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Cover:
Further work on the warm water vents first seen on the Galapagos Rift in 1977 and the discovery this year of hot water "smokers" on the East Pacific Rise have provided considerable excitement among oceanographers. The unusual animal communities surrounding the Galapagos vents and also found on the East Pacific Rise are represented on the cover by a photograph of the remarkable tube worms, the Vestimentifera, taken by Jack Donnelly, head of the *Alvin* group. The black smoker was photographed by Associate Scientist Bob Ballard, whose discussion of the discoveries begins on page 8. The embossed representation of *Alvin* was designed by Yeorgos Lampathakis, Art Director for Television and Educational Films of the National Geographic Society. It appeared on invitations to previews of a National Geographic/WQED-TV television special entitled "Dive to the Edge of Creation" aired on public television 8 January 1980. It is used here with the permission of the National Geographic Society and the Gulf Oil Corporation, underwriter of the television program.

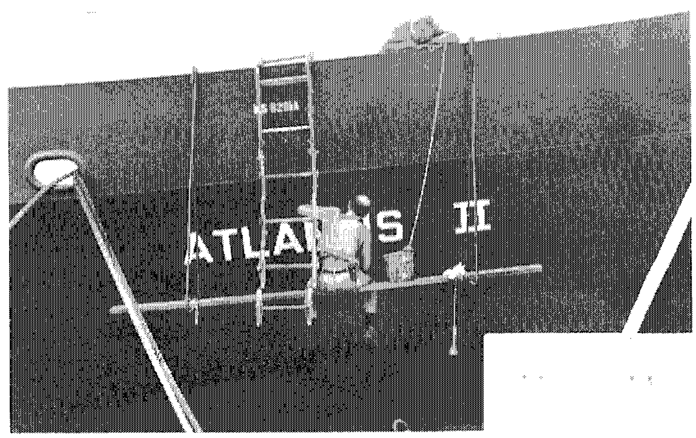
Annual Report 1979:
Vicky Cullen, Editor
Leyden Press, Plymouth, MA, Printer

VICKY CULLEN

Woods Hole pier, two ships in.

DAVID HOSOM, BENTHOS

George Tupper steadies a grapnel aboard *Oceanus*.



VICKY CULLEN

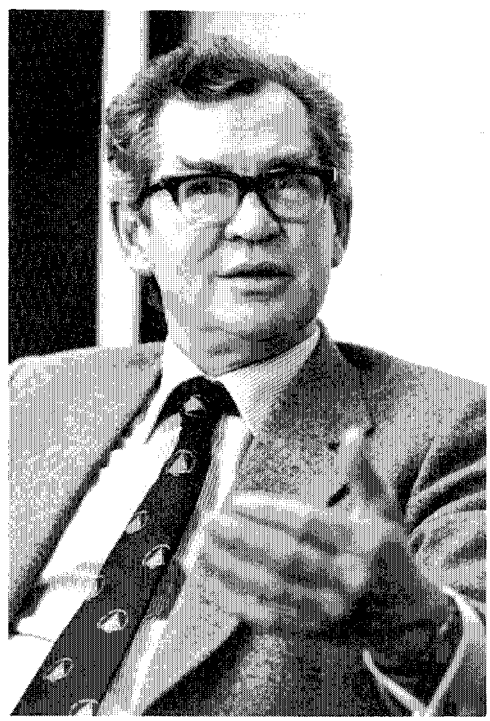
Tom Sheeran does some *Atlantis II* sprucing up with moral support from Millard Klinke.

Director's Comments

IN September 1979 we invited distinguished representatives of science and industry to advise us on plans for the future of the Institution. A major concern was how the structure of the Institution relates to the structure of the science — how do we produce a pattern in the management within our institutional society that can capture the opportunities of oceanography in the future?

Our subject is a microcosm of all the scientific disciplines — this is its fascination and also the source of problems in organization, both inside and outside the Institution. At one extreme we have geology and geophysics with its encompassing paradigm of plate tectonics providing an intellectual foundation for major cooperative endeavours on a massive international scale. The Institution plays a significant role in this work, but the organization of this research is, rightly, at a national level. At the other extreme we have marine biology still searching for a new paradigm to integrate the field and, in the meantime, producing such fascinating examples as the Galapagos benthic ecosystem. These and other studies are like a set of caricatures emphasizing some new features of ecology, ignoring others, but dependent on a knowledge of the physical and chemical environment within which they exist. Physical oceanography is intermediate with major, but still partial, insights into the fine structure, the mesoscale, and the whole ocean processes. Can these different scales be integrated? Is the problem merely technical (computing needs) or (as with meteorology) are there basic conceptual barriers dividing the field between the short-term, small-scale ocean "weather" and the larger and longer processes of ocean "climate?"

We have in oceanography not only a division between disciplines, but each aspect has its own different location in the cycle of integration (of paradigms and caricatures). It may be that in a few years we shall have a new coherence in biology and a fragmentation in geophysics as we search more deeply for the underlying causes of phenomena in both fields. We cannot predict these futures (it would not be science if we could), so nationally and institutionally we must create patterns of management which reflect the present and potential achievement. We must not be so rigid as to prevent the diversity of caricatures nor so unstructured that we cannot cope with major paradigms. At the same time we have a new dimension in the social implications of our work which adds to the excitement but complicates the management. How do we produce a managerial structure which adequately mirrors the intellectual and social maps? Much of this organization has to be considered at the national or international level, but for our future in the Institution we should assay the task of presenting a comparable diversity within our own community. These general questions formed the context of discussions with the Advisory Committee. The Committee approved the general concern with societal problems and supported increasing involvement by the Institution in the three areas of biochemistry, coastal research, and theoretical studies. These initiatives should complement and not weaken the Departments, which should participate fully in the planning. The Committee stressed that a crucial factor will be the intellectual leadership for these initiatives. This must be strong enough to give directions but be guided by advice drawn from the Institution as a whole.



LARRY CAGLE, THE STATE

John H. Steele
Director

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. Among the research interests of Institution biologists are microbiology, planktonology, benthic biology, physiology, aquaculture, and pollution. 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 a salt marsh ecosystem, and there are research projects on aquaculture and waste water recycling and on the productivity of a salmon river in Canada.

Chemistry

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 oceans 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.

