Table of Contents

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Cover:
Electron micrographs of radiolarian shells are rendered here in high contrast. Radiolarians are single-celled microscopic members of the plankton community that lives in the surface waters of the ocean. When they die, their shells settle to the bottom of the ocean, where they, along with the shells of other animals in their phylum, cover large areas. The skeletons are constructed of opal often arranged in delicate and complex architecture. Susumu Honjo's contribution to this report on page 16 discusses contemporary populations of plankton, and the contributions of William Berggren (page 10), G. P. Lohmann (page 12), and Bruce Corliss (page 14) consider what can be learned from study of plankton fossils. The photographs from which the cover illustrations were made were taken by Kozo Takahashi, a Joint Program student in Honjo's laboratory.

Annual Report 1980:
Vicky Cullen, Editor & Designer
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VICKY CULLEN

R/V *Oceanus* departs Woods Hole in May 1980 to set test moorings for the Long Term Upper Ocean Study.

Director's Comments

NINETEEN eighty was an eventful year during which we celebrated our fiftieth anniversary with many and diverse activities involving the Corporation, Associates, and the local community. Two major international meetings were held in Woods Hole to consider the past achievements in oceanography and to assess future developments.

Amid all these celebrations the work of the Institution proceeded as vigorously as ever and some of the accomplishments of the past year are described in this report. One of the important events of 1980 was the establishment of our Coastal Research Center. The Institution is concerned with the oceans of the world and, properly, most of our research is in the "blue water." Yet we have always had special interests on the continental shelf since Dr. Bigelow's work in the Gulf of Maine. The study of this part of the seas often appears parochial; yet, for practical as well as scientific reasons, we need to be able to generalize about the complicated mixture of physical, chemical, and biological events which occur along the coast and on the continental shelf. The new Center is intended to enhance the Institution's continuing research on these problems. Three studies have been defined – to synthesize (in collaboration with colleagues from other institutions) the widespread but fragmented knowledge of Georges Bank; to evaluate the scientific basis for quantitative estimation of the role of particulate matter in the "assimilative capacity" of coastal areas; to design new instrument technology for coastal research.

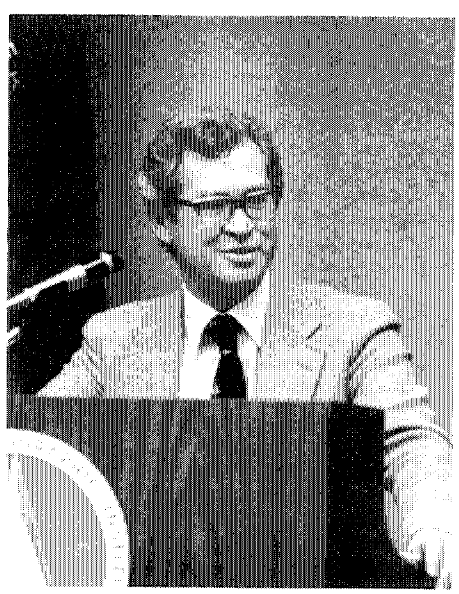
Experimental studies play a crucial role in research on the coastal region, especially in relation to any perturbations we may wish to impose. Thus an immediate need for the work of the Center was an expansion in facilities for such experimental work. A special building was designed for this purpose, funds have been provided, and we expect construction to be completed in 1981.

The rapid establishment of the Coastal Research Center as part of the Institution's activities emphasizes the need to diversify our work, especially in relation to the requirements of society for information about the marine environment. Undoubtedly, this will remain a major factor in our future planning. We see a renewed general emphasis on engineering. And the seas are a prime area where developments in technology limit our use and our research in the oceans. It is exhilarating to find that one's ivory tower is quite suddenly at the center of major social controversy. And oceanographers have responded well to an almost bewildering variety of externally posed problems.

But we should avoid allowing the balance to shift too far towards the provision of solutions to pressing environmental problems. As well as these immediate aspects, we must pursue the development of our science as an intellectual discipline. The branches of science dealing with the physical and biological environment are still sometimes regarded as relatively soft compared with the rigor of the classical disciplines – a mixture of inadequate hypotheses and uncertain data. I believe this is a profoundly mistaken view of the nature of geophysical and ecological studies. At present, some of the most exciting ideas in science concern the dynamics of complex systems, and these arise typically in environmental questions concerning turbulence and ecosystem structure. We have come to realize that some of the superficial uncertainties, appearing often as a lack of knowledge, may prefigure deeper questions of indeterminacy. The best known examples are in weather prediction, but the same concepts are being studied for aquatic and ecological systems. The intellectual and conceptual development of this picture of an inherently indeterminate reality may be more significant, to society as well as to ourselves (and to our funding), than application of our present knowledge to our immediate environmental problems.

Thus we must be involved in education, not only of our future colleagues, but of other scientists, as well as the larger society. In the 19th century, the traditional education of those destined for leadership was the classical perfection of a dead language and its culture. More recently, pure mathematics is used often to epitomize ideals of exactness and of certainty. Are such ideals appropriate in our present time, and to be contrasted with a lack of clarity in our scientific dealings with the environment? I believe that, in the future, we can provide the sense of elegance, the elements of rigor, together with the texture of a world exhibiting both mystery and coherence.

John H. Steele
Director



ELIZABETH FYE

John Steele

Areas of Interest

Biology

THE broad aim of biological oceanographers is to study the temporal and spatial distributions of populations of marine organisms and their interactions with each other and their environment. The work is predominantly ecological in nature and provides the basic information required to understand how the ocean works biologically. Among the research interests of Institution biologists are microbiology, planktonology, benthic biology, physiology, animal behavior, and aquaculture. Work on marine pollution includes research on the effects of drilling muds and hydrocarbons. The "patchy" distribution of many marine animals is under investigation as are the physiological adaptations of deep sea organisms to sparseness of food, low temperatures, and high pressures. Answers to questions about the food supply in the oceans are sought in studies of particles falling from the surface waters through the water column to the bottom of the sea, in upwelling areas where deep nutrient-rich waters replace surface waters that are driven offshore by prevailing winds, and in laboratory experiments that complement field investigations. The use of sound by marine animals and their sensitivity to electrical fields are being studied. Other work concentrates on salt marsh ecology and conservation, and there are research projects on aquaculture and waste water recycling and on the productivity of a salmon river in Canada.

Geology & Geophysics

THE tectonic, volcanic, and sedimentation processes that determine the shape and underlying structure of the sea floor are studied by marine geologists and geophysicists. The structure, evolution, and dynamics of the oceanic crust and lithosphere are investigated by applying the principles of structural geology to direct and remote observations of the seabed, by petrologic and geochemical analyses of rock samples, and by various geophysical methods, including seismology, gravity, magnetism, and geothermal measurements. Special attention is given to the divergent plate boundaries where concentrated heat flow fuels a major hydrothermal circulation system and where rocks originating deep in the earth are brought up to the sea floor in transform faults and in the axes of mid-ocean ridges. Detailed studies are being made of rifted continental margins and marginal basins and of the convergent plate margins where oceanic crust sinks beneath continents or island arcs creating deep sea trenches and the major belts of earthquake and volcanic activity. Research on particulate flux, carbonate and silicate dissolution, and other processes involved in the transport of biogenic material to the sea floor is vigorously pursued. The results are essential to a better understanding of the fossil record which reveals historical changes in climate and oceanic environment caused by the shifting of continents and oceans over the earth's surface through geologic time. Also important to the deciphering of the fossil record and to the understanding of sea floor morphology is the study of sediment dynamics, including slumping, turbidity currents, and the sculpting of abyssal sediments by deep sea currents. Research activity is focused also in the shallower areas of the oceans where marine geologists study the processes that determine the shape and structure of continental shelves and slopes and processes that shape the coastal zone.

Chemistry

CHEMICAL oceanographers are concerned with the composition of the ocean environment. They seek to understand the processes that have brought seawater and sediments to their present composition and that contribute to the observed variability. They also seek understanding of the extent to which the environment may be changed by both natural and man-made phenomena operating on a variety of time scales. Input from rivers and reactions at the air-sea, seawater-sediment boundaries and seawater-volcanic rock interaction at spreading centers are under investigation as chemists consider the processes taking place at major ocean boundaries. Some critical questions in chemical oceanography revolve around transformations in particles as they fall from the surface waters to the bottom of the water column. The genesis and composition of the oceanic crust and its interaction with seawater is important to a general understanding of the oceanic system. Work on the fluxes of organic carbon includes determination of the amount of organic carbon produced in surface waters, the distribution, nature, and biogeochemistry of specific organic compounds in the marine environment, and studies of processes responsible for formation and diagenesis of organic matter in sediments. While studying radioactive isotopes in the ocean whether as a natural occurrence or as a form of pollution, chemists are also finding the known decay rates of the isotopes useful as indicators for studying rates of water circulation and of biological and chemical processes that change the composition of seawater.

Physical Oceanography

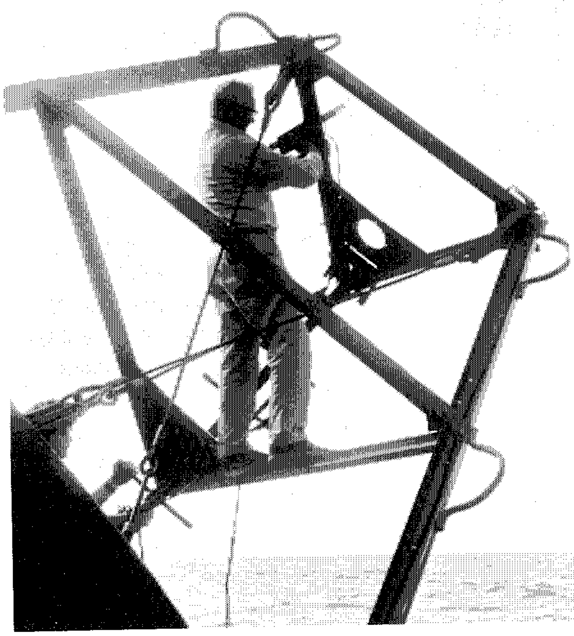
OCEAN currents, their driving forces, and their interactions are the major interests of physical oceanographers. Such properties as variations in temperature, salinity, pressure, and large and small scale motions of the waters are measured with a variety of instruments lowered from ships, moored in place, or set to drift with the currents. Their data are plotted and analyzed toward an understanding of why and how the waters move as they do. 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, and the technology of extended-period measurement is constantly upgraded so that trends can be followed. 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.

Ocean Engineering

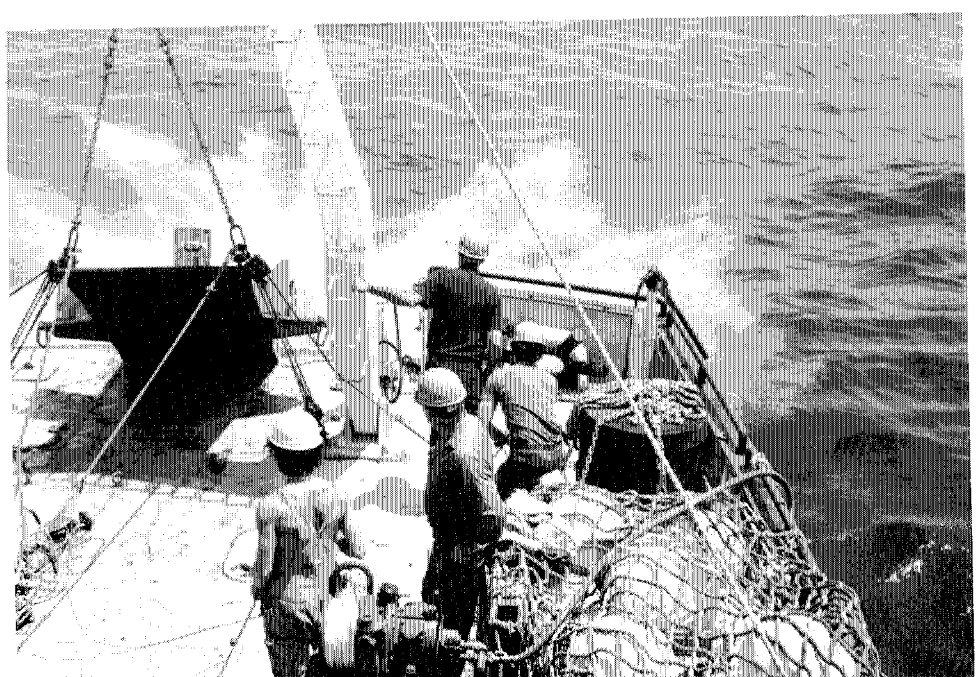
MOST of the endeavors of the Ocean Engineering Department center about the fact that the oceans are in constant motion of many scales. This motion is a representation of the forces acting on the ocean, and understanding these forces and the resultant movement is a challenging problem. Measurement of this motion is equally challenging, ranging from measurements of flow and turbulence within centimeters of the bottom in order to understand the effects of waves and currents on sediments to tracking the motion of neutrally buoyant floats being carried by deep currents over hundreds of kilometers in the ocean. The techniques for making these measurements combine some of all of the engineering and scientific disciplines, as does interpreting the results. Mechanical structures and moorings are needed for some systems, laser and high frequency acoustics are used in measurements of small space scales, low frequency acoustics is used for large space scales; all require high quality engineering. Acoustics is also used as a tool to examine the structure of the bottom and the transport of material, inert or alive, by the movement of the water. Exploration of the deep ocean bottom, particularly along the great ridge systems of the seas, poses special problems in engineering and navigation, uses of photography and television, signal transmission, instrumentation, and submersibles. Computers are an everyday tool in the ongoing programs. Improvements in in situ long term instruments are being made as the technology of low power, small size solid state equipment advances. Both of these require depth in the understanding of signal processing theoretically and practically.

Marine Policy & Ocean Management

THE Marine Policy and Ocean Management program supports research by marine and social scientists on the social, economic, and political aspects of problems generated by man's use of the sea. The program supports a small marine policy staff and offers advanced fellowships to individuals from such fields as anthropology, economics, international affairs, law, political science, and the marine sciences who are interested in applying their training and experience to marine policy and ocean management questions. The program also sponsors lectures, workshops, and seminars on policy-related subjects. Present research in the Program focuses on six categories: coastal zone management issues, fisheries management, offshore energy development, ocean mineral resource issues, ocean waste disposal policies, and marine science issues.



These photographs were taken on *Oceanus* Voyage 85 in May 1980 during a cruise for the Long Term Upper Ocean Study (LOTUS) by Chief Scientist Mel Briscoe. At left, Clayt Collins attaches flashing light to surface discus float for LOTUS test mooring. Above, Eric Spencer and Pat O'Malley apply identifying graphics to top float of sub-surface mooring. Bottom photo shows splash created by float launch. Below, Jeff Simon, photographer on assignment for *Life* magazine, gets bird's-eye view of float launch. *Life* featured the Institution's 50th anniversary in August 1980 issue.



Reports on Research

DURING the first year of the new decade, several WHOI scientists have been heavily involved in the start-up phases of some major multi-institutional and multi-disciplinary programs. These include the Transient Tracers in the Ocean program (TTO), the Warm Core Rings Experiment, and the Coastal Ocean Dynamics Experiment (CODE). The TTO program is designed to study the rate at which deep water is being formed from surface water in the world's oceans by determining the distribution of chemical and radioactive transient chemicals introduced by man. The results of this work will form an important base for our future understanding of many ocean/atmosphere interactions including pollutant distribution, the carbon dioxide problem, and climate.

The Warm Core Rings Experiment will involve biologists, chemists, and physicists in the study of the warm core rings that spin off the northwest boundary of the Gulf Stream. Physicists will study the dynamics of the rings (e.g., why do they form? why do they persist?) while biologists and chemists study the environmental evolution of the warm water trapped in the ring cores and the nature of the interaction between the contrasting warm and cold water environments.

CODE is a major systematic study designed to determine the mechanisms involved in driving the circulation of coastal regions of the oceans. How do winds, tides, the motion of the deep ocean and other forces interact to form the complex patterns of currents and contrasting water types characteristic of many continental shelf regions?

These programs will add to the growing number of multi-institutional endeavors that, during the last decade, have come to be a major fraction of our total research effort. A brief discussion of one of the ongoing multi-institutional projects, the High Energy Benthic Boundary Layer Experiment (HEBBLE), begins our report for 1980.

However, despite the increase of larger programs, some very significant research is being accomplished by individuals and smaller groups of scientists, and we devote most of our report this year to brief discussions of some of these achievements.

A fascinating record of the earth's past history is entombed within the sediments of the deep sea floor. In three articles we see how an understanding of the taxonomy, stratigraphy, and biogeographic distribution patterns of two particular groups of microfossils, foraminifera and calcareous nannoplankton, contributes to our knowledge of the history of past changes in climate and oceanic circulation.

Berggren describes how the similar distribution patterns of agglutinated benthic foraminifera in two geographically widely separated areas and geologically distinct settings are interpreted in terms of a present day ecologic model. Lohmann demonstrates the use of calcareous benthic foraminifera and nannoplankton in two case studies, one dealing with the development of stagnant (unoxygenated) bottom waters in the deep Mediterranean Sea and the other with distribution patterns in the Pacific Ocean during the Miocene Epoch as a reflection of past climatic changes. Corliss discusses the intimate relationship between deep sea benthic foraminifera and hydrographic properties of water masses to evaluate the history of the Antarctic Circumpolar Current during the past 1.5 million years.

The accumulation of fossilized animals and plants in sediments is a complex function of many factors. Some of the most important factors are the changes that take place as dead organisms settle through the ocean water column, and the contributions of Deuser and Honjo describe studies of these effects.

An understanding of the fluxes of chemicals through the ocean is one of our goals. In recent years we have learned that the studies of both natural and artificial radioisotope distributions in the ocean provide a powerful tool for reaching this goal. The article by Bacon describes the use of one such tracer and points to the discovery of an ocean boundary adsorption process that may be of great significance in controlling the oceanic distribution of many reactive heavy metals.

Studies of the motion of the deep ocean have always been a strong component of our work, and the contributions of Price, Webb, and Bradley and of Stommel describe two new thrusts in this area. Similarly, aquaculture studies have been a steady part of our efforts for a number of years, and Ryther and Naiman present two of the recent programs.

Studies in marine policy and ocean management have been a growing part of our overall effort. With the increased utilization of the ocean and its resources by both government and industry and with the growth of regulations, marine science has become one of the foundations for management decisions. Several important economic and social problems are currently under cooperative investigation by members of the Marine Policy and Ocean Management program and Institution scientists. The last article, by Finn, describes one of these concerned with the management of coastal resources.

Derek Spencer
Associate Director for Research

The HEBBLE Project

Charles Hollister, Brian Tucholke,
Albert Williams 3rd, and Richard Chandler

THE dynamic interaction of the seabed with the water flowing just above it is of interest not only for characterizing present environmental conditions, but also for interpreting paleoceanographic history through buried sedimentary sequences. While the simplest bed response to a flow is adjustment toward equilibrium with that flow, this response is complicated by a host of factors including sediment grain-size distribution, electrochemical cohesion, existing bedforms, organic binding, and incipient cementation. These in turn are controlled by sedimentary mineralogy, processes that initially delivered the debris to the sea floor, in situ biologic reworking, and the intra-sediment geochemical framework. When the flow over the bed in itself is variable, and it both resuspends and deposits sediment, we are faced with sorting out and interpreting a mixture of flow and seabed parameters, some of which are and some of which are not in equilibrium.

The High Energy Benthic Boundary Layer Experiment (HEBBLE) is aimed at significantly increasing our understanding of the geological effects of strong ocean bottom currents in the deep-ocean benthic boundary layer, generally defined as within 100 meters of the sea floor. This multi-institutional effort is the joint project of sedimentologists, physical oceanographers, biologists, and ocean engineers combining their skills (see table) to address the scientific problems of sediment transport in a high energy flow such as the Western Boundary Undercurrent in the North Atlantic. At a March 1978 planning meeting, the investigators identified major fields of interest; these included long-term measurements of ocean floor bedforms, sediment properties, turbulent flow structure, suspended sediment concentrations and fluxes, mixed layer thickness, and horizontal density gradients in a carefully surveyed site. The experimental plan integrates state-of-the-art models of momentum and sediment transport with refined, innovative instrumentation and careful, controlled laboratory experiments. The program is supported under the auspices of the Office of Naval Research with technical assistance from the Jet Propulsion Laboratory through the Technology Transfer Division of NASA.

Selecting a study area for HEBBLE proved to be a relatively simple task. Our interest in deep-sea high energy flow necessitated concentration on the best available examples: deep western boundary currents in a topographically uncomplex region. Furthermore, most bottom current and sedimentary-bedform data collected in such areas came from the western North Atlantic, most notably through the efforts of scientists at WHOI and the Lamont-Doherty Geological Observatory. Bottom photographs taken in the 1960s on the continental rise 250 miles south of Nova Scotia depicted very definite smoothing and "crag and tail" lineations, suggesting the presence of a geologically significant bottom current system flowing toward the southwest. Sediment cores from the same area revealed sediment structures, textures, and grain sizes peculiar to high energy regimes, and correlation of these two data sets provided substantive evidence of strong, relatively uniform flow over hundreds to thousands of years. Although the Blake-Bahama Outer Ridge exhibited many of these characteristics, the presence of turbulence-inducing furrows in the sea floor led us to discard it as a primary site for reasons of topographic complexity.

Beginning in July 1979 HEBBLE investigators have conducted four oceanographic cruises to the candidate site on the lower continental rise 250 miles east of Nantucket. We have examined the regional geologic framework, begun continuous monitoring of the abyssal currents and tested instrument systems in preparation for long-term experiments. The cruises have already yielded some fascinating and unexpected results.

Most of the nearly 100 camera stations taken to date on the continental rise have revealed small-scale (centimeters) crag and tail bedforms occurring with larger (10 centimeter) two-dimensional longitudinal ripples. The simplest bedform region, apparently without rip-

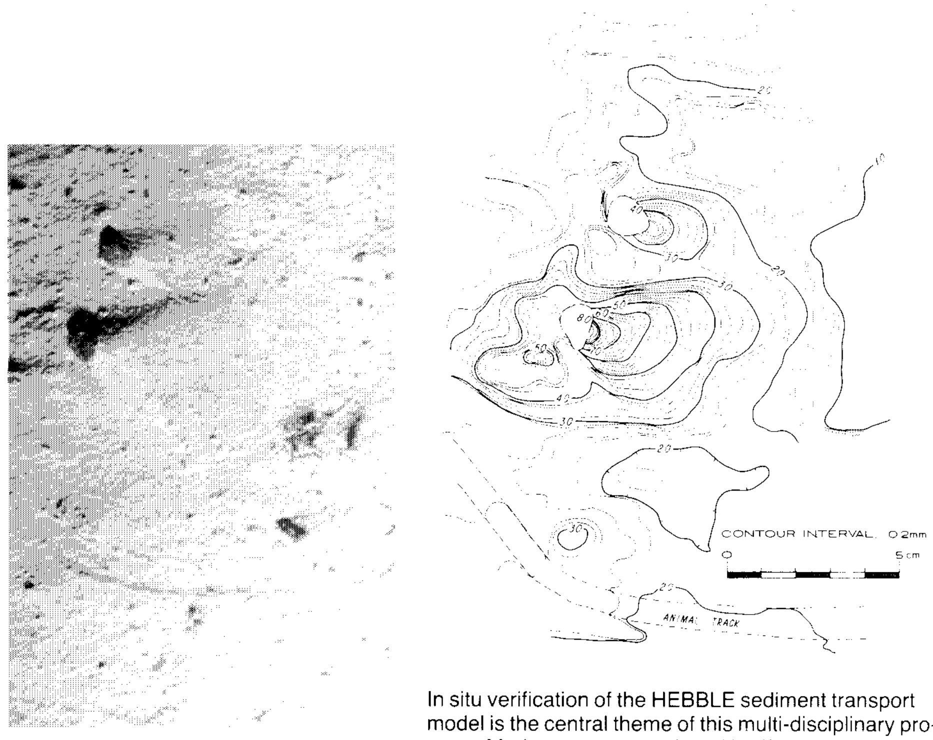
VICKY CULLEN

Brian Tucholke, seated, and, from left, Charley Hollister, Sandy Williams, and Rick Chandler.

ples but with lineations, lies at about 4,600 meters water depth. Detailed analysis of the smallest bedforms visible in the photographs shows deviations in individual direction that suggest flow variability on short time scales (days to months), but the dominant flow component is WSW parallel to the bathymetric contours. In deeper water, ripples that probably take months or years to form are also oriented parallel to the regional isobaths, providing further evidence of a contour-following current system.

In general, the bottom boundary layer appears to be well mixed with respect to temperature (it is isothermal) and turbidity. Thickness of this layer is highly variable, with a range of 15 to 160 meters and an average of approximately 60 meters. Potential temperatures in the mixed layer below four kilometers depth vary between 1.753 and 1.840°C, a range of less than 0.1°C.

An array of current meters has been used to measure velocity between 0.3 centimeters and 15 meters above the bottom; heated wires (such as those used in anemometry) and an acoustic vector current meter are now in use (a laser Doppler velocity meter will be used to extend the velocity profile down to one centimeter in 1981). These measure the stress indirectly at a single height above the bottom and can be used to estimate the bottom shear stress from a profile of single point measurements. The results are being compared to stress estimates from the velocity profile obtained with Savonius rotors. Under low flow conditions (6 centimeters per second at one meter above bottom), the Reynolds stress estimate of bottom shear stress and the velocity profile estimate agree reasonably well. Under these conditions, however, there is negligible suspension of particulate matter and the bedform roughness does not change. While agreement between the two methods is gratifying in this simple case, we have not yet measured



In situ verification of the HEBBLE sediment transport model is the central theme of this multi-disciplinary program. Modern current-produced bedforms ("crag and tail") were photographed with a stereo camera system at 5-kilometer depth. The contour map at 0.2 millimeter scale was then drawn of the features photographed. Aerial photogrammetric techniques will be employed to determine sediment flux caused by high stress fluid events.

