The Woods Hole Oceanographic Institution was established in 1930 with the aid of grants from the Rockefeller Foundation and the Carnegie Corporation after the need for an oceanographic research laboratory on the Atlantic coast had been emphasized by a study under the sponsorship of the National Academy of Sciences.

From modest beginnings with a single building in Woods Hole and the sailing vessel *Atlantis* as ocean-going laboratory, the physical facilities of the Institution have grown to encompass four large laboratories and three large research vessels. The scientific and technical staff numbers about 200, there is a support staff of about 600, and the annual operating budget is about $22 million.

A wide variety of oceanographic studies are underway in engineering and the basic disciplines of physics, chemistry, biology, geophysics, and geology. A graduate education program established jointly with the Massachusetts Institute of Technology in 1968 includes about 80 students studying toward Ph.D.'s. Studies by Woods Hole scientists are supported largely by the National Science Foundation and the Office of Naval Research with additional support from other government agencies, from private endowment funds, and from foundation and individual grants.

Over the years, although the size and influence of the Institution have increased considerably, the work pursued by its staff has concentrated on the complex but single objective of learning more about the world's oceans. Basic research, and education leading to more basic research, are the principal and vital functions of this private, non-profit corporation.

COVER PHOTO by Laurence Armi shows the deck of R/V *Knorr* as moorings were set and recovered by the Buoy Group of the Physical Oceanography Department between Bermuda and the Mid-Atlantic Ridge for the Russian-American POLYMODE experiment.

Annual Report of the
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

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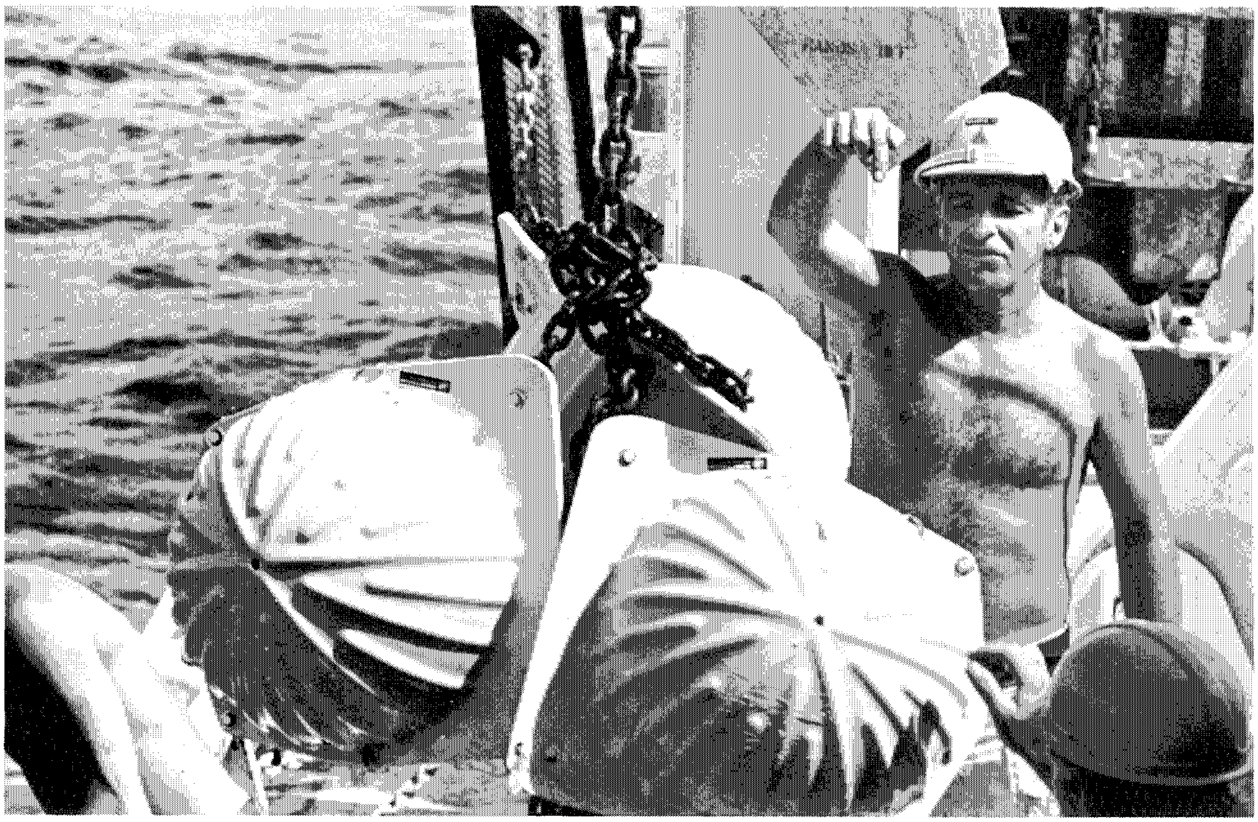


CHARLES ERIKSEN

Acting Bosun Ken Bazner signals crane operator aboard *Atlantis II.*

KEITH VON DER HEYDT

A-II spent most of 1976 exploring the Indian Ocean.

DIRECTOR'S REPORT

Freedom of Research and the Law of the Sea: Prospects and Problems

Almost a decade has passed since Maltese Ambassador to the United Nations Arvid Pardo startled the diplomatic world with his proposal that the UN declare the seabed "beyond the limits of national jurisdiction" to be "the common heritage of mankind," not subject to appropriation by any nation for its sole use.

Some observers called it the high point of UN history when, in 1970, the 25th General Assembly followed Pardo's lead and set forth a Declaration of Principles agreeing that deepsea resources are, indeed, "the common heritage of mankind." Some delegates from developing nations reasoned that if the seabed is part of their heritage, then somehow, by ways mysterious and unclear, science and technology would provide a harvest of resources rich enough to supply all their needs.

Unhappily, during the subsequent Law of the Sea negotiations national greed and pride have bargained away most of Pardo's "common heritage." The delegates have been more concerned with flag rights, mineral resources, and national prestige and security. The most notable effect of the negotiations so far, after five long and difficult sessions, has been the movement towards increased coastal state jurisdiction through the very considerable seaward extension of national boundaries. The strong developing world drive for national sovereignty in the 200-mile economic zone runs directly counter to the issue of freedom of scientific research.

In early planning for the Law of the Sea Conference, the question of scientific research at sea was deliberately avoided, at least by our own planners. The United States working papers presented to the Seabeds Committee in 1970 made no proposals for oceanographic research. But the hope that science would remain a nonproblem was unfounded. Today it is one of the key issues remaining before the Conference, and the outlook for a satisfactory solution is very dim, indeed.

When I first went to sea as Chief Scientist on the Research Vessel *Atlantis* 30 years ago, no clearance was needed. My distinguished predecessor, Columbus Iselin, would simply write a letter saying that we were doing science. Ports were open to us, and on some occasions the local governor even held a reception for all hands. Our friends in the State Department would take a dim view, indeed, if I tried this same approach today.

Arvid Pardo said it very well: *Scientific research is in modern times not undertaken merely to satisfy the curiosity of a few scientists about the world in which we live. It is an essential prerequisite to technological advance; drafting of national regulations to control ocean pollution is impossible without continuing research; only through research are we able to locate seabed areas likely to contain mineral deposits; management of living resources of the seas is inconceivable without intense and continuing scientific research. Scientific research, in short, is the condition* sine qua non *for the development of the oceans for the benefit of mankind. It must consequently enjoy maximum freedom.*

The question now is whether oceanic research can continue to be unrestricted or will it be subject to the consent of each coastal state for work not only in the territorial waters but also in the 200 mile economic zone. The United States' position is that consent should not be required for open scientific research that will be published and available to everyone provided the coastal state has advance notice of the work, is invited to participate in the research, shares in the samples and data, and is assisted with data analysis. We feel this is a generous position, but not many agree with us.

The Group of 77, which now numbers about 110 developing nations but keeps the magic double sevens title, has taken the position that consent for research in the economic zone must be obtained from the coastal state. Some of these countries suspect that oceanography is nothing more than the handmaiden of military domination and industrial exploitation. They are concerned that knowledge results in exploitation, that they do not have the capability to take advantage of the scientific research, and that science and technology are widening the economic gap rather than contributing to the solution of their economic problems. Many of these countries are still in the shadow of the colonial age and too much of their history supports their concerns. The Russians reversed their original position at the last session of the Conference and joined the Group of 77, perhaps in response to our unilateral adoption of a 200-mile fishing zone.

Refusal of permission for research not only interferes with scientific work but also can deprive the coastal state of the benefits of the investigations. A case in point was our plan to study an upwelling area where vertical currents bring nutrients from the ocean bottom to surface waters. Since upwelling results from offshore winds blowing surface water away from the beach, it would have been necessary to come within waters claimed by the coastal state.

Upwelling is nature's way of refertilizing surface water as nutrient-rich bottom waters are brought to the surface where photosynthesis can take place. Resulting rich green-plant growth creates a base for good fishing grounds through the food chain. Results of our research would have been freely available to the coastal state, which urgently needed a native fishery to reduce malnutrition there. The work not done for lack of clearance was a greater loss to that country than to the oceanographers.

Unhappily, this is not an isolated case. Oceanographers already feel the impact of other nations' changing attitudes. Records of the University National Oceanographic Laboratory System, coordinator of the US academic fleet, indicate that about half the cruises scheduled in the past year for work in waters claimed by other nations have been denied clearance or have been cancelled because of clearance difficulties. Some 18 nations were involved in such inhibition of oceanographic research. Woods Hole ships have been blocked from working in the vicinity of at least 10 nations during that time.

Oceanographers attach great importance to work in the proposed economic zone. Our three large ships have spent an average of 38 percent of operating time over a five year period in areas which will be included in other nations' economic zones. I believe more than 75 percent of the most interesting and most important problems occur in this economic zone; essentially all the problems relating to pollution control, management of fisheries, and marine resources for the rest of this century will be in this zone.

The real challenge before us and before the Law of the Sea Conference is preservation of freedom for scientific research. Though the outlook is dim, I do not agree with those of my colleagues who feel that we would be better off with no treaty and that we should work to defeat ratification. I feel, instead, that we must take some dramatic step to demonstrate our determination.

Since deepsea mining has become a major obstacle to the negotiations, one suggestion is that the US Congress should pass legislation favorable to deepsea mining and that we should proceed with US mining activities. If this were done, my own preference would be for the formation of an open-ended consortium of like-minded nations. It remains unclear, however, just how this would alleviate the science issue unless it were accompanied by a strong declaration of new purpose on all facets of the treaty.

A second suggestion more directly aligned with the problem of scientific freedom is that of Dr. John Craven, Dean of Marine Programs at the University of Hawaii. He has proposed three major research cruises off the shores of a number of coastal states outside the territorial sea but inside the 200-mile economic zone. Research to be conducted would be of benefit to the coastal state, which would be notified exactly in accordance with the "obligations regime" advanced by the US at the Law of the Sea Conference. Dr. Craven explains: *It should be made very clear that we are not requesting consent, but it should be equally clear that we intend to visit the ports of the representative coastal states for supplies and necessaries, and that an opportunity would thereby be afforded to officials of the coastal state to board the ship where results of the cruises could be presented to them. The proposal will, of course, raise a dilemma on the part of each coastal state whether to create an international incident in the face of a friendly and constructive scientific contribution by the United States, or to ignore the cruise, or to grant consent even though such consent was not requested.* What would such a series of cruises accomplish? It would show that the United States fully intends to stand firm on the issue of scientific research and that our proposed coastal state involvement in the research adequately protects their rights in the economic zone.

A third suggestion has arisen from discussions within our staff at Woods Hole. This is for a special but modest Congressional appropriation, perhaps $20 million, to support joint US and developing nation research projects. Such projects should be truly joint ventures with full participation from both sides and should be reviewed in the proposal stage by an appropriate international body such as the Intergovernmental Oceanographic Commission or the Division of Marine Science of UNESCO.

Perhaps one of these steps along with an agreement on freedom of basic research with the Russians may persuade other nations to change their positions and bring us closer to a continuing guarantee for freedom of research. Without some dramatic action by the United States, be it a strong proclamation, active mining of the deep sea, special cruises into forbidden water, threats of nonratification, genuine offer of help in funding joint research, or mutual accord with the Russians, I see no chance that the cause of scientific freedom can avoid a significant setback as a result of these negotiations — a sacrifice on the altar of political expediency.

PAUL M. FYE

DEPARTMENTS

BIOLOGY

Scientists in the Biology Department study ecology, physiology, and zoogeography of marine organisms. Microbiology, benthic biology, planktonology, sensory physiology, and biochemistry are among the major areas of research. The effects of pollutants on marine ecosystems are under investigation as are the physiological adaptations of deep sea organisms to pressure and scarcity of food. Other work concentrates on a salt marsh ecosystem and there are research projects on aquaculture and waste water recycling and on the productivity of a salmon river in Canada.

CHEMISTRY

Marine chemists study the composition of seawater, how and why it varies from place to place, and how it is affected by natural and human phenomena. The distribution and composition of suspended matter in the water column and the water contained in the sediments are also subjects of chemical investigation. The genesis and composition of the oceanic crust and its interaction with seawater is important to a general understanding of the sea as a system. Work on the fluxes of organic carbon includes determination of the amount of organic carbon produced by photosynthesis in the surface water and studies of processes responsible for the formation of marine organic compounds and their long-term fate. Detection of low-level petroleum and radionuclide contamination in marine organisms and sediments, routes and rates of the various contaminants moving about in seawater, and assessments of their distribution and fate in sediments are included among the concerns of Institution chemists.

GEOLOGY & GEOPHYSICS

The shape of the seafloor and its underlying structures as well as the physical properties of sediment and seafloor are studied by marine geologists and geophysicists. The structure, evolution, and dynamics of the oceanic crust and lithosphere are investigated through studies of variations, often minute, in gravity, magnetism, and temperature along with seismic studies of crustal components and layering of overlying sediment. Detailed studies are being made of continental margins and marginal basins as well as the margins of the huge crustal plates on which the continents ride. Measurements of particulate flux and the dissolution of carbonates and silicates and determination of sediment dynamics contribute to an understanding of deposition on the seafloor. Analysis of the fossil record in rocks and sediment reveals historical changes in climate and oceanic circulation patterns, volcanic activity, and other geologic events.

OCEAN ENGINEERING

Scientists in the Ocean Engineering Department study sound propagation in seawater and how it is affected by temporal and spatial variations in temperature, density, and other factors. Sound waves are employed to detect and measure organisms, physical properties, and pollutants. Development of instruments for use in the hostile marine environment and their refinement for reliability, accuracy, and endurance are among the important tasks of the Ocean Engineering Department. Computers are vital to modern oceanography both at sea and in land-based analysis of data, and much of this development is the responsibility of computer groups within the Ocean Engineering Department. The Alvin group, responsible for development of the submersible as a unique scientific window on the depths of the ocean, is also based here.

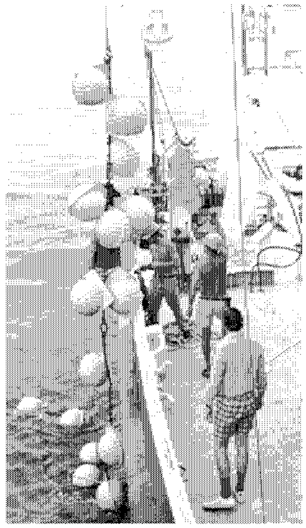
PHYSICAL OCEANOGRAPHY

Ocean current systems and their driving forces are the major interest of physical oceanographers. Such properties as variations in temperature, salinity, pressure, and large and small-scale motions of the waters are measured and plotted on long cruise tracks and with moored instruments. Exchanges of energy between air and sea present important questions as one affects the other and their interaction becomes part of the world climate. Effects of bottom and coastal topography on ocean circulation systems are under investigation. Advancement of technology for extended-period measurements is mandatory so that trends can be recognized. Large and small current systems are modelled toward the ultimate goal of understanding the structure and movement of the world's oceans and the interaction of the sea with its boundaries.

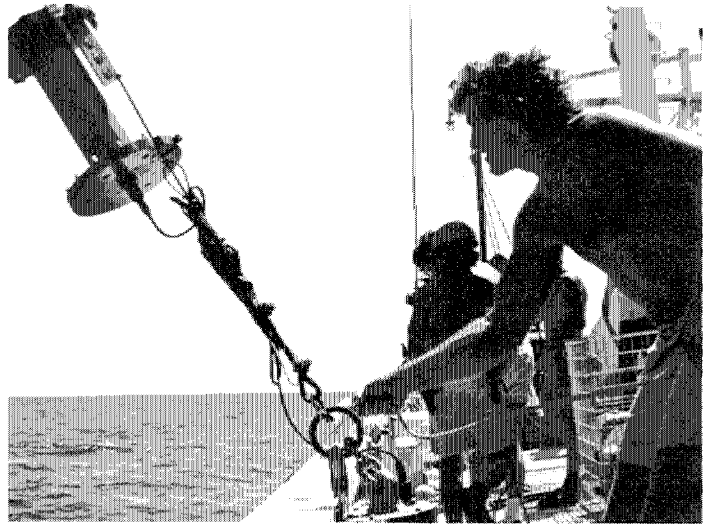
MARINE POLICY AND OCEAN MANAGEMENT

The Marine Policy and Ocean Management program supports interdisciplinary research by marine and social scientists on problems generated by man's increasing use of the sea. The program offers fellowships and research opportunities to individuals from such fields as anthropology, economics, international affairs, law, management, and political science. Program participants work with scientists while investigating marine related problems in their own disciplines.

VICKY CULLEN



CHARLES ERIKSEN



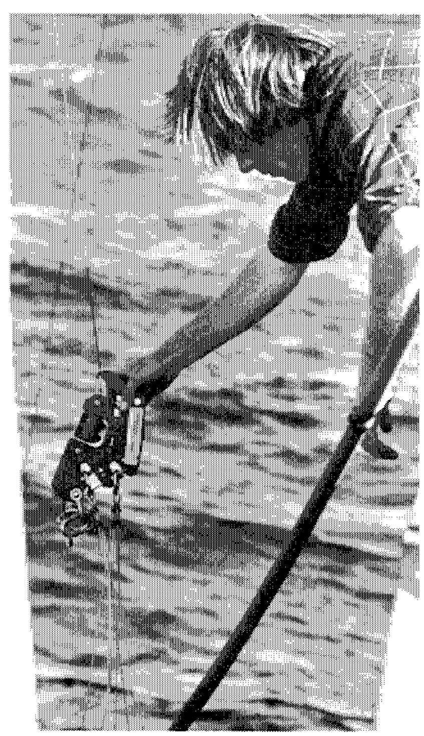
GEORGE TUPPER

RESEARCH HIGHLIGHTS

This section is not an attempt to give an overall view of research underway at the Institution but rather a discussion of a few problems under investigation. An idea of the diversity of our research may be gained from the publications list in Appendix IV. Sound in the sea is discussed here both as a research problem in itself and as a tool for learning about the ocean. Studies of large ocean current systems are described by two physical oceanographers. The section on the marine environment ranges over several topics: statistical ecology, electric and magnetic responses in fish, movement of polychlorinated biphenyls through the ocean and atmosphere, phytoplankton growth rates, and bluefin tuna migration. Under the water and sediment heading, chemical reactions at the water/rock interface on the seafloor, dating of water masses with radioactive tracers, vertical flux of particles in the sea, and paleogeography of the southwestern Atlantic are all considered. Names of the scientists engaged in the research discussed are given in italics beneath the title of each subject. Manuscripts contributed by these researchers were compiled and edited by Bostwick Ketchum.

BRUCE TRIPP

BRUCE TRIPP



BRUCE TRIPP

Sound in the Sea

Seawater is virtually opaque to both light and radio waves, but it is relatively transparent to that form of mechanical energy known as sound. Because sound is easy to transmit, it is used in a variety of ways to explore and study the oceans. Echo sounders routinely probe the depths to trace the outlines of bottom topography. Air guns, electrical sparkers, and explosives generate stronger sound pulses which penetrate bottom sediments to provide information about ocean subbottom structures. Cameras, dredges, and other underwater instruments are guided to points of interest by sound beams. Submersibles, such as *DSRV Alvin*, are steered over the bottom by precision acoustic navigation systems.

Variability in Sound Transmission

Robert C. Spindel and Robert P. Porter

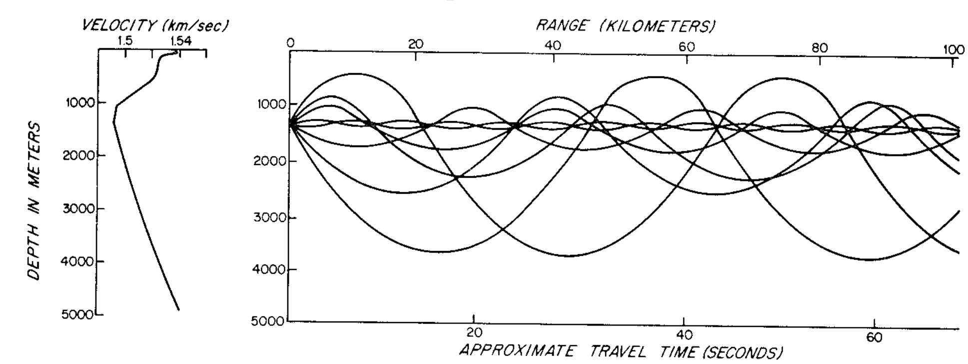
Three phenomena associated with underwater sound transmission are fundamental to its application. First, high frequency sound is greatly attenuated whereas low frequency sound experiences little loss. Thus, a low frequency tone, say middle A on the piano with a frequency of 440 Hertz (cycles per second), can be transmitted for many hundreds of miles, but a high frequency tone, say 20,000 Hertz (20 kHz), which is at the upper limit of human hearing, can be transmitted only a few miles. Second, sound travels relatively slowly in the ocean, about 1,500 meters per second, compared with the speed of light in air which is 300 million meters per second. Finally, sound waves do not travel in straight lines, but are bent, or refracted, by changes in the physical properties of seawater which control sound velocity in the ocean. Energy is refracted downwards in the upper part of the ocean where sound velocity is decreasing to a minimum value at mid-depth. It is refracted upwards in the lower part of the ocean where sound velocity again increases. Thus, sound energy transfer follows many paths but the propagation is greatest at mid-depths in the "sound channel," characteristic of most of the deep oceans of the world.

Sound transmission is also altered by changes in the temperature and currents along its path. These alterations drastically affect the clarity of sound transmission and reflect the average condition of the ocean along the transmission path. A unique acoustic system has been developed at Woods Hole to study small scale acoustic fluctuations caused by oceanic variations. A low frequency sound source is moored in the ocean, and measurements are taken by instruments moored at various distances and depths from the source. The source transmits a continuous wave; the receivers measure the phase and amplitude of the wave after it has propagated through the ocean. The phase is the number of cycles of the wave that have passed an observation point and is a measure of the travel time of the wave. The average travel time varies in response to changes of current and temperature along the sound path, producing a change in the phase of the signal at the receiver. The change in phase, or travel time, is a sensitive indicator of the average conditions along the sound path. The amplitude is the peak-to-trough height and is a measure of the intensity of the wave. The amplitude of the received wave varies because the transmitted wave travels along several different paths, each undergoing its own individual sound velocity change. Thus, the resultant signal is the sum of many replicas of the transmitted signal. They can combine constructively or destructively. Changes in amplitude of 10,000 to 1 (-40 decibels) can occur in a matter of minutes. A typical record of acoustic amplitude and phase shows a large random variation in amplitude but signal minima of as much as -50 decibels are seen at about seven hours and eighteen hours. The phase cycles or repeats itself roughly every twelve hours which is very near the tidal period. The travel time of the waves changes by about 0.1 seconds during this tidal period.

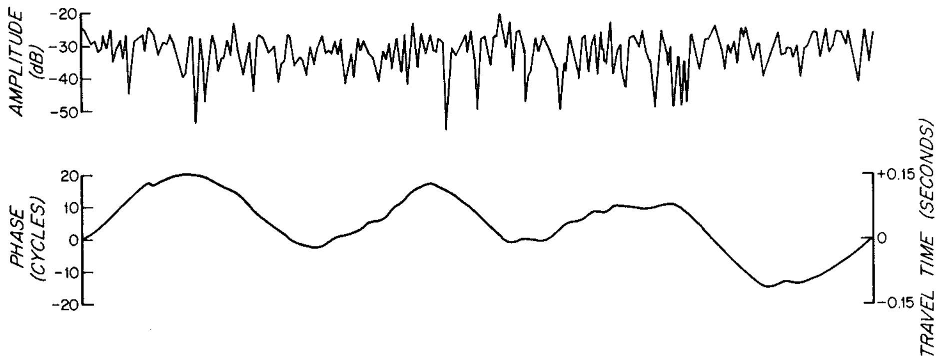
Phase can change because the state of the ocean has changed or because the source and receiver have moved. If we are to measure phase changes caused by oceanic variations, we must either eliminate the motion or measure it precisely. Source and receiver moorings sway with deep ocean currents and can move in

FRANK MEDEIROS

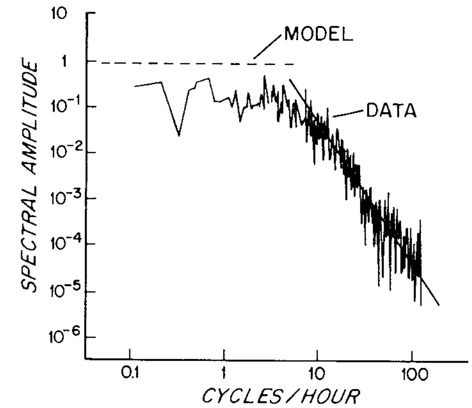
Bob Spindel and Bob Porter with sound records.



Variation of sound velocity with depth and refraction of various ray paths in the ocean.



Amplitude (above) and phase (below) of 2-day 220 Hertz acoustic transmission over 300-kilometer range.



Acoustic phase rate spectrum and internal wave model prediction.

rough circles with a diameter of about 300 meters. This motion can produce apparent phase changes of 40 cycles or more while phase changes due to oceanic variations are of the order of only a few cycles. The motion of sources and receivers are tracked acoustically with a precision navigation system developed at Woods Hole for this purpose. Acoustic beacons are placed around the base of each mooring, about 5 kilometers distant. A special receiver is attached to the mooring or built into the acoustic receiver. This system can detect 3 centimeter changes in mooring position.

Vertical internal wave oscillations produce changes in the average sound speed since water of differing temperature is displaced vertically. They exist in the ocean because of slight variations in density and have been observed in almost all parts of the world's oceans. The displacement of isotherms changes the sound velocity along oceanic transmission paths and the resulting sound speed variations are shown by the phase of the received acoustic signal. The frequency spectrum of the rate of change of phase can be compared with an internal wave model. Internal waves do not exist above the local ocean buoyancy frequency so that the model prediction ends abruptly. The acoustic data falls sharply at this point also suggesting strongly that the acoustic phase behavior is a result of internal wave isotherm displacements.

Experience with acoustic phase measurements has indicated the great influence that small variations in the ocean's structure have on acoustic transmissions. The quantitative relationships between acoustic fluctuations and such phenomena as internal tides and internal waves can now be predicted and verified experimentally. New experiments are underway to use this information to monitor the ocean acoustically, that is, to use the acoustic signal itself to measure the state of ocean variations. ■

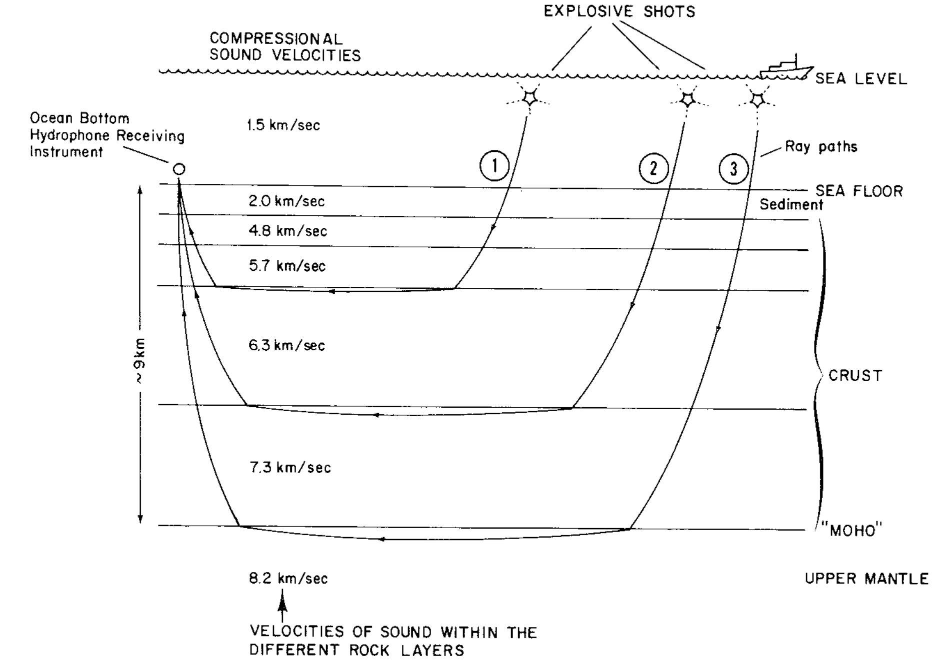
Echos from Beneath the Seabed

Carl O. Bowin and Graham M. Purdy

Underwater sound is used to delineate the configuration of the sea floor, the layering and distortion of the sediments underlying the sea floor, and the thickness and compressional velocity of sound in the earth's crust and upper mantle. Echo sounding using 12 kilohertz (kHz) and 3.5 kHz transducers provides precise information on the depth and shape of the sea floor. The records from the 3.5 kHz pulses also show the contours of sediment layers down to about one-quarter km below the sea floor. *Continuous seismic profiling* (CSP) provides a cross-sectional profile of the structure of the rocks and sediments below the ocean bottom. Air gun sound sources which produce lower frequency sound (15 to 150 Hz) with greater energy than normal echo sounding transducers are used to obtain echos (reflections) from layer boundaries as much as 4 to 5 kilometers below the sea floor. In *multi-channel seismic reflection profiling,* several hydrophones separated by a fixed distance are towed behind the ship and the air gun is fired at time intervals corresponding with the ship's passage over the sea floor by that same distance. Repeated echos from reflectors below the bottom are received both by the same hydrophone through different geometric paths and by different hydrophones through similar paths. Computer processing of these data allows the structure below the sea floor to be resolved with greater clarity than with a single reflection path. The differing sonic ray paths recorded also permit the determination of the compressional velocity of the sediments and rocks, important information to aid in interpreting the types of rock present and their lateral correlation.

To determine crustal type—that is, either continental (typically 30 kilometers thick) or oceanic (typically 6-7 kilometers thick)—we employ *seismic refraction* that probes many kilometers below the base of the sediments with low frequency (4-15 Hz) sound that is critically refracted along boundaries between rock layers having different seismic velocities.