Geology & Geophysics

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

Ocean Engineering

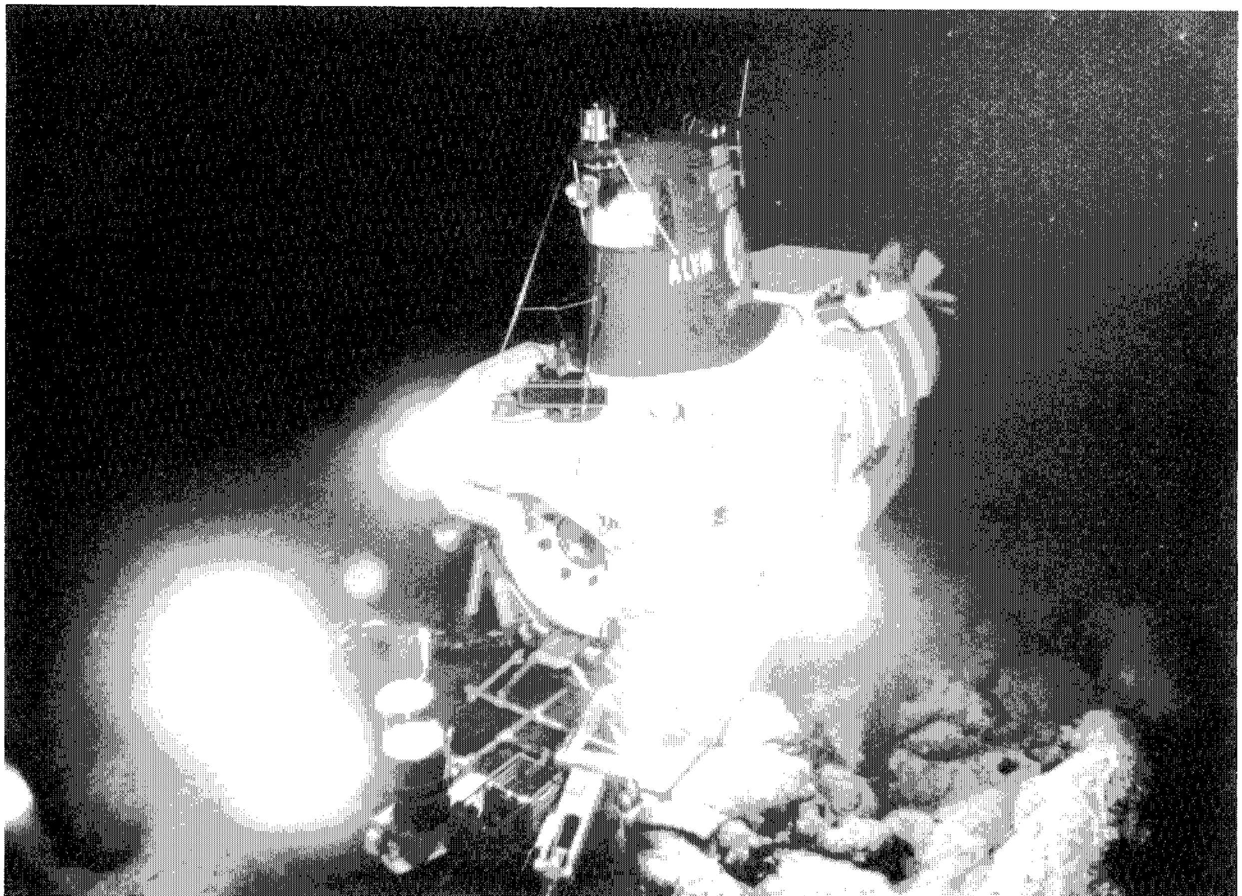
THE solution of engineering problems in the ocean requires an interdisciplinary approach utilizing both traditional engineering concepts, from the fields of mechanical, electrical, civil, and chemical engineering as well as naval architecture, and principles of physics and oceanography. This interdisciplinary approach is reflected in the wide variety of research topics being investigated by members of the Ocean Engineering Department. Development of instruments for use in the hostile marine environment and their refinement for reliability, accuracy, and endurance are among the important topics being investigated. Laser and acoustic technolgies are being applied to the study of turbulence and sediment transport in order to provide high quality data sets for these processes. The Department has several programs in both high and low frequency acoustics. The influence of temporal and spatial variations in temperature, density, and other factors on sound propagation in seawater is being studied. Sound waves are employed to detect and measure organisms, physical properties, and pollutants in the water. The measurement programs are complemented by theoretical analysis and modeling of important processes affecting surface and internal wave behavior, shallow water coastal currents, and sediment transport. The Ocean Engineering Department also provides singular services to the oceanographic community: the *Alvin* group offers a unique scientific window to study the depths of the ocean; the computer group is responsible for much of the development and maintenance of sea-going and land-based computer facilities at the Institution.

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 is 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.

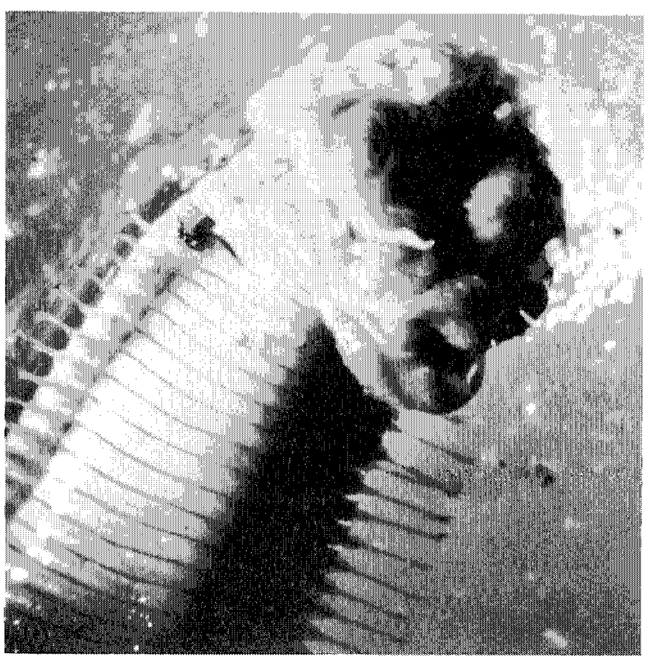
Marine Policy and Ocean Management

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.



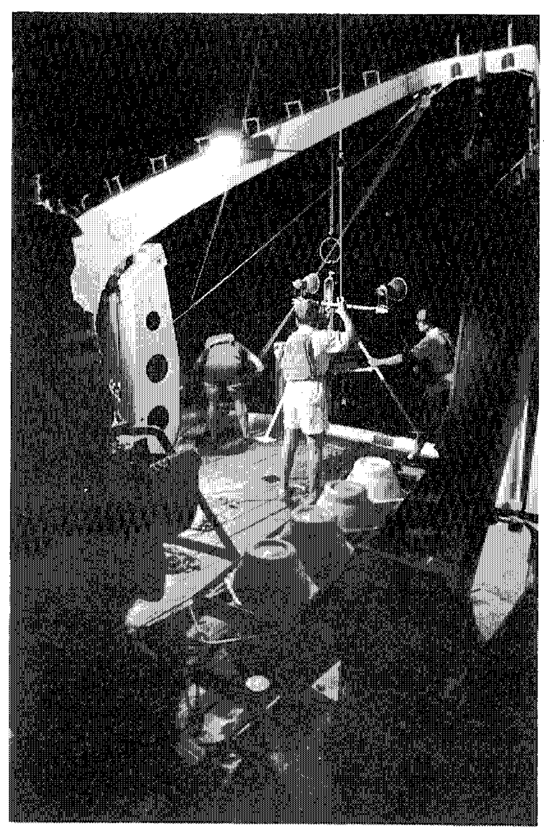
EMORY KRISTOF AND ALVIN CHANDLER · NGS

Alvin was photographed near a Galapagos vent at a depth of more than 2,000 meters by a National Geographic camera.



NATIONAL GEOGRAPHIC SOCIETY

The "Pompeii worm," which cements its tube near the hot chimneys on the East Pacific Rise, has been named *Alvinella pompejana.*



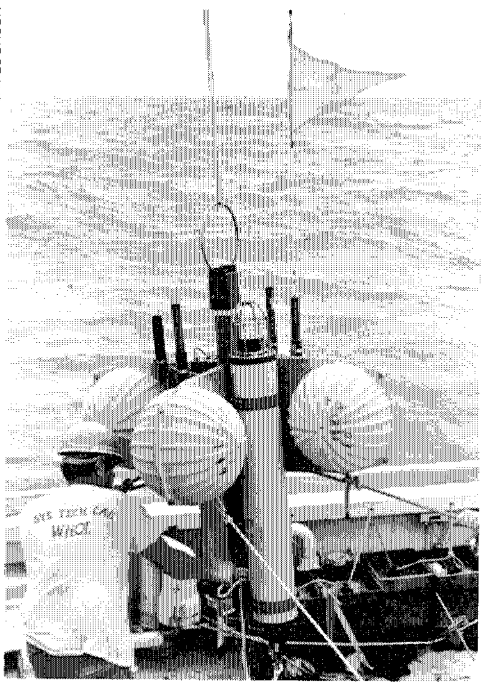
ALLEN GUNDERSON

Remote control movie camera is launched from R/V *Gilliss* for filming *Alvin* at work in the vent area as part of a National Geographic TV special.

