which partial melt forms. Due to its lower viscosity and density, the partial melt zone develops a gravitational instability leading to regularly spaced concentrations of melt which rise to the surface to form crustal magma chambers.

tectonic process, the basalt produced by melting of the peridotite has erupted elsewhere, most likley some distance from the fracture zone area along the adjacent ocean ridge segment. This required that magma produced by melting of the peridotite beneath the fracture zone drain laterally through the mantle to a volcanic center beneath an adjacent ridge segment, rather than rising vertically through the ascending mantle. Since the melt is lighter than the mantle in which it forms, intuitively you would expect the melt to drain straight upwards, not flow sideways.

Whitehead, the physical oceanographer among us, pointed out that this actually conformed to a fundamental fluid dynamic principle: Rayleigh Taylor Instability. This principle is illustrated in Figure 1, where a line of light fluid has been injected horizontally into a denser more viscous fluid. As expected, the line floats upwards due to its lower density, but at the same time it also goes unstable. Small protrusions develop at evenly-spaced instability points, into which the fluid from the line drains. Eventually most of the fluid ascends in upward floating drops to the surface from the instability points. The partially molten mantle ascending between two diverging lithospheric plates is, in effect, precisely such a situation, giving rise to the simple intuitive model shown in Figure 2. This model explains why magmas do not flow uniformly up through the mantle to the base of the crust beneath ocean ridges, segregating instead at depth and erupting at regularly-spaced volcanic centers.

This effort coincided with the work of Schouten, a geophysicist, who had been working on the segmentation of ocean ridges by fracture zones. Careful examination shows that the ocean ridges consist of individual spreading segments. The break between segments may be an offset at a fracture zone or a depression along the ridge axis. Another Institution colleague, Robert Ballard, and French scientist Jean Francheteau have shown that each such segment is also defined by a volcanic high or eruptive center located near its midpoint. These segments and their volcanic highs are very regularly spaced along the ocean ridges, a spacing which we have found to be consistent with the numerical predictions of the fluid dynamic model used to explain the distribution of the peridotites.

We have thus been able to construct an extraordinarily detailed model emphasizing the three-dimensional variability of the ocean crust and lithosphere (Figure 3). In this model, ocean ridge volcanism is regarded as similar to that occurring in island arcs, with the ridges marked by strings of regularly-spaced volcanic centers overlying similarly-spaced instability points in the athenosphere. As a consequence of spreading, however, the magmatic centers are undergoing continuous extension and large volcanic edifices, such as island arc volcanos, are not constructed. Instead, ribbons of basaltic crust are formed parallel to the spreading direction centered on the individual volcanic centers. Where the magma supply is attenuated, as at the very slow spreading centers, these crustal ribbons may fail to overlap, leaving large intervening strips of exposed mantle.

When the ocean ridges are viewed from this new framework, we have found that previously inexplicable features of the sea floor make sense. One such feature are V-shaped topographic trends centered on the ocean ridges. These ridges often seem to consist of chains of small volcanos or seamounts originating at a magmatic center located at the ridge axis. Their orientation, however, is oblique rather than parallel to the spreading direction, in apparent contradiction to the model which we have just related. A key point, however, is that that magmatic centers in our model are rooted in the instability points in the underlying athenosphere, not in the lithosphere. If the lithosphere is migrating over the athenosphere, then the volcanic centers may be forced to migrate systematically with time long the ridge axis, with the instability points in the overidden athenosphere. This would cause each new seamount formed on the ridge axis to form some distance down the ridge from the last one, which with the continuous spreading would produce a V-shaped volcanic ridge originating at the present day location of the magmatic center above the instability point in the athenosphere.

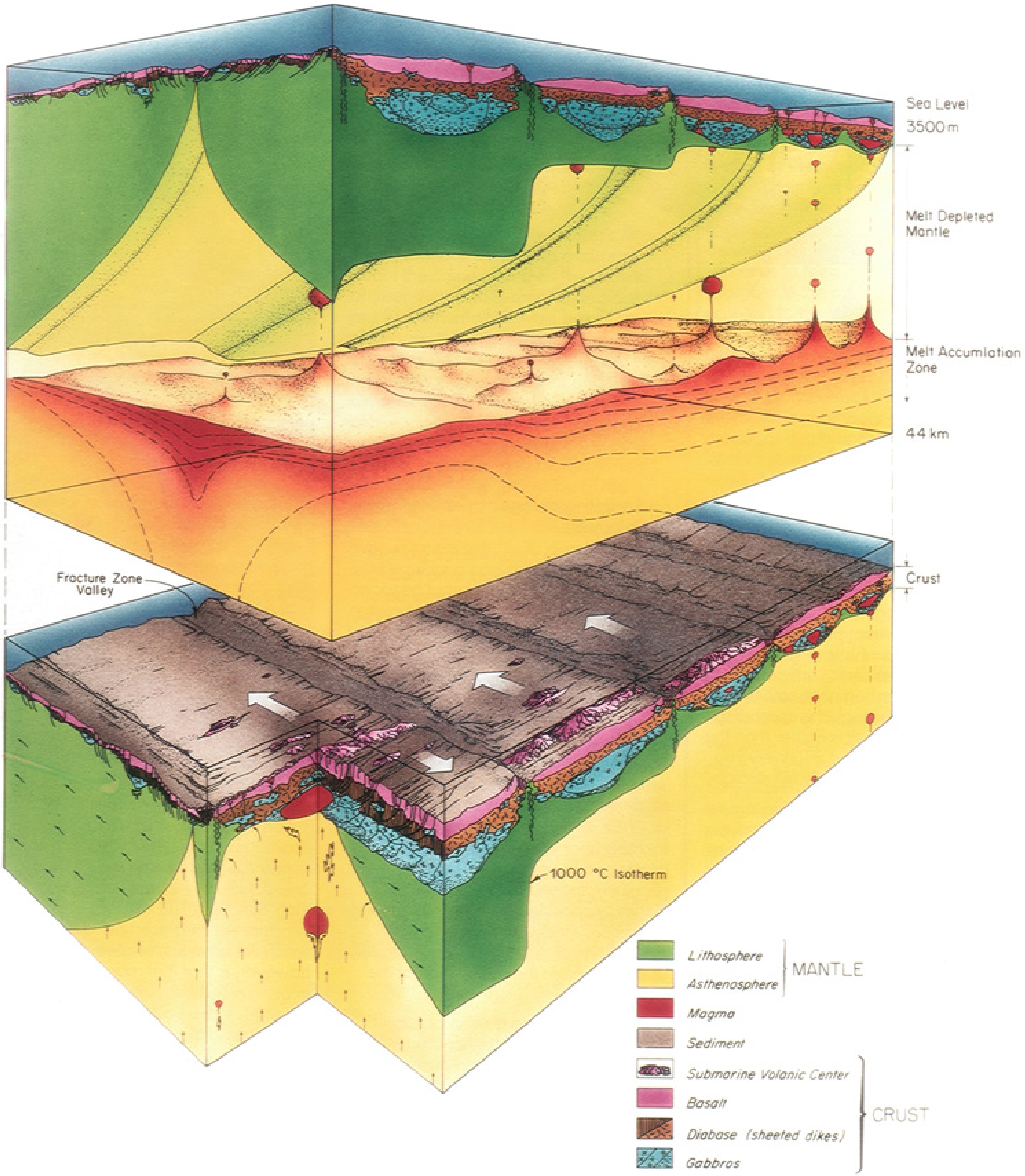


Figure 3: A geologically more realistic model of segmented spreading centers and the way they may be fed by the instability in the lower mantle.

If this model is correct, it has significant implications for the motions of the mantle. Around the earth there are great chains of ocean islands, such as the Emperor Seamount Chain which originates with the island of Hawaii in the Pacific, which are systematically oriented with relation to each other and whose origin appear to be unrelated to the ocean ridges. Geophysicist Jason Morgan of Princeton University suggested that these were the result of volcanic centers located above plumes of mantle material originating in a fixed deep mantle reference frame. This "framework" has since been widely used as the reference frame for the motions of the lithospheric plates related to sea floor spreading. What this extension of our model implies, however, is that the "deep" mantle reference frame of Morgan actually extends to the base of the lithosphere - to within roughly one hundred kilometers (62 miles) of the earth's surface. The test of this hypothesis is whether or not the V-shaped trends can be rationalized to the absolute motions of the ocean ridges over Morgan's mantle reference frame. We have found that such a test fits predicted V-shaped trends to those observed remarkably well. This is a very exciting result, but must be regarded as preliminary since the number of well-documented V-shaped trends in the rift mountains of the ocean ridges is still small. These results do, however, pose an exciting possibility which commands more detailed exploration of the seafloor topography away from the axes of the ridges, where most of the high quality bathymetric data has been collected to date.

New Technology for Deep Sea Exploration

Dana R. Yoerger and Jules S. Jaffe

New technology for exploration of the sea floor is being produced at the Deep Submergence Laboratory in the Institution's Ocean Engineering Department through a program of engineering research, development and field operations. The goals of these programs are to permit scientists to study the sea floor more efficiently and to perform tasks that are not supported by current technology. The cornerstone of these efforts is the ARGO/JASON system, a complimentary set of remotely operated vehicles (ROVs).

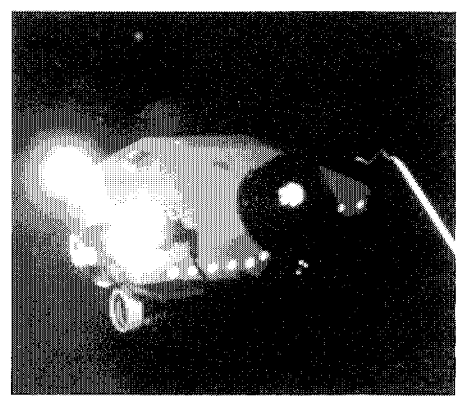
The ARGO vehicle is designed to provide scientists on the surface with simultaneous optical and acoustic real-time electronic images. While ARGO continues to evolve, it is an operational system and has been used on the R.M.S. *Titanic* discovery cruise and on the ARGORISE geology expedition to the East Pacific Rise in 1985.

JASON will be utilized after ARGO has located and surveyed items of interest. Capabilities will include close-up imaging and manipulators to permit sampling and to operate or recover instruments. JASON's movements will be coordinated with its cameras and manipulators by a supervisory control system, permitting systematic detailed survey, inspection and dexterous manipulation. The JASON program includes engineering research utilizing a shallow water test bed vehicle. The development effort has also been supplemented by other projects, including the development of JASON JR., a small remotely operated vehicle which is used as a maneuverable imaging platform from another submersible. JASON JR. and the Institution's manned submersible ALVIN surveyed the wreck of the *Titanic* in 1986.

The ARGO/JASON project relies on engineering research efforts in areas where system requirements exceed the current state-of-the-art. Specific areas include imaging and image processing, the dynamics and control of ARGO, and the telerobotic control system for JASON and its manipulators.

Shelley Lauzon

Shelley Lauzon



Top: Dana Yoerger. Middle: Jules Jaffe. Bottom: Prototype vehicle JASON JR. photographed by DSV *Alvin* on the deck of R.M.S. *Titanic* in July 1986.

Sensing and processing of visual and sonar images offer new research frontiers which will aid deep ocean exploration. In order to maximize the performance of an imaging system, sensors must be designed with a knowledge of the effect of environmental variables. In the visual domain, we have created a system of computer programs entitled UNCLES (Underwater Camera Light Experiment System) which simulates the underwater propagation of light. Systematic exploration of various lighting system geometries has allowed us to design camera/lighting systems which minimize the backscatter component. With the application of digital image processing techniques to the images produced by an underwater viewing system, useful images can now be obtained at greater distances and with better resolution than were previously possible.

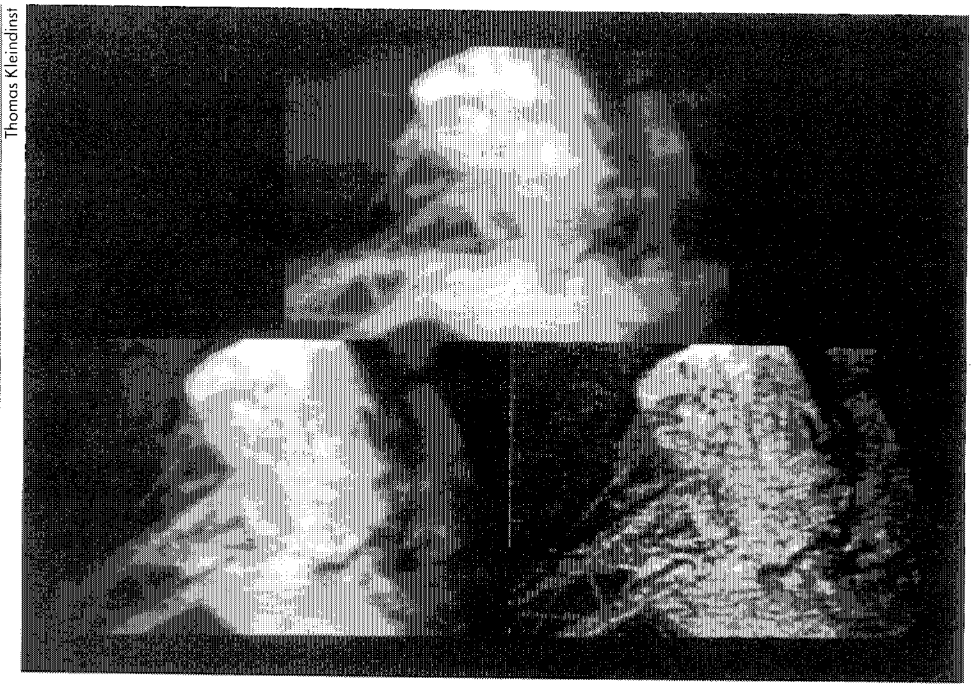
Three-dimensional sonar sensing of underwater images is also under investigation. An innovative technique which permits the simultaneous transmission and reception of multiple beams has been developed and will allow us to generate three-dimensional sonar images at video rates. This will be of great value in situations where visibility is impaired.

The dynamics of vehicles towed at great depth are being studied to make ARGO a better sensor platform and to permit ARGO to hold station while JASON is deployed. The program includes a modelling effort using new techniques for analyzing the dynamics of the vehicle and its cable and an experimental program to verify such models at sea. The results of this effort will contribute directly to ARGO/JASON, but will also provide valuable insight for related efforts such as deployment and recovery of instruments on the sea floor and borehole reentry. From the perspective of the scientific user, this work will produce more capable and reliable towed vehicles.

A research program in telerobotics will make JASON and similar underwater robots more effective and easier to use. Using supervisory control techniques, scientists at the surface will be able to specify the movements of the remote vehicle or its manipulator arms through several different types of interfaces. A computer control system will execute those commands, dealing with the complex dynamics of the vehicle and the manipulators and the disturbance forces and providing the scientists with feedback. The purpose of the computer control system will not be to make the remote vehicle and manipulators autonomous, but rather to provide more capability and to present simpler dynamics to the human pilot.

Telerobotics will offer the scientific user capabilities not available today. Precision navigation and control will permit highly structured observations, which may be used to produce high-quality mosaics when combined with the types of electronic imaging developed for ARGO. Precise, coordinated control of both vehicle and manipulators will allow tasks to be performed without landing on the sea floor, improving efficiency in sampling. Finally, proper automatic control of interaction forces between a manipulator and the remote environment will allow complex tasks to be performed, including operation and servicing of instruments, scientific sampling and salvage.

Thomas Kleindinst



The results of the application of image processing techniques to a *Titanic* cruise video image. The sequence is the original image (top), equalizing the image contrast (lower left) and then applying a resolution enhancement filter (lower right).

1986 Degree Recipients

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

Doctor of Philosophy

VERNON L. ASPER
B.A. Messiah College
M.S. University of Hawaii
Special Field: Marine Geology
Dissertation: *Accelerated Settling of Particulate Matter by 'Marine Snow' Aggregates*

PATRICIA M. BIESIOT
B.S., M.S. Bowling Green University
Special Field: Biological Oceanography
Dissertation: *Changes in Midgut Gland Morphology and Digestive Enzyme Activities Associated with Development in Early Stages of the American Lobster* Homarus americanus

BRIAN J. BINDER
S.B. Massachusetts Institute of Technology
Special Field: Biological Oceanography
Dissertation: *The Physiology of Dormancy and Germination in Cysts of the Marine Dinoflagellate* Scrippsiella Trochoidea

BRUCE J. BROWNAWELL
B.S. Depaul University
Special Field: Chemical Oceanography
Dissertation: *The Role of Colloidal Organic Matter in the Marine Geochemistry of PCBs*

KENNETH O. BUESSELER
B.A. University of California, San Diego
Special Field: Chemical Oceanography
Dissertation: *Plutonium Isotopes in the North Atlantic*

JOSHUA K. HOYT
S.B., M.S. Massachusetts Institute of Technology
Special Field: Oceanographic Engineering
Dissertation: *The Flying Fish, An Untethered Oceanographic Sensor Platform with Acoustic Homing Capability*

ANN P. MCNICHOL
B.S. Trinity College
Special Field: Chemical Oceanography
Dissertation: *A Study of the Remineralization of Organic Carbon in Nearshore Sediments Using Carbon Isotopes*

BORIS MORO
B.A. University of Zagreb, Yugoslavia
M.A. State University of New York, Stony Brook
Special Field: Physical Oceanography
Dissertation: *Analysis of Certain Inviscid Flows on the Beta-Plane*

GLEN T. SHEN
S.B. Massachusetts Institute of Technology
Special Field: Chemical Oceanography
Dissertation: *Lead and Cadmium Geochemistry of Corals: Reconstruction of Historic Perturbations in the Upper Ocean*

ARTHUR J. SPIVACK
S.B. Massachusetts Institute of Technology
Special Field: Chemical Oceanography
Dissertation: *Boron Isotope Geochemistry*

STEPHEN A. SWIFT
B.A. Dartmouth College
Special Field: Marine Geology
Dissertation: *Cenozoic Geology of the Continental Slope and Rise off Western Nova Scotia*

Doctor of Science

YEHUDA AGNON
B.Sc., M.Sc. Hebrew University, Israel
Special Field: Oceanographic Engineering
Dissertation: *Nonlinear Diffraction of Ocean Gravity Waves*

MICHAEL S. BRUNO
B.S. New Jersey Institute of Technology
M.S. University of California, Berkeley
Special Field: Oceanographic Engineering
Dissertation: *A Coupled Hydrodynamic and Ice Floe Movement Model*

JOHN J. POLCARI
B.S. United States Naval Academy
M.S. Massachusetts Institute of Technology
Special Field: Oceanographic Engineering
Dissertation: *Acoustic Mode Coherence in the Arctic Ocean*

PETER J. STEIN
B.S. Massachusetts Institute of Technology
Special Field: Oceanographic Engineering
Dissertation: *Acoustic Monopole in a Floating Ice Plate*

MICHAEL S. WENGROVITZ
B.S.E.E. University of Virginia
M.S.E.E. Southern Methodist University
Special Field: Oceanographic Engineering
Dissertation: *The Hilbert-Hankel Transform and Its Application to Shallow Water*

Part of the Information Processing and Communications Laboratory's (IPCL) facilities in Clark Laboratory. IPCL is one of eight laboratories in the Ocean Engineering Department.

Shelley Lauzon

Dean's Comments

Charles D. Hollister

We were busy in 1986 developing the Ocean Ventures Fund for MIT/WHOI Joint Program students and other young investigators just getting started in their careers. Most of our research at the Woods Hole Oceanographic Institution is funded by federal agencies, which are traditionally conservative and may take a year or more to approve a research proposal. Such a funding climate discourages risk-taking and innovation, especially by young and unproven scientists.

The Ocean Ventures Fund was created in response to the frustrating status quo, our need for more financial support in the Education budget, and a strong belief that our young scientists should be allowed to take chances in following their curiosity. These budding scientists bring a fresh, unbiased approach and a willingness to question the long accepted. The Fund gives students direct access to private money which previously was available only to established scientists. The Fund also strives to review proposals quickly, allowing a fast and timely funding response to unpredictable events, such as a volcanic eruption or earthquake.

Another Success Story:

A growing concern is the Joint Program's small applicant pool which reflects a national trend of fewer undergraduates opting for careers in science and engineering. In an effort to reverse this trend the Office of Naval Research this year approved a grant for a workshop proposed by the MIT/WHOI Joint Program and the University of Washington. The workshop, scheduled for the summers of 1987 and 1988, is designed to bring undergraduate science and engineering professors up-to-date on oceanography and oceanographic engineering. Our hope is that the professors will spread the word about the excitement of oceanography to their students.

Shelley Lauzon

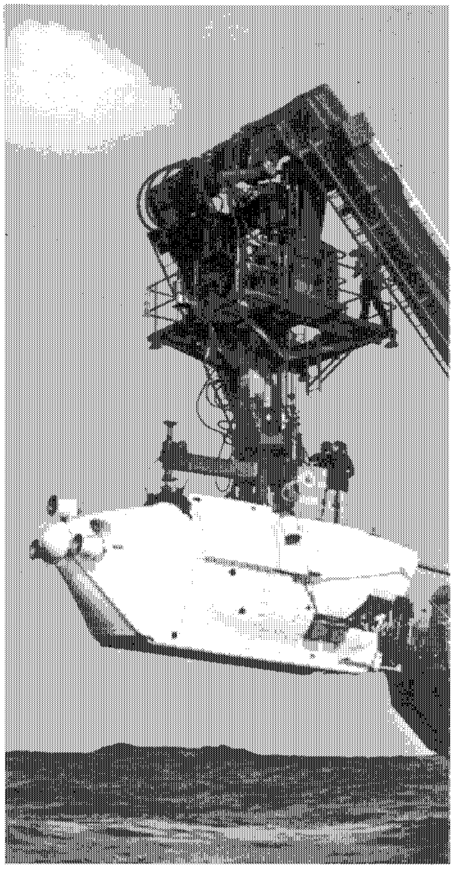
Top: Joint Program student Sara Bennett discusses her research with fellow student Mark McCaffrey (partly hidden) and Dean Hollister. Bottom: A Summer Student Fellow studies biological samples.

Thirteen doctoral degrees were awarded in 1986 to graduates of the MIT/WHOI Joint Graduate Program, bringing the total number of degrees awarded since 1968 to 192 (Ph.D. - 149, Sc.D - 19, Engineer - 21, and WHOI Ph.D. - 3.)

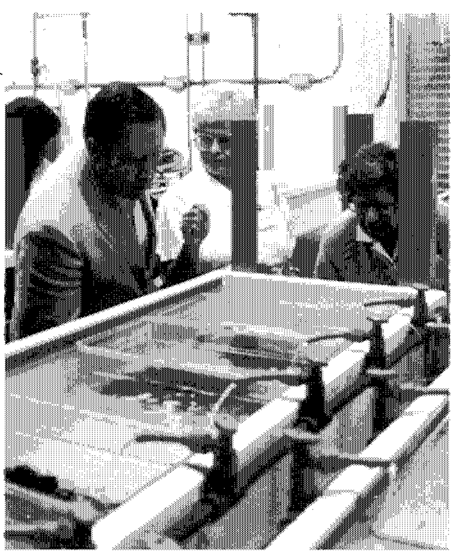
Twenty Summer Student Fellows were selected from 271 applicants representing more than 100 colleges and universities in the U.S. and abroad. The Fellows spent their twelve-week research programs working with scientific staff representing all five departments.