Last year we designed and built a special receiver to record on the sea bed the sound energy refracted from deep layers. This ocean bottom hydrophone, designed by Don Koelsch of the Geology and Geophysics Department, has significantly improved the resolution and accuracy with which we can determine deep crustal and upper mantle structures using the seismic refraction method. It floats 2-3 meters above the sea floor in water depths of up to 6,000 meters, records on magnetic tape the output of a single pressure-compensated hydrophone and an internal crystal controlled chronometer accurate to about 3 seconds per year. The instrument returns to the surface upon acoustic command from the shooting ship. It can record continuously for 10 days in the frequency band 4-60 Hz and is fitted with an acoustic transponder which



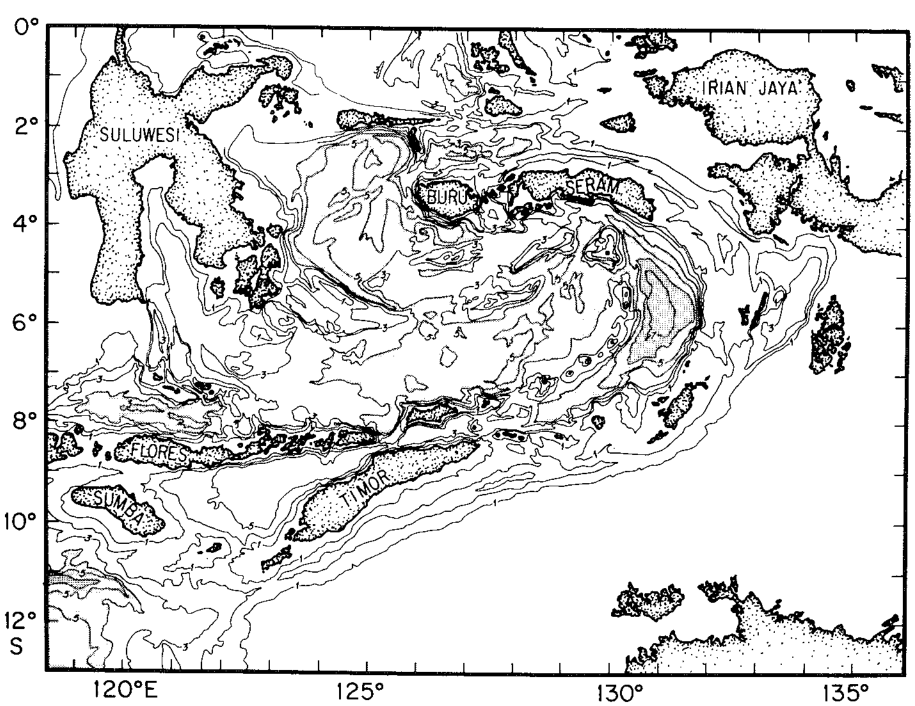
Schematic of critically refracted ray paths through the sea floor.

may be interrogated during the experiment to permit the accurate placement of explosive charges and to aid in speedy relocation and recovery of the instrument upon completion of the experiment. Air guns produce insufficient energy for this work so instead we use discrete TNT explosive charges of 2 to 150 kilograms.

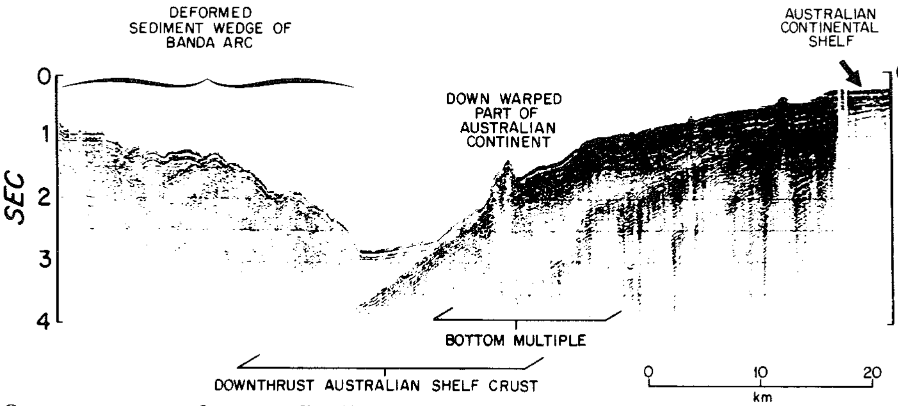
The simplest type of experiment consists of deploying a single receiver and then steaming away on a constant course firing charges of increasing size at 5-15 minute intervals. A schematic depiction of refracted sound paths through the sea floor is shown in the figure above. The first sound to arrive at the receiving hydrophone travels through different layers of the crust and upper mantle as the separation increases between sound source and receiving device. As the range increases, the source of the first refracted arrival is from a deeper crustal layer with higher sound velocity. The length of the "shooting" line is thus dependent upon the depth of penetration desired: typically 50 kilometers for oceanic crust, 200 kilometers for continental crust and as much as 1,000-2,000 kilometers if data is sought on the deep structure of the lithosphere.

The ocean bottom hydrophone has a number of significant advantages over the conventional free-floating sonobuoys commonly used in the past. By placing the receiver on the sea floor, definition of thin shallow layers is greatly improved in the region immediately around the receiver itself. Consistently high signal-to-noise ratios that are weather-independent are assured by having the receiver well away from surface currents, winds, and waves. The ocean bottom hydrophone remains fixed and is not subject to wind and current drift which can confuse the record of any free-floating receiver. These advantages considerably broaden the capabilities of the seismic refraction technique, so that it is now practical for us to tackle more complex structural problems.

A 1976 *Atlantis II* cruise to the Banda Sea in Eastern Indonesia illustrates the importance of sound to geological and geophysical studies of the structure and evolution of the earth. The Banda Sea region is particularly interesting because the small island arc that encloses that sea appears to be trying to swallow the Australian continent! Most active island arcs mark locations where two tectonic plates converge, and the crust of an adjacent ocean is being subducted, or downthrust, beneath the crust and upper mantle (collectively called the lithosphere) of the island arc itself. Thousands of kilometers of ocean crust have disappeared beneath island arcs during the last 200 million years. Downgoing oceanic lithospheric plates have been traced as deep as 700 kilometers in some places. Near that depth the downthrust material loses its distinctive identity and becomes assimilated into the upper mantle. Continental lithosphere is lighter than oceanic lithosphere—that is why continents stand high with respect to the sea floor—and it is generally considered impossible for continental lithosphere to be subducted.



Banda Sea Island Arc. The Weber Deep, indicated by coarse stippling, is found anomalously between the inner volcanic arc and the outer deformed arc. Finer stippling indicates 4,000 meter contour.



Continuous seismic reflection profile of boundary where the Australian plate is subducting beneath the Banda Island arc.

Mike Purdy discusses data with visiting Indonesian scientists in main lab of *Atlantis II*.

Such an attempt, it is argued, would choke a subduction zone and cause subduction to cease at that site. The Banda arc is a test of that hypothesis.

The curving Banda island arc, like other arcs of the world, has active volcanoes and a deep trench, the Weber Deep with depths of over 7 kilometers. Unlike all other arcs, however, the Banda arc has the greatest curvature of any active arc on the earth, and the shallow-water Australian continental shelf is on the convex or outer side of the arc, rather than on the concave side. Separating the shelf and the arc is a shallow trough, only 1,500 to 3,000 meters deep, where the Australian continental shelf appears to be subducting.

In order to begin unravelling the complex evolutionary history of this tectonically active region, all of the methods described above were used to map the major oceanic and continental structure units. We found that the Banda Sea and the inner trough bounding its eastern side and including the Weber Deep are areas of oceanic crust surrounded by a series of arcuate trough and ridge structures with crust more than 20 kilometers thick. The continuous seismic reflection profiles obtained document that the layered sediments on the Australian shelf are warped downward and pass beneath deformed sediments on the outer flank of the Banda arc. We also observe deformation in the shelf sediments in some locations where they are warped downward. This tells us that continental crust is presently being subducted beneath the Banda arc. Integration of the seismic reflection and refraction data with gravity, magnetic, heat-flow, and geologic data also collected during this expedition will help to resolve how long this process has been occurring and hence to what depth continental crust has been subducted.

The Banda Sea study is an example of a new genre of multi-national, multi-institutional cooperative oceanographic research endeavors in foreign territorial waters. It was unnecessary for the Woods Hole Oceanographic Institution or the United States State Department to request permission of Indonesia to conduct investigations in their territorial waters, since the Indonesian Ministry of Mines requested approval from the Government of Indonesia for foreign U.S. research ships to participate in the cooperative program. In addition to the Woods Hole Oceanographic Institution as the lead organization, cooperating organizations include Scripps Institution of Oceanography, Cornell University, and Lamont-Doherty Geological Observatory in the United States; the Ministry of Mines, Geological Survey, Hydrographic Office, and Pertamina in Indonesia; the Bureau of Mineral Resources and Flinders University in Australia; the University of Malaya in Malaysia; and Chelsea College and Imperial College in England. Participating research vessels were *R/V Atlantis II* of the Woods Hole Oceanographic Institution, *R/V Thomas Washington* of the Scripps Institution of Oceanography, and *M/V Kelapa* chartered by the Indonesian Ministry of Mines and the Indonesian Geological Survey. ■

Acoustic Backscattering

Marshall H. Orr

Acoustic energy, in addition to being reflected from the ocean bottom, can also be reflected from objects within the water column. The military has long used acoustic systems for the detection of submerged submarines, and commercial and private fishermen use acoustic systems to detect and track fish or schools of fish. When the sound wave interacts with a submerged object, it is scattered in all directions, a part of the energy being reflected or "backscattered" to the receiver on the ship. We have used echo sounders operating at frequencies of 47.5 and 200 kHz to detect organisms and particles suspended in the water column. Particles of 35 millimeters and 7 millimeters have a maximum backscattering cross section at these frequencies. These sizes are typical of many zooplankton in the sea. Research problems addressed also include horizontal and vertical distributions of particulates and reflection from strong thermal gradients which may be the result of particulates captured on the density layers or reflections from the thermal gradient itself.

The sea is full of particles with maximum abundance in the range of 1-50 millionths of a meter (μm). They are much more abundant in coastal waters than they are in the waters of the open ocean. It is, indeed, the backscattering of light from these particles which gives coastal waters their typically green coloration in comparison to the blue color of clear, deep ocean water. The particles originate and are added to the ocean by river drainage, by wave and current resuspension of ocean sediments, by particles falling from the atmosphere, and by waste disposal resulting from man's activities. The organisms that live in the sea and their waste products, such as fecal pellets and fragments in the process of decomposition, are important contributors to the particles in the ocean. The distribution, source, and fate of particulate matter in the sea is of interest to physical oceanographers, marine biologists, geologists, and chemists.

Sound offers a powerful tool for the study of the distribution of particulate matter in the sea. Specially designed acoustic backscattering systems with highly sensitive hydrophones and receivers have been developed and constructed at the Institution and applied to various problems during the past year. Previously, acoustic systems have been designed to avoid the interference of backscattering from small particles so that the return from a good reflector, such as the ocean bottom or a submarine, is not confused by intermediate targets. During World War II, however, finely tuned sonar systems detected discrete layers within the ocean water column and it was found that these layers, called scattering layers, migrate towards the surface at night and towards deeper water at dawn. These vertical migrations over depth ranges as great as 600 to 800 meters at speeds up to 7.5 meters per minute indicated that the layers were composed of living organisms. The depth of the layer, determined by acoustics, helped the biologist to determine the depth at which his net should be towed in order to obtain samples of the deep scattering layer organisms.

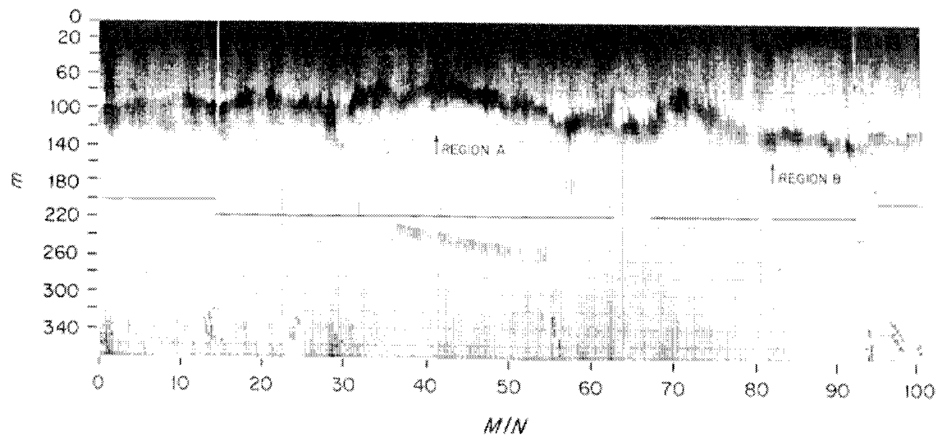
With more sophisticated acoustic devices and modern plankton nets, the efficiency of sampling populations at mid-depths in the ocean can be greatly increased. These modern nets are equipped with sensors to determine pressure, temperature, conductivity, and water flow. The results are continually recorded on shipboard where controls can be used to command the opening and closing of the net at selected times or depths.

During a recent interdisciplinary cruise to the North Atlantic Ocean, the two-frequency acoustic echo sounder system was used in conjunction with the collection of organisms in modern nets. A section of the acoustic data collected with the 47.5 kHz profiler is illustrated. In Region A, the layer of organisms appears to be all above the 100 meter depth. In Region B, the organisms appear to be all below the 100 meter depth. Obviously, biological samples taken only about an hour apart immediately above or below this depth could show very different amounts of biomass.

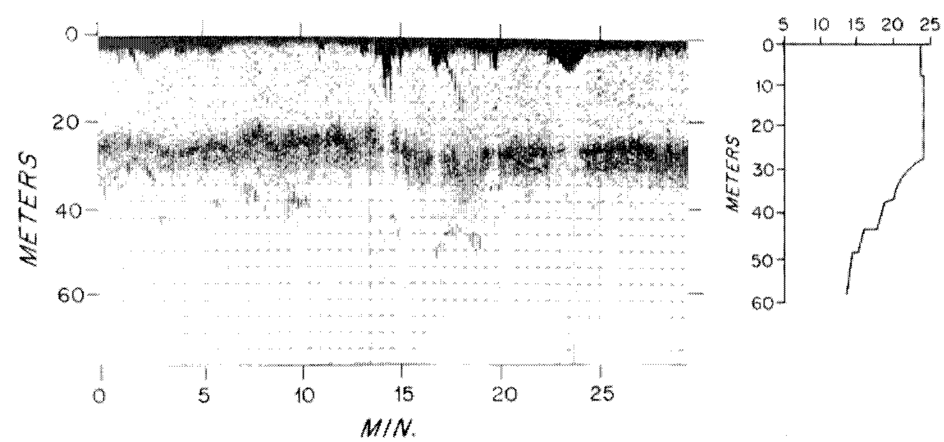
On another cruise in a warm core Gulf Stream ring, the record from the 200 kHz echo sounder shows a scattering layer at the same depth as the strong gradient in temperature. This record was made while the ship was drifting on a calm day. The high frequency vertical oscillation appears due to the ship's roll with a period of about 10 seconds. The longer period vertical displacement on the order of several minutes may be attributable to the passage of an internal wave.

A more practical application of acoustic backscattering has been made in tracking the particulate matter produced by waste materials dumped from a barge at sea. This program is a cooperative one with scientists of the National Oceanic and Atmospheric Administration. Its objective is to determine the dispersal of chemical wastes released from these barges and the mechanisms of dispersal and to evaluate the effects of such waste disposal on marine life. This study was conducted at the ocean dump site located 195 kilometers southeast of Ambrose Light Tower at the entrance to New York Harbor.

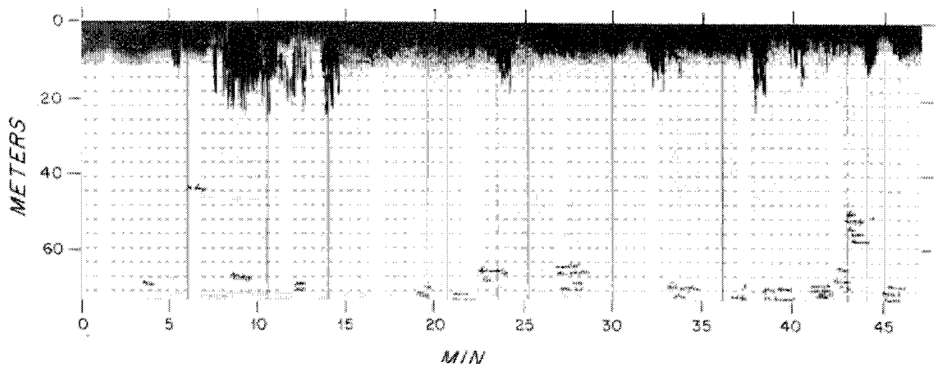
Each barge contains about one million gallons of industrial wastes which are released over a period of about two hours while underway at a speed of about 2 knots. Some of the material released forms flocculent particles when it interacts with seawater. The two-



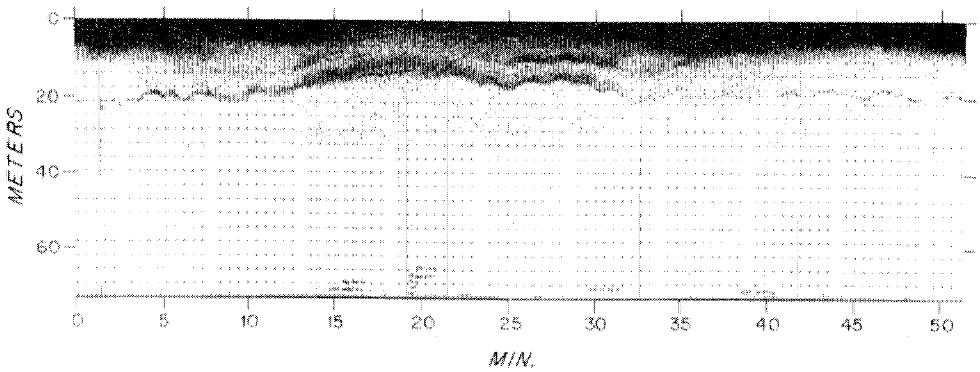
47.5 kHz profile, ship speed 10 knots.



200 kHz profile, ship drifting, weather calm.



200 kHz profile following barge.



200 kHz profile 10 hours later.

frequency acoustic backscattering system was used during two cruises in 1976 to track the waste material after disposal.

The record obtained using the 200 kHz system from the *Knorr* as it followed in the wake of the barge showed discrete patches of the waste distributed within the upper 20 to 25 meters. When the transducer was outside the center of the wake, particulates were not seen at these depths, but were confined to the upper 10 meters. The 47.5 kHz record indicated that some of the waste accumulated on the seasonal thermocline at 40 meters.

Ten hours after this discharge, the data obtained for the 200 kHz system show that the particulate phase of the waste is arranged in layers above the seasonal thermocline. The 47.5 kHz record again showed accumulation on the thermocline and some penetration through the thermocline to depths of 60 to 80 meters.

The acoustic system thus reveals that the particulate materials in a dumped waste will concentrate on density layers within and above the thermocline and remain above the thermocline in the mixed layer for considerable periods of time following disposal. Since it is known that marine organisms will also concentrate at the thermocline and within the mixed layer, the organisms may be occupying just the part of the environment where the waste is most concentrated. Eventually, with the help of acoustically guided sampling systems for both chemical and biological samples, it may be possible to determine the impact of open-ocean waste disposal on the marine environment. ■

Animal Sounds

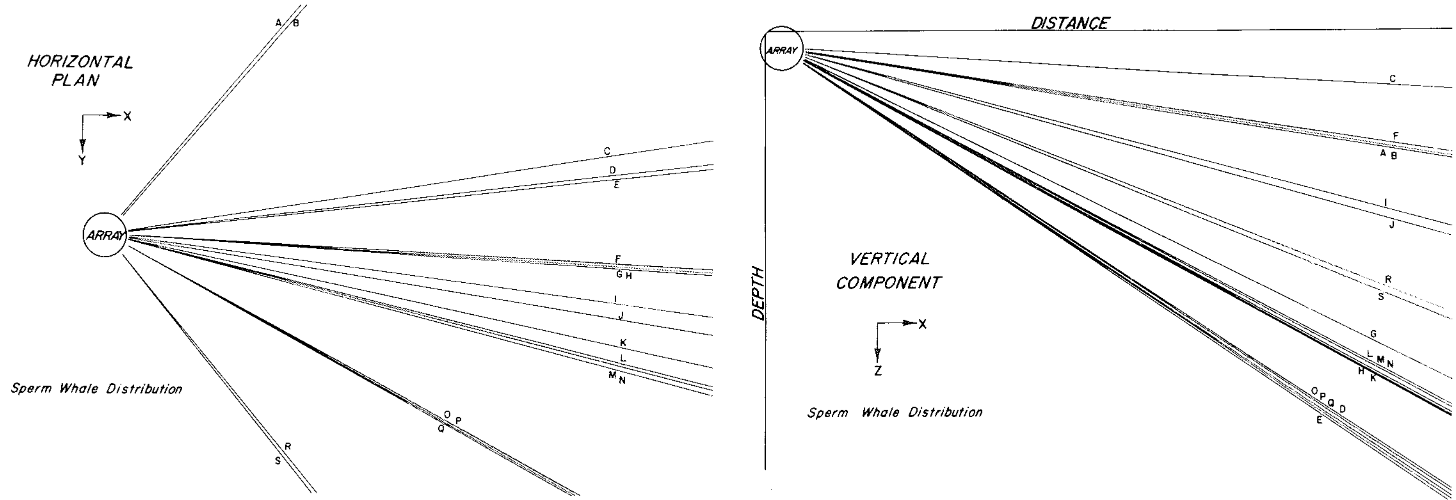
William E. Schevill and William A. Watkins

Marine mammals produce sounds which may be used in echo location, food finding, and communication. Many other marine animals, such as fish and crustaceans, also produce their own characteristic sounds. All of these animal noises are part of the background or ambient noise in the sea. They are received by hydrophones and recorded along with the sound of particular interest for the research.

The acoustic behavior of marine animals, including whales, porpoises, and seals, has been studied at the Institution since 1948 when William Schevill and Barbara Lawrence first identified the white porpoise (*Delphinaprerus leucas*) as the species producing the sound they were hearing. This work has progressed from the discovery and basic analysis of underwater sound produced by more than forty species of marine mammals to studies of their hearing and sound production, their use of echo location, directionality of sound propagation, voluntary level variations, seasonal differences in sounds, and correlation of the acoustics with both behavior and distribution of the animals.

A four-hydrophone array is used to provide information on the direction and range of the sound-producing animal from the ship. The hydrophones are arranged in a loose three-dimensional array; one is lowered off the ship's stern, one off the bow; one is allowed to drift away from the side, and one is hung deep in the water. Pinger sounds are introduced into the water to locate the hydrophone positions from the relative sound arrival times at each sensor. The arrival-time differences of animal sounds at these hydrophones can then be used to compute the location for a near-by sound source and the direction for more distant sources.

Recordings of sperm whale (*Physeter catadon*) sounds show a consistent scatter of sound-source direction in both horizontal and vertical bearings on different animals. During each dive the whales routinely appear to be distributed 100 or more meters apart throughout a large volume of water. Though widely separated underwater, the whales in each of the eight pods studied regrouped to surface together for breathing. The whales within each group seem to maintain acoustic contact with each other, and their underwater spatial distribution patterns suggest foraging behavior. Analysis of the sounds of one pod of nineteen sperm whales, at a distance of at least one kilometer, showed an underwater spread of acoustic bearing of over 100 degrees horizontally and 30 degrees ver-



Vertical and horizontal lines of relative direction for 19 sperm whales illustrate how the whales fan out after diving. The bearings were derived from positions calculated from sound arrival time differences on a 3-dimensional hydrophone array. The animals are about a kilometer from the hydrophones.

tically. From other records, this appears to be a consistent behavior.

The characteristic pulsed clicking sounds of sperm whales are often produced in stereotyped sequences unique to individual animals. Short coda sequences of about one second duration occur particularly when animals meet underwater and appear to be used in exchanges between animals. Other stereotyped sequences are longer and have particular rhythms of pulse grouping.

Analyses of longer recordings of sperm whale sounds show interesting clicking behavior that does not seem to fit the notion of their use of these sounds for echo location or finding food. We have traced the sounds made by individual animals for as long as four hours. They do not produce clicks continuously; sometimes they are silent for much of a dive sequence. One or two animals in a group often appear to be acoustically dominant while the other whales are heard only occasionally. At the surface, they are sometimes silent and sometimes clicking noisily. We are unable to differentiate between clicks produced at depth and those from whales near the surface, as might be expected with changing pressure if the sounds are produced by mechanisms using air.

A cruise in June of 1976 to an area about 250 miles northeast of Bermuda was designed to assess the occurrence of sperm whales in deep water. We found them in the same areas they frequented in the days of the New England whale fishery, but they were not found only 100 miles away—where they also were not found during the whaling period. Our 1976 spring aerial survey of cetaceans in Cape Cod waters found fewer animals than in previous years but more species: five whale and three porpoise species. Our studies of the feeding behavior of baleen whales were enhanced on one occasion when we observed at length more than twenty whales—finbacks and humpbacks—as they fed together on schooled fish.

Study of aerial photographs of whales has recently confirmed our impression of the possibility for repeated recognition of individuals. The head growths, called callosities, on right whales appear to be relatively stable and permit identification. We have seen one right whale cow over four consecutive years. The first year, she was with a very small calf. The calf was mostly grown the second year and a small adult the third year, but still with the cow. This year, that calf was missing, but the cow again had a new calf, confirming a three-year reproductive cycle in these whales.

FRANK MEDEIROS

Bill Watkins, Karen Moore, animal sound records.

A study of underwater sounds from ribbon seals (*Phoca [Histriophoca] fasciata*) recorded by G. Carleton Ray of Johns Hopkins University defined the high-level springtime sounds heard in arctic ambient noise. The predominant sound from ribbon seals is a high-level downward sweep in frequency of 2 to 5 kHz, beginning at 7 to 5 kHz. Extrapolating from other springtime underwater seal sounds, a social function is suggested for these sounds, probably involving reproductive or territorial behavior.

Analyses of porpoise (*Cephalorhynchus heavisidii*) sounds recorded by Peter Best off South Africa this year allowed us to put into perspective the recordings we had made earlier of three other species of *Cephalorhynchus*—*C. hectori* off New Zealand and *C. eutropia* and *C. commersonii* off southern South America. The "cry" sound was the most prominent one heard from all four species. All of the sounds were pulsed and relatively low level. They were comparable in many ways to sounds produced by *Phocoena phocoena* which has similar appearance, habitat, and behavior. ■

Ocean Currents

North Atlantic Circulation
Valentine Worthington

Twenty years ago Columbus O'D. Iselin, the Institution's second director, charged Valentine Worthington with a study of North Atlantic circulation patterns. Iselin also wrote, however, "The problem of oceanic circulation is such that we cannot hope for a satisfactory solution for a long time." Worthington's monograph *On the North Atlantic Circulation* was published in 1976 as Number 6 of The Johns Hopkins Oceanographic Studies. It presents a fundamentally new circulation pattern in which two anticyclonic gyres on the western side of the ocean contain all the action.

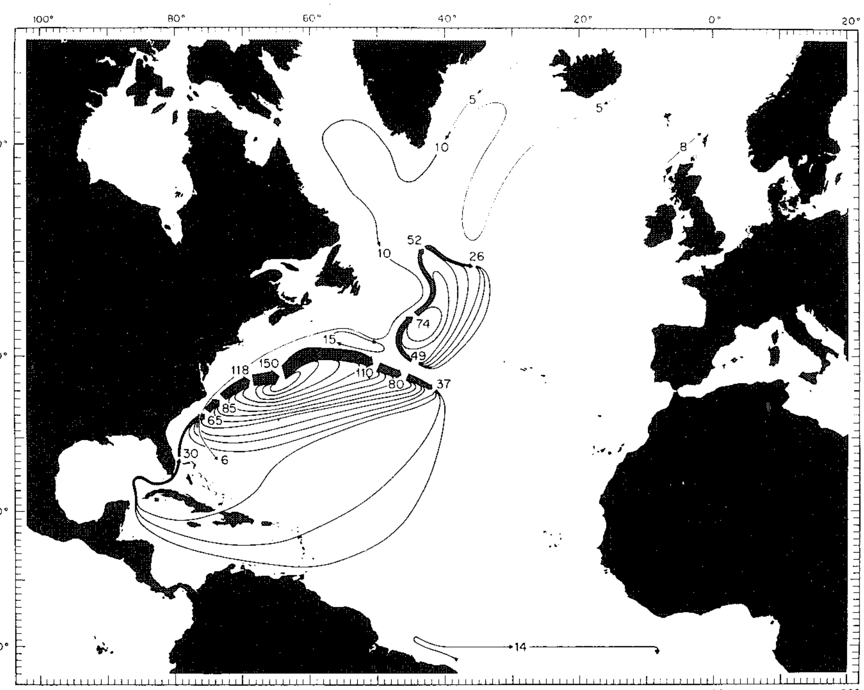
The North Atlantic is the only ocean whose physical characteristics are very well known oceanwide and top to bottom. This is largely as a result of a survey undertaken by Woods Hole oceanographers, in collaboration with British and German investigators, during the International Geophysical Year 1957-58. The simple, physical description of the water masses of this ocean has already been presented in three atlases. Worthington's work on the circulation pattern represents the more difficult task of relating these water masses to the internal pressure field in the ocean and arriving at a picture of its general circulation.

Three previous attempts have been made at this task, one by Iselin himself and two others by H. U. Sverdrup and by Henry Stommel. These oceanographers presented circulation diagrams in which the transport of water is illustrated by flow lines, each flow line representing a stated volume transport of water expressed in millions of cubic meters per second. It is a measure of the complexity of the ocean that Stommel's circulation pattern was fundamentally different from those of the first two, and this present work is fundamentally different from all three of them. Worthington's circulation pattern has been found unpalatable by some oceanographers—in fact, during the somewhat lengthy period between the submission of the manuscript and its publication two papers have appeared rebutting it.

Oceanographers agree that there are narrow and very powerful currents flowing northward and eastward off the American continental slope—the Gulf Stream system. Recent direct current measurements have shown that the Gulf Stream increases enormously in transport as it flows northward to Cape Hatteras and then eastward. A further point of agreement is that the Gulf Stream diminishes southeast of the Grand Banks of Newfoundland. In all the other circulation patterns this diminution is caused by branching of the Stream with a large branch flowing northward past Newfoundland. In this circulation pattern branching is rejected and the current flowing north is interpreted as the western side of a separate anticyclonic gyre. The original reasoning for this appeared fifteen years ago when it was shown that the northward flowing current contained much more dissolved oxygen than did the Gulf Stream. In fact, all the water above 1,000 meters encompassed by the northern gyre has a higher oxygen concentration than that of the Sargasso Sea—the area encompassed by the southern gyre which is the Gulf Stream system.