SHELLEY LAUZON

Randy Goodlett and Polly Vermersch tend tanks containing stressed phytoplankton communities at the Environmental Systems Laboratory.

JAMES BRODA



Butch Grant readies ocean bottom hydrophone for launch from *Atlantis II*.

JAMES DOUTT

A.B. Gordon Coltharp and Dick Nowak aboard *Oceanus*.

STUDIES of the ocean environment are advancing on many fronts, and in this annual report we present a snapshot of our progress on a few of these.

Since the introduction of the concept of sea floor spreading, the nature of the earth's crust and the processes operating to form new crust at spreading centers have been subjects of intense interest. During the last two years, exploration of some of the fastest spreading centers on the East Pacific Rise have led to a major increase in our understanding of these phenomena. However, these studies, which are being conducted in cooperation with scientists from the Scripps Institution of Oceanography, Oregon State University, Massachusetts Institute of Technology, and other institutions, have much broader significance than was originally anticipated. The discovery of hydrothermal vents issuing hot sulphur- and mineral-rich water from the sea floor, surrounded by and supporting oases of life and depositing mineral ores on the sea floor, has opened a door through which marine biologists and chemists are finding a wealth of new information.

The existence of a whole ecosystem based on chemosynthetic production of life is both exciting and important in the opportunities that it presents. However, bacterial processes, the bacterial production of life, and the bacterial degradation of organic matter in the ocean have long been recognized as important phenomena affecting the composition of the ocean and the life in it, and in this report we present an overview of some of our recent studies in this field.

One of the most important tools that we can use to understand processes involved in the formation of the earth's crust is seismology. We are currently participating in a major multi-institutional program, Project ROSE, that is designed to provide detailed quantitative knowledge of the structure of the crust under a mid-ocean ridge spreading center. The field phase of this program has been successfully completed, and after study of the high quality results we expect to make very significant strides in our understanding of the driving mechanisms of plate tectonics, which, in turn, will provide critical input to subjects such as earthquake prediction.

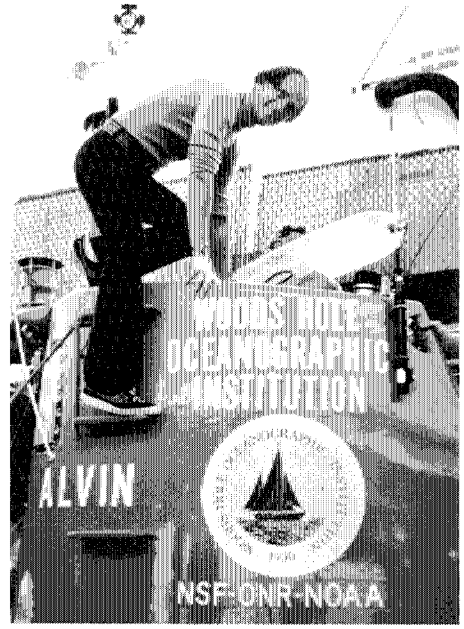
An understanding of the motions of ocean water is no less important to us than the motions of the crust. The ocean has been described as the "flywheel" of the earth's weather and climate system, but we do not yet know how this flywheel works. We do know that the ocean and atmosphere exchange energy, momentum, and materials and that transport within the ocean is very slow compared with the atmosphere. The uptake of heat by the ocean in equatorial regions, its transport to high latitudes by ocean currents and its release back to the atmosphere is just one example of an ocean-atmosphere interaction that we must understand before we can solve the riddle of the flywheel. In this report we present three brief accounts that illustrate some aspects of our work on ocean heat transport in the North Atlantic Ocean, take an interesting look at the progress in our knowledge of a major ocean current system since the last century, and present a description of the development of an important new tool, "acoustic tomography," that we anticipate will play a major role in our future understanding of the motions of the world's oceans.

In recent years, developments in analytical technology have given us the opportunity to take a much closer look at the details of our ocean world. In the area of marine organic geochemistry, the progress has been particularly rapid. Organic matter in the ocean is produced by and utilized by marine organisms, but our studies are revealing that significant quantities of the organic matter in the ocean are derived from terrestrial sources and that, to an increasing extent, the marine environment is being invaded by anthropogenic substances. The last presentation provides a glimpse of our studies on one of the least known aspects of organic matter in seawater, the volatile substances.

Derek Spencer
Associate Director for Research

Hydrothermal Vents on the Galapagos Rift and the East Pacific Rise

Robert Ballard



AL GIDDINGS, SEA FILMS, INC

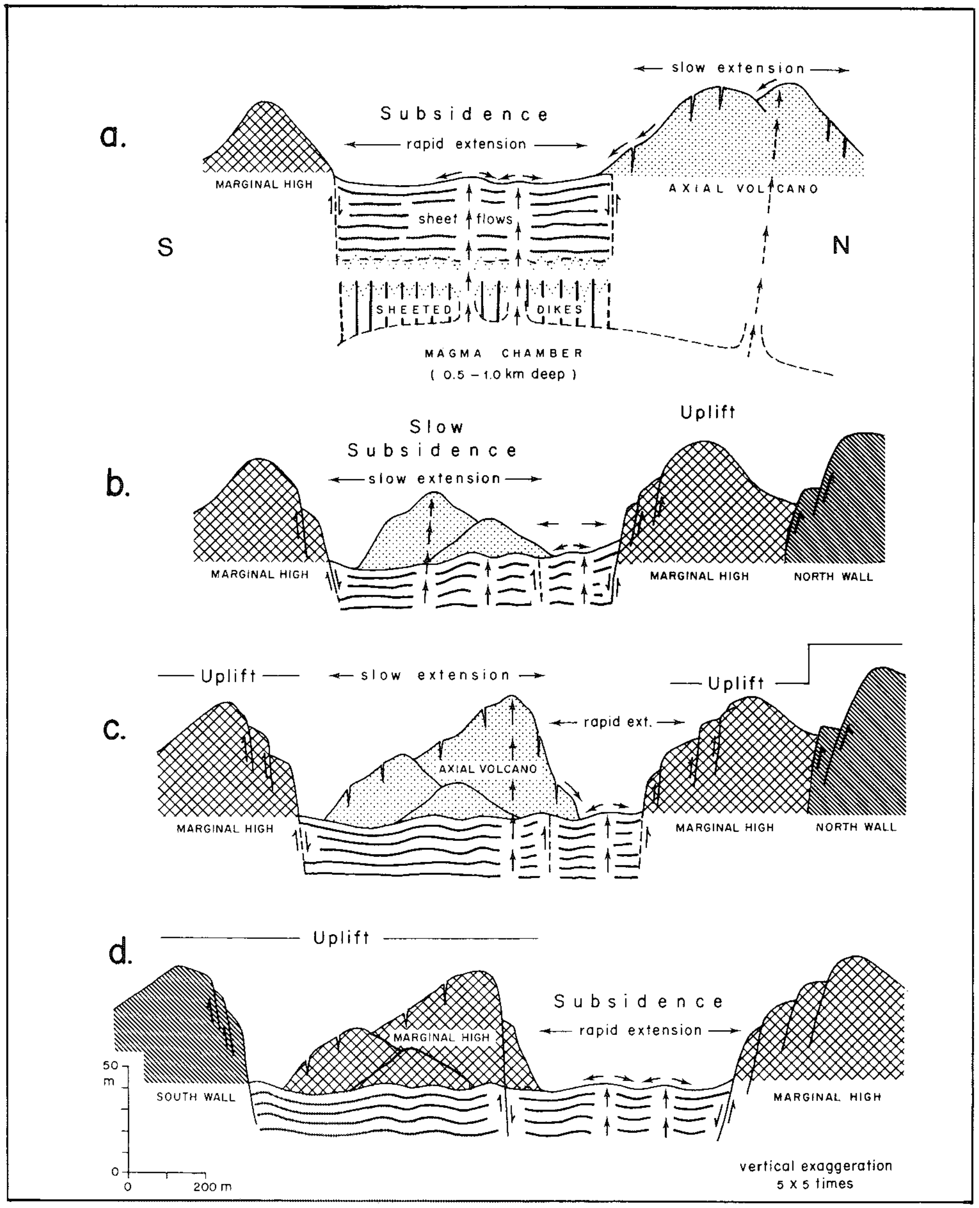
Bob Ballard

In early 1979 a major oceanographic expedition took an interdisciplinary and interinstitutional group of scientists to the Galapagos Rift where warm water vents and their attendant communities of unusual marine life were first found in 1977. Once the vent area was relocated, the three legs of the voyage were devoted in succession chiefly to biology, geology, and chemistry. A total of 29 *Alvin* dives were made in January, February, and March, and some 80,000 photographs were taken with the towed camera sled, ANGUS, in the Galapagos research area.