Ashore & Afloat

Rod Catanach



Shelley Lauzon



Top: *Alvin's* new appearance following a five-month overhaul in early 1986. Bottom: New Associates view trays of *aplysia* (sea slugs) being cultivated at the Environmental Systems Laboratory for biomedical research.

A major overhaul of DSV *Alvin's* propulsion and electrical systems was undertaken during the winter months to provide better maneuverability and additional power and lighting to meet scientific needs. The sub's hydraulic propulsion system, with a large stern and two small side lift propellers, was replaced with six direct drive electric thrusters. Numerous other improvements were made to the sub's operating systems during the five-month overhaul. *Alvin* and *Atlantis II* returned to service in May.

Former Director Paul M. Fye and Senior Scientist Robert D. Ballard played major roles in the development of the Living Seas Pavilion at Walt Disney World's EPCOT Center, which opened in January. Other Institution staff provided technical assistance during the exhibit's development.

"Planet Earth," a seven-part PBS series featuring *Alvin* and several Institution scientists, premiered 22 January. WHOI provided film footage and considerable resource material, and many staff were interviewed for the project.

Social Scientist James M. Broadus III became Director of the Marine Policy Center 3 February, succeeding Paul M. Fye who had served as Acting Director since April 1985 when David A. Ross resigned to assume the chairmanship of the Geology and Geophysics Department. Broadus is well-known for his research on the economics of marine minerals and seabed mining.

Five endowed J. Seward Johnson Chairs in Oceanography, one for each of the scientific departments, were established to advance the Institution's graduate education programs. 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) will coordinate the departmental education programs in conjunction with the Institution's Education Council. The chairs are named for long-time WHOI benefactor, the late J. Seward Johnson, who was committed to improving graduate education in oceanography. Each chair is awarded for a three-year term with a possible single renewal for an additional three years and provides up to six months of salary support each year.

The Atlantic slave trade was the topic of Black History Month activities in February cosponsored by the Institution and other Woods Hole scientific laboratories. A series of lectures and the annual harambee, or ethnic feast, attracted several hundred members of the community.

More than 60 women attended the annual Women's Dinner 26 February at Fenno House.

Tracy Goldsmith was awarded the Institution's sixth $1,000 college scholarship 15 March as the overall winner of the Falmouth Science Fair for her project on the water budget of Falmouth's Long Pond. Many staff members served as judges.

Routine maintenance and upgrading on R/V *Atlantis II* was completed in late March. Additional bunk space for four scientists, for a total of 19 science berths, was incorporated into the former electronics laboratory. A Global Positioning System (GPS) for precision navigation and a commercial communications system, INMARSAT, with teletype and high quality voice communication, were installed on the ship. Other maintenance and upgrading included overhaul of the bow thruster, ship's service generator, steering system, main engines and air conditioning system.

Controller Gary B. Walker was named Assistant Director for Finance and Administration 1 April, succeeding Joseph Kiebala, Jr., who retired after ten years of service to the Institution.

Two hundred-sixty attended the Associates Dinner 9 April at the Museum of Science in Boston, and 130 gathered 15 April at the New York Yacht Club. Senior Scientist Robert D. Ballard of the Ocean Engineering Department spoke on "*Titanic* Operation: The Beginning of a New Era in Underwater Exploration" at both dinners.

The biannual WHOI Golf Classic was held 3 May and 18 October at the Otis Golf Course, with more than 40 employees participating in each tournament.

More than 80 participated in New Associates Day 23 May. Tours of laboratories, the dock area and R/V *Knorr* and several scientific lectures on Institution research programs were offered.

The Department of Defense's University Research Initiative Program (URIP) awarded the Institution $12,614,250 in block funding for ocean modelling and remote sensing activities over a five-year period. The grant was the largest of 86 awarded to 70 institutions selected from nearly 1,000 proposals from 175 universities for fiscal 1986-1987. Subcontracts with Harvard University and MIT are included as part of the award.

Hot water vents, several thousand feet deeper than their Pacific counterparts, were explored by *Alvin* and *Atlantis II* in May and June along the Mid-Atlantic Ridge. Scientists found two previously unknown species of eyeless shrimp and large flat eel-like swimmers around the vents, where chimneys spew water up to 350°C (660°F). A six-sided creature, thought to be extinct until photographed a few years ago, was captured for laboratory study in Woods Hole. Senior Scientist Geoffrey Thompson of the Chemistry Department and several department colleagues were involved in the program.

The 57th Annual Meetings of the Trustees and Members of the Corporation were held 13 June at Clark Laboratory. Director John H. Steele was elected President of the Corporation, succeeding Paul M. Fye who had held the post since 1961. Associate Director for Scientific Operations George D. Grice and Consultant for Marine Operations and Planning Robertson P. Dinsmore gave the science report on "The Academic Research Fleet: Present and Future."

Later that day Senior Scientist Robert C. Spindel of the Ocean Engineering Department gave the Associates Lecture on "The Laboratories of the Ocean Engineering Department from Deep Ocean to the Coast," attended by more than 200 Associates and their guests. Open Houses in the laboratories of Chemist John W. Farrington, Geologist Kozo Takahashi and Biologist William A. Watkins followed, with a reception and dinner on the Fenno House grounds concluding the day's events.

"Celebrate New England" was the theme of a five-week Channel 7 tour in May and June with live broadcasts from two locations in each state. The Institution was the last stop 18-20 June as WNEV anchors Tom Ellis and Dionne Willis broadcast the six and eleven p.m. news from atop the Iselin Marine Facility. Short segments on Institution activities were featured during the newscasts.

A return trip to the R.M.S. *Titanic* 9-28 July to test the Deep Submergence Laboratory's prototype vehicle JASON JR. provided remarkable photographs and videotape of the sunken luxury liner. *Alvin* made eleven dives to the wreck, landing on the bow and stern sections while maneuvering JASON JR. along the ship's hull and down the grand staircase deep within the ship. More than 60 hours of videotape and some 60,000 still images taken by Alvin, JASON JR. and the towed still camera sled ANGUS (Acoustically Navigated Geological Underwater Survey) were collected during the expedition headed by Senior Scientist Robert D. Ballard. Hundreds of media visited the Institution during the cruise and thousands called the Publications and Information Office, which coordinated the media and public aspects of the expedition. A standing-room only crowd of 400 media representatives from around the world attended the news conference 30 July at the National Geographic Society in Washington.

The summer 1986 issue of Oceanus Magazine on science and management issues of the Great Barrier Reef was selected as the first Commemorative Project of the American-Australian Bicentennial Foundation. Institution staff, including Director John Steele and Oceanus Editor Paul Ryan, attended a 30 July reception at the Australian Embassy in Washington officially marking publication of the issue.

Asterias, in full dress, led the Parade of Ships 12 July in celebration of Falmouth's Tricentennial. Many employees and their spouses assisted in the production of a Tricentennial quilt, donated to the Town of Falmouth 15 June on the 300th anniversary of the signing of the town charter. One of the colorful quilt's border designs representing town history and landmarks, is R/V *Knorr*. A display on the quilt's production was placed in the Clark Lobby through the summer.

R/V's *Knorr* and *Oceanus* spent the first part of the year working together on the Frontal Air-Sea Interaction Experiment (FASINEX) off Bermuda, conducted by the Physical Oceanography Department. After a variety of spring and summer cruises, the vessels remained at the Institution pier during the last four months of 1986 due to lack of funding for science programs. During the lay-ups vessel crews performed routine maintenance and upkeep and sailed in relief positions aboard *Atlantis II*.

After a busy summer schedule, *Atlantis II* and *Alvin* departed Woods Hole 20 September for an eighteen-month to two-year voyage in the Pacific. A variety of programs were conducted for scientists from around the country

Retiring President Paul Fye (center) was presented a half-hull model of R/V *Atlantis* during Annual Meeting activities in June. At left is Chairman of the Board Guy Nichols, at right Director and new President John Steele.

Anne Rabushka

Karen Walsh

Shelley Lauzon

Anne Rabushka

Thomas Kleindinst

Top: Martin Bowen speaks with Channel 5 reporter Maryanne Kane following the *Titanic* cruise in July. Second from top: Space Shuttle Atlantis Astronauts Woody Spring (left) and Jerry Ross spoke with local media and high school students during their visit in November. Third from top: Assistant Scientist Cheryl Ann Butman, the Ocean Engineering Department's first female scientific staff member. Bottom: A thirty-year service award was presented to Art Voorhis and 1986 retirees honored during December ceremonies. Director John Steele is at right.

along the U.S. East Coast and in the Gulf of Mexico before the ship transited the Panama Canal in November. The ship and sub spent the holidays in San Diego.

Numerous honors and awards were received by Institution staff during the year. Payroll Administrator Laura A. Murphy was chosen the 1986 Young Career Woman by the Falmouth Business and Professional Women's Club.

Senior Scientist James R. Heirtzler of the Geology and Geophysics Department was honored by the National Science Foundation with the naming of the Heirtzler Ice Piedmont in Antartica. Heirtzler's research on seafloor spreading provided the geologic framework which explained the formation of the seas surrounding Antarctica.

Research Specialist George R. Hampson of the Biology Department was appointed to the Waquoit Bay National Estuarine Sanctuary advisory committee by Falmouth Selectmen. Hampson also serves as the town's representative on the Massachusetts Coastal Zone Management advisory committee.

Cheryl Ann Butman became the first woman member of the Ocean Engineering Department's scientific staff with an appointment as an assistant scientist. A graduate of the MIT/WHOI Joint Graduate Program with a doctorate in biological oceanography, her research focuses on hydrodynamics and other engineering studies related to biological research. Later in the year she was the only oceanographer chosen to receive the Office of Naval Research's Young Investigator Award for 1986. Twelve awards were made from 400 applicants, 50 of them in ocean science. The award, a three-year grant, is designed to acknowledge and support outstanding young scientists with research programs that address fundamental scientific issues and are relevant to the U.S. Navy.

Associate Scientist Robert A. Weller of the Physical Oceanography Department was named one of three outstanding young scientists by the American Geophysical Union, receiving that organization's 1986 James B. Macelwane Award.

Senior Scientist Henry M. Stommel of the Physical Oceanography Department received the first Albert-Defant Medal 14 April at a special session of the German Meteorological Society for his "oustanding contributions to oceanography, in particular to the dynamics of the large-scale ocean circulation, steady and time varying, both observationally and theoretically."

Senior Scientist Elazar Uchupi of the Geology and Geophysics Department was commended by the National Aeronautics and Space Administration (NASA) for his assistance in the search for Space Shuttle Challenger. NASA cited Uchupi's rapid response to providing detailed original bottom topography charts in the vicinity of Cape Canaveral; the charts were reproduced and used extensively by the Navy, Coast Guard and NASA ships involved in recovery operations.

Assistant Scientist Mark Kurz of the Chemistry Department was selected by the Geochemical Society of America to receive its F.W. Clarke Medal. The award is made for "a single outstanding contribution to geochemistry or cosmochemistry published as a single paper or series of papers on a single topic" and is presented to an investigator under 35 years of age.

Postdoctoral Investigator Kathryn A. Kelly of the Physical Oceanography Department was named an assistant scientist, the first woman to join that department's scientific staff.

Senior Scientist Susumu Honjo of the Geology and Geophysics Department traveled to Japan to receive a special Advanced Scientific Contribution Award in Space and Oceans from the Government of Hokkaido and the Junior Chamber of Commerce. More than 1,700 heard lectures by Honjo and other award recipients Sir Edmund Hillary (Humanitarian and Adventure Planning Award) and NASA Astronaut Dr. Anna Fisher (Engineering and Space Award).

Senior Scientist Robert D. Ballard of the Ocean Engineering Department received the Washburn Award from the Boston Museum of Science 29 October. The award is presented annually "to an individual anywhere in the world who has made an outstanding contribution toward public understanding of science and appreciation of its fascination and of the vital role it plays in our lives."

Research Specialist James R. McCullough of the Physical Oceanography Department was awarded the 1986 Compass Distinguished Achievement Award from the Marine Technology Society for his contribution to the advancement of the state of the art of navigation in a cooperative project with the U.S. Geological Survey.

George A. Smith began his duties as Controller 2 September, succeeding Gary B. Walker who assumed the post of Assistant Director for Finance and Administration 1 April.

A fifteen-nautical-mile area around the Galapagos Islands was designated a protected marine resource reserve as a result of studies by the Institution's Marine Policy Center. Center personnel have worked with the Government of Ecuador for several years to develop a marine resource management plan for the archipelago.

New employees were briefed on Institution policies, practices and procedures at the Employee Orientation 26 September. The Personnel Office periodically sponsors these sessions, which include a motor tour of facilities and a scientific presentation.

More than 50 Associates participated in a new Volunteer Program undertaken in June to provide much-needed assistance for the Publications and Information Office and its Exhibit Center. Volunteers served from July through September, assisting in routine projects related to the *Titanic* expedition and staffing the Exhibit Center. The program was developed by the Publications and Information and Development Offices and was coordinated by Associates Joel Davis and Eloise Soderland. An appreciation luncheon was held 30 September at Carriage House. The highly successful program will continue in 1987.

Physical Oceanographer John Allen of Oregon State University received the Institution's third Bostwick Ketchum Award 1 October. Allen presented a lecture on "Large-Scale Dynamics of the Coastal Ocean" and met with Institution colleagues and students at a reception following the lecture at Endeavour House.

Nine hundred visited the Exhibit Center during the Massachusetts COASTWEEK 86 celebration 6-13 October. A record 30,000 viewed the exhibits at Endeavour House during the summer months.

More than 400 Associates and guests attended the annual Day of Science 10 October at Clark Laboratory. Lectures were given by Biologist Donald M. Anderson (red tide and shellfish toxicity), Biologist Philip S. Lobel (coral reef fishes), Marine Policy Research Fellow Andrew Solow (sea level rise) and Research Assistant Martin F. Bowen (deep submersible technology and the *Titanic* expedition).

Two members of the Space Shuttle Atlantis Flight 61-B crew visited the Institution 25-26 November to return a piece of the mast of R/V *Atlantis* which flew as a memento during the shuttle's first scientific mission 26 November – 3 December 1985. The NASA astronauts had a brief tour of Institution facilities, discussed remote sensing and other space-related research programs with staff members, and were guests at a reception and dinner. Local high school students and the media met the astronauts at a news conference 26 November.

A thirty-year service award was presented 5 December to Associate Scientist Arthur Voorhis of the Physical Oceanography Department in ceremonies in Clark 507. Sixteen other 1986 retirees, who with Voorhis represent 392 years of service to the Institution, were also honored.

The Institution Christmas Party was held 12 December at Shoreway Acres Motel in Falmouth, attended by more than 150.

Among the many visitors to the Institution in 1986 were members of the New England section of the Marine Technology Society, who met 15 January in Clark 507 to hear Ocean Engineering Department Chairman Robert C. Spindel discuss "Advances in Ocean Acoustic Tomography." Leonid Dmitriev, chief of petrology at the Vernadsky Institution of Geochemistry of the U.S.S.R.'s Academy of Sciences, spent ten days in Woods Hole in late January as part of a three-month U.S. visit to exchange data and samples with fellow geologists. Three groups from the Naval War College visited WHOI for a day-long program of scientific presentations and visits to the dock area and a ship; mid-level foreign naval officers in the Naval Staff Course representing more than twenty nations spent the day 7 April and 3 November and senior officers enrolled in the Naval Command College visited 22 April.

Senior cadets from the U.S. Coast Guard Academy spent the day 24 April; host was Robertson P. Dinsmore, a retired Coast Guard Captain. Massachusetts Congressman Edward Boland met with staff members 28 April and spoke on "Science and the Federal Budget" at a luncheon at Carriage House. Members of the Board of Regents of Texas A & M University toured facilities and held discussions with the Directorate 8 May in an effort to develop a plan for a marine research institution in Galveston; the University's R/V *Gyre* was at the WHOI pier for a short port call between North Atlantic cruises during the Regents' visit. The Ocean Studies Board of the National Research Council met at Carriage House 11-12 August; Director John H. Steele is a member of the Board. U.S. Navy visitors included Eric Hartwig, Acting Director of Environmental Sciences at the Office of Naval Research, who met with members of the Directorate 21 August to discuss research programs. Captain Craig Dorman of the Navy Space and Naval Warfare Systems Command spent 21-24 August in Woods Hole for a series of meetings with Institution staff, and Admiral K. R. McKee of the Naval Nuclear Propulsion Laboratory met with staff 10-11 September. Congresswoman Claudine Schneider (R-RI), a member of the House Merchant Marine and Fisheries and Science and Technology Committees, met with staff during a 27 August visit. More than 325 scientists from twenty-four nations gathered in Woods Hole 6-13 September for the Second International Conference on Paleoceanography; Senior Scientist William A. Berggren of the Geology and Geophysics Department was President of the Organizing Committee. Twenty graduate students from Boston University's Science Writing Program spent the day 15 October learning about Institution activities. Vannevar Bush Fellows from MIT visited laboratories and heard informal presentations 8 October as part of their year-long program to learn more about science and technology for their roles as reporters of those fields. Numerous other media visited during the year to conduct interviews and film segments for television, radio and film projects.

Publications

1986 Publications of record as of February 1, 1987. Entries are listed by department. Institution contribution number appears at the end of each entry. 1985 publications not listed in the 1985 Annual Report are included here.

Biology

Alldredge, Alice L., Jonathan J. Cole, David A. Caron. Production of heterotrophic bacteria inhabiting macroscopic organic aggregates (marine snow) from surface waters. *Limnol. Oceanogr.*, 31(1): 68-78. (1986)

Anderson, Donald M. Paralytic shellfish poisoning. In: *Natural Toxins and Human Pathogens in the Marine Environment: Problems and Research Needs*, Rita R. Colwell, ed. Report of a Sea Grant-sponsored workshop (Publication Number UM-SG-TS-85-01): 19-28. (1985)

Anderson, Donald M., Bruce A. Keafer. Dinoflagellate cyst dynamics in coastal and estuarine waters. In: *Toxic Dinoflagellates*, D. M. Anderson, A. White and D. G. Baden, eds. Elsevier Science Publ., New York: 219-224. (1985) 5959

Anderson, O. Ketil, Joel C. Goldman, David A. Caron, Mark R. Dennett. Nutrient cycling in a microflagellate food chain: III. Phosphorus dynamics. *Mar. Ecol. Prog. Ser.*, 31: 47-55. (1986) 6060

Belkin, Shimshon, Douglas C. Nelson, Holger W. Jannasch. Symbiotic assimilation of CO_2 in two hydrothermal vent animals, the mussel *Bathymodiolus thermophilus* and the tube worm *Riftia pachyptila*. *Biol. Bull.*, 170: 110-121. (1986) 5969

Belkin, Shimshon, Carl O. Wirsen, Holger W. Jannasch. A new sulfur-reducing, extremely thermophilic eubacterium from a submarine thermal vent. *Appl. Env. Microbiol.*, 51(6): 1180-1185. (1986) 6061

Binder, Brian J., Donald M. Anderson. Green light-mediated photomorphogenesis in a dinoflagellate resting cyst. *Nature (London)*, 322(6080): 659-661. (1986) 6167

Binder, Robert L., John J. Stegeman, John J. Lech. Induction of cytochrome P-450-dependent monoxygenase systems in embryos and eleutheroembryos of the killfish *Fundulus heteroclitus*. *Chem. Biol. Interact.*, 55: 185-202. (1985) 5895

Block, Barbara A., Francis G. Carey. Warm brain and eye temperatures in sharks. *J. Compar. Physiol.*, 156: 229-236. (1985) 6052

Bucklin, A., N. H. Marcus. Genetic differentiation of populations of the planktonic copepod *Labidocera aestiva*. *Mar. Biol.*, 84(3): 219-24. (1985) 5810

Bucklin, A., P. H. Wiebe. Genetic heterogeneity in euphausiid populations: *Euphausia krohnii* and *Nematoscelis megalops* in North Atlantic slope water. *Limnol. Oceanogr.*, 31(6): 1346-1352. (1986) 5928

Capuzzo, Judith M., John M. Teal, Robert K. Bastian. Ecological and human health criteria for cross ecosystem comparison of waste disposal impacts. In: *The Role of the Oceans as a Waste Disposal Option*, G. Kullenberg, ed. Reidel Publ., Boston: 347-360. (1986) 5925

Caron, David A., Paul G. Davis, Laurence P. Madin, John McN. Sieburth. Enrichment of microbial populations in macroaggregates (marine snow) from surface waters of the North Atlantic. *J. Mar. Res.*, 4(3): 543-565. (1986) 6243

Caron, David A., Joel C. Goldman, O. Ketil Anderson, Mark R. Dennett. Nutrient cycling in a microflagellate food chain: II. Population dynamics and carbon cycling. *Mar. Ecol. Prog. Ser.*, 24: 243-254. (1985) 5864

Caron, David A., Joel C. Goldman, Mark R. Dennett. Effect of temperature on growth, respiration and nutrient regeneration by an omnivorous microflagellate. *Appl. Environ. Microbiol.*, 52(6): 1340-1347. (1986) 6320

Caron, David A., Francais R. Pick, David R. S. Lean. Chroococcoid cyanobacteria in Lake Ontario: Vertical and seasonal distributions during 1982. *J. Phycol.*, 21: 171-175. (1985)

Caswell, Hal. Life cycle models for plants. *Lect. Math. Life Sci.*, 18: 171-233. (1986) 6202

Caswell, Hal. Evolutionary demography of clonal reproduction. In: *Population Biology and Evolution of Clonal Organisms*, Jeremy B. C. Jackson, Leo W. Buss and Robert E. Cook, eds. Yale University, New Haven, CT: 187-224. (1985) 5586

Caswell, Hal, Daniel E. Weeks. Two-sex models: Chaos, extinction, and other dynamic consequences of sex. *Am. Nat.*, 128(5): 707-735. (1986) 5933

Cetta, C. M., L. P. Madin, P. Kremer. Respiration and excretion by oceanic salps. *Mar. Biol.*, 91: 529-537. (1986) 5988

Cheney, Jerry. Spatial and temporal abundance patterns of oceanic chaetognaths in the western North Atlantic - I. hydrographic and seasonal abundance patterns. *Deep-Sea Res.*, 32(9): 1041-1059. (1985) 5775

Cheney, Jerry. Spatial and temporal abundance patterns of oceanic chaetognaths in the western North Atlantic - II. vertical distributions and migrations. *Deep-Sea Res.*, 32(9): 1061-1075. (1985) 5776

Child, Allen C., G. R. Harbison. Parasitic association between a pycnogonid and a scyphomedusa in midwinter. *J. Mar. Biol. Assoc. UK*, 66: 113-117. (1986) 5892

Collie, Jermemy S. Life history and production of three amphipod species on Georges Bank. *Mar. Ecol. Prog. Ser.*, 22: 229-238. (1985) 5762

Cornell, Neal W., John J. Stegeman, Michael J. Kerich, Bruce R. Woodin. Metabolite and enzyme contents of freeze-clamped liver of the marine fish *Stenotomus chrysops*. *Comp. Biochem. Physiol.*, 85B: 669-674. (1986) 6149

Dacey, John W. H., Stuart G. Wakeham. Oceanic dimethylsulfide: Production during zooplankton grazing on phytoplankton. *Science*, 233: 1314-1316. (1986) 6165