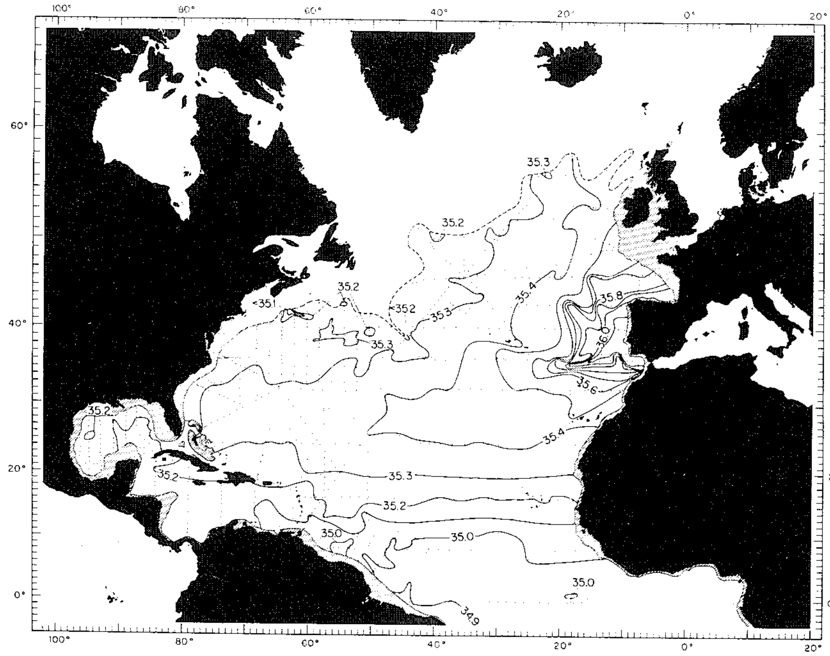
It is theoretically possible that a branch of the Gulf Stream could pick up oxygen by mixing with cold, oxygen-rich water to the east of it, but *all* water flowing north must return south unless the inhabitants of Europe are to be drowned, and this return flow must divest itself of the excess oxygen before re-entering the Sargasso Sea. At depths below 1,000 meters, other physical and chemical dissimilarities are found between the waters of the northern gyre and the Sargasso Sea.

Why are these gyres interpreted as being confined to west? The answer can be found in the salinity of the 10°C iso-



Circulation diagram for total top-to-bottom circulation in the North Atlantic. Each flow line represents 10 million cubic meters per second.

thermal surface. It is dominated by the saline Mediterranean outflow, a vast salty tongue reaching from Gibraltar to the Bahamas and extending northward past the British Isles. The northern limit of 10° water marks the northern limits of the circulation pattern. The two gyres, with minor exceptions, transport only water with salinities between 35.2 and 35.3 parts per thousand (‰). Mediterranean outflow water, with salinity greater than 35.3 ‰, probably gets involved with the general circulation, but in quantities too small to measure. The total outflow through the Strait of Gibraltar is 1 million cubic meters per second compared to the Gulf Stream transport of 80 million cubic meters per second, at depths where Gulf Stream water can be distinguished from Mediterranean water. The three flow lines (30 million cubic meters per second) that pass through the Caribbean Sea and appear to violate the tongue of Mediterranean water actually represent shallow water which passes above it. Thus, the circulation pattern shown is totally consistent with the water masses of the North Atlantic.


Salinity (parts per thousand) at the 10°C surface in the North Atlantic.

The principal objection to this circulation scheme is its admitted failure to achieve geostrophic balance, whereby all pressure gradients calculated from the density distribution must be accompanied, exactly, by water movements dictated by the geostrophic equation. Geostrophy states that a large volume of water *must* flow around the Grand Banks; water mass distribution says that it cannot. This quandary remains to be resolved. Worthington notes that if this treatise has done nothing more, it has rekindled the interest of theoretical oceanographers in the large-scale general circulation of the oceans. ■

Physics of Ocean Currents
Peter B. Rhines

Modern methods of observing the ocean, many of them developed at Woods Hole, have recently shown us a wealth of detail little suspected by classical oceanographers. This is particularly true of ocean currents, which were a "solved" problem in the fifties, and yet are a mystery of the seventies. The classical tool for calculation of ocean currents was measurements of salinity and temperature at sparsely distributed points. This emphasized a smooth, large-scale picture of the flow. Direct measurements, using current meters and drifting floats, show most of the ocean to be moving chaotically.

Perhaps it is just as well that we were not given the complex truth all at once, for it might have discouraged us from the long investigation of the theoretical laws governing ocean currents that took the classical theory of ocean circulation as a starting point. It would be a correct theory if the winds and sun exerted much weaker driving forces on the circulation than they do. In a weakly driven ocean the average flow would respond only to the average driving force, with complementary unsteady wave-like flows responding to the time-varying atmospheric forces. The steady and unsteady parts of the flow would be independent of one another. In such an ocean, the average westerly winds at mid-latitudes, and the equatorial easterlies would drive the Gulf Stream and its recirculation. The storms and seasonal weather would excite waves in the ocean interior.

Realistically, however, strong winds and sun, even if steady, cause chaotic, unsteady currents. The actual Gulf Stream, for example, meanders wildly after it leaves the coast at Cape Hatteras. It would do so even if winds were steady. And in the realistic ocean, the unsteady currents can combine to alter the time-average circulation.

We have tried to produce a set of dynamic rules that predict how the strongly-driven oceans will behave. We are interested in the current patterns, and the distribution of trace chemicals and heat that they produce. A deeper question is the flow of energy about the ocean. Unlike chemical tracers, energy may pass freely from one water mass to the next, so that is is not easy to follow, but this flow will give us a cause-and-effect statement of what drives what in the ocean. This understanding is now very much lacking, for the ocean is a complex and delicate machine in which forces exerted, say, in the Greenland Sea, may next year be felt in the tropical seas. The adjustment time of the ocean to changes in the driving forces is so long as to defy experimentation; it takes decades to adjust to wind changes, and centuries to adjust to changes in solar heating.

The set of "behavioral" rules for ocean currents suggests, for example, that if left to their own devices the *scale* of the currents will increase with time; small eddies cluster together to form larger ones. Currents at the surface, if strong enough, will try to pull the abyssal waters into a sympathetic motion. The roughness of the sea floor will break a broad current into small eddies, while exerting important retarding forces on it. Currents that encounter a western continental boundary will break into smaller flows, while those encountering an eastern margin will coalesce into larger flow patterns.

Written down with explicit mathematics, these statements of "tendency" form pieces of the jig-saw puzzle that we are all trying to solve. It is particularly interesting that newer work shows there to be an intimate relation between the ability of the ocean to stir itself up—that is, to disperse chemical tracers—and the force patterns which determine the long-term mean circulation. Given measurements of the distribution, for example, of radioactive tritium rained into the sea from nuclear bomb tests, we can now evaluate those forces which have set the ocean interior moving.

Such "interactions" are bringing together specialists from diverse branches of the science. More and more, we find it impossible to study the physics of ocean currents in isolation from biology, chemistry, and geophysics. On the technical side, as well, we must be diverse today. The research on ocean eddies and currents has required engineering developments, the results from mathematics, statistical physics, and also extensive use of computers for model building. This has been made possible by our newly established telephone link to the powerful computer at the National Center for Atmospheric Research in Colorado.

The goal of understanding ocean current dynamics is quite abstract, but its close neighbors are the pressing problems of seabed nuclear waste disposal, fisheries, and climate prediction.

In fact, this is a time in which science, more and more, impinges on everyday life. It makes us conscious that our work will be judged in an arena larger than the academic studies and libraries of our classical past. ■

The Marine Environment

Statistical Ecology

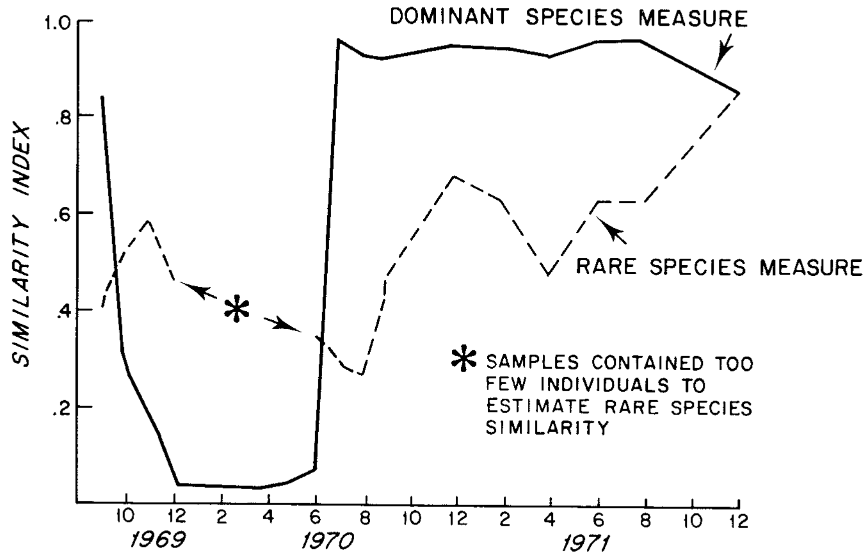
Woollcott K. Smith

The number of environmental survey programs has increased in recent years in response to the growing concern about the environmental effects of man's activities and the need to monitor and regulate these activities. The programs must be efficiently designed and carefully analyzed so that the results will be scientifically valid and also be useful in making environmental policy decisions.

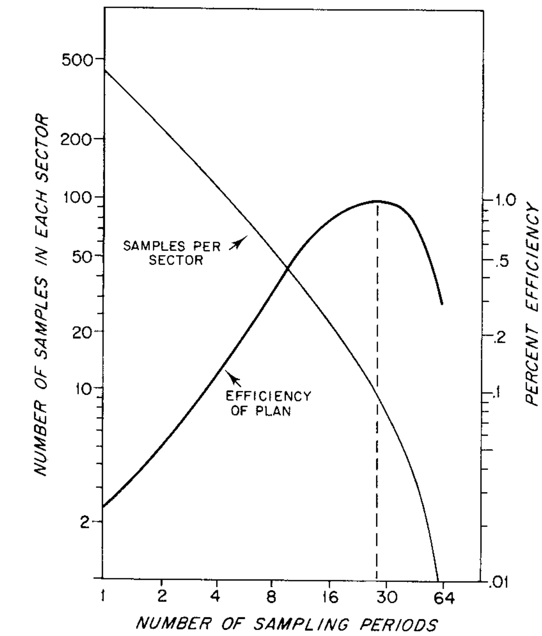
Understanding man's impact on living communities would be a simpler matter if we could observe these communities directly and in detail as we can observe a forest or a field. However, for biological communities in the ocean, observations are limited to samples taken with collecting devices such as plankton nets, midwater trawls, benthic cores, and sleds. The purpose of statistical ecology is to understand, through use of mathematical and statistical methods, the relation between collections taken from the sea and the biological characteristic they represent in nature. This is not theoretical ecology but, rather, an attempt to develop sampling methods and analytical techniques to test existing theories. Our work can be divided into two areas, the design of sampling programs to improve environmental surveys and the development of statistical methods for estimating community diversity and similarity from small samples of the complete community.

A specific problem is to design a survey to estimate the average value of an environmental parameter, such as the average concentration of a pollutant in an estuary, that varies with time. Measuring the concentration at a single location at various times is clearly not sufficient; the concentration will vary with location because of water circulation patterns, winds, and tides. Similarly, knowing exactly the average concentration on a specific day will be of little use in estimating the mean concentration throughout a season or a year since concentration will vary as a result of tidal fluctuation, river runoff, and variation in the activities that produce the pollutant. Since the survey must be conducted within a fixed budget, there is a trade-off between repeating a survey at different times and sampling intensively at a single time.

Sampling theory for time-varying processes permits planning of the survey to allocate sampling effort efficiently provided enough is known about the natural variation. For example, what is an efficient design of a survey to compare the abundance of ichthyoplankton densities in the upper and lower halves of Mount Hope Bay, Rhode Island? The total funds available the survey are limited; the cost of a boat and crew for each sampling period is fifteen times the cost of analyzing a single sample. We were able to estimate the time-varying properties of the ichthyoplankton densities from data obtained in previous years. The most efficient plan proved to be to sample the estuary thirty times during the year with nine samples each time in each half of the Bay. Sampling plans that differ slightly from the most efficient plan are still relatively efficient, allowing the scientists some flexibility in selecting a sampling program. However, fewer sampling



Similarity measure reflects recovery from Wild Harbor oil spill.



Relative efficiencies of ichthyoplankton sampling strategies in Mount Hope Bay.

periods, even though more samples could be analyzed for each, proved less efficient and so did more frequent sampling with too few samples in each period.

Survey plans must take into account the particular difficulties with sampling in the marine environment. In contrast to the problem described above one may want to analyze the impact of a single catastrophic event, such as an oil spill. In this situation, a sampling program must be started on short notice in areas where little is known about the biological or physical variation. We have suggested a two-stage sampling procedure as a solution for this problem. First, a large group of samples are collected and preserved for later analysis. In the second stage, field data obtained in the first stage are used to subsample efficiently for the more expensive and time-consuming biological and chemical analysis.

The biological effect of a pollutant may be to eliminate the more sensitive species from the community, their place being taken by more resistant opportunistic species. This sequence reduces the *species diversity* of the community, which depends upon the number of species and their relative abundance. A community of high diversity has many species, each with about the same abundance, while a community of low diversity has few abundant species. Recovery can be evaluated by determining the *similarity* of the recovered community with those of control areas unaffected by the event.

If we could completely census a community, counting all individuals of each species, we could completely describe the diversity of the community or the similarity between communities. In practice, however, relatively small numbers of individuals are sampled and identified to spe- infer the community properties from the small sample.

thesmall sample.

A number of quantitative measures have been proposed to describe species diversity or similarity. Most of these indices tend to underestimate the true values—the smaller the samples, usually the greater the underestimate. A measure that not only reflects true community diversity but also has good sampling properties is based on work done several years ago by Senior Scientist Howard Sanders. A family of diversity measures, called *expected species diversity,* has some surprisingly good sampling properties. The estimators were unbiased and, on average, the estimated diversity would be the same as the diversity calculated from the whole community. Likewise, a measure of similarity that is relatively insensitive to sample size, called *normalized expected species shared,* has been developed. This has been used to investigate the recovery of benthic communities following a spill of No. 2 fuel oil in the vicinity of Wild Harbor near Woods Hole in September 1969. The similarity measure compared samples taken after the spill with samples taken in 1973 after the benthic community had nearly recovered. One estimate that is sensitive only to the dominant species in the community showed a rapid decline, followed by low values for several months, and then a rapid recovery. A measure that is also sensitive to the rarer species gave a slower decline followed by a period when there were too few individuals in the sample to permit calculation of the index for the rare species followed in turn by a slower and more erratic period of recovery. The index for both the abundant and rarer species approached 0.9 after about two years, indicating that the community had nearly returned to normal.

Ecologists have developed many interesting models for the ways in which complex natural systems react to changes in the environment. The basic problem has been to devise experiments and provide data to test and validate these hypotheses. Improved design of sampling procedures and better quantitative measures of community properties should improve our understanding of biological processes in the sea and of the ways natural communities respond to environmental stresses, including those imposed on the systems by man's activities. ■

Transport Processes of PCBs in the Atlantic

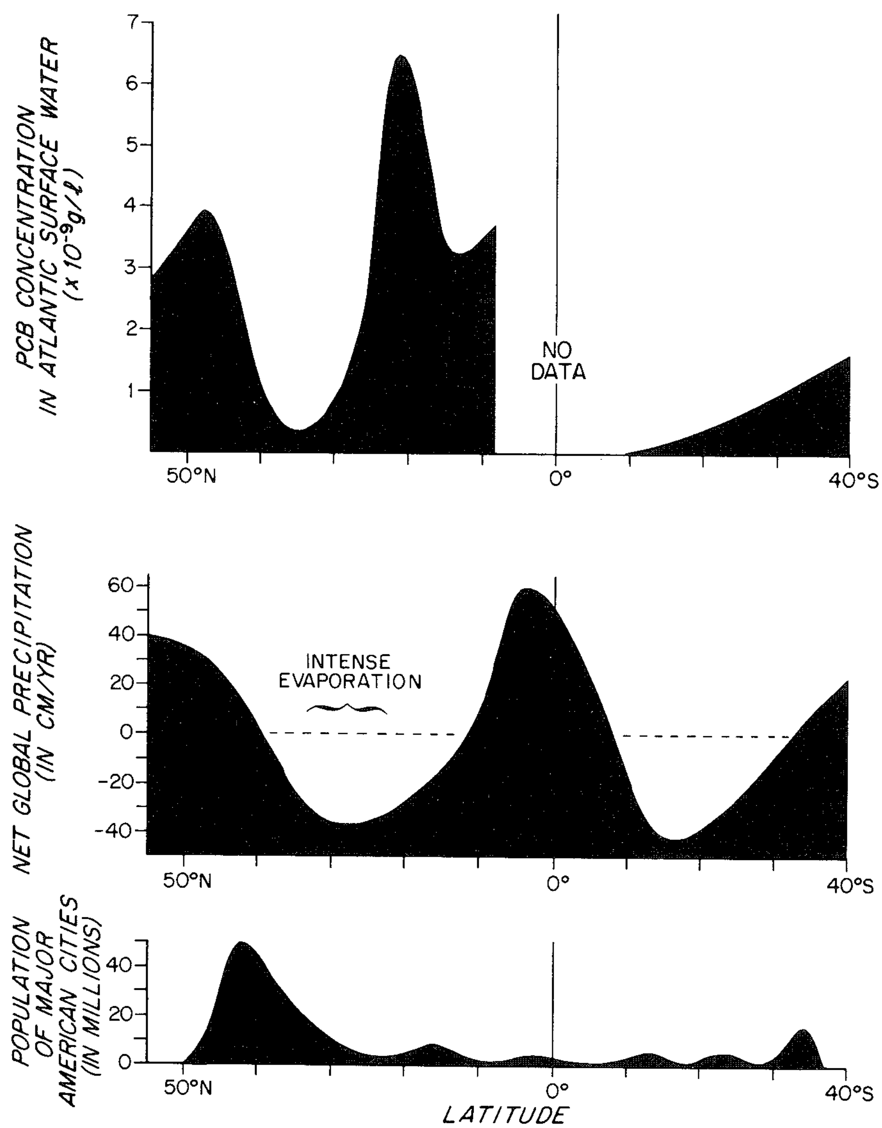
George R. Harvey

Polychlorinated biphenyls (PCBs) are toxic industrial fluids used in many products and processes of the electric, plastic, and chemical industries. Their uses stem from their high resistance to thermal, chemical, and biological degradation. These same properties also insure that if PCBs are released into the open environment they will have very long lifetimes—at least long enough to reach the oceans. Over one million tons of PCBs have been manufactured worldwide since the 1930s, mostly in the United States. Some unknown fraction has leaked to the environment and is found in the oceans. Our studies have concentrated on determining the pathways of PCBs to and within the Atlantic Ocean. Our intention has been to learn more about the transport of marine organic matter and to be able to predict where pollutants go in the Atlantic.

PCBs are viscous liquids with low but measurable volatilities and are only very slightly soluble in water. Their physical properties are intermediate between the inorganic salts and the true gases, such as nitrogen or freon, whose distributions in the oceans have been studied. Thus, we decided that an extrapolation of distribution patterns and pathways from salts and gases to PCBs was not justified. The following summary of our findings supports our original decision that PCBs, and similar organic compounds such as DDT, required a separate study.

Most of the PCB manufacture and use in the world has been in the United States and Japan. PCBs enter the Atlantic Ocean mainly by transport in the atmosphere from their sources in North America. Since PCBs are industrial chemicals, their major uses and accompanying release will be from the areas of greatest population density. Over 50% of the population of the Americas lives between 35° and 45°N latitude, i.e., the northern third of the United States. The prevailing southwesterly winds will carry the PCBs from these cities over the northwest Atlantic, but fallout on dry particles and in rain is rapid so that atmospheric concentrations of PCBs fall off dramatically with increasing distance from land. Thus, we expected to find a maximum concentration of PCBs in the waters between 40° and 50°N latitude, and there is, indeed, a concentration maximum in the North Atlantic at about 45–50°N. However, quite unexpectedly there is an even greater maximum in the tropical North Atlantic, where the population and industrial density is insignificant. Input of PCBs from Europe via western Africa in the northeast trade-winds is unlikely to be important, and there are no major wind systems that could bring so much PCB by this route to the tropical Atlantic.

Thus, some large-scale process must translocate to the tropics the PCBs entering the Atlantic off New England. One such process which seems to be strongly related to PCB distribution is the global rainfall-evaporation system illustrated below. The net precipitation plotted on the vertical axis is the sum of the annual rainfall minus the annual evaporation for each latitude. PCBs are known to be volatile and can also co-evaporate with water at temperatures that are hundreds of degrees below their boiling point. Thus, the lower PCB concentrations found between 30° and 40°N latitude



Comparison of PCB concentrations in Atlantic surface water with global precipitation and population density.

are well within the latitudes of net annual loss of water between about 12° and 40°N. Interestingly, the PCB maximum at about 20°N is offset about 15° latitude to the north from the precipitation maximum. One reason for this apparent discrepancy is that the PCB data were collected only in the open Atlantic Ocean while the rainfall data were collected from stations situated around the globe, mainly on land. The maximum net annual precipitation for the Atlantic Ocean may be further north than for the rest of the planet. Our PCB data certainly suggest that this may be the case, but there are not enough data to know.

The transport pattern which emerges from these observations is as follows: PCBs enter the Atlantic Ocean via the atmosphere, in the southwesterly winds, mainly between 35° and 45°N. Washout in rain and fallout on particles occurs throughout the pathway of the southwesterlies. The PCB fallout in these latitudes can move in three ways: 1) northerly in the North Atlantic Current into the Arctic; 2) southerly by being entrained in the clockwise gyre of the North Atlantic; 3) southerly by codistillation with evaporating water, especially those PCBs carried southerly into the mid-latitudes in the gyre. The PCBs which are returned to the atmosphere over the open ocean can be carried either north or south depending on the latitude, longitude, and prevailing winds. That portion of the cycling PCBs which reaches the tropical North Atlantic is subjected to frequent washout in the copious rainfall which is prevalent in those latitudes and which makes re-evaporation less likely. Thus, the tropical Atlantic serves as a temporary sink or repository for the PCBs until they can be transported northward in the northerly component of the great clockwise gyre in the western Atlantic.

It is well known that there is little transfer of surface water or lower atmospheric air masses across the equator from the North to the South Atlantic. Unfortunately, no PCB measurements have been made between 9°N and 10°S latitudes so we do not know exactly where the sharp decrease occurs.

Two environmental consequences should be mentioned as a result of our findings on PCB transport. It is somewhat ironic that the highest concentration of PCBs build up in the more biologically productive areas of the North Atlantic while the relatively barren mid-latitudes are protected from PCB build up by the geophysical processes discussed. Finally, use of PCB and other similar chemicals such as the chlorinated insecticides in the tropics will predictably have a maximum impact on the waters in those latitudes. Toxic concentrations of chemicals could easily accumulate in surface waters in a short period of time, especially during the rainy season. Since most of the DDT usage is now in the tropics, its concentration in those waters should be closely watched. ■

Phytoplankton Nutrition

Joel C. Goldman

The interrelation of marine chemistry and marine biology is one of the major puzzles in the marine environment. Senior Oceanographer Emeritus Alfred Redfield long ago posed the perplexing question: Is the chemical composition of plankton governed by the chemistry of seawater or do the chemical needs of plankton strongly influence the chemistry of the oceans? Redfield raised this question after he and others observed that the inorganic nitrogen and phosphorus concentration in oceanic surface waters became depleted at about the same time after the spring plankton bloom. It was also shown that the average ratio of these elements in plankton was similar to the proportion in which they were removed from seawater—about 15 atoms of nitrogen for each phosphorus atom. In response to these ideas, and working with Dr. Redfield, Associate Director Bostwick Ketchum was demonstrating that under conditions of prior phosphorus starvation, laboratory cultures of phytoplankton assimilate large quantities of this nutrient and, by changing the culture conditions, the nitrogen-to-phosphorus ratios within the cell can be greatly altered.

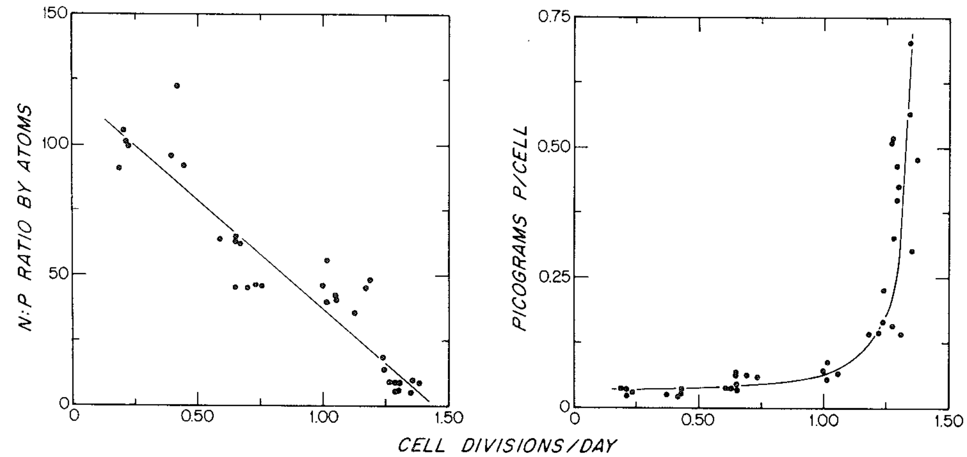
To expand on these two seemingly opposing ideas, a series of laboratory studies have been underway at the Environmental Systems Laboratory on nutrient-limited growth of phytoplankton. The continuous culture growth chambers used in these investigations have a special advantage over other types of culture devices because they allow ready manipulation of the growth rate of test algal species through control of the flow rate of the entering medium. After a period of adjustment, a steady-state population of cells is established so that the growth rate is equal to the rate at which liquid is displaced, and the number of new cells grown in the chamber is just balanced by the cells leaving.

Using the chrysophyte *Monochrysis lutheri*, we have shown that the nitrogen-to-phosphorous ratio within the cell may be as great as 100 to 1 when the growth rate is severely limited by the availability of phosphorus and reduces to Redfield's value of 15 to 1 only when the cell is growing close to its maximum rate and is no longer nutrient limited. Hence, the nitrogen-to-phosphorus ratio of oceanic phytoplankton suggests that the populations are either growing extremely rapidly or are not phosphorus limited. From other measurements, we know the former not to be true, and so we are left with the possibility that phosphorus may not be an important limiting nutrient in marine waters.

In these experiments the nitrogen-to-phosphorus ratio was largely controlled by the variable phosphorus content of the cell. Throughout the range of growth rates the cellular nitrogen content remained nearly constant, but the phosphorus content increased greatly as the phosphorus limitation decreased.

When nitrogen is the nutrient limiting growth, the nitrogen content of phytoplankton cells is also dependent on the growth rate, but less so than phosphorus.

For example, under ammonia-limited growth there is an eightfold increase in the nitrogen content per cell between low and high growth rates, whereas for phosphorus the increase is about thirtyfold. In addition, the rate of ammonia uptake is extremely rapid, indicating that the turnover time of this nutrient in natural waters is likewise fast. Hence, our inability to measure detectable levels of ammonia in oceanic surface waters may be due in large part to its rapid cycling within the marine food chain rather than to its absence. The importance of ammonia as a major source of inorganic nitrogen for phytoplankton growth in marine waters may have been grossly underrated.



Nitrogen-to-phosphorus ratio in algae growing at different rates and the phosphorus content per cell.

The chemistry of seawater is significantly affected both by the assimilation of nutrients by phytoplankton and by the subsequent oxidation of the organic matter formed by bacteria. Peter Brewer of the Chemistry Department hypothesized that the variations in alkalinity observed throughout the oceanic water column were strongly influenced by the cationic and anionic nutrients assimilated or released by microorganisms. For example, when ammonia (NH_4^+) is assimilated, hydrogen ions or protons (H^+) are released with a decrease in alkalinity; when nitrate (NO_3^-) is assimilated, hydroxyl (OH^-) ions are released, raising the alkalinity. We tested this hypothesis by growing phytoplankton in continuous culture first on ammonia and then on nitrate as a nitrogen source. As expected, there was a decrease in alkalinity with ammonia uptake and an increase when nitrate was used. The role microbes play in affecting the oceanic carbon dioxide system, particularly the formation and dissolution of calcium carbonate, needs to be re-examined.

In addition to using the continuous culture technique to answer fundamental microbial and chemical questions, it has been used as a bioassay tool in studying the effects of various pollutants on marine phytoplankton growth. In one continuous culture bioassay we compared the potential of different wastewaters from treatment plants in the Southern New England region to support phytoplankton growth when discharged to the coastal environment. In these wastewaters the nitrogen-to-phosphorus ratio is commonly about 5 to 1, even though the ratio in the phytoplankton averages 15 to 1 and in coastal waters is typically between 10 and 20 to 1. By growing a test alga in varying dilutions of wastewater with seawater we clearly identified nitrogen as the growth-limiting nutrient in coastal waters. In our assays the production of algal biomass was a linear function of the total inorganic nitrogen concentration and was unrelated to either the phosphorus level or the origin and degree of treatment of the wastewaters.

Chlorine is typically used to control condenser fouling in coastal power plants. To determine the effects of this biocide on entrained phytoplankton, the

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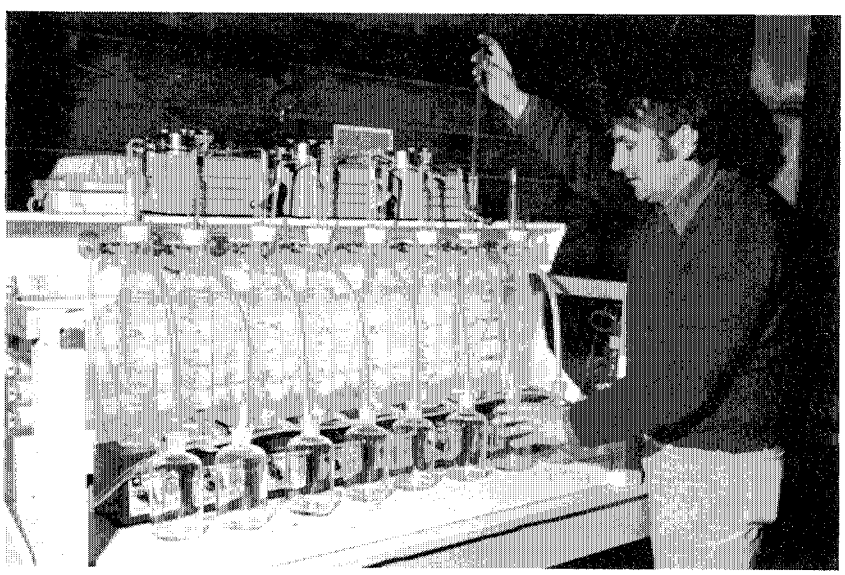
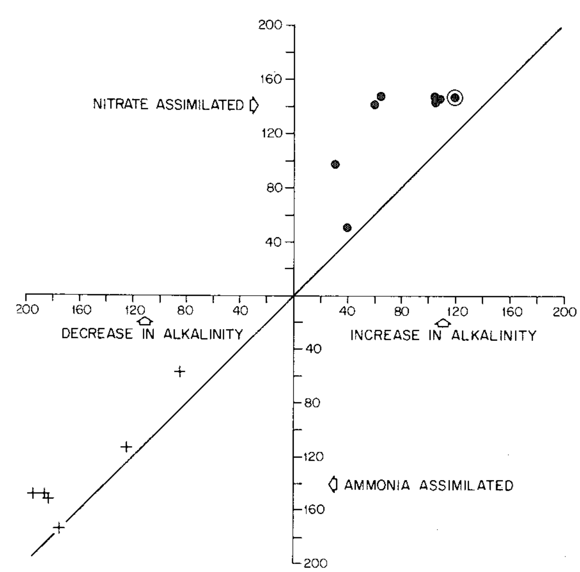


Joel Goldman works with growth chamber equipment at Environmental Systems Laboratory.