Succeeding work with *Alvin* and ANGUS on the East Pacific Rise at 21° north, where theory indicated additional vents should be found, brought a new set of scientific surprises. Here the vents emitted not only the milky, precipitate-laden water we had found at the Galapagos sites but also dense clouds of black and white mineral-laden water, and water temperatures soared as high as 400°C (750°F). These vents surely hold one of the keys to understanding the emplacement of metal deposits on the earth. Animal communities similar to those on the Galapagos Rift were also seen clustered around the cooler of these vents.

Geologically, the key to understanding the origin of the vents lies in understanding the volcanic and tectonic evolution of the rift valley itself. Analysis of data and observations from explorations on the mid-ocean rift system that began in the early seventies with work on the Mid-Atlantic Ridge (Project FAMOUS, French-American Mid-Ocean Undersea Study) has allowed us to begin to construct an evolutionary model. The eruptive cycle begins with the outpouring from a sub-sea-floor magma chamber of massive lava flows which flood the depressions of the inner rift (A in figure). As the volcanic activity begins to wane and channelization develops in the lava lakes, more discrete pillow flows occur (B), and this leads to the formation of a new axial volcanic ridge similar to that observed in the slow-spreading (one to two centimeters per year) centers such as the FAMOUS area. In faster spreading areas, such as the Galapagos Rift which moves about six centimeters per year, the ridge is flanked by slightly older lava lakes (C and D).

The lava lakes themselves contain a highly varied morphology compared to the relatively uniform pillow highs. Due



Rift valley evolutionary model

to drainback into the sub-surface plumbing, a shallow magma chamber, or lateral drainage, large craters develop in the lake surface and contain folded, blocky, and frequently whorled lava surfaces. The walls of the drainback craters are coated with a delicate sequence of horizontal ribs which appear to be "bath-tub rings" formed as the lake surface subsides. Tall, impressive pillars found around the lake margins are cooled by the vertical escape of water through the margins of the flow —when knocked over by *Alvin*, the pillars are found to be hollow, glass-lined chimneys.

Clearly, the entire mid-ocean ridge system is not in the same stage of development along its entire length at any one time. Though only five kilometers of rift valley axis were traversed in 1977, a clear age gradient could be seen. An eastern extrusive axis dominated by maturely fissured pillow terrain grades westward into younger volcanic terrain dominated by unfissured sheet flows and extensive lava lakes. All five active hydrothermal vents located in the inner rift valley are situated along a wedge of fissures cutting into this young volcanic zone. Additional evidence of the age gradient was collected as our observations were extended both east and west during the work in 1979 when an additional 15 kilometers of rift valley were mapped with ANGUS and selected features were further investigated with *Alvin*.

A similar program was undertaken at 21°N on the East Pacific Rise in April and May of 1979. The age gradient was again clearly in evidence, and 25 active hydrothermal vent fields were located within the young extrusive zone along a strip seven kilometers long and only 200 to 300 meters wide. As in the case of the Galapagos Rift, the temperature of the vent water also increases along this gradient, although the 23°C (73°F) maximum that seemed high in the Galapagos vents was dwarfed by the very high temperatures on the East Pacific Rise.

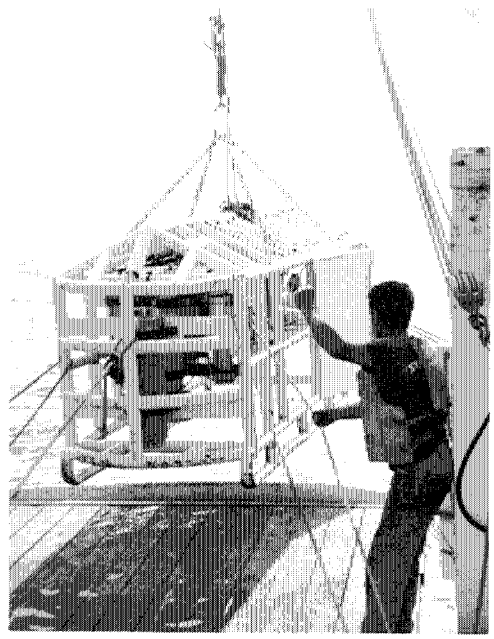
Both Galapagos-style warm vents and sulfide-mound, high-temperature vents were found at 21°N. The Galapagos-style vents emit warm water from hairline cracks and small fissures in the pillow ridge terrain over a horizontal zone 10 to 30 meters across. Their flow rates are on the order of centimeters per second. The fauna associated with these vent areas (see Fred Grassle's contribution below) are their most visible feature. In contrast, the sulfide-mound, hot-water vents are most notable for their geological attributes. The water flows out at rate of several meters per second through a limited number of discrete chimneys or stacks superposed on basal mounds built directly on fresh basalt pillows or flows. The basal structures are oxidized to colors of ochre, orange, and black, and their overall dimensions range up to 15 by 30 meters laterally. They are honeycombed with burrowlike channels suggesting the possibility that they preserve molds of preexisting worm tubes. Vent constructions one to five meters high rise above the base mound elevations of two meters or more, and hydrothermal effects (staining, organisms, manganese coatings) extend tens of meters away from the vents. Actively forming massive sulfide deposits occur within the vent chimneys at high temperature springs, while inactive sulfide mound deposits occur slightly off-axis from the cooler vents. Mineral deposits include sphalerite, pyrite, chalcopyrite (and other iron, copper, and zinc sulfides), anhydrite, sulfur, barite, opal, and talc. The chimneys exhibit a distinct concentric zoning of sulfide minerals which suggests episodicity in the physical and chemical properties of the vents.

Future research plans include returns to the Galapagos and East Pacific Rise areas toward a better delineation of such features as the age gradients — it is expected that the sequence of terrain traveling down the rift valley axis should pass from one center of young volcanic activity through older terrain and back into another active area. No study so far has investigated a sufficient length of the rift valley to observe the total wave length of this predicted cycle.

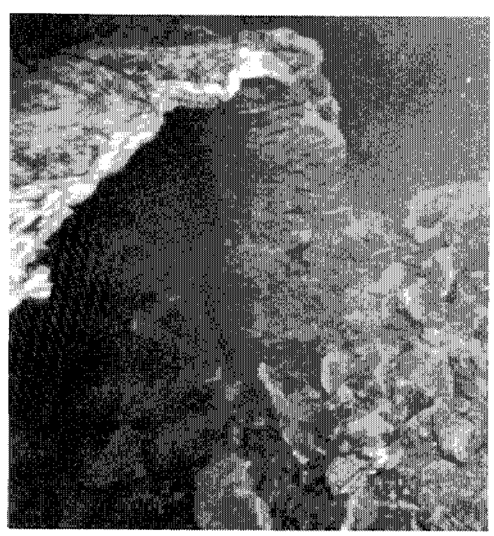
So far we have explored only about 40 kilometers of the 60,000 kilometer mid-ocean ridge system, and we have looked only at slow and medium rate spreading centers. The fast spreading centers, which move about 17 centimeters per year, such as the one near Easter Island we are planning to begin exploring in 1980, may hold new exciting discoveries.