Davis, Paul G., David A. Caron, Paul W. Johnson, John McN. Sieburth. Phototrophic and apochlorotic components of picoplankton and nanoplankton in the North Atlantic: Geographic, vertical, seasonal and diel distributions. *Mar. Ecol. Prog. Ser.*, 21: 15-26. (1985)

Derby, Jenifer G. Smith, Judith M. Capuzzo. Physiological and behavioral effects of drilling fluid on marine crustaceans. In: *Wastes in the Ocean, Volume 4: Energy Wastes in the Ocean*, I. W. Duedall, D. R. Kester, P. K. Park and B. H. Ketchum, eds. Wiley-Interscience, New York: 289-305. (1985)

Fiala, Gerhard, Karl O. Stetter, Holger W. Jannasch, Thomas A. Langworthy, Jerzy Madon. *Staphylothermus marinus* sp.nov. represents a novel genus of extremely thermophilic submarine heterotrophic archaebacteria growing up at 93°C. *Syst. Appl. Microbiol.*, 8: 106-113. (1986) 6150

Fujita, R. M., J. C. Goldman. Nutrient flux and growth of the red alga *Gracilaria tikvahiae* McLachlan (Rhodophyta). *Bot. Mar.*, 28: 265-268. (1985) 5377

Gallager, Scott M., Roger Mann, Glenn C. Sasaki. Lipid as an index of growth and viability in three species of bivalve larvae. *Aquaculture*, 56: 81-103. (1986) 5919

Gallager, Scott M., Roger Mann. Individual variability in lipid content of bivalve quantified histochemically by absorption photometry. *J. Plankton Res.*, 8(5): 927-937. (1986) 5920

Gallager, Scott M., Roger Mann. Growth and survival of larvae of *Mercenaria mercenaria* (L.) and *Crassostrea virginica* (Gmelin) relative to broodstock conditioning and lipid content of eggs. *Aquaculture*, 56: 105-121. (1986) 5921

Gilmer, R. W., G. R. Harbison. Morphology and field behavior of pteropod molluscs: Feeding methods in the families Cavolinidae, Limacinidae and Peraclididae (Gastropoda: Thecosomata). *Mar. Biol.*, 91: 47-57. (1986) 5857

Gilmer, Ronald W. Preservation artifacts and their effects on the study of euthecosomatous pteropod molluscs. *Veliger*, 29(1): 48-52. (1986) 5944

Goldman, Joel C. On phytoplankton growth rates and particulate C:N:P ratios at low light. *Limnol. Oceanogr.*, 31(6): 1358-1363. (1986) 6083

Goldman, Joel C., Mark R. Dennett. Dark CO_2 uptake by the diatom *Chaetoceros simplex* in response to nitrogen pulsing. *Mar. Biol.*, 90: 493-500. (1986) 5982

Grassle, J. Frederick. Ecology of deep-sea hydrothermal vent communities. *Adv. Mar. Biol.*, 23: 301-362. (1986) 5987

Grassle, J. Frederick, Susan Brown-Leger, Linda Morse-Porteous, Rosemarie Petrecca, Isabelle Williams. Deep-sea fauna of sediments in the vicinity of hydrothermal vents. *Bull. Biol. Soc. Wash.*, 6: 443-452. (1985) 5763

Harbison, G. R. On the classification and evolution of the Ctenophora. In: *The Origins and Relationships of Lower Invertebrates. The Systematics Association Special Volume No. 28.* S. Conway Morris, J. D. George, R. Gibson, and H. M. Platt, eds. Clarendon Press, Oxford, England: 79-100. (1985) 5607

Harbison, G. R., R. W. Gilmer. Effects of behavior on sediment trap collections: Implications for the calculation of aragonite fluxes. *Deep-Sea Res.*, 33(8): 1017-1024. (1986) 6133

Harbison, G. R., V. L. Mcalister, R. W. Gilmer. Response of the salp, *Pegea confoederata*, to high levels of particulate material: Starvation in the midst of plenty. *Limnol. Oceanogr.*, 31(2): 371-382. (1986) 5958

Harbison, G. R., R. L. Miller. Not all ctenophores are hermaphrodites. Studies on the systematics, distribution, sexuality and development of two species of *Ocyropsis*. *Mar. Biol.*, 90: 413-324. (1986) 5637

Harbison, Richard, Russell Reichelt. Some string figures from Papua-New Guinea. In: *Bulletin of String Figures Association, No. 11*, P. D. Noble and Hiroshi Noguchi, eds. Nippon Ayatori Kyokai, Tokyo, Japan: 18-27. (1985) 5402

Hitchcock, Gary L., Joel Goldman, Mark R. Dennett. Photosynthate partitioning in cultured marine phytoplankton: Metabolic patterns in a marine diatom under constant and variable light intensities. *Mar. Ecol. Prog. Ser.*, 30: 77-84. (1986) 5733

Howes, Brian, John W. H. Dacey, D. D. Goehringer. Factors controlling the growth form of *Spartina alterniflora*: Feedbacks between above-ground production, sediment oxidation, nitrogen and salinity. *J. Ecol.*, 74: 881-898. (1986) 5650

Hulburt, E. M. Adaptation and equivalence in open-ocean photoplankton. *Mar. Biol.*, 89: 303-309. (1985) 5809

Hulburt, Edward M. Format for phytoplankton productivity in Casco Bay, Maine and in the southern Sargasso Sea. *Bull. Mar. Sci.*, 37(3): 808-826. (1985) 4738

Hulburt, Edward M. Use of logical equivalence in modeling ecological relations of oceanic phytoplankton. *Ecol. Model.*, 27: 25-43. (1985) 5765

Hulburt, Edward M. Adaptation and niche breadth of phytoplankton species along a nutrient gradient in the ocean. *J. Plankton Res.*, 7(4): 581-594. (1985)

Jacobson, Dean M., Donald M. Anderson. Thecate heterotrophic dinoflagellates: Feeding behavior and mechanisms. *J. Phycol.*, 22: 249-258. (1986) 6044

Jannasch, H. W., C. O. Wirsen. Biochemical versatility of chemosynthetic bacteria at deep sea hydrothermal vents. *Bull. Biol. Soc. Wash.*, 6: 325-334. (1985) 5720

Jannasch, Holger W. Leben in der Tiefsee auf chemosynthetischer Basis. *Naturwissenschaften*, 72: 285-290. (1985) 5887

Jannasch, Holger W., Carl O. Wirsen, Douglas C. Nelson, Lesley A. Robertson. *Thiomicrospira crunogena* sp. nov., a colorless sulfur oxidizing bacterium from a deep sea hydrothermal vent. *Int. J. Syst. Bacteriol.*, 35: 422-424. (1985) 5688

King, Gary M., B. L. Howes, J. W. H. Dacey. Short-term end products of sulfate reduction in a salt marsh:

Formation of acid volatile sulfides, elemental sulfur and pyrite. *Geochim. Cosmochim. Acta*, 49: 1561-1566. (1985) 5855

Klotz, Alan V., John J. Stegeman, Bruce R. Woodin, Elisabeth A. Snowberger, Paul E. Thomas, Christopher Walsh. Cytochrome P-450 isozymes from the marine teleost *Stenotomus chrysops*: Their roles in steroid hydroxylation and the influence of cytochrome b_5. *Biochem. Biophys.*, 249(2): 326-338. (1986) 6159

Kroon, Hans de, Anton Plaisier, Jan van Groenenendael, Hal Caswell. Elasticity: The relative contribution of demographic parameters of population growth rate. *Ecology*, 67(5): 1427-1431. (1986) 6105

Lobel, P. S., J. E. Randall. Swarming behavior of the hyperiid amphipod *Anchylomera blossevilli*. *J. Plankton Res.*, 8(2): 253-262. (1986) 6062

Lobel, P. S., A. R. Robinson. Transport and entrapment of fish larvae by ocean mesoscale eddies and currents in Hawaiian waters. *Deep-Sea Res.*, 33(4): 483-500. (1986)

Lobel, Phillip S., Steve Neudecker. Diurnal periodicity of spawning activity by the hamlet fish, *Hypoplectrus guttavarius* (Serranidae). In: *The Ecology of Coral Reefs*, Marjoire L. Reaka, ed. (Results of a workshop held by the American Society of Zoologists, Philadelphia, Pennsylvania, December 1983) NOAA's Undersea Research Program, Vol. 3 No.1: 71-86. (1985)

Madin, L., G. R. Harbison, T. Rioux. Blue water diving equipment and procedures used at Woods Hole Oceanographic Institution. Appendix C. In: *Blue Water Diving Guidelines*, John N. Heine, ed. California Sea Grant College Program Publication No. T-CSGCP-014. University of California, La Jolla, CA: 43-46. (1986)

Madin, L. P. *In situ* photography of gelatinous zooplankton. In: *Underwater Photography and Television for Scientists*, J. D. George, G. I. Lythgoe and J. N. Lythgoe, eds. Clarendon Pr., Oxford, England: 65-86. (1985)

Mann, Roger, Scott M. Gallagher. Growth morphometry and biochemical composition of the wood boring molluscs *Teredo navalis* L., *Bankia gouldi* (Bartsch), and *Nototeredo knoxi* (Bartsch) (Bivalvia:Teredinidae). *J. Exp. Mar. Biol.*, 85: 229-251. (1985) 5682

Marcus, Nancy H. Population dynamics of marine copepods: The importance of photoperiodism. *Am. Zool.*, 26: 469-477. (1986) 5886

Marcus, Nancy H. Population dynamics of marine copepods: The importance of genetic variation. *Bull. Mar. Sci.*, 37(2): 684-690. (1985) 5731

Marcus, Nancy H. Introduction to the symposium: Photoperiodism in the marine environment. *Am. Zool.*, 26: 387-388. (1986)

Marcus, Nancy H., Charlotte M. Fuller. Subitaneous and diapause eggs of *Labidocera aestiva* Wheeler (Copepoda : Calanoida): Differences in fall velocity and density. *J. Exp. Mar. Biol. Ecol.*, 99: 247-256. (1986)

Marcus, Nancy H., Jutta Schmidt-Gengenbach. Recruitment of individuals into the plankton: The importance of bioturbation. *Limnol. Oceanogr.*, 31(1): 206-210. (1986) 5774

McCormick, Stephen D., Robert J. Naiman. Hypoosmoregulation in an anadromous teleost: Influence of sex and maturation. *J. Exp. Zool.*, 234: 193-198. (1985) 5418

McDowell, Donald M., Robert J. Naiman. Structure and function of a benthic invertebrate stream community influenced by beaver (Castor canadensis). *Oceanologica*, 68: 481-489. (1986) 6022

McElroy, Anne E. *In vivo* metabolism of benz(a)anthracene by the polychaete *Nereis virens*. *Marine Environ. Res.*, 17: 133-136. (1985) 5986

Naiman, Robert J., Jerry M. Melillo, John E. Hobbie. Ecosystems alteration of boreal forest streams by beaver (*Castor canadensis*). *Ecology*, 67(5): 1254-1269. (1986) 5827

Olson, Robert J., Sallie W. Chisholm. Effects of light and nitrogen limitation on the cell cycle of the dinoflagellate *Amphidinium carteri*. *J. Plankton Res.*, 8(4): 785-793. (1986)

Olson, Robert J., Daniel Vaulot, Sallie W. Chisholm. Effects of environmental stresses on the cell cycle of two marine phytoplankton species. *Plant Physiol.*, 80: 918-925. (1986)

Olson, Robert J., Carl Watras, Sallie W. Chisholm. Patterns of individual cell growth in marine centric diatoms. *J. Gen. Microbiol.*, 132: 1197-1204. (1986)

Park, Sang S., Haruko Miller, Alan V. Klotz, Pamela J. Kloepper-Sams, John J. Stegeman, Harry V. Gelboin. Monoclonal antibodies to liver microsomal cytochrome P-450E of the marine fish, *stenotomus chrysops* (scup): Cross reactivity with 3-methylcholanthrene induced rat cytochrome P-450. *Arch. Bio. Chem. Biophys.*, 249(2): 339-350. (1986) 6145

Pichinoty, F., J. B. Waterbury, M. Mandel, J. Asselineau. *Bacillus gordonae* sp. nov., une nouvelle espece appartenant au second groupe morphologique, degradant divers composes aromatiques. *Ann. Inst. Pasteur/Microbiol.*, 137A: 65-78. (1986)

Sanders, H. L., J. A. Allen. Studies on deep-sea protobranchia (bivalvia), the family Malletiidae. *Bull. Br. Mus. Nat. Hist. Zool.*, 49(2): 195-238. (1985) 5696

Sasaki, G. C., J. M. Capuzzo, P. Biesiot. Nutritional and bioenergetic considerations in the early development of the American lobster *Homarus americanus*. *Can. J. Fish. Aquat. Sci.*, 43(11): 2311-2319. (1986) 6041

Scheltema, Amelia H. Aplacophoran family Prochaetodermatidae in the North American Basin, including *Chevroderma n.g.* and *Spathoderma n.g.* (Mollusca: Chaetodermomorpha). *Biol. Bull.*, 169: 484-529. (1985) 5930

Scheltema, Rudolf S. Long-distance dispersal by planktonic larvae of shoal-water benthic invertebrates among central Pacific islands. *Bull. Mar. Sci.*, 39(2): 241-256. (1986) 5838

Scheltema, Rudolph S. On dispersal and planktonic larvae of benthic invertebrates: An eclectic overview and summary of problems. *Bull. Mar. Res.*, 39(2): 290-322. (1986) 6261

Schevill, William E. International code of Zoological Nomenclature and a paradigm: The name *Physetter catodon* Linnaeus 1758. *Mar. Mammal Sci.*, 2(2): 153-157. (1986) 6079

Stegeman, J. J. Benzo[a]pyrene oxidation and microsomal enzyme activity in the mussel (*Mytilus edulis*) and other bivalve mollusc species from the Western North Atlantic. *Mar. Biol.*, 89: 21-30. (1985) 5889

Stegeman, John J., Margaret O. James. Individual variation in patterns of benzo[a]pyrene metabolism in the marine fish scup (*Stenotomus chrysops*). *Mar. Environ. Res.*, 17: 122-124. (1985) 5932

Stegeman, John J., Pamela J. Kloepper-Sams, John W. Farrington. Monooxygenase induction and chlorobiphenyls in the deep sea fish *Coryphaenoides armatus*. *Science*, 231: 1287-1289. (1986) 6014

Stegeman, John J., Bruce R. Woodin, Sang S. Park, Pamela J. Kloepper-Sams, Harry V. Gelboin. Microsomal cytochrome P-450 function in fish evaluated with polyclonal and monoclonal antibodies to cytochrome P-450E from scup (*Stenotomus chrysops*). *Mar. Environ. Res.*, 17: 83-86. (1985) 5931

Stoecker, D. K., W. G. Sunda, L. H. Davis. Effects of copper and zinc on two planktonic ciliates. *Mar. Biol.*, 92: 21-29. (1986) 5871

Stoecker, Diane K., Terry L. Cucci, Edward M. Hulbert, Clarice M. Yentsch. Selective feeding by *Balanion* sp. (Ciliata:Balanionidae) on phytoplankton that best support its growth. *J. Exp. Mar. Biol. Ecol.*, 95: 113-130. (1986) 5872

Teal, John M. Role of one salt marsh in coastal productivity. In: *Proceedings of the International Symposium on Utilization of Coastal Ecosystems: Planning, Pollution and Productivity, 21-27 Nov 1982, Rio Grande, Brazil, Volume 1*, Ning Labbish Chao and William Kirby-Smith, eds. Editora de Furg, Rio Grande: 241-258. (1985) 5683

Tyack, Peter. Whistle repertoires of two bottlenosed dolphins, *Tursiops truncatus*: Mimicry of signature whistles? *Behav. Ecol. Sociobiol.*, 18: 251-257S. (1986) 5929

Vaccaro, Ralph F., Nathaniel Corwin, James R. Mitchell. Residential waste-water-ground water interactions in the vicinity of Mares Pond, Falmouth, Cape Cod. *J. Boston. Soc. Civ. Eng.*, 71(1+2): 123-145. (1985) 5665

Valiela, Ivan, John M. Teal, Sarah D. Allen, Richard van Etten, Dale Goehringer, Suzanne Volkmann. Decomposition in salt marsh ecosystems: The phases and major factors affecting disappearance of above-ground organic matter. *J. Exp. Mar. Ecol.*, 89: 29-54. (1985) 5681

Valiela, Ivan, John M. Teal, Charlotte Cogswell, Jean Hartman, Sarah Allen, Richard Van Etten, Dale Goehringer. Some long-term consequences of sewage contamination in salt marsh ecosystems. In: *Ecological Considerations in Wetlands Treatment of Municipal Wastewater*, P. J. Godfrey, E. R. Kaynor, S. Pelczarki and J. Benforado, eds. Van Nostrand Reinhold, New York: 301-316. (1985)

Watkins, William A. Whale reactions to human activities in Cape Cod waters. *Mar. Mammal Sci.*, 2(4): 251-262. (1986) 6072

Watras, Carl J., Veronique C. Garcon, Robert J. Olson, Sallie W. Chisholm, Donald M. Anderson. Effect of zooplankton grazing on estuarine blooms of the toxic dinoflagellate *Gonyaulax tamarensis*. *J. Plankton Res.*, 7(6): 891-908. (1985) 5811

Watson, Stanley W., Eberhard Bock, Frederica W. Valois, John B. Waterbury, Ursula Scholosser. *Nitrospira marina* gen. nov. sp. nov.: A chemolithotrophic nitrate-oxidizing bacterium. *Arch. Microbiol.*, 144: 1-7. (1986) 6081

Weinberg, J. R., H. Caswell, R. B. Whitlatch. Demographic importance of ecological interactions: How much do statistics tell us? *Mar. Biol.*, 93: 305-310. (1986) 6037

Wirsen, C. O., J. H. Tuttle, H. W. Jannasch. Activities of sulfur-oxidizing bacteria at the 21°N East Pacific Rise vent site. *Mar. Biol.*, 92: 449-456. (1986) 6071

Wirsen, C. O., Holger W. Jannasch. Microbial transformations in deep-sea sediments: Free vehicle studies. *Mar. Biol.*, 91: 277-284. (1986) 5946

Wood, A. Michelle, P. K. Horan, K. Muirhead, D. A. Phinney, C. M. Yentsch, J. B. Waterbury. Discrimination between pigment types of marine *Synechococcus* spp. by scanning spectroscopy, epifluorescence microscopy, and flow cytometry. *Limnol. Oceanogr.*, 30(6): 1303-1315. (1985) 6056

Chemistry

Anderson, Agneta, Cindy Lee, Farooq Azam, Ake Hagstrom. Release of aminoacids and inorganic nutrients by heterotrophic marine microflagellates. *Mar. Ecol. Prog. Ser.*, 23: 99-106. (1985) 5616

Benavides, Livia M., Ellen R. M. Druffel. Sclerosponge growth rate as determined by ^{210}Pb and ^{14}C chronologies. *Coral Reefs*, 4: 221-224. (1986) 5955

Boyle, E. A., S. D. Chapnick, G. T. Shen, M. P. Bacon. Temporal variability of lead in the western North Atlantic Ocean. *J. Geophys. Res.*, 91(C7): 8573-8593. (1986) 6098

Brewer, P. G., K. W. Bruland, R. W. Eppley, J. J. McCarthy. Global Ocean Flux Study (GOFS): Status of the U.S. GOFS Program. *Eos*, 67(44): 827-832. (1986) 6336

Brewer, Peter G. What controls the variability of carbon dioxide in the surface ocean? A plea for complete information. In: *Dynamic Processes in the Chemistry of the Upper Ocean*, J. D. Burton, P. G. Brewer and R. Chesselet, eds. Plenum Pr., New York: 215-231. (1986) 6170

Brewer, Peter G., A. L. Bradshaw, R. T. Williams. Measurements of total carbon dioxide and alkalinity in the North Atlantic Ocean in 1981. In: *The Changing Carbon Cycle. A Global Analysis*, John R. Trabalka and David E. Reichle, eds. Springer-Verlag, New York: 348-370. (1986)

Brownawell, Bruce J., John W. Farrington. Biogeochemistry of PCBs in interstitial waters of a coastal marine sediment. *Geochim. Cosmochim. Acta*, 50: 157-169. (1986) 5839

Buesseler, Ken O., Hugh D. Livingston, Edward R. Sholkovitz. $^{239,240}Pu$ and excess ^{210}Pb inventories along the shelf and slope of the northeast U.S.A. *Earth Planet Sci. Lett.*, 76: 10-22. (1985) 5912)

Cochran, J. Kirk, Anne E. Carey, Edward R. Sholkovitz, Lolita D. Surprenant. Geochemistry of uranium and thorium in coastal marine sediments and sediment pore waters. *Geochim. Cosmichim. Acta*, 50: 663-680. (1986) 5283

Cochran, J. Kirk. Particle mixing rates in sediments of the eastern equatorial Pacific: Evidence from ^{210}Pb, $^{239,240}Pu$ and ^{137}Cs distributions at MANOP sites. *Geochim. Cosmochim. Acta*, 49: 1195-1210. (1985) 5804

Cole, J. J., C. Lee. Rapid microbial metabolism of non-protein amino acids in the sea. *Biogeochemistry*, 2(3): 299-331. (1986) 6076

De Baar, Hein J., Michael P. Bacon, Peter G. Brewer. Rare earth elements in the Pacific and Atlantic Oceans. *Geochim. Cosmichim. Acta*, 49: 1943-1959. (1985) 5750

De Baar, Hein J., Peter G. Brewer, Michael P. Bacon. Anomalies in rare earth distributions in seawater: Gd and Tb. *Geochim. Cosmichim. Acta*, 49: 1961-1969. (1985) 5751

Deuser, W. G. Seasonal and interannual variations in deep-water particle fluxes in the Sargasso Sea and their relation to surface hydrography. *Deep-Sea Res.*, 33(2): 225-246. (1986) 5935

Druffel, Ellen R. M., Livia M. Benavides. Input of excess CO_2 to the surface ocean based on $^{13}C/^{12}C$ ratios in a banded Jamaican sclerosponge. *Nature(London)*, 321(6055): 58-61. (1986) 5914

Druffel, Ellen R. M., Susumu Honjo, Sheila Griffin, C. S. Wong. Radiocarbon in particulate matter from the eastern sub-Arctic Pacific Ocean: Evidence of a source of terrestrial carbon to the deep sea. *Radiocarbon*, 28(2A): 397-407. (1986) 6053

Farrington, J. W., R. W. Tripp, A. C. Davis, J. Sulanowski. One view of the role of scientific information in the solution of enviro-economic problems. In: *Proceedings of the International Symposium on Utilization of Coastal Ecosystems: Planning, Pollution and Productivity, 21-27 Nov. 1982, Rio Grande, Brazil. Vol. 1.* Ning Labbish Chao and William Kirby-Smith, eds. Duke Univ. Marine Lab., Beaufort: 73-102. (1985) 5371

Farrington, John W. Fossil fuel aromatic hydrocarbon biogeochemistry in the marine environment: Research challenges. In: *Strategies and Advanced Techniques for Marine Pollution Studies: Mediterranean Sea. NATO Advanced Studies Institute Series Vol. G9.* C. S. Giam and H. J. -M. Dou, eds. Springer-Verlag, New York: 113-142. (1986) 5907