Changes in seawater alkalinity produced by nitrate or ammonia assimilation by phytoplankton in continuous culture.

continuous culture was used as a physical model of an actual power plant. A steady-state population of a test alga was subjected to sudden and temporary increases of temperature and chlorine separately and in combination. This simulates conditions the organisms would experience as they were pumped through a power plant and discharged back into the receiving water. Our results indicate that even though the entrained phytoplankton are seriously affected by chlorine, so long as they are not completely destroyed their short generation time allows them to recover rapidly. Because of this and the fact that only a small percentage of the total phytoplankton population in coastal waters is ever entrained, the effect of chlorine on the primary producers is minimal compared to its effect on organisms higher up the food chain, such as larval fish and invertebrates that are also easily entrained. ■

Electroreception in Marine Elasmobranchs

Adrianus J. Kalmijn

Marine sharks, skates, and rays are extremely sensitive to weak electric fields in their aquatic environment. Operating from direct current to a frequency of about 8 Hz, they respond to voltage gradients as low as 1/100 of a microvolt measured over a distance of 1 centimeter (0.01 μv/cm). These low-level electric fields are received in the delicate sensory structures, called ampullae of Lorenzini, located in the protruding snouts of the elasmobranch fishes.

Aquatic animals produce weak direct current and low-frequency electric fields which stem from potential differences at their skin-water interfaces—in fishes, for example, between the mucous membranes lining the mouth and the gill epithelia in the pharynx. Sharks, skates, and rays take advantage of these bioelectric fields in predation and, when motivated by odor, zero in electrically on even small prey hiding in the sand.

Elasmobranchs may also orient to the large-scale electric fields induced by ocean currents flowing through the earth's magnetic field, either to compensate for passive drift or to follow the currents during migration. Furthermore, when actively swimming through the earth's magnetic field, sharks, skates, and rays induce local electric fields that may give the animals their compass heading. Indeed, we recently successfully trained small stingrays to take their food at a position predetermined by the direction of the ambient magnetic field.

Our original behavioral experiments on electrically evoked feeding attacks were carried out under well-controlled laboratory conditions on captive sharks and skates. In order to conduct field experiments, we had to approach the animals without introducing galvanic fields or any other disturbances that might interfere with the animals' normal behavior. First, we learned from longline fishing off Cape Cod in 1976 that the predatory smooth dogfish, the shark *Mustelus canis,* regularly frequents the shallow inshore waters of Vineyard Sound on its nightly feeding excursions. We then arranged to observe the animals and analyze the electrical aspects of their feeding behavior from an inflatable rubber raft with the aid of a glass-bottom viewing box and sealed, battery-operated underwater lights.

With the raft anchored in 8 feet of water over a sand patch devoid of seaweed, we attracted the sharks to the area by chumming with macerated herring which was introduced through a polyvinyl hose running from the boat to the bottom. The chum line was attached to a polypropylene rope stretched over the ocean floor along with two pairs of salt-bridge electrodes, one on each side of the odor source and 30 centimeters from it. During the tests, a steady direct current was passed between one pair of electrodes; the other pair functioned as the control. The strength of the field corresponded to the bioelectric fields of small prey. The electrode pair to be energized could be selected at will.

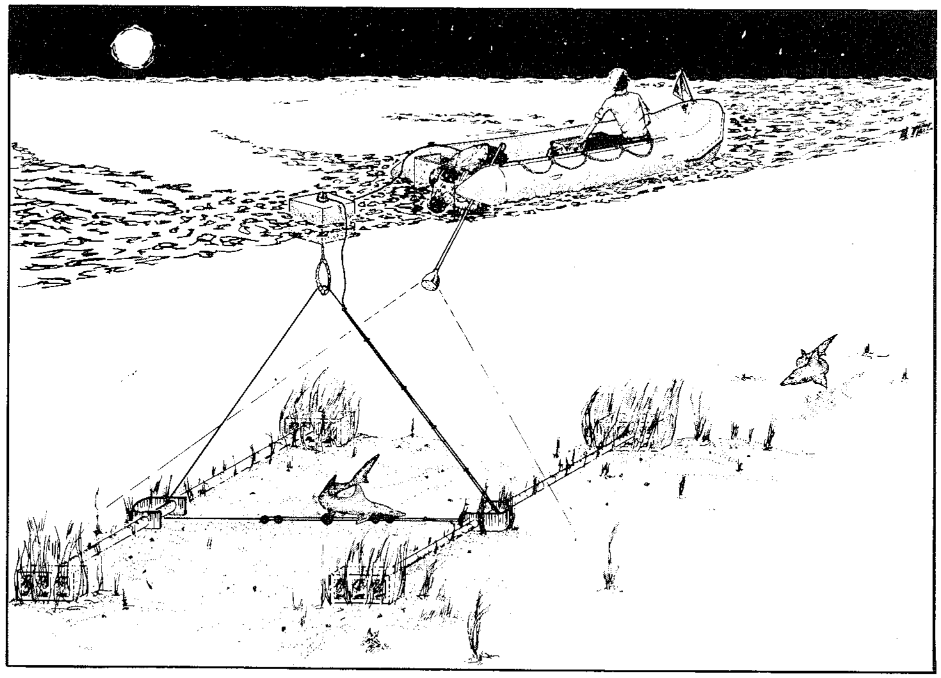
After the sharks entered the experimental area, they began searching over the sand, apparently trying to locate the presumed odor-releasing prey. Both young and mature sharks took part in our tests. Sometimes they came in alone, often, however, in packs of two to five. Remarkably enough, when nearing the odor source, they did not bite at the opening of the chum line but, from a distance of about 25 centimeters, turned sharply to the current-passing electrodes and viciously attacked the electrically simulated prey. However, they never paid any attention to the control electrodes.

These observations clearly demonstrate that sharks, freely roaming in their natural habitat, can detect and take their prey by the exclusive use of their electric sense. The experiments also show that at short range the electric fields override the usually more vague odor cues which arouse and attract the animals from a distance. The odor of a wounded prey lingers long after the animal is gone. Therefore, when following an odor trail, the sharks need more localized and precise cues to spot their prey accurately and to seize them by surprise.

Other fish also visited the experimental area, including the American eel, *Anguilla rostrata,* which has been reported to respond to weak electric fields. They, as well as some large crabs, often nibbled at the chum-line outlet, but showed no interest in the activated electrodes. However, similar tests on the electro-sensitive catfish, *Ictalurus nebulosus,* in a local freshwater pond yielded basically the same results as with the sharks.

Although the experiments have been primarily designed to study the sensory behavior of the sharks, they also strongly indicate that attacks on humans and underwater gear may be elicited and guided by electric fields resembling those of regular prey. The human body, especially when the skin is damaged, creates direct current bioelectric fields that sharks may detect from distances up to 1 meter. The galvanic fields of metals on the body usually are even stronger. Shielding the sources of electricity and diverting the sharks to alternative electrical sources which release a discouraging agent may prevent electrically-evoked shark bites.

Encouraged by the successes of our oceanic endeavors and support from the Eppley Foundation, we are presently outfitting a mobile, non-galvanic working platform (a modified Boston Whaler) for comparative studies on the electrical sensory performances of not only the shallow-water, bottom-dwelling sharks but also of the open-ocean, pelagic sharks of the Cape Cod area. The Whaler will also enable us to extend our laboratory measurements on bioelectric and inanimate electric fields to the natural habitats of the fish. Thus, our field experiments have opened up new avenues to a better understanding of the elasmobranchs' remarkable sensory abilities. ■



MICHAEL MELLO

Drawing of apparatus used to attract smooth dogfish in Buzzards Bay.

Tuna Migrations and Seawater Temperatures

Francis G. Carey

The habits and movements of the giant bluefin tuna inhabiting the North Atlantic have been under study at the Institution for some time. This mobile species shows marked changes in the pattern of its movements as it ages. The young fish, one to five years old, appear in the summer off the eastern U.S. coast between Hatteras and Cape Cod, where they are the subject of an intensive purse seine fishery. In the winter months these fish move offshore into the Atlantic, but little is known of their movements while they are far out to sea. Some of them cross the Atlantic to Europe where they appear among a concentration of small bluefin in the Bay of Biscay. Our tag returns indicate that the number of fish making such crossings varies greatly from one year to another. The small fish seem to stay in the warm water and return to our shelf waters when the summer temperature has risen to 18°C.

Bluefin tuna become sexually mature at six to eight years old and 150 to 300 pounds, when some of them start to spawn in the warm waters on the other side of the Gulf Stream at about the latitude of Cape Cod.

As they continue to grow, their behavior changes. The giant fish, now 300 to 1,000 pounds, move inshore to the rich northern bays where they feed heavily on squid, mackerel, and herring, adding up to 20% of their weight as fat during the course of this season. These summer feeding grounds extend from about the latitude of Cape Cod north through Canadian waters to Newfoundland and up to Norway on the eastern side of the Atlantic. By winter, they have moved offshore and, as with the smaller fish, we know little about their movements during that season. In the spring there are dramatic spawning migrations as large numbers of giant bluefin move north through the Straits of Florida and along the Spanish and Moroccan coasts toward their spawning grounds in the Gulf of Mexico and the Caribbean Sea in the west and the Mediterranean in the east. Then the giant fish move back to their feeding areas to complete their yearly cycle.

Temperature is a particularly interesting variable in the life of bluefin tuna. Their high body temperature—commonly 10°C higher than the surrounding water—is unusual. The giant fish appear to be able to control their body temperature to a relatively constant value, and we think that this ability makes it possible for them to tolerate an extreme range of temperatures—from near 30°C as they pass over the Bahama Banks to 6°C in northern waters. Thus they can take advantage of the large amounts of food available in the nutrient-rich northern waters during the summer and yet move to tropical areas where conditions are suitable for spawning and the development of their young. Though we have no experimental evidence yet, we expect that the more limited range of the small fish is related to the absence of an ability to control temperature.

One intriguing question about the giant bluefin is how they find their way across the great ocean distances they travel in their yearly cycle. What routes do they follow and what clues do they use? We have made a beginning toward answering these questions with a series of acoustic telemetry experiments. A small transmitter is attached to a hooked fish which is then released and followed. The transmitter broadcasts information on the water temperature or depth, and by using a bathythermograph on the tracking vessel we can infer depth from water temperature or vice versa. We have records from sixteen bluefin now; one of them extends over 2½ days and 130 miles. The fish were captured in shallow areas but most of them moved toward deep water on release. With some interesting exceptions, the fish seemed to respond to thermal gradients. They commonly swim just beneath the warm mixed layer, not in the warmest water, or in the cold depths, but right in the sharp gradient of the thermocline. This suggests that the fish may be using the steepest part of the thermal gradient to orient their depth. This may be a good position for finding food or for joining other tuna, as these are schooling fish.

The next step in these experiments is to move from shelf water, where most of our work has been done, into the open ocean to follow a fish on its long journey north from the Straits of Florida. Such an experiment will tell us whether the fish move with the Gulf Stream or out across the Sargasso Sea. From satellite sea-surface temperature pictures, we will be able to tell if the route is affected by thermal fronts or eddies, and from bathythermograph data we will learn the water temperature features at the depth selected by the fish. ■

Water and Sediments

Seawater-Rock Interactions

Geoffrey Thompson

The sea receives materials from several sources but those from the rivers far exceed those from any other source and provide some 90% of the total oceanic inputs. The composition of average river water is very different from that of seawater, not only in the total salt content (130 ppm vs. 35,000 ppm) but in the relative proportions of the various anions and cations. Only the chloride, sodium, and magnesium ions are relatively more abundant in sea salt than in river salt. Thus a simple evaporative process would not change rivers to oceans but would produce a highly alkaline, sodium bicarbonate-rich lake. The sea does not have an infinite capacity to receive salt-laden stream supply; for instance, silica would require only 20,000 years to double its present oceanic amount. Therefore, there must be reactions occurring in or at the boundaries of the oceans that not only remove excess inputs but "reproportion" or "buffer" those inputs to give seawater the composition we see today.

Most chemical oceanographers are agreed that the ocean composition has not greatly changed over the past tens of millions of years so that the inputs must be balanced by losses. We do not know what controls the chemical composition, what the reactions are, and whether they are a function of equilibria laws and thus independent of the rate of input or are kinetically variable and change to balance changes in input rates. In any event, to evaluate a chemical mass balance between rivers and oceans we must seek the input and output fluxes and the reactions controlling present seawater composition.

With present knowledge, we cannot adequately balance all cation budgets, particularly the alkaline (sodium and potassium) and alkaline earth (calcium and magnesium) metals, nor can all the inferred reactions between aluminosilicate minerals and seawater be observed. We have not been able to balance the anion budgets and have had to invoke direct input of volatiles such as water and chloride and sulfate ions from the earth's mantle by some degassing mechanism.

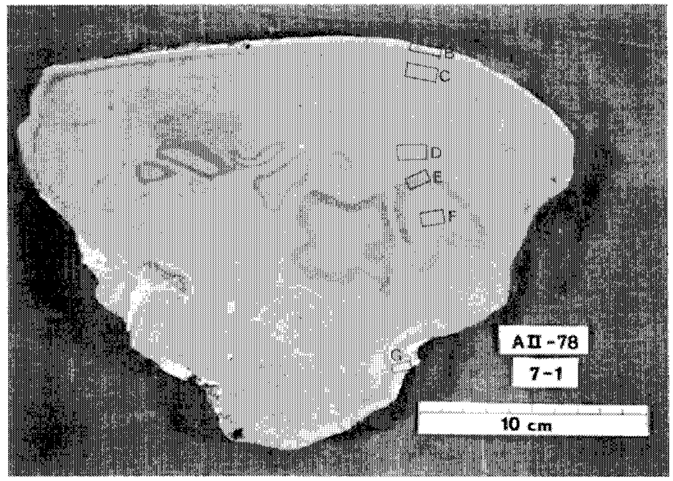
Constituent or Ion	Mean River Water ppm	Mean River Water % in salt	Mean Seawater ppm	Mean Seawater % in salt
Chloride (Cl^-)	7.8	6.02	19,000	55.12
Sodium (Na^+)	6.3	4.87	10,500	30.46
Magnesium (Mg^{2+})	4.1	3.17	1,300	3.77
Sulfate (SO_4^{2-})	11.2	8.65	2,650	7.69
Potassium (K^+)	2.3	1.78	380	1.10
Calcium (Ca^{2+})	15	11.58	400	1.15
Bicarbonate (HCO_3^-)	58.4	45.10	140	0.41
Silicate (SiO_2)	13.1	10.12	6	0.02
Nitrate (NO_3^-)	1	.77	—	—
Iron (Fe^{2+})	0.67	.52	—	—
Aluminium (Al)	0.01	.008	0.001	<<.01
Bromine (Br^-)	—	—	65	0.19
Carbonate (CO_3^{2-})	—	—	18	0.05
Strontium (Sr^{2+})	—	—	8	0.02
Dissolved Organic Carbon	9.6	7.41	0.5	<.01
Total	129.5	100	34,467	100

Major constituents dissolved in river and sea water and their proportions of the salt content.

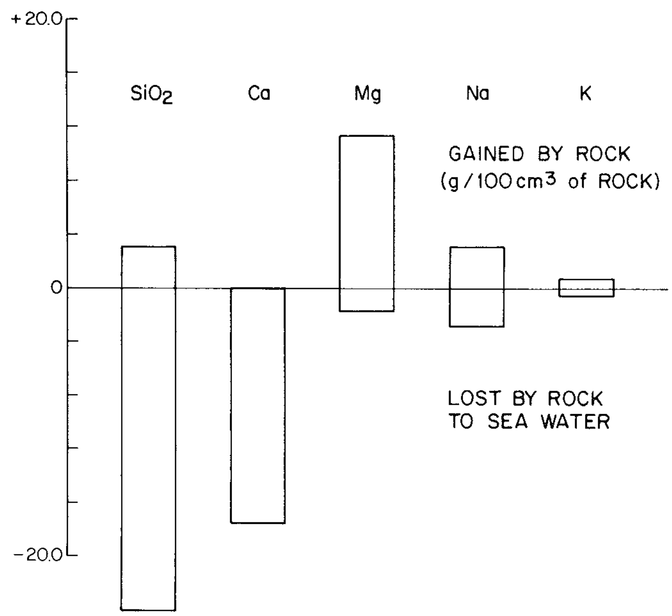
The imbalance in cations could be explained if the inputs into the oceans have changed drastically in geologic time, or if seawater has changed in composition over the past few million years, of if there are fluxes and reactions occurring in the oceans which we have not yet recognized. Since the bulk of geologic and isotopic evidence does not favor the first two inferences, we must look to the third possibility.

Much of the past work by geochemists, chemical oceanographers, and physical chemists indicates that complex reactions and fluxes must be involved in sediment-seawater interactions. We now know that during sea floor spreading, at the diverging plate margins, new mantle-derived igneous rock is exposed and made available for reaction with seawater. A few years ago our work on the petrology and geochemistry of these new mantle inputs indicated that igneous rocks exposed on the sea floor undergo slow reactions with seawater at ambient bottom temperatures. These weathering reactions take place over millions of years and over large areas of the sea floor. Also, where hot igneous rocks are extruded near the mid-ocean ridges, some have undergone reactions with the heated seawater. Indirect evidence from geophysical observation implies that seawater must circulate through the new crust in quite large amounts and at rapid rates in order to remove much of the heat that accompanies the formation of new crust. The presence of metal-rich sediments on active ridges also supports the idea that these circulating solutions may leach metals from the igneous rocks and concentrate them on the sea floor.

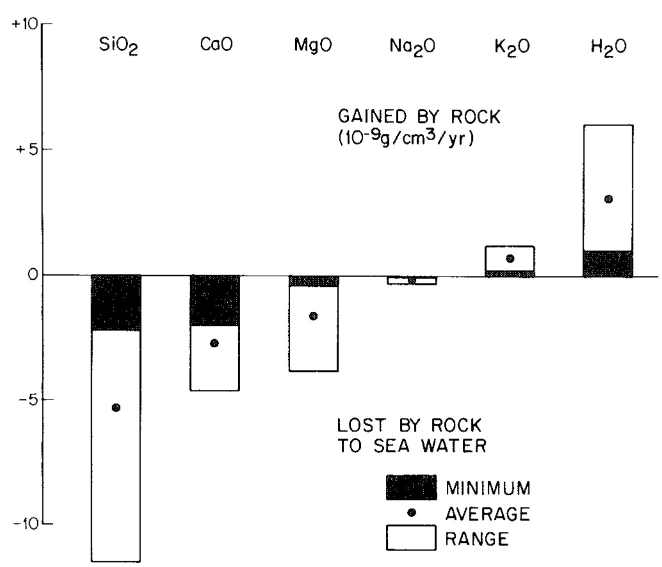
The hypothesis we are testing is that the seawater-igneous rock interface on the sea floor provides a critical source and sink for various ions and is an important reaction site in the control of the composition of seawater. To test this hypothesis we have to learn which ions are exchanged between rock and seawater and what is the magnitude and rate of the reaction. Are the fluxes large enough to be considered significant in the geochemical mass balance? Our calculations are based on direct observations and analyses of sea floor rocks, mostly erupted volcanics known as basalt, the most abundant igneous rock



Basalt altered by seawater and showing various reaction zones. Squares indicate where sub-samples were taken to assess changes in composition.



Hydrothermal alteration of oceanic basalt.



Low temperature weathering of oceanic basalts.

on the sea floor. The chosen samples have undergone various degrees of alteration at high or low temperature, but sufficient unaltered material remains so we can make precise mass balances between original and altered material to calculate directions and elemental fluxes.

Hydrothermal alteration is caused by interactions between basalts and seawater at elevated temperatures in regions close to the diverging plate margins (i.e., mid-ocean ridges). These processes result in significant element exchange between the solid and liquid phases. New mineral phases formed are indicative of temperatures from 100–400°C. The measured fluxes for some of the cations indicate that this is an important and significant sink for magnesium and a potential source for oceanic and sedimentary silicates and calcium. Elements leached from the rocks also include strontium, iron, manganese, copper, nickel, zinc, boron, lithium, and barium. In addition to magnesium, water is gained by the rock, and the exchanges of sodium and potassium appear about equal in each direction. *In situ* solutions rich in metals can be produced and may precipitate and concentrate these ions into iron-sulfide ores or iron and manganese oxide and hydroxide phases dependent on the local chemical environment.

During low temperature weathering, considerable amounts of silicon, calcium, magnesium, and sodium are slowly lost from the basalt while water and potassium are progressively gained by the rock from seawater. This reaction is probably significant in acting as a major sink for the alkali elements potassium, rubidium, and lithium. These fluxes could remove excess river inputs if 0.1 to 1.5 kilometers of igneous crust has been weathered over a period of eighty million years.

Major unknowns in our calculations are the amounts of rock altered—we are now working actively on rocks recovered by the Deep-Sea Drilling Program to give us some indication as to the depth in the basement seawater can penetrate. Other important areas of investigation include direct observation and analysis of the fluid phase after reaction; so far we have only looked at the altered rocks and some ores precipitated from the solution. A major program is now underway using the deep submersible *Alvin* to sample hot springs where heated seawater that has reacted with igneous rock is being debouched back onto the ocean floor on the Galapagos Rift. Analyses of that solution and rates of debouching will be important in further assessing the geochemical fluxes. ■

Radioactive Tracers in the Sea: Tritium-Helium Dating

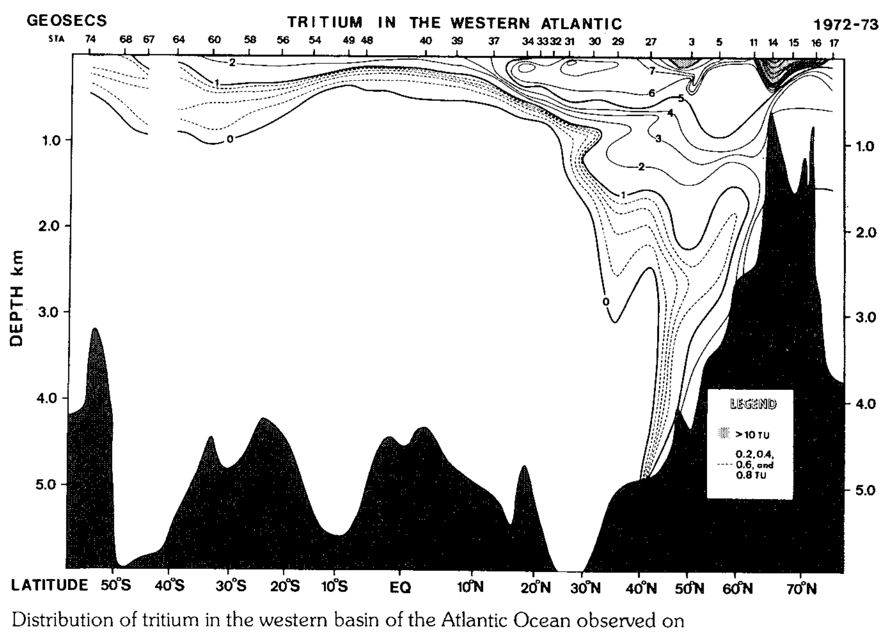
William J. Jenkins

One of the major concerns of modern oceanography is to understand the rates of biological, chemical, and physical processes that occur in the sea. Such understanding will help us to evaluate man's impact upon his environment. Unfortunately, such knowledge is not easily obtainable, because a study of the steady-state behavior of the oceans does not readily yield the dynamics of the processes responsible for what we see. This is very much akin to trying to deduce the tone and quality of a bell by just looking at it.

One approach to gaining such information is to study the distribution of transient radioactive tracers in the oceans. Testing of nuclear weapons during the 1950s and 1960s produced a number of radioactive elements in a pulse-like fashion, and these chemicals have since been redistributing themselves in the environment. The study of how they do this can yield valuable information on the dynamics of physical processes in the oceans.

One of these radio-tracers, tritium, the heaviest isotope of hydrogen, is penetrating into the Atlantic Ocean. Throughout most of the North and South Atlantic, the distribution is limited to the upper kilometer, the waters above the permanent thermocline. In the North, the area of the Labrador Sea, however, the tritium penetrates to greater depths. In this area, deep and bottom water is being formed and sinking to greater depths, carrying the tritium with it.

While much information can be gained from this kind of study, such information is necessarily large-scale and general, and it is often ambiguous because we are



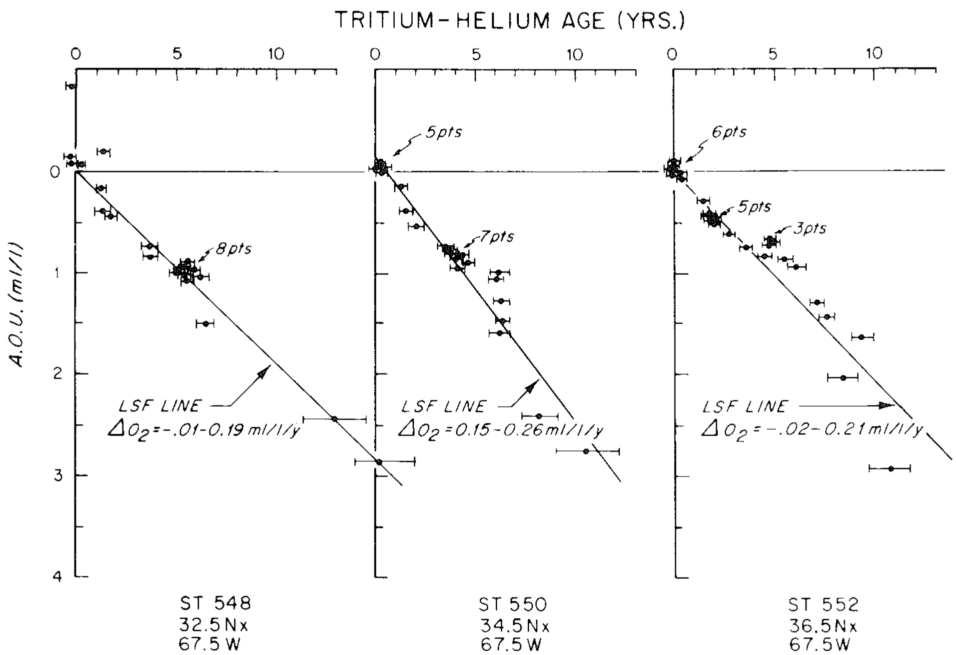
Distribution of tritium in the western basin of the Atlantic Ocean observed on GEOSECS cruise by H. G. Östland of the University of Miami.

using but one tool to discern many complicated processes. Fortunately, there is a method for looking at finer scale processes which yields a different type of information. Since tritium (^3H) is radioactive, it is transformed by radioactive decay at a fixed rate to the stable, nonradioactive isotope, helium-3 (^3He). In any given sample, half of the tritium converts to helium-3 in 12.3 years. This relationship can be exploited in the oceans to "date" water masses, much as carbon-14 has been used to date archeological artifacts.

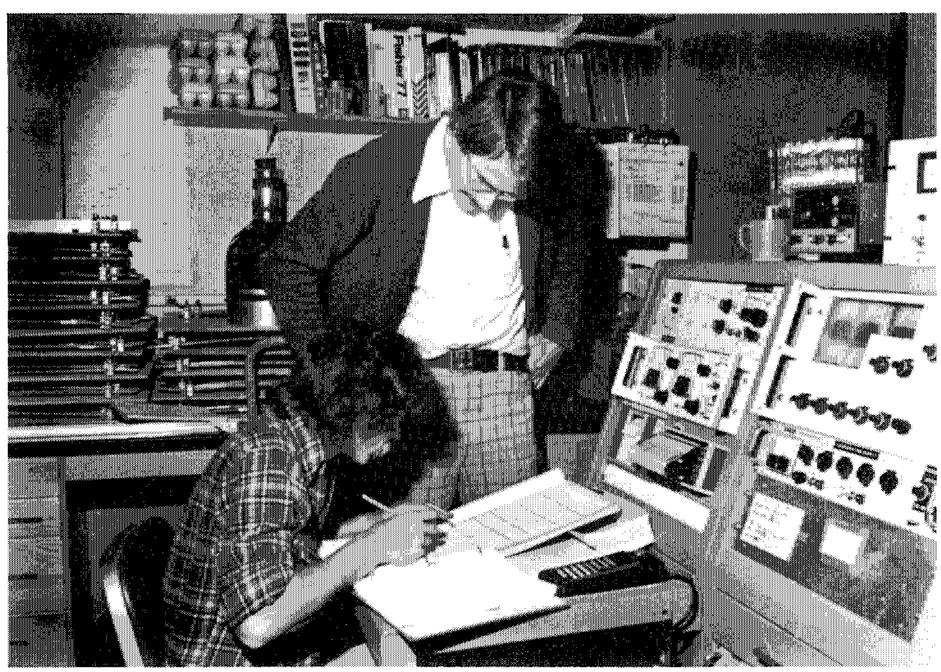
At the sea surface, tritium is continually decaying and producing helium-3 which then escapes into the atmosphere. However, when the parcel of water sinks below the surface and loses contact with the atmosphere, this helium-3 can no longer escape and therefore begins to build up at a rate controlled by the amount of tritium originally present. The clock is now ticking away. At any time, "τ," we can take a sample of water, and by determining the amount of tritium and "tritiugenic" helium-3, we can calculate the time elapsed since the parcel was at the sea surface. In an area such as the Sargasso Sea, we can detect times as short as two months using this technique. Only half a dozen laboratories in the world can measure the low-level oceanic tritium, and only one other laboratory can measure helium-3 with the sensitivity required for this kind of study.

This clock has been used to time the rate of oxygen changes in the sea. Photosynthesis produces oxygen, but since it is light-dependent it occurs only near the sea surface, where gas exchange tends to maintain dissolved oxygen concentrations near solubility equilibrium values. Below the surface, biological activity in the absence of light results in a net consumption of oxygen in the process of the decomposition of organic matter. No longer in equilibrium with the atmosphere, the dissolved oxygen concentration decreases as time goes by producing the oxygen minimum layer in the ocean. It should, therefore, be possible to use the "tritium-helium clock" to calibrate the "oxygen clock" and thereby determine an oxygen utilization rate.

The figure at right shows such a calibration for three stations in the Sargasso Sea. The apparent oxygen utilization is the deficit of oxygen compared to what would normally be dissolved from the atmosphere by water of the observed salinity and temperature. This is related to the time since the seawater was last at or near the surface as determined from the tritium and helium content. The slope of the relationship, as denoted by the straight lines, represents the rate at which oxygen is utilized. Three things are evident from this diagram. First, since all of the lines essentially intercept zero, the "tritium-helium" and "oxygen" clocks are both set to zero in the surface, as we had originally assumed. Second, the slopes are quite similar, suggesting a uniformity of conditions in the Sargasso Sea. The average rates of oxygen consumption at these three stations range from .19 to .26 milliliters of oxygen per liter per year (ml/1/yr). Third, there appear to be significant and systematic deviations from



Apparent oxygen utilization as function of the tritium-helium age.