HEBBLE Project Principal Investigators

Institution	Investigator	Specialty
Woods Hole Oceanographic Institution	C. Hollister (Director)	photogrammetry
	Y. Agrawal	laser Doppler velocimetry in turbulence studies
	M. Orr	acoustic backscattering
	S. Swift*	settling velocity and photogrammetry
	B. Tucholke*	bedforms and sedimentology
	A. Williams	current velocity and Reynolds stress
Lamont-Doherty Geological Observatory	P. Biscaye	turbulent mixing
	W. Gardner*	suspended particle concentration
	M. Richardson*	current velocity and resuspension
	A. Shor*	bathymetric interpretation
University of Rhode Island	E. Laine*	seismic stratigraphy
	A. Silva	geotechnical properties
	M. Wimbush	boundary layer hydrodynamics
Florida State University	D. Thistle	sedimentological bioturbation
	G. Weatherly	mixed layer current measurement and modeling
University of South Florida	K. Carder	settling particle holography
	G. Gust	turbulence structure determination
Jet Propulsion Laboratory	D. Collins	NASA technology transfer (autonomous instrumentation, image processing, data handling)
University of New Hampshire	J. Irish	bottom pressure gradients
Scripps Institution of Oceanography	P. Lonsdale	site survey and sonar interpretation
University of Washington	A. Nowell	near bottom flow modeling
Massachusetts Institute of Technology	C. Paola*	bottom roughness parameterization
	J. Southard	critical erosion stress
Wayne State University	J. Yingst	biogenic sedimentology
Oregon State University	R. Zaneveld	optical transmissometry

*Present or former students in the MIT WHOI Joint Program in Oceanography the effect of stronger flow on the stress. Repeated or longer deployments are being designed to capture more energetic events.

A series of conductivity-temperature-depth sections taken across the current axis in September 1979 revealed the presence of a thin (less than 100 kilometers across, hundreds of meters high) "filament" of colder, less saline water traveling at 20 centimeters per second or more toward the southwest along the 4,900 meter isobath. Preliminary data invites speculation concerning the origin of this water; high silica content and 1.7°C temperatures have led investigators from Florida State University to classify it as errant Antarctic Bottom Water. If this proves to be the case, we hope to spark a lively discussion and possibly a reconsideration of modern theories of North Atlantic bottom circulation.

Major periods of extremely turbid water (so-called "benthic storms") were recorded during late summer 1979 by an Oregon State University transmissometer placed near the current axis. The sudden changes in suspended particle concentration evidenced by the sharp boundaries of the storms, particularly at the trailing edge, indicate that the clouds are finite in size and are being advected by currents; the more gradual change at the leading edge suggests the possibility of local resuspension of sediments. The turbidity encountered during one of these storms in August surpassed all previously recorded suspended sediment levels anywhere in the deep ocean. Suspended matter concentrations as high as 12,000 micrograms per liter have been measured – values nearly 100 times higher than those in a normal near-bottom nepheloid (particle-laden) layer.

Plans for 1981 include a 30-day Deep-Tow survey of selected portions of the HEBBLE study area, as well as continued in situ current meter, nephelometer, and transmissometer measurements. Progress will continue in refining instrumentation for long-duration data collection, which is the next step in our characterization of the region. The culmination of HEBBLE is presently scheduled for about 1985 when a suite of instruments will be lowered to the bottom for autonomous sampling and recording "events" for a period of at least six months. By the end of that time we hope to have a complete set of biological, geological, and physical oceanographic parameters by which we can characterize high energy processes in the bottom boundary layer. The results are intended to be extrapolated to other such areas that are now known to be active on the western sides of all major ocean basins.

Studies in Agglutinated Benthic Foraminifera

William Berggren

FORAMINIFERA are single-celled amoeboid marine organisms, which, in most instances, build a shelled test of calcium carbonate. The group forms a significant constituent of many marine sediments. It ranges back through time to the Early Paleozoic, about 450 million years ago. Informally, three subgroups of foraminifera are distinguished: planktonics, larger-sized benthics, and smaller benthics.

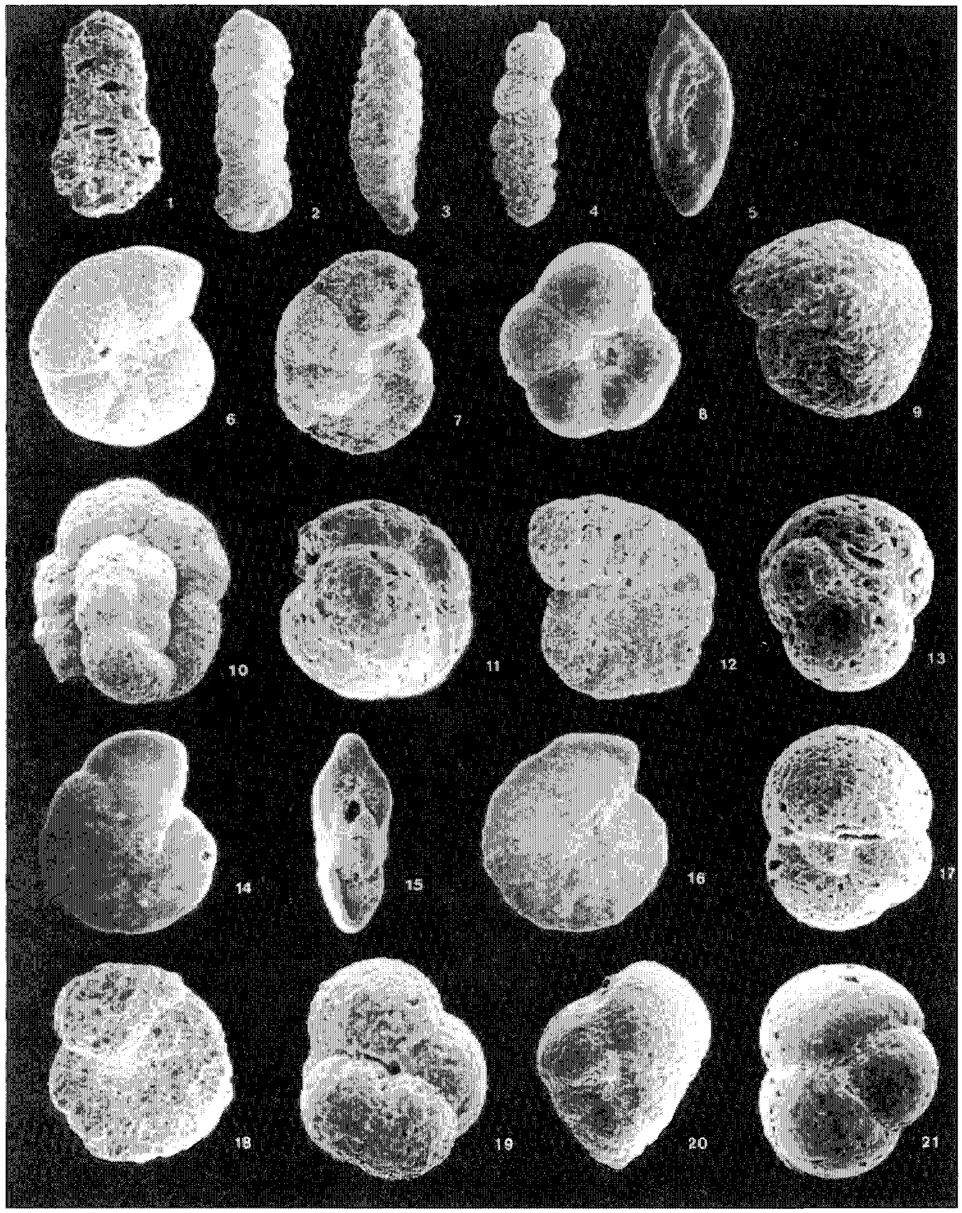
The benthic foraminifera come in two kinds, those with calcareous shells and those with agglutinated shells. The latter use an organic-type glue that is essentially an unknown substance to cement foreign particles on the sea floor. This group is of particular interest to us as part of a larger study on the use of benthic foraminifera as stratigraphic and paleoecologic tools in petroleum exploration. The study began as a result of a chance coincidence. While visiting the Woods Hole Oceanographic Institution in 1976, Felix Gradstein of the Canadian Geological Survey in Halifax, Nova Scotia, noticed, while comparing microfossil samples from oil wells on the eastern Canadian continental shelf with samples of comparable age from oil wells in the North Sea, that virtually identical agglutinated assemblages of benthic foraminifera characterized both areas. Further comparison of these assemblages with samples from the "flysch"* sediments of the tectonically active basins of the Carpathian Mountains of Southern Poland revealed further similarities. We suddenly realized that these complex and enigmatic microfossils apparently enjoyed widespread geographic distribution under what appeared to be dissimilar geologic settings, and we set about investigating them. At that time comparatively little work had been done on this group outside of eastern Europe where these faunas are found extensively developed in the Carpathian and Caucasus Mountains.

This project has now been underway for about three years. We have been fortunate in receiving financial support from a consortium of domestic oil companies; this aid has been recently augmented by the support of the Norwegian National Oil Company, Statoil.

*Flysch: from the Swiss-German dialect = "terrain that slips." The term flysch refers to orogenically controlled sediments formed in foredeeps during the active, uplift phase of geographic belts. Characteristic clastic sediments are shales and fine grained sandstones.


VICKY CULLEN

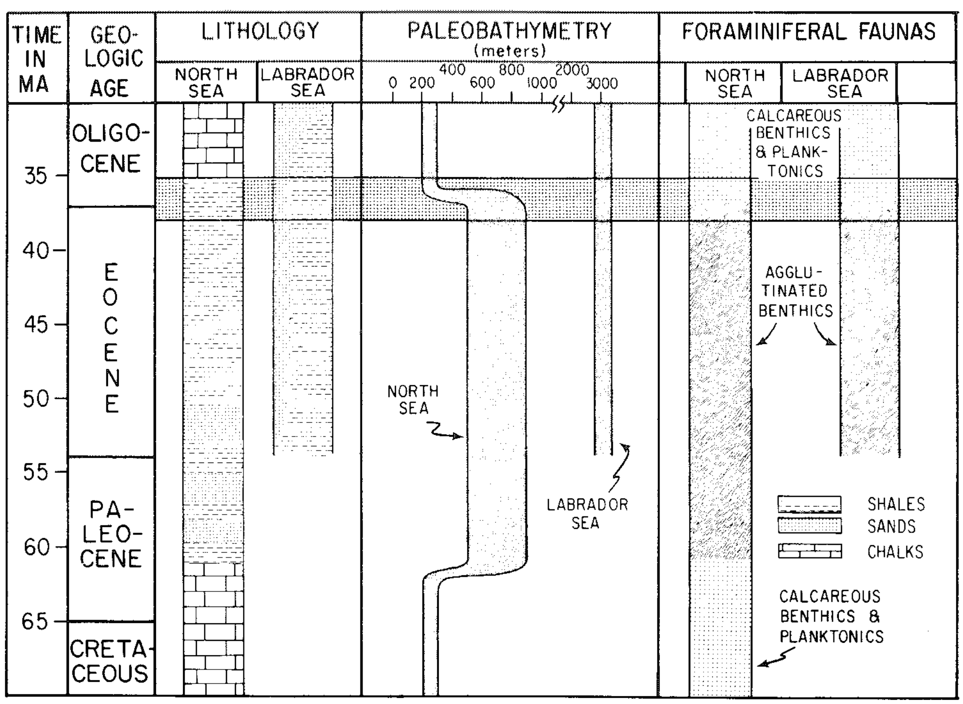
Bill Berggren



◊ Twenty-one agglutinate-shell benthic foraminifera from a single site show the morphologic heterogeneity of this group. Actual sizes of these forams range from 0.5 to 1 millimeter.

We have concentrated in the early stages of this project in coming to grips with the complex taxonomy (i.e., learning how to properly organize and classify the various forms) of this morphologically heterogeneous group. Next we have attempted to determine the stratigraphic range of the various taxa in an attempt to determine whether some of them might be useful as index forms for purposes of correlation either locally (intrabasin) or regionally (transoceanic or interoceanic).

Although we have made definite progress understanding the taxonomy (see upper figure) and stratigraphy of agglutinated benthic foraminiferal assemblages, we have been confronted by a dilemma in accounting for the factors governing their distribution in space and time. For instance, agglutinated benthic foraminiferal assemblages common in the Paleogene sediments of the North Sea Basin and Eastern Canadian margin disappear essentially simultaneously with similar assemblages in the deepest part of the Labrador Sea about 37 million years ago. Paleowater depths in these areas were about several hundred meters and over three kilometers respectively. We have definite evidence that depth is not a controlling factor: these assemblages are found in sediments which can be shown to have been formed at depths ranging from a minimum of about 300 to 500 meters to the deepest depth of the ocean, in excess of five kilometers. Rather we infer, at least in the deep sea, hydrographic properties (low oxygen, low pH, high carbon dioxide, and thus more cor-



◊ Agglutinated ("flysch-type") benthic foraminiferal faunas span essentially the same interval of the Paleogene (about 60 to 35 million years ago) in the Labrador Sea and the North Sea. The simultaneous disappearance of these faunas about 35 million years ago is somewhat enigmatic and a single, unifying explanation seems difficult. Rather uniform environmental conditions persisted across the interval of disappearance in the Labrador Sea, whereas in the North Sea a significant shallowing occurred accompanied by significant changes in sedimentation. Disappearance in the Labrador Sea may be related to a global oxygenation event associated with a change in deep water circulation. In the North Sea the disappearance may be related to sediment infilling and change of the restricted basin setting to oxygenated, shallower conditions.

rosive waters) are critical to the development of the predominantly agglutinating assemblages. Nevertheless, similar conditions may develop in reducing substrates associated with high organic matter and poor circulation. Predominantly agglutinated assemblages are probably favored in such substrates and/or in areas with the requisite hydrographic properties.

A major faunal change occurs about 37 million years ago at the boundary between two geologic epochs known as the Eocene (below) and the Oligocene (above). Agglutinated foraminiferal assemblages – virtually the sole faunal constituents of the organic-rich shales in the North Sea and Canadian margin – disappear at that time and are replaced by shallow water calcareous benthic and planktonic faunas.

In the deep Labrador Sea similar agglutinated assemblages disappear simultaneously under rather uniform environmental conditions (lower figure p.11). The fact that lithology and percent organic carbon remain relatively constant across the faunal change in the deep Labrador Sea suggests that these properties may not be critical to the development of predominantly agglutinated assemblages.

We speculate that the initiation of cold, oxygenated bottom waters in the northern North Atlantic, inferred from sediment distribution patterns, may have been responsible for the replacement of the agglutinated assemblage in the deep Labrador Sea by a calcareous assemblage. This event may be related, in turn, to a global oxygenation event associated with a major cooling and change in deep water circulation in the ocean that is currently receiving the attention of paleoceanographers at several institutions.

In the North Sea and Eastern Canadian margin the disappearance of the agglutinated assemblage about 37 million years ago may have been due to sediment infilling and change of the restricted basin setting to oxygenated, shallower conditions. Thus the change in these areas would be related to local tectonic and sedimentologic changes. The temporal congruity of this major extinction event which is seen to have occurred under vastly different spatial conditions renders difficult an interpretation based on a single, unifying cause. The paradox remains and spurs us on in our future research in seeking an explanation.

The next phase of our study will involve an integration of stratigraphic data with geologic-geophysical data from oil companies in an attempt to delineate the paleoecology and paleobathymetric distribution patterns of agglutinated taxa. Depositional conditions in the North Sea during the interval of 60 to 35 million years ago ranged from shallow water muddy deltas to deep sea fan deposits (not unlike those accumulating today in the deep distal margins of the Nile and Ganges deltaic systems). We have spent the past two summers visiting oil companies in the circum-North Sea area and have received considerable cooperation from several of them which we believe will enable us to gain an understanding of the relationship of the paleogeographic distribution of various taxa to specific paleoenvironments. In this way we hope to make the agglutinated benthic foraminifera a useful tool in stratigraphic and paleoenvironmental studies associated with exploration for petroleum in flysch basins around the world.

Fossil Records of Ocean Experiments

G.P. Lohmann

VICKY CULLEN

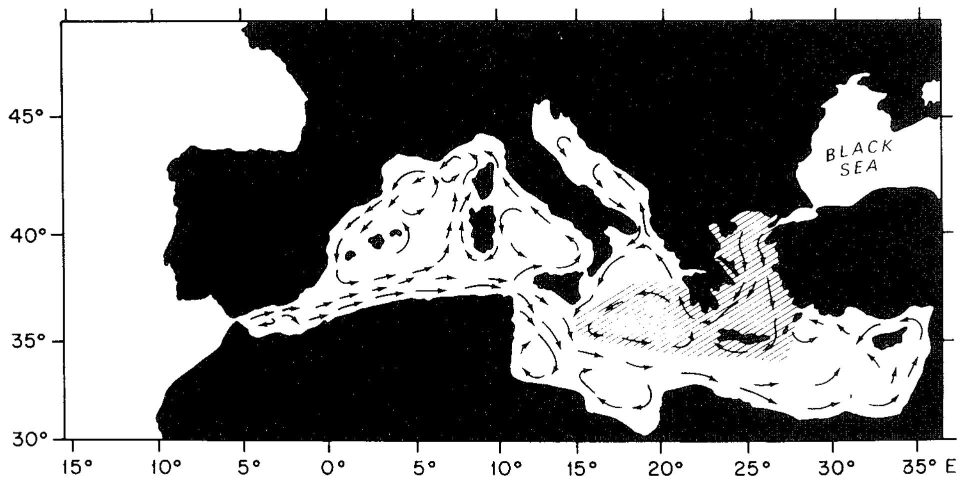
Pat Lohmann

THERE are many experiments that would increase our knowledge of the ocean if only they were feasible. For example, we would have a much better understanding of how the growth of polar ice caps influences world climate and ocean circulation if only we could experimentally vary their size and shape, or even melt them away entirely. We would learn a great deal about the dynamics of the ocean's surface and deep circulation if we could study the effects of altering the geometry of the ocean basins, or of opening and closing connections between oceans, or of drastically changing the ocean's salinity. But besides the obvious physical difficulties preventing us from conducting such experiments, they would have to be watched for thousands of years just to allow the ocean to fully respond. Fortunately, many of these experiments have already been done and records of them remain.

There have been dramatic changes in the geometry of the ocean basins, in the distribution of ice, and in the character and sources of deep water over the past 100 million years, and records of these natural experiments are preserved as fossils in marine sediments. Although the marine fossil record is incomplete and often ambiguous, it provides a unique record of large scale ocean experiments that might be easily designed but could never realistically be carried out. With all its difficulties, the fossil record gives the paleontologist one important advantage over colleagues in other marine sciences, accessibility to time. As a marine micropaleontologist, I have been trying to interpret this record in oceanographic terms.

We recently studied the oceanographic changes associated with stagnating in the Mediterranean Sea. Today surface waters in the eastern Mediterra-

MODERN SURFACE CIRCULATION OF THE MEDITERRANEAN SEA



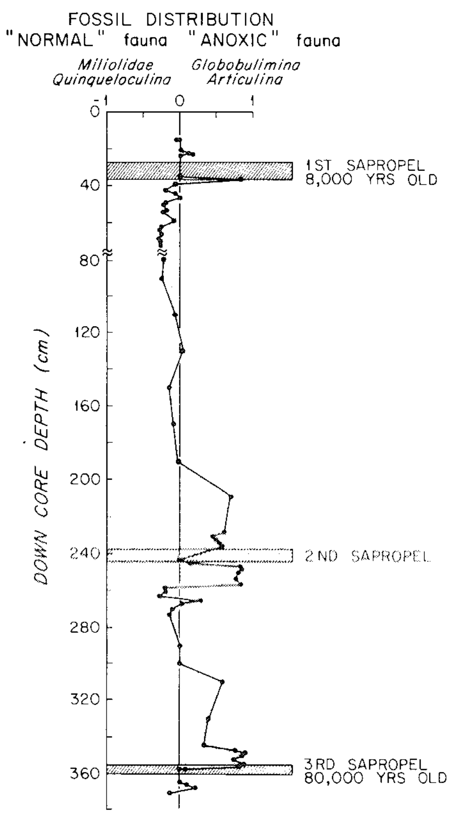
Hatched area shows modern distribution of fossil planktonic fauna associated with ancient stagnations of the Mediterranean. Today it is associated with the outflow of brackish water from the Black Sea. During stagnations this fauna, and presumably the brackish water, covered the eastern Mediterranean.

nean, which are made more dense by evaporation, sink and flow out at depth through the Straits of Gibraltar into the Atlantic. This water is replaced by Atlantic water flowing in at the surface. The result is to flush out the deep Mediterranean with oxygen-rich surface water. This style of circulation can be stopped or even reversed by making the surface of the Mediterranean less salty, producing either stagnation or inflow of deep, oxygen-poor Atlantic water. In either case, oxygen would be depleted in the deeper parts of the Mediterranean as their access to surface water was restricted.

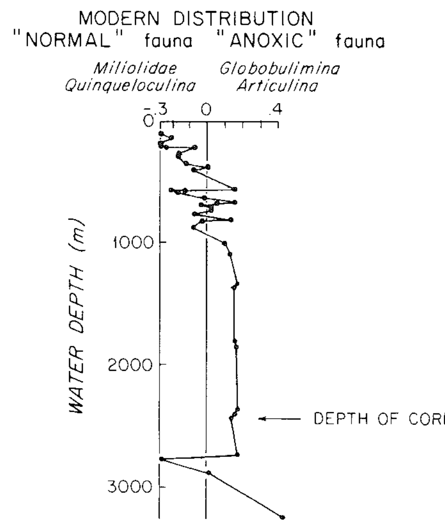
Both the marine sediments and fossil record show that such changes have happened many times over the past five million years. We can view each time this happened as an experiment that allows us to study the effects of completely altering the circulation of a major sea. The ultimate effects on the Mediterranean have been periodic annihilations of bottom dwelling organisms and deposition of black, organic sediments, but the fossil record also shows the sequence of changes that led up to each stagnation and then caused recirculation.

Fossil surface-dwelling, planktonic foraminifera that we recovered from the black, organic oozes show that the surface circulation that existed at times of stagnation can be produced simply by intensifying certain aspects of the present-day circulation (see upper figure). Increasing the flow of fresher water from the Black Sea effectively puts a lid over the eastern Mediterranean and prevents surface waters from sinking.

Fossil bottom-dwelling foraminifera from this same area show that the resulting stagnations developed slowly and that anoxia of the bottom waters and annihilation of benthic organisms were the final result of a gradual, continuous process. As the Mediterranean stagnates, the "normal" benthic fauna retreats to shallower water and "anoxic" faunas, more tolerant of oxygen-poor waters, replace them (see left figure). Finally, as bottom waters become depleted in oxygen below some critical level, even these "anoxic" faunas are forced out and black sediments accumulate. As the Mediterranean recirculates, first the "anoxic" faunas, then the "normal" faunas return. In the fossil record we studied, a complete cycle of stagnation and recirculation lasts about 25,000 years and the most recent fauna recovered from the sea floor indicates that even today the deep Mediterranean has not fully recovered from its last stagnation 8,000 years ago.



Distribution of fossil benthic fauna is shown in a sediment core recovered from about 2,500 meters in the eastern Mediterranean. The sapropels are black, organic sediments deposited during stagnations. These anoxic sediments contain no remains of benthic organisms, but there is a distinct "anoxic" fauna associated with immediately adjacent sediments. A "normal" benthic fauna characterizes sediments deposited during recirculation and reoxygenation of deep waters.

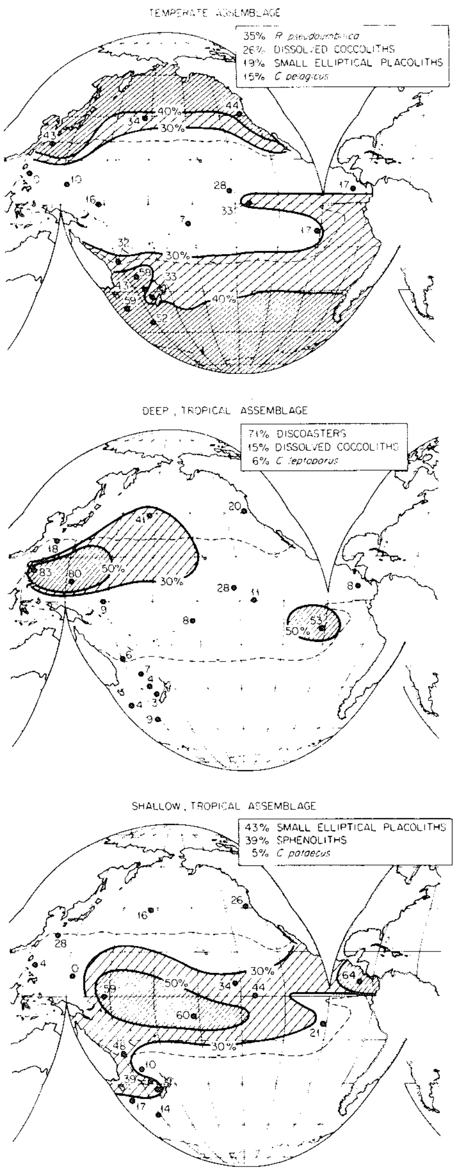


Modern distribution of fossil benthic faunas show that the fauna associated with deposition of Mediterranean sediments under oxygenated conditions at 2,500 meters in the past is today restricted to relatively shallow, more oxygenated water. The fauna most closely associated with organic sediments deposited during stagnation of the Mediterranean are now living in deep water.

A major limitation of our studies is that the ecology of many organisms is not well enough known to allow understanding of the environmental significance of their fossil remains. Determining this is often the greatest challenge in reconstructing past ocean environments. In our studies of the Mediterranean we were able to determine the environmental significance of the fossil record directly by comparing the fossil faunas we found with their modern living counterparts (see figures). In general this cannot be done since most older, fossil organisms are extinct.

We are currently reconstructing the Miocene oceanography of the Pacific

Ocean between 5 and 25 million years ago as part of the CENOP (Cenozoic Paleoceanography) project sponsored by the National Science Foundation. This period of time is especially interesting because it was during the Miocene that the southern polar ice cap grew, giving us the opportunity to study its effects on climate and ocean circulation. Also during the Late Miocene (between 5.5 and 5.0 million years ago), circulation between the Mediterranean and the world oceans was temporarily blocked. This gradually allowed the Mediterranean to dry up and removed nearly six percent of the ocean's salt in the process.