Farrington, John W., Alan C. Davis, Bruce J. Brownawell, Bruce W. Tripp, C. Hovey Clifford, Joaquim Livramento. Biogeochemistry of polychlorinated biphenyls in the Acushnet River Estuary, Massachusetts. In: *Organic Marine Geochemistry* (Developed from a symposium sponsored by the Division of Geochemistry at the 189th Meeting of the American Chemical Society, Miami Beach, Florida, April 28-May 3, 1985). Mary L. Sohn, ed. *ACS Symp. Ser.*, 305: 174-197. (1986) 6043

Farrington, John W., Stuart G. Wakeham, Joaquim B. Livramento, Bruce W. Tripp, John Teal. Aromatic hydrocarbons in New York Bight polychaetes: Ultraviolet fluorescence analyses and gas chromatography/gas chromatography-mass spectrometry analyses. *Environ. Sci. Technol.*, 20: 69-72. (1986) 5798

Farrington, John W., John Westall. Organic chemical pollutants in the oceans and groundwater: A review of fundamental chemical properties and biogeochemistry. In: *The Role of the Oceans as a Waste Disposal Option.* G. Kullenberg, ed. Reidel Publ., Dordrecht, Holland: 361-425. (1986) 6006

Gagosian, Robert B. Air-sea exchange of particulate organic matter: The sources and long-range transport of lipids in aerosols. In: *The Role of Air-Sea Exchange in Geochemical Cycling*, P. Buat-Menard, ed. D. Reidel Publ., Dordrecht, Holland: 409-442. (1986) 6094

Hemleben, Christoph, Michael Spindler, Ingrid Breitinger, Werner G. Deuser. Field and laboratory studies on the ontogeny and ecology of some Globorotaliid species from the Sargasso Sea off Bermuda. *J. Foraminiferal Res.*, 15(4): 254-272. (1985) 5882

Huh, C. A., M. P. Bacon. Determination of thorium concentration in seawater by neutron activation analysis. *Anal. Chem.*, 57(11): 2138-2142. (1985) 5878

Knap, Anthony H., Kandace S. Binkley, Werner G. Deuser. Synthetic organic chemicals in the deep Sargasso Sea. *Nature (London)*, 319(6054): 572-574. (1986) 5956

Kurz, Mark D. Cosmogenic helium in a terrestrial igneous rock. *Nature (London)*, 320(6061): 435-439. (1986) 6059

Lalou, C., G. Thompson, P. A. Rona, E. Brichet, C. Jehanno. Chronology of selected hydrothermal Mn oxide deposits from the transatlantic geotraverse 'TAG' area, Mid-Atlantic Ridge 26°N. *Geochim. Cosomochim. Acta*, 50: 1737-1743. (1986) 6082

Livingston, H. D., W. R. Clarke, S. Honjo, E. Izdar, T. Konuk, E. Degens, V. Ittekkot. Chernobyl fallout studies in the Black Sea and other ocean areas. In: *A Compendium of the Environmental Measurements Laboratory's Research Projects Related to the Chernobyl Nuclear Accident.* H. L. Volchok and N. Chieco, eds. Environmental Measurements Laboratory Report EML-460: 214-223. (1986) 6256

Livingston, Hugh D. Anthropogenic radiotracer evolution in the Central Greenland Sea. *Rit Fiskideildar*, 9: 43-54. (1985) 5990

McConachy, T. F., R. D. Ballard, M. J. Mottl, R. P. Von Herzen. Geological form and setting of a hydrothermal vent field at 10°56'N, East Pacific Rise: A detailed study using *ANGUS* and *ALVIN*. *Geology*, 14: 295-298. (1986) 6018

Mok, Henry Y. I., Ellen R. M. Druffel, William M. Rampone. Dating gallstones from atmospheric radiocarbon produced by nuclear bomb explosions. *N. Engl. J. Med.*, 314: 1075-1077. (1986) 6102

Mottl, M. J., E. R. Druffel, S. R. Hart, J. R. Lawrence, E. S. Saltzman. Chemistry of hot water sampled from basaltic basement in Hole 504B, Deep Sea Drilling Project Leg 83, Costa Rica Rift. *Initial Rep. Deep Sea Drill. Proj.*, LXXXIII: 315-328. (1985) 5577

Palmer, D. R., P. A. Rona, M. J. Mottl. Acoustic imaging of high-temperature hydrothermal plumes at seafloor spreading centers. *J. Acoust. Soc. Am.*, 80(3): 888-898. (1986) 6007

Pederson, T. F., S. J. Malcolm, E. R. Sholkovitz. Lightweight gravity corer for undistributed sampling of soft sediments. *Can. J. Earth Sci.*, 22: 133-135. (1985)

Requejo, A. G., Jean K. Whelan, Paul D. Boehm. Hydrocarbon geochemistry and biological markers in Orca and Pygmy basin sediments (Sites 618 and 619). *Initial Rep. Deep Sea Drill. Proj.*, XCVI: 785-793. (1986) 6101

Schilling, J. G., G. Thompson, R. Kingsley, S. Humphris. Hotspot-migrating ridge interaction in the South Atlantic. *Nature(London)*, 313(5999): 187-191. (1985) 5797

Seyfried, W. E., E. C. Thornton, F. L. Sayles. Heat-transfer experiment in marine pelagic clay: Implications for subseabed disposal of high-level radioactive waste and contact metamorphism in the Guaymas Basin, Gulf of California. *Chem. Geol.*, 53: 135-153. (1985) 5800

Shibata, Tsugio, Geoffrey Thompson. Peridotites from the Mid-Atlantic Ridge at 43°N and their petrogenetic relation to abyssal theoleiites. *Contrib. Mineral. Petrol.*, 93: 144-159. (1986) 5840

Shimmield, G. B., J. W. Murray, John Thomas, M. P. Bacon, R. F. Anderson, N. B. Price. Distribution and behavior of ^{230}Th and ^{231}Pa at an ocean margin, Baja California, Mexico. *Geochim. Cosmochim. Acta*, 50: 2499-2507. (1986) 6317

Sholkovitz, Edward R. Redox-related geochemistry in lakes: Alkali metals, alkaline-earth elements, and ^{137}Cs. In: *Chemical Processes in Lakes*, Werner Stumm, ed. Wiley-Interscience, New York: 119-142. (1985) 5536

Thompson, G., W. B. Bryan, R. Ballard, K. Hamuro, W. G. Melson. Axial processes along a segment of the East Pacific Rise, 10°-12°N. *Nature(London)*, 318(6045): 429-433. (1985) 5962

Tripp, Bruce W., John W. Farrington. Using sentinel organisms to monitor chemical changes in the coastal zone: Progress or paralysis. In: *Gambling with the Shore. Proceedings of the Ninth Annual Conference of the Coastal Society. October 14-17, 1984. Atlantic City, NJ.* The Coastal Society: 195-202. (1985) 5830

Wakeham, Stuart C., Elizabeth A. Canuel, Peter H. Doering. Geochemistry of volatile organic compounds in seawater: Mesocosm experience with ^{14}C-model compounds. *Geochim. Cosmochim. Acta*, 50: 1163-1172. (1986) 6095

Wakeham, Stuart G., Elizabeth A. Canuel, Peter H. Doering. Behavior of aliphatic hydrocarbons in coastal seawater: Mesocosm experiments with [^{14}C] octadecane and [^{14}C] decane. *Environ. Sci. Technol.*, 20(6): 574-580. (1986) 5893

Wakeham, Stuart G., Elizabeth A. Canuel, Peter H. Deoring, John E. Hobbie, John V.K. Helfrich, Gayle R.G. Lough. Biogeochemistry of toluene in coastal seawater: Radiotracer experiments in controlled ecosystems. *Biogeochemistry*, 1: 307-328. (1985) 5799

Whelan, Jean K. Geochemistry summary – Leg 96 – The Mississippi Fan. *Initial Rep. Deep Sea Drill. Proj.*, XCVI: 691-695. (1986)

Whelan, Jean K., J. W. Farrington, M. E. Tarafa. Maturity of organic matter and migration of hydrocarbons in two Alaskan North Slope wells. *Adv. Org. Chem.*, 10: 207-219. (1986) 6146

Whelan, Jean K., Ronald Oremland, Martha Tarafa, Richard Smith, Robert Howarth, Cindy Lee. Evidence for sulfate-reducing and methane-producing micro-organisms in sediments from Sites 618, 619 and 622. *Initial Rep. Deep Sea Drill. Proj.*, XCVI: 767-774. (1986) 6029

Whelan, Jean K., Martha Tarafa. Organic matter in Leg 96 sediments: Characterization by pyrolysis. *Initial Rep. Deep Sea Drill. Proj.*, XCVI: 757-766. (1986) 6028

Whelan, Jean K., Martha E. Tarafa, Evelyn B. Sherr. Phenolic and lignin pyrolysis products of plants, seston, and sediments in a Georgia estuary. In: *Organic Marine Geochemistry* (Developed from a symposium sponsored by the Division of Geochemistry at the 189th Meeting of the American Chemical Society, Miami Beach, Florida, April 28-May, 1985). Mary L. Sohn, Ed. *ACS Symp. Ser.*, 305: 62-75. (1986) 6055

Zafiriou, Oliver C. Atmospheric, oceanic, and interfacial photochemistry as factors influencing air-sea exchange fluxes and processes. In: *Role of Air-Sea Exchange in Geochemical Cycling*, P. Buat-Menard, ed. Reidel Publ., Dordrecht, Holland: 185-207. (1986)

Zafiriou, Oliver C. Photochemistry and the sea-surface microlayer: Natural processes and potential as a technique. In: *Dynamic Processes in the Chemistry of the Upper Ocean*, J. D. Burton, P. G. Brewer and R. Chesselet, eds. Plenum Pr., New York: 129-135. (1986) 5520

Zafiriou, Oliver C., Mary B. True. Interferences in environmental analysis of NO by NO plus O_3 detectors: A rapid screening technique. *Environ. Sci. Technol.*, 20(6): 594-596. (1986) 5966

Geology & Geophysics

Aubrey, D., K. O. Emery. Australia – An unstable platform for tide-gauge measurements of changing sea levels. *J. Geol.*, 94: 699-712. (1986) 5973

Aubrey, D. G. Hydrodynamic controls on sediment transport in well-mixed bays and estuaries. In: *Physics of Shallow Estuaries and Bays*, J. Van de Kreeke, ed., *Lecture Notes on Coastal and Estuarine Studies, 16*, Springer-Verlag, New York: 245-258. (1986) 5908

Aubrey, D. G., K. O. Emery. Relative sea levels of Japan from tide-gauge records. *Geol. Soc. Am. Bull.*, 97: 194-205. (1986) 5816

Aubrey, D. G., P. E. Speer. Study of non-linear tidal propagation in shallow inlet/estuarine systems. Part I. Observations. *Estuarine Coastal Shelf Sci.*, 21: 185-205. (1985) 5674

Aubrey, David G. Recent sea levels from tide gauges: Problems and prognosis. In: *Glaciers, Ice Sheets, and Sea Level: Effects of a CO_2-Induced Climate Change. Report of a Workshop Held in Seattle, Washington, September 13-15, 1984.* National Academy Press, Washington, DC: 73-91. (1985) 5845

Aubrey, David G., K. O. Emery. Reply (Discussion of paper – Optimal eigenfunction expansions: A contradiction in terms, by R. Ehrlich and I. Lerche). *Geol. Soc. Am. Bull., 97:* 1282. (1986)

Aubrey, David G., Robert M. Ross. Quantitative description of beach cycles. *Mar. Geol., 69:* 155-170. (1985) 5859

Aubry, M. P., E. A. Hailwood, H. A. Townsend. Magnetic and calcareous-nannofossil stratigraphy of the lower Palaeogene *J. Geol. Soc. London,* 143: 729-735. (1986)

Aubry, Marie-Pierre. Northwestern European Paleogene magnetostratigraphy, biostratigraphy and paleogeography: Calcereous nannofossil evidence. *Geology,* 13: 198-202. (1985) 5843

Aubry, Marie-Pierre. Paleogene calcareous nannoplankton biostratigraphy of northwestern Europe. *Palaeogr. Palaeoclimatol. Palaeoecol.,* 55: 267-334. (1986) 6000

Becker, Keir, Marcus G. Langseth, Richard P. Von Herzen, Roger N. Anderson, Michael A. Hobart. Deep crustal geothermal measurements, Hole 504B, Deep Sea Drilling Project Legs 69, 70, 83, and 92. *Initial Rep. Deep Sea Drill. Proj.,* LXXXIII: 405-418. (1985)

Berggren, W. A., D. V. Kent, J. A. Van Couvering. Neogene: Part 2 Neogene geochronology and chronostratigraphy. In: *The Chronology of the Geological Record,* N. J. Snelling, ed. Blackwell Scientific Publ., Oxford, England: 211-260. (1985) 5496

Berggren, W. A., Dennis V. Kent, John J. Flynn. Jurassic to Paleogene: Part 2 Paleogene geochronology and chronostratigraphy. In: *The Chronology of the Geological Record,* N. J. Snelling, ed. Blackwell Scientific Publ., Oxford, England: 141-195. (1985) 5307

Berggren, William A. Geochronology of the Eocene/Oligocene boundary. In: *Terminal Eocene Events,* Ch. Pomerol and I. Premoli-Silva, eds. Elsevier Science Publ., Amsterdam: 349-356. (1986) 5971

Berggren, William A., R. K. Olsson. North Atlantic Mesozoic and Cenozoic paleobiogeography. In: *The Geology of North America, Volume M, The Western North Atlantic Region,* P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 565-587. (1986) 5977

Berggren, William A., Dennis V. Kent, John J. Flynn, John A. Van Couvering. Cenozoic geochronology. *Geol. Soc. Am. Bull., 96:* 1407-1418. (1985) 5478

Bowin, Carl. Gravity and geoid anomalies in the Caribbean region: A progress report. In: *Transactions of the First Geological Conference of the Geological Society of Trinidad and Tobago:* 281-287 (1985) 5999

Bowin, Carl. Topography at the core-mantle boundary. *Geophys. Res. Lett.,* 13(13): 1513-1516. (1986) 6330

Bowin, Carl. Global gravity maps and the structure of the Earth. In: *The Utility of Regional Gravity and Magnetic Anomaly Maps,* William J. Hinze, ed. Society of Exploration Geophysicists, Tulsa, OK: 88-101. (1985) 5549

Bowin, Carl, Julie Allen. Geophysical data base and processing system. In: *Proceedings of the Fourth Working Symposium on Oceanographic Data Systems, February 4-6, 1986, San Diego, CA,* IEEE Computer Society Press, Washington, DC: 178-183. (1986) 6075

Bowin, Carl, Edward Scheer, Woollcott Smith. Depth estimates from ratios of gravity, geoid, and gravity gradient anomalies. *Geophysics,* 51(1): 123-136. (1986) 5684

Boyle, E. A., L. D. Keigwin. Comparison of Atlantic and Pacific paleochemical records for the last 215,000 years: Changes in deep ocean circulation and chemical inventories. *Earth Planet. Sci. Lett., 76:* 135-150. (1985) 6025

Brocher, Thomas M., John I. Ewing. Comparison of high-resolution seismic methods for determining seabed velocities in shallow water. *J. Acoust. Soc. Am.,* 79(2): 286-298. (1986) 5937

Bryan, W. B., F. A. Frey. Petrologic and geochemical evolution of pre-1 Ma western North Atlantic lithosphere. In: *The Geology of North America, Volume M, The Western North Atlantic Region,* P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 271-296. (1986) 5989

Bryan, Wilford, B. Tectonic controls on initial continental rifting and the evolution of young ocean basins – a planetary perspective. *Tectonophysics,* 132: 103-115. (1986) 6154

Bryan, Wilfred, B. Linked evolutionary data arrays: A logical structure for petrologic modelling of multisource, multiprocess magmatic systems. *J. Geophys. Res.,* 91(B6): 5891-5900. (1986) 5891

Butler, Rhett, Thomas M. Brocher, Jose A. Rial. Inner core experiments: Teleseismic exploration of the antipode. *Eos,* 67(8): 89, 93-94. (1986) 5904

Collins, John A., Thomas M. Brocher, Jeffrey A. Karson. Two-dimensional seismic reflection modeling of the inferred oceanic crust/mantle transition in the Bay of Islands ophiolite. *J. Geophys. Res.,* 91(B12): 12520-12538. (1986) 6193

Corliss, Bruce H. Microhabitats of benthic foraminifera within deep-sea sediments. *Nature (London),* 314(6010): 435-438. (1985) 5729

Cox, C. S., S. C. Constable, A. D. Chave, S. C. Webb. Controlled-source electromagnetic sounding of the oceanic lithosphere. *Nature (London),* 320(6057): 52-54. (1986) 6049

Curry, W. B., G. P. Lohmann. Late quaternary carbonate sedimentation at the Sierra Leone Rise (eastern equatorial Atlantic Ocean). *Mar. Geol.,* 70: 223-250. (1986) 5976

Deterick, R. S., R. P. Von Herzon, B. Parsons, D. Sandwell, M. Dougherty. Heat flow observations on the Bermuda Rise and thermal models of midplate swells. *J. Geophys. Res.,* 91(B3): 3701-3723. (1986)

Dillon, William P., Frank T. Manheim, Lubomir F. Jansa, Gudmundur Palmason, Brian E. Tucholke, Richard S. Landrum. Resource potential of the western North Atlantic Basin. In: *The Geology of North America, Volume M, The Western North Atlantic Region,* P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 661-676. (1986) 6099

Ehrmann, Lisa M., Lloyd D. Keigwin. Middle pliocene change in planktonic foraminiferal fauna at site 606. *Initial Rep. Deep Sea Drill. Proj.,* XCIV: 921-924. (1986) 5909

Ellis, J. P., J. D. Milliman. Calcium carbonate suspended in Arabian Gulf and Red Sea waters: Biogenic and detrital, not 'chemogenic'. *J. Sediment. Petrol.,* 55(6): 805-808. (1985) 5917

Emery, K. O. Causes of changes in relative sea levels during the past century and at present. In: *California's Battered Coast. Proceedings from a Conference on Coastal Erosion, San Diego, February 6-8, 1985,* Jim McGrath, ed. California Coastal Commission: 3-5. (1985)

Emery, K. O., D. G. Aubrey Relative sea-level changes from tide-gauge records of eastern Asia mainland. *Mar. Geol.,* 72: 33-45. (1986) 5874

Emery, K. O., D. G. Aubrey Relative sea-level changes from tide-gauge records of western North America. *J. Geophys. Res.,* 91(B14): 13941-13953. (1986) 6058

Emery, K. O., R. S. Deitz, G. G. Kuhn, R. E. Stevenson, J. R. Curray. Memorials – Francis Parker Shepard (1897-1985). *Bull. Am. Assoc. Petrol. Geol.,* 70: 331-333. (1986)

Fischer, K. M., G. M. Purdy. Seismic amplitude modeling and the shallow crustal structure of the East Pacific Rise at 12°N. *J. Geophys. Res.,* 91(B14): 14006-14014. (1986) 6333

Fox, P. J., R. H. Moody, J. A. Karson, E. Bonatti, W. S. F. Kidd, K. Crane, D. G. Gallo, J. B. Stroup, D. J. Fronari, D. Elthon, P. Hamlyn, J. F. Casey. Geology of the oceanographer transform: The transform domain. *Mar. Geophys. Res.,* 7: 329-358. (1985) 5992

Gao, Liang, K. O. Emery, L. D. Keigwin. Late Quaternary stable isotope paleoceanography off southern California. *Deep-Sea Res.,* 32(12): 1469-1484. (1985) 5894

Goud, Margaret R., Jeffrey A. Karson. Tectonics of short-offset, slow-slipping transform zones in the *FAMOUS* area, *Mar. Geophys. Res.,* 7: 489-514. (1985) 5926

Honjo, Susumu. Oceanic particles and pelagic sedimentation in the western North Atlantic Ocean. In: *The Geology of North America, Volume M, The Western North Atlantic Region,* P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 469-478. (1986) 5664

Horai, Ki-iti, R. P. Von Herzen. Measurement of heat flow on Leg 86 of the Deep Sea Drilling Project. *Initial Rep. Deep Sea Drill. Proj.,* LXXXVI: 756-777. (1985)

Hutchinson, I., R. P. Von Herzen, K. E. Louden, J. G. Sclater, J. Jemsek. Heat flow in the Balearic and Tyrrhenian basins, western Mediterranean. *J. Geophys. Res.,* 90(B1): 685-701. (1985) 5745

Johnson, David A., Catherine A. Nigrini. Synchronous and time-transgressive Neogene radiolarian datum levels in the Equatorial Indian and Pacific Oceans. *Mar. Micropaleontol.,* 9: 489-523. (1985) 5965

Karson, J. A., P. J. Fox. Geological and geophysical investigation of the Mid-Cayman Spreading Center: Seismic velocity measurements and implications for the constitution of layer 3. *Geophys. J. R. Astron. Soc.,* 85: 389-411. (1986) 5910

Keigwin, L. D. Pliocene stable isotope record of deep sea drilling project site 606: Sequential events of ^{18}O enrichment beginning at 3.1 MA. *Initial Rep. Deep Sea Drill. Proj.,* XCIV: 911-920. (1986) 6031

Keigwin, L. D., M. P. Aubry, D. V. Kent. North Atlantic late miocene stable-isotope stratigraphy, biostratigraphy and magnetostratigraphy. *Initial Rep. Deep Sea Drill. Proj.,* XCIV: 935-963. (1986) 6030

Keigwin, L. D., E. A. Boyle. Carbon isotopes in deep-sea benthic foraminifera: Precession and changes in low-latitude biomass. In: *The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present,* E. T. Sundquist and W. S. Broecker, eds. *Geophys. Monogr.,* 32: 319-328. (1985) 5837

Keigwin, Lloyd D., Bruce H. Corliss. Stable isotopes in late middle Eocene to Oligocene foraminifera. *Geol. Soc. Am. Bull.,* 97: 335-345. (1986) 6015

Kimball, K. L., F. S. Spear, H. J. B. Dick. High temperature alterations of abyssal ultramafics from the Islas Orcades Fracture Zone, South America. *Contrib. Mineral. Petrol.,* 91: 307-320. (1985)

Kinder, Thomas H., George W. Heburn, Albert W. Green. Some aspects of the Caribbean circulation. *Mar. Geol.,* 68: 25-52. (1985)

Klitgord, Kim D., Hans Schouten. Plate kinematics of the central Atlantic. In: *The Geology of North America, Volume M, The Western North Atlantic Region,* P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 351-378. (1986)

Kong, Laura, Thomas M. Brocher, Ralph A. Stephen. Spreading rate dependence of oceanic seismic layer 2. *Geophys. Res. Lett.,* 12(5): 219-222. (1985) 5905

Lazarus, David. Three-dimensional measurement of microfossil morphology. *J. Paleontol.,* 60(4): 961-964. (1986) 5881

Lazarus, David. Tempo and mode of morphologic evolution near the origin of the radiolarian lineage *Pterocanium prismatium. Paleobiology,* 12(2): 175-189. (1986) 6001

Ling, Hsin Yi, Kozo Takahashi. Silicoflagellate genus *Octactis* Schiller 1925: A synonym of the genus *Distephanus. Micropaleontology,* 31(1): 76-81. (1985)

Little, S. A., R. A. Stephen. Costa Rica Rift borehole seismic experiment, Deep-Sea Drilling Project Hole 504B, Leg 92. *Initial Rep. Deep Sea Drill. Proj.,* LXXXIII: 517-528. (1985) 5779