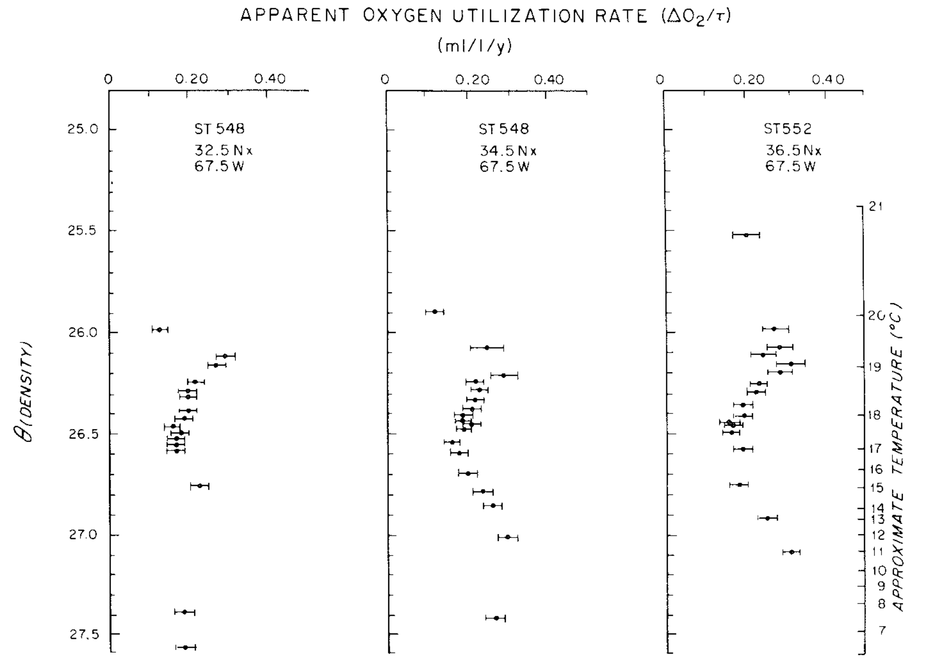
FRANK MEDEIROS

Bill Jenkins, standing, and Dick Boudreau at mass spectrometer used to analyze water samples for tritium and helium content.

the general trends, which can be investigated by taking our analysis one step further.

If we perform the calibration for each individual sample by dividing the oxygen deficit (ΔO_2) by the tritium-helium age (τ), we can obtain complete profiles of apparent oxygen utilization rates (AOUR) — see figure. In this case, we've plotted the AOUR as a function of density, rather than depth, to enhance the station-to-station correspondence. A given water mass maintains its density, but may appear at different depths at various stations as a result of internal waves or ocean currents. Since density increases with depth, these profiles resemble roughly what one sees as a function of depth. The apparent oxygen utilization rate for all three of these stations is vertically identical for a given density, and the values differ by no more than the error of estimate, shown by the horizontal line for each data point. The rate is not constant with depth but tends to be at minimum values at mid-depths.

What is clearly evident is that this technique of tritium-helium dating can yield valuable and detailed information on the rates of physical, chemical, and biological processes in the sea. When coupled with other biological and chemical measurements, this technique could lead to the first determinations of quantitative causal relations between the rates of chemical (and biochemical) reactions in the sea and the biological and chemical environments in which they occur. ■



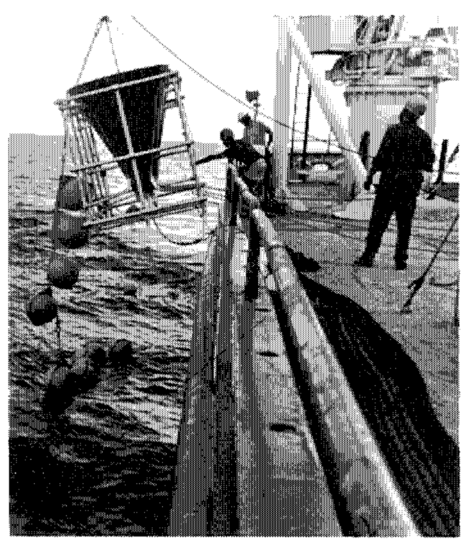
Apparent oxygen utilization rate as measured by tritium-helium dating for three locations in the Sargasso Sea.

Settling Large Particles

Susumu Honjo

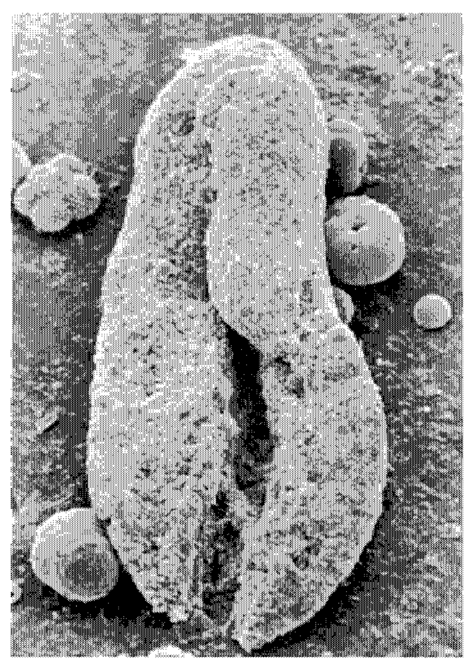
Since the discovery of abyssal fauna by the *Challenger* expedition a century ago (1872-1876), the sedimentary mechanism for transport of nutrients and other substances to the sea floor has been the subject of oceanographers' speculation. Most of the organic material is produced in the illuminated surface layers by photosynthesis, but the ubiquitous bottom-dwelling organisms, a mile below, must eat. What mechanisms transport the near-surface produced organic matter to these depths?

Studies of particles in the ocean have shown that their size distribution may be described as an exponential function with median diameters of 2 to 8 millionths of a meter (μm) and larger particles are rare. However, a sphere of 20 μm, for example, contains one thousand times



NANCY GREEN

Large-particle sediment trap is launched from *R/V Knorr*. Up to five traps are in the water at once —see mooring diagram on next page. Plastic-covered glass balls provide floatation.



MARGARET GOREAU

Electron micrograph of copepod fecal pellet typical of large particles discussed here. Outer membrane has decomposed. Close-up of exposed surface is shown on page 32.

more volume than one of 2 μm. With a density of about 1.4, the larger sphere would sink at a velocity of 10 meters per day while the smaller one would take about one hundred days to settle the same distance. Despite the low abundance of larger particles, the exponential increase in mass and sinking velocity with size shifts the predominant fraction of mass flux of settling particles to the larger size ranges.

The fecal pellets of planktonic organisms are one source of large particles. Over 95% of plant matter produced in the pelagic environment is eventually eaten by zooplankton. Food uptake by filter feeding zooplankton is not controlled by physiological demand but by an automated filtering process. When excess food is present, they become glutted and the excess food and skeletal particles are ejected as calorie-rich fecal pellets.

The probability of catching scarce large particles with conventional hydrocasting equipment, such as Niskin bottles, is exceedingly low. One of the alternative tools for collecting such rare and fast sinking large particles is a sediment trap. Direct evidence of fecal transport was obtained by sediment trap experiments in the Tongue of the Ocean and in the Central Sargasso Sea. Many of the particles consisted of excellently preserved calcareous shells (coccoliths) from a wide variety of species, and diatoms and clay minerals were also common, as expected. A large number of small fecal pellets was also collected and examined in detail under electron microscopes. The morphology indicates that these pellets were produced by small zooplankton, such as copepods. Some larger pellets appeared to be from tunicates and other larger animals. The pellets range from 100 to 500 microns in diameter.

A cylindrical pellet of approximately 60 x 200 microns sinks 150 meters per day. At the moment of voiding, the surface of a copepod pellet is covered by a protective surface cover called a peritrophic membrane. Time series exposure of such fresh pellets to seawater demonstrated that microbial activity degrades peritrophic membranes in several minutes at 27°C, in several hours at 20°C, and in several days at 15°C. Biodegradation virtually stops at 5°C, so

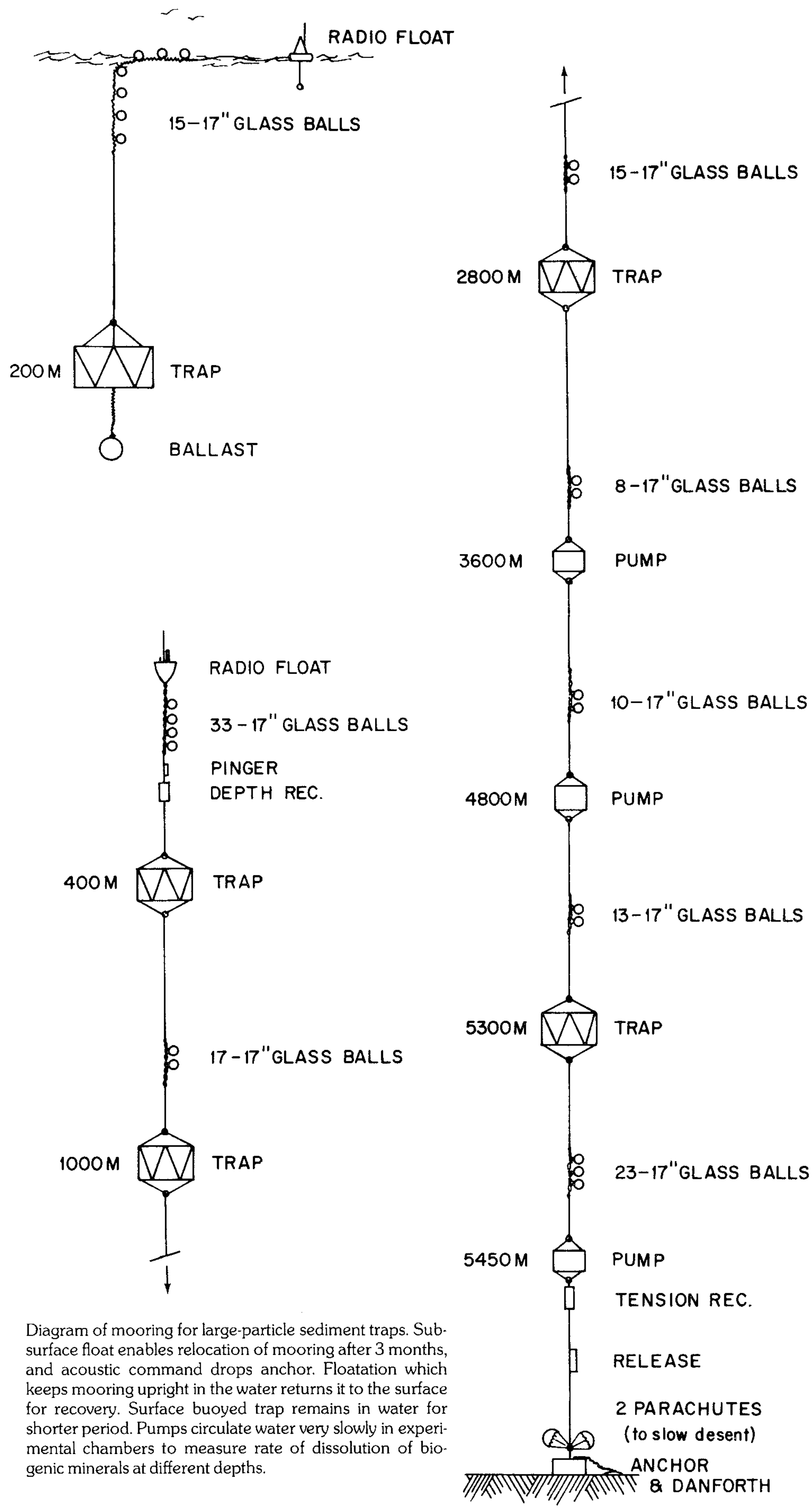
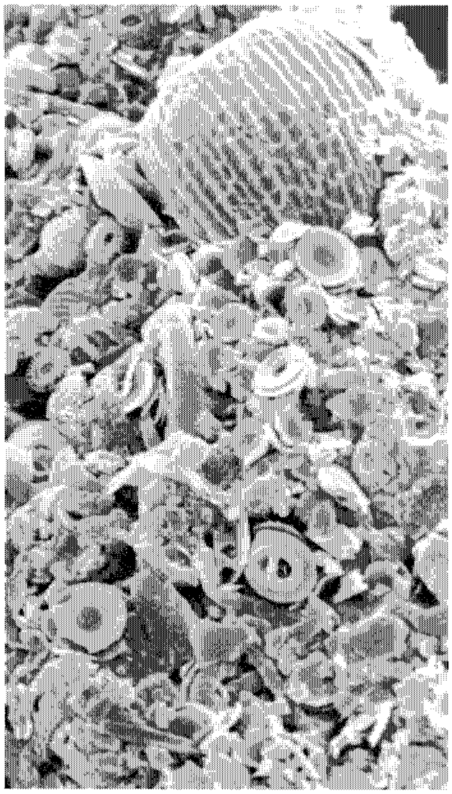


Diagram of mooring for large-particle sediment traps. Subsurface float enables relocation of mooring after 3 months, and acoustic command drops anchor. Floatation which keeps mooring upright in the water returns it to the surface for recovery. Surface buoyed trap remains in water for shorter period. Pumps circulate water very slowly in experimental chambers to measure rate of dissolution of biogenic minerals at different depths.

MARGARET GOREAU



Electron microscope magnification of fecal pellet shows partially digested cell material of phytoplankton consumed by near-surface organisms.

if a pellet can reach the 5° isotherm, usually located at about 1,000 meters, the chance of its reaching the bottom significantly increases.

When the surface membrane of a pellet is perforated by partial biodegradation, the fluid contents and associated nutrients diffuse out as the pellet descends a short distance. Strongly biodegraded fecal pellets usually are found in shallow water and in lower latitudes where the water temperature is high. The decomposition of the membrane and partial release of the contents may explain, in part, the recycling mechanism of critical nutrients such as phosphorus, nitrogen, and organic carbon in shallow water over the continental shelves. Solid matter remains inside the membrane, however, and the pellet keeps descending in deeper water. Dispersion of the contents of a pellet continues throughout sinking, and the expelled particles remain in the water column as suspended particles. Thus, the flux of large particles may be one of the major means of nutrient transport to the ocean floor as well as the source of suspended particulates in the water column. ■

Benthonic Foraminifera and Late Pleistocene Oceanography

George P. Lohmann

Oceanographers have traditionally traced deep water masses by delineating the spatial distributions of their physical and chemical properties. Recent work at the Institution has shown that, where these deep water masses impinge upon the bottom sediments, characteristic assemblages of deep-living benthonic foraminifera are found. Because the remains of these organisms are eventually preserved and gradually buried in oceanic sediments, they are uniquely valuable in reconstructing the history of deep water circulation. These fossil, benthonic foraminifera thus preserve a geological record of the ecological response of once-living organisms to the ephemeral physical and chemical properties of the overlying bottom water. The sediments at various depths in the core can be dated, and, since the assemblage of benthonic foraminifera identifies the water mass present when the sediment was formed, these data can be used to trace the deep water masses through time.

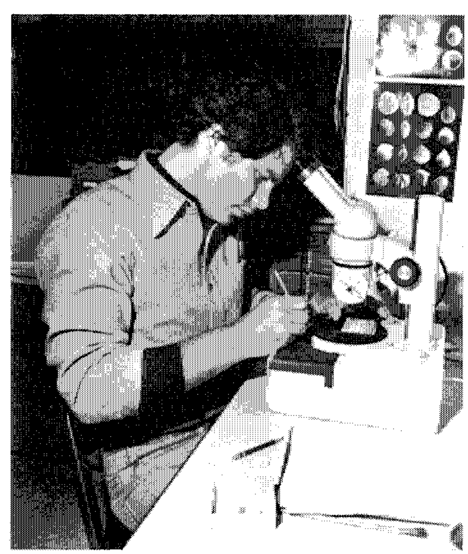
The three principal deep water masses of the Western South Atlantic today can each be characterized by their benthonic foraminiferal fauna. Where Antarctic Bottom Water (AABW), the deepest and coldest deep water, intersects the sea floor, the local benthonic foraminiferal fauna is characterized by the predominance of a single species, *Epistominella umbonifera*. The overlying North Atlantic Deep Water (NADW), a warmer, highly oxygenated water, is characterized by a much more diverse assemblage, particularly *Pyrgo, Nummoloculina, Quinqueloculina, Planulina wuellerstorfi,* and *Cibicidoides kullenbergi*. This water mass is bounded above and below by the Circumpolar Water (CPW), a deep water mass depleted in oxygen and associated with a unique fauna characterized by *Uvigerina peregrina* and *Globocassidulina subglobosa*.

During cruises of *Atlantis II* in 1971 and *Chain* in 1974, bottom cores were obtained along the sloping sides of the Rio Grande Rise in the Western South Atlantic Ocean. Because of the sloping sides, one can reconstruct a vertical profile showing the distribution at various depths in the water column of the foraminiferal assemblages and their associated water mass not only for present-day conditions but also, at various depths within the core, for positions occupied by these water masses at different times in the geologic past.

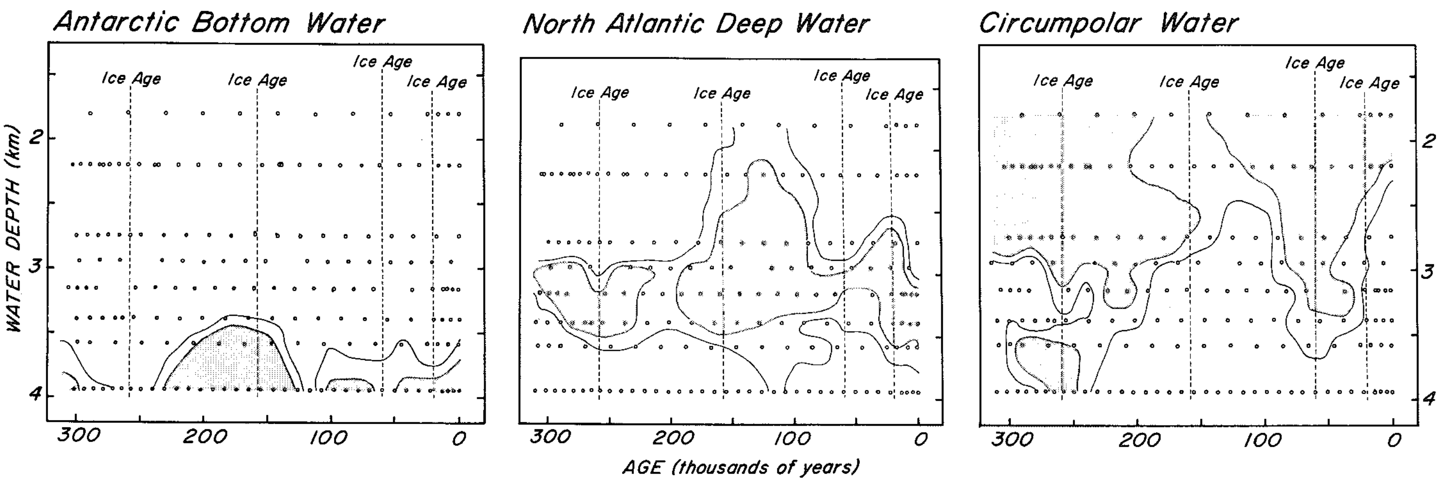
The carbonate content of the sediment is a gross measurement of the total abundance of foraminifera, since the fossilized tests are made of carbonate material. During the last several hundred thousand years, the earth has experienced ice age climates at 260, 160, 70, and 20 thousand years ago. The carbonate deposition during these glacial periods for each ice age was less than the deposition rate during interglacial periods.

A study of the benthonic foraminifera in these cores has made it possible to reconstruct Late Pleistocene deep oceanography of the Western South Atlantic and to examine the response of the deep ocean circulation to glacial-interglacial climatic changes. Marked changes in the abundance of the three major deep water masses of this area have occurred as evidenced by the presence of the characteristic foraminiferal

FRANK MEDEIROS



Pat Lohmann uses microscope in separating tiny fossils by type.

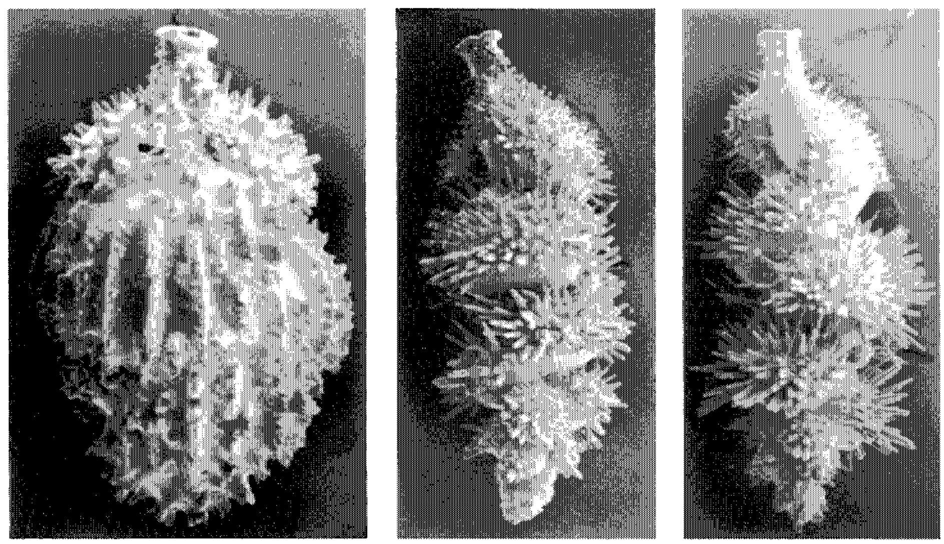


Variation in the amount and distribution of various deep water masses as derived from the forminiferal fauna.

fauna in sediments at various depths on the sloping bottom of the Rio Grande Rise. The foraminiferal fauna which is today associated with Antarctic Bottom Water shows major variations with time in the amount of this water present in the deep Western South Atlantic. During the ice age 260,000 years ago, there was much less Antarctic Bottom Water than there is observed today, but, by contrast, there was much more of this water during the period from 170,000 to 230,000 years ago. During the ice age of 260,000 years ago, when the Antarctic Bottom Water was absent, its place was apparently taken by the Circumpolar Water.

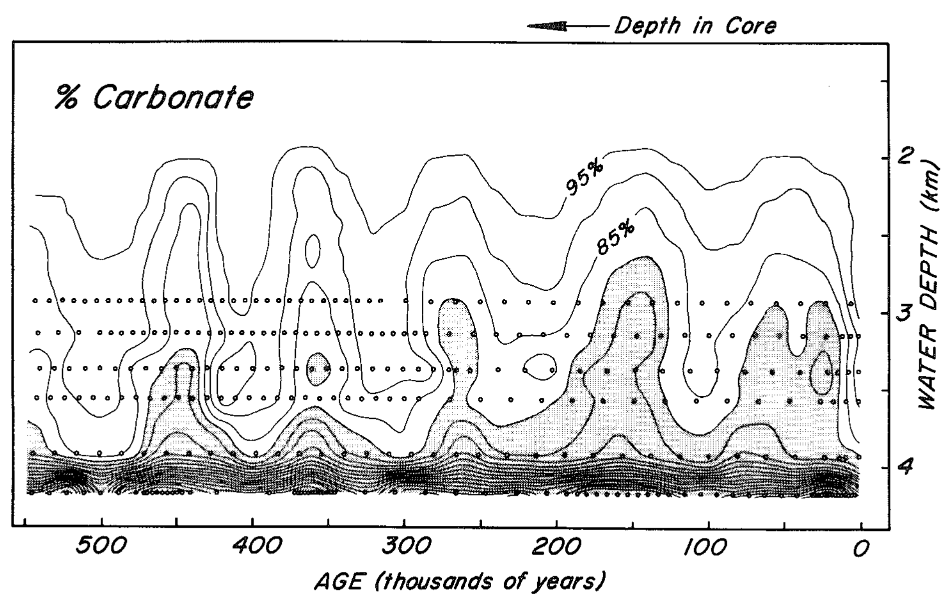
At shallower depths, above 3.5 kilometers, the amounts of North Atlantic Deep Water and Circumpolar Water have varied widely during the Late Pleistocene as indicated by their associated fossil benthonic foraminifera. Water at these depths during the ice ages 20,000 and 160,000 years ago was predominantly North Atlantic Deep Water. By contrast, during the ice ages 70,000 and 260,000 years ago, the deep South Atlantic was dominated by the Circumpolar Water.

As reconstructed from the benthonic foraminifera, the deep ocean has, at different times, responded in quite different ways to the occurrence of an ice age. During certain ice ages the production of deep Atlantic waters increased over present levels, and the Western South Atlantic was filled with North Atlantic Deep Water and Antarctic Bottom Water at the expense of Circumpolar Water. During other ice ages, production of Atlantic deep and bottom waters nearly ceased.■

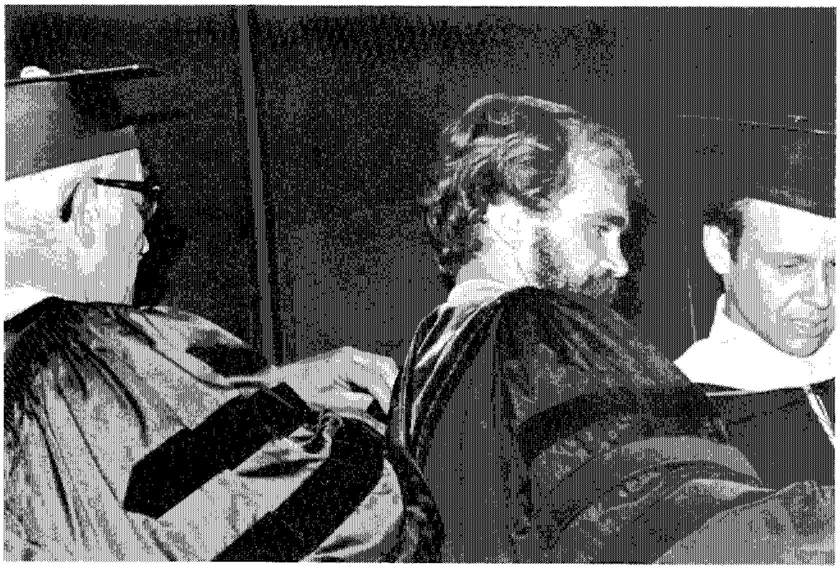


MARGARET GOREAU

Uvigerina peregrina Cushman and *U. auberiana* d'Orbigny are characteristic species of Circumpolar Water benthonic foraminiferal fauna preferring deep waters with high dissolved nutrient content and low oxygen.



Periodic variations in the carbonate content of deep sea sediments during the last 500,000 years. Times of decreased carbonate deposition (shaded) were ice ages.

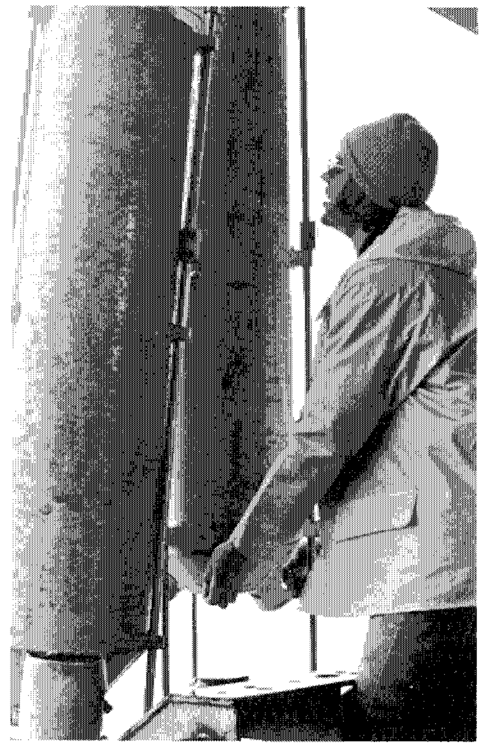


Dr. Fye adjusts hood of biology graduate Andrew Jahn who talks with Assistant Dean Jake Peirson at Clark Laboratory ceremony in June.

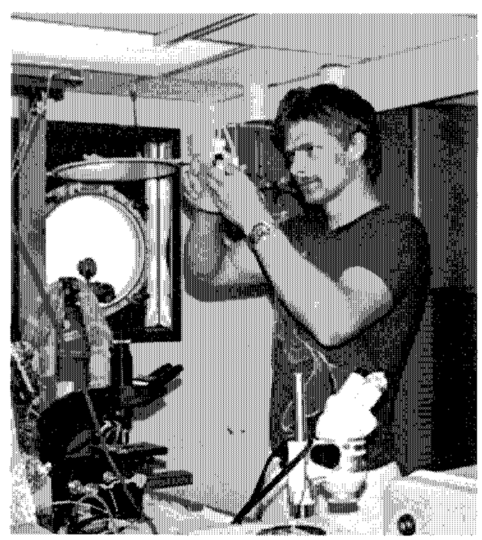
Brad Butman ('75), George Wong ('76), students Jamie Austin and Susan Humphris, and Rich Jaffee ('76) gathered after ceremony before celebration clambake.

Wong receives congratulations from the Director as Peirson waits to present gift to new graduate following commencement address.

Chemistry student Mary Scranton works in *Atlantis II* laboratory during Indian Ocean cruise.



Chemistry student Bob Anderson handles water sampling bottles aboard *Knorr* in eastern Atlantic.



Biology student Neil Swanberg prepares scuba-collected samples in laboratory of *Oceanus*.

REPORT OF THE DEAN OF GRADUATE STUDIES

The Institution awarded its first independent Ph.D. degree at a special ceremony held at the Clark Laboratory in June of 1976, and 11 doctoral degrees were awarded during the year in the Joint Program with the Massachusetts Institute of Technology. The names of the degree recipients are listed on the next page.

The award of an independent graduate degree in oceanography by the Woods Hole Oceanographic Institution was made possible under the charter modification of 11 November 1967. The principal framework for our graduate program since then has been a joint endeavor with MIT. It had, however, always been contemplated that this would be supplemented by an independent degree program, and this was authorized by the Trustees in 1970. Subsequently, four students have been enrolled in the Woods Hole Program. Since 50 doctorates have been awarded under the Joint Program and its current enrollment is nearly 80 students, it is obvious that the award of our first independent degree has primarily symbolic significance. This point was made by Director Paul M. Fye when he spoke at the June commencement:

The degree we confer today . . . does not represent the first product of this Institution's commitment to graduate education. It is more accurate to say that this first independent degree represents the full maturation of the Institution's educational development which was launched some eight years ago. In short, the milestone we mark today is the coming of age of this Institution as a center for advanced education, as well as for research.

Dr. Fye then went on to review the developments in graduate education at the Institution since 1967:

Our most significant accomplishment has been the successful integration of a formal educational program into the research life of the Institution. Indeed, it is worth emphasizing that education could never be truly successful here unless it became but another dimension to our research activities.

The successful development of a formal graduate program without changing the basic framework of the Institution required the efforts and commitment of many individuals — staff, students, and administrators alike. We have had to learn a great many things. Some were mundane, though unavoidable, such as how to adjust to the crazy schedules and travels of oceanographers. Other problems have been more fundamental, such as learning how to balance staff members' educational efforts with their research work and how to give full credit for their total accomplishments when the time came for reappointment or promotion. It was critical to the success of our educational efforts to address this problem fairly and forthrightly because a heavy responsibility for the educational program has fallen primarily on the shoulders of our younger staff members.

Several years ago when we were considering how to go about the establishment of a graduate program, two policy decisions were made which later events have shown to have been critical to the success of our program. One was the decision to avoid any distinction between our research and our educational staff . . . . Fortunately, we resisted the temptation to create a separate educational staff and instead chose the harder but more fundamental task of building education into all aspects of the Institution's life.