Late Miocene nannoplankton assemblages differentiated latitudinally by climate and bathymetrically by selective dissolution.

In our study we have been using fossil nannoplankton as paleoceanographic indicators. These nannoplankton are the remains of planktonic marine calcareous algae. Since most Miocene nannoplankton are now extinct, we have had to infer their environmental significance by reconstructing their original geographic distributions (see figures left). As plants, nannoplankton must live within the photic zone near the surface of the ocean, so the fact that they reflect latitudinal climatic differences was expected. But because they are composed of calcite they tend to dissolve on the sea floor, some more easily than others, depending on their construction.

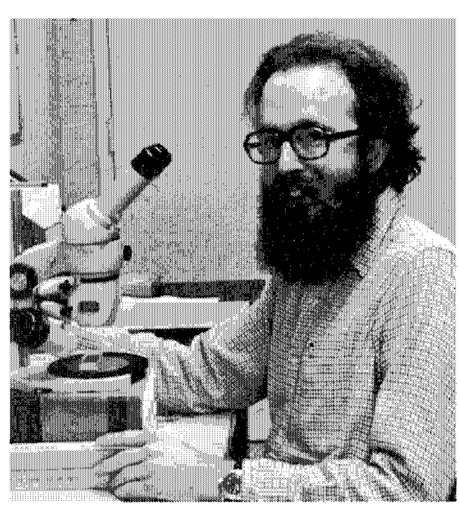
We found that certain tropical nannoplankton are especially fragile so that dissolution shifts the composition of shallow, undissolved assemblages toward more resistant species and produces a distinct dissolved assemblage in deeper water. As a result the fossil Miocene nannoplankton record changes in both climate and dissolution, and we are now using this knowledge to reconstruct both climate and dissolution histories of the late Miocene Pacific Ocean.

Quaternary Paleocirculation of the Antarctic Circumpolar Current

Bruce Corliss

THE Quaternary was a time of major climatic change characterized by oscillations of Northern Hemisphere ice sheets during the last 1.8 million years. During glacial periods, the ice sheets covered extensive areas in North America and Eurasia, the areal extent of polar sea ice was expanded, sea surface temperatures were generally cooled by 1 to 2°C, and the pole to equator thermal gradients were steepened. Interglacial intervals had climatic conditions similar to the present climate with reduced extent of sea ice and warmer temperatures than glacial intervals. An important aspect of Quaternary paleoceanography is to determine the deep and bottom water circulation during this interval and to assess the influence of deep circulation upon the earth's climate and oceanic processes.

A study is presently underway to determine the history of the Antarctic Circumpolar Current during the Quaternary by analyzing deep-sea benthonic foraminifera in sediment cores from the southeastern Indian Ocean sector of the Southern Ocean. The Antarctic Circumpolar Current flows eastward around Antarctica between approximately 40° and 65°S and is one of the major currents in the ocean with a transport on the order of 125 Sverdrups (1 Sverdrup equals one million cubic meters per second). The current extends from the surface to about 4,000 meters, and serves to mix the deep water in the ocean, contributing significant amounts of circumpolar water to all of the deep ocean basins. Recent studies have shown that it is possible to reconstruct deep-water circulation through the analysis of benthonic foraminifera: distinct assemblages of foraminifera are associated with different deep and bottom water masses in the oceans. These assemblages probably reflect the different hydrographic properties of each water mass. The history of bottom or deep water circulation at any one area can be determined by analyzing the benthonic foraminifera found in

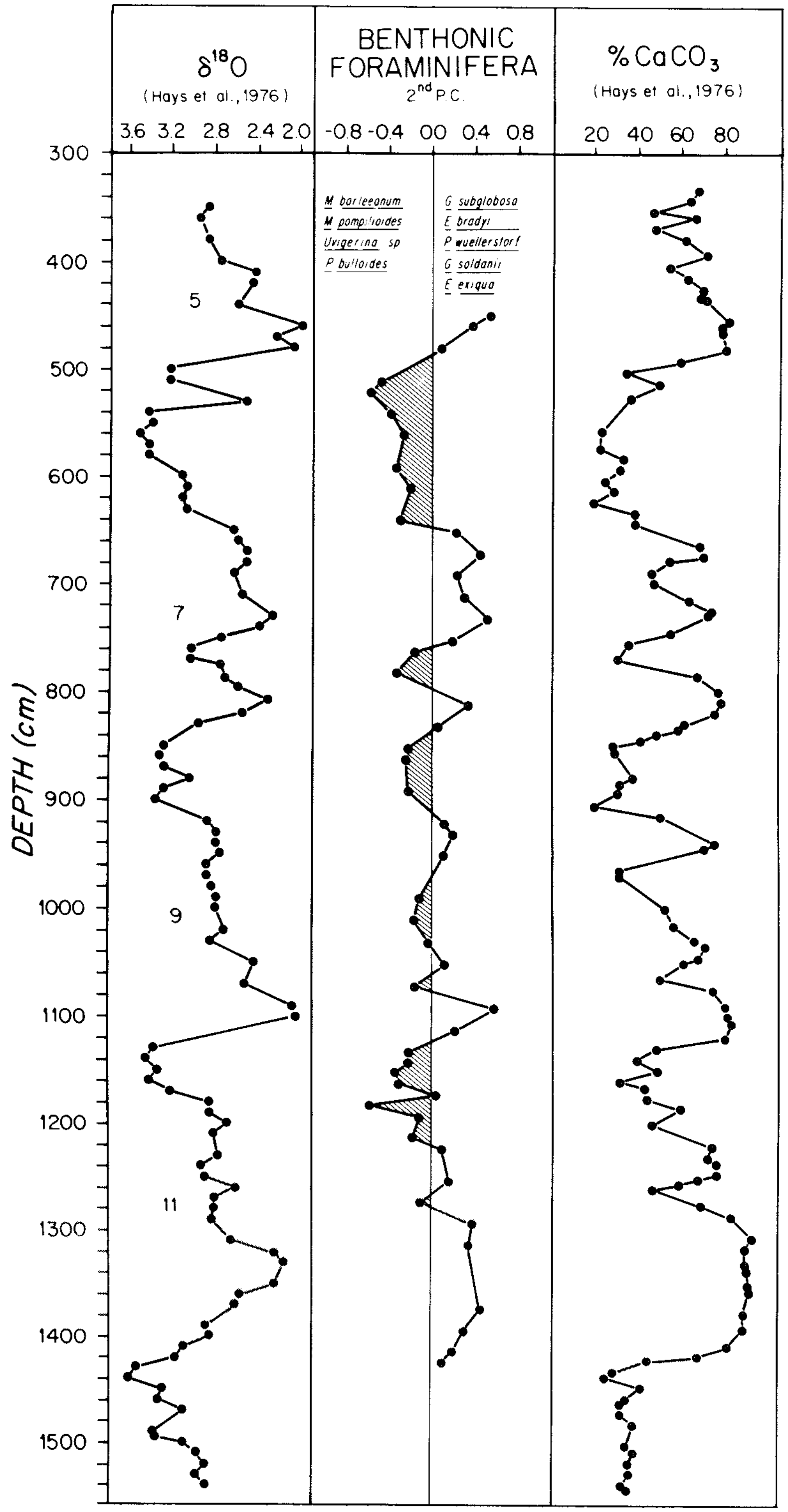

VICKY CULLEN

Bruce Corliss

deep-sea sediment cores. The presence of a particular assemblage indicates the presence of the associated water mass at that time.

Analysis of one core, E49-18, taken from 3,253 meters on the Southeast Indian Ridge revealed the presence of two faunal assemblages. The first assemblage dominated by *Globocassidulina subglobosa* is found during warm interglacial times and is similar to the fauna found in the area at the present time. The second assemblage, dominated by *Melonis barleeanum*, *Melonis pompilioides*, and *Uvigerina*, is present during glacial intervals. This assemblage has not been reported anywhere in the present-day oceans, and this may indicate that a deep water mass is present within the Antarctic Circumpolar Current during glacial times that is quite different from any deep water that is found at present. The faunal data suggest that this "Glacial Deep Water" may have had less oxygen than the present day Antarctic Circumpolar Current water as a result of the water being older with a longer residence time. Analysis of three other subantarctic cores supports the faunal interpretation made in E49-18.

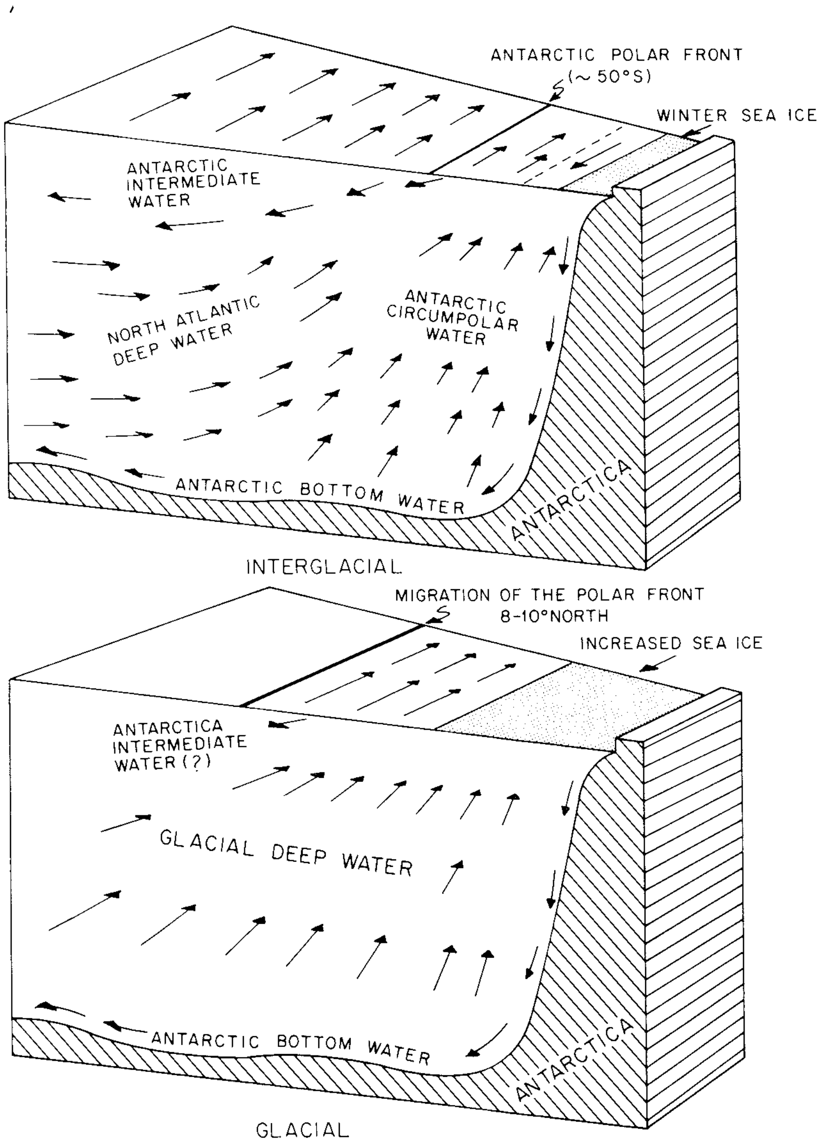
The presence of a Glacial Deep Water in the Southern Ocean may be linked to North Atlantic circulation changes during glacial periods. North Atlantic Deep Water presently forms in the Norwegian Sea and flows south to the Southern Ocean where it becomes an important component of the Antarctic Circumpolar Current. Several workers have presented benthonic foraminiferal evidence that suggests the production of North Atlantic Deep Water decreases or stops during glacial times and is replaced by Glacial Deep Water in the North Atlantic. The cessation of North Atlantic Deep Water may influence the nature of the circumpolar current by changing the hydrographic properties of its deep water, and it may account for the presence of Glacial Deep Water in the Southern Ocean as inferred from the benthonic foraminiferal data. The faunal data in the cores from the southeast Indian Ocean show that the North Atlantic and Southern Ocean circulation changes are directly linked. The glacial faunas are similar and the timing of the faunal changes also coincide in both areas. Thus, Glacial Deep Water may be present



Oxygen isotope stratigraphy, benthonic foraminiferal data, and percentage of calcium carbonate is plotted for core E49-18. The isotopic curve reflects the glacial-interglacial oscillations of Northern Hemisphere ice volume with glacial periods indicated by high oxygen-18 values. Principal component analysis of the benthonic foraminifera was used to identify faunal assemblages: negative values indicate the importance of the *Melonis* assemblage, and positive values indicate the importance of the *G. subglobosa* assemblage.

throughout the Atlantic and Southern Oceans and be an important component of deep water circulation during the ice ages.

Fluctuations in the amount of calcium carbonate in bottom sediments have been recorded in all of the oceans and appear related to glacial-interglacial climatic cycles. Comparison of the benthonic foraminiferal record and carbonate cycles in E49-18 show that low carbonate intervals correspond to the presence of Glacial Deep Water. This is coincident with the idea that the Glacial



◊ Schematic drawing shows Southern Ocean circulation at present and interglacial times and glacial intervals.

Deep Water is old water with low oxygen and higher carbon dioxide than the North Atlantic Deep Water or the Antarctic Circumpolar Current water and, therefore, is more corrosive to deep-sea carbonates. These data suggest that carbonate cycles observed in sediments from the Southern Ocean beneath the circumpolar current may be controlled by changes in deep circulation during the Quaternary.

In February 1980 additional piston core material was taken during *Atlantis II* Cruise 107 to the South Atlantic sector of the Southern Ocean. These cores taken near the Meteor Seamount beneath the circumpolar current will be analyzed in 1981 to continue the ongoing research to determine the circulation history of the Antarctic Circumpolar Current.

The Youngest Microfossils

Susumu Honjo

IN recent decades intensive investigation of microfossils in deep ocean sediments has uncovered fascinating details of the ocean's geological past environment. The most useful microfossils are the remains of pelagic (open ocean) plankton. Their distribution and evolution are controlled by the regional and local water masses, which reflect the climate of the planet. Each microfossil carries rich but complex signals that represent the oceanic environment which groomed that individual plankton. Micropaleontologists can decifer the signals and translate them into indications of past ocean temperature, salinity, distribution of sea ice, and many other oceanographic and climatic parameters.

Study of the living counterpart of microfossils has recently begun to be known as neontology. A neontologist utilizes biological, ecological methods but is interested only in the hard, mineralized tissue of the animal. Oddly enough, little is known about living plankton communities compared to the massive information available on microfossils, particularly those found in Cenozoic sediment. PARFLUX, a Woods Hole Oceanographic Institution program designed to assess the net particulate sedimentation through deep ocean layers, has made major strides forward in neontology.

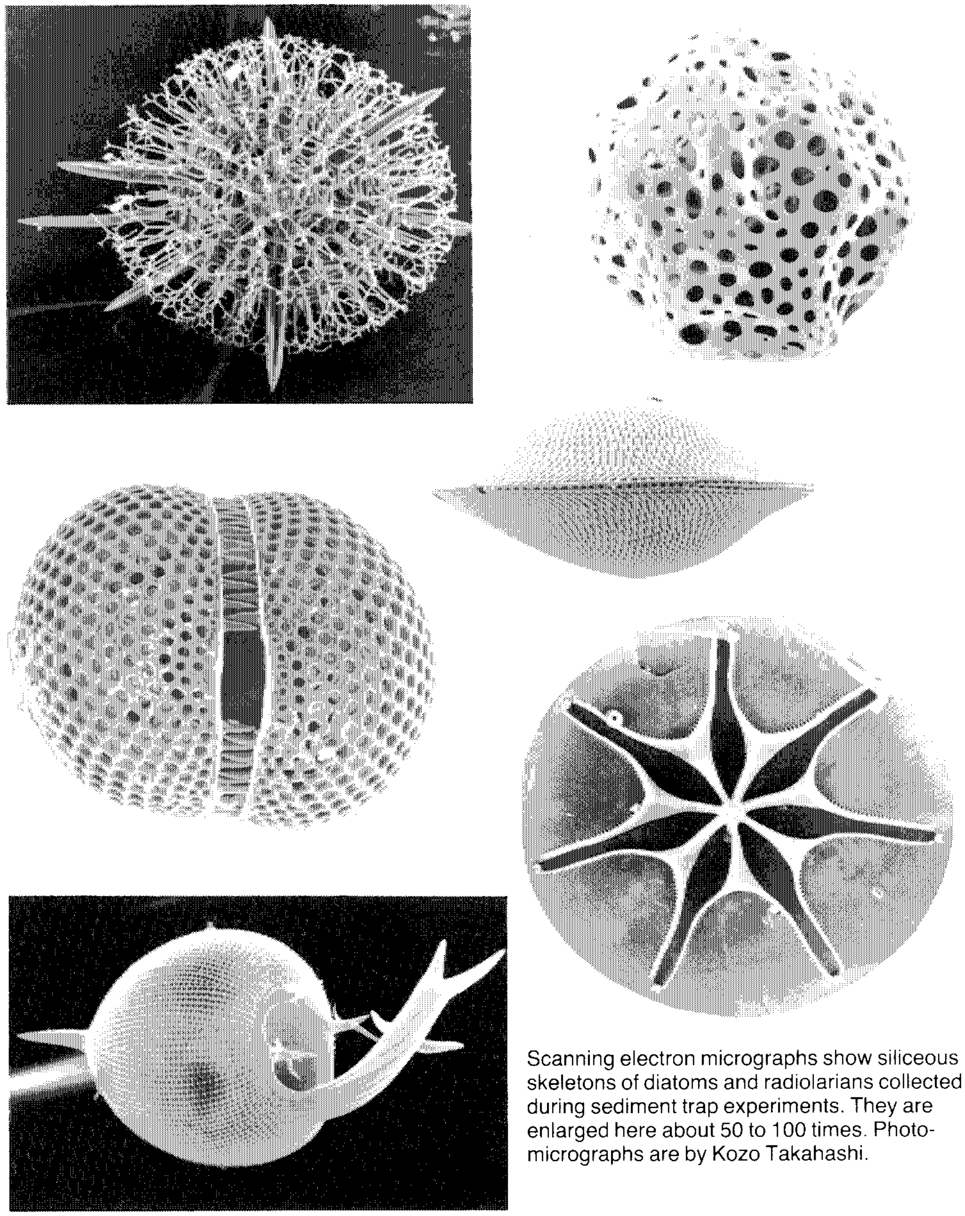
There are basically two reasons why an accurate representation of the open ocean community is difficult to obtain. First, because of their relatively small standing crops and patchy distribution, a plankton sample collected by a plankton net is not adequate for a precise comparison with its sedimentary counterpart. Second, recent research indicates that the major part of the vertical transport of small particles is carried out by aggregates of particles. Small skeletal remains do not settle down individually through the water column but rather thousands of them are packed into a larger particle in the near surface water layer, usually as the feces of zooplankton which graze on phytoplankton. Aggregates sink through the deep water column and arrive at the abyss within a few days to a few weeks.

However, large fecal aggregates may be eaten several times by animals living in the deep water. This is called copraphagy. Indigestible particles, such as some silicate and carbonate skeletons, may pass through the guts of many animals before they reach the sea floor, and digestible particles have many chances to be removed from the descending rain of debris. Particles which are not incorporated into the larger fast-settling particles may change their characteristics through chemical reaction with seawater or even disappear before they reach the bottom. For example, Acantharia skeletons, which are built of a soluble mineral called celestite, are rarely eaten by zooplankton. Thus, they are not protected while they settle, and they dissolve very quickly in the upper regions of the ocean.

While aggregates are almost impossible to collect by such devices as towed nets or briefly lowered collection bottles, the large, cone-shaped, floating PARFLUX sediment traps moored for several months in one place have provided many precious samples from deep water stations in temperate to tropical climatic zones of the Pacific and Atlantic Oceans over the past five years. The samples have been studied intensely by scientists from several disciplines including mineralogy, radiochemistry, and organic geochemistry, and their studies have begun to reveal exciting frontiers in ocean particle science. For example, the rate of introduction of organic carbon to the sea floor has now been assessed by the use of sediment traps. Organic carbon is the vital food supply used by benthic organisms.

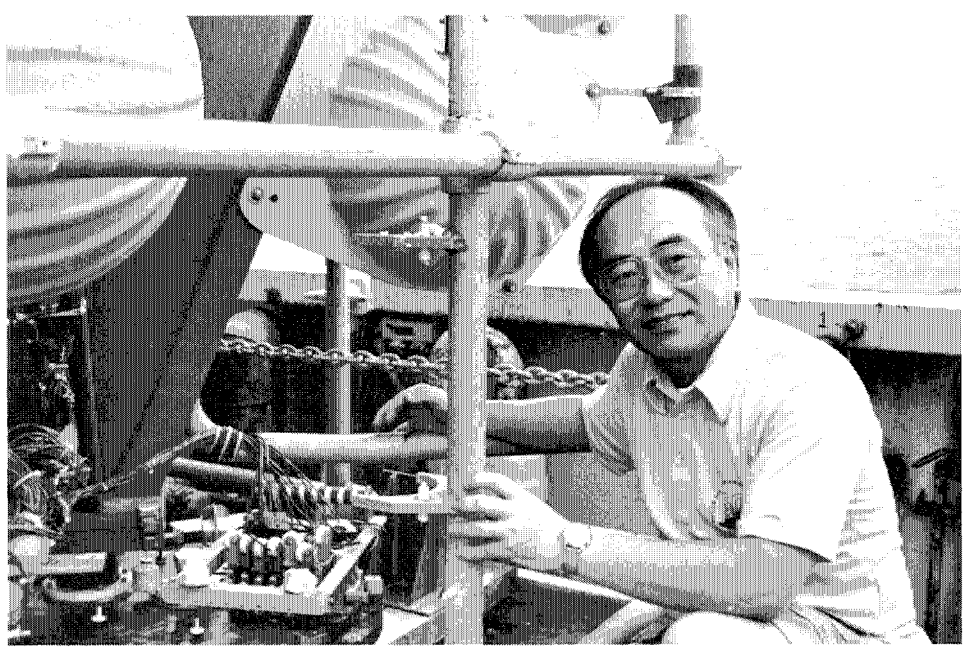
A team of micropaleontologists, experts in various taxa of microfossils, investigating the "most recent" microfossils collected in PARFLUX traps have identified at least 12 well-preserved major micropaleontological taxa and found that the modern community appears to be far more complex than its microfossil counterpart. For example, usually only several radiolarian species are found in an abyssal sediment sample while, surprisingly, more than 150 species may be found in a sediment trap deployed just above the abyssal collection site.

The plankton's exquisite microarchitecture is being revealed by the scanning electron microscope, and studies are underway on taxonomy and morphology as well as geochemistry, isotopic and trace element composition, and other areas of inquiry.



Scanning electron micrographs show siliceous skeletons of diatoms and radiolarians collected during sediment trap experiments. They are enlarged here about 50 to 100 times. Photomicrographs are by Kozo Takahashi.

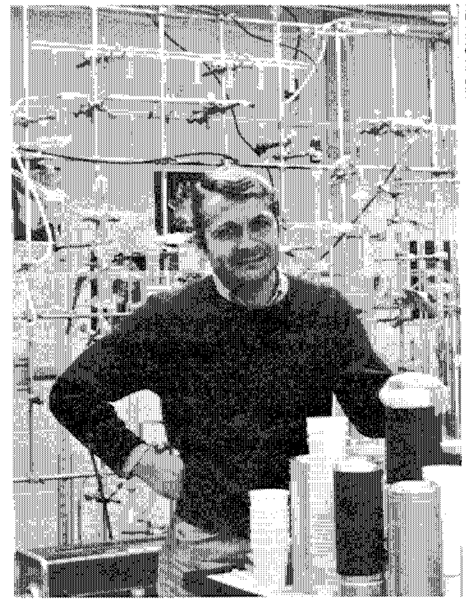
STEVEN MANGANINI



Sus Honjo is shown aboard R/V *Knorr* following recovery of sediment trap after 16 months on mooring. Apparatus at left rotates a new sample cup under collection cone every two months.

Seasonality in the Particle Flux to the Deep Sea

Werner Deuser



Werner Deuser

SINCE April 1978 we have been intercepting the rain of particles sinking from the surface of the Sargasso Sea near Bermuda with a sediment trap moored 3,200 meters below the sea surface and 1,000 meters above the sea floor. The trap consists of a funnel with a top cross section of 1.5 meters and a collection cup at the bottom which is sealed at a predetermined time. Every two months we collect two to six grams of material accumulated in the cup. About 90 percent consists of the remains and products of organisms – skeletal parts of tiny algae and of mostly small animals, organic matter, and fecal pellets. Most of the remainder is wind-blown dust. Almost all types of particles and chemical constituents we have identified thus far, be they of biological or other origin, arrive in our trap in seasonally varying amounts. The peak arrival time in deep water coincides with the peak of algal productivity in the surface water in late winter and spring. The lows of both deep-water particle flux and algal productivity occur in late summer and fall. While the total amounts of material we catch vary by about threefold, the flux of the skeletal remains of some organisms, such as certain foraminifera, may vary by more than a thousandfold in the course of the year.