Matsuda, Jun-Ichi, Richard P. Von Herzen. Thermal conductivity variation in a deep-sea sediment core and its relation to H_2O, Ca and Si content. *Deep-Sea Res.*, 33(2): 165-175. (1986) 5848

McCave, I. N. Local and global aspects of the bottom nepheloid layers in the world ocean. *Neth. J. Sea Res.*, 20(2/3): 167-181. (1986)

McCave, I. N. Mechanics of deposition of fine-grained sediments from nepheloid layers. *Geo. Mar. Lett.*, 4: 243-245. (1985)

McCave, I. N., R. J. Bryant, H. Cook, C. A. Coughanower. Evaluation of a laser-diffraction-size analyser for use with natural sediments. *J. Sediment. Petrol.*, 56(4): 561-564. (1986) 6027

McCave, I. N., Brian E. Tucholke. Deep current-controlled sedimentation in the western North Atlantic. In: *The Geology of North America, Volume M, The Western North Atlantic Region*, P. R. Vogt and B. E. Tucholke, eds. The Geological Society of America, Boulder, CO: 451-468. (1986) 5970

McNutt, Marcia. Nonuniform magnetization of seamounts: A least square approach. *J. Geophys. Res.*, 91(B3): 3686-3700. (1986)

McNutt, Marcia, Loren Shure. Estimating the compensation depth of the Hawaiian swell with linear filters. *J. Geophys. Res.*, 91(B14): 13915-13923. (1986) 6048

Miller, Kenneth G., Marie-Pierre Aubry, M. J. Khan. Oligocene-Miocene biostratigraphy, magnetostratigraphy, and isotopic stratigraphy of the western North Atlantic. *Geology*, 13: 257-261. (1985) 5850

Morin, Roger H., Richard P. Von Herzen. Geothermal measurements at Deep Sea Drilling Project Site 587. *Initial Rep. Deep Sea Drill. Proj.*, XC: 1317-1324. (1985)

Mountain, Gregory S., Brian E. Tucholke. Mesozoic and Cenozoic geology of the U.S. Atlantic continental slope and rise. In: *Geologic Evolution of the United States Atlantic Margin*, C. Wylie Poag, ed. Van Nostrand Reinhold, New York: 293-341. (1985) 5608

Parker, William C., Anthony J. Arnold, William A. Berggren. Analog morphocorrelation: A new technique with implications for high resolution stratig-
raphy. *Palaios*, 1: 183-188. (1986) 6126

Purdy, G. M. Determination of the seismic velocity structure of sediments using both sources and receiver near the ocean floor. *Mar. Geophys. Res.*, 75-91. (1986) 6131

Purdy, G. M., Robert S. Detrick. Crustal structure of the Mid-Atlantic Ridge at 23°N from seismic refraction studies. *J. Geophys. Res.*, 91(3B): 3739-3762. (1986) 5918

Purdy, G. M., John Ewing. Seismic structure of the ocean crust. In: *The Geology of North America, Volume M, The Western North Atlantic Region*, P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 313-330. (1986) 5730

Roex, Anton P. le, Henry J. B. Dick, Arch M. Reid, Fred A. Frey, Anthony J. Eiklank, Stan R. Hart. Petrology and geochemistry of basalts from the American-Antarctic Ridge, Southern Ocean: Implications for the westward influence of the Bouvet mantle plume. *Contrib. Min. Petrol.*, 90: 367-380. (1985) 5943

Ross, David A., Elazar Uchupi, Robert S. White. Geology of the Persian Gulf – Gulf of Oman region: A synthesis. *Rev. Geophys. Space Phys.*, 24(3): 537-556. (1986) 5879

Ruddiman, W. F., J. Backman, J. Baldauf, P. Hooper, L. Keigwin, K. Miller, M. Raymo, E. Thomas. Leg 94 paleoenvironmental synthesis. *Initial Rep. Deep Sea Drill. Proj.*, XCIV: 1207-1215. (1986)

Schweitzer, Peter N., Roger L. Kaesler, G. P. Lohmann. Ontogeny and heterochrony in the ostracode *Cavellina* Coryell from Lower Permian rocks in Kansas. *Paleobiology*, 12(3): 290-301. (1986) 6128

Seymour, Richard J., David G. Aubrey. Rhythmic beach cusp formation: A conceptual synthesis. *Mar. Geol.*, 65: 289-304. (1985) 5627

Shaw, Peter. Extending the linear regime of the seismic waveform inversion problem. *Geophys. Res. Lett.*, 13(11): 1157-1160. (1986) 6292

Shaw, Peter R., John A. Orcutt. Waveform inversion of seismic refraction data and applications to young Pacific crust. *Geophys. J. R. Astron. Soc.*, 82: 375-414, (1985)

Solheim, Anders, Stephanie Louise Pfirman. Sea-floor morphology outside a grounded, surging glacier, Brasvellbreen, Svalbard. *Mar. Geol.*, 65: 127-143. (1985) 5743

Stephen, R. A., F. Cardo-Casas, C. H. Cheng. Finite-difference synthetic acoustic logs. *Geophysics*, 50(10): 1588-1609. (1985)

Swift, Stephen A., Cynthia J. Ebinger, Brian E. Tucholke. Seismic stratigraphic correlation across the New England Seamounts, western North Atlantic. *Geology*, 14: 346-349. (1986) 6013

Takahashi, Kozo. Seasonal fluxes of pelagic diatoms in the subarctic Pacific, 1982-1983. *Deep-Sea Res.*, 33(9): 1225-1251. (1986) 6107

Toomey, Douglas R., Sean C. Solomon, G. M. Purdy, Mark H. Murray. Microearthquakes beneath the median valley of the Mid-Atlantic Ridge near 23°N: Hypocenters and focal mechanisms. *J. Geophys. Res.*, 90(B7): 5443-5458. (1985) 5836

Tucholke, B. E., F. W. McCoy. Paleogeographic and paleobathymetric evaluation of the North Atlantic Ocean. In: *The Geology of North America, Volume M, The Western North Atlantic Region*, P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 589-602. (1986) 5980

Tucholke, Brian E. Structure of basement and distribution of sediments in the western North Atlantic. In: *The Geology of North America, Volume M, The Western North Atlantic Region*, P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 331-340. (1986) 5972

Tucholke, Brian E. Analysis of a longitudinal ripple from the Nova Scotian continental rise – Comment. *Mar. Geol.*, 72: 371-373. (1986)

Tucholke, Brian E., Virginia A. Fry. Basement structure and sediment distribution in the northwest Atlantic Ocean. *Am. Assoc. Pet. Geol. Bull.*, 69(12): 2077-2097. (1985) 5915

Tucholke, Brian E., Gregory S. Mountain. Tertiary paleoceanography of the western North Atlantic. In: *The Geology of North America, Volume M, The Western North Atlantic Region*, P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 631-650. (1986) 6125

Tucholke, Brian E., Peter R. Vogt. Perspectives on the geology of the North Atlantic Ocean. In: *The Geology of North America, Volume M, The Western North Atlantic Region*, P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO.: 1-18. (1986)

Uchupi, Elazar, David A. Ross. Tectonic style of the northern Red Sea. *Geo-Mar. Lett.*, 5: 203-209. (1986) 5861

Vogt, Peter R., Brian E. Tucholke. Imaging the ocean floor: History and state of the art. In: *The Geology of North America, Volume M, The Western North Atlantic Region*, P. R. Vogt and B. E. Tucholke, eds. Geological Society of America, Boulder, CO: 19-44. (1986) 6226

Watts, A. B., U. S. ten Brink, P. Buhl, T. M. Brocher. Multichannel seismic study of lithospheric flexure across the Hawaiian-Emperor seamount chain. *Nature (London)*, 315(6015): 105-111. (1985) 5710

Webb, S. C., S. C. Constable, C. S. Cox, T. K. Deaton. Seafloor electric field instrument. *J. Geoelectr.*, 37: 1115-1129. (1985)

Webb, Spahr C. Coherent pressure fluctuations observed at two sites on the deep sea floor. *Geophys. Res. Lett.*, 13(1): 141-144. (1986) 6078

Webb, Spahr C., Steven C. Constable. Microseism propagation between two sites on the deep seafloor. *Bull. Seismol. Soc. Am.*, 76: 1433-1445. (1986) 6086

Ocean Engineering

Berteaux, H. O., R. L. Boy. Wave tank study of moored buoy hulls for air-sea interaction applications. In: *Oceans '86 Conference Record, Washington, DC, September 23-25, 1986.* IEEE, New York: 259-270. (1986) 6211

Butman, C.A., W. D. Grant, K. D. Stolzenbach. Predictions of sediment trap biases in turbulent flows: A theoretical analysis based on observations from the literature. *J. Mar. Res.*, 44(3): 601-644. (1986) 5939

Butman, Cheryl Ann. Sediment trap biases in turbulent flows: Results from a laboratory flume study. *J. Mar. Res.*, 44(3): 645-693. (1986) 6036

Butman, Cheryl Ann. Larval settlement of soft-sediment invertebrates: Some predictions based on an analysis of near-bottom velocity profiles. In: *Marine Interfaces Ecohydrodynamics*, J. C. J. Nihoul, ed. Elsevier, New York: 487-513. (1986) 6046

Converse, C. H., H. J. Williams, III, P. D. Fucile, R. W. Schmitt. Free ocean vehicle to measure optical microstructure. In: *Current Practices and New Technology in Ocean Engineering – OED Vol. 11*, T. McGuinness and H. H. Shih, eds. American Society of Mechanical Engineers, New York: 341-345. (1986) 6096

Cornuelle, B., C. Wunsch, D. Behringer, T. Birdsall, M. Brown, R. Heinmiller, R. Knox, K. Mertger, J. Speisberger, R. Spindel, D. Webb, P. Worcester. Tomographic maps of the ocean mesoscale. Part I: Pure acoustics. *J. Phys. Oceanogr.*, 15(2): 134-152. (1985) 5961

Desaubies, Yves, Ching-Sang Chiu, James H. Miller. Acoustic mode propagation in a range-dependent ocean. *J. Acoust. Soc. Am.*, 80(4): 1148-1160. (1986) 5890

Frisk, George V., James A. Doutt, Earl E. Hays. Geoacoustic models for the Icelandic Basin. *J. Acoust. Soc. Am.*, 80(2): 591-600. (1986) 5835

Frisk, George V., James F. Lynch, James A. Doutt. Determination of geoacoustic models in shallow water. In: *Ocean Seismo-Acoustics*, Tuncay Akal and Jonathan M. Berkson, eds. Plenum Publ., New York: 693-702. (1986)

Graber, Hans C., Ole S. Madsen. Parametric wind wave model for arbitrary water depths. In: *The Ocean Surface, Wave Breaking, Turbulent Mixing and Radio Probing*, Y. Toba and H. Mitsuyasu, eds. Reidel Publ., Dordrecht, Holland: 193-199. (1985)

Grant, William D., Albert J. Williams, III, Thomas F. Gross. Description of the bottom boundary layer at the HEBBLE site: Low-frequency forcing, bottom stress and temperature structure. *Mar. Geol.*, 66: 219-241. (1985) 5703

Gross, Thomas F. Modeling time dependence in a tidal boundary layer. *Cont. Shelf Res.*, 6(3): 431-448. (1986) 5979

Gross, Thomas F., Albert J. Williams, III, William D. Grant. Long-term *in situ* calculations of kinetic energy and Reynolds stress in a deep sea boundary layer. *J. Geophys. Res.*, 91(C7): 8461-8469. (1986) 6155

Hess, F. R., K. W. Bedford. Acoustic Backscatter System (ABSS): The instrument and some preliminary results. In: *Deep Ocean Sediment Transport*, A. R. M. Nowell and C. D. Hollister, eds. Elsevier, New York [Reprinted from *Mar. Geol.*, 66(1-4)]: 357-379. (1985)

Lawrence, Martin W. Ray theory modeling applied to low-frequency acoustic interaction with horizontally stratified ocean bottoms. *J. Acoust. Soc. Am.*, 78(2): 649-658. (1985) 5753

Madsen, Ole S. Hydrodynamic force on circular cylinders. *Appl. Ocean Res.*, 8(3): 151-155. (1986) 6023

Renard, V., R. Hekinian, J. Francheteau, R. D. Ballard, H. Backer. Submersible observations at the axis of the ultra-fast-spreading East Pacific Rise (17°30' to 20°30'S). *Earth Planet. Sci. Lett.*, 75: 339-353. (1985) 6050

Rizzoli, Paola Malanotte. Gulf Stream variability for acoustic tomography. *Deep-Sea Res.*, 32(2): 237-250. (1985)

Speisberger, John L., Robert C. Spindel. Gulf Stream tomography: Preliminary results from an experiment. In: *Gulf Stream Workshop.*

Proceedings. (Held at the University of Rhode Island, W. Alton Jones Conference Center, West Greenwich, Rhode Island, 23-26 April 1985): II.479-II.494. (1985)

Spindel, R. C. Ocean acoustic tomography: A review. In: *Current Practices and New Technology in Ocean Engineering – OED Vol. 11,* T. McGuinness and H. H. Shih, eds. American Society of Mechanical Engineers, New York: 7-13. (1986) 6057

Terry, William. Standards – why bother? In: *Proceedings of the IEEE Third Working Conference on Current Measurement, Arlie, Virginia, January 22-24, 1986:* 221-224. (1986) 6138

Weinstein, E., Anthony J. Weiss. Lower bounds on the mean square estimation error. *Proc. IEEE, 73(9):* 1433-1434. (1985) 5791

Weiss, Anthony J., Ehud Weinstein. Lower bounds on the mean square error in random parameter estimation. *IEEE Trans. Inf. Theory,* IT-31(5): 680-682. (1985) 5737

Worcester, Peter F., Robert C. Spindel, Bruce M. Howe. Reciprocal acoustic transmissions: Instrumentation for mesoscale monitoring of ocean currents. *IEEE J. Oceanic Eng.,* OE-10(2): 123-137. (1985) 5960

Yoerger, Dana, Jean-Jacques E. Slotine. Robust trajectory control of underwater vehicles. *IEEE J. Oceanic Eng.,* OE-10(4): 462-470. (1985) 5802

Yoerger, Dana E., James B. Newman, Jean-Jacques E. Slotine. Supervisory control system for the JASON ROV. *IEEE J. Oceanic Eng.,* OE-11(3): 392-400. (1986) 6183

Physical Oceanography

Atkinson, Larry P., Kenneth H. Brink, Russ E. Davis, Burton E. Jones, Theresa Paluszkiewicz, David W. Stuart. Mesoscale hydrographic variability in the vicinity of Points Conception and Arguello during April – May 1983: The OPUS 1983 Experiement. *J. Geophys. Res.,* 91(C11): 12899-12918. (1986)

Badan-Dangon, Antoine, Kenneth H. Brink, Robert L. Smith. On the dynamical structure of the midshelf water column off northwest Africa. *Cont. Shelf Res.,* 5(6): 629-644. (1986)

Beardsley, R., M. Briscoe, R. Signell, S. Longworth. VMCM S4 current meter intercomparison on a surface mooring in shallow water. In: *Proceedings of the Third IEEE Working Conference on Current Measurement,* Gerald F. Appell and William E. Woodward, eds. IEEE, New York: 7-12. (1986)

Beardsley, R. C. Inter-comparison between the VACM and new EG&G VMCM on a surface mooring. In: *Proceedings of the IEEE Third Working Conference on Current Measurement,* Gerald F. Appell and William E. Woodward, eds. IEEE, New York: 52-62. (1986)

Bennett, Sara L. Relationship between vertical, diapycnal, and isopycnal velocity and mixing in the ocean general circulation. *J. Phys. Oceanogr.,* 16(1): 167-174. (1986) 5901

Bishop, James K. B., Terrence M. Joyce. Spatial distributions and variability of suspended particulate matter in warm core-ring 82B. *Deep-Sea Res.,* 33(11/12): 1741-1760. (1986) 6238

Bradshaw, Alvin L., Karl E. Schleicher. Empirical equation of state for pure water in the oceanographic region of temperature and pressure determined from direct measurements. *J. Chem. Eng. Data,* 31: 189-194. (1986) 5898

Brink, K. H. Scattering of long coastal-trapped waves due to bottom irregularities. *Dyn. Atmos. Oceans,* 10: 149-164. (1986) 5862

Brink, K. H. Some aspects of physical processes in coastal upwelling. In: *Simposio Internacional Sobre Las Areas de Afloramiento mas Importantes del Oestre Africano (Cabo Blanco y Benguela).* Instituto de Investigaciones Pesqueras, Barcelona: 5-14. (1985)

Brink, K. H., R. D. Muench. Circulation in the Point Conception – Santa Barbara Channel region. *J. Geophys. Res.,* 91(C1): 877-895. (1985) 5949

Brown, Ellen, W. Brechner Owens, Harry L. Bryden. Eddy potential vorticity fluxes in the Gulf Stream recirculation. *J. Phys. Oceanogr.,* 16(3): 523-531. (1986) 5805

Caldwell, Patrick C., D. W. Stuart, K. H. Brink. Mesoscale wind variability near Point Conception, California during spring 1983. *J. Climate Appl. Meteorol.,* 25(9): 1241-1254. (1986)

Cessi, Paola, Joseph Pedlosky. On the role of tomography in the ocean circulation. *J. Mar. Res.,* 44: 445-471. (1986) 6090

Chapman, David C. Simple model of the formation and maintenance of the shelf/slope front in the Middle Atlantic Bight. *J. Phys. Oceanogr.,* 16(7): 1274-1279. (1986) 6080

Chapman, David C., John A. Barth, Robert C. Beardsley, Richard G. Fairbanks. On the continuity of mean flow between the Scotian Shelf and the Middle Atlantic Bight. *J. Phys. Oceanogr.,* 16(4): 758-772. (1986) 5877

Churchill, James H., Peter C. Cornillon, George W. Milkowski. Cyclonic eddy and shelf-slope water exchange associated with a Gulf Stream warm-core ring. *J. Geophys. Res.,* 91(C8): 9615-9623. (1986) 6118

Clarke, Allan J., K. H. Brink. Response of stratified, frictional flow of shelf and slope waters to fluctuating large-scale, low-frequency wind forcing. *J. Phys. Res.,* 15(4): 439-453. (1985) 5697

Csanady, G. T. A zero potential vorticity model for the North Brazilian Coastal Current. *J. Mar. Res.,* 43: 553-579. (1985) 5702

Csanady, G. T. Mass transfer to and from small particles in the sea. *Limnol. Oceanogr.,* 31(2): 237-248. (1986) 6032

Csanady, G. T. Dispersal of particulate waste on an open continental shelf. In: *The Role of the Oceans as a Waste Disposal Option,* G. Kullenberg, ed. Reidel Publ., Dordrecht, Holland: 551-561. (1986)

Csanady, G. T. On cross-gyre transports. *J. Phys. Oceanogr.,* 16(10): 1703-1711. (1986) 6139

Flagg, Charles N., R. Lee Gordon, Scott McDowell. Hydrographic and current observations on the continental slope and shelf of the western equatorial Atlantic. *J. Phys. Oceanogr.,* 16(8): 1412-1429. (1986) 5670

Fofonoff, N. P. Gulf Stream observations. In: *Gulf Stream Workshop. Proceedings.* (Held at the University of Rhode Island, W. Alton Jones Conference Center, West Greenwich, Rhode Island, 23-26 April 1985): II.1-II.20. (1985)

Gent, Peter R., James R. Luyten. How much energy propagates vertically in the equatorial oceans? *J. Phys. Oceanogr.,* 15(7): 997-1007. (1985)

Hall, Melinda M. Diagnostic investigation of kinetic energy budgets in a numerical model. *J. Geophys. Res.,* 91(C2): 2555-2568. (1986) 5984

Hall, Melinda M. Horizontal and vertical structure of the Gulf Stream at 68°W. *J. Phys. Oceanogr.,* 16: 1814-1828. (1986) 6038

Hall, Melinda M. Assessing the energetics and dynamics of the Gulf Stream at 68°W from moored current measurements. *J. Mar. Res.,* 44: 423-443. (1986) 6252

Hogg, N. G., R. S. Pickart. Recirculation and the deep Gulf Stream. In: *Gulf Stream Workshop. Proceedings.* (Held at the University of Rhode Island, W. Alton Jones Conference Center, West Greenwich, Rhode Island, 23-26 April 1985): II.288-II.303. (1985)

Hogg, N. G., H. M. Stommel. The heton, an elementary interaction between discrete baroclinic geostrophic vortices, and its implications concerning eddy heat-flow. *Proc. R. Soc. London Ser. A,* 397: 1-20. (1985) 5617

Hogg, Nelson. Recent Gulf Stream theoretical work and pertinent observations. In: *Gulf Stream Workshop. Proceedings.* (Held at the University of Rhode Island, W. Alton Jones Conference Center, West Greenwich, Rhode Island, 23-26 April 1985): II.45-II.57. (1985)

Hogg, Nelson G. On the correction of temperature and velocity time series for mooring motion. *J. Atmos. Oceanic Technol.,* 3(1): 204-214. (1986) 5897

Hogg, Nelson G., Robert S. Pickart, Ross, M. Hendry, William Smethie. On the northern recirculation gyre of the Gulf Stream. *Deep-Sea Res.,* 33(9): 1139-1165. (1986) 6190

Holland, William R., William J. Schmitz. Zonal penetration scale of model midlatitude jets. *J. Phys. Oceanogr.,* 15(12): 1859-1875. (1985) 5903

Hua, Bach Lien, James C. Mcwilliams, W. Brechner Owens. Objective analysis of the POLYMODE Local Dynamics Experiment. Part 2: Streamfunction and potential vorticity fields during the Intensive Period. *J. Phys. Oceanogr.,* 16(3): 506-522. (1986) 5806

Huppert, Herpert E., R. Stephen, J. Sparks, John A. Whitehead, Mark A. Hallworth. Replenishment of magma chambers by light inputs. *J. Geophys. Res.,* 91(B6): 6113-6122. (1986)

Joyce, T. M., C. Wunsch, S. D. Pierce. Synoptic Gulf Stream velocity profiles through simultaneous inversion of hydrographic and acoustic doppler. *J. Geophys. Res.,* 91(C6): 7573-7585. (1986) 6068

Joyce, Terrence, Bruce A. Warren, Lynne D. Talley. On the geothermal heating of the abyssal Subarctic Pacific Ocean. *Deep-Sea Res.,* 33(8): 1003-1015. (1986) 6109

Joyce, Terrence, M. Structure and evolution of Gulf Stream warm-core rings: A physical characterization. In: *Dynamic Processes in the Chemistry of the Upper Ocean,* J. D. Burton, P. G. Brewer and R. Chesselet, eds. Plenum Pr., New York: 79-915. (1986)

Kase, Rolf H., James F. Price, Philip L. Richardson, Walter Zenk. Quasi-synoptic survey of the thermocline circulation and water mass distribution within the Canary Basin. *J. Geophys. Res.,* 91(C8): 9739-9748. (1986) 6047

Kelly, K. A., R. E. Davis. Analysis of errors in sea surface temperature in a series of infrared images from NOAA 6. *J. Geophys. Res.,* 91(C2): 2633-2644. (1986)

Kelly, Kathryn A. Separating clouds from ocean in infrared images. *Remote Sensing Environ.,* 17(1): 67-83. (1985)