The second important policy choice made at the outset was the decision to have a partnership with MIT. We entered an agreement novel in higher education: a partnership of two independent institutions for the purpose of awarding a single degree. The joint educational effort with MIT has been a striking success among a variety of institutional arrangements which have been tried across the country. Both institutions have benefited enormously because they were willing to set aside parochial concerns for the sake of a common goal. From the perspective of the Woods Hole Oceanographic Institution, the joint agreement meant that we could build a graduate program by concentrating on what we could do best.

The awarding of the first independent degree by the Institution inevitably raises questions about the relative emphasis the independent program might be given in the future vis-à-vis the Joint Program. Dr. Fye emphasized that the event did not imply any change in emphasis, that it simply represents another alternative. We expect the independent doctorate to be limited, at least in the near future, to specialized situations where the Institution is uniquely qualified to meet the needs of a given student.

Dr. Fye described the students who have been attracted to our new endeavor in what are perhaps his most significant remarks:

The essential ingredient in the success of our new graduate program has been the students who have been attracted to it. Not only have they been intellectually outstanding, but they have, it seems to me, been equally outstanding in the personal qualities of independence and initiative.

The group of 12 Ph.D.'s who graduated in 1976 well justify Dr. Fye's remarks. All of them fully capitalized on the research opportunities available within our graduate programs. One student, for example, covered most of the North Atlantic by participating in 14 different Woods Hole cruises. In acquiring data for his thesis he made 127 scuba dives in the open ocean. Another student, whose thesis was on the structure of the Mid-Atlantic Ridge, participated in Project FAMOUS, a comprehensive study of a part of the Ridge using the submersible *Alvin* and a wide range of geological and geophysical measurements from several surface ships. Not only did this student have the opportunity to work in the expedition as a colleague with scientists from several institutions, but he also had immediate access to the vast range of data from the project.

Perhaps the most objective evidence that the 1976 graduates contributed vigorously to the research life of the Institution is the fact that the 12 of them were authors or co-authors of 40 scientific publications *while* they were graduate students. Amazingly enough, one of them authored or co-authored 11 scientific papers before receiving the Ph.D.

ROBERT W. MORSE

DEGREE RECIPIENTS — 1976

Woods Hole Oceanographic Institution
Doctoral Degree Program

Doctor of Philosophy

ANDREW E. JAHN
B.S., University of California, Davis
Special Field: Biological Oceanography
Dissertation: *On the Midwater Fish Faunas of Gulf Stream Rings with Respect to Habitat Differences between Slope Water and Northern Sargasso Sea*

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

Doctor of Philosophy

MICHAEL P. BACON
B.S., Michigan State University
Special Field: Chemical Oceanography
Dissertation: *Applications of Pb-210 and Ra-226 and PO-210/Pb-210 Disequilibria in the Study of Marine Geochemical Processes*

DOUGLAS C. BIGGS
B.A., Franklin and Marshall College
Special Field: Biological Oceanography
Dissertation: *Nutritional Ecology of* Agalma okeni *and Other Siphonophores from the Epipelagic Western North Atlantic Ocean*

EDWARD A. BOYLE
B.A., University of California, San Diego
Special Field: Chemical Oceanography
Dissertation: *The Marine Geochemistry of Trace Metals*

ROBERT B. CAMPENOT
B.A., Rutgers University
Special Field: Biological Oceanography
Dissertation: *Effects of High Hydrostatic Pressure on Neuromuscular Transmission in Shallow-Living and Deep-Living Crustaceans*

DALE B. HAIDVOGEL
S.B., Massachusetts Institute of Technology
Special Field: Physical Oceanography
Dissertation: *The Sensitivity and Predictability of Mesoscale Eddies in an Idealized Model Ocean*

RICHARD J. JAFFEE
Sc.B., Brown University
Special Field: Ocean Engineering
Dissertation: *The Effect of Internal Waves on Long Range Acoustic Propagation in the Ocean*

KEITH E. LOUDEN
B.S., Oberlin College
M.Ed., Temple University
Special Field: Marine Geophysics
Dissertation: *The Origin and Tectonic History of the Southwest Philippine Sea*

KENNETH C. MACDONALD
B.S., University of California, Berkeley
Special Field: Marine Geophysics
Dissertation: *Detailed Studies of the Structure, Tectonics, Near-Bottom Magnetic Anomalies and Microearthquake Seismicity of the Mid-Atlantic Ridge Near 37°N*

TRACY McLELLAN
S.B., Massachusetts Institute of Technology
Special Field: Biological Oceanography
Dissertation: *Functional Anatomy of the Macrouridae (Teleostei, Gadiformes)*

KENNETH A. POEHLS
B.S., University of California, Los Angeles
Special Field: Marine Geophysics
Dissertation: *Geomagnetic Variations in the Northwest Atlantic: Implications for the Electrical Resistivity of the Oceanic Lithosphere*

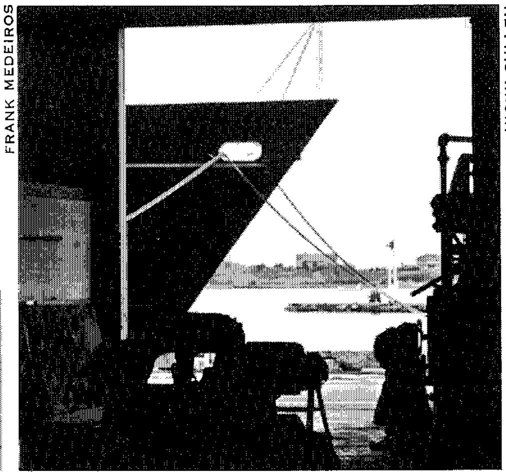
GEORGE T. F. WONG
B.S., California State College at Los Angeles
Special Field: Chemical Oceanography
Dissertation: *Dissolved Inorganic and Particulate Iodine in the Oceans*


FRANK MEDEIROS

Dolores Chausse at computer terminal.


FRANK MEDEIROS

Asterias in Woods Hole harbor.


VICKY CULLEN

Bow of *Knorr* viewed from Iselin shop.

ASHORE and AFLOAT

ATLANTIS II carried the U.S. Bicentennial flag all the way across the Indian Ocean in 1976 during extensive multidisciplinary studies of the least known of the world's oceans. Studies during a dozen legs of Voyage #93 included a detailed examination of the junction of the Antarctic, African, and Indian plates, physical oceanography at the equator around 53 degrees east, deep circulation investigations, and definition of the structure and evolution of the Banda Island arc and the Banda Sea region.

Three executive appointments were announced in January. Joseph Kiebala was named Assistant Director for Administration; he came to the Institution from a position as Vice President for Business Affairs at Wellesley College. Capt. Robertson P. Dinsmore became Chairman of the Facilities and Marine Operations Department following several years based at the Institution as Executive Secretary of the University-National Oceanographic Laboratory System. John I. Ewing came to Woods Hole as Chairman of the Department of Geology and Geophysics from the Lamont-Doherty Geological Observatory of Columbia University, where he was Associate Director and Adjunct Professor of Geology.

Knorr, Alvin, and *Lulu* embarked in February on the second major expedition to tectonic plate spreading centers of the world as they traveled to the Cayman Trough in the Caribbean. Field operations of the highly successful Project FAMOUS (French-American Mid-Ocean Undersea Study) in 1974 had provided man's first view of deep ocean volcanic terrain with 15 dives on the Mid-Atlantic Ridge. Another 15 dives in the Cayman Trough early in 1976 provided scientists with 75 sampling and observation stations in investigations of steep 6,000-foot scarps discovered on either side of the Trough. The expedition's seismic equipment was deployed just after a major earthquake in nearby Guatemala, and the scientists recorded the aftershocks of the second large quake in the series centered between Cuba and Jamaica. These were the first recordings ever made of major shocks on a subsea boundary.

K. O. Emery received the Rosenstiel Award in Oceanographic Science for 1975 at the Annual Meeting of the American Association for the Advancement of Science in Boston in February. The award consists of $5,000, a certificate, and an invitation to spend a week of lectures and discussion at the Rosenstiel School of Marine and Atmospheric Sciences at the University of Miami. The award citation read: "for outstanding studies and syntheses of the continental margins and marginal seas of the world, for effectively bringing this knowledge to bear in national and international forums concerned with oceanographic science and marine resources, and for an unparalleled record in training many of today's leading marine geologists."

A February testimonial dinner was held for Associate Scientist Frank J. Mather III in New Orleans in connection with the Marine Recreational Fisheries Symposium of the Sport Fishing Institute. The occasion was "in recognition of thirty years devoted to the advancement of man's understanding of pelagic big-game fishes . . . His scientific studies concerning migrations, exploitation rates, mortality, and biology of billfishes, tunas, and other oceanic game fishes have contributed to a growing international awareness of the finite nature of fish stocks, concern for the condition of certain species and, in many nations, a growing resolve to protect species that are particularly threatened by overfishing and an altered environment."

Following completion of pierside outfitting in Woods Hole, *Oceanus* embarked on her first full-scale research cruise in mid-April with a short voyage for mooring recovery, equipment testing, and topographic surveying. The following longer cruise was devoted principally to deep benthic trawling on the lower continental rise and abyss between Woods Hole and Bermuda. She carried out a full schedule of research cruises during the rest of the year and also made a special 1 July voyage to take some 200 Corporation Members and Associates to watch the Tall Ships parade out of Narragansett Bay. The ship's library was dedicated August 3 in the name of Max C. Fleischman, whose foundation granted the Institution funds in 1971 for design work on a new ship, which eventually became *Oceanus*. The library dedication was followed by a short demonstration cruise for special guests Anna J. Harrison, member of the National Science Board; Mary Johrde, head of the National Science Foundation Division of Oceanography; and Oceanographer of the Navy Rear Admiral J. Edward Snyder, Jr.

The ninth J. Seward Johnson Marine Policy Lecture was presented in May by Dr. Vincent E. McKelvey, Director of the United States Geological Survey. His topic was "The Oceans: International Policy Frontiers." Following a review of the history of ocean policy, jurisdictional, and management problems, Dr. McKelvey related some of his experiences as a representative to the Economic and Technical Subcommittee of the United Nations Committee on Peaceful Uses of Seabed and Ocean Floor Beyond the Limits of National Jurisdiction. He also discussed some of the issues and problems of the Law of the Sea Conference.

The first graduate degree granted solely by the Woods Hole Oceanographic Institution was presented in June to Biologist Andrew Jahn. The Dean's Report on page 35 gives details.

Institution Provost Arthur Maxwell began a two-year term as president of the 10,000-member American Geophysical Union on 1 July.

A telegram to the Director from the Soviet Research Vessel *Akademik Kurchatov* received 2 July read, "By request of the scientific staff and crew members of the 22nd cruise of the Research Vessel *Akademic Kurchatov* as well as from us personally, we send W.H.O.I. people our best greetings in connection with this outstanding day of your state history. Wish you and all our friends in W.H.O.I. success in oceanography and our joint programs. Sincerely, Victor Neyman, Leader of Expedition, and Nikolay Apekhtin, Captain."

During the summer, *Alvin* participated in a study that reflects the growing environmental and energy concerns about nuclear wastes. The sub facilitated the recovery for the Environmental Protection Agency of a low-level radioactive waste container that had lain in 2,800 meters of water for some 15 years. Guided by photos taken from *Alvin* the previous year and the sub's precise navigation system, a net-like bridle specially designed at the Institution was dropped over the chosen drum to distribute lifting weight and prevent any rupture, as the end-strengh of the drum was unknown. The container was then lifted aboard the escort vessel for transfer to Brookhaven National Laboratory.

A study conducted by several Marine Policy and Ocean Management Fellows on "Effects on Commercial Fishing of Petroleum Development off the Northeastern United States" was published during the summer. The cooperative effort of several policy fellows and a fisherman, the report discusses the nature and character of interactions to be anticipated between the fishing and oil industries, identifies specific areas of conflict and cooperation, and makes recommendations for minimizing conflict and maximizing cooperation.

Dr. Robert Ballard, Associate Scientist in the Geology and Geophysics Department, was announced as the recipient of the 1976 award for science from the Underwater Society of America in recognition of his work early in the year as chief scientist for the expedition to the Cayman Trough spreading center.

The Annual Associates Day of Science brought more than 200 guests to Woods Hole early in October for lectures on extended fishing jurisdiction, salt marshes, physical observations of an Antarctic polar front, and electromagnetic response in marine and freshwater fish. There were also openhouse visits to laboratories, exhibits, and lectures throughout the Institution.

A massive oil spill off Nantucket in late December from the grounded tanker *Argo Merchant* took *Oceanus* on two blustery cruises to take samples in the area expected to be affected by the spill. There was also extensive sampling in the intertidal area on Nantucket to provide baseline information against the possibility, fortunately unrealized, that the oil might come ashore there.

Atlantis II spent Christmas of 1976 at sea as the ship steamed from Singapore to Goa, India. Work on the cruise included retrieval of a mooring set in the spring and underway sampling and profiling designed to aid understanding of equatorial ocean response to monsoon forcing.

Alvin made December test dives in the Bahamas for the 1977 diving season to bring the year's dive total to 90, a new annual record.

IN MEMORIAM

W. Van Alan Clark, Sr.

7 December 1887 — 14 October 1976

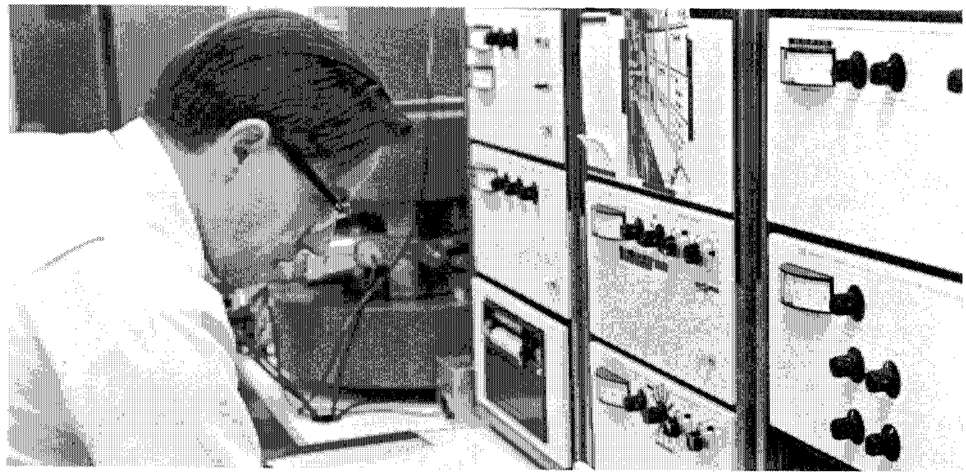
W. VAN ALAN CLARK and his wife, Edna McConnell Clark, who survives him, have inspired and encouraged the scientific accomplishments of the Institution as neighbors, benefactors, and special friends for more than two decades.

Mr. Clark was among the early friends of the Institution who began the active Associates Program. He became a member in 1953 and a Life Member in 1970. He was elected a Member of the Corporation in 1967 and an Honorary Trustee in 1970. He had served on the Trustees Quissett Campus Building Committee since 1973. The Clarks' contributions and constant interest helped us initiate the Graduate Education Program in 1968 and assisted significantly in the construction of the Clark Laboratory, which bears their name. Their inspiring advice, affectionate concern, and enthusiasm for the Woods Hole Oceanographic Institution has been expressed in faithful attendance at Corporation meetings, Associates functions, and other Institution activities.

The Clark Laboratory fulfilled a vision of the Clarks. In regard to their 1968 contribution to the education program, Mr. Clark said, "There is a time when things begin to fit together. The facts are clear — the importance of the oceans of the world, the need for highly skilled oceanographers, the concentration of research talent in Woods Hole — all indicate that now is the time here at the Institution to develop what will be the world's best program for training future oceanographers." On the occasion of the dedication of the Clark Laboratory in 1974, he added, "If you want to plant for the future, plant men and women in an environment where they can grow and bear fruit for the common good." To this end, he gave of his time, encouragement, wise counsel, and inspiration.

Following completion of a degree in engineering at Cornell University, Mr. Clark's early positions were with Consolidated Gas of New York, Astoria Light, Heat and Power of New York, Brooklyn Union Gas, the U.S. Shipping Board Emergency Fleet Corporation, and Avon Products, Inc. Since his retirement as Chairman of the Board of Avon Products, he has been Honorary Chairman.

Mr. Clark's other interests have included serving as Director of the Rockland National Bank, Vice President of the Rockland County Council of the Boy Scouts of America, and he was a member of the American Chemical Society of New York State.



Max Blumer

3 August 1923 — 11 February 1977

SENIOR SCIENTIST MAX BLUMER, a native of Switzerland, joined the chemistry staff of the Institution in 1959. For biographical notes accompanying a 1976 article in *Scientific American*, he wrote, "I have been fortunate in finding an environment where I could remain intimately involved with the experiment. Nature is too complex and my anticipation of the unexpected is too limited to allow me to delegate most observations. This attitude has been rewarded many times when I have suddenly found a consistent explanation for seemingly independent observations, often separated by many years." He was the author of 99 publications in geochemistry and analytical chemistry and five publications in electronics as well as co-author of two patents.

Following completion of his Ph.D. at the University of Basel and postdoctoral research years at the University of Minnesota and the Scripps Institution of Oceanography, Dr. Blumer worked for several years in European Shell Oil Company laboratories where he began work with hydrocarbons that would continue through his career. He did extensive analysis of water, sediment, and organism samples from the area polluted by the West Falmouth oil spill in 1969. On the basis of this work, he called for worldwide assessment of the influx of petroleum to the ocean, extreme caution in the use and transportation of petroleum, and research into the impact of oil pollution on the marine environment.

In a tribute to Blumer, Chemistry Department Chairman Derek Spencer and another friend and colleague, Senior Scientist Vaughan Bowen, wrote: *Max Blumer has had a distinguished career marked with major contributions to organic geochemistry. Although there have been many individual highlights in his work, it is the dedication to new knowledge and his constant drive to press analytical techniques to their ultimate resolution that have given the touch of greatness to his endeavors. In 1950 Max published his first report of "fossil pigments" in Swiss carbonate rocks of marine origin; in 1961 he published his first report of the concentrations of carcinogenic hydrocarbons in soils. His research ever since has been animated by two themes: first, the chemical diversity to be observed in nature and its significance in organic chemistry; second, questions posed by the distribution of toxic and carcinogenic organic compounds throughout the environment, often from man's activities. But an even longer-standing interest in the niceties of quantitative analytical chemistry can be seen to have pervaded each step of his work. It has never been enough to Max to know that petroleum hydrocarbons were released or that pigments were present; so long as an analytical procedure existed that could show which specific compounds and their relative abundance, he pursued this knowledge ruthlessly and often with the result of improving by several quantum jumps the sensitivity or precision of his chosen techniques. His stimulation, example, and leadership will continue to be vital factors in the development of environmental chemistry.*

William Charles Schroeder
10 January 1895 — 12 January 1977

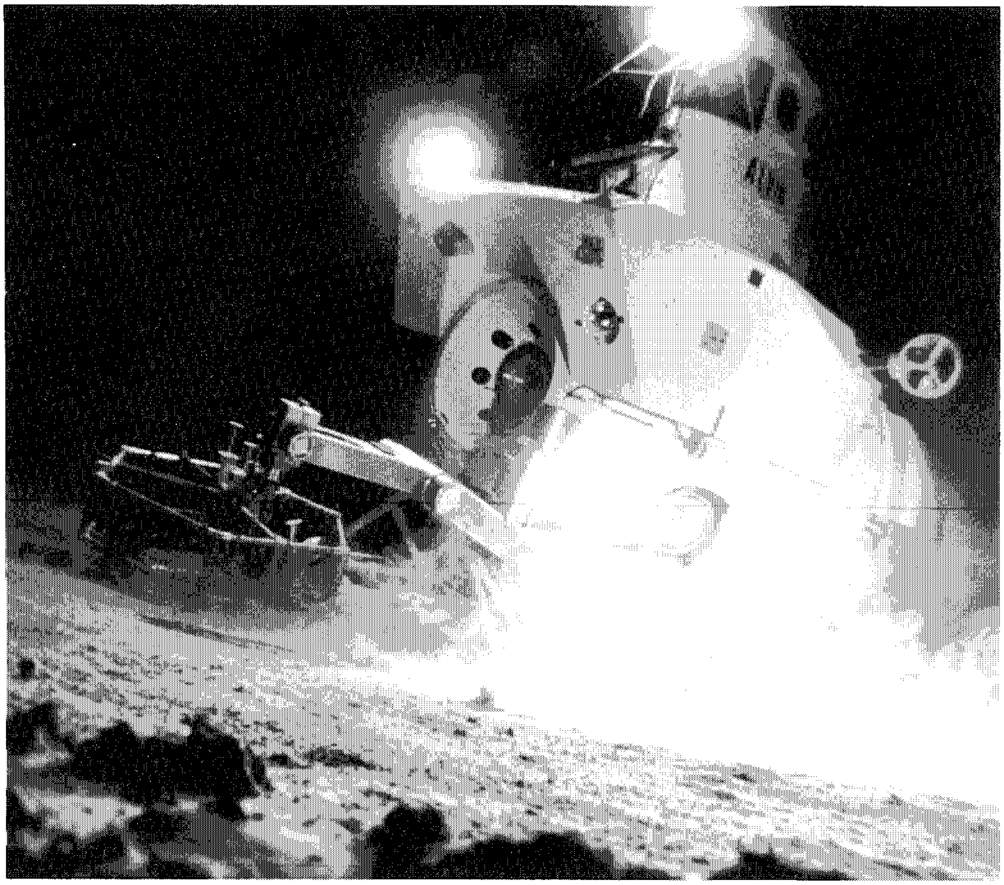
WILLIAM CHARLES SCHROEDER was part of the Woods Hole Oceanographic Institution nearly from its beginning. He was then in his upper thirties and well along in his career as an ichthyologist. When I first met him, a few years earlier, he was with the old Bureau of Fisheries. He had begun working at the Museum of Comparative Zoology about 1924 along with several other Bureau of Fisheries people encouraged and invited by Dr. Henry B. Bigelow. Schroeder collaborated increasingly with Dr. Bigelow and in 1936 received a museum appointment as Associate Curator of Fishes.

In the meantime, he had followed Dr. Bigelow to Woods Hole, where in May 1932 he was appointed Business Manager, a job he stayed with until soon after World War II, when he was appointed Ichthyologist. During most of the first twenty years of the Woods Hole Oceanographic Institution, there were no professional administrators; from Director on down, such duties were discharged by active scientists. I remember Dr. Bigelow telling why he had just picked Schroeder for Business Manager: "Bill's the only marine scientist I know who can pinch a nickel harder than I can."

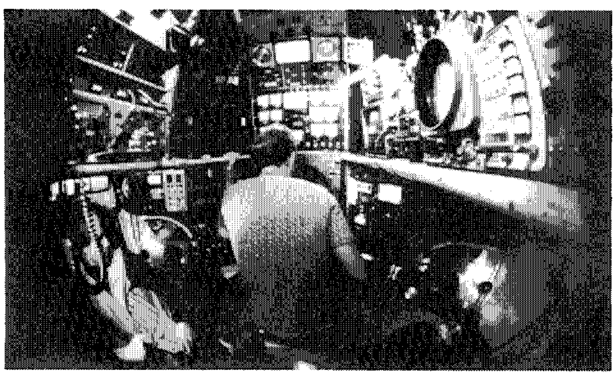
This was an accurate analysis, all right, but it touched only part of Schroeder's character. He was unsparing of his own effort and patience in helping others in matters ichthyological and social. The hospitality of Bill and Ada Schroeder was widely known and respected. Schroeder's unassumingly modest but extensive generosity in personal affairs, including his ichthyological expertise as well as his genial sociability, contrasted sharply with his rigorously conscientious parsimony in institutional matters large and small. Schroeder exasperated the skipper of Atlantis, *Capt. Fred McMurray, by his consistent refusal to supply the ship with Major Grey's chutney, much admired by the captain as an essential addition to curry. It cost 99¢ a bottle, nearly an order of magnitude more than the lesser sauces available. Said Schroeder: "I wouldn't buy anything that expensive for the table." Said McMurray: "But we only use it on condemned meat." No use, no chutney. (For years I used to bring the ship a bottle when I went on a cruise.)*

But while a few old-timers remember Schroeder at the lunches in Young & Yee's in Cambridge, or as host in his big house in Newton, or out in Woods Hole harbor with Dr. Bigelow fishing for tautog during lunch hour, he is more widely remembered for his solid scientific contributions to ichthyology (a considerable body — some sixty — of systematic papers and books, many as co-author with Dr. Bigelow) and to fisheries (both his earlier work in the Bureau of Fisheries and such later contributions as pointing the way to our local deep water lobster fishery).

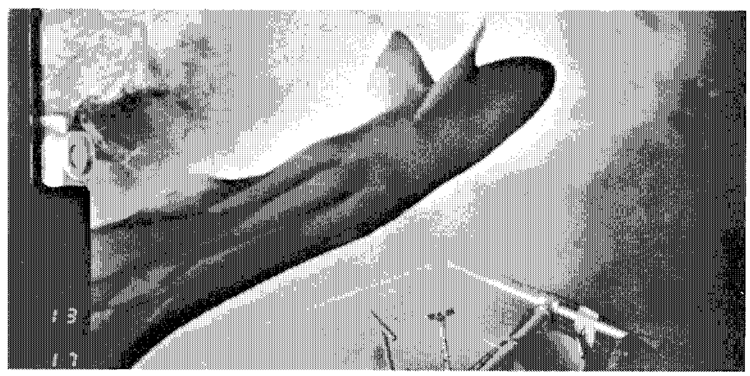
• William E. Schevill



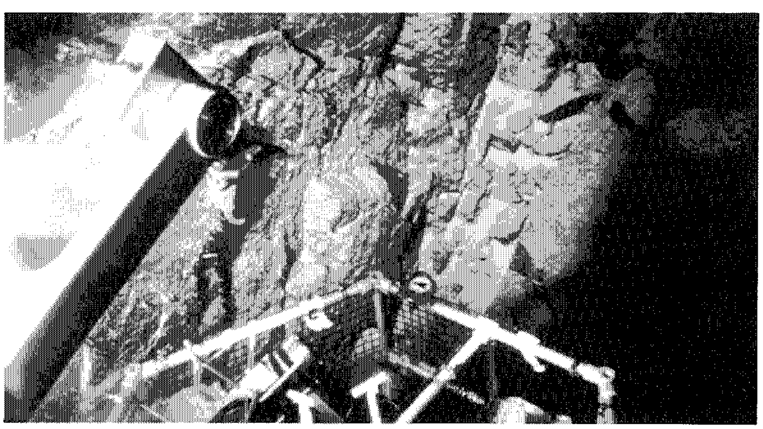
This photograph of DSRV *Alvin* was taken at 3,000 meters in the Caribbean's Cayman Trough with a camera developed by the National Geographic Society and Benthos Inc. Camera and strobe were carried to the depths in the sub's sample basket and then placed on a ledge with the mechanical arm. A photoflash from *Alvin* triggered the camera and its strobe for the portrait. Photo equipment was then retrieved, and the diving work continued. The Cayman Trough expedition was the second major exploration of a tectonic plate spreading center boundary (the first was the French-American Mid-Ocean Undersea Study — Project FAMOUS — with major submersible work on the Mid-Atlantic Ridge in 1974).

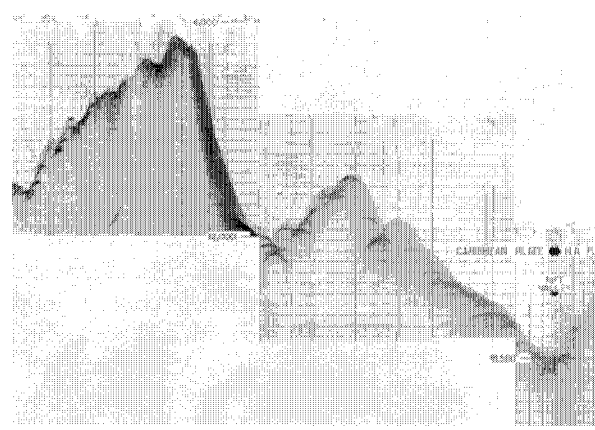


Two-meter personnel sphere is packed with equipment and three people. The pilot, back to camera, looks out of forward viewport to maneuver sub and manipulate equipment.



Meter-long cirrate octopus, rarely seen alive, was photographed in the Cayman Trough by an automatic camera mounted in the upper body of *Alvin*. Fins resembling ears aid the animal in swimming.





Surveys just before the diving began revealed steep scarps on either side of the Cayman Trough. Contours of the Caribbean plate side of the trough are shown in the seismic profiles at right. The base of these scarps occurs just at *Alvin's* 3,660 meter (12,000 foot) depth limit, so the sub was able to take a suite of samples right up the face of the fault. *Alvin* made 15 dives in the Cayman Trough.

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Larry Haas views samples at ESL.

VICKI MCALISTER

Larry Madin, standing, and Bob Campenot check plankton net haul.