ANGUS

Whorled lava surfaces were found on drainback craters.


KATHLEEN CRANE

The ANGUS camera is ready for launch during Galapagos exploration.

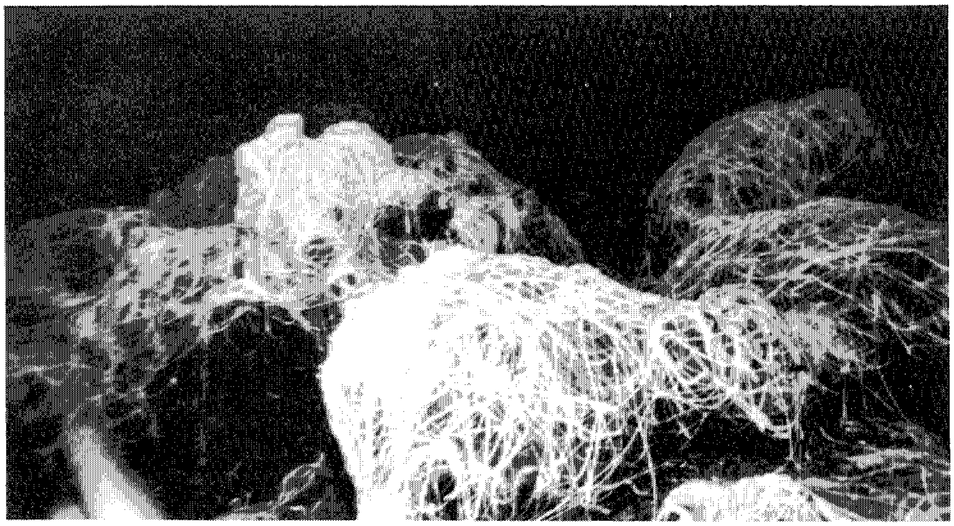

JOHN EDMOND, MIT

Bent over pillar once allowed vertical escape of water from beneath lava lake margin.

Hydrothermal Vent Ecosystems

J. Frederick Grassle

JAMES CHILDRESS, UC-SB



"Spaghetti" were found to be enteropneusts.

KATHLEEN CRANE

This field of Vestimentifera was photographed at the vent known as "Rose Garden."

ROBERT HESSLER, SIO

"Dandelions," found to be siphonophores, are seen here with clam and mussel shells.

THE discovery by geologists in 1977 of unusual life forms around the warm-water vents at the Galapagos spreading center led to a series of visits by biologists in January/February and December 1979. The expedition participants from nearly a dozen institutions included microbiologists, biochemists, physiologists, geneticists, ecologists, and specialists in the various animal groups. Because of the high density of large animals and high productivity of microorganisms, we were able to accomplish some of the first cooperative studies of a full range of biological processes in the deep sea. With *Alvin* we could collect and bring to the surface living animals and microorganisms in good condition for futher studies in the laboratory. *Alvin's* manipulators enabled us to place experiments for studies of metabolic rates, growth, and colonization.

A series of microbiological collections and experiments confirmed that bacteria are the primary producers of what may be described as a new kind of ecosystem. The vent animals live directly or indirectly on bacterial food produced from hydrogen sulfide, carbon dioxide, and oxygen in the vent water. Cell counts in the rapidly mixing water above the vents average 5×10^5 to 10^6 per milliliter. The analysis of ATP, an indirect measure of metabolically active biomass, indicated productivities two to four times higher than in the photosynthetically productive surface waters and two to three orders of magnitude higher than in a control sample taken near the bottom but some distance away from the vents.

We were able to identify a number of remarkable animals previously known only from photographs taken in 1977. The white "spaghetti" proved to be enteropneusts, wormlike relatives of the early ancestors of vertebrates, normally found living in sediments. Fragile yellowish balls suspended just above the bottom and nicknamed "dandelions" in 1977 proved very difficult to collect, but a single intact specimen was ultimately collected with a specially developed slurp gun. It was found to be a benthic siphonophore (a relative of the Portuguese man-of-war) belonging to the family Rhodaliidae. Although members of this group were first collected during the Challenger Expedition (1872-76), they have seldom been collected whole and have been assumed to occur in the water column above the bottom.

A new family of crab was collected in large numbers for physiological studies, and several were kept alive for almost three months after the January/February expedition. Studies of their metabolic rates at different temperatures and pressures indicate they need pressures of at least 125 atmospheres to survive and are killed at about 400 atmospheres. Their metabolic rates are similar to those of shallow-living crabs at comparable temperatures. The Galapagos crabs are able to remove oxygen from water at very low partial pressures, so they probably rely largely on aerobic (oxygen-dependent) metabolism in the vent waters. The upper temperature limit for the crabs is greater than 22°C at *in situ* pressures.

Many shells of the large white clam were found around dead vents. Living specimens were observed nestled among the large mussels surrounding live vents, but they were never abundant. Clams collected thus far range up to 264 millimeters (10 inches) in length. The anatomy of the large clam places it in the family Vesicomyidae, genus *Calyptogena.* Thorium-228/radium-228 activity ratios have been used to estimate the age of a 22-centimeter-long clam at less than 10 years.

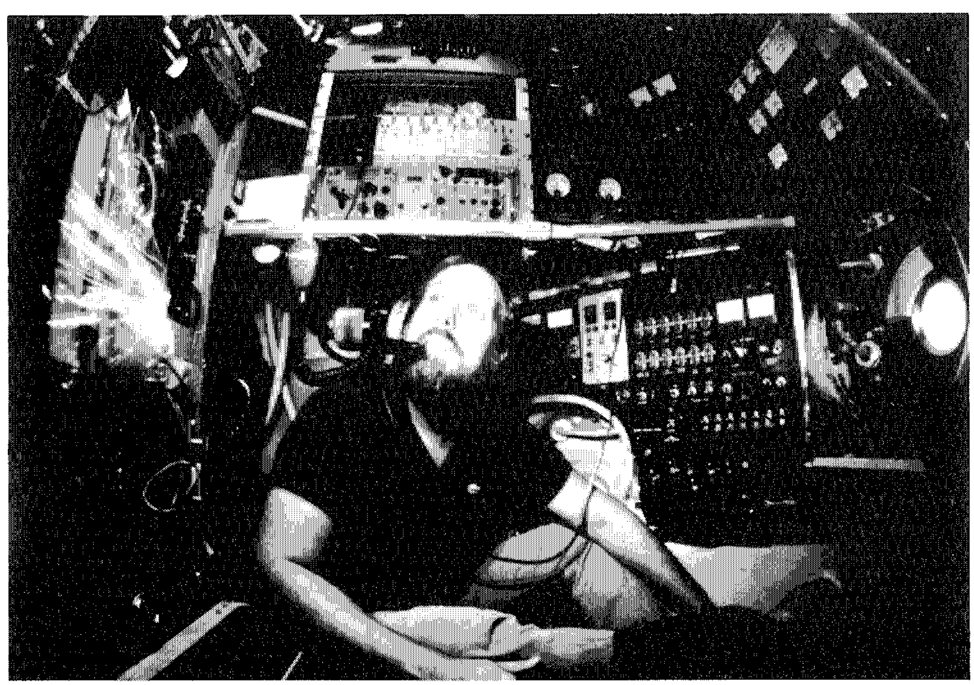
The brilliantly red-plumed worm is another new family in a very unusual class, the Vestimentifera, first discovered in 1966 off California. The adaptations, morphology, and taxonomic relations of these giant worms are the subject of intense investigation. They have no gut and may live directly on the organic soup emanating from the vents. They also have an unusual metabolism, perhaps related to the large amounts of hydrogen sulfide in the water. Specimens ranging from 45 to 76 centimeters (17 to 30 inches) were collected in 1977. The tube of the largest animal collected in 1979 measured 2.6 meters (8.5 feet) and its body after preservation was 1.5 meters (5 feet) long and about 5 centimeters (2 inches) in diameter.