Kinder, Thomas H., David C. Chapman, John A. Whitehead. Westward intensification of the mean circulation on the Bering Sea shelf. *J. Phys. Oceanogr.,* 16(7): 1217-1229 (1986) 5994

Klein, Patrice, Joseph Pedlosky. Numerical study of baroclinic instability at large supercriticality. *J. Atmos. Sci.,* 43(12): 1243-1262. (1986) 6085

Lentz, S. J., C. D. Winant. Subinertial currents on the southern California shelf. *J. Phys. Oceanogr.,* 16: 1737-1750. (1986)

Lindstrom, Eric J., Curtis C. Ebbesmeyer, W. Brechner Owens. Structure of origin of a small cyclonic eddy observed during the POLYMODE Local Dynamics Experiment. *J. Phys. Oceanogr.,* 16(3): 562-570. (1986) 5008

Luyten, J., H. Stommel. A beta-control of buoyancy-driven geostrophic flows. *Tellus,* 38A: 88-91. (1986)

Luyten, James, Henry Stommel. Gyres driven by combined wind and buoyancy flux. *J. Phys. Oceanogr.,* 16(9): 1551-1560. (1986) 6017

Luyten, James A., Henry M. Stommel. Experiments with cross-gyre flow patterns on a beta-plane. *Deep-Sea Res.,* 33(7): 963-972. (1986) 6120

Malanotte-Rizzoli, Paola, William R. Holland. Gyre-scale acoustic tomography: Modeling simulations. *J. Phys. Oceanogr.,* 15: 416-438. (1985)

Mangum, L. J., S. P. Hayes, J. M. Toole. Eastern Pacific Ocean circulation near the onset of the 1982/83 El Nino. *J. Geophys. Res.,* 91(C7): 8428-8436. (1986) 5985

McWilliams, James C., W. Brechner Owens, Bach-Lien Hua. Objective analysis of the POLYMODE Local Dynamics Experiment. Part 1: General formalism and statistical model selection. *J. Phys. Oceanogr.,* 16(3): 483-504 (1986) 5172

Nelson, David M., Hugh W. Ducklow, Gary L. Hitchcock, Mark A. Brzezinski, Timothy J. Cowles, Christopher Garside, Richard W. Gould, Terrence M. Joyce, Christopher Langdon, James J. McCarthy, Charles S. Yentsch. Distribution and composition of biogenic particulate matter in a Gulf Stream warm-core ring. *Deep-Sea Res.,* 32(11): 1347-1369. (1985) 5865

Niiler, Pearn P., William J. Schmitz, Dong-Kyu Lee. Geostrophic volume transport in high eddy-energy areas of Kuroshio Extension and Gulf Stream. *J. Phys. Res.*, 15(7): 825-843. (1985) 5777

Olson, D. B., R. W. Schmitt, M. Kennelly, T. M. Joyce. Two-layer diagnostic model of the long-term physical evolution of warm-core ring 82B. *J. Geophys. Res.*, 90(C5): 8813-8822. (1985) 5796

Pedlosky, Joseph. Buoyancy and wind-driven ventilated thermocline. *J. Phys. Oceanogr.*, 16(6): 1077-1087. (1986) 6070

Pettigrew, N. R., R. C. Beardsley, J. D. Irish. Field evaluations of a bottom-mounted acoustic doppler profiler and conventional current meter moorings. In: *Proceedings of the IEEE Third Working Conference on Current Measurement*, Gerald F. Appell and William E. Woodward, eds. IEEE, New York: 153-162. (1986)

Pratt, L. J. Hydraulic control of sill flow with bottom friction. *J. Phys. Oceanogr.*, 16: 1970-1980. (1986) 6198

Pratt, L. J., Melvin E. Stearn. Dynamics of potential vorticity fronts and eddy detachment. *J. Phys. Oceanogr.*, 16(6): 1101-1120. (1986)

Price, James F., Robert A. Weller, Robert Pinkel. Diurnal cycling: Observations and models of the upper ocean response to diurnal heating, cooling and wind mixing. *J. Geophys. Res.*, 91(C7): 8411-8427. (1986) 5427

Reverdin, Gilles, James Luyten. Near-surface meanders in the equatorial Indian Ocean. *J. Phys. Oceangr.*, 16(6): 1088-1100. (1986)

Rhines, Peter B. Vorticity dynamics of the oceanic general circulation, *Ann. Rev. Fluid Mech.*, 18: 433-497. (1986)

Richardson, P. L., D. Walsh. Mapping climatological seasonal variations of surface currents in the tropical Atlantic using ship drifts. *J. Geophys. Res.*, 91(C9): 10537-10550. (1986) 6069

Richardson, Philip L. Derelicts and drifters. *Nat. Hist.*, 94(6): 42-49. (1985)

Riser, Stephen C., W. Brechner Owens, H. Thomas Rossby, Curtis C. Ebbesmeyer. Structure, dynamics, and origin of a small-scale lens of water in the western North Atlantic thermocline. *J. Phys. Oceanogr.*, 16(3): 572-590. (1986) 5518

Rossby, T., J. Price, D. Webb. Spatial and temporal evolution of a cluster of SOFAR floats in the POLYMODE Local Dynamics Experiments (LDE). *J. Phys. Oceaogr.*, 16(3): 428-442. (1986) 5563

Schmitt, Raymond W., Rolf G. Lueck, Terrence M. Joyce. Fine- and microstructure at the edge of a warm core ring. *Deep-Sea Res.*, 33(11/12): 1665-1689. (1986) 6216

Schmitz, William J. SOFAR float trajectories associated with the Newfoundland Basin. *J. Mar. Res.*, 43: 461-778. (1985) 5819

Schmitz, William J., William R. Holland. Observed and modelled flow characteristics near the Gulf Stream and Kuroshio Extension. *J. Geophys. Res.*, 91(C8): 9624-9638. (1986) 6121

Stage, Steven A., Robert A. Weller. Frontal Air-Sea Interaction Experiment (FASINEX), part II: Experimental plan. *Bull. Am. Meteorol. Soc.*, 67(1): 16-20. (1986) 6034

Stage, Steven A., Robert A. Weller. Frontal Air-Sea Interaction Experiment (FASINEX), part I: Background and scientific objectives. *Bull. Am. Meteorol. Soc.*, 66(12): 1511-1520. (1985) 6033

Stramma, Lothar, Peter Cornillon, Robert A. Weller, James F. Price, Melbourne G. Briscoe. Large diurnal sea surface temperature variability: Satellite and *in situ* measurements. *J. Phys. Oceanogr.*, 16(5): 827-837. (1986) 5953

Stramma, Lothar, Peter Cornillon, James F. Price. Satellite observations of sea surface cooling by hurricanes. *J. Geophys. Res.*, 91(C4): 5031-5035. (1986) 6063

Whitehead, J.A. Buoyancy-driven instabilities of low-viscosity zones as models of magma-rich zones. *J. Geophys. Res.*, 91(B9): 9303-9314. (1986) 5906

Whitehead, John A. Flow of a homogeneous rotating fluid through straits. *Geophys. Astrophys. Fluid Dyn.*, 36: 187-205. (1986) 6004

Whitehead, John A., Karl R. Helfrich. Korteweg-deVries equation from laboratory conduit and magma migration equations. *Geophys. Res. Lett.*, 13(6): 545-546. (1986) 6191

Whitehead, John A., David C. Chapman. Laboratory observations of a gravity current on a sloping bottom: The generation of shelf waves. *J. Phys. Oceanogr.*, 172: 373-399. (1986) 5851

Marine Policy & Ocean Management

Archer, Jack H. Concept of coastal zone management. In: *Proceedings of the International Symposium on Utilization of Coastal Ecosystems: Planning, Pollution, and Productivity, 21-27 Nov 1982, Rio Grande, Brazil, Volume 1*, Ning Labbish Chao and William Kirby-Smith, eds. Editora de Furg, Rio Grande: 27-38. (1985)

Bowen, Robert E., Timothy M. Hennessey. Adjacent state issues for the United States in establishing an Exclusive Economic Zone: The cases of Canada and Mexico. *Ocean Dev. Int. Law*, 15(3/4): 355-375. (1985)

Broadus, J. M. Asian Pacific marine minerals and industry structure. *Mar. Resource Econ.*, 3(1): 63-88. (1986) 6084

Broadus, James M. Poor fish of Redondo!: Managing the Galapagos waters. *Oceanus* 28(1): 95-99. (1985)

Broadus, James M., Robert E. Bowen. Developing a U.S. research strategy for marine polymetallic sulfides. *Ocean Dev. Int. Law*, 17(1/2/3): 91-130. (1986)

Cycon, Dean E. Legal and regulatory issues in marine archaeology. *Oceanus*, 28(1): 78-84. (1985)

Cycon, Dean E. Who owns the *Titanic*? *Oceanus*, 28(4): 94-95. (1985)

Frazer, Nat. Survival from egg to adulthood in a declining population of loggerhead turtles, *Caretta caretta*. *Herpetologica*, 42(1): 47-55. (1986)

Frazer, Nat, Rosamund C. Ladner. Growth curve for green sea turtles, *Chelonia mydas*, in the U.S. Virgin Islands, 1913-14. *Copeia*, 3: 798-802. (1986) 5829

Frazer, Nat B. Relationship of clutch size and frequency to body size in loggerhead turtles, *Carretta carretta*. *J. Hertetol.*, 20(1): 81-84. (1986)

Frazer, Nat B., Llewellyn M. Ehrhart. Preliminary growth models for green, *Chelonia mydas*, and loggerhead, *Caretta caretta*, turtles in the wild. Copeia, 1: 73-79. (1985)

Hoagland, Porter, III. Seabed mining patent activity: Some first steps toward an understanding of strategic behavior. *J. Resour. Manag. Technol.*, 14(3): 211-222. (1986) 6346

Hoagland, Porter, III. Role of the U.S. Coast Guard. *Oceanus*, 28(2): 67-73. (1985)

Leschine, Thomas M., James M. Broadus. Economic and operational considerations of offshore disposal of sewage sludge. In: *Wastes in the Ocean, Volume 5. Deep-Sea Waste Disposal*, Dana R. Kester, Wayne V. Burt, Judith M. Capuzzo, P. Kilho, Bostwick H. Ketchum and Iver W. Duedall eds. John Wiley & Sons, New York: 287-315. (1985)

Morris, Michael A. The 1984 Argentine-Chilean pact of peace and friendship. *Oceanus*, 28(2): 93-96. (1985)

Peterson, M. J. Antarctic implications of the new Law of the Sea. *Ocean Dev. Int. Law*, 16(2): 137-181. (1986) 5653

Pires-Filho, Ivon d'Almeida. Priority of maritime liens in the Western Hemisphere: How secure is your claim? *Univ. Miami Inter-Am. Law Rev.*, 16(3): 505-537. (1985) 5784

Silva, Maynard, Ingrid Desilvestre. Marine and coastal protected areas in Latin America: A preliminary assessment. *Coastal Zone Manage. J.*, 14(4): 311-347. (1986)

Silva Maynard, Lauriston King. Ocean resources and intergovernmental relations: The record to 1980. In: *Ocean Resources and U.S. Intergovernmental Relations in the 1980s*. Maynard Silva, ed. Westview Press, Boulder, CO: 75-104. (1986)

Silva, Maynard, Mark Meo. Louisiana response to land subsidence and coastal erosion. *Oceans '85*, : 594-599. (1985)

Silva, Maynard E. Land Grant and Sea Grant: Implications and limitations of the model. *Ocean Dev. Int. Law*, 17(1/2/3): 59-90. (1986) 5465

General (Administration)

Kaharl, Victoria. Ships on stilts. *Science 86*, 7(3): 54-60. (1986)

Kaharl, Victoria. Eti glubing ne vsegda spokoiny. *Amerika*, 353: 16-18. (1986)

Kaharl, Victoria A. Sea drifters. *Omni*, Jul: 53-58. (1986)

Klein, Patrice, John H. Steele. Some physical factors affecting ecosystems. *J.Mar.Sci.*, 43: 337-350. (1985) 5693

Nowell, Arthur R. M., Charles D. Hollister. Objectives and rationale of HEBBLE. In: *Deep Ocean Sediment*, A. R. M. Nowell and C. D. Hollister, eds. Elsevier, New York [Reprinted from *Mar.Geol.*,66(1-4)] : 1-11. (1985)

Steele, John H. Natural variability and waste disposal options. In: *The Role of the Oceans as a Waste Disposal Option*, G. Kullenberg, ed. Reidel Publ, Dordrecht, Holland: 27-38S. (1986)

Steele, John H. Upper ocean chemistry: Space and time scales. In: *Dynamic Processes in the Chemistry of the Upper Ocean*, J. D. Burton, P. G. Brewer, and R. Chesselet, eds. Plenum Pr., New York: 29 - 39. (1986)

Monographs

Burton, J. D., P. G. Brewer and R. Chesselet, eds. **Dynamic Processes in the Chemistry of the Upper Ocean.** New York: Plenum Press. 1986.

Kamerkovich, V. M., A. S. Monin and A. D. Voorhis. **Polymode Atlas.** Woods Hole: Woods Hole Oceanographic Institution. 1986. WHOI Contribution Number 6077.

Morkhoven, P. C. M. van, William A. Berggren and Anne S. Edwards. **Cenozoic Cosmopolitan Deep-Water Benthic Foraminifera.** (Bull. Centres Rech. Explor. -Prod. Elf-Aquitaine, Mem.11) Pau Cedex, France: Societe Nationale Elf Aquitaine. 1986.

Silva, Maynard, ed. **Ocean Resources and U.S. Intergovernmental Relations in the 1980's.** Boulder, CO: Westview Press. 1986.

Vogt, Peter R. and Brian E. Tucholke, eds. **The Western North Atlantic Region. The Geology of North America, Volume M.** Boulder, CO: Geological Society of America. 1986.

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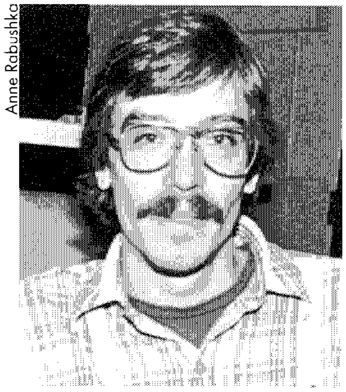

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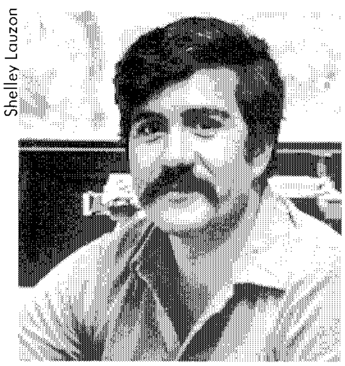

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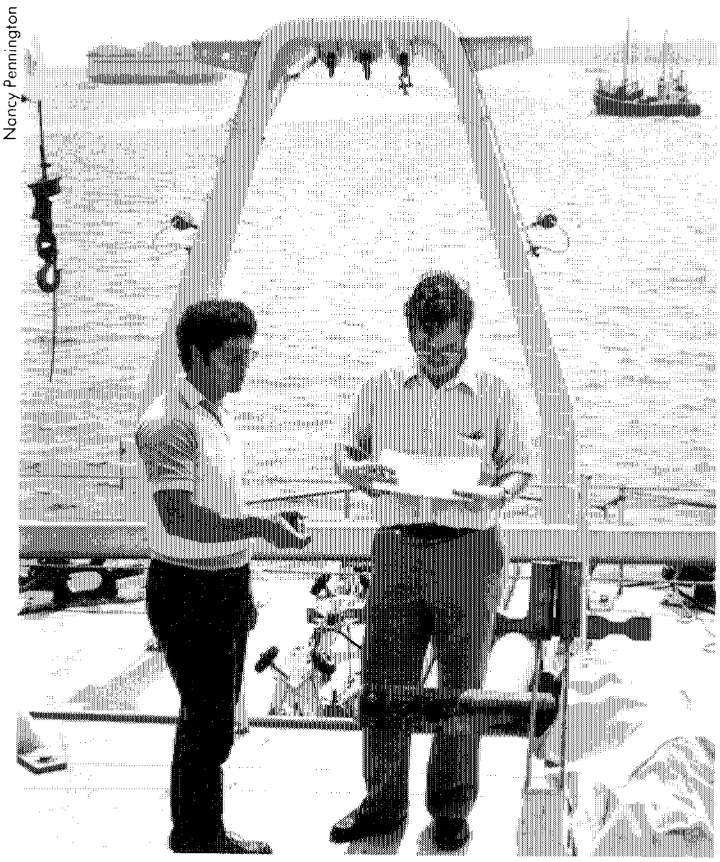
Lawrence J. Pratt, Assistant Scientist
James F. Price, Associate Scientist
Philip L. Richardson, Associate Scientist
Karl E. Schleicher, Oceanographic Engineer
Raymond W. Schmitt, Associate Scientist
William J. Schmitz, Jr., Senior Scientist
Marvel C. Stalcup, Physical Oceanographer
Henry M. Stommel, Senior Scientist
John M. Toole, Associate Scientist
Richard P. Trask, Research Associate
George H. Tupper, Research Associate
James R. Valdes, Research Associate
William S. von Arx, Scientist Emeritus
Bruce A. Warren, Senior Scientist
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


Nancy Pennington

Rick Trask (left) and Bob Weller prepare for a physical oceanography cruise aboard *Knorr*.

Mary E. Woodgate-Jones, Research Associate
L. Valentine Worthington, Scientist Emeritus
A. Cleo Zani, Research Associate

Marine Policy & Ocean Management

James M. Broadus, Director, Marine Policy and Ocean Management, Social Scientist
Steven F. Edwards, Social Scientist
Porter R. Hoagland III, Research Associate
+Maynard E. Silva, Political Scientist

+ Leave of Absence

Postdoctoral Investigators

Dennis A. Bazylinski (Biology)
Blair H. Brumley (Ocean Engineering)
Kenneth O. Buesseler (Chemistry)
Ching-Sang Chiu (Ocean Engineering)
Tim K. Eichenberg (MP&OM)
Wayne R. Geyer (Ocean Engineering)
David M. Glover (Chemistry)
Mark Grosenbaugh (Ocean Engineering)
Karl R. Helfrich (Physical Oceanography)
Eric L. Kunze (Physical Oceanography)
Angelika F. Lippert (Physical Oceanography)
Juergen Mienert (Geology & Geophysics)
Andrew R. Solow (MP&OM)
Stephen A. Swift (Geology & Geophysics)
Christine M. Webb (Ocean Engineering)

Shelley Lauzon

Anne Rabushka

Anne Rabushka

Shelley Lauzon

Top to bottom: Jeanne Young, Lewis Greene, Paul Tibbetts and Molly Lumping.

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James E. Bird
L. Susan Brown-Leger
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Mary Ann Daher
Linda H. Davis
Gregg R. Dietzman
Margaret S. Dimmock
Diana G. Franks
Dale D. Goehringer
Linda R. Hare
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Bruce A. Lancaster
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Jane M. Peterson
Rosemarie F. Petrecca
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Emile M. Bergeron
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Martin F. Bowen
Rodney M. Catanach
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Bruce R. Cole
Aganoris Collins
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Susan F. Witzell
Martin C. Woodward

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Carol A. Alessi
R. Lorraine Barbour
Karin A. Bohr
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Maureen E. Carragher
Cynthia L. Chandler
Dolores H. Chausse
Jane A. Dunworth
+Erika A. Francis
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Ruth A. Gorski
Veta M. Green
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Joseph R. Poirier
Laurie A. Raymond
John B. Reese
Mabel M. Reese
Samuel T. Simkins
R. David Simoneau
Ann Spencer
Robert J. Stanley

+Leave of Absence

Susan A. Tarbell
Robert D. Tavares
John H. Thomson
Toshiko T. Turner
Cynthia T. Tynan
Bryan S. Way
Christine M. Wooding
Scott E. Worrilow
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Ellen M. Gately
Ethel F. LeFave
Jane P. Zentz

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Mary Jane Tucci
Wayne R. Vincent
Gordon H. Volkmann
Margaret M. Walden
Joan E. Watkins
N. Joye Wirsen
Jeanne A. Young
Dianna M. Zaia

+ Leave of Absence

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Gordon K. Glass .... Executive Assistant/Ocean Engineering
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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
Judith L. Kleindinst .... Executive Assistant/Biology
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Virginia A. Lefavor .... Accounting Operations Administrator
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R. David Rudden, Jr. .... Assistant Controller
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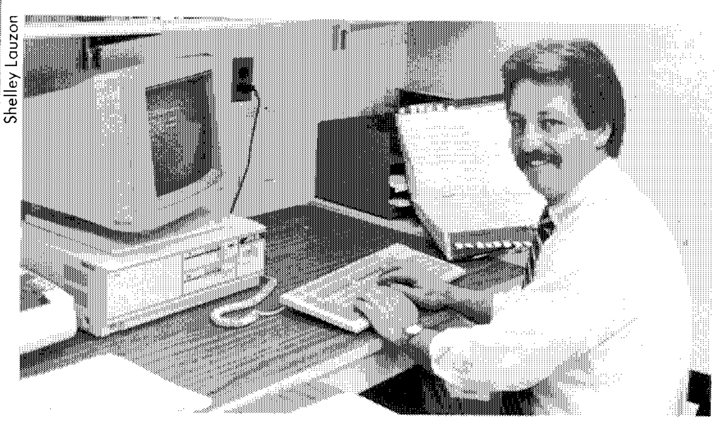
Mary Nan Weiss .... Executive Assistant/Associates Program
Alan W. White .... Marine Science Advisor
Barbara Wickenden .... Personnel Manager


Shelley Lauzon


Shelley Lauzon

Top: Carol Winn. Bottom: Phil McClung.

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Frederick A. Brauneis
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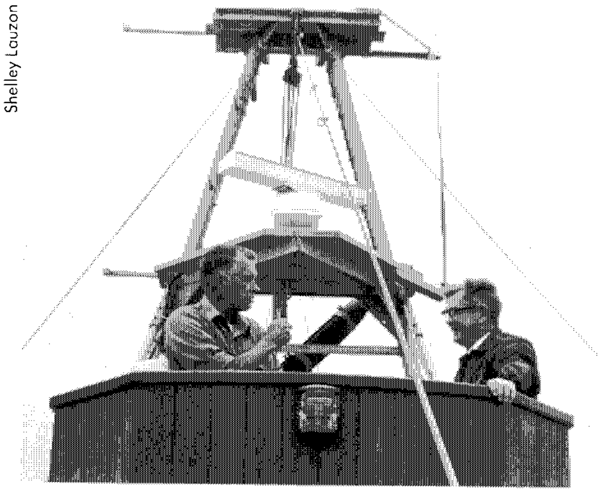

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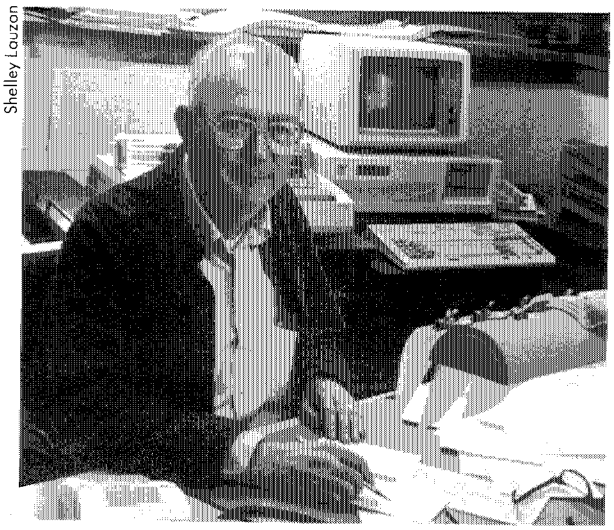

Above: John Lobo. Top right: Dick Colburn (left) and John Steele aboard *Asterias*. Bottom right: Bill Dunkle.