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WILLIAM M. DUNKLE, JR., *Research Associate*
KENNETH O. EMERY, *Senior Scientist*
Henry Bryant Bigelow Oceanographer
ROBERT G. GOLDSBOROUGH, *Research Associate*
BILAL UL HAQ, *Associate Scientist*
Adjunct Docent, University of Stockholm
JAMES R. HEIRTZLER, *Senior Scientist*
CHARLES D. HOLLISTER, *Associate Scientist*
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SUSUMU HONJO, *Associate Scientist*
Adjunct Professor, Syracuse University
DAVID A. JOHNSON, *Associate Scientist*
SYDNEY T. KNOTT, *Hydroacoustics Engineer*
DONALD E. KOELSCH, *Electronics Engineer*
GEORGE P. LOHMANN, *Assistant Scientist*
JOHN D. MILLIMAN, *Associate Scientist*
Non-resident Staff Member, West Indies Laboratory, Fairleigh Dickinson University
DAVID M. OWEN, *Research Associate*
JOSEPH D. PHILLIPS, *Associate Scientist*
KENNETH E. PRADA, *Electronics Engineer*
GRAHAM M. PURDY, *Assistant Scientist*
DAVID A. ROSS, *Associate Scientist*
Visiting Instructor, Fletcher School of Law and Diplomacy; Visiting Instructor, Massachusetts Institute of Technology
HANS A. SCHOUTEN, *Associate Scientist*
COLIN P. SUMMERHAYES, *Assistant Scientist*
RUDOLF C. TJALSMA, *Assistant Scientist*
ELAZAR UCHUPI, *Associate Scientist*
ALLYN C. VINE, *Senior Scientist*
KEITH VON DER HEYDT, *Research Associate*
RICHARD P. VON HERZEN, *Senior Scientist*
DAVID WALL, *Associate Scientist*
WARREN E. WITZELL, SR., *Hydroacoustics Engineer*
EARL M. YOUNG, *Research Associate*

Department of Ocean Engineering

EARL E. HAYS, Department Chairman,
Senior Scientist
JAMES M. ADAMS, *Research Associate*
LINCOLN BAXTER, II, *Applied Physicist*
STANLEY W. BERGSTROM, *Research Associate*
DAVID S. BITTERMAN, JR., *Research Associate*
EDWARD L. BLAND, JR., *Research Associate*
PAUL R. BOUTIN, *Research Associate*
ALBERT M. BRADLEY, *Research Associate*
CLAYTON W. COLLINS, JR., *Research Associate*
JOHN D. DONNELLY, *Research Associate*
(D.S.R.V. Pilot)
JAMES A. DOUTT, *Research Associate*
WILLARD DOW, *Electronics Engineer*
ROBERT G. DREVER, *Electronics Engineer*
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(D.S.R.V. Pilot)
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ROGER A. GOLDSMITH, *Research Associate*
FREDERICK R. HESS, *Research Associate*
DAVID S. HOSOM, *Research Associate*
MARY M. HUNT, *Research Associate*
MAXINE M. JONES, *Research Associate*
PETER E. KALLIO, *Research Associate*
RICHARD L. KOEHLER, *Electrical Engineer*
WILLIAM S. LITTLE, JR., *Research Associate*
WILLIAM M. MARQUET, *Instrumentation Engineer*
JAMES W. MAVOR, JR., *Mechanical Engineer*
Lecturer, Dept. of Ocean Engineering, M.I.T.
*MARVIN J. McCAMIS, *Research Associate*
PAUL C. MURRAY, *Research Associate*
RICHARD T. NOWAK, *Acoustics Engineer*
MARSHALL H. ORR, *Assistant Scientist*
KENNETH R. PEAL, *Research Associate*
ROBERT P. PORTER, *Associate Scientist*
GEORGE H. POWER, *Computer Analyst*
MELVIN A. ROSENFELD, *Manager*
Information Processing Center; Senior Scientist
RICHARD M. SAWDO, *Research Associate*
ARNOLD G. SHARP, *Research Associate*
LAWRENCE A. SHUMAKER, *Manager*
Deep Submergence Engineering & Operations Section, Oceanographic Engineer
WOOLLCOTT K. SMITH, *Research Associate*
ROBERT C. SPINDEL, *Associate Scientist*
JESSE H. STANBROUGH, JR., *Research Physicist*
CONSTANTINE D. TOLLIOS, *Computer Engineer*
BARRIE B. WALDEN, *Research Associate*
ROBERT G. WALDEN, *Manager*,
Ocean Structures and Moorings Section, Electronics Engineer
ROGER S. WALEN, *Research Associate*
DOUGLAS C. WEBB, *Manager, Instrument Section*,
Electrical Engineer, Senior Research Specialist
JACQUELINE H. WEBSTER, *Computer Analyst*
ALBERT J. WILLIAMS, III, *Associate Scientist*
VALENTINE P. WILSON, *Research Associate*
(D.S.R.V. Pilot)
CLIFFORD L. WINGET, *Electromechanical Engineer*
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Department of Physical Oceanography

VALENTINE WORTHINGTON
Department Chairman
Senior Scientist
LAURENCE D. ARMI, *Assistant Scientist*
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ALVIN L. BRADSHAW, *Applied Physicist*
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JOHN G. BRUCE, JR., *Research Associate*
DEAN F. BUMPUS, *Senior Scientist*
ANDREW F. BUNKER, *Associate Scientist*
JOSEPH CHASE, *Associate Scientist*
Visiting Lecturer, State College at Bridgewater
GABRIEL T. CSANADY, *Senior Scientist*
C. GODFREY DAY, *Research Associate*
JEROME P. DEAN, *Research Associate*
JOHN H. DUNLAP, *Research Associate*
GIFFORD C. EWING, *Senior Scientist, Emeritus*
NICHOLAS P. FOFONOFF, *Senior Scientist*
Gordon McKay Professor of the Practice of Physical Oceanography, Harvard University; Associate of the Center for Earth & Planetary Physics, Harvard University
FREDERICK C. FUGLISTER, *Senior Scientist, Emeritus*
*ROBERT H. HEINMILLER, *Buoy Engineer*
NELSON G. HOGG, *Assistant Scientist*
TERRENCE M. JOYCE, *Assistant Scientist*
ELI J. KATZ, *Associate Scientist*
JAMES R. LUYTEN, *Associate Scientist*
JOHN A. MALTAIS, *Research Associate*
GERARD H. MARTINEAU, *Research Associate*
MICHAEL S. McCARTNEY, *Assistant Scientist*
JAMES R. McCULLOUGH, *Instrument Engineer*
WILLIAM G. METCALF, *Associate Scientist*
ROBERT C. MILLARD, JR., *Research Associate*
ARTHUR R. MILLER, *Associate Scientist*
BERTHOLD H. G. PADE, *Research Associate*
CHARLES E. PARKER, *Research Associate*
RICHARD E. PAYNE, *Research Associate*
PETER B. RHINES, *Senior Scientist*
PHILIP L. RICHARDSON, *Assistant Scientist*
THOMAS B. SANFORD, *Associate Scientist*
KARL E. SCHLEICHER, *Oceanographic Engineer*
WILLIAM J. SCHMITZ, JR., *Associate Scientist*
ELIZABETH H. SCHROEDER, *Research Associate*
ALLARD T. SPENCER, *Design Engineer*
*MARVEL C. STALCUP, *Physical Oceanographer*
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ARTHUR D. VOORHIS, *Associate Scientist*
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Marine Policy and Ocean Management

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SUSAN B. PETERSON, *Research Associate*
LEAH J. SMITH, *Research Associate*

*Leave of Absence

Postdoctoral Investigators in 1976

RICHARD P. BLAKEMORE (Chemistry)
JUDITH M. CAPUZZO (Biology)
CHARLES C. ERIKSEN (Physical Oceanography)
NICHOLAS S. FISHER (Chemistry)
MURALIDHARA B. GAVINI (Chemistry)
PAUL A. GILLESPIE (Biology)
RICHARD J. JAFFEE (Ocean Engineering)
CYNTHIA L. LEE (Chemistry)
DAVID M. NELSON (Biology)
W. BRECHNER OWENS (Physical Oceanography)
JOHN N. SKILBECK (Physical Oceanography)
JOHN B. WATERBURY (Biology)

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Belastock, Rebecca A.
Bowker, Paul C.
Boyd, Steven H.
Brown-Leger, L. Susan
Davidson, John A.
Dennett, Mark R.
Ellis, Elaine M.
Gibson, Victoria R.
Gunning, Anita H.
Harrison, Karen S.
Hayward, Nancy A.
Hoar, Peter R.
Kneale, Douglas C.
Konnerth, Andrew, Jr.
LaPointe, Brian E.
*Lawrence, Sarah A.
Losordo, Thomas M.
McAlister, Vicki L.
Molyneaux, Stephen J.
Moore, Karen E.
Morse, Linda S.
Palmer, Carl D.
Persson, Norma Y.
Peterson, Jane M.
Quinby, Helen L.
Rogers, Mary D.
Sherman, Albert C.
Stanley, Helen I.
Stenberg, Richard W.
Taylor, Rodman E., Jr.
Volkmann, Suzanne B.
Whoriskey, Frederick G., Jr.
Williams, Isabelle P.

Department of Chemistry

Andrews, John E., III
Azarian, Debra M.
Blakesley, Barbara A.
Boudreau, Richard D.
Brady, Lynette
Brockhurst, Barbara J.
Callahan, Sharon L.
Casso, Susan A.
Clarke, William R.
Collins, Anne C.
Davis, Alan C.
Fleer, Alan P.
Glibert, Patricia M.
Gordon, Alan G.
Graham, Linda B.
Hunt, Gary T.
Johnson, Christine
Lavoie, Robert G.
Newman, Sally
Nigrelli, Gale E.
Oldershaw, Robert L.
Olson, Brenda L.
Olson, Charles A.
Palmieri, Julianne
Ross, Edith H.
Schneider, David L.
Shafer, Deborah K.
Smith, C. L. Roy
Sulanowski, Margaret M.
Surprenant, Lolita D.
Tripp, Bruce W.
True, Mary B.

Department of Geology & Geophysics

Akens, John J.
Allen, Ben G.
Allison, Donna F.
Berry, Mary E.
Broda, James E.
**Canning, Christine J.
Connell, John F.
Davies, Rodman F.
Dynan, Suzanne E.
Ellis, Jeffrey P.
Farmer, Harlow G., 3rd
Galbraith, Nancy R.
Gegg, Stephen R.
Goreau, Margaret
Gove, Leon A.
Grant, Carlton W., Jr.
Groman, Robert C.
Handy, Robert E.
Hays, Helen C.
Hindley, Pamela E.
Kroll, Jane D.
Mooney, Robert C.
O'Brien, Thomas F.
Parmenter, Carol M.
Peters, Christopher S.
Riley, Anne S.
Ruiter, Robert G.
Scheer, Catherine O.
Scheer, Edward K.
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Toner, Lois G.
Tonge, Sandra M.
Whiteley, Lynn T.
Witzell, Grace M.
Wooding, Christine M.

Department of Ocean Engineering

Aldrich, Thomas B.
Bardsley, Brian L.
Barnes, Nancy
Bartlett, Arthur C.
Beatty, Keith W.
Broderson, George
Chute, Edward H.
Clay, Peter R.
Cole, Bruce R.
Collins, Aganoris
Connell, William L.
Crook, Thomas
Deane, Stanley R.
Denton, Edward A.
Doherty, Kenneth W.
Evans, Emily
Fairhurst, Kenneth D.
Francis, Keith A.
Freund, William F., Jr.
Gibson, George W.
Goff, William E.
Gould, Matthew R.
Gunderson, Allen C.
Gustafson, Carl W.
Gustavsson, James R.
Hampton, Carolyn S.
Hardy, Carl C.
Hilliard, Channing N., Jr.
Hollis, Ralph M.
Kennedy, Percy L., Jr.
Kucharski, William M.
Langhorst, Douglas A.
Letendre, William J.
Liberatore, Stephen P.
Lyon, Thomas
Lyons, Mary Jane
Mason, David
McCarthy, Jack W.
McElroy, Marguerite K.
Meier, George A.
Morehouse, Clayton B.
Morton, Alfred W.
Muzzey, Charlotte A.
O'Malley, Patrick
Page, William F.
Pires, Clara Y.
Pires, Karen M.
Polloni, Christopher F.
Porteous, John
Rosenblad, Stanley G.
Sass, Warren J.
Schuler, Frederick J.
*Shepard, George W.
Shultz, William S.
Stern, Margaret P.
Terry, William E., Jr.
Thayer, Robert J.
Vaillancourt, Dennis G.
Williar, James A.
Witzell, Susan F.
**Woods, Donald E.

Department of Physical Oceanography

Armstrong, Harold C.
Bailey, Phyllis T.
Barbour, Rose L.
Bauchmann, Nancy J.
Chaffee, Margaret A.
Drew, Roberta E.
Frank, Winifred H.
Frazel, Robert E.
Gaffron, Barbara
Guillard, Elizabeth D.
Haight, Doris I.
Herrity, Catherine M.
Horn, William H.
Knapp, George P., III
LaRochelle, Roderigue A.
Moore, Douglas E.
Noyes, Robert, Jr.
Ostrom, William M.
Poirier, Joseph R.
Reese, Mabel M.
Simkins, Samuel T.
Simoneau, R. David
Spencer, Ann
Stanley, Robert J.
Swartz, H. Marshall, Jr.
Tarbell, Susan A.
Tupper, George H.
Valdes, James R.
White, Judith A.
Whitlatch, Ann W.
Williams, Audrey L.
Zemanovic, Marguerite E.
Zuck, Richard A.

*Leave of Absence
**Disability Leave of Absence

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HENRI O. BERTEAUX .... Institution Staff Engineer
H. LAWRENCE CLARK .... Executive Assistant / UNOLS
GEORGE CONWAY .... Controller
VICKY CULLEN .... Public Information Representative
GORDON K. GLASS .... Executive Assistant / Ocean Engineering
MAUREEN A. GREENAWALT .... Executive Assistant / Geology & Geophysics
ARTHUR T. HENDERSON .... Procurement Manager
JOHN L. HEYL .... Special Assistant for Private Resources
HARTLEY HOSKINS .... Coordinator, Ocean Industries Program
CHARLES S. INNIS, JR. .... Executive Assistant to Directorate
SUSAN KADAR .... Executive Assistant / Chemistry
PHYLLIS N. LAKING .... Executive Assistant / Administration
JACK N. LINDON .... Personnel Benefits Administrator
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A. LAWRENCE PEIRSON III .... Assistant Dean & Registrar
*WILLIAM O. RAINNIE, JR. .... Special Assistant for Private Resources
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PAUL R. RYAN .... Assistant Editor, "Oceanus"
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Administrative Personnel

Annan, Deborah H.
Atchison, Doris
Backus, Denise
Battee, Howard
Battee, Janice R.
Botelho, Eleanor M.
Botelho, Linda J.
Brown, Norma H.
Burgess, Cheryl A.
Cannon, Janet M.
Chalmers, Agnes C.
Crinkley, Kathryn L.
Dean, Mildred W.
Fennelly, Cyril L.
Fernandez, Laura A.
Foster, Penny C.
Graham, Russell G.
Green, Nancy H.
Hatzikon, Kaleroy L.
Henry, Ann E.
Hurter, Colleen D.
Ingram, Ruth C.
Jenney, Philomena S.
Korgen, Judith K.
Liberatore, Wendy W.
Long, Shirley-Anne
Lovering, Judith W.
Martin, Ann
Martin, Loretta M.
Mattson, Pamela C.
McClung, Philip E.
Mendousa, Tina C.
Merson, Carole R.
Molyneaux, Ruthanne
Moniz, Mozart P.
Murphy, Cheryl C.
Picard, Eleanor P.
Pineault, Florence T.
Pykosz, Patricia A.
Quigley, Alexsandra A.
Reed, Linda R.
Reeves, Jeannette W.
Royer, Michelle E.
Rudden, R. David, Jr.
Silva, Kathleen L.
Smart, Charlotte M.
Smoler, Gail F.
Souza, Carol J.
Spooner, Brent F.
Sprague, Evelyn M.
Tavares, Maurice J.
Thayer, Mary C.
Thomas, Patricia A.
Waskilewicz, Shirley
Wege, Jane P.
Wildes, Nancy K.
Willert, Clarice S.

Facilities and Marine Operations Staff

DAVID F. CASILES .... Master, R/V ATLANTIS II
RICHARD H. DIMMOCK .... Port Engineer
ROBERTSON P. DINSMORE .... Chairman, Facilities and Marine Operations Department
RICHARD S. EDWARDS .... Marine Superintendent
RICHARD C. FLEGENHEIMER .... Master, R/V LULU
EMERSON H. HILLER .... Master, R/V KNORR
WALTER G. HUCKABEE, SR. .... Chief Engineer, R/V CHAIN
JONATHAN LEIBY .... Naval Architect
BARRETT H. McLAUGHLIN .... Chief Engineer, R/V KNORR
ALFRED F. MEDEIROS, JR. .... Chief Engineer, R/V LULU
*PAUL R. MERCADO .... Chief Engineer, R/V OCEANUS
JAMES R. MITCHELL .... Manager of Facilities
MICHAEL PALMIERI, JR. .... Master, R/V OCEANUS
JOHN F. PIKE .... Port Captain
RAYMOND R. RIOUX .... Chief Engineer, R/V ATLANTIS II
J. PAUL THOMPSON .... Assistant Facilities Manager
ANDREW L. WESSLING, JR. .... Manager of Services

Facilities Personnel

Acton, Edward F.
†Anders, Wilbur J.
Baker, Ernest E.
Bowman, Richard W.
Brauneis, Frederick A.
Carlson, Gustaf A.
Charette, Ernest G.
Clemishaw, Charles
Clough, Auguste K.
Costa, Arthur
Croft, Donald A.
Dastous, Roland L.
Davis, Robert C.
Eggleston, Fred S., Jr.
Ferreira, Anthony
Field, Michael J.
Grosch, Douglas T.
LeBlanc, Donald F.
Lobo, Wayne F.
Matthews, Francis
Mayberry, Ernest
Mendousa, Anthony G.
Oakes, Harry E.
Page, Stephen G.
Peters, Charles J., Jr.
Phares, Edward J.
Pucci, Joseph F.
Rennie, Thomas D.
Ross, David F.
Smart, Thomas H.
Vallesio, Barbara M.
Walsh, John F.
Weeks, Robert G.
White, Haskel E.
Wing, Asa S.
Wing, Carleton R.
Woodward, Martin C.
Young, Carleton F.

*Leave of Absence
†Deceased, 21 January 1976

Facilities and Marine Operations Staff *(continued)*

Services Personnel

Aiguier, Edgar L.
Alexander, Robert M.
Anderson, Norman E.
Barrett, Francis J., III
Beford, Joseph R.
Black, Earle N.
Bourne, Wallace T.
Breivogel, Richard J.
Burt, Sandra J.
†Carver, Kenneth W.
Cassidy, Bernard J.
Coneybear, Edna W.
Corr, James P.
Craft, Ronald C.
Creighton, James E.
Crobar, John A.
Crouse, Porter A.
Davis, Frances L.
Davis, Ruth H.
DeSanti, Judith C.
Dodge, William B.
Dunlap, Frances W.
Eastman, Arthur C.
Ferreira, Catherine H.
Ferreira, Steven R.
Fontana, Victor F.
Galvin, Yvonne S.
Gandy, Curtis, III
Gervais, Linda A.
Gibson, Laurence E.
Gifford, James E.
Greenawalt, Charles A.
Gunter, Carol A.
Halle, Rene C., Jr.
Hickey, Mark V.
Hindley, Robert J.
Holcomb, Frank E.
Holland, Howard A.
Johnson, Harold W.
Kelley, Robert F.
Kennedy, Percy L., Sr.
Lajoie, Therese S.
Lewis, Daniel M.
Livingston, Stella J.
Lowe, Robert G.
Martin, Donald J.
Martin, Olive
Masse, Roland G.
Medeiros, Frank
Meinert, Dorothy
Mello, Michael A.
Mogardo, Juanita A.
Motta, Joseph F.
Murphy, Jay R.
Pineault, Eugene A.
Ramsey, William S., Jr.
Ranney, John M.
**Reeves, A. Stanley
Rice, John E.
Rioux, Robert R.
Sage, Eben A.
Simmons, Roland R.
Souza, Donald P.
Stimpson, John W.
Swan, James A.
Tavares, William R., Jr.
Walker, Jean D.
Williams, Ronald J.
Woods, Ronald E.
Woodward, Fred C., Jr.
Woodward, Ruth F.
Zwinakis, Jeffrey A.

Marine Personnel

Austin, Joel T.
Babbitt, Herbert L.
Baker, Robert W.
Baker, William R.
Bazner, Kenneth E.
Bizzozero, John P.
Bradford, Thomas W.
Brady, George F.
Brennan, Edward J.
Broderick, Edward R.
*Bumer, John Q.
*Carty, Paul F.
Clinton, Harry F.
Colburn, Arthur D., Jr.
Cotter, Jerome M.
*Cox, David E.
Dawicki, Michael J.
Dunlap, George A.
Dunn, Arthur J.
Eident, William A.
Elliott, Kittie E.
Filipetti, Arno
Flaherty, Peter M.
Fortes, Eugene
Gassert, John M.
Gordon, Robert L.
Hartke, David L.
Hayden, David L.
Higgins, Jeffrey R.
Howland, Paul C.
Hutchinson, John J.
Jefferson, Albert C.
Johnston, Alexander T.
Kay, John K.
Kennedy, John J.
LeSueur, Jeffrey E.
Leahy, James E.
LePage, Joseph A.
Lobo, John T.
MacKinnon, Glen T.
MacLeod, Ian M.
Martin, John W.
Metzger, Donald J., Jr.
Moniz, Michael F.
*Moye, William E.
Munns, Robert G.
Murphy, George E.
Mysona, Eugene J.
O'Connor, Brendan R.
Ocampo, Conrad H.
O'Neil, Thomas F.
Palardy, Omer J.
Pierce, George E.
Pierce, Samuel F.
Polsky, Jason M.
Pope, Christopher M.
Ribeiro, Joseph
Rossetti, Michael F.
Rougas, Harry
Sepanara, James M.
Smith, Martin G.
Smith, Robert E.
Soucy, Trefton A.
Stack, William M.
Stanton, Harry H.
*Sweet, John K., Jr.
Warecki, Joseph
Wegman, Ernest C., Jr.
Wellwood, Warren D.
White, Ronald
Wickenden, Richard S., II

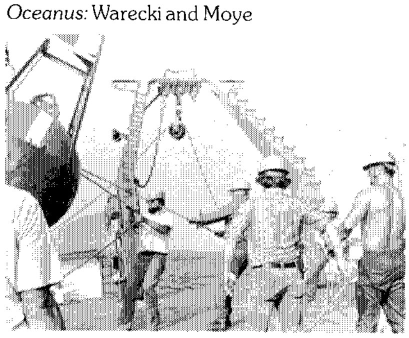
*Leave of Absence
**Disability Leave of Absence
†Deceased, 19 December 1976

BRUCE TRIPP

Knorr: Cotter, Dunlap, Broderick

VICKY CULLEN

Oceanus: Warecki and Moye



ROBERT BEARDSLEY

Brown, Warecki, Vermersch, Clay, Rossetti

BRUCE TRIPP

Knorr: Brennan

Fellows, Students, and Visitors

Appendix III

Postdoctoral Scholars
Awardees 1976-77

SHERMAN T. CROUGH
Stanford University

ALAN W. ELZERMAN
University of Wisconsin

JOHN N. LUDDEN
University of Manchester, England

NANCY H. MARCUS
Yale University

JOHN W. M. RUDD
University of Manitoba, Canada
Freshwater Institute

ROBERT B. WHITLATCH
University of Chicago

Marine Policy and Ocean Management
Awardees 1976-77

PETER H. FRICKE
University of Durham, England

JOHN E. KELLY
Brown University

THOMAS M. LESCHINE
University of Pittsburgh

ARNOLD L. LUM
University of California, Davis

YOSHIAKI MATSUDA
University of Georgia

BERRIEN MOORE, III
University of Virginia

FRANCISCO J. PALACIO
University of Miami

MARY E. REARDON
Harvard University

M. LAMIN SARR, Trainee
Brown University

EDWARD WENK, JR.,
Senior Fellow
University of Washington

Jesse Smith Noyes Postdoctoral Fellows in Aquaculture
Awardees 1976-77

JAMES A. DeBOER
Oregon State University

CHRISTOPHER F. D'ELIA
University of Georgia

LEONARD W. HAAS
College of William and Mary

ROGER L. MANN
Marine Science Laboratories
Menai Bridge, United Kingdom

Woods Hole Program
1976-77 Academic Year

PHILIP M. GSCHWEND
California Institute of Technology

PETER B. ORTNER
Yale University

M.I.T./W.H.O.I. Joint Graduate Program
1976-77 Academic Year

ROBERT ANDERSON
University of Washington

JAMES A. AUSTIN, JR.
Amherst College

ROBERT L. BINDER
University of Pennsylvania

JAMES K. B. BISHOP
University of British Columbia, Canada

LARRY E. BRAND
University of Texas

NANCY A. BRAY
University of California, Berkeley

SCOTT R. BRIGGS
Brown University

JAMES R. BROOKS
University of Southern California

ALICE L. CANTELOW
University of California,
San Diego

CATHERINE M. CETTA
University of Connecticut

ALAN D. CHAVE
Harvey Mudd College

JERRY CHENEY
Lamar University

ALAIN COLIN DE VERDIERE
Ecole de Physique Chimie de Paris,
France

ROBERT W. COLLIER
Massachusetts Institute of Technology

MICHAEL S. CONNOR
Stanford University

JOHN CROWE
Columbia University

RUSSELL L. CUHEL
University of California, San Diego

ERIC A. D'ASARO
Harvard University

ROBERT S. DETRICK
University of California, San Diego

JONATHAN EREZ
Hebrew University, Israel

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Appendix IV

Publications

As of 15 March 1977. W.H.O.I. contribution number follows entry.

Biology

D.C. BIGGS and G.R. HARBISON. The Siphonophore *Bathyphysa sibogae* Lens and Van Riemsdijk, 1908, in the Sargasso Sea, with Notes on its Natural History. *Bull. Mar. Sci.*, 26(1):14-18. 1976. No. 3542

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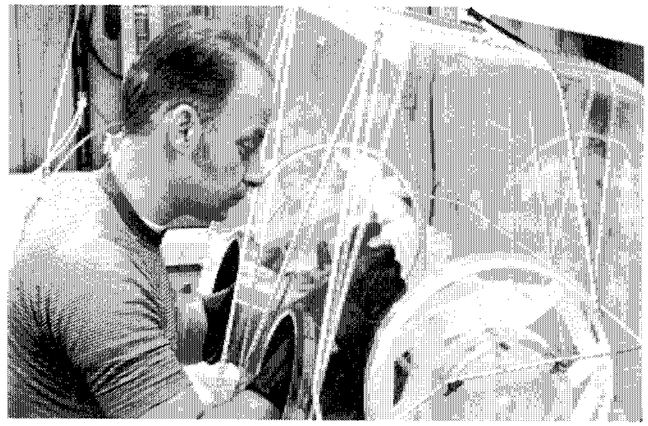

SUSAN KADAR

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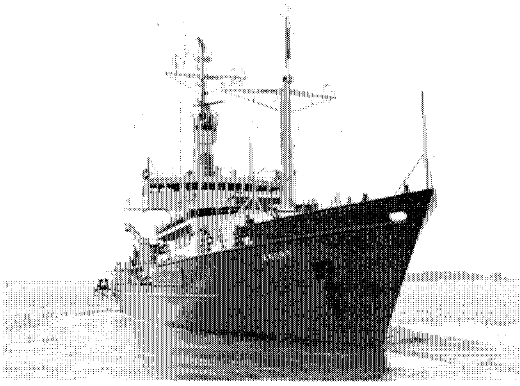
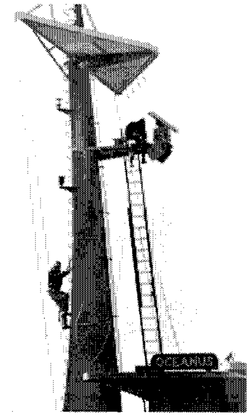
Voyage Statistics for 1976

Appendix V



VICKY CULLEN



VICKY CULLEN

GEORGE TUPPER

Knorr in Woods Hole harbor

Outfitting *Oceanus*

Dave Hartke at *Atlantis II* wheel

R/V ATLANTIS II

Total Nautical Miles for 1976 — 50,898

Voyage No.	*Depart*	*Arrive*	*Ports*		*Area of Operations*	*Chief Scientist*
93-III	(22 Dec)	8 Jan	(Cape Town)	Cape Town	South Atlantic	Farrington
IV	13 Jan	8 Feb	Cape Town	Durban	Antarctic and South Indian Ocean	Sayles
V	13 Feb	8 Mar	Durban	Mauritius	Indian Ocean	Hoskins
VI	12 Mar	4 Apr	Mauritius	Mauritius	Indian Ocean	Hoskins
VII	8 Apr	6 May	Mauritius	Mombasa	Indian Ocean	Bunce
VIII	10 May	23 May	Mombasa	Mombasa	Indian Ocean	Luyten
IX	25 May	21 Jun	Mombasa	Mombasa	Indian Ocean	Luyten
X	1 Jul	20 Jul	Mombasa	Mauritius	Indian Ocean	Warren
XI	23 Jul	20 Aug	Mauritius	Port Hedland	Indian Ocean	Warren
XIA	23 Aug	27 Aug	Port Hedland	Darwin	Australian Coast	Warren
XII	2 Sep	28 Sep	Darwin	Ujung Pandang	Indonesian Sea	Bowin
XIII	1 Oct	25 Oct	Ujung Pandang	Darwin	Northeast Indian Ocean	Bowin
XIV	29 Oct	26 Nov	Darwin	Singapore	Northeast Indian Ocean (To Shipyard)	Heirtzler
XV	12 Dec	(Enroute-ETA 10 Jan)	Singapore	(Goa)	Equatorial Indian Ocean	Tupper

R/V KNORR

Total Nautical Miles for 1976 — 32,141

Voyage No.	*Depart*	*Arrive*	*Ports*		*Area of Operations*	*Chief Scientist*
54-I	1 Jan	7 Jan	Woods Hole	Guantanamo Bay		Driscoll
	7 Jan	8 Jan	Guantanamo Bay	Montego Bay		Driscoll
II	11 Jan	5 Feb	Montego Bay	Georgetown	Cayman Trough	Ballard/Uchupi
III	9 Feb	23 Feb	Georgetown	Montego Bay	Cayman Trough	Uchupi
	23 Feb	26 Feb	Montego Bay	San Juan		Uchupi
IV	2 Mar	3 Mar	San Juan	St. Thomas		Purdy
	3 Mar	1 Apr	St. Thomas	Cadiz	Kane Fracture Zone	Purdy
V	6 Apr	30 Apr	Cadiz	Ostend	Iberian Coastal Waters	Burke
VI	7 May	5 Jun	Ostend	Reykjavik	Eastern North Atlantic	Spencer
VII	8 Jun	5 Jul	Reykjavik	Woods Hole	Western North Atlantic	Gagosian
55	8 Jul	9 Jul	Woods Hole	Staten Island	Shipyard	
	13 Jul	14 Jul	Staten Island	Woods Hole		
56	15 Jul	15 Jul	Woods Hole	Woods Hole	Continental Shelf	Honjo
57	21 Jul	28 Jul	Woods Hole	Woods Hole	Continental Shelf	Harvey
58-I	31 Jul	13 Aug	Woods Hole	Woods Hole	Deep Water Dumpsite #106	Rowe
II	18 Aug	26 Aug	Woods Hole	Woods Hole	Deep Water Dumpsite #106	Williams
III	27 Aug	7 Sep	Woods Hole	Woods Hole	Deep Water Dumpsite #106	Williams
59	7 Sep	8 Sep	Woods Hole	New York	Shipyard	
	17 Sep	18 Sep	New York	Woods Hole		
60	29 Sep	28 Oct	Woods Hole	Woods Hole	Western North Atlantic	Bradley
61	3 Nov	22 Nov	Woods Hole	Woods Hole	New England Sea Mounts	Tollios
62	30 Nov	21 Dec	Woods Hole	Woods Hole	Northern Sargasso Sea	Wiebe

R/V OCEANUS

Total Nautical Miles for 1976 — 27,025

Voyage No.	Depart	Arrive	Ports		Area of Operations	Chief Scientist
2	10 Feb	10 Feb	Woods Hole	Newport, RI	Shipyard	
	23 Feb	23 Feb	Newport, RI	Woods Hole		
3	8 Apr	8 Apr	Woods Hole	Woods Hole	Trials	
4	15 Apr	18 Apr	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Beardsley
5	22 Apr	1 May	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Haedrich
	2 May	4 May	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Haedrich
6	10 May	10 May	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Rowe
	10 May	22 May	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Rowe
7	27 May	13 Jun	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Webb
8	19 Jun	19 Jun	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Watson
	19 Jun	29 Jun	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Watson
9	1 Jul	1 Jul	Woods Hole	Woods Hole	Tall Ships	
10	7 Jul	9 Jul	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Grassle
	9 Jul	21 Jul	Woods Hole	Woods Hole	Gay Head-Bermuda Transect	Grassle
11	23 Jul	1 Aug	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Harbison
12	3 Aug	3 Aug	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Murphy
13-I	6 Aug	6 Aug	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Wunsch
II	7 Aug	9 Aug	Woods Hole	New Bedford	Hurricane Evasion	Beardsley
	10 Aug	12 Aug	New Bedford	Woods Hole		
III	12 Aug	23 Aug	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Beardsley
IV	25 Aug	26 Aug	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Shillingford
14	31 Aug	1 Sep	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Honjo
15	18 Sep	8 Oct	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Webb
16-I	16 Oct	26 Oct	Woods Hole	Bermuda	Sargasso Sea	Spindel
II	31 Oct	5 Nov	Bermuda	Bermuda	Sargasso Sea	Katz
	5 Nov	14 Nov	Bermuda	Bermuda	Sargasso Sea	Katz
III	18 Nov	25 Nov	Bermuda	Woods Hole	Sargasso Sea	Spindel
17	3 Dec	10 Dec	Woods Hole	Woods Hole	Continental Shelf and Slope Waters	Butman
18	14 Dec	20 Dec	Woods Hole	Woods Hole	South of Gulf Stream	Jannasch
19	20 Dec	21 Dec	Woods Hole	Woods Hole	East of Cape Cod — Oil Spill	Milliman
20	28 Dec	29 Dec	Woods Hole	Woods Hole	South of Cape Cod — Oil Spill	Milliman