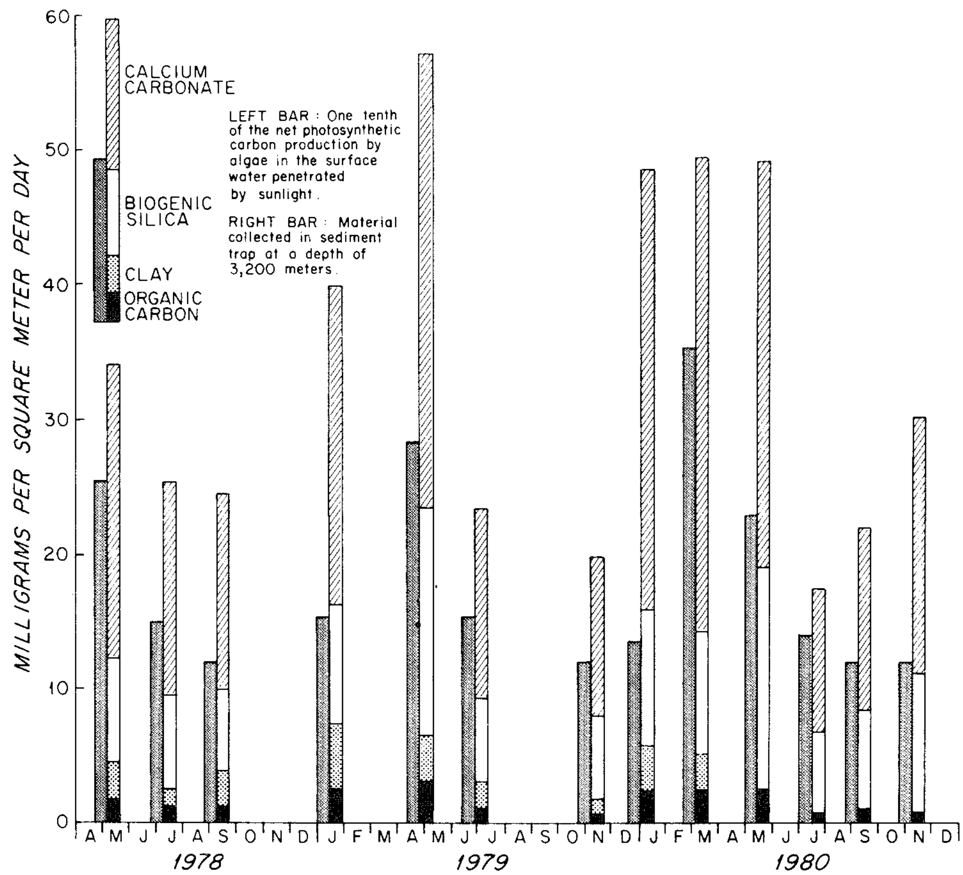
The more important findings of our study thus far can be summarized as follows:

(1) Although the deep sea is always dark and unchangingly cold, its animals are coupled to the seasonal changes of the surface ocean through an annual cycle in the quantity of food available to them. Their food is the organic matter raining down from above. In the subtropical Sargasso Sea we find about four times as much coming down in spring as in late summer and fall. This seasonally fluctuating food supply may be the explanation for annual growth bands and seasonal breeding cycles reported for some deep-sea animals. Until now, these had been puzzling phenomena.

(2) The numbers, types, and isotopic compositions of skeletal parts of many planktonic plants and animals undergo significant changes in the course of the year. For example, the abundances of many species of planktonic foraminifera and the oxygen isotopic composition of their calcium carbonate skeletons respond to the annual temperature cycle of the surface ocean. Both of these signals are almost immediately transmitted to the sea floor through the sinking of the skeletons. Understanding the significance and extent of their variations in today's environment will lead to the deciphering of seasonal variations of past environments, through analysis of fossil specimens, and to a better understanding of climatic variations.

(3) Animals and plants living in the ocean appear to be very efficient in removing particles from the water by filtering or by aggregating them into larger particles which rapidly sink to the bottom. Even atmospheric dust particles, which fall into the ocean and individually might spend years sinking to the sea floor, appear to be rapidly filtered out of the water by small animals in their constant search for food. The indigestible particles are ejected as parts of fecal pellets which, because of their much greater size, sink much more rapidly. Because of their high content of highly adsorptive organic matter, these pellets, as well as other organic remains of plants and animals, may gather up additional material during their descent.

(4) Even extremely fine particles sink into deep water in a matter of weeks as



passengers in or on larger aggregates. It appears that the bulk of the sediment on the sea floor arrives in the form of such relatively large, fast-sinking particles.

This rapidity of transport and the efficient removal of particles from the water by organisms imply an ability of the ocean to cleanse itself rapidly of particulate inputs, be they natural or man-made, and to transmit them promptly to the sea floor, the ultimate repository of the earth's surface.

Lead-210 as a Tracer of Reactive Heavy Metals

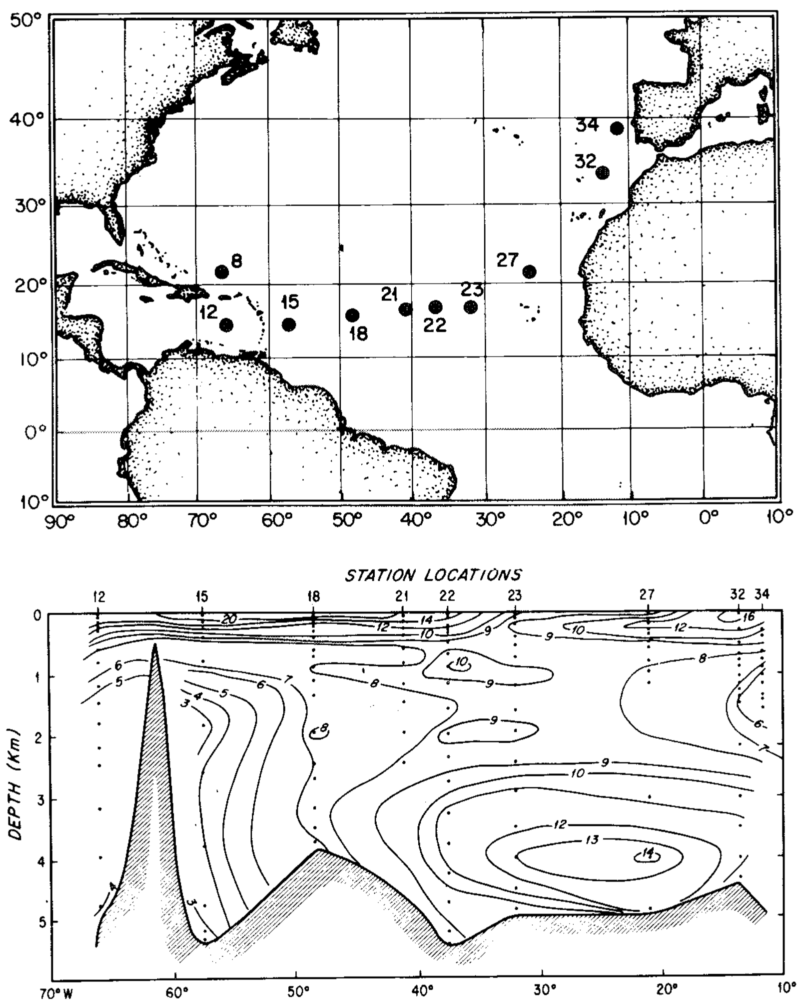
Michael Bacon

DISTRIBUTIONS of certain natural radioactive elements in seawater are of special interest because of the information they can yield about rates of geochemical processes that remove chemical species from the ocean. Such information is fundamental to our understanding of how seawater composition is controlled, and it is of considerable practical importance in predicting how fast the ocean can cleanse itself of heavy-metal burdens imposed by human activities.

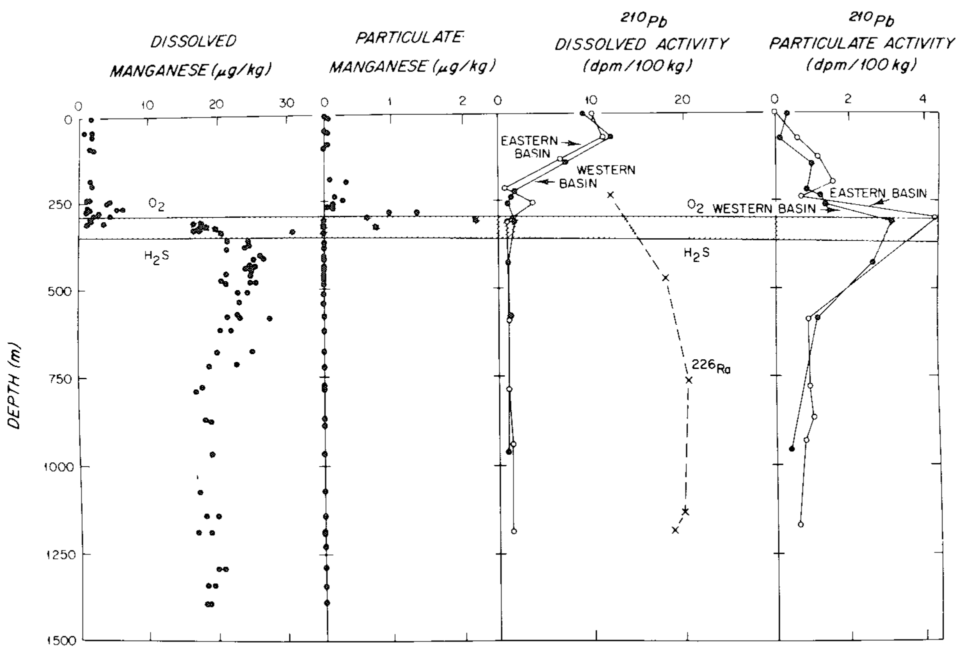
Lead-210 is a naturally-occurring radionuclide belonging to the uranium decay series. Because of its suitable radioactive half-life (22.3 years), it is a particularly valuable geochemical tracer for studying the fate of reactive elements in the ocean. Two modes of lead-210 supply to the ocean exist: (1) deposition on the sea surface from the atmosphere, where lead-210 originates from decay of radon-222, a radioactive gas that emanates from the continent; and (2) production throughout the water column following radioactive decay of radium-226, a radioactive alkaline earth dissolved in seawater. Rates of supply by both processes can be determined with acceptable accuracy. Thus we have, in effect, a natural tracer experiment occurring in which lead-210 is being added to the ocean at a known, constant rate. Our task is to measure the distribution of lead-210 that results and, from that distribution, to deduce the rate at which lead-210 undergoes removal from the water column and to locate the sites at which the removal reactions occur.

Lead is a reactive element in the sense that it is removed from the ocean rapidly (turnover time less than 100 years or so). Concentrations of ordinary stable lead in deep ocean water are extremely low and can be measured only with great difficulty. From earlier studies it was estimated that the residence time of lead-210 in the deep ocean is approximately 50 years, and it was generally believed that removal occurs by chemical adsorption at solid surfaces followed by transport with the flux of sinking particles to the sea floor. Studies in our laboratories, however, have indicated that too little lead-210 is found in the sinking particulate matter to account for the entire removal flux of lead-210, and we believe that much of the removal occurs by reaction at the sediment/seawater interface. The vertical section of lead-210 in the Atlantic Ocean illustrated below supports such a hypothesis. It shows gradients of decreasing concentration toward the bottom and toward the side boundaries that can be explained only if significant losses of lead-210 occur at the boundaries.

The exact mechanism by which lead-210 is taken up at the ocean boundaries is not known, but we believe that the process involves coprecipitation with manganese and iron oxides forming at, or near, the sediment/seawater inter-

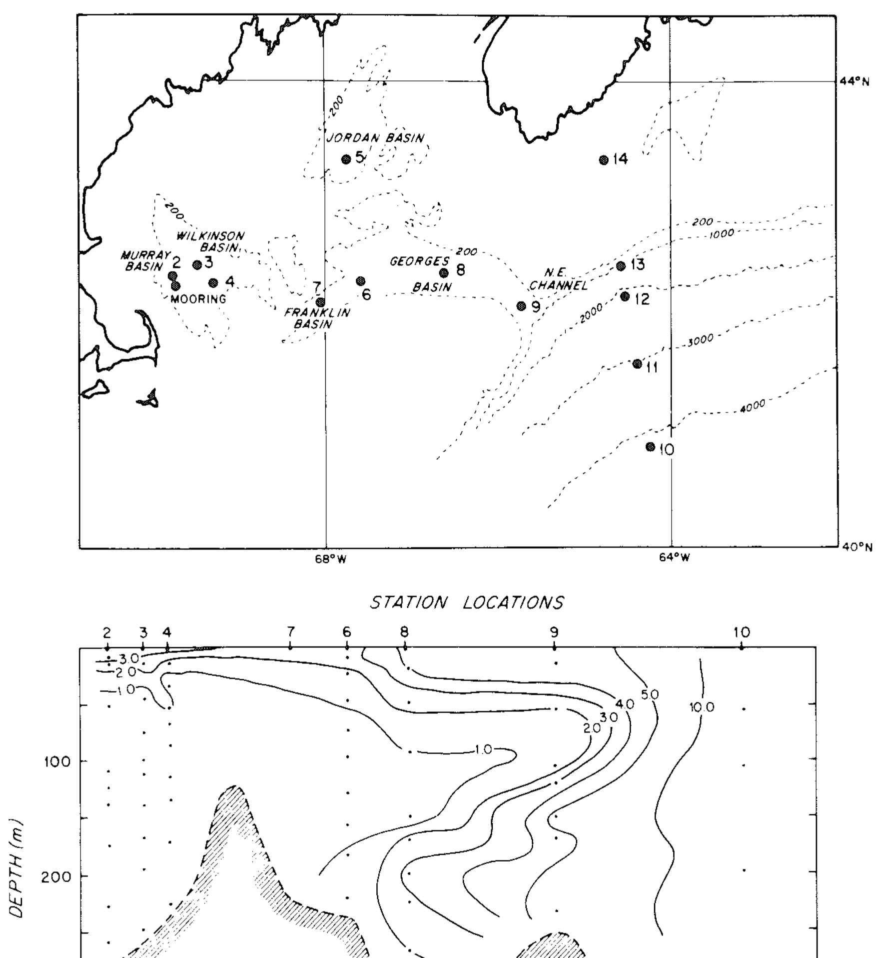


Distribution of dissolved lead-210 in a transatlantic section is shown. Concentration units are disintegrations per minute per 100 kilograms of seawater.



Distributions of manganese, lead-210, and radium are shown for the Cariaco Trench. The zone of transition from oxic to anoxic, sulfide-containing water is shaded.

Mike Bacon



Distribution of lead-210 on the New England continental shelf in September 1977.

face. Evidence for such a process is given by the results shown at left from the Cariaco Trench, an anoxic basin on the continental shelf north of Venezuela. There the deep anoxic water contains large amounts of hydrogen sulfide. In such a basin there is continuous redox (oxidation-reduction) cycling of manganese and iron such that oxide particles are continually forming just above the oxygen/hydrogen sulfide interface, as shown by the high concentrations of particulate manganese in that zone. The high concentrations of dissolved manganese below the boundary are caused by reduction to the more soluble Mn(II). Upward mixing and reoxidation to insoluble Mn(IV) complete the cycle. Lead-210 shows very low concentration in the Cariaco Trench, not only in the deep water, where sulfides form, but also in the zone of manganese oxidation. Similar redox cycling occurs in marine sediments, and in organic-rich hemipelagic sediments near continental margins the redox boundary lies close to the sediment/seawater interface. Such areas may play an especially important role in controlling the distribution and ultimate geochemical fate of a variety of heavy metals, radionuclides, and other chemical substances in the ocean. Recent work in our laboratories indicates that this is the case for the actinide elements thorium and protactinium as well as for lead-210. In future work we hope to be able to define more clearly the relationship between redox cycles in the sediment column and scavenging of radionuclides from the water column.

The geochemical significance of ocean margins can also be seen in the distribution of lead-210 in surface waters, as illustrated in the vertical section across the New England continental shelf. High concentrations offshore are sustained mainly by the input of lead-210 from the atmosphere. Over the shelf, much lower concentrations are found indicating that removal of lead-210 is much faster there than it is offshore. The enhanced removal may be due to high biological productivity, high fluxes of particles in the coastal zone, or reaction at the sea floor. We are presently determining the seasonal variations of lead-210 concentration in the Gulf of Maine and will attempt to determine how the removal rate of lead-210 in the coastal waters responds to changes in biological productivity and other oceanographic variables.

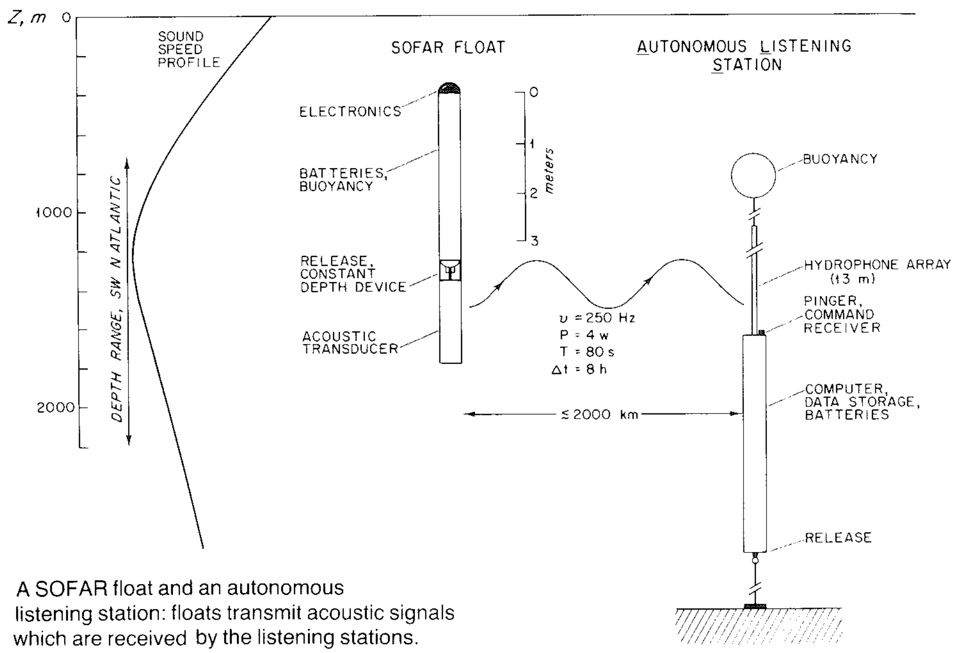
SOFAR Float Program

James Price, Douglas Webb, and Albert Bradley

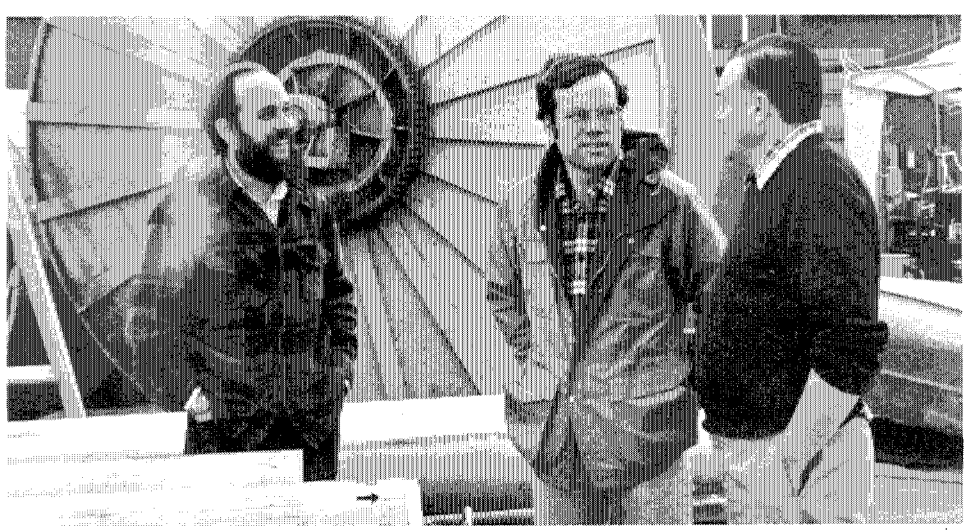
OCEAN currents may be described in either of two ways. The more common Eulerian* description gives the history of velocity at fixed points. Moored current meter measurements pioneered at WHOI during the 1960s provide oceanographers with an Eulerian description of ocean currents at an ever-increasing number of locations throughout the world's ocean. The alternative Lagrangian* description of ocean currents gives the position history of water particles. For research on some theoretical and practical problems – for example, the dispersal of pollutants – this Lagrangian description is most natural. SOFAR floats and Autonomous Listening Stations (ALSs) developed at WHOI during the 1970s are a unique means for making long-term, Lagrangian measurements of deep ocean currents.

SOFAR floats are ballasted to be neutrally buoyant at a target depth, typically within the 700 to 2,000 meter range. They drift freely with the current and thus serve to tag the surrounding water. The floats are tracked by powerful, low-frequency acoustic signals which they transmit three times daily. These signals are partially trapped within the sound speed minimum layer (or sound fixing and ranging, SOFAR, channel) and propagate great distances without suffering bottom or surface reflection. The signals are received by ALSs deployed in a network surrounding the experimental area. The useful maximum signalling range of SOFAR floats is about 2,000 kilometers, and their lifetime is up to three years. ALSs must be serviced at least annually to recover data and replace batteries and mooring hardware.

A recent deployment of SOFAR floats and ALSs was made during a 1978 POLYMODE experiment in the Sargasso Sea southwest of Bermuda. Twenty floats were deployed in a cluster at 1,300 meters depth (see figure right). The subsequent motion of those floats clearly shows the currents associated



A SOFAR float and an autonomous listening station: floats transmit acoustic signals which are received by the listening stations.

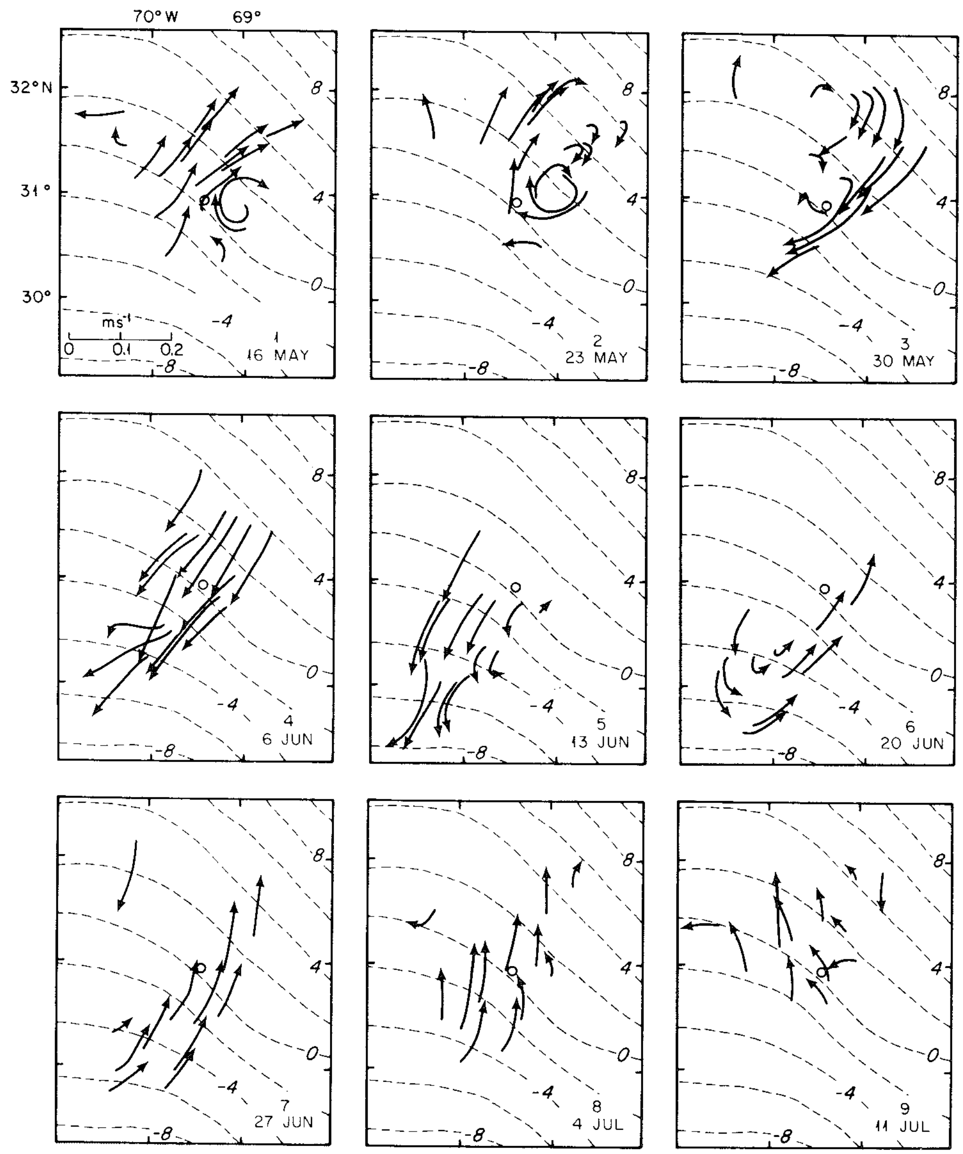


Al Bradley, Jim Price, and Doug Webb.

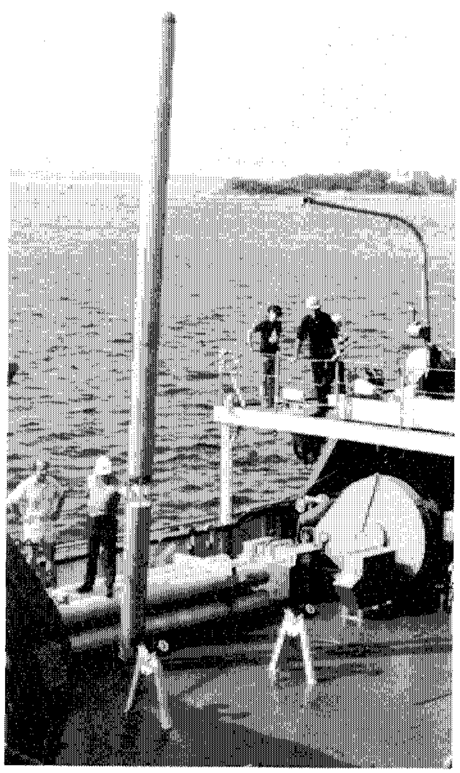
*Euler and Lagrange were 18th century European mathematicians who made major contributions to the theory of fluid mechanics.

with a powerful, large-scale planetary wave. The float cluster oscillated along a line northeast to southwest with a period of about 50 days. Note that when the float cluster changed speed and direction (panels 2 to 3, and 5 to 6), the change began on the right side of the cluster and propagated leftward across the cluster. Detailed analyses indicate that this wave had phase propagation toward the northwest at about 5 kilometers per day, and that its wavelength was about 340 kilometers. Other observations indicate that the currents associated with this wave were nearly uniform from the surface to the 5,300-meter ocean bottom. The mass transport per half wavelength was correspondingly large, approximately 75 x 10^6 m^3 sec^{-1} (Sverdrups), comparable to the transport of the Gulf Stream at this latitude. Problems we are now investigating include finding the energy source for such planetary waves. Possible sources include the Gulf Stream, which can apparently generate such waves as it meanders, and intense baroclinic (surface intensified) currents within the Sargasso Sea.