Facilities, Services and Marine Operations Staff

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
Ernest G. Charette	Assistant Facilities Manager
Arthur D. Colburn, Jr.	Boat Operator, ASTERIAS
Don C. Collasius	Pilot, DSV ALVIN
Vicky C. Cullen	Manager, Graphic Services
Richard H. Dimmock	Port Engineer
Robertson P. Dinsmore	Consultant for Marine Operations and Planning
William M. Dunkle, Jr.	Research Associate, Data Library
Richard S. Edwards	Marine Superintendent
Dudley B. Foster	Pilot, DSV ALVIN
Richard E. Galat	Facilities Engineer
Denzel E. Gleason	Pilot, DSV ALVIN
James E. Hardiman	Pilot, DSV ALVIN
Ralph M. Hollis	Chief Pilot, DSV ALVIN
Paul C. Howland	Master, R/V OCEANUS
Jonathan Leiby	Naval Architect
Barbara J. Martineau	Marine Operations Administrator
William E. McKeon	Facilities Manager
Donald A. Moller	Marine Operations Coordinator
Harry E. Oakes	Chief Engineer, R/V KNORR
Terrence M. Rioux	Diving Safety Officer
Eric W. Spencer	Safety Officer
Ernest C. Wegman	Chief Engineer, R/V OCEANUS
Carolyn P. Winn	Research Librarian

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Bernard J. Cassidy
James P. Corr
Stephen J. Corrigan
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Robert F. Kelley
Thomas N. Kleindinst
William N. Lange
E. Paul Oberlander
Andrew E. Olson
John Porteous

Food Services Personnel

Sheila T. Payne
Barbara R. Dufresne
Barbara J. Sylvester

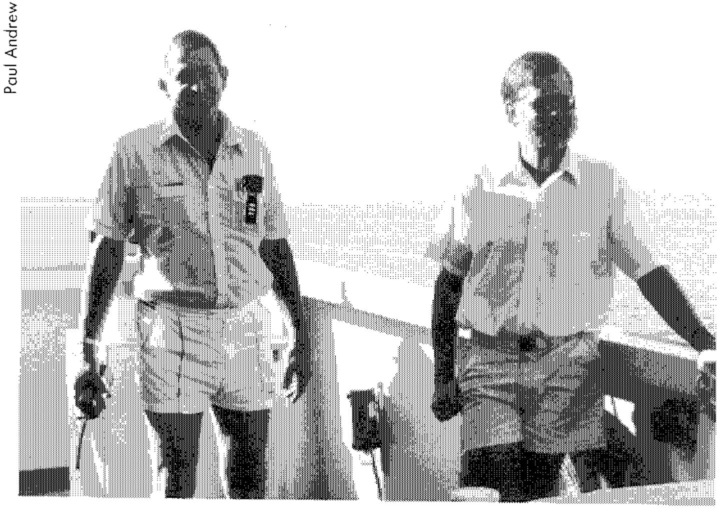
Marine Operations

Edward H. Chute
Alden H. Cook
Kittie E. Elliott
Stephen G. Page
Shawna R. Schurr

ALVIN Operations

Gary Rajcula
John F. Salzig
David M. Sanders
Margaret P. Stern
Paul D. Tibbetts

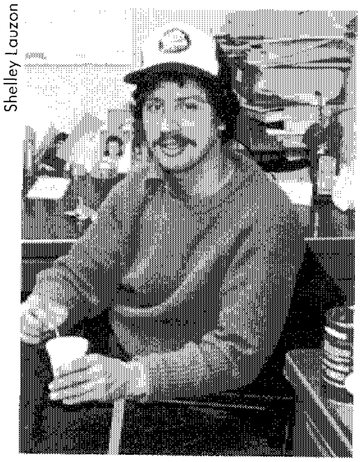
Paul Andrew



Anne Rabushko

Shelley Lauzon

Shelley Lauzon



Shelley Lauzon

Clockwise from top left: Reuben Baker (left) and Terry Barber, Jim Hardiman, Bob Wichterman, Lewis Saffron and George Heimerdinger.

Marine Personnel

Wayne A. Bailey
Courtenay Barber III
Mitchell G. Barros
Gunter H. Bauerlin
Kenneth E. Bazner
Harold A. Bean
Richard C. Bean
Stephen M. Bean
Lawrence T. Bearse
Richard J. Bowen
Edward R. Brodrick
David F. Casiles
Gary B. Chiljean
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Alberto Collasius, Jr.
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Donald H. Cook, Jr.
Lawrence P. Costello
Jerome M. Cotter
Robert W. Craig
Stephen M. Cross
Hugh B. Dakers
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Roger J. Dube
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Peter M. Flaherty
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Christopher M. Griner
David Guadalupe
Joseph A. Guzaj
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William A. Holm
Roger W. Hunt
Albert C. Jefferson
John P. Kamataris
J. Kevin Kay
John T. Lobo
Tomas M. A. Macedo
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Michael Palmieri, Jr.
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Richard F. Simpkin
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Harry H. Stanton
Adam B. Steinberg
John K. Sweet, Jr.
Herman Wagner
Stephen A. Walsh
Stephen T. Wessling

\+ Leave of Absence

EMPLOYEES RETIRING DURING 1986

Edward F. Acton
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Edward L. Bland, Jr.
Richard J. Breivogel
James E. Gifford
Joseph Kiebala, Jr.
Joseph F. Motta
Florence T. Pineault
Howard L. Sanders
Harold Van Siclen
Arthur D. Voorhis
Roger Walen
Valentine P. Wilson

Fellows, Students & Visitors

MIT/WHOI Joint Graduate Program 1986-1987

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Dartmouth College
Sara L. Bennett
Colorado State University
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Yale University
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University of California, Santa Cruz
Barbara V. Braatz
Smith College
Esther C. Brady
University of Massachusetts, Amherst
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United States Naval Academy
Jeffrey W. Campbell
United States Naval Academy
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United States Naval Academy
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Massachusetts Institute of Technology
Paola Cessi
University of Bologna, Italy
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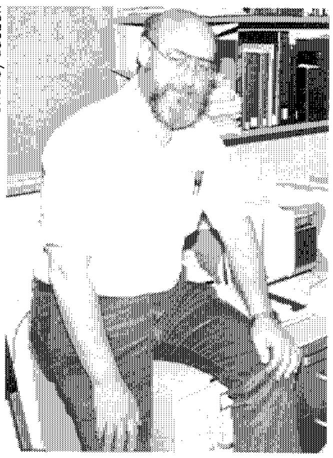
University of Rochester
Elisabeth A. Snowberger
Washington University
Kevin G. Speer
University of California, Santa Barbara

Anne Rabushka

Shelley Lauzon



Anne Rabushka

Shelley Lauzon

Top to bottom: Jim Broadus, John Farrington, Sus Honjo and Andy Maffei.

William S. Spitzer
Harvard University
W. Kenneth Stewart
Florida Atlantic University
Cape Fear Technical Institute
Lucia Susani
Brown University
Dajun Tang
University of Science and Technology, PRC
Institute of Acoustics, PRC
LuAnne Thompson
University of California, Davis
Harvard University
Douglas R. Toomey
Pennsylvania State University
D. Andrew Trivett
Dalhousie University, Canada
Technical University of Nova Scotia, Canada
Thomas W. Trull
University of Michigan
Eli Tziperman
Hebrew University, Israel
Lisa A. Urry
Tufts University
Cindy L. Van Dover
Rutgers University
University of California, Los Angeles
Alexander F. M. J. van Geen
University of Washington
Gregory M. Vaughn
United States Naval Academy
Marymount College of Virginia
Padmaraj Vengayil
Indian Institute of Technology, India
University of Florida
M. Ross Vennell
University of Auckland, New Zealand
Sophie Wacongne
University of Pierre and Marie Curie, France
David Walsh
Earlham College
Xiaoming Wang
Shandong College of Oceanography, PRC
University of Rhode Island
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College of William and Mary
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Cambridge University, United Kingdom
Imperial College, United Kingdom
John L. Wilkin
University of Auckland, New Zealand
Joanne M. Willey
University of Pennsylvania
University of Pennsylvania, School of Nursing
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Indiana University
Tamara M. Wood
Union College
Janice C. Zemba
University of California, Irvine

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University of Miami
Jean Christophe Sempere
University of California, Santa Barbara
Daniel Simpson
University of California, Davis

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National Center for Atmospheric Research
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Centre National d'Etudes Spatiales, France
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Scripps Institution of Oceanography
Suzanne T. McDaniel
Pennsylvania State University
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Scripps Institution of Oceanography
Jet Propulsion Laboratory
Geoffrey Eglinton
University of Bristol, United Kingdom

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University of Massachusetts, Amherst
Christopher C. Joyner*
George Washington University
Kilaparti Ramakrishna
Harvard Law School

*Senior Fellow

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Fort Lewis College
Bettina Bartschat
Massachusetts Institute of Technology
Ken Bauer
University of Wyoming
Ronald Bertasi
Colgate University
Shen Chen
Kagoshima University, Japan
Scott France
Concordia University
Anand Gnanadesikan
Princeton University
Peter Hernes
Luther College
Michael Holzrichter
Colorado School of Mines
Franz Hover
Ohio Northern University
James Howell
Michigan Technical University
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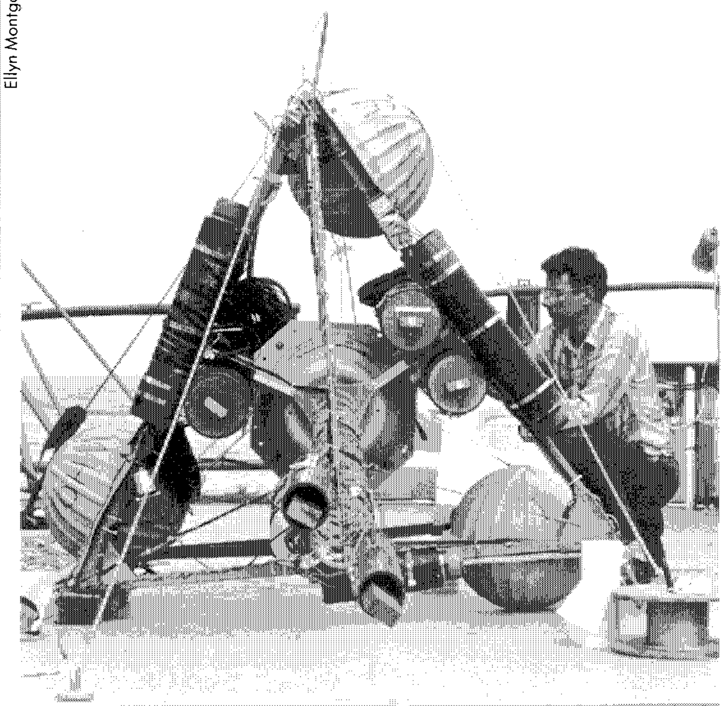
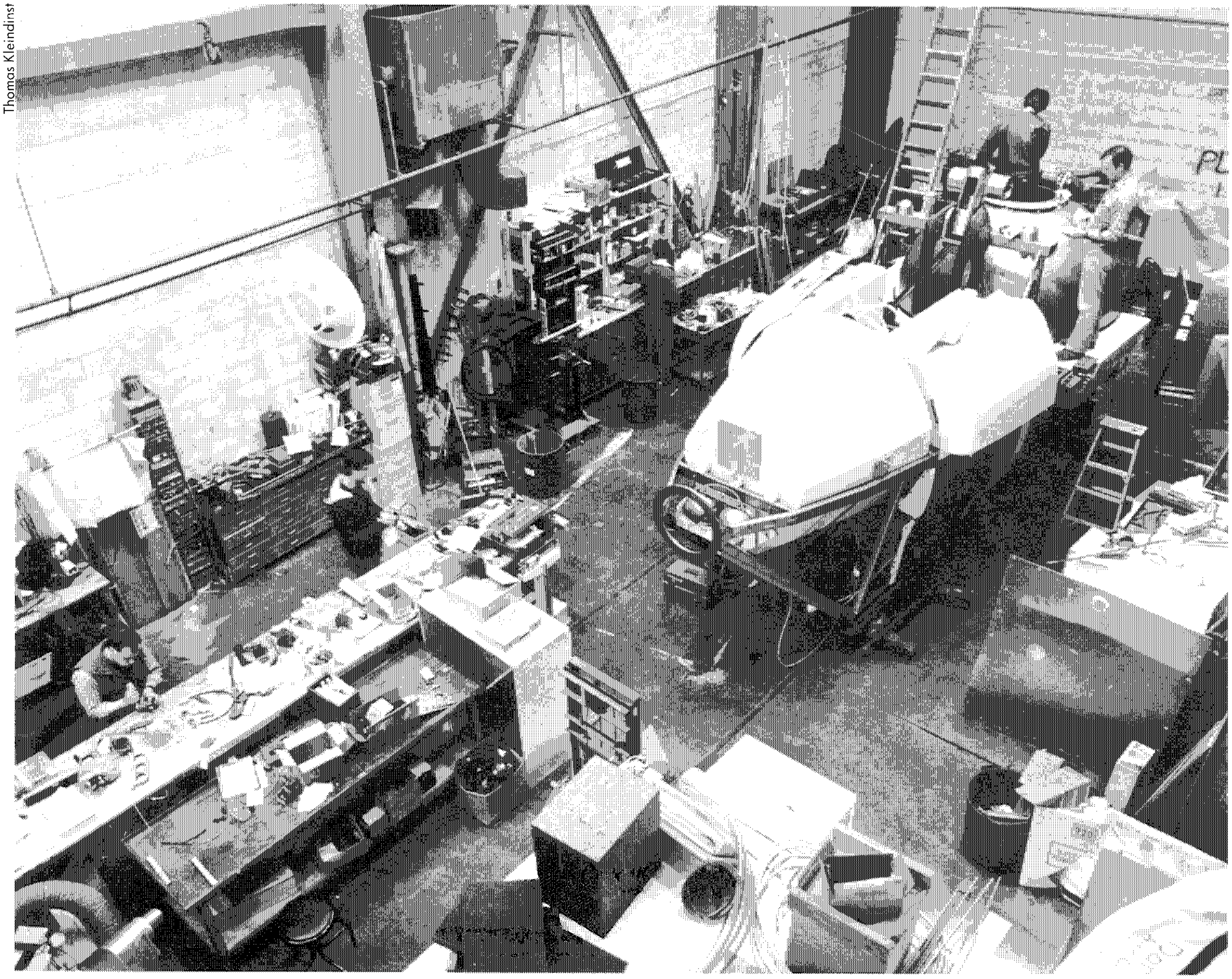


Anne Robushka

Top: Sandy Williams works on a RiNo (Richardson Number) float aboard *Knorr* before a July test at the HEBBLE (High Energy Benthic Boundary Layer Experiment) site off Nova Scotia. The instrument measures internal waves. Bottom: Associate Scientist Dave Aubrey was interviewed by Channel 10 (Providence, RI) meteorologist Jeff Latham for a June series on our changing climate and sea level rise.

Thomas Kleindinst



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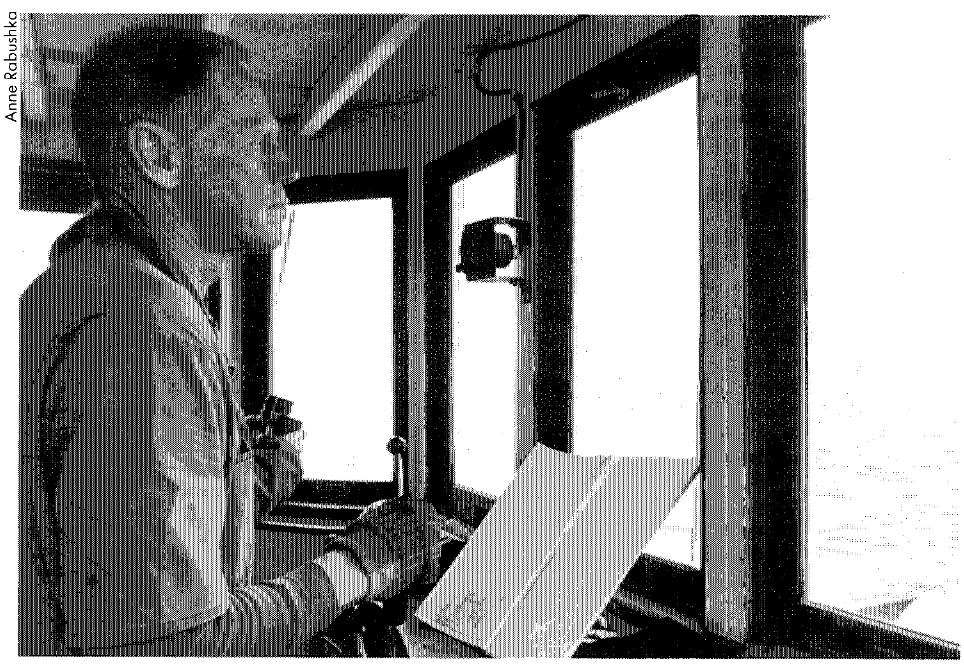

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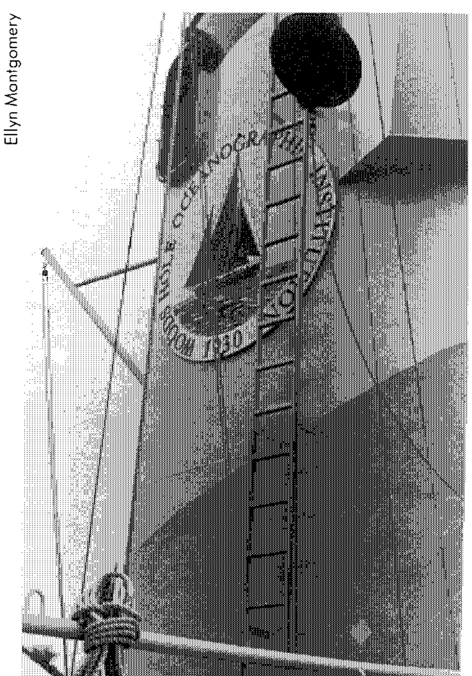


Top: The Iselin high bay was transformed into a workshop during the *Alvin* overhaul in early 1986. Bottom left: Dick Edwards aboard *John A. Edwards*. Bottom right: The Institution logo on the *Knorr* stack.

Voyage Statistics

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

Total Nautical Miles for 1986 – 19,020 miles
Total Days at Sea – 192 days
Total Dives – 116 dives

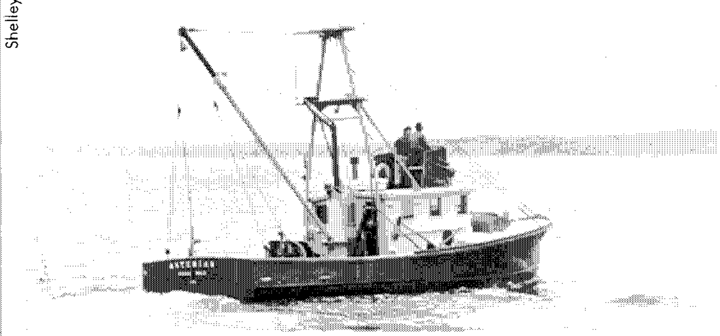
Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
Trial	10 Apr-10 Apr	Sea trials in Vineyard Sound for Coast Guard certification	Woods Hole	
114-I	1 May-14 May	Seven *Alvin* dives in the vicinity of Bermuda for pilot training and to test and certify *Alvin* following major modifications and overhaul	St. George's, Bermuda	Walden/Akens
114-II	16 May-18 Jun	Geological and geochemical studies of sea floor spreading processes and hydrothermal vents on the Mid-Atlantic Ridge at 23° and 26°N; twenty-three *Alvin* dives, SEA BEAM surveys, camera tows and rock dredges	St. George's, Bermuda	Karson (Duke) Rona (NOAA)
114-III	21 Jun-2 Jul	Seven *Alvin* dives at Deep Ocean Station-2 in the Western North Atlantic for retrieval of corrosion and sediment infauna experiments; test lowerings of benthic lander	Woods Hole	Sayles
115	9 Jul-28 Jul	Twelve *Alvin* dives to test new deep ocean imaging systems, including the tethered robotic vehicle Jason, Jr., at the RMS *Titanic* site in the Western North Atlantic	Woods Hole	Ballard
116	2 Aug-15 Aug	Geological investigations of the effects of the 1929 Grand Banks Earthquake on the Eastern Valley of the Laurentian Submarine Fan; eight *Alvin* dives, SEA BEAM surveys and seismic profiling	Woods Hole	Shor (LDGO)
117	19 Aug-15 Sep	Evaluation of deep submersible observation, sampling, imaging, and data collection techniques for application to deep ocean tracer studies; twelve *Alvin* dives in the Eastern North Atlantic	Woods Hole	Livingston
118-I	20 Sep-7 Oct	Fifteen *Alvin* dives, SEA BEAM surveys, and box core stations for identification and investigation of dynamic geological processes in the Delaware Canyon system	Charleston, South Carolina	Stubblefield (NOAA)
118-II	11 Oct-22 Oct	Investigation of the benthic biological and microbiological communities associated with the West Florida Escarpment cold seeps; seven *Alvin* dives	Tampa, Florida	Carney (LSU)
118-III	26 Oct-8 Nov	Twelve *Alvin* dives for continuation of geological and chemical studies of cold seeps on the West Florida Escarpment	Tampa, Florida	Paull (SIO)
118-IV	12 Nov-17 Nov 19 Nov	Studies of distribution and physiological characteristics of phytoplankton using XBT stations and hydrographic casts	Cristobal, Panama Balboa, Panama	Olson
118-V	21 Nov-25 Nov	Three *Alvin* dives for chemical and biological studies of processes at the sediment-water interface in the Panama Basin	Puntarenas, Costa Rica	Aller (SUNY, Stony Brook)
118-VI	25 Nov-4 Dec	Transit from Puntarenas, Costa Rica	San Diego, California	
118-VII	11 Dec-18 Dec	Studies of the mechanisms and rates of sediment deposition, sediment mixing and deposit feeding by organisms in the Santa Catalina Basin; seven *Alvin* dives, box cores, camera casts, and deployment of free vehicle samplers	San Diego, California	C. Smith (UW)

R/V *Knorr*

Total Nautical Miles for 1986 – 16,330 miles
Total Days at Sea – 152 days

Voyage	*Cruise Period*	*Principal Objective, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
119-I	7 Jan-21 Jan	Location of an oceanic front and deployment of moorings for investigations of local air-sea interaction processes near Bermuda for the Frontal Air-Sea Interaction Experiment (FASINEX)	St. George's, Bermuda	Weller Erikson (MIT)
119-II	23 Jan-7 Feb	Continuation of physical oceanography studies for the FASINEX program	St. George's, Bermuda	Weller Erikson (MIT)
119-III	10 Feb-13 Feb	Transit from St. George's, Bermuda	Woods Hole	Worrilow
120	9 Apr-15 Apr	Continuation of investigations and time series measurements of fluvial stress from the Western Boundary Undercurrent on the Nova Scotian Continental Rise as part of the High Energy Benthic Boundary Layer Experiment (HEBBLE)	Woods Hole	Hollister
121	22 Apr-20 May	Sampling and measurement of natural and transient tracers to determine horizontal and vertical exchanges between the slope waters and the interior of the Western Sargasso Sea as part of the Western Boundary Exchange of Tracers program	Woods Hole	Jenkins
122	28 May-1 Jun	Tests of a new sensor package for the Multiple Opening/Closing Net Environmental Sensing System (MOCNESS) and a refurbished CTD system; physical and biological studies of streamers spiraling into a warm core ring	Woods Hole	Wiebe
123	5 Jun-25 Jun	Continuation of physical oceanography studies and recovery of moorings for the FASINEX program	Woods Hole	Weller
124	10 Jul-17 Jul	Continuation of geology studies for the HEBBLE program; test lowering of the SEADUCT benthic inverted flume; deployment and recovery of OMNI tripod, Free Vehicle Stereo Camera (FVSC) and Benthic Autonomous Settling Tube (BEAST) tripod	Woods Hole	Hollister
125-I	26 Jul-2 Aug	Transit from Woods Hole	Tampa, Florida	
125-II	8 Aug-25 Aug	Studies of the geological processes that formed and modified the West Florida Escarpment and the frequency and distribution of chemosynthetic communities	Tampa, Florida	Spiess (SIO)
125-III	27 Aug-2 Sep	Transit from Tampa, Florida	Woods Hole	
126	8 Sep-18 Sep	Continuation of geology studies for the HEBBLE program; SEADUCT deployment, recovery of instrument tripods	Woods Hole	Hollister
127	26 Sep-28 Sep	Continuation of engineering and operational tests of the SEADUCT instrument	Woods Hole	Hollister

Shelley Lauzon



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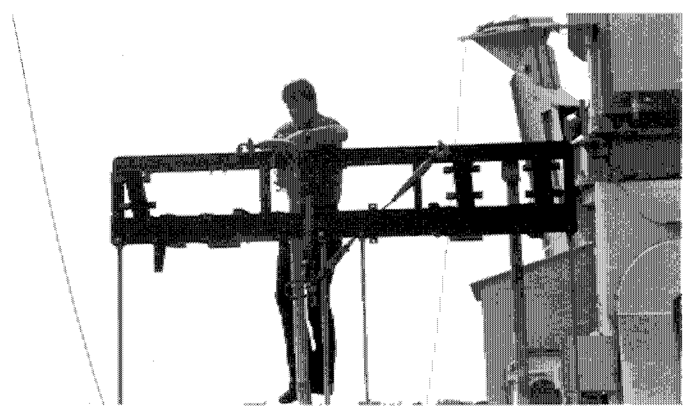

Left: *Asterias*. Right: Peter Wiebe works on the MOCNESS aboard *Knorr* prior to a summer cruise.