R/V LULU and DSRV ALVIN

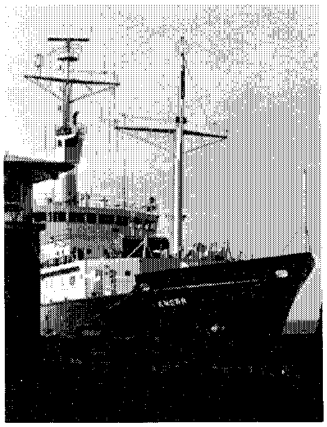
Total Nautical Miles for 1976 — 8,862

LULU Voyage No.	Depart	Arrive	Ports		ALVIN Dives	Area of Operations	Chief Scientist
83	2 Jan	7 Jan	Miami	Guantanamo Bay			
	8 Jan	22 Jan	In Guantanamo Bay		4	1976 Pre-season Test Dives	Shumaker
	22 Jan	25 Jan	Guantanamo Bay	Georgetown			
	27 Jan	5 Feb	Georgetown	Georgetown	7	Cayman Trough	Ballard
	10 Feb	11 Feb	Georgetown	Georgetown	2	Cayman Trough	Ballard
	12 Feb	17 Feb	Georgetown	Georgetown	3	Cayman Trough	Ballard
	17 Feb	22 Feb	Georgetown	Georgetown	4	Cayman Trough	Ballard
	22 Feb	25 Feb	Georgetown	Guantanamo Bay			
	28 Feb	6 Mar	Guantanamo Bay	San Juan, PR			
	16 Mar	16 Mar	San Juan	Frederiksted, VI			
					14	St. Croix Range	Wells/Von Perbandt
	1 Apr	2 Apr	Frederiksted	San Juan			
	4 Apr	15 Apr	San Juan	Nassau, BI	5	Navidad Bank	Heezen
	17 Apr	29 Apr	In and out of Bahamian Ports		9		Turner/Bliss/ Santos/Von Perbandt
	29 Apr	6 May	Clifton Pier	Woods Hole			
					1	Woods Hole Harbor	Shumaker
84	7 Jun	12 Jun	Woods Hole	Woods Hole	3	Continental Shelf	Wirsen
	14 Jun	16 Jun	Woods Hole	Woods Hole	1	Continental Shelf	Jannasch
85	22 Jun	1 Jul	Woods Hole	Woods Hole	8	Continental Shelf	Rowe
86	7 Jul	16 Jul	Woods Hole	Woods Hole	8	Continental Shelf	Uzmann
					1	Woods Hole Harbor (Test Dive)	Donnelly
87	27 Jul	5 Aug	Woods Hole	Woods Hole	5	Continental Shelf	Dyer
88	11 Aug	21 Aug	Woods Hole	Woods Hole	6	Continental Shelf	Jannasch
	22 Aug	2 Nov	Annual Overhaul		1	Woods Hole Harbor (Test Dive)	Donnelly
89	3 Nov	3 Nov	Woods Hole	Newport		Shipyard	
	10 Nov	10 Nov	Newport	Woods Hole			
					1	Woods Hole Harbor (Test Dive)	Donnelly
90	5 Dec	14 Dec	Woods Hole	Nassau			
	15 Dec	15 Dec	Nassau	Andros			
					6	1977 Pre-season Test Dives	Shumaker
							Total Dives 90

1976 Sponsors of Research and Education

Appendix VII

American Geological Institute
American Petroleum Institute
Amoco International Oil Company
Associates of the Woods Hole
  Oceanographic Institution
Atlantic Richfield Company
Atlantic Tuna Club
Babylon Tuna Club
Bermuda Anglers Club
Cabot Foundation Inc.
California Institute of Technology
Canada
  Province of Quebec
    Ministry of Tourism
Chevron Oil Field Research Company
Cities Service Oil Company
Columbia University
  Lamont-Doherty Geological
  Observatory
Compagnie Française Des Petroles
Continental Oil Company
Energy Resources Company, Inc.
Eppley Foundation for Research
Exxon Corporation
  Exxon Company, U.S.A.
  Exxon Research & Engineering
    Company
Freeport Tuna Club
Getty Oil Company
Green Harbor Tuna Club
Harbor Branch Foundation
International Business Machines
  Corporation
International Light Tackle
  Tournament Association
Jersey Cape Fishing Tournament
George Frederick Jewett Foundation
The Johns Hopkins University
  Applied Physics Laboratory
Laurel Foundation
Marathon Oil Company
Marine Biological Laboratory
Marlin Conservation Club
Commonwealth of Massachusetts
Massachusetts Institute of Technology
Massachusetts Lobstermen's
  Association, Inc.
Andrew W. Mellon Foundation
Mobil Research & Development
  Corporation
Naval Post Graduate School
  Foundation, Inc.
New England Farm & Garden
  Association, Inc.
New Orleans Big Game Fishing Club
Northeast Utilities
Jessie Smith Noyes Foundation, Inc.
Ocean City Light Tackle Club
Ocean City Marlin Club, Inc.
Pew Memorial Trust
Phillips Petroleum
Port Aransas Rod & Reel Club
University of Rhode Island
Sailfish Club of Florida, Inc.
Scaife Family Charitable Trusts
Schiff Foundation
Sheepshead Bay Tuna Club
Shell Oil Company
Sippican Corporation
Sport Fishing Institute
Seth Sprague Educational
  & Charitable Foundation
Standard Oil Company of California
Sun Oil Company
Tai-Ping Foundation, Inc.
Texaco Inc.
Union Oil Company of California
U.S. Atlantic Tuna Tournament
United States
  Department of Commerce
    National Oceanic & Atmospheric
      Administration
    National Marine Fisheries Service
  Energy Research & Development
    Administration
    Brookhaven National Laboratory
  Environmental Protection Agency
  Department of Health, Education &
    Welfare
    National Institutes of Health
    Public Health Service
  Department of the Interior
    Bureau of Land Management
    U.S. Geological Survey
  National Aeronautics & Space
    Administration
    Johnson Spacecraft Center
  National Science Foundation
  Navy Department
    Naval Air Systems Command
      Naval Air Development Center
    Naval Electronics Systems Command
    Naval Facilities Engineering Command
    Naval Research Laboratory
    Naval Undersea Center
    Naval Underwater Systems Center
    Office of Naval Research
  Nuclear Regulatory Commission
  State Department
    Supply & Transportation Division
  Transportation Department
    Coast Guard
University of California
University of Rhode Island
University of Washington
Victoria Foundation
Virginia Beach Anglers Club, Inc.
Virginia Bluewater Gamefish Association
Yale University



VICKY CULLEN

KEITH VON DER HEYDT

KEITH VON DER HEYDT

Financial Highlights

The Institution's operating revenue increased 9% in 1976, compared with 5½% in 1975. The major cost categories changed as follows:

	1976	1975	Increase (Decrease)
Research Salaries and Benefits	$ 6,333,000	$ 5,806,000	9%
Vessel Operations	4,601,000	4,735,000	(3%)
Other Direct Costs	6,811,000	6,047,000	13%
Graduate Studies Program	898,000	1,064,000	(16%)
General and Administrative	2,691,000	2,357,000	14%

A comparison of the Endowment Fund activity for the years 1976 and 1975 is as follows:

Assets at Market Quotations	$37,650,000	$30,484,000	24%
Additions to Principal	2,942,000	25,000	
Total Income Received	1,499,000	1,330,000	13%
Unit Value of General Fund	.9026	.7927	14%
Income per Unit	.0416	.0384	8%

Other statistics of interest are:

Gross Payroll	$11,052,000	$10,092,000	10%
Retirement Trust Contribution	1,100,000	908,000	21%

Gifts and grants from private sources including the 802 Institution Associates, private foundations, industrial corporations, and friends totalled $4,024,000 in 1976.

Your attention is invited to the notes accompanying the Financial Statements audited by Coopers & Lybrand which explain significant accounting policies.

Joseph Kiebala, Jr.
Assistant Director for Administration
Edwin D. Brooks, Jr.
Treasurer
George E. Conway
Controller

Balance Sheet: 31 December 1976 and 1975

ASSETS

	1976	1975
Current Fund Assets (Note A):		
Cash	$ 137,863	$ 376,308
Short-term investments, at cost which approximates market	2,650,000	800,000
Reimbursable contract costs:		
Billed	694,850	1,394,162
Unbilled	1,305,941	1,446,393
Supplies, prepaid expenses and deferred charges	569,562	484,375
Due to plant fund	(779,904)	(482,460)
Due (to) from endowment and similar funds	(2,283)	42,590
	4,576,029	**4,061,368**
Endowment and Similar Fund Assets (Notes A and B):		
Separately invested, at market	24,069,718	18,974,325
Pooled investments, at market	13,577,576	11,551,996
Due (to) from current fund	2,283	(42,590)
	37,649,577	**30,483,731**
Annuity Fund Assets (Note A):		
Investments, at market (cost $74,162 in 1976 and $82,655 in 1975)	77,465	78,000
Cash	6,661	–
	84,126	**78,000**
Plant Fund Assets (Note A):		
Laboratory, plant and equipment	16,184,368	16,036,736
Atlantis II	4,831,130	4,831,130
Other vessels, equipment and property	3,231,836	3,220,709
	24,247,334	24,088,575
Less accumulated depreciation	6,458,120	5,785,181
	17,789,214	18,303,394
Due from current fund	779,904	482,460
	18,569,118	**18,785,854**
	$60,878,850	**$53,408,953**

LIABILITIES AND FUND BALANCES

	1976	1975
Current Fund Liabilities and Balances:		
Accounts payable and other accrued expenses	$ 852,398	$ 437,156
Accrued vacation	641,348	603,464
Unexpended balances of restricted funds	1,076,743	1,357,272
Unrestricted balances designated for:		
Income and salary stabilization	1,637,097	1,539,541
Working capital and contingency	134,050	123,935
Ocean industry program (Note G)	234,393	–
Total unrestricted balances	2,005,540	1,663,476
	4,576,029	**4,061,368**
Endowment and Similar Fund Balances:		
Endowment:		
Income restricted	22,433,697	19,649,747
Income unrestricted	2,695,843	2,364,333
Term endowment	3,676,393	3,224,538
Quasi-endowment:		
Restricted (Note C)	5,730,770	5,009,836
Unrestricted	3,112,874	235,277
	37,649,577	**30,483,731**
Annuity Fund Liabilities and Balance:		
Annuities payable	31,642	33,624
Fund balance	52,484	44,376
	84,126	**78,000**
Plant Fund Balances:		
Invested in plant	17,789,214	18,303,394
Unexpended	779,904	482,460
	18,569,118	**18,785,854**
	$60,878,850	**$53,408,953**

Statement of Changes in Fund Balances for the years ended 31 December 1976 and 1975

	Endowment and Similar Funds	Annuity Fund	Plant Fund: Invested in Plant	Plant Fund: Unexpended	Current Fund: Restricted	Current Fund: Unrestricted
1975						
Balances at December 31, 1974	$26,606,205	$27,905	$18,623,694	$(1,464,586)	$1,235,560	$1,571,034
Increases:						
Gifts and grants received	22,000			1,759,974	10,832,354	79,034
Contract revenues earned					8,108,451	
Endowment and similar funds and annuity investment income		2,817			1,049,371	280,941
Other				6,348		647,525
Net increase in realized and unrealized appreciation	3,897,338	17,250				
Decreases:						
Expenditures					(19,910,276)	(785,058)
Unfunded depreciation (Note A)			(263,228)			
Other		(3,596)	(6,348)			
Transfers — additions (deductions):						
Transfers to endowment and similar funds	2,604				(2,604)	
Transfers from unrestricted endowment and similar funds principal (Note C)	(44,416)				44,416	
Transfers to plant fund				130,000		(130,000)
Invested in plant			359,055	(359,055)		
Funded depreciation			(409,779)	409,779		
Balances at December 31, 1975	30,483,731	44,376	18,303,394	482,460	1,357,272	1,663,476
1976						
Increases:						
Gifts and grants received	35,345		1,850	2,420,546	11,345,714	355,460
Transfers from restricted to unrestricted (Note G)					(234,393)	234,393
Contract revenues earned					8,837,708	
Endowment and similar funds and annuity investment income		3,759			1,143,602	292,668
Other				2,439		674,476
Net increase in realized and unrealized appreciation	4,224,115	7,719				
Decreases:						
Expenditures					(21,236,077)	(820,630)
Unfunded depreciation (Note A)			(263,228)			
Net loss on disposal of plant fund assets			(904)			
Other		(3,370)	(2,439)			
Transfers — additions (deductions):						
Transfers to endowment and similar funds	2,906,386			(2,500,000)	(137,083)	(269,303)
Transfers to plant fund				125,000		(125,000)
Invested in plant			182,951	(182,951)		
Funded depreciation			(432,410)	432,410		
Balances at December 31, 1976	$37,649,577	$52,484	$17,789,214	$ 779,904	$ 1,076,743	$2,005,540

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

Statement of Current Fund Revenues, Expenses and Transfers for the years ended 31 December 1976 and 1975

	1976	1975
Revenues		
Sponsored research:		
Government	$18,576,747	$17,083,106
Nongovernment	1,669,813	1,675,449
	20,246,560	18,758,555
Education funds availed of	989,517	1,151,721
Total restricted	21,236,077	19,910,276
Unrestricted:		
Fees	199,796	185,599
Endowment and similar fund income	292,668	280,941
Gifts (Notes E and G)	589,853	79,034
Tuition	234,091	221,057
Other	240,589	240,869
Total unrestricted	1,556,997	1,007,500
Total revenue	**22,793,074**	**20,917,776**
Expenses and Transfers		
Sponsored research:		
Salaries and fringe benefits	6,332,583	5,805,937
Ships and submersibles	4,600,610	4,734,804
Materials and equipment	3,826,308	3,351,820
Laboratory costs	1,330,639	1,258,089
Other	1,653,942	1,437,245
	17,744,082	16,587,895
Education:		
Faculty expense	222,672	217,488
Student expense	370,207	377,467
Other expense	304,725	469,327
	897,604	1,064,282
Institutional research	274,832	238,142
Other unrestricted activity (Note C)	449,593	447,833
General and administrative:		
Allocated to sponsored research	2,502,478	2,170,660
Allocated to education	91,913	87,439
Allocated to other	96,205	99,083
	2,690,596	2,357,182
Total expenses	**22,056,707**	**20,695,334**
Nonmandatory transfers:		
To quasi-endowment fund (Note E)	269,303	—
To plant fund, unexpended	125,000	130,000
Total expenses and nonmandatory transfers	**22,451,010**	**20,825,334**
Net increase in unrestricted current fund	**$ 342,064**	**$ 92,442**
Designated for:		
Income and salary stabilization	97,556	93,646
Ocean industry program (Note G)	234,393	—
Working capital and contingency	10,115	(1,204)
	$ 342,064	$ 92,442

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

Notes to Financial Statements

A. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES:

Fund Accounting

In order to comply with the internal and external limitations and 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 a nominal value of $1. (Income from such investments is not significant.)

Net investment income is distributed to all funds in the year received and for pooled investments, income 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.

The Institution follows the accrual basis of accounting except that investment income is recorded on a cash basis. The difference between such basis and the accrual basis does not have a material effect on the determination of investment income earned on a year-to-year basis.

Contracts and Grants

Revenues associated with contracts and grants are generally recognized as related costs are incurred.

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 5% on buildings, 3⅓% on Atlantis II and 5% to 33⅓% on equipment. Depreciation expense on Institution-purchased plant assets amounting to $432,410 in 1976 and $409,779 in 1975 has been charged to operating expenses. Depreciation on certain government funded facilities (Atlantis II, Laboratory for Marine Science and the dock facility, amounting to $263,228 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.

Annuity Funds

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

B. ENDOWMENT AND SIMILAR FUND INVESTMENTS:

The cost and market value of separately invested and pooled investments are as follows:

	December 31, 1976 Cost	December 31, 1976 Market	December 31, 1975 Cost	December 31, 1975 Market
Separately invested:				
Government and government agencies	$ 2,550,958	$ 2,601,000	$ 2,083,626	$ 2,058,000
Bonds	4,943,822	5,074,100	5,641,958	5,505,790
Common stocks	13,207,679	14,717,075	11,338,771	11,216,400
Savings deposits	1,413,000	1,413,000	–	–
Cash	264,543	264,543	194,135	194,135
	$22,380,002	**$24,069,718**	**$19,258,490**	**$18,974,325**

	December 31, 1976 Cost	December 31, 1976 Market	December 31, 1975 Cost	December 31, 1975 Market
Pooled investments:				
Government and government agencies	$ 1,408,468	$ 1,452,000	$ 2,061,329	$ 2,051,300
Bonds	3,560,884	3,617,120	3,948,474	3,641,210
Preferred stocks	59,704	27,000	59,704	21,000
Common stocks	7,129,057	7,909,563	5,985,936	5,777,304
Savings deposits	401,000	401,000	–	–
Real estate	45,152	45,152	47,435	47,435
Cash	118,741	118,741	2,710	2,710
Other assets	7,000	7,000	11,037	11,037
	$12,730,006	**$13,577,576**	**$12,116,625**	**$11,551,996**

C. ENDOWMENT AND SIMILAR FUND INCOME:

Income from endowment and similar funds consisted of the following:

	1976	1975
Income earned	$1,499,002	$1,330,312
Principal availed of	–	44,416
Gross income	1,499,002	1,374,728
Investment management costs	62,732	–
Net income	$1,436,270	$1,374,728

Prior to 1976, income was distributed to certain restricted quasi-endowment funds (principal expendable for same restricted purpose as income) at a fixed annual rate (5% of a three-year moving average of the unit value of the fund). If necessary to meet this distribution, principal was availed of. In 1976, the Institution changed this policy and only actual income earned by these funds is available for distribution.

In 1976, the Institution adopted the policy of charging endowment income earned with the costs of managing investments. In 1975 such costs ($49,407) were recorded as unrestricted current fund expense.

D. RETIREMENT PLAN:

The Institution has a noncontributory 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 $1,137,800 in 1976 and $928,200 in 1975, including $37,800 and $20,200, respectively, relating to expenses of the retirement trust.

During 1976, the Institution revised certain actuarial assumptions, the effect of which was to reduce pension cost by approximately $60,000. In addition, the adoption of a cost-of-living feature for benefit payments caused pension expense to increase approximately $85,000 as compared to 1975. The full impact of this latter change (approximately $265,000) will not be reflected in pension costs until 1977.

At the most recent valuation date (January 1, 1976), the actuarially computed value of vested benefits exceeded the assets of the trust by approximately $460,000. At that date, unfunded prior service costs, which will be funded through future annual accruals, approximated $5,110,000.

E. CURRENT YEAR GIFTS:

In 1976, the Institution sold its 100% ownership of Deep Sea Marina, Inc. The net proceeds of the sale ($269,303) have been reflected as a current unrestricted gift, and have been transferred to quasi-endowment funds.

During 1976, the Institution received a gift of a 53-foot sport-fishing boat which has been assigned a nominal value of $1.

F. DEFERRED SUBSCRIPTION REVENUES:

Prior to 1976, subscription revenue for Oceanus Magazine was recognized on a cash basis. In 1976 the Institution adopted the accrual basis of accounting for such revenue in recognition of its growing significance to unrestricted operations and, accordingly, $70,000 of subscription revenue has been deferred at December 31, 1976. Had similar accounting been employed at December 31, 1975, $30,000 would have been deferred at that date.

G. OCEAN INDUSTRY PROGRAM:

On December 31, 1976, the unexpended balance of the Ocean Industry Program Fund ($234,393) was transferred from unexpended balances of restricted funds to unrestricted current gift income in recognition of a revised interpretation of the terms of the related gifts. In 1977 and therafter, activity associated with these funds will be recorded in the unrestricted current fund. Had activity in this program been accounted for on an unrestricted basis in prior years, the net increase in the unrestricted current fund balance would have been $38,912 less in 1976 and $110,479 more in 1975.

Report of Certified Public Accountants

To the Board of Trustees of
Woods Hole Oceanographic Institution:

We have examined the balance sheets of Woods Hole Oceanographic Institution as of December 31, 1976 and 1975, and the related statements of changes in fund balances, and of current fund revenues, expenses and transfers for the years then ended. Our examinations were made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the aforementioned financial statements present fairly the financial position of Woods Hole Oceanographic Institution as of December 31, 1976 and 1975, the changes in its fund balances, and its current fund revenues, expenses and transfers for the years then ended, in conformity with generally accepted accounting principles applied on a consistent basis.

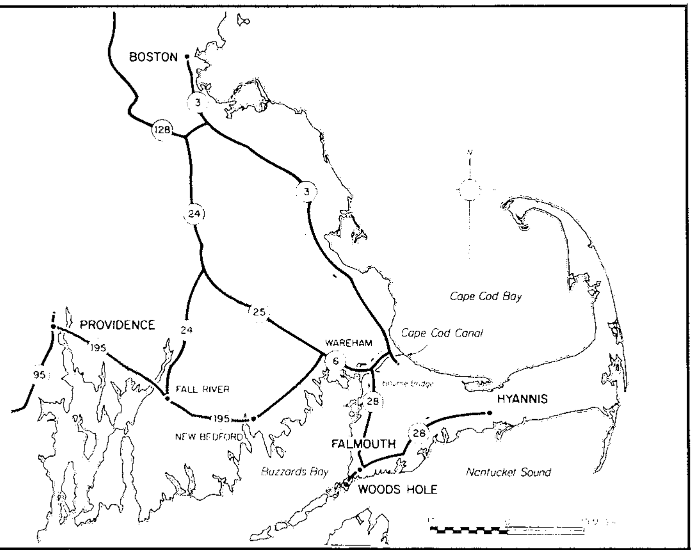
Coopers & Lybrand

Boston, Massachusetts
April 6, 1977

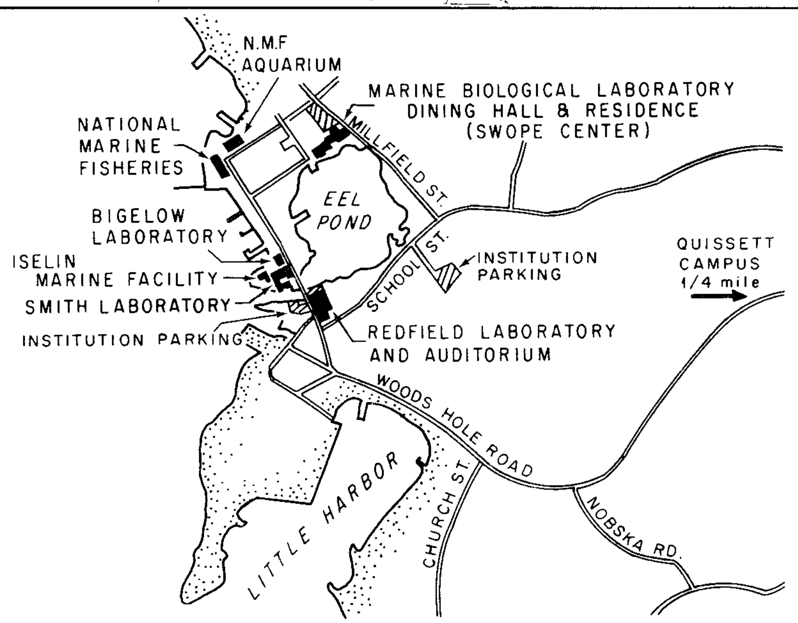
Woods Hole Oceanographic Institution
Annual Report 1976

Vicky Cullen, Editor
Leyden Press, Plymouth, MA, Printer

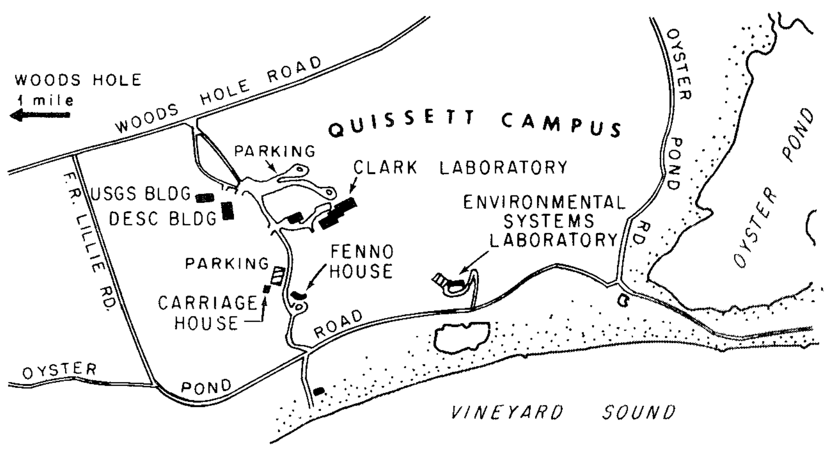
Location of Woods Hole



Woods Hole Facilities



Quissett Campus



BACK COVER: Upper left photo by Keith von der Heydt of an Indian Ocean sunset from R/V *Atlantis II;* upper right cluster of hardhats on R/V *Knorr* by Laurence Armi; lower left plankton net on hydrowire by Vicky Cullen; lower right *Alvin* descending by John Porteous.

Guest Students *(continued)*

GEORGE PERRY
Southampton College

DANIEL PICTROWSKI
University of Massachusetts

JERRI POTTER
Johnson State College

LINDA RAPP
Germantown Academy

JAMES F. REMILLARD, JR.
Framingham State College

MICHAEL R. ROMAN
University of New Hampshire

KENNETH ROSE
University of Connecticut

LEIGH ROYDEN
Harvard University

WILMA SAFFRAN
Cornell University

RICHARD SEARS
Nasson College

ELIZABETH SEIDENBERG
Bard College

THOMAS SKOPEK
Massachusetts Institute of Technology

MICHAEL STROMAN
University of Massachusetts

JACEK SULANOWSKI
University of Chicago

EULALIE SULLIVAN
Smith College

LAWRENCE UCHMANOWICZ
Falmouth High School

ANNE M. WOOD
University of Georgia

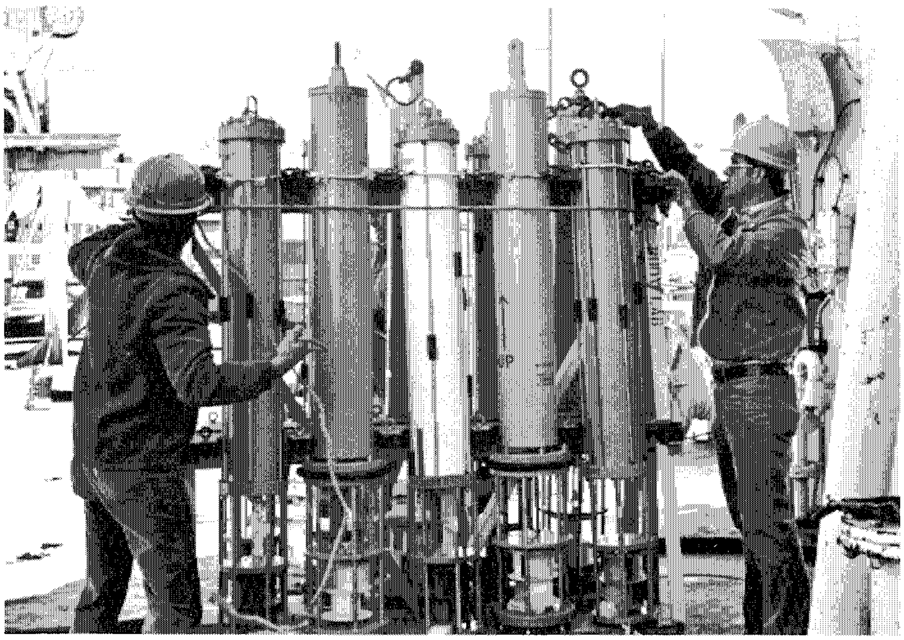
CYNTHIA WIGLEY
Falmouth High School

JOHN ZAWALICH
Bates College

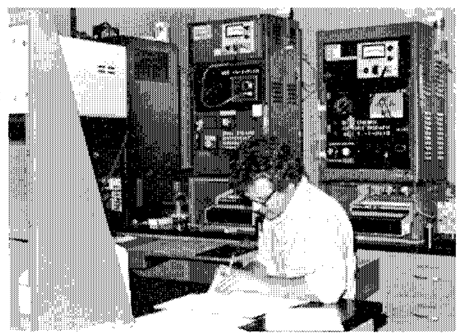
Jake Hornor Trainees

HERBERT A. BARROW, JR.
University of Washington

ROBERT J. CRUZ
New Bedford High School

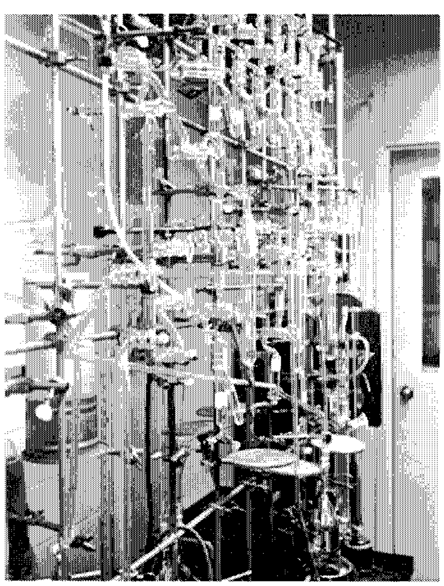

Joe Poirier and Jerry Dean unload current meters.

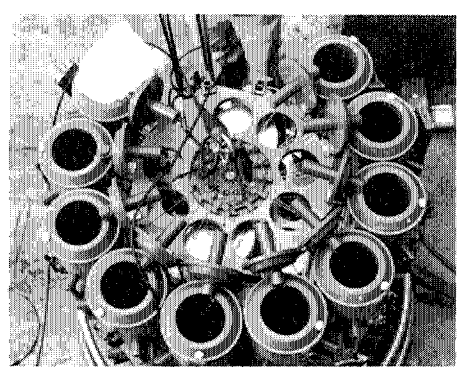
VICKY CULLEN


VICKY CULLEN
Charlie Olson works in Clark lab.


VICKI MCALISTER
Jim Craddock mends nets.

VICKY CULLEN
Visiting scientists wait to cast off.


VICKY CULLEN
Chemical apparatus in Werner Deuser's lab.


SUSAN KADAR
Rosette sampler is one of chemistry's tools.