Numerous smaller animals were also obtained, and many of them promise to be as interesting as the larger ones collected. One, a small shrimplike Leptostracan crustacean, has comblike structures at the end of its eyestalks where eyes would normally be. This sort of eyestalk modification has never been observed in other crustaceans. The combs are probably used to scrape food in the form of microorganisms from the hard rock and mussel surfaces. There are also new families of limpets including at least one filter feeder whose nearest relatives lived in the Paleozoic era.

For reasons not clearly understood, each species occurs at a different distance from the vents. Pillow lava formations farthest from the vents are largely barren except for occasional corals, anemones, or sea cucumbers. Approaching a vent, crabs, enteropneusts, and dandelions appear. Then clam beds, mussels, serpulid worms, and large numbers of small anemones are located at intermediate distances. Although the distribution of mussels and crabs extends into the supply of warm water (10 to 15°C, 50 to 59°F, occasionally higher), most of the animals are living at the ambient temperature of 2°C (36°F). The vestimentiferan worms live only in the warm vent water in clusters ranging from a dense field spread along a 50-meter fissure in one vent area (called Rose Garden) to only two or three small individuals in the narrow vent openings at another. The warm water is also the preferred habitat of a pink bythitid fish which is often seen with its head directed down into the vent flow, probably in a feeding posture.

The hydrothermal vents contain a combination of unusual factors, such as elevated temperatures, high pressures, and a unique chemical environment that supports a rich concentration of active sulfur bacteria. Growth and metabolic rates are high compared with other deep-sea regions. The more changeable environment and rich food supply appear to favor species with rapid growth and a relatively short life span.

We still do not know what the larval stages of vent organisms look like or how they find the vents. It appears that vents may last only a few decades so that new vent areas must continually be available for colonization. At least some species must have long-lived planktonic larvae — the discovery of many of the same animals at the high temperature vents on the East Pacific Rise 1,800 miles away indicates that vent communities are likely to be distributed over great distances along ridge axes. The worm encrusting the chimneylike smokers and brought back by geologists from the East Pacific Rise expedition is yet another new family of polychaete worm. Preparations made from material encasing the worms show a dense and fairly uniform microbial population. Plans are underway for a biological expedition to this area in 1981.



AL GIDDINGS, SEA FILMS, INC.

Fred Grassle sits inside *Alvin's* personnel sphere.

Spreading Center Hot Springs: A Geochemist's View

Michael Mottl

GEOCHEMISTS have at least as much reason to be excited over the discovery and sampling of spreading center hot springs as do geologists and biologists for the simple reason that these springs are largely or entirely seawater-fed. The water exiting from the springs was originally ocean water which percolated down through cracks and voids in the newly formed crust. Because the fresh basalt is rubbly and porous, and because deep, tectonically induced fractures are abundant, seawater penetrates deeply into the crust, where it becomes heated by contact with the hot rock. The minerals which make up a basalt rock are not stable in the presence of seawater, so that chemical reactions between the rock and seawater begin as soon as the two come into contact. At the low temperature prevailing on the sea floor these reactions occur extremely slowly, but at the high temperatures reached within the crust they are much more rapid. These reactions result in chemical modification of both the rocks and the seawater as elements are transferred from the basalt minerals into solution and from the now-modified seawater into the more stable alteration minerals which form. Thus, by the time the heated seawater finds its way up to the sea floor again, where it appears as a hot spring, it is chemically no longer seawater. The whole process results in a net transport of some elements, such as magnesium, from the oceans into the crust, while other elements such as calcium, iron, manganese, and silicon are transported from the basaltic crust into the oceans.

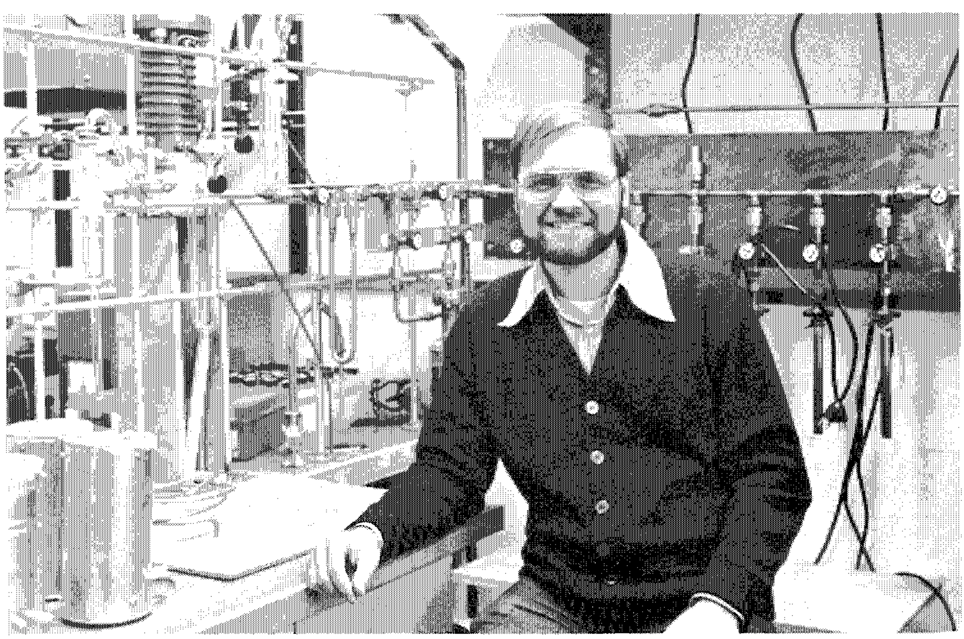
The heat balance for mid-ocean ridges, as derived by geophysicists, strongly suggests that this process occurs on a massive scale and at rates that are fast enough actually to control the chemistry of seawater itself, or at least the concentrations of some of its major components. It has been estimated that the entire volume of the oceans circulates through young oceanic crust every seven million years, and that 20 to 40 percent of the total heat loss from the solid earth occurs by this process, in the form of warm submarine springs.

Besides its importance for the chemistry of seawater and of the oceanic crust, this process has another geochemically interesting aspect: that of submarine metal deposits. Seawater, when heated to high temperatures and chemically modified, has the capacity to leach metals such as iron, manganese, copper, and zinc from the rocks of the crust, along with sulfur, and transport them to the sea floor, where they may precipitate locally as metallic sulfides or oxides, or be carried long distances in bottom waters. This general process of metal transport and deposition by hot, saline solutions (not necessarily seawater) has given rise to one of the most economically important classes of ore deposits mined on land, known as hydrothermal ore deposits. Some of these deposits, such as the copper deposit on Cyprus which has been mined since ancient times, formed on the sea floor and have since been uplifted and exposed. Sampling of submarine hot spring waters and associated deposits provides an opportunity to study the ore-forming process directly, as it happens.

Geoff Thompson and I have been studying various aspects of seawater interaction with the basaltic ocean crust for several years, both in the laboratory and in the field. Our samples have included the entire range of products, from altered rock to solutions to precipitates. The year 1979 was an exceptionally fruitful year for all three types of samples.

The year started auspiciously with a return trip with *Alvin* to the site of the warm springs on the Galapagos Spreading Center first sampled in 1977. John Edmond of MIT collected a few very useful water samples which served to confirm the biggest surprise of the 1977 work: waters from some of the Galapagos vents are significantly depleted in both soldium and chloride relative to seawater. Although the waters are only warm (up to 23°C) as they exit, the relatively low temperature is due to extensive shallow subsurface mixing with normal ocean bottom water, which is only about 2°C. The chemical data indicate that the hot-water end-member was probably at 320 to 380°C just prior to mixing. The sodium and chloride depletions suggest that some of these solutions may have been even hotter (in excess of 500°C) at some time during their journey through the crust, according to a model we have developed based on experimental data. I was pleased to find that, for those vents not showing sodium and chloride depletions, concentrations of 11 of the 14

VICKY CULLEN



Mike Mottl

chemical species analyzed were predicted with a high degree of accuracy by the laboratory experiments I performed a few years ago.