R/V Oceanus

Total Nautical Miles for 1986 – 23,874 miles
Total Days at Sea – 199 days

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call (Destination)	Chief Scientist
174-I	4 Jan-19 Jan	Studies of spatial variability of pore water gradients and composition	St. George's, Bermuda	Sayles
174-II	23 Jan-30 Jan	Investigations of time and space variability of oceanic carbon dioxide	Woods Hole	Brewer
175-I	5 Feb 8 Feb-11 Feb	Transit from Woods Hole for the Frontal Air-Sea Interaction Experiment (FASINEX); testing of shipboard sensors and equipment	St. George's, Bermuda	Pollard (IOS) Regier (SIO)
175-II	12 Feb-12 Mar	Investigations of local air-sea interaction processes at an oceanic front for the FASINEX program	Woods Hole	Weller
176-I	18 Mar-21 Mar	Engineering tests of a High Performance Oceanographic Mooring (HIPOM) in the Gulf Stream	St. George's, Bermuda	Clay
176-II	22 Mar-2 Apr	Physical studies, including XBT and acoustic doppler measurements, along a transect of the North Atlantic	Tangier, Morocco	Stommel
176-III	5 Apr-15 Apr	Investigations of the internal hydraulic processes governing water exchange between the Atlantic and Mediterranean as they are affected by the narrows and sills of the Gibraltar Straits	Cadiz, Spain	Armi (SIO)
176-IV	15 Apr-18 Apr	Continuation of studies of internal hydraulic processes and water exchange at the Gibraltar Straits	Cadiz, Spain	Boyle (MIT)
176-V	18 Apr-27 Apr	Continuation of studies of internal hydraulic processes and water exchange at the Gibraltar Straits	Cadiz, Spain	Armi (SIO)
176-VI	2 May-16 May	Continuation of studies of internal hydraulic processes and water exchange at the Gibraltar Straits	Cadiz, Spain	Gregg (UW)
176-VII	21 May-6 Jun	Diving, plankton net tows and midwater trawls for observation and collection of gelatinous zooplankton and microzooplankton in the Eastern North Atlantic	Funchal, Madeira	Harbison
176-VIII	9 Jun-18 Jun	Continuation of studies of gelatinous zooplankton and microzooplankton in the Eastern North Atlantic	Cadiz, Spain	Harbison
176-IX	21 Jun-30 Jun	Transit from Cadiz, Spain	St. George's, Bermuda	
176-X	30 Jun-5 Jul	Deployment of a High Performance Oceanographic Mooring (HIPOM) in the Gulf Stream	Woods Hole	Clay
177-I	28 Jul-11 Aug	Diving, plankton net tows and midwater trawls for observation and collection of gelatinous zooplankton, microzooplankton and marine snow in the Gulf Stream	Norfolk, Virginia	Harbison
177-II	12 Aug-25 Aug	Continuation of biological studies of gelatinous zooplankton, microzooplankton and marine snow in the Gulf Stream	Woods Hole	Harbison
178	9 Sep-13 Sep	Bottom sampling in the vicinity of drilling sites as part of the continuing Georges Bank Monitoring Program	Woods Hole	Bothner (USGS)
179	14 Sep-22 Sep	Investigations of the nature, composition and distribution of particulate matter in the near-bottom environment and within the water column in the Gulf of Maine	Woods Hole	Youngbluth (HBOI)
180	30 Dec-30 Jan 1987	Microearthquake studies of the Central Transform Region of the Kane Fracture Zone	Woods Hole	Purdy

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Top: Chairman of the Board Guy Nichols. Middle: Associate Scientist Kozo Takahashi explains his research projects during the Annual Meeting Open Houses June 13. Bottom: Associates President, Honorary Trustee and Corporation Member James "Spike" Coles with guest William Hazen at the Associates Dinner April 15 at the New York Yacht Club.

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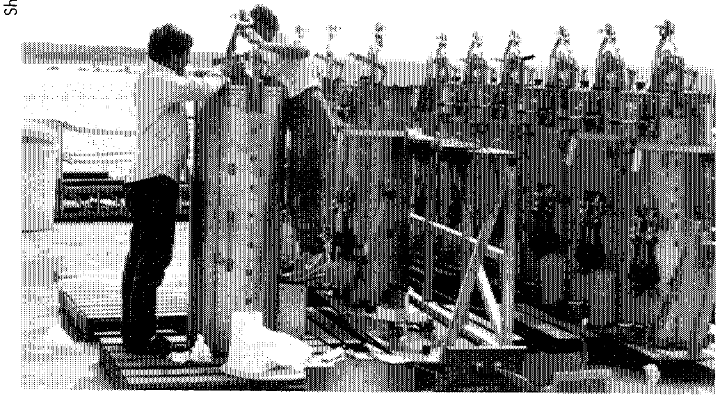

Preparing water samplers for a chemistry cruise.

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Woods Hole, MA

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In Memoriam

The Institution gratefully acknowledges the service and support of Gifford C. Ewing, Frank B. Jewett, Jr., Augustus P. Loring, and Robert S. Morison who died in 1986.

Jayne Campbell

Anne Rabushka

Anne Rabushka

Top to bottom: Chris von Alt with daughter Exa aboard *Atlantis II*, Bob Hindley instructs employees in a CPR class, Diving Safety Officer Terry Rioux.

1986 Sources of Support for Research and Education

AFG Industries
ALCOA Foundation
Alden Electronic & Impulse Recording Equipment Company, Inc.
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Christopher Frantz
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Earl Ewing Hays
Philomena Jenney
Noel B. McLean
Lawrason Riggs III
Frank W. Tchitcherine
David Tenney
Mr. and Mrs. William Waddell
Audrey Williams

Financial Statements

Highlights:

The Institution's total operating revenue decreased 2.5% in 1986 to $49,787,948 compared with a 4% increase and total revenues of $51,052,546 in 1985. Excess current unrestricted funds of $800,000 were transferred to Unexpended Plant Funds and $500,000 to replenish the Director's Innovative Fund.

Funding for sponsored research programs decreased 3% in 1986 as compared to 1985 as summarized below. Government sponsored research was $38,664,000 in 1986 compared to $38,551,000 in 1985. This static funding level continued to reflect uncertainties associated with the Federal budget deficit. Non-Government research decreased 24.5% to $4,377,000 in 1986 from $5,800,000 in 1985. The previous year figure included funds from the Howard Hughes Medical Institute to renovate the Environmental Systems Laboratory. The remainder of the decrease was due primarily to reduced use of our vessels by other organizations.

	1986	*1985*	*Increase (Decrease)*
National Science Foundation	$20,332,000	$22,618,000	(10.1%)
Office of Naval Research	15,465,000	12,741,000	21.4%
Department of Energy	529,000	672,000	(21.3%)
National Oceanic & Atmospheric Administration	1,581,000	1,416,000	11.7%
Other Government	757,000	1,104,000	(31.4%)
Restricted Endowment Income	360,000	502,000	(28.3%)
Other Gifts, Grants, and Contracts	4,017,000	5,298,000	(24.2%)
	$43,041,000	$44,351,000	(3.0%)

Gifts and grants from private sources, including over 1,500 WHOI Associates, totaled $3,675,000 in 1986, an increase of $1,899,000 compared to 1985:

Gifts to Endowment	$2,177,000
Young Scientists Program	58,000
Marine Policy & Ocean Management	600,000
Study of Buzzards Bay	85,000
Education Program	22,000
Coastal Research Programs	83,000
Sperm Whale Communication	100,000
Oceanographic Ventures Fund	60,000
Biological Sciences Program	75,000
Other Research Programs	15,000
Unrestricted Gifts	400,000
	$3,675,000

Capital expenditures, including year-end work in process, were $1,443,000, a 10.5% increase over 1985 expenditures of $1,306,000. Included in 1986 expenditures was $683,000 for continued renovations to 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 unrestricted income.

Other statistics of interest are:

	1986	*1985*	*Increase (Decrease)*
Number of Employees	781	795	(1.8%)
Total Compensation (including Overtime and Benefits)	$27,768,000	$27,257,000	1.9%
Endowment Income (net)	3,544,000	3,658,000	(3.1%)
Gifts to Endowment	2,177,000	172,000	1165.7%
Endowment Principal (year-end at market value)	82,174,000	68,659,000	19.7%
Sponsored Programs Backlog	26,568,000	25,190,000	5.5%

Funds availed of in support of the Education Program were derived principally from endowment income received in 1986 totaling $2,102,000. In addition to other funds restricted for education, unrestricted funds of $513,000 were availed of for the Education Program. Funds of $1,221,000 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.

Gary B. Walker
Assistant Director for Finance & Administration
Kenneth S. Safe, Jr.
Treasurer
George A. Smith
Controller

Balance Sheets
December 31, 1986 and 1985

ASSETS	1986	1985
Current Fund Assets (Note A):		
Cash	$ (685,794)	$ (555,213)
Short-term investments, at cost which approximates market	17,428,255	18,751,964
Accrued interest and dividends	900,948	801,934
Reimbursable costs and fees:		
Billed	384,911	544,569
Unbilled	683,941	582,666
Other receivables	390,689	327,245
Inventories	313,720	369,264
Deferred charges and prepaid expenses	427,172	210,776
Deferred fixed rate variances	(629,817)	(1,485,523)
Due to other funds	(7,665,874)	(7,101,406)
	11,548,151	**12,446,276**
Endowment and Similar Fund Assets (Note A):		
Investments, at market (cost $60,976,802 in 1986 and $50,919,826 in 1985)		
Bonds	24,843,837	22,644,406
Stocks	45,857,353	41,080,060
Other	1,722,750	897,732
Total investments (Note B)	72,423,940	64,622,198
Cash and cash equivalents	9,701,653	4,008,126
Pooled income fund investments, at market	153,744	133,057
Due to current fund	(105,785)	(104,408)
Total endowment	82,173,552	68,658,973
Annuity Fund Investments, at market	136,245	127,193
	82,309,797	**68,786,166**
Plant Fund Assets (Note A)		
Land, buildings, and improvements	24,546,048	23,522,041
Vessels and dock facilities	7,442,492	7,425,434
Laboratory and other equipment	3,710,294	3,308,223
Work in progress	65,963	119,357
	35,764,797	34,375,055
Less accumulated depreciation	14,481,605	13,064,204
	21,283,192	21,310,851
Due from current fund	7,771,659	7,205,814
	29,054,851	**28,516,665**
	$122,912,799	**$109,749,107**

LIABILITIES AND FUND BALANCES	1986	1985
Current Fund Liabilities and Balances:		
Accounts payable, other accrued expenses and deferred revenues	$ 1,744,956	$ 1,372,156
Accrued payroll related liabilities	2,293,328	2,022,777
Unexpended balances restricted for:		
Sponsored research	4,273,293	3,548,519
Education program	847,880	589,632
Total restricted balances	5,121,173	4,138,151
Unrestricted balances designated for:		
Director's innovative fund	648,961	500,000
Income and salary stabilization	—	3,513,304
Ocean industry program	151,308	218,994
Unrestricted current fund	1,588,425	680,894
Total unrestricted balances	2,388,694	4,913,192
	11,548,151	**12,446,276**
Endowment and Similar Fund Liabilities and Balances:		
Endowment:		
Income restricted	48,355,583	41,872,777
Income unrestricted	944,202	823,704
Quasi-endowment:		
Income restricted	11,470,444	9,944,212
Income unrestricted	21,403,323	16,018,280
Total endowment	82,173,552	68,658,973
Annuity	136,245	127,193
	82,309,797	**68,786,166**
Plant Fund Balances:		
Invested in plant	21,283,192	21,310,851
Unexpended, unrestricted	7,771,659	7,205,814
	29,054,851	**28,516,665**
	$122,912,799	**$109,749,107**

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

Statement of Current Fund Revenues, Expenses and Transfers for the years ended December 31, 1986 and 1985

	1986	1985
Revenues		
Sponsored research:		
Government	$38,664,406	$38,551,142
Nongovernment	4,376,959	5,799,530
	43,041,365	44,350,672
Education funds availed of	2,203,120	2,052,140
Total restricted	45,244,485	46,402,812
Unrestricted:		
Fees	460,488	658,685
Endowment and similar fund income	965,602	898,559
Gifts	400,186	525,320
Tuition	1,025,881	849,566
Investment income	1,049,389	1,191,524
Oceanus subscriptions	339,305	238,308
Other	302,612	287,772
Total unrestricted	4,543,463	4,649,734
Total revenues	**49,787,948**	**51,052,546**
Expenses		
Sponsored research:		
Salaries and fringe benefits	13,809,940	13,671,989
Ships and submersibles	7,323,171	7,830,485
Materials and equipment	6,116,117	6,454,005
Subcontracts	2,034,696	1,164,526
Laboratory overhead	3,871,336	3,948,449
Other	5,725,025	6,590,036
General and administrative	4,161,080	4,691,182
	43,041,365	44,350,672
Education:		
Faculty expense	996,812	575,731
Student expense	789,080	1,038,298
Postdoctoral programs	420,664	426,282
Other	270,076	239,631
General and administrative	239,428	250,483
	2,716,060	2,530,425
Unsponsored research	549,915	567,183
Oceanus magazine	341,793	323,250
Other activities	676,482	705,961
General and administrative	158,526	155,322
	1,726,716	1,751,716
Total expenses	**47,484,141**	**48,632,813**
Net increase before transfers	**2,303,807**	**2,419,733**
Transfers - to/(from):		
Director's Innovative Fund	500,000	500,000
Income and salary stabilization reserve	–	299,520
Designated reserves	(46,763)	(43,119)
Endowment fund	175,000	29,000
Plant fund, unexpended	800,000	1,500,000
Total transfers	**1,428,237**	**2,285,401**
Net increase – unrestricted current fund	**$ 875,570**	**$ 134,332**

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

Statement of Changes in Fund Balances for the year ended December 31, 1986

	Current Fund			Endowment and Similar Funds	Plant Fund		Total All Funds	
	Restricted	Unrestricted	Total		Invested In Plant	Unexpended	1986	1985
Increases:								
Gifts, grants and contracts:								
Government	$39,153,660		$39,153,660				$ 39,153,660	$ 40,683,899
Nongovernment	4,350,725	$ 400,186	4,750,911	$ 2,176,724			6,927,635	6,476,073
Endowment and similar funds investment income (Note D)	2,578,189	965,602	3,543,791				3,543,791	3,657,602
Net increase in realized and unrealized appreciation				7,380,219			7,380,219	12,015,371
Other	53,079	3,209,636	3,262,715	280			3,262,995	3,303,830
Total increases	46,135,653	4,575,424	50,711,077	9,557,223			60,268,300	66,136,775
Decreases:								
Expenditures	(45,244,485)	(2,239,656)	(47,484,141)				(47,484,141)	(48,632,813)
Depreciation (Note A)					$(1,470,764)	$1,208,950	(261,814)	(261,814)
Other	(2,004)		(2,004)				(2,004)	(5,419)
Total decreases	(45,246,489)	(2,239,656)	(47,486,145)		(1,470,764)	1,208,950	(47,747,959)	(48,900,046)
Net change before transfers	889,164	2,335,768	3,224,932	9,557,223	(1,470,764)	1,208,950	12,520,341	17,236,729
Transfers – to/(from):								
Current revenues to plant fund		(800,000)	(800,000)			800,000	–	–
Current revenues to endowment fund	(362)	(452,742)	(453,104)	453,104			–	–
Income and salary stabilization reserve to endowment fund		(3,513,304)	(3,513,304)	3,513,304			–	–
Current revenues to education	94,220	(94,220)					–	–
Plant asset additions					1,443,105	(1,443,105)	–	
Total transfers	93,858	(4,860,266)	(4,766,408)	3,966,408	1,443,105	(643,105)	–	–
Change in fund balance for the year	983,022	(2,524.498)	(1,541,476)	13,523,631	(27,659)	565,845	12,520,341	17,236,729
Fund balance, December 31, 1985	4,138,151	4,913,192	9,051,343	68,786,166	21,310,851	7,205,814	106,354,174	89,096,106
Fund balance, December 31, 1986	**$ 5,121,173**	**$2,388,694**	**$ 7,509,867**	**$82,309,797**	**$21,283,192**	**$7,771,659**	**$118,874,515**	**$106,332,835**

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 sheet of Woods Hole Oceanographic Institution as of December 31, 1986, and the related statement of changes in fund balances, and of current fund revenues, expenses and transfers for the year then ended. Our examination was 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. We previously examined and reported upon the financial statements of the Institution for the year ended December 31, 1985; totals for that year are shown for comparative purposes.

In our opinion, the financial statements referred to above present fairly the financial position of Woods Hole Oceanographic Institution as of December 31, 1986, the changes in its fund balances, and its current fund revenues, expenses and transfers for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

Coopers & Lybrand

Boston, Massachusetts
March 27, 1987

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.

Contracts and Grants
Revenues earned on contracts and grants are recognized as related costs are incurred. Beginning with fiscal 1978, the Institution has negotiated with the federal government fixed rates for the recovery of certain indirect costs. Such recoveries are subject to carryforward provisions that provide for 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 $1,208,950 in 1986 and $1,090,686 in 1985 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.

Reclassifications
Certain accounts in the 1985 financial statement presentation have been reclassified to conform with the 1986 presentation.

B. Endowment and Similar Fund Investments:

The cost and market value of investments held at December 31, 1986, and 1985, are as follows:

	December 31, 1986		December 31, 1985	
	Cost	Market	Cost	Market
Government and government agencies	$15,374,873	$16,123,155	$13,766,881	$15,143,553
Convertible bonds	1,170,903	1,332,750	945,900	1,021,125
Corporate bonds	7,048,912	7,387,932	6,096,258	6,479,728
Common stocks	35,659,364	45,857,353	29,213,055	41,080,060
Other	1,722,750	1,722,750	897,732	897,732
Total investments	**$60,976,802**	**$72,423,940**	**$50,919,826**	**$64,622,198**

C. Investment Units:

The value of an investment unit at December 31, 1986, and 1985, was $1.7144 and $1.5343, respectively. The investment income per unit for 1986 and 1985 was $.0761 and $.0819 respectively.

	1986	1985
Unit value beginning of year	$1.5343	$1.2652
Unit value end of year	1.7144	1.5343
Net change for the year	.1801	.2691
Investment income per unit for the year	.0761	.0819
Total return per unit	**$.2562**	**$.3510**

D. Endowment and Similar Fund Income:

Income of endowment and similar funds consisted of the following:

	1986	1985
Dividends	$1,059,090	$1,127,993
Interest	2,868,373	2,861,294
	3,927,463	3,989,287
Investment management costs	(383,672)	(331,685)
Net investment income	**$3,543,791**	**$3,657,602**

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 $2,249,026 in 1986 and $2,329,000 in 1985, including $262,026 and $221,000, respectively, relating to expenses of the retirement trust. Accumulated plan benefits and net assets available for plan benefits as of January 1, 1986 (the most recent valuation date), with comparative totals for January 1, 1985, are as follows:

	January 1 1986	1985
Actuarial present value of accumulated plan benefits:		
Vested	$26,975,044	$23,978,594
Nonvested	525,316	1,292,780
Total actuarial present value of accumulated plan benefits	**$27,500,360**	**$25,271,374**
Net assets available for plan benefits	**$46,216,924**	**$35,726,839**

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 (as defined) or elect early retirement with certain time in service limitations. The cost of retiree health care is recognized as an expense when paid. These costs totaled $143,144 in 1986 and $119,300 in 1985.

WOODS HOLE OCEANOGRAPHIC INSTITUTION
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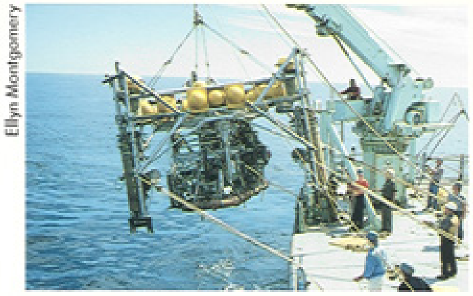
Shelley Lauzon

Shelley Lauzon

Clockwise from top left: R/V *Knorr* at the Institution pier; deployment of Seaduct during a summer R/V *Knorr* cruise; R/V *Atlantis II* in rough seas; bollards on R.M.S. *Titanic* photographed by DSV *Alvin* during a July cruise; Mound of tube worms at cold seep on West Florida Escarpment; coring device prepared for launch; Bigelow Laboratory as seen from the Iselin Mall.

James Broda

Ellyn Montgomery



Craig Dickson

ALVIN Photo

Holger Jannasch