SOFAR floats and ALSs are today being used to explore the currents of the deep Gulf Stream and the North Atlantic subtropical gyre. Our field is new enough that within the next several years we will more than double the number of deep ocean Lagrangian measurements made to date. Still further ahead, SOFAR floats and ALSs will be used in an investigation of a naturally occurring tracer, the high salinity Mediterranean outflow, and to determine the dispersal that can be expected at possible ocean nuclear waste disposal sites.



Week-long "snapshots" are shown of SOFAR float trajectories at a depth of 1,300 meters from an experiment conducted in 1978 southwest of Bermuda. The panels are about 300 by 350 kilometers in size. Note the wavelike oscillation of floats from northeast to southwest.

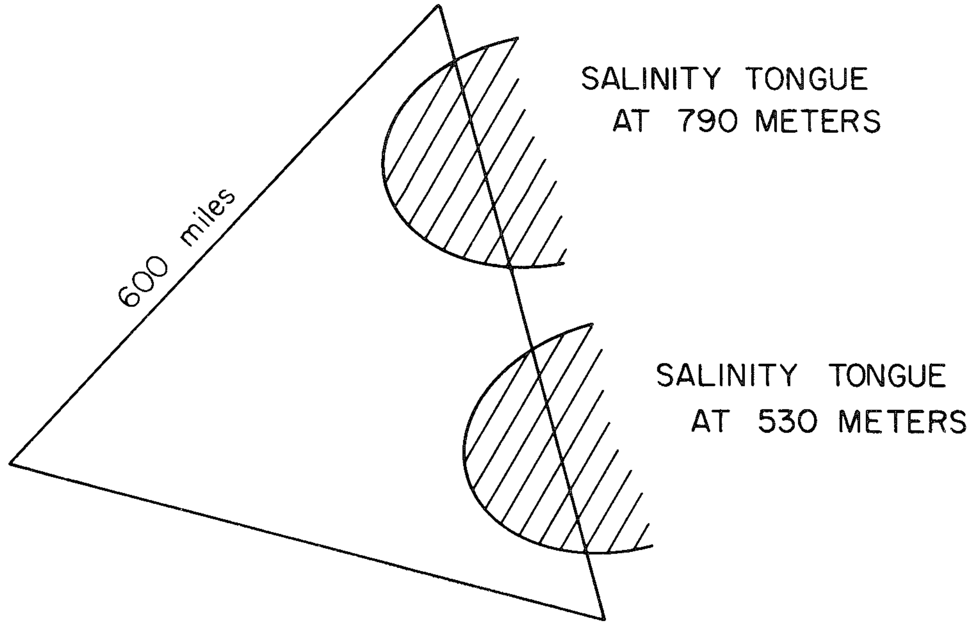


KENNETH FAIRHURST

SOFAR floats are loaded aboard *Oceanus*.

The Beta-Spiral

Henry Stommel



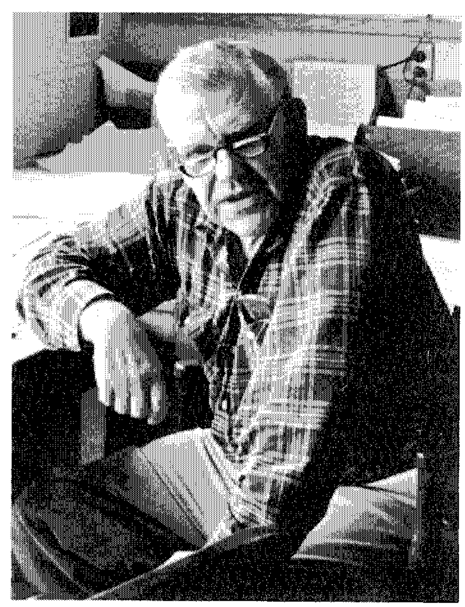
Beta spiral field work has been concentrated in a triangular area 600 miles on a side southwest of the Azores. Illustration shows southward deflection of the high salinity tongue of Mediterranean water extending into the research area.

As our knowledge of the physics of ocean circulation grows, we are gradually becoming able to map out various regions, or provinces, in the ocean where different kinds of dynamical balances prevail. Thus, we now recognize that there are regions of strong eddy activity and quiescent regions with weak eddy energy. The quiet regions include the eastern portions of sub-tropical gyres. In the North Atlantic this means the region between 20°N and 40°N on the eastern side of the Mid-Atlantic Ridge. Conventional scientific wisdom indicates that this region is governed by what is called a "linear vorticity dynamical regime." At any one location the currents veer with depth in what has come to be called "the beta-spiral." It is one more manifestation of the effect of the variation of the Coriolis parameter (sideways drift caused by the earth's rotation) with latitude. Other manifestations are the western intensification of circulations to form currents like the Gulf Stream, the westward migration of mid-ocean eddies, and a general tendency for oceanic turbulence to be converted from disorderly chaotic motions to more orderly wavelike phenomena.

Since the fall of 1978, David Behringer of NOAA and I have conducted three surveys of a region of the subtropical gyre in the North Atlantic southwest of the Azores in order to obtain some highly resolved data about the so-called beta-spiral. The object has been to discover whether the dynamical constraints involved are steady enough, realistic enough, and well enough conditioned in a mathematical sense to be useful for determination of the absolute velocity field in the ocean from hydrographic stations alone. In the course of the work an excellent body of data has been accumulated which can help in interpreting the distribution of passive tracers like salinity and oxygen and of radioactive tracers. Our research area is in an excellent position for observation of tracers such as tritium/helium-3 and carbon-14 that are introduced onto density surfaces in the wintertime when the bottom of the mixed layers is sealed off from the surface by the growth of the shallow spring thermocline. As it is pumped down by convergence of wind-drift in the upper layer in regions slightly to the north, its traverse through the area can be traced over a period of more than three years. Meaningful interpretation of its movement is made possible by the simplicity of the flow patterns, the nearness of the source region, and the availability of independent estimates of the level of eddy diffusivity from salinity distribution.

As a result we have developed a pretty clear idea of how water in the upper 500 meters of the subtropical gyre is pumped down from the surface layer, how fast it moves, its rate of production and mixing (the paths it follows), and how it depends upon seasonal variability of the properties and depth of the mixed layer. We believe that the new work has led to a better understanding of the central provinces of the ocean. For example, the area of our concentration straddles the Mediterranean outflow at thermocline depth, and the data is good enough to reveal a southward deflection of the high salinity tongue of Mediterranean water within the thermocline. There is an interannual wobble of the subtropical gyre amounting to about 100-mile excursions in the north/south direction for periods longer than a year (and this is consistent with the limited data from the POLYMODE cluster B slightly to the west), but more data is required to verify this, since our data seems to span less than one period.

In the next few years Drs. Price, Richardson, and Schmitz plan to place a number of SOFAR floats in the beta-spiral region to verify the direction and the amplitude of the mean velocities that have been calculated there by the beta-spiral method.



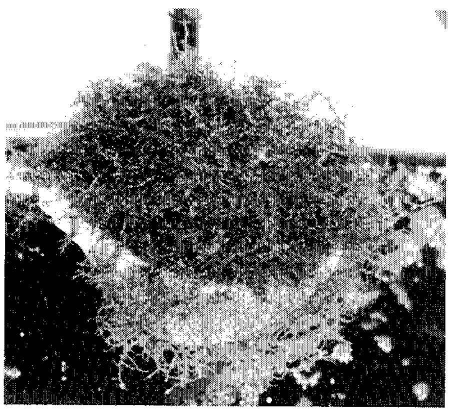
VICKY CULLEN

Hank Stommel

Biomass

John Ryther

THE cultivation of photosynthetic crops for the specific purpose of converting their biomass to fuel is a new and, as yet, untried concept. The basic technology for such an undertaking is, of course, available in agriculture and the related fields involved in the production of food and fiber. However, the monetary value of plants grown for such purposes is normally an order of magnitude or more greater than their potential value as fuel, even if all of their stored


JOHN RYTHER

Gracilaria tikvahiae netted from culture in Woods Hole.

energy were recoverable. Because of that, and in view of the increasing world demand for food and fiber, it therefore seems unlikely that crops presently in production will find competitive use as an energy source in the foreseeable future, with the exception of temporary or localized surpluses and those portions of cultivated plants that are not now utilized and are currently treated as waste.

It follows, then, not only that species not presently cultivated must be grown for energy crops, but also that they must be grown in areas that are not suitable for the cultivation of food and fiber. Further, and most important, they must be produced within the framework of an entirely new budgetary concept, one that is based upon energy rather than exclusively financial considerations, for the energy required to prepare and fertilize the land, grow, harvest, and process the crop, and convert it to fuel must be less than the energy content of the fuel produced. Finally, energy crops must be highly productive. All of the systems analyses that have been conducted to date of proposed fuel crops have agreed that the major economic and energy cost involved is in the production of the feed stock and that yield – organic matter produced per unit of area and time – is the single most sensitive parameter in the equation.

The macroscopic algae, or seaweeds, appear to satisfy most of these requirements. Certainly, the oceans are the largest uncultivated and underutilized pastures on earth. Some few species of seaweeds do have commercial value as food in eastern countries or for their contained chemicals – hydrocolloids such as agar, alginic acid, and carrageenan – but these markets are small. Others find limited use as low-value products for feed, compost, or fertilizers. Most have no commercial value, and some are considered an aesthetic nuisance when they grow or accumulate to high densities in heavily populated bays and estuaries.

For the past five years we have examined the potential of seaweeds as an energy crop, first at the Woods Hole Environmental Systems Laboratory and more recently at the Harbor Branch Foundation in Ft. Pierce, Florida, where the plants will grow throughout the year. After screening over 50 species of indigenous algae for such characteristics as sustained growth rate, ease of handling, and freedom from chronic cultivation problems, we concentrated on the red seaweed *Gracilaria tikvahiae*, a semitropical species that lives through the year in Florida and as a summer annual in Woods Hole. *Gracilaria* has the added advantage that it contains the polysaccharide agar and is already commercially harvested and even cultivated in some parts of the world for that product. Our selection of the species, however, was based on its exceptionally high growth rate and the fact that a clone collected from the drift algae community in the Indian River, near Ft. Pierce, has remained sterile and has grown only vegetatively for over three years. Most seaweeds stop growing and usually fragment or disintegrate when they periodically become sexually reproductive and develop fruiting bodies. Annual yields of our clone of *G. tikvahiae*, grown under intensive cultivation with 25 or more exchanges of enriched seawater per day, under vigorous aeration sufficient to maintain the seaweed in suspension, and with the incremental growth harvested back each week to maintain the culture at its optimal density, has averaged nearly 35 grams dry weight per square meter per day. That yield extrapolates to 127 dry metric tons per hectare per year (52 tons per acre per year), making it the most productive photosynthetic plant for which reliable data are available.

However, the highly energy intensive culture methods used to obtain those


JOHN RYTHER

Screening tanks for evaluating growth potential of different seaweed species at Harbor Branch Foundation in Florida.

John Ryther

high yields would not be cost-effective, economically or in terms of energy balance. Passive, nonintensive methods of growing the same seaweed on the bottoms of ponds in Southern Taiwan result in yields an order of magnitude lower (about 15 tons per hectare per year). We are now studying the growth-limiting factors that determine yields in the two culture systems in the hope that we may be able to reduce cost and energy inputs while maintaining high yields.

Also for the past three years, we have continuously fermented *Gracilaria* in homemade anaerobic digesters producing biogas containing 60 percent methane at a mean rate of 0.4 liters per gram volatile solids and with a bioconversion efficiency of 48 percent. A major accomplishment has been the recycling of nutrients from the digester residue back into the seaweeds with an overall efficiency of 73 percent. Nitrogen fertilizer alone represents over half the total energy cost of conventional agriculture, so nutrient recycling of digester residue is a logical and necessary procedure. Efforts are continuing to increase the recycling efficiency.

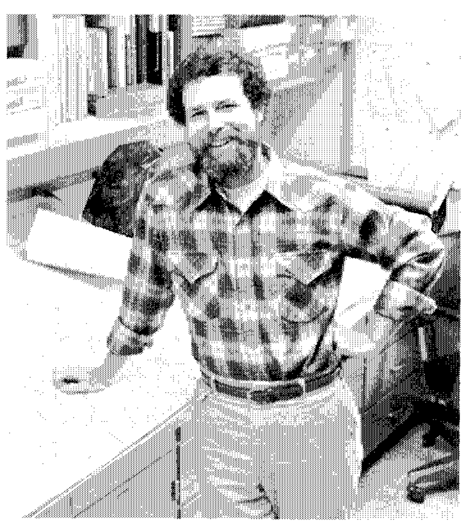
Another important discovery during the past few months is the fact that *Gracilaria*, and other seaweeds, that are nutrient-starved can soak up and store enough inorganic nitrogen and phosphorus to double their internal concentration of these elements in no more than six to eight hours, in the light or the dark, following which the plants are able to grow at their maximum rate for periods of one to two weeks (depending upon solar radiation) in water containing no measurable nutrients until they double in biomass and their internal nutrient concentration is again reduced by half. This, plus the ability of the seaweeds to reassimilate the nutrients from the residue of their own digestion, makes possible a new closed-cycle strategy for seaweed energy farming that will be tested and evaluated in the coming months.

Experimental Sea Ranching of Brook Trout

Robert Naiman

BROOK trout (*Salvelinus fontinalis*), occurring naturally in seawater along the Atlantic coast as far south as Cape Cod and inland from Georgia to Hudson Bay, have been widely introduced throughout the world as a highly esteemed and popular game fish. Where the trout have free access to the ocean their life history is similar to that of the well known salmon. In sea running populations, brook trout usually move to the ocean for feeding in late spring and summer and return to rivers in autumn for spawning and overwintering. Often these anadromous fish are considerably larger than those remaining in freshwater for their entire life.

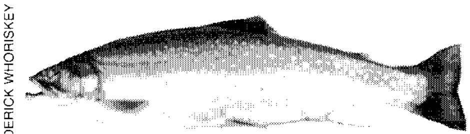
The idea of sea ranching brook trout, instead of more conventional salmon species, grew out of the considerable research conducted over the past 13 years by John Gibson, Richard Haedrich, Geoff Power, and others on salmonid ecology at the Institution's Matamek Research Station in Quebec. They found that anadromous brook trout occurred in the area, occasionally reached large sizes (up to five pounds), apparently returned to rivers each year instead of making extensive migrations and remaining at sea for longer periods such as Atlantic salmon do, and they appeared to return to their river of origin. These characteristics made them a prime candidate for developing a moderate effort, high yield fishery which could quickly supplement the rapidly declining stocks of Atlantic salmon. With this background the objectives of our study were (a) to enhance the production of brook trout over river populations by increasing the growing season and food availability through exploitation of underutilized food resources at sea, (b) to compare growth and production in natural and artificial sea trout populations, and (c) to explore the suitability of sea ranching brook trout as a small scale enterprise.



VICKY CULLEN

Bob Naiman

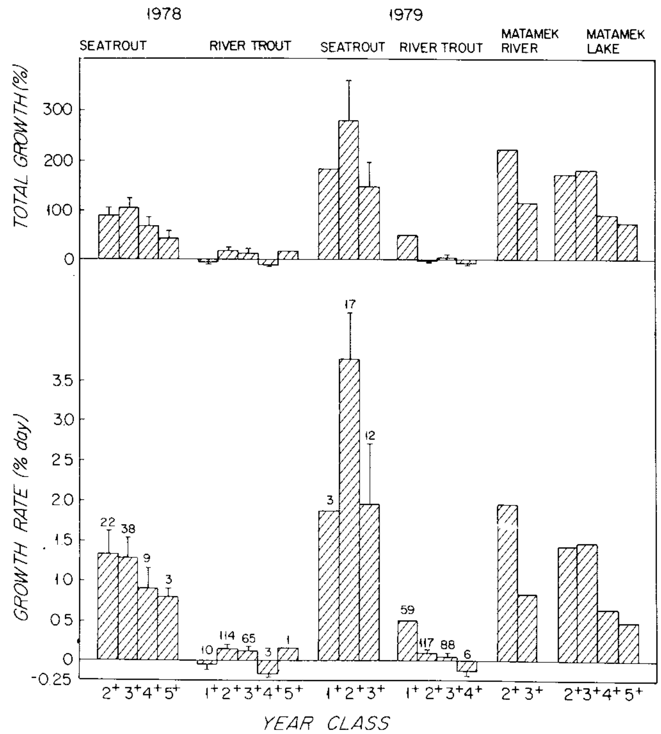
The Matamek Research Station proved to be an ideal location for conducting such an experiment. The Matamek River, protected for scientific research by the Province of Quebec, does not have a natural population of sea run brook trout due to an impassible waterfall near the ocean which blocks access to spawning grounds. Meanwhile the nearby Moisie River has a large, natural, sea run population.



FREDERICK WHORISKEY

A natural sea run brook trout about 16 inches long is shown from the Matamek River. Sea trout in this region can be as large as 5 pounds.

During late spring and summer of 1978 and 1979, brook trout from the upper Matamek River were tagged and released in the estuary and allowed free movement between the waterfall and the sea. Fish were recaptured two to four months later as they returned to freshwater. Averaged over two years, 34 percent of the released fish were recaptured. Best returns were in the two- and three-year-old fish with 38



Total growth as percentage increase of body weight and mean daily growth rate during the summer season are shown for tagged sea run brook trout and tagged brook trout remaining in the river. Tagging slowed growth during the experiments, so growth of untagged brook trout from Matamek Lake and the Matamek River are given for comparison.

percent and 62 percent recaptured, respectively. In contrast, tagged Atlantic salmon smolts leaving the Matamek River typically yield returns of only one percent or less. Straying of transplanted brook trout to other rivers was negligible (less than one percent). All year classes developed sea run brook trout but the largest percentages occurred in older fish (over two years) where 15 to 75 percent of a particular year class returned with a sea trout morphology. Sea run trout fed heavily on small crustaceans and sand launce, and growth rates for all age classes were greater than five times those of brook trout remaining in the river. In addition, sea run fish were much heavier for a given length than river fish of comparable age, presumably as a function of an increased food supply at sea.

Comparisons of our results with data on other anadromous species of trout and char underscore the high potential for sea ranching as a moderate effort, high yield aquaculture technique. Successful sea ranching of brook trout would greatly increase salmonid production for sport or commercial purposes in the coastal zone. From the studies completed it is clear sea run brook trout exhibit tremendous growth compared to river fish, they circumvent problems associated with high density hatchery rearing, they have a dependable food resource at sea, they exhibit a high percent return, they do not enter the high seas fishery, they are a native fish, and they have the taste and color of a salmon. All these factors make sea ranching of brook trout attractive where enhanced production of salmonid fishes is desired, particularly in view of the projected low cost compared to other methods.

Despite the successes of the first two years there are still a number of problems to be investigated before a full scale sea ranching project can be realized. Several of these are currently being examined by members of our research team. Postdoctoral Scholar Linn Montgomery and Research Assistant Frederick Whoriskey are investigating movements and growth of natural sea run brook trout in the Moisie River system relative to food availability in the sea. At present, we know extremely little about the life of brook trout at sea, when they naturally leave and return to rivers, how they exploit their marine food supply, or the carrying capacity of estuaries for increased stocks of these fish. Geoff Black, a research assistant at the Matamek Research Station, is identifying key parasites which will be used to indicate whether trout caught in freshwater have spent some time at sea. Finally, our most difficult problem is being attacked by Stephen McCormick, a WHOI-MIT graduate student. During the field experiments young fish, typically less than two years old, moved immediately back into freshwater where they grew slowly. This suggested that the physiological mechanisms necessary for survival and growth in seawater were not yet available to young fish. Assisted with funds from the NOAA Sea Grant Program, Steve is now examining the physiological basis for the ability of juvenile brook trout to survive (osmoregulate) upon exposure to seawater and to grow well in that medium. The main objective of this study is to determine the optimal size-age combination allowing satisfactory salinity tolerance and a subsequent migration to, and growth in, seawater.

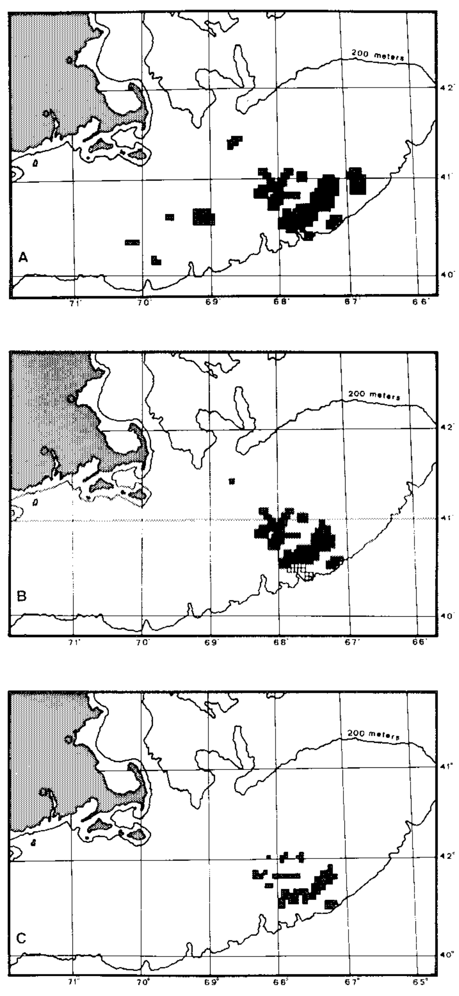
Already at the end of its third year, and supported by the Matamek Research Program, Province of Quebec, the WHOI Education Office, and Sea Grant, the sea ranching project will continue for at least two more years. This coming field season we will be examining other natural populations for variations in life history patterns in response to drainage basin and estuarine geomorphology and hydrology. In the final year an economic evaluation is planned as well as an extensive analysis of the tremendous data base already compiled. With the project's completion, we anticipate having enough key problems solved and enough basic information to implement a larger scale project where our newly gained insights will be applied to the enhancement of salmonid production in the coastal zone.

Organizing the Federal Effort to Manage Marine Resources: Georges Bank and Other Cases

Daniel Finn

THE authority of the federal government offshore has grown progressively since 1899, when Congress authorized the Army Corps of Engineers to regulate discharges and construction in American waters that could obstruct navigation. The greatest single leap was the Truman Proclamation of 1945 which claimed control over the continental shelf of the United States and allowed the federal government, through the Department of the Interior, exclusive supervision of the development of outer continental shelf oil and gas resources. Other federal programs were enacted as knowledge of the characteristics and values of marine resources increased and developments occurred which appeared to threaten those values. Congress in 1972 established wide-ranging permit programs administered by the Environmental Protection Agency (EPA) and the Corps to control activities in wetlands, estuaries, and offshore waters. In the same year the EPA was given authority to control ocean dumping originating at U.S. ports, and the Coast Guard was given broad authority to regulate oil tankers and other vessels operating in U.S. waters. In 1976, another major extension of federal jurisdiction was made when Congress enacted the Fishery Management and Conservation Act providing for regulation by the United States of most of the fishery resources within two hundred miles of the coast. The National Oceanic and Atmospheric Administration (NOAA) was created by order of President Nixon in 1970, but until this year – with the passage of acts regulating the development of ocean thermal energy conversion (OTEC) facilities and deep seabed mining for maganese nodules – the agency has not had major regulatory responsibilities except for fisheries.

As federal authority grew incrementally in the absence of a centralized administration, a variety of programs came to be established within many different federal agencies. Fears that federal agencies administering such single-purpose programs would not give sufficient consideration to the environment led to passage of the National Environmental Policy Act (NEPA) in 1969. Later, Congressional recognition that regulatory programs alone would not necessarily provide sufficient protection for valuable marine resources led to passage of resource protection statutes like the Endangered Species Act (1973) and Marine Mammal Protection Act (1972). Programs like coastal zone management and marine sanctuaries were also established to provide for comprehensive management of the resources of especially valuable marine areas – state coastal zones and certain specially designated areas of the ocean. While such statutes provided a basis for more effective protection of marine resources they also provided many occasions for federal agencies to disagree about marine resource policy. Under NEPA, agencies may provide their opinions on the environmental aspects of actions proposed by other agencies. The Endangered Species Act empowers NOAA to provide its opinion on whether proposed actions could jeopardize marine species. The designation of a marine sanctuary by the Department of Commerce on the advice of NOAA could override the decisions of other federal agencies, such as the Department of the Interior in administering its oil and gas development program.