Perhaps the year's most exciting discovery came in May, when *Alvin* and ANGUS located truly *hot* springs for the first time, on the East Pacific Rise at 21°N. These waters are actively precipitating iron, copper, and zinc sulfides in profusion, at 200 to 350°C. The sulfides were sampled by the Scripps group in May, but the waters were too hot to handle. Cliff Winget of the Ocean Engineering Department and I worked with John Edmond of MIT and Dick Holland of Harvard over the summer, and together we came up with a satisfactory technique for sampling the hot waters. This was done successfully in November, on a return trip with *Alvin*. These solutions are presently being analyzed at MIT, along with some 400 pounds of ore-grade sulfide deposits. These solutions do *not* show a chloride depletion.

While Edmond, Holland, and others were diving in *Alvin*, I was aboard *D/V Glomar Challenger* as the sole WHOI representative on Leg 69 of the Deep Sea Drilling Project. We drilled 500 meters (1,640 feet) — 200 meters into basaltic basement — into an active hydrothermal system on six million-year-old crust on the Costa Rica Rift, the easternmost segment of the Galapagos Spreading Center. (During Leg 70, under cochief scientist Dick Von Herzen of WHOI, *Challenger* returned to the same hole and drilled it another 350 meters deeper. It is thus one of the deepest holes into basement ever drilled.) From the portion of the hole drilled on Leg 69, we sampled formation water from basaltic basement for the first time ever: modified seawater circulating through the crust at 70°C. We also made the first direct measurements of the *in situ* permeability of the oceanic crust, these due largely to the perseverance of Roger Anderson of Lamont-Doherty Geological Observatory. I am presently analyzing the solution samples, along with several dozen samples of hydrothermally altered basalt. These samples from deeper in the crust will shed light on internal crustal processes which produce the warm springs at the sea floor.

In the year to come we will be using *Alvin* again, this time to get a closer look at the "guts" of a fossil hydrothermal system exposed in the walls of the Kane Fracture Zone in the Atlantic. We have already recovered hydrothermal quartz containing iron and copper sulfides from this locality, all deposited as veins from hot, modified seawater circulating through cracks in the crust. If 1980 is as revealing as was 1979, we will all be very pleased indeed.

Deep Sea Microbiology

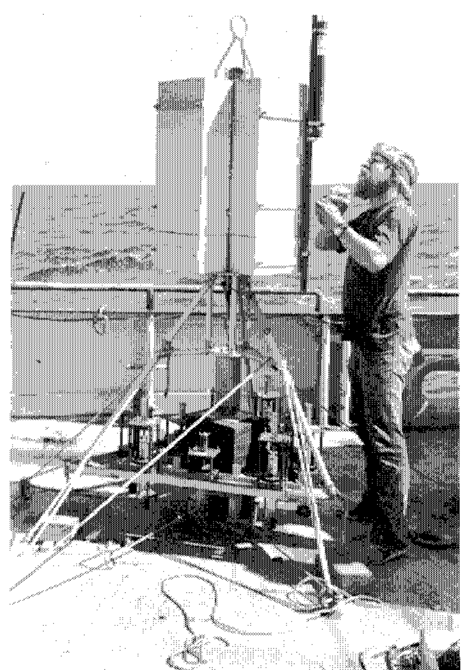
Holger Jannasch

THE oceans represent about 99 percent of the biosphere by volume, and every drop of seawater contains microorganisms. They carry out biochemical transformations of organic and inorganic materials which are essential to the fertility of the oceans. The larger part of this huge volume lies below a depth of 1,000 meters in the dark and is subjected to hydrostatic pressures of 100 atmospheres or more and to very constant temperatures near the freezing point. We are studying the effect of these deep sea conditions on the metabolic activities of marine bacteria. Although their rates of metabolism are generally low in pelagic deep-sea water — as compared, for example, to estuarine waters or soil — the enormous multiplication factor renders these activities fundamentally significant.

Carl Wirsen, Steve Molyneaux, and I, with great help from Craig Taylor and the engineering skills of Kenneth Doherty and Clifford Winget, have developed two major approaches to the study of deep sea microbiology: 1) *in situ* inoculation and incubation of test materials directly on the deep sea floor and 2) laboratory studies on samples which have been retrieved from the deep sea without decompression and without changes of temperature. The *in situ* incubation studies are carried out with the research submersible *Alvin* and with newly developed free-falling and recoverable tripods. During work with *Alvin*, we developed new ideas for the design of automated procedures which can be carried out by unmanned free-falling tripods at practically any depth. These *in situ* experiments are supplemented in the laboratory by detailed studies using pressure-retaining culture vessels.

Based on the proper control experiments carried out at normal pressure, we found that deep sea pressures retard microbial processes considerably. Vice versa, decompression may increase metabolic rates. These results obtained with natural microbial populations are now being followed up with pure culture (single species) studies using a high-pressure chamber we constructed to isolate deep sea bacteria which have never been decompressed.

Complete pressure adaptation, a feature we have not yet demonstrated in bacterial enrichments from deep-sea water and sediments, has been reported elsewhere for an isolate obtained from a



HOLGER JANNASCH

Carl Wirsen prepares recoverable tripod for deep-sea microbiological work.

rotting amphipod. To check the possible activity of such organisms *in situ* we have included an automated trap and growth chamber for amphipods in our tripod experiments. So far, we have noticed interesting qualitative differences between the metabolism of the amphipods as compared to their bacterial gut flora.

Russell Cuhel, a graduate student in our laboratory, does the biochemical fractionations in these deep sea amphipod experiments. His specific thesis research, now entering the last year, deals with the assimilatory sulfur metabolism of marine bacteria with the ultimate aim of assessing the technique of the incorporation of radiolabeled sulfur into proteins as a measure of microbial productivity.

Our decade-old interest and experience in studies of the marine sulfur-oxidizing bacteria became very useful when a thorough investigation of the biological phenomena observed with the recently discovered Galapagos Rift vents was initiated. Data from two 1979 cruises support the hypothesis that the striking animal populations clustered around the vents at a depth of 2,250 meters depend for their fundamental food supply on the bacterial reduction of inorganic carbon to organic matter. This "chemosynthetic" primary production is based on the bacterial oxidation of hydrogen sulfide as the source of energy. This process is equivalent to plant "photosynthesis" based on light as the source of energy. Since hydrogen sulfide is produced geothermically, these deep sea vent communities are the only known ecosystems supported entirely by terrestrial rather than solar energy. Since last fall, Ned Ruby, a postdoctoral investigator, has been working with us on the 200-odd bacterial isolates obtained from the Galapagos Rift vents.

Since it appears to work so well on the deep sea floor, we are running test experiments now in order to find out whether the chemosynthetic production


VICKY CULLEN

Holger Jannasch

of biomass could be useful as single cell protein production and food source for shellfish in aquaculture. Our first efforts in this direction concern the construction of a pilot plant in the Institution's Environmental Systems Laboratory which is well equipped for installing seawater flow systems.

Biomedical Resources of the Sea

Stanley Watson

BACTERIA and invertebrates coexisted on Earth millions of years before the evolution of vertebrates. Since the primary role of bacteria is to decompose organic matter, both living and dead, the primitive invertebrates had to develop immune mechanisms to prevent bacteria from invading their tissues.

Immune systems in humans and other vertebrates have been studied in detail, but little is known about the defense mechanisms of invertebrates. Antibodies in vertebrates serve as the primary defense mechanism. When antibody formation is suppressed, these animals become vulnerable to bacterial attack. Invertebrates do not produce antibodies, yet they are resistant to bacterial diseases. We are studying the immune systems in invertebrates in hopes that some of the findings could be applied in the medical field.