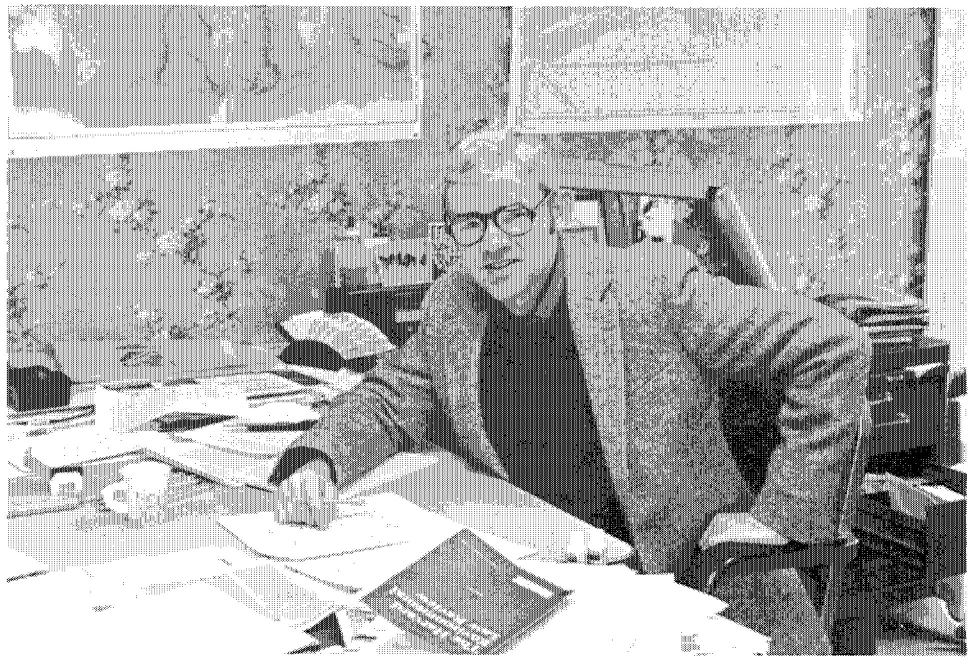


Areas proposed or actually leased on Georges Bank: (A) the 178 tracts originally presented in Interior's final environmental statement; (B) the 128 tracts later proposed by Interior, including the 12 tracts deleted (open boxes) upon agreement with NOAA: (C) the 63 tracts actually leased.

The interrelationships of these federal programs became a major issue in the litigation over oil and gas leasing on Georges Bank. Several New England states and environmental organizations persuaded the First Circuit Court of Appeals that in issuing leases the Interior Department was required to avoid unreasonable risks to fisheries and even to consider the possibility that the Commerce Department might designate a marine sanctuary in the area that could affect how oil and gas operations were conducted. After this decision, Interior proceeded with its leasing plans, but NOAA, on behalf of the Commerce Department, extensively criticized Interior's plans on the basis of the potential effect of drilling on the fisheries and even – on petition by the Conservation Law Foundation, a plaintiff in the lawsuit – began to consider designating Georges Bank as a marine sanctuary in order to override Interior's plans. NOAA had also previously provided its opinion that oil and gas operations could affect endangered whales sometimes observed in the area. After this disagreement, NOAA and Interior concluded an agreement that permitted oil and gas leases to be issued. Although Interior made some concessions, the agreement appeared to many not to resolve all the issues NOAA had raised. The agreement was upheld in court, however. Leases have now been issued and the lawsuit has recently been settled – under terms which require the government to reconsider designation of a marine sanctuary in the future. Meanwhile, an interagency biological task force has been established to help monitor the effects of oil operations.

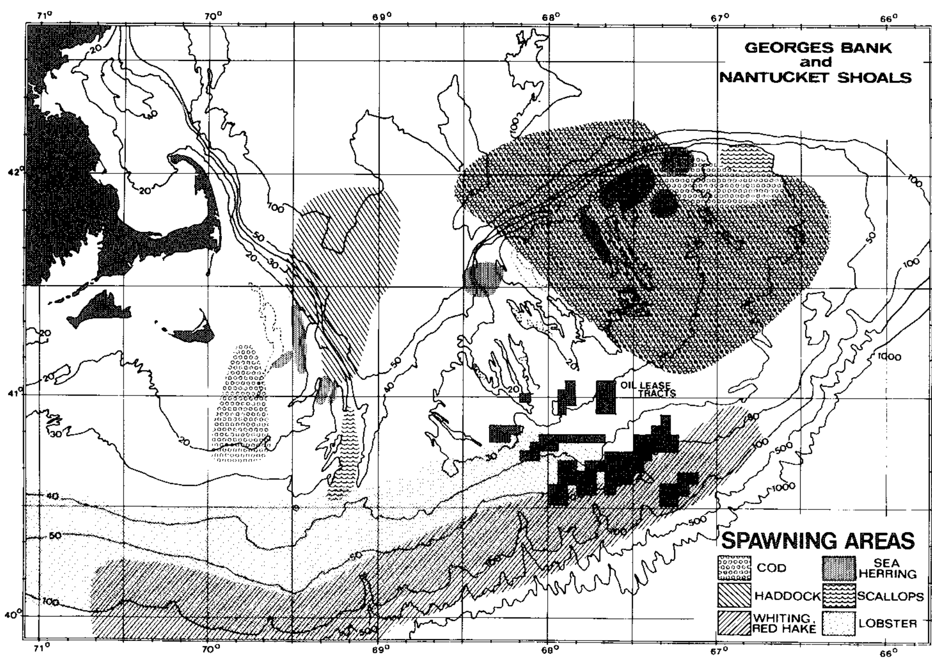
The conflict that has arisen in the Georges Bank and other cases among federal agencies administering marine programs suggests that a more orderly administrative process should be devised. Although government reorganization – putting various marine programs under one roof – could perhaps reduce political conflict, it would not necessarily resolve the real conflicts that exist among the objectives of the federal programs. Relationships among federal agencies ensure that a broader range of concerns are addressed in making decisions that affect marine resources. But to avoid unproductive administrative stalemates and delays due to litigation, ways should be found to normalize the process of interagency consultation. These could include long-term cooperative programs of study and management, the use of hearings and rulemaking in conflicts, and formal interagency dispute resolution procedures including referral of disagreements to high-level committees, commissions, or the President.

In the case of the marine sanctuaries program, its nature requires special efforts at coordination. Although it provides an opportunity to achieve comprehensive management of especially valuable marine areas, conflict between NOAA and other agencies is probable because the program can be used to override the actions of these agencies. This can be observed in the Georges Bank case in which NOAA began consideration of a marine sanctuary after Interior had been proceeding toward its lease sale for several years. It would appear desirable, therefore, for the administrators of the marine sanctuaries program to institute a regular schedule of designations based on scientific and management studies. The objectives of the program should be further clarified to determine in what situations designation is appropriate and what activities should be regulated and how.



VICKY CULLEN

Dan Finn



Tracts for which bids were offered during the Georges Bank lease sale are plotted against the spawning areas of major commercial fisheries. Some scientists believe that spills or discharges from oil operations on the leases could affect commercial fisheries, especially if the eggs or larvae of fishery species are exposed to significant pollution by hydrocarbons or other substances associated with drilling.

Bigelow Medal

THE eighth Henry Bryant Bigelow Medal was presented 18 June 1980 to Microbiologist Holger Windekilde Jannasch, a Senior Scientist in the Institution's Biology Department, by Chairman of the Board Charles F. Adams in ceremonies at the Clark Laboratory.

The award citation reads: "in recognition of his creative contributions to marine microbiology by providing us with an understanding of the fundamentals of microbial processes in the sea and the dynamics of oceanic food chains."

The following tribute to Holger Jannasch was presented by Assistant Scientist Judith M. Capuzzo:

"Microbial processes dictate the rate, magnitude and nature of biological production in the sea. How these processes operate and interact with other trophic levels in diverse oceanic environments is fundamental to understanding the functioning of oceanic food chains. Through innovative laboratory and field research during the past two decades, Dr. Holger W. Jannasch has documented the significance of bacteria in these broad areas of marine biological research.

"Holger's research programs in microbiology have produced a wealth of truly remarkable scientific information on the occurrence, physiology, metabolism and significance of bacteria in the marine environment. His contributions to the development of chemostat culture techniques are an achievement in themselves, and his use of chemostats has resulted in significant findings pertinent to interpreting the responses of bacteria to low nutrient concentrations and the uptake and utilization of organic compounds. Applications of this technique have also been used to elucidate such diverse phenomena as heterotrophic activity, psychrophilic vs. mesophilic competition, sulfur transformations and the influence of particulate matter on bacterial metabolism.

"In addition to his laboratory studies of microbial physiology, Holger has also demonstrated a unique ability for planning and conducting cleverly conceived scientific experiments at sea. His work in the deep ocean is an excellent example of his innovative approach to the study of microbial activity. With the use of the DSRV *Alvin* and the design and development of highly sophisticated free-vehicles instrumented for collection, pressure retention, culturing and subsampling undecompressed bacterial populations from great depths, Holger and his co-workers successfully conducted the first in situ experiments of microbial decomposition in the deep sea. Through these experiment they have identified the effect of pressure on microbial metabolism and documented the extremely slow rates of microbial decomposition in the deep sea. These results provide insights into the fragile nature of deep sea food chains as well as sobering thoughts for using the ocean as a repository for society's wastes.

ELIZABETH FYE

Holger Jannasch

FRANK MEDEIROS

Chairman Charles F. Adams presents the Bigelow Medal to Holger Jannasch at Clark Laboratory ceremony.

"The recent discovery of dense assemblages of benthic animals in the vicinity of thermal vents in the Galapagos Rift area at a depth of 2,500 meters was complemented by an equally exciting discovery of the role of bacterial chemosynthesis in the food chain dynamics of this area. Measurements by Holger and his co-workers of living microbial biomass and in situ growth rates of microbial populations in the vent areas have indicated that chemosynthetic primary production, based on the utilization of sulfur compounds, is the principal source of organic matter for these exceptionally dense animal populations. Further elucidation of the complexity of this system and quantification of chemosynthetic production awaits future research and Holger will no doubt remain in the forefront of these continuing efforts.

"In short, Holger's achievements have not only led to an understanding of the fundamentals of microbial processes in the sea but have also provided impetus and direction for future advancements in the field of marine microbiology."

1980 DEGREE RECIPIENTS

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

Doctor of Philosophy

LARRY E. BRAND
B.A., University of Texas
Special Field: Biological Oceanography
Dissertation: *Genetic Variability and Differentiation in Niche Components of Marine Phytoplankton Species*

NANCY A. BRAY
B.S., University of California, Berkeley
Special Field: Physical Oceanography
Dissertation: *Seasonal Variability in the Intermediate Waters of the Eastern North Atlantic*

SCOTT R. BRIGGS
A.B., Sc.B., Brown University
Special Field: Marine Geology
Dissertation: *A Study of Middle Ground Shoal (41° 28'N, 70°41'W) Sand-Wave Migration and the Local Mean-Velocity Field*

ALAN D. CHAVE
B.S., Harvey Mudd College
Special Field: Marine Geophysics
Dissertation: *Application of Time Series Analysis to Geophysical Data*

MICHAEL S. CONNOR
B.S., Stanford University
Special Field: Biological Oceanography
Dissertation: *Snail Grazing Effects on the Composition and Metabolism of Benthic Diatom Communities and Subsequent Effects on Fish Growth*

ERIC A. D'ASARO
A.B., S.M., Harvard University
Special Field: Physical Oceanography
Dissertation: *Structure and Dynamics of the Benthic Boundary Layer Above the Hatteras Abyssal Plain*

MICHAEL G. FITZGERALD
B.S., University of New Orleans
Special Field: Marine Geology
Dissertation: *Anthropogenic Influence on the Sedimentary Regime of an Urban Estuary –Boston Harbor*

LEE-LUENG FU
B.S., National Taiwan University
Special Field: Physical Oceanography
Dissertation: *Observation and Models of Inertial Waves in the Deep Ocean*

JOY A. GEISELMAN
B.A., Carleton College
Special Field: Biological Oceanography
Dissertation: *Ecology of Chemical Defenses of Algae Against the Herbivorous Snail,* Littorina Littorea,*in the New England Rocky Intertidal Community*

KENNETH E. GREEN
B.S., Massachusetts Institute of Technology
Special Field: Marine Geophysics
Dissertation: *Geothermal Processes at the Galapagos Spreading Center*

SUSAN M. HENRICHS
B.S., University of Washington
Special Field: Chemical Oceanography
Dissertation: *Biogeochemistry of Dissolved Free Amino Acids in Marine Sediments*

DOUGLAS S. LUTHER
S.B., Massachusetts Institute of Technology
Special Field: Physical Oceanography
Dissertation: *Observations of Long Period Waves in the Tropical Oceans and Atmosphere*

MARY J. RICHARDSON
B.A., Smith College
Special Field: Marine Geology
Dissertation: *Composition and Characterizations of Particles in the Ocean: Evidence for Present Day Resuspension*

DEAN H. ROEMMICH
B.A., Swarthmore College
Special Field: Physical Oceanography
Dissertation: *The Application of Inverse Methods to Problems in Ocean Circulation*

JOHN SHAI-FU SHIH
B.S., M.S., Stanford University
Special Field: Marine Geology
Dissertation: *The Nature and Origin of Fine-Scale Sea-Floor Relief*

ALEXANDER N. SHOR
B.A., Harvard University
Special Field: Marine Geology
Dissertation: *Bottom Currents and Abyssal Sedimentation Processes South of Iceland*

ROBERT F. STALLARD
B.S., Massachusetts Institute of Technology
Special Field: Chemical Oceanography
Dissertation: *Major Element Geochemistry of the Amazon River System*

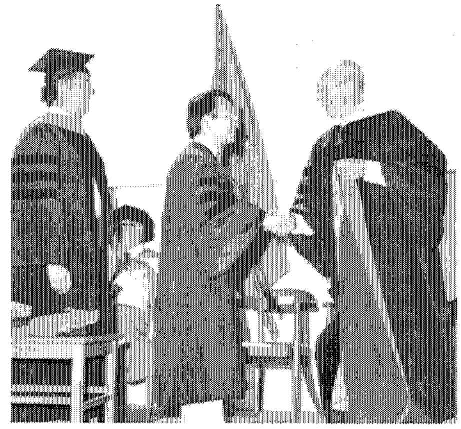
NEIL R. SWANBERG
B.S., University of California, Davis
Special Field: Biological Oceanography
Dissertation: *The Ecology of Colonial Radiolarians: Their Colony Morphology, Trophic Interactions and Association, Behavior, Distribution, and the Photosynthesis of their Symbionts*

Doctor of Science

JOHN M. TOOLE
B.A., University of Maine, Orono
Special Field: Physical Oceanography
Dissertation: *Wintertime Convection and Frontal Interleaving in the Southern Ocean*

Ocean Engineer

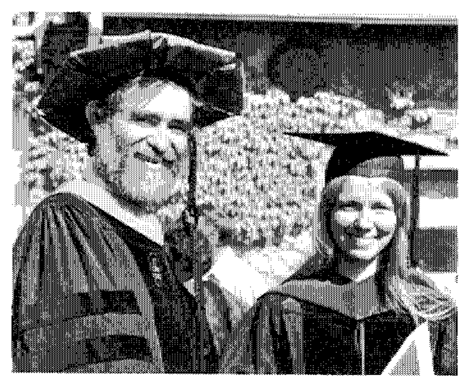
STEPHEN P. KOCH
B.S.E., Purdue University
Special Field: Oceanographic Engineering
Dissertation: *Propagation and Attenuation Characteristics of Multilayered Media*


FRANK MEDEIROS

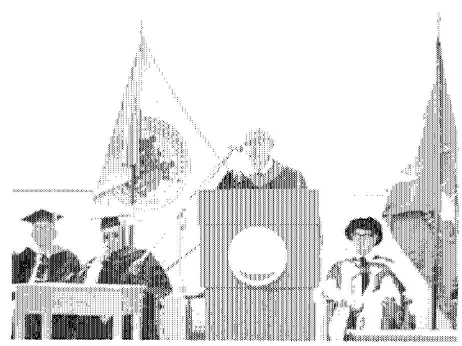
Deans Hollister, left, of WHOI and Wadleigh of MIT with June graduate Lee-lueng Fu.


VICKY CULLEN

Dean Roemmich, left, is escorted to platform to receive his degree by Assistant Dean Peirson.


VICKY CULLEN

Joy Geiselman and her advisor, John Teal, were all smiles at the post-graduation reception.


SHELLEY LAUZON

Commencement address is given by Cecil Green.

Dean's Comments

DURING my first complete year as Dean, we have been involved in a number of new and exciting activities that have made the year both a learning experience for me and a time in which I hope we have laid a solid foundation for the immediate future. My concern and energies have been directed towards strengthening and solidifying the still very young (only 12 years old) graduate education program.

Two very important activities took place during the year that will serve to help us meet some of the challenges facing graduate education in science in these days of tightening budgets and shrinking talent pools. We completed, along with our colleagues at the Massachusetts Institute of Technology, a thorough in-house review of the MIT/WHOI Joint Program in Oceanography/Oceanographic Engineering. We also convened in Woods Hole a two-day meeting of the major academic officers in charge of the graduate education programs in oceanography at eleven prominent oceanographic institutions presently offering doctoral degrees in all the principal fields of oceanography. The purpose, to discuss mutual concerns and problems in ocean science graduate education and to learn more about each other, was certainly attained. The success of this first "Deans' Retreat" will most likely foster annual meetings to be hosted in turn by each of the participating institutions.

From both of these activities, we gained an even greater realization of the seriousness of the shortage of qualified applicants for the physical sciences and engineering. Accordingly, we embarked on a modest experimental recruiting effort, during which certain staff members, including myself, visited a dozen universities and spoke to well over 100 prospective marine science students. We concentrated our efforts on students in math, physics, geology, and chemistry, as these are the areas where there is clearly a dearth of qualified applicants and a lesser tendency to consider oceanography as a possible career choice. Also, it is in these areas, as well as engineering, that the best students are being courted by industry, mainly petroleum companies, at very attractive salaries. We are optimistic that our recruiting efforts will bring favorable results soon and also expect that our colleagues across the country will be making similar efforts at encouraging students to enter the field of ocean science.

Although small by most standards, the Joint Program has an excellent reputation for quality students. We can be proud of the fact that in addition to having the highest acceptance rate, the Joint Program has attracted the highest percentage of holders of National Science Foundation Graduate Fellowships, and carries an overall drop-out rate significantly lower than that of our competitor schools. Students in the Joint Program also tend to take about one year less to complete the Doctoral degree than do students enrolled with the other major oceanography schools.

During this year, the 50th Anniversary year of the Institution and the tenth year after the first formal Joint Program commencement in Woods Hole, we held our second formal graduation exercises. A record number of graduates, seventeen, received degrees during the 1979-80 academic year, and sixteen of the program's over 100 alumni returned to participate in the exercises along with more than 100 corporation members, faculty, and staff of both institutions. The program highlight was an inspiring address by Cecil Green, who emphasized "collaboration and giving credit," two themes which I feel could easily be used to describe the MIT/WHOI Joint Program education effort.

Though my efforts have been devoted in large part to the graduate program, our continuing programs in support of Postdoctoral Scholars, Marine Policy Fellows, Summer Student Fellows, Minority Trainees, and volunteer Guest Students were as strong as ever in 1980. I was particularly pleased to have the occasion at the Fall Associates' Day of Science to give special thanks to the Associates, who have been so supportive of the popular and extremely valuable Summer Student Fellowship Program for undergraduates. Although still not as successful as we would like, the Minority Traineeship Program is unique among the programs of oceanographic institutions as the only such opportunity for college level members of the minority groups.

Financial support for the Education Program is of increasing concern. We hope to be able to adjust to the changing climate for funding by reaching out to new and different sources. In this vein, it was particularly exciting to see the inception of the new Coastal Research Center this year, which brings a timely focus on this area of study. The Center has already contributed to the Education Program through its support of both Graduate Students and Postdoctoral Scholars and will certainly be playing an important role in keeping the Education Program viable in the future.

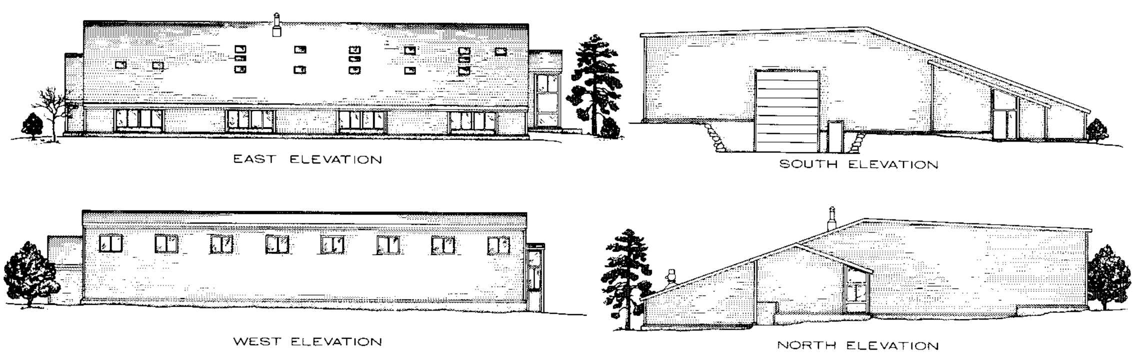
Charles D. Hollister
Dean of Graduate Studies

Ashore & Afloat

THE year-long celebration of the Institution's 50th anniversary in 1980 got off to an exciting start 8 January with the premiere of "Dive to the Edge of Creation," an hour-long public television feature documenting DSRV *Alvin's* 1979 expedition to the hot vents and their unusual animal communities on the Pacific's Galapagos Rift. The film, the first of four 1980 National Geographic specials, won an Emmy Award for individual achievement in an informational program and featured Associate Scientists Robert D. Ballard and J. Frederick Grassle.

Dr. Frank Press, science and technology advisor to President Jimmy Carter, brought White House greetings to the 300 persons attending the 50th anniversary dinner and dance 15 January at Boston's Copley Plaza Hotel. The winter meeting of the Corporation was held earlier in the day, the anniversary of the first Corporation meeting. The occasion happened to coincide with *Alvin*'s 1,000th dive, made for the National Oceanic and Atmospheric Administration on the Galapagos Rift.

A grant of $1.75 million from The Andrew W. Mellon Foundation was announced at the dinner and dance by Noel B. McLean, campaign chairman of the Institution's $52 million fund raising drive. The grant helped to establish the Coastal Research Center and provided initial support for a permanent fund in support of innovative research in oceanography.

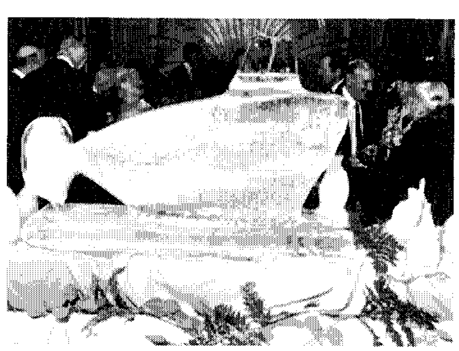


Drawings show views of the Coastal Research Laboratory to be constructed on the Quissett Campus in 1981 as part of the Coastal Research Laboratory.

A growing need within the Institution for a focal point for scientific work on nearshore problems was met with the establishment of the Coastal Research Center. Director John H. Steele announced the appointment of Senior Scientist John H. Ryther as the Center's first director and Associate Scientist John W. Farrington as chairman of the Center's planning committee. Later in the year, a grant of $120,000 from the Charles E. Culpeper Foundation was announced to support planning activities for the Coastal Research Center, and a $350,000 challenge grant from The Kresge Foundation was received to help fund construction of an experimental laboratory at the Center, to be developed around existing facilities of the Environmental Systems Laboratory.

A Falmouth High School student, Ted Inoue, received the Institution's $750 college scholarship for a spectroscopy and astronomy project he entered in the Falmouth Science Fair 15 March.

Several hundred persons attended a 50th anniversary public lecture, "Last of the Grain Ships," by yachtsman Elliot Knowlton 12 March. A short film taken in 1939 aboard the square rigger *Passat* documented the last grain race around Cape Horn by commercially operated square riggers. A 50th Anniversary Film Festival in February and March featured such marine classics as "Moby Dick" and "African Queen."



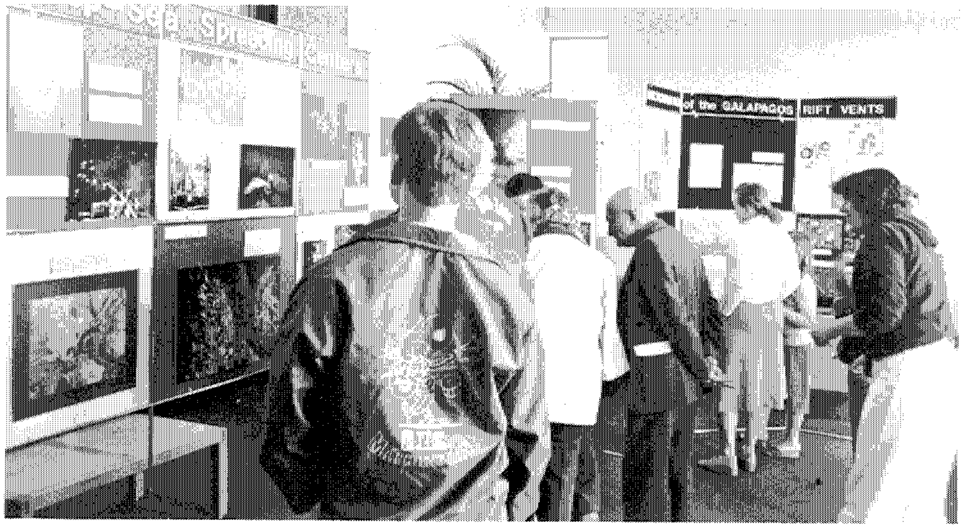
BOSTON GLOBE

An ice sculpture of *Alvin* formed the cocktail party centerpiece for the 50th anniversary dinner dance at the Copley Plaza in Boston.

The second International Ocean Dumping Symposium in April attracted more than 200 scientists from nine countries to Woods Hole for four days of discussions on the technical and scientific problems associated with disposal of dredged and radioactive wastes.

The Institution's 50th Anniversary Open House 10 May drew an estimated 3,000 persons to Quissett Campus and village facilities to view exhibits and films, speak with staff members, and tour R/V *Knorr* and R/V *Lulu*.

Among the many visitors to the Institution during 1980 were A. Thomas Young, director of NASA's Goddard Space Flight Center, and the Center's Director of Applications, W. H. Meredith, who met with Director Steele and other staff members to discuss remote sensing by satellites. Jean Claude Pujol from France's Centre National pour l'Exploitation des Oceans (CNEXO) met with members of the Directorate and the deep submergence group to discuss submersible design and operation. In June officials from the State Department involved in the Law



SHELLEY LAUZON

of the Sea treaty negotiations met with Institution staff members to discuss the treaty's impact on marine scientific research. Thirteen members of Congressional committees concerned with National Science Foundation (NSF) appropriations spent two days in Woods Hole in August as part of the annual inspection of NSF-supported activities. A two-day Nantucket Shoals Workshop on Remote Sensing cosponsored by the Institution and the Naval Research Laboratory was attended by twenty-five scientists from private and government laboratories. The National Academy of Sciences Ocean Policy Committee, chaired by Corporation President Paul M. Fye, met in Woods Hole 7 to 10 September for a series of workshops and panels on the Law of the Sea treaty and other topics; Senior Scientist David A. Ross is chairman of the Academy's Ocean Sciences Policy Committee. Representatives of New England banks and banking interests attended a one-day symposium on marine policy issues in November. Trustees of the New England Aquarium held their fall meeting at the Institution and were addressed by Associate Director for Research Derek W. Spencer on current research activities. Semi-annual presentations were organized for members of the Institution's Ocean Industry Program and the Naval War College's Naval Staff Course for foreign officers.

Open House visitors examine exhibits at the Clark Laboratory.

JEFFREY ELLIS

Associate Scientist John Milliman was U. S. Scientific Project Coordinator for the first American research cruise in Chinese waters in more than 30 years. NOAA's R/V *Oceanographer* worked with a Chinese vessel in May for studies of sediment dynamics, biology, and ocean chemistry in the East China Sea. Photo shows Milliman with Chinese colleagues on Shanghai pier.

Ambassador Tommy Thong Bee Koh, permanent representative of the Republic of Singapore to the United Nations, presented the twelfth J. Seward Johnson Marine Policy Lecture 4 June on "Should the United States Ratify the New Law of the Sea Treaty?"

Presentation of the eighth Henry Bryant Bigelow Medal to Senior Scientist Holger W. Jannasch 18 June commenced two days of activities held in conjunction with the Annual Meeting of the Trustees and Corporation. Following the medal presentation, the new Geosciences Research Center was dedicated to former Chairman of the Board Noel B. McLean. The McLean Laboratory was constructed with a $1.55 million grant from the Fleischmann Foundation and will house the Institution's extensive collection of deep sea rocks, sediment cores, and other geological samples collected by the Geology and Geophysics Department during the past fifty years. The first occupants of the new building arrived in late August, and movement of the samples began in October.

DSRV *Alvin* and her tender R/V *Lulu* returned to Woods Hole 15 February after a 15-month absence to work in the Pacific. The vessels underwent several

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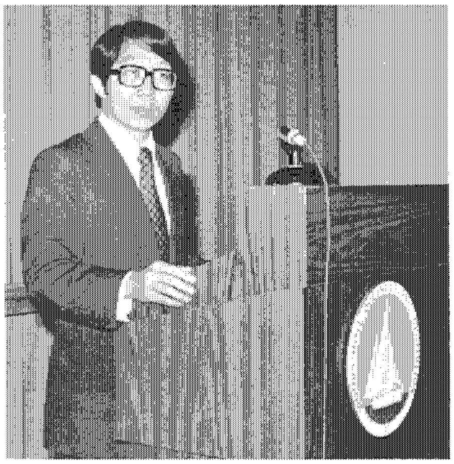

Ambassador Koh discussed ratification of the Law of the Sea treaty in Johnson Lecture.

months of maintenance and repair in the spring, and new buoyancy material was added to the sub during a month-long lay-up in September.

R/V *Knorr* rescued a Belgian sailor in May when his 30-foot sloop, *Nanesse*, struck an unknown object and sank near Bermuda.

The 40-foot *Asterias*, built in 1931 for a total cost of $6,559.91, was sold for $15,000 in a sealed bid auction in July to Ocean Research Equipment, Inc. of Falmouth. Her replacement, the 46-foot *Asterias*, was put into service 1 July.

R/V *Atlantis II* returned to Woods Hole 17 November after a thirteen-month, 52,560-mile voyage in the South Atlantic Ocean, her first research cruise since conversion from steam to diesel power.

Director John H. Steele was one of 79 individuals elected to membership in the American Academy of Arts and Sciences. Senior Scientist James R. Heirtzler was elected a Fellow of the American Association for the Advancement of Science in recognition of "meritorious contributions to the advancement of science." Senior Scientist Henry M. Stommel was one of three recipients of the first Archibald G. Huntsman Award, established in 1980 by the Bedford Institute of Oceanography in Nova Scotia to honor Professor Huntsman, once a Trustee and Member of the WHOI Corporation.

Senior Scientist David A. Ross was appointed Director of the Marine Policy and Ocean Management Program, succeeding Senior Scientist Robert W. Morse who had been director since 1977.

Corporation President Paul M. Fye was one of ten recipients of the 1980 Fellows Award from the Marine Technology Society for contributions to marine science and technology. Dean Emeritus H. Burr Steinbach was honored with the dedication of the 1980 Symposium of the Society of General Physiologists, held in Woods Hole in August.

A dozen unusual craft participated in the "Anything But a Boat Regatta" 9 August in Great Harbor as part of the continuing 50th anniversary celebration. An estimated 200 persons watched as the flotilla attempted to complete the race course powered by swim fins, snow shovels, pedals, and even a lawn mower motor. The winner was a raft of fourteen spheres lashed together and powered by a precision crew of fourteen

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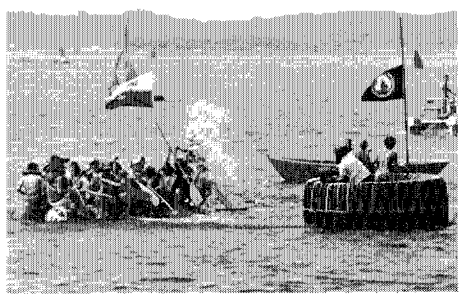


Anything-But-a-Boat Regatta winner "Lotta Balls" rounds the marker in Great Harbor.

employees of Ocean Research Equipment, Inc. of Falmouth.

Eight hundred employees and their guests attended the Employee's 50th Anniversary Clambake 17 August on the Fenno House grounds.

More than 300 Associates, Corporation Members, and guests aboard R/V *Knorr* and another 100 aboard *Cape Cod Princess* departed Woods Hole 16 September for a day at the first of the America's Cup Races off Newport, Rhode Island. Everyone enjoyed the adventure as *Freedom* beat the challenger *Australia*.

Scientists and marine historians from all over the world gathered in Woods Hole in late September for two weeks of meetings on the past, present, and future of oceanography. The Third International Congress on the History of Oceanography convened 22 September with an afternoon session on the history of the Institution. Seventy papers were presented during the five-day meeting. The proceedings are collected in a volume entitled *Oceanography: The Past* coedited by Senior Scientist Emeritus Mary Sears and Yale Professor Emeritus of Biology Daniel Merriman, who was Congress Chairman (and a crew member on the maiden voyage of *Atlantis*). Evening speakers included Rear Admiral Ross N. Williams, Oceanographer of the Navy;

SHELLEY LAUZON

Noel McLean, right, views exhibit on his years with Institution at McLean Lab dedication.

I. Bernard Cohen of Harvard University; Corporation Member George Moses; and Scientist Emeritus Kenneth O. Emery. The concluding speaker 26 September was Ambassador Hamilton Shirley Amerasinghe, President of the Third United Nations Conference on the Law of the Sea, who presented the thirteenth J. Seward Johnson Marine Policy Lecture, "The Law of the Sea and Its Contribution to International Peace."

Discussions of the past led to the present and future when Senior Scientist Peter G. Brewer convened on 29 September a symposium entitled "Will We Use the Oceans Wisely - The Next Fifty Years in Oceanography." This was the final event in the 50th anniversary celebration. Papers presented during the four-day symposium considered problems on the small or local, oceanic regional, global, and human scales.

Afternoon panel sessions considered environmental problems and public policy, military and security uses of the ocean, ocean science and the international regime, and institutional and educational challenges. The proceedings are being assembled in a companion volume to that of the Congress entitled *Oceanography: The Present and Future.*

VICKY CULLEN

A host of colleagues gathered in September to celebrate publication of a volume in honor of Henry Stommel's 60th birthday. Here Stommel, right, chats with Koji Hidaka of Japan and Gerold Siedler of Germany.

CAPE COD TIMES PHOTO BY MILTON MOORE

Disassembly for overhaul begins for *Alvin* in the high crane bay.

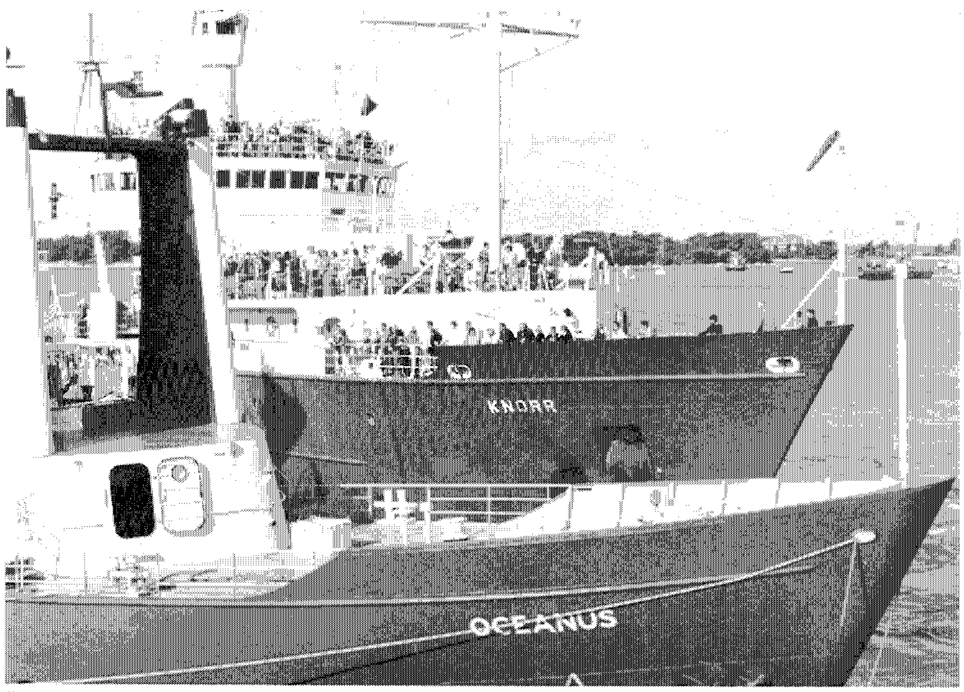
A $150,000 grant from the Exxon Education Foundation will support planning activities for the Center for Analysis of Marine Systems (CAMS). Senior Scientist Peter B. Rhines was appointed director of the Center, which will bring scientists and those concerned with marine policy questions together to work on problems best studied by computer simulation and modeling techniques. Associate Scientist William J. Jenkins was named chairman of the CAMS planning committee.

More than 300 attended the Annual Associates' Day of Science 10 October. In recognition of 1980 as the Year of the Coast, morning speakers focused on beach erosion, the ocean quahog as a new resource, currents in the coastal boundary layer, and the new Coastal Research Center. Poster sessions were popular attractions at the afternoon open house in McLean Laboratory, and visitors toured the Environmental Systems Laboratory and other facilities.

The Institution paid tribute to Senior Scientist Alfred C. Redfield on his 90th birthday 15 November with publication of *The Tides of the Waters of New England and New York.* Scientists Emeriti Mary Sears and William von Arx assisted with publication of the limited edition volume, which Dr. Redfield began writing at age 85 and completed at age 88.

Institution employees participated in the second annual Falmouth Chamber of Commerce Christmas parade 7 December and won second prize in the nonprofit division for their entry, "Hometown to the World." The float featured a globe, the Woods Hole drawbridge, and people in native costumes representing the many nations visited by Institution ships.

Thirty-year service awards were presented 19 December to Captain David F. Casiles, Captain Arthur D. Colburn, Sr., Steward/Cook Samuel F. Pierce, Departmental Executive Assistant Kaleroy L. Hatzikon, and Research Specialist Karl E. Schleicher. Fourteen retirees with 296 years of service to the Institution were also honored.



VICKY CULLEN

R/V *Knorr* backs from the WHOI pier bound for the America's Cup race.

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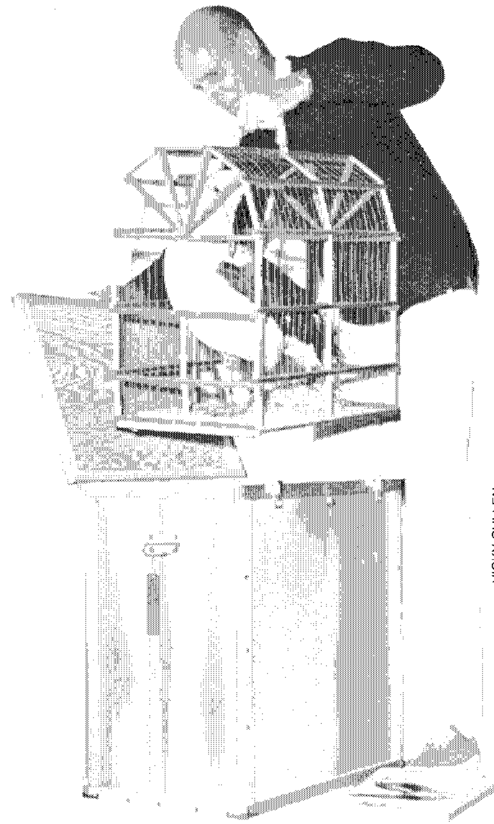
The MBL Club served as general headquarters for both meetings. Florence Mellor, far left, was registrar.



VICKY CULLEN

Art Maxwell extracts the famous Albatross Award from its packing case. Award was presented posthumously to John Isaacs of Scripps at the congress.

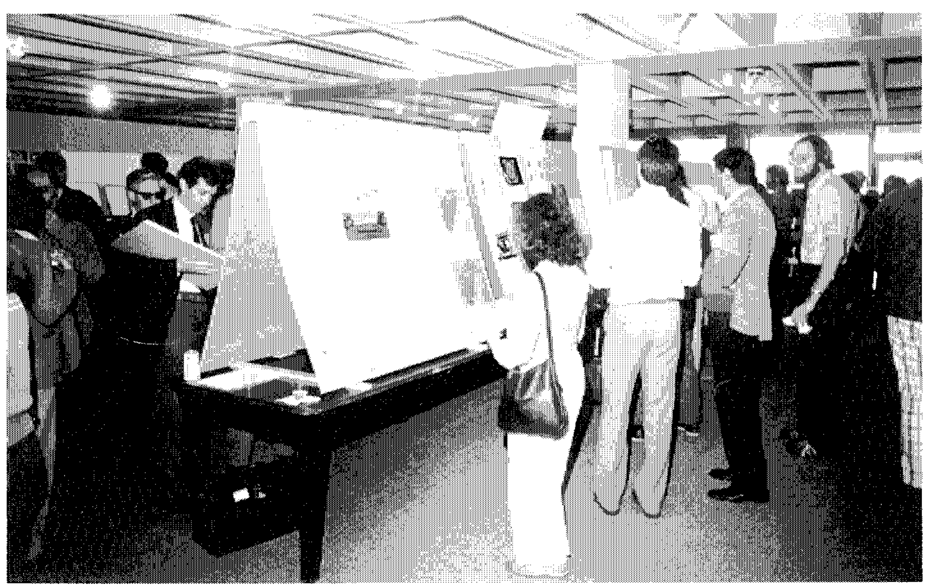
AMY RADER

Foreign registrants attend history session.

Photos on this page were taken at the Third International Congress on the History of Oceanography and a 50th anniversary symposium entitled "Will We Use the Oceans Wisely — the Next 50 Years in Oceanography." Both were held in Woods Hole in the fall of 1980.

AMY RADER

Dan Merriman presides at a history session.



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A mid-week poster session was held for symposium participants.

Publications

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Institution contribution number appears at end of each entry.

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J. G. Bruce, D. R. Quadfasel and J. C. Swallow. Somali eddy formation during the commencement of the Southwest monsoon, 1978. *J. geophys. Res.*, 85(C11): 6654-6660. 4496

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A-II Captain Casiles, center, and 2nd Mate Zuckovich, right, with Beagle Channel pilot.

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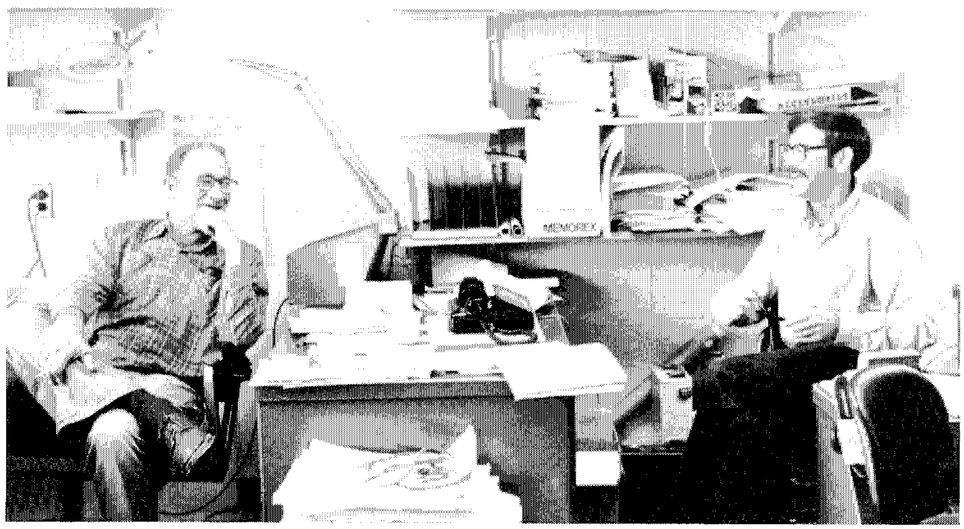
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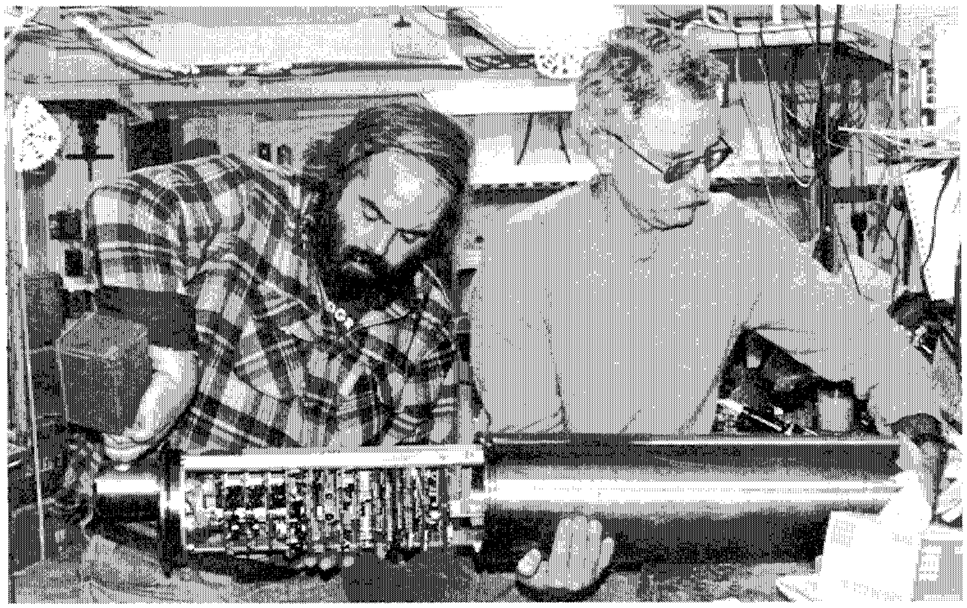

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Bill Grant loosens block on USGS catamaran.

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+Leave of Absence
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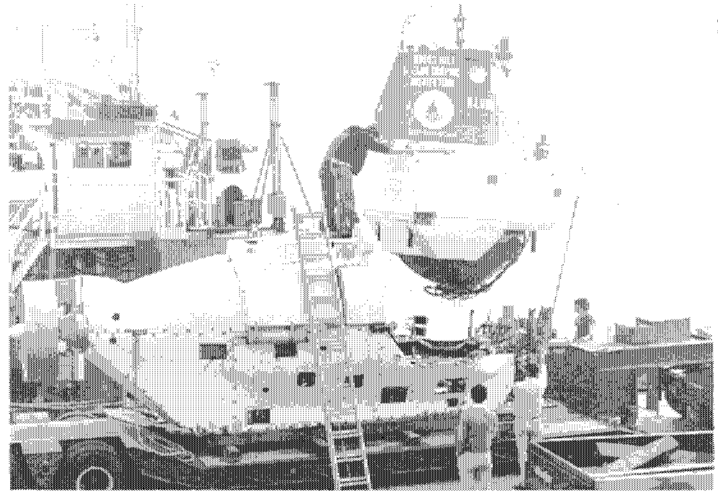

SHELLEY LAUZON

Above, *Alvin* is reassembled after post-overhaul testing; right, *Knorr* A. B. Frank Tibbetts; below, a quiet moment on the fantail of *Atlantis II*.

JERRY DEAN

SHELLEY LAUZON

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Voyage Statistics

SHELLEY LAUZON

SHELLEY LAUZON

MARGARET SULANOWSKI

Above left, the new *Asterias* gets dockside outfitting; left, a welcome-home sign for *Atlantis II* after her long South Atlantic voyage; above, *A-II* Second Mate Dave Megathlin, left, and Radio Officer Butch Smith in Rio de Janeiro.

R/V Atlantis II

Total Nautical Miles for 1980 — 38,004 miles
Total Days at Sea — 272 days

Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call*	*Chief Scientist*
107-IV	17 Jan-31 Jan	Physical oceanography in the Drake Passage for ISOS Program	Punta Arenas, Chile	Nowlin (TAMU)
107-V	5 Feb-27 Feb	ISOS in Drake Passage	Punta Arenas	Nowlin (TAMU)
107-VI	5 Mar-7 Apr	Petrology, geophysics, and coring along the Atlantic plate boundary from Drake Passage to Bouvet Triple Junction	Cape Town, South Africa	Dick
107-VII	12 Apr-16 May	Geological and geochemical studies of the islands of Tristan da Cunha and adjacent ridge sediment	Rio de Janeiro, Brazil	Humphris-Lohmann
107-VIII	22 May-20 Jun	Moored and hydrographic observations in Vema Channel to measure the flux of Antarctic bottom water and the dynamics of flow through passages	Rio de Janeiro	Hogg
107-IX	26 Jun-25 Jul	Geophysics, coring, photography, magnetics, and hydrography to study late Cenozoic abyssal circulation	Mar del Plata, Argentina	Johnson
107-X	5 Aug-6 Sep	Southern Ocean Water Mass Renewal and Circulation Studies: hydrographic data in the southwestern Argentine Basin, Western Scotia Sea, and northern Drake Passage	Punta Arenas	Georgi
107-XI	13 Sep-16 Oct	Determination of the horizontal distribution of convective mixed layer depth in the sub-Antarctic zone as related to the formation of Antarctic Intermediate Water	Punta Arenas	McCartney
107-XII	22 Oct-17 Nov	Transit	Woods Hole	

R/V Knorr

Total Nautical Miles for 1980 — 25,500 miles
Total Days at Sea — 237 days

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call	Chief Scientist
77-I	24 Feb-20 Mar	Heat flow and seismic reflection to study the variability of heat flow with sediment thickness on late Mesozoic oceanic crust	St. George, Bermuda	Sclater (MIT)
77-II	24 Mar-20 Apr	High resolution seismic reflection and refraction experiments to determine quantitative estimates of the small scale variability in seismic structure of normal ocean crust	Woods Hole	Purdy
78	25 Apr-4 May	Detailed reconnaissance of the temporal and spatial variability of high energy fluid events and resulting sedimentary bedforms on the Scotian Continental Rise for HEBBLE Project	Woods Hole	Williams
79-I	17 May-20 May	Transit	St. George	Bryan
79-II	23 May-19 Jun	Mapping of sea floor structure and lithologic units in the Kane Fracture Zone, *Alvin* support	Ponta Delgada, The Azores	Bryan
79-III	24 Jun-18 Jul	Research on the structure and constitution of the oceanic lithosphere of Oceanographer Transform Fault and its temporal and spatial evolution, *Alvin* support	Woods Hole	Crane (LDGO)
80	24 Jul-17 Aug	Site surveys for *Glomar Challenger* drilling on the Atlantic coastal margin	Woods Hole	Ewing
81-I	22 Aug-29 Aug	Atlantic Coastal Ecosystem Investigation: study of rate processes and distribution of chemical properties, biological populations, and circulation of water masses on the continental shelf of the Middle Atlantic Bight and adjacent estuaries	Governor's Island, NY	Rowe (Brookhaven)
81-II	30 Aug-11 Sep		Woods Hole	Walsh (Brookhaven)
82	16 Sep	America's Cup Race	Woods Hole	Watson
83	20 Sep-9 Oct	Continuation of HEBBLE Project	Woods Hole	Hollister/ Williams
84	16 Oct-11 Nov	Pilot cruise for Transient Tracers in the Ocean program, CTD survey for Gulf Stream Extension experiment	Woods Hole	Brewer
85	16 Nov-6 Dec	Recovery of moorings for Gulf Stream Extension experiment, Long Term Upper Ocean Study, and University of Rhode Island experiment	Woods Hole	Fofonoff
86	9 Dec	U.S. Navy inspection	Woods Hole	Dinsmore

R/V Oceanus

Total Nautical Miles for 1980 — 34,880 miles
Total Days at Sea — 245 days

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call	Chief Scientist
78-I	18 Jan-8 Feb	Marine geochemistry of radioactive elements in the western North Atlantic	Bridgetown, Barbados	Bacon
78-II	12 Feb-18 Feb	Test and evaluation of air deployed oceanographic mooring automatic anchoring concept	Belem, Brazil	Walden
78-III	21 Feb-7 Mar	Study of the response of the upper ocean to the annual cycle of atmospheric forcing in the western equatorial Atlantic	Recife, Brazil	Katz (LDGO)
78-IV	10 Mar-4 Apr	CTD measurements for beta-spiral calculations	Ponta Delgada, The Azores	Stommel
78-V	10 Apr-26 Apr	Hydrographic observations across the core of Labrador Sea Water near Grand Banks	Woods Hole	McCartney
79	1 May-9 May	Site surveys and installation of test moorings for Long Term Upper Ocean Study at 34°N, 70°W	Woods Hole	Briscoe

80	11 May-19 May	Conventional and high pressure sample collection for studies of heterotrophic activity of deep sea microbial populations	Woods Hole	Jannasch
81	23 May-1 Jun	Study of sediment transport processes on Georges Bank for USGS	Woods Hole	Butman (USGS)
82	16 Jun-27 Jun	Biology of gelatinous zooplankton in the Sargasso Sea	Woods Hole	Madin
83	1 Jul-12 Jul	Collection and culturing of phytoplankton	Woods Hole	Murphy (Bigelow)
84	21 Jul-28 Jul	Study of deep sea microbial populations, collection of zooplankton, gravity coring	Woods Hole	Wirsen
85	2 Aug-11 Aug	Continuation of Long Term Upper Ocean Study	Woods Hole	Briscoe
86-I	15 Aug-1 Sep	Marine geochemistry of organics in particulates in sea-water and surface samples on the slope, rise, and Bermuda Rise	St. George, Bermuda	Bacon
86-II	2 Sep-14 Sep	Biogeochemical and geochemical studies of the water column and surface sediments at stations in the western North Atlantic	Woods Hole	Farrington
87	22 Sep-15 Oct	POLYMODE float program: recovery and resetting of autonomous listening stations, deployment of SOFAR floats	Woods Hole	Valdes
88	23 Oct-31 Oct	USGS sediment transport work on Georges Bank, Lydonia Canyon, south of Nantucket, off New Jersey	Woods Hole	Butman (USGS)
89	6 Nov-18 Nov	Study of ocean processes in acoustic variability and acoustic tomography	Woods Hole	Frisk
90	24 Nov-3 Dec	USGS sediment transport work on Georges Bank	Woods Hole	Butman (USGS)

DSRV Alvin and R/V Lulu

The submersible Alvin is a Navy-owned national oceanographic facility supported by NSF, ONR, and NOAA and operated by this Institution.

Total Nautical Miles for 1980 — 12,924 miles
Total Days at Sea — 192 days
Total Dives — 89

Lulu Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call*	*Chief Scientist*
103-VI	1 Jan-21 Jan	9 dives for geological work on the Galapagos Rift	Balboa, Panama	Malahoff (NOAA)
103-VII	26 Jan-15 Feb	Transit to Woods Hole with stop at Miami, Florida	Woods Hole	
104-I	15 May-19 May 24 May-25 May	Transit 2 test dives near Bermuda	St. George, Bermuda	Donnelly
104-II	26 May-23 Jun	9 dives for geology and chemistry in the Kane Fracture Zone	Ponta Delgada, The Azores	Bryan
104-III	27 Jun-20 Jul	10 dives for geology in Oceanographer Fracture Zone	St. George	Fox (SUNY)
104-IV	24 Jul-8 Aug	8 dives for biology at Deep Ocean Station #2	Woods Hole	Grassle
105	15 Aug-22 Aug	3 dives for biology in Oceanographer Canyon	Woods Hole	Cooper Uzmann (NOAA)
106	27 Aug-5 Sep	9 dives for geology of Lydonia Canyon	Woods Hole	Slater (USGS)
107-I	1 Oct-13 Oct	7 dives for geology in Wilmington Geotechnical Corridor	Norfolk, VA	Lambert (NOAA)
107-II	17 Oct-2 Nov	10 dives for geology on Blake Escarpment	Nassau, Bahamas	Dillon (USGS)
107-III	7 Nov-8 Nov 9 Nov-14 Nov	4 dives for indoctrination and training 6 dives for biology in the Tongue of the Ocean	Nassau Nassau	Maxwell Grassle
107-IV	18 Nov-20 Nov	3 dives for biological resettlement work near DSDP Hole #98	Nassau	Hecker (LDGO)
107-V	23 Nov-30 Nov	Transit	Christiansted, St. Croix	
107-VI	5 Dec-16 Dec	Biology at Virgin Islands Deep Ocean Station	Christiansted	Grassle

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In Memoriam

Alona E. Evans

27 Feb. 1917 - 23 Sept. 1980

DR. Alona E. Evans had served as a Member of the Corporation since 1975. She had been a member of the Wellesley College faculty since 1945 and was named the Elizabeth Kendall Professor of Political Science in 1966. A specialist in international criminal law and the American criminal justice system, Dr. Evans was the first woman elected to the Board of Editors of the *American Journal of International Law*, and in 1980 she was also the first woman to be named president of the American Society of International Law. She wrote extensively on extradition, aircraft hijacking, and the legal status of political refugees.

Dr. Evans completed A. B. and Ph.D. degrees at Duke University, and she was the recipient of an American Association of University Women Achievement Award in 1971.

Philip B. Armstrong

26 March 1898 – 12 January 1981

DR. Philip B. Armstrong was elected a Member of the Corporation in 1950 and became an Honorary Member in 1974. His long association with the Marine Biological Laboratory began in 1925 when he was a student conducting investigations in embryology. He later served MBL as trustee and clerk of the corporation and he served as director of the laboratory from 1950 to 1966, an important period of growth and recovery from the effects of World War II.

Dr. Armstrong received a B.S. from Massachusetts State College and completed an M.D. at Cornell University, where he then spent 10 years as instructor and assistant professor of anatomy. Following two years on the faculty of the University of Alabama medical school, Dr. Armstrong went to the College of Medicine of the State University of New York at Syracuse where he spent the remainder of his career. For many of his active years and throughout his retirement he maintained a summer home in Woods Hole.

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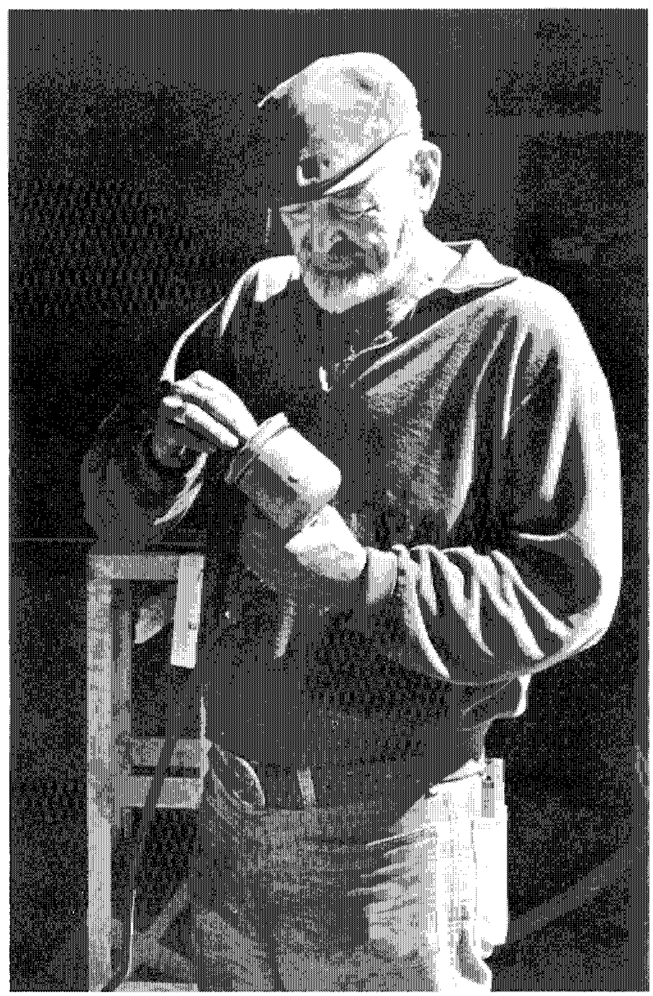

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Above left, collectors from the New England Aquarium sort mud samples; above right, Stephanie Pfirman keeps records during survey work at Nauset Inlet; above, Maxine Jones and Martin Blumenthal do computer work in the main lab on *Oceanus* Voyage 85; right, George Broderson changes sander disc during *Alvin* overhaul work.

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Financial Statements

Financial Highlights

The Institution's total operating revenue increased 6% in 1980, compared with 12% in 1979. Unrestricted income increased 20% in 1980, compared with 39% in 1979. Excess current unrestricted funds of $1,290,000 were transferred to Unexpended Plant Funds, an increase over the $250,000 transferred in 1979.

Funding for sponsored programs was derived from the following sources:

	1980	*1979*	*Increase (Decrease)*
National Science Foundation:			
Science Projects	$ 7,739,000	$ 7,291,000	6.1%
Facilities Projects	6,271,000	7,073,000	(11.3%)
Office of Naval Research	7,044,000	6,822,000	3.3%
Department of Energy	1,206,000	1,233,000	(2.2%)
National Oceanic & Atmospheric Administration	1,361,000	1,188,000	14.6%
Other Government	2,507,000	2,022,000	24.0%
Restricted Endowment Income	350,000	332,000	5.4%
Other Restricted Gifts and Grants	1,966,000	1,350,000	45.6%
	$28,444,000	$27,311,000	4.2%
Other statistics of interest are:			
Full-time Equivalent Employees	780	762	2.4%
Total Compensation (including overtime & employee benefits)	$17,888,000	$16,223,000	10.3%
Retirement Trust Contribution	1,880,000	1,680,000	11.9%
Endowment Income (net)	1,965,000	1,920,000	2.4%
Additions to Endowment Principal	1,054,000	47,000	
Endowment Principal (year-end at market value)	41,954,000	36,457,000	15.1%

Five-year comparison of selected financial data adjusted for effects of CPI changes, shown in average 1980 dollars (thousands):

	1980	*1979*	*1978*	*1977*	*1976*
Sponsored Research	$28,444	$31,004	$31,481	$29,329	$29,307
Unrestricted Income	3,155	2,979	2,374	2,555	2,254
Total Operating Expenses	31,265	33,986	34,524	32,353	31,927
Physical Plant Operating Costs	2,015	1,939	2,058	2,126	2,041
General & Administrative Costs	3,627	3,853	3,938	3,835	3,895
Education Program Costs	1,390	1,444	1,204	1,309	1,432

Gifts and grants from private sources including the 1,216 Institution Associates totaled $3,072,000 in 1980 of which $2,138,000 was restricted as follows:

Addition to Endowment Principal	$ 829,000
Laboratory Construction	500,000
Marine Policy & Ocean Management	350,000
Benthonic Foraminifera Studies	100,000
Education Program	52,000
Center for Analysis of Marine Systems	50,000
Coastal Studies Center	40,000
Other Research Programs	217,000
	$2,138,000

Funds availed of in support of the Education Program were derived principally from endowment income received in 1980 totaling $966,000. And, in addition to other funds restricted for education, unrestricted funds of $175,000 were availed of. Research contracts and grants provided student support in the amount of $298,000.

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

Joseph Kiebala, Jr.
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George E. Conway
Controller

Report of the Certified Public Accountants

To the Board of Trustees of Woods Hole Oceanographic Institution:

We have examined the balance sheets of Woods Hole Oceanographic Institution as of December 31, 1980 and 1979, 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 financial statements referred to above present fairly the financial position of Woods Hole Oceanographic Institution as of December 31, 1980 and 1979, 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
March 20, 1981

Balance Sheets, December 31, 1980 and 1979

ASSETS	1980	1979
Current Fund Assets (Note A):		
Cash	$ 1,740,108	$ 699,191
Short-term investments, at cost which approximates market	5,050,000	5,635,000
Reimbursable costs:		
Billed	2,501,154	1,269,388
Unbilled	1,448,127	2,658,842
Other receivables	194,924	183,397
Inventories	532,911	306,228
Deferred charges and prepaid expenses	301,055	257,808
Due to plant fund	(3,647,365)	(2,855,761)
Due to endowment and similar funds	(3,043)	(140)
	8,117,871	**8,153,953**
Endowment and Similar Fund Assets (Notes A and B):		
Investments at market	41,401,407	36,218,153
Cash	549,841	238,661
Due from current fund	3,043	140
	41,954,291	**36,456,954**
Annuity Fund Assets (Note A):		
Investments, at market (cost $70,513 in 1980 and $70,528 in 1979)	87,713	73,752
Cash	2,573	3,396
	90,286	**77,148**
Plant Fund Assets (Note A):		
Land, buildings and improvements	17,257,421	15,941,206
Vessels and dock facilities	7,362,401	7,356,418
Laboratory and other equipment	2,881,719	2,669,031
	27,501,541	25,966,655
Less accumulated depreciation	9,360,268	8,566,609
	18,141,273	**17,400,046**
Due from current fund	3,647,365	2,855,761
	21,788,638	**20,255,807**
	$71,951,086	**$64,943,862**

LIABILITIES AND FUND BALANCES	1980	1979
Current Fund Liabilities and Balances:		
Accounts payable and other accrued expenses	$ 1,251,466	$ 1,467,792
Accrued vacation	907,951	813,320
Deferred subscription revenue	107,064	82,773
Deferred research revenue	(74,039)	688,089
Unexpended balances of restricted funds	2,814,826	2,061,908
Unrestricted balances designated for:		
Income and salary stabilization	2,288,368	2,114,040
Ocean industry program	218,259	191,632
Fiftieth Anniversary Fund	396,776	412,207
Working capital	207,200	322,192
Total unrestricted balances	3,110,603	3,040,071
	8,117,871	**8,153,953**
Endowment and Similar Fund Liabilities and Balances:		
Endowment:		
Income restricted	25,052,059	21,358,092
Income unrestricted	3,234,866	2,875,237
Term endowment	3,970,510	3,552,904
Quasi-endowment:		
Restricted	6,281,323	5,615,524
Unrestricted	3,415,533	3,055,197
	41,954,291	**36,456,954**
Annuity Fund Liabilities and Balance:		
Annuities payable	26,651	27,838
Fund balance	63,635	49,310
	90,286	**77,148**
Plant Fund Balances:		
Invested in plant	18,141,273	17,400,046
Unexpended:		
Restricted	1,090,000	1,504,515
Unrestricted	2,557,365	1,351,246
Total unexpended balances	3,647,365	2,855,761
	21,788,638	**20,255,807**
	$71,951,086	**$64,943,862**

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

Statement of Current Fund Revenues, Expenses and Transfers for the years ended December 31, 1980 and 1979

	1980	1979
Revenues		
Sponsored research:		
Government	$26.625.841	$25.629.474
Nongovernment	1.817.921	1.681.927
	28.443.762	27.311.401
Education funds availed of	1.215.885	1.121.145
Total restricted	29.659.647	28.432.546
Unrestricted:		
Fees	375.997	230.117
Endowment and similar fund income	522.985	517.781
Gifts	934.431	880.601
Tuition	336.606	316.338
Investment income	614.154	440.653
Oceanus subscriptions	204.949	151.255
Other	165.635	87.448
Total unrestricted	3.154.757	2.624.193
Total revenues	**32,814,404**	**31,056,739**
Expenses and Transfers		
Sponsored research:		
Salaries and fringe benefits	8.705.149	8.173.696
Ships and submersibles	6.555.716	4.870.204
Materials and equipment	3.623.029	2.978.553
Sub-contracts	964.845	2.724.305
Laboratory overhead	1.556.735	1.657.499
Other	3.876.035	3.755.560
General and administrative	3.162.253	3.151.584
	28.443.762	27.311.401
Education:		
Faculty expense	290.393	280.307
Student expense	496.739	469.620
Post-doctoral programs	228.850	273.547
Other expense	242.078	128.405
General and administrative	132.325	119.766
	1,390.385	1.271.645
Unsponsored research	663.501	592.276
Oceanus magazine	255.598	236.126
Other activities	397.084	416.922
General and administrative	115.159	110.285
	1.431.342	1.355.609
Total expenses	**31,265,489**	**29,938,655**
Nonmandatory transfers:		
To plant fund, unexpended	1.290.000	250.000
Total expenses and non-mandatory transfers	**32,555,489**	**30,188,655**
Net increase in unrestricted current fund	**$ 258,915**	**$ 868,084**
Designated for:		
Income and salary stabilization	174.328	172.594
Ocean industry program	(9.748)	58.666
Fiftieth Anniversary Fund	209.676	344.949
Working capital	(115.341)	291.875
	$ 258.915	$ 868.084

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

Statement of Changes in Fund Balances for the years ended December 31, 1980 and 1979

	Current Fund			Endowment and Similar Funds	Annuity Fund	Plant Fund		Total Funds
	Restricted	Unrestricted	Total			Invested in Plant	Unexpended	
1980								
Increases:								
Gifts, grants, and contracts:								
Government	$26,625,841		$26,625,841					$26,625,841
Nongovernment	2,285,817	$ 934,781	3,220,598	$ 828,518			$ 504,645	4,553,761
Endowment and similar funds investment income (Note D)	1,442,388	522,985	1,965,373					1,965,373
Net increase in realized and unrealized appreciation			—	4,443,257				4,443,257
Other	95,349	1,697,341	1,792,690		$14,325			1,807,015
Total increases	30,449,395	3,155,107	33,604,502	5,271,775	14,325		504,645	39,395,247
Decreases:								
Expenditures (including $594,458 of funded depreciation)	(29,659,647)	(1,605,843)	(31,265,490)				594,458	(30,671,032)
Depreciation (Note A)			—			$ (856,272)		(856,272)
Total decreases	(29,659,647)	(1,605,843)	(31,265,490)			(856,272)	594,458	(31,527,304)
Net change before transfers	789,748	1,549,264	2,339,012	5,271,775	14,325	(856,272)	1,099,103	7,867,943
Transfers — additions (deductions):								
Transfers to unrestricted funds	(36,375)	36,375	—					—
Transfers to endowment and similar funds	(455)	(225,107)	(225,562)	225,562				—
Transfers to plant fund		(1,290,000)	(1,290,000)				1,290,000	—
Plant asset additions			—			1,597,499	(1,597,499)	—
Total transfers	(36,830)	(1,478,732)	(1,515,562)	225,562		1,597,499	(307,499)	—
Change in fund balance for the year	752,918	70,532	823,450	5,497,337	14,325	741,227	791,604	7,867,943
Fund balance, December 31, 1979	2,061,908	3,040,071	5,101,979	36,456,954	49,310	17,400,046	2,855,761	61,864,050
Fund balance, December 31, 1980	$ 2,814,826	$ 3,110,603	$ 5,925,429	$41,954,291	$63,635	$18,141,273	$3,647,365	$69,731,993
1979								
Increases:								
Gifts, grants, and contracts:								
Government	$25,629,474		$25,629,474					$25,629,474
Nongovernment	1,967,492	$ 880,601	2,848,093	$ 46,598			$1,625,000	4,519,691
Endowment and similar funds investment income (Note D)	1,402,443	517,781	1,920,224					1,920,224
Net increase in realized and unrealized appreciation			—	1,376,706				1,376,706
Other		1,225,811	1,225,811		$ 3,446			1,229,257
Total increases	28,999,409	2,624,193	31,623,602	1,423,304	3,446		1,625,000	34,675,352
Decreases:								
Expenditures (including $586,213 of funded depreciation)	(28,432,546)	(1,506,109)	(29,938,655)				586,213	(29,352,442)
Depreciation (Note A)			—			$ (819,660)		(819,660)
Total decreases	(28,432,546)	(1,506,109)	(29,938,655)			(819,660)	586,213	(30,172,102)
Net change before transfers	566,863	1,118,084	1,684,947	1,423,304	3,446	(819,660)	2,211,213	4,503,250
Transfers — additions (deductions):								
Transfers to endowment and similar funds	(308)		(308)	308				—
Transfers to plant fund		(250,000)	(250,000)				250,000	—
Plant asset additions			—			694,782	(694,782)	—
Total transfers	(308)	(250,000)	(250,308)	308		694,782	(444,782)	—
Change in fund balance for the year	566,555	868,084	1,434,639	1,423,612	3,446	(124,878)	1,766,431	4,503,250
Fund balance, December 31, 1978	1,495,353	2,171,987	3,667,340	35,033,342	45,864	17,524,924	1,089,330	57,360,800
Fund balance, December 31, 1979	$ 2,061,908	$3,040,071	$ 5,101,979	$36,456,954	$49,310	$17,400,046	$2,855,761	$61,864,050

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

Notes to Financial Statements

A. Summary of Significant Accounting Policies:

Fund Accounting

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

Investments

Investments in securities are stated at market value determined as follows: securities traded on a national securities exchange are valued at the last reported sales price on the last business day of the year; securities traded in the over-the-counter market and listed securities for which no sales prices were reported on that day are valued at closing bid prices. Investments for which a readily determinable market value cannot be established are stated at 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. Realized and unrealized gains and losses are attributed to the principal balance of the funds involved.

The Institution follows the accrual basis of accounting except that endowment and similar fund 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 recognized as related costs are incurred. Beginning with fiscal 1978, the Institution has negotiated with the government fixed rates for the recovery of certain indirect costs. Such recoveries are subject to carryforward provisions that provide for an adjustment to be included in negotiation of future fixed rates.

Gifts

Gifts are recorded in the applicable funds when received. Noncash gifts are generally recorded at market value on the date of gift although certain noncash gifts for which a readily determinable market value cannot be established are recorded at a nominal value of $1 until such time as the value becomes known. Unrestricted gifts are recognized as revenue when received and restricted gifts are recognized as revenue as they are expended for their stated purposes.

Plant

Plant assets are stated at cost. Depreciation is provided at annual rates of 2% to 5% on buildings, 3 ⅓% on Atlantis II and 5% to 33 ⅓% on equipment. Depreciation expense on Institution-purchased plant assets amounting to $594,458 in 1980 and $586,213 in 1979 has been charged to operating expenses. Depreciation on certain government funded facilities (Atlantis II, Laboratory for Marine Science and the dock facility, amounting to $261,814 in each year) is accounted for as a direct reduction of the plant asset and invested in plant fund. Title to the research vessel Atlantis II is contingent upon its continued use for oceanographic research.

The Institution consolidates available cash from the Plant Fund with other cash in the Current Fund for investment.

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.

Reclassification of 1979 Balances

Certain balances in the 1979 financial statements have been reclassified to conform with the 1980 presentation.

B. Endowment and Similar Fund Investments:

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

	December 31, 1980 Cost	December 31, 1980 Market	December 31, 1979 Cost	December 31, 1979 Market
Separately invested:				
Government and government agencies	$ 2,193,065	$ 1,734,250	$ 2,520,228	$ 2,177,000
Bonds	4,580,691	4,088,751	3,308,747	2,999,000
Common stocks	10,583,332	14,120,000	11,785,518	12,602,100
Cash	79,981	79,981	66,563	66,563
Total separately invested	**17,437,069**	**20,022,982**	**17,681,056**	**17,844,663**
Pooled investments:				
Pool A				
Government and government agencies	2,141,275	1,962,000	2,209,548	2,023,000
Bonds	2,859,328	2,412,426	2,060,573	1,837,000
Common stocks	7,859,838	10,310,447	8,556,255	9,328,403
Real estate	39,733	39,733	42,775	42,775
Cash	249,840	249,840	139,229	139,229
	13,150,014	14,974,446	13,008,380	13,370,407
Pool B				
Government and government agencies	1,840,550	1,567,500	1,719,969	1,528,000
Bonds	824,410	732,700	596,573	523,000
Common stocks	3,542,946	4,433,600	2,981,382	3,157,848
Cash	220,020	220,020	32,896	32,896
	6,427,926	6,953,820	5,330,820	5,241,744
Total pooled investments	**19,577,940**	**21,928,266**	**18,339,200**	**18,612,151**
Total investments	**$37,015,009**	**$41,951,248**	**$36,020,256**	**$36,456,814**

C. Pooled Investment Units:

The value of a pooled investment unit was as follows:

	Pool A	Pool B
December 31, 1980	$.9749	$.9312
December 31, 1979	$.8724	$.8329

The pooled investment income per unit was as follows:

	Pool A	Pool B
1980	$.0468	$.0446
1979	$.0450	$.0522

D. Endowment and Similar Fund Income:

Income of endowment and similar funds consisted of the following:

	1980	1979
Dividends	$1,059,791	$1,020,275
Interest	972,031	973,277
Other	2,994	2,994
	2,034,816	1,996,546
Investment management costs	(69,443)	(76,322)
Net investment income	$1,965,373	$1,920,224

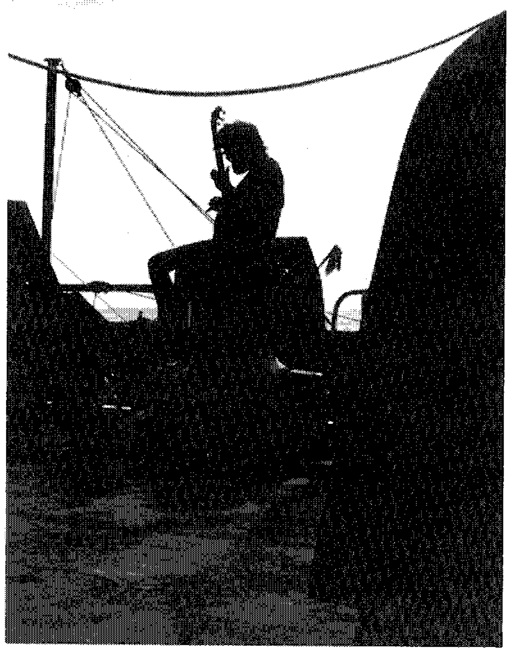
E. Retirement Plan:

The Institution has a noncontributory defined benefit trusteed retirement plan covering substantially all full-time employees. The Institution's policy is to fund pension cost accrued which includes amortization of prior service costs over a 30-year period. Retirement plan costs charged to operating expense amounted to $2,011,000 in 1980 and $1,765,000 in 1979, including $131,000 and $85,000, respectively, relating to expenses of the retirement trust. As of the most recent valuation date, (January 1, 1980) the comparison of accumulated plan benefits and plan net assets is as follows:

Actuarial present value of accumulated plan benefits:	
Vested	$13,428,566
Nonvested	205,088
	$13,633,654
Net assets available for plan benefits	$13,136,065

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

TOM BOLMER



Third Mate Denis Howard and banjo on *Knorr* 80.

SHELLEY LAUZON

R/V *Knorr* begins test cruise for Transient Tracers program.

TOM BOLMER

Tommy O'Brien catches up on paper work on *Knorr* 80.