In these studies *Limulus polyphemus* (horseshoe crab), one of the oldest animals on Earth, has served as our primary research tool. Our studies suggest this animal resists bacterial attack by 1) forming a blood clot at the site of bacterial infection, 2) neutralizing toxic compounds excreted by the bacteria, and 3) possessing potential bactericidal agent(s) in the blood.

Studies on the blood clotting mechanism led to the development of a test now widely used in the biomedical field. The clotting of the blood cells in the horseshoe crab is triggered by the presence of lipopolysaccharide (LPS), a component of the cell walls of all gram-negative bacteria. The clotting factors, which can be extracted from the blood cells, contain an enzyme that is activated by LPS; once activated the enzyme acts upon a low molecular weight (23,000) clotting protein cleaving off a polypeptide chain which results in polymerization of the clotting protein. This entire reaction, known as the Limulus amebocyte lysate (LAL) test, can be carried out in a test tube and used to quantitate LPS in solutions.

The early studies on the LAL test were carried out by Drs. Bang and Levin at the Woods Hole Marine Biological Laboratory. Their original LAL test had limited use because of low and variable sensitivity. We increased the sensitivity and lowered the variability of the test by removing an inhibitor, a lipoprotein, from the LAL. With this inhibitor removed 10^{-12} gram (one millionth of a millionth of a gram) of LPS per milliliter can be detected.

The removal of the inhibitor in LAL has made it possible to use this test in the pharmaceutical and medical fields. In the pharmaceutical industry it is used to check LPS contamination in injectable drugs, and in the medical field to determine the concentration of LPS in body fluids such as urine, spinal fluid, and blood.

The need for this test stems from the fact that LPS is one of the most biologically active molecules known to man. When LPS enters the blood stream, it causes a cascading series of events leading to capillary permeability, intravascular clotting, platelet aggregation, pyrogenic reactions, and ultimately death. Because of this toxicity, injectable drugs must be tested to insure that a minimal level of LPS is not exceeded. The LAL test is now widely used for this purpose by pharmaceutical companies.

In the medical field the LAL test can be used to diagnose gram-negative spinal meningitis and some urinary infections. Probably the most important potential use of the LAL test is for the detection of LPS in patients' blood, a condition known as endotoxemia. Many types of patients (e.g., burn and cancer victims) are very susceptible to bacterial infections which often result in endotoxemia. Although endotoxemia is a major cause of death, a reliable diagnostic test for its detection is not available.

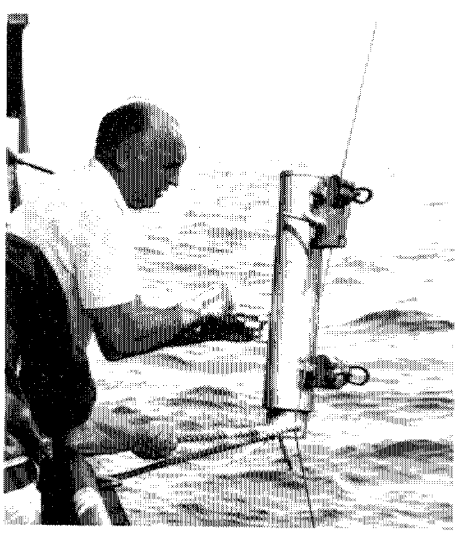
In the past, factors in the blood inhibited the LAL test. Recently we have found ways to inactivate these inhibitors and in the laboratory we are able to quantitate the LPS concentration in blood samples. This method is now undergoing clinical trials to determine if this test can be used routinely in hospitals.

The substances which inhibit the LAL test are present in the blood of both vertebrates and invertebrates. These factors biologically inactivate LPS, providing protection against these toxic molecules. One of these inhibitors is a lipoprotein while the second may be associated with the complement system. These inhibitors can detoxify only limited concentrations of LPS. If the level of LPS in the blood exceeds their inactivating capability, endotoxemia results. At the present time no clinical remedy for endotoxemia exists. If these inhibitors could be isolated and concentrated, possibly they could be used in the treatment of endotoxemia. Future studies will be focused in this direction.

We also studied bactericidal substances which serve as the third immune system in horseshoe crabs and other marine invertebrates. We demonstrated that an extract of horseshoe crab blood killed 90 percent of *Escherichia coli* (a common intestinal bacterium) cells after a 30-minute exposure. This extract also killed many other enteric bacteria as well as some fungi and gram-positive bacteria. Continuing studies will aim at the isolation, purification, and utilization of these bactericidal agents.

It is suspected that additional mechanisms for protection against bacteria may exist in a variety of invertebrate animals. Further studies on these protective mechanisms may have far reaching applications in the field of medicine.

Other scientific disciplines may also gain from basic studies on immune mechanisms found in marine invertebrates. For example, our laboratory has modified the LAL test to estimate bacterial biomass in the ocean. Using this technique we have demonstrated that bacteria comprise a significant fraction of the microbial biomass in the marine environment. We have shown that bacteria within the euphotic zone (upper 100 meters where there is enough light for photosynthesis to take place) comprise 10 to 15 percent of the microbial biomass and below 100 meters bacteria may comprise over 90 percent of the microbial biomass. Employment of the LAL technique, in conjunction with other modern techniques for measuring microbial biomass, has altered previously existing concepts regarding the concentration, distribution, and importance of bacteria in the ocean.



FREDERICA VALOIS

Stan Watson

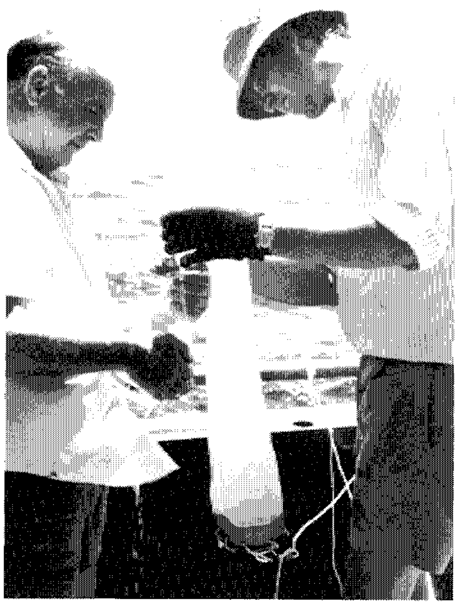
The Discovery, Distribution, and Role in Primary Productivity of a Unicellular, Marine, Planktonic Cyanobacterium

John Waterbury and Stanley Watson

THE cyanobacteria (blue-green algae) are a morphologically diverse group of bacteria that make their living by performing oxygenic photosynthesis* in a wide variety of habitats. They are often important components of fresh water planktonic communities, where as many as 24 genera and over 100 species are known to form extensive blooms. Until the present study, marine planktonic cyanobacteria were thought to be restricted to a few filamentous types, notably *Trichodesmium*. This organism often forms extensive blooms in the tropical oceans and has generated considerable interest because of its reputed ability to fix nitrogen. A portion of our research effort is devoted to the biology of *Trichodesmium*, but this report concerns the discovery of small, unicellular, marine, planktonic cyanobacteria that appear to be not only ubiquitous in marine waters but present in large numbers and responsible for a significant portion of the total primary productivity.

The fact that they have remained undetected can be attributed to their small size (0.7 to 1.5 microns). Conventional light microscopy, even employing phase contrast optics, could not distinguish these small cyanobacteria from the many other bacteria present in seawater. Their discovery was made possible when techniques employing epifluorescence microscopy began to be used extensively for the direct enumeration of bacteria in water samples. During the course of examining acridine orange

*Photosynthetic organisms can be divided into two groups on the basis of the type of photosynthesis they perform. The cyanobacteria and all higher plants perform oxygenic photosynthesis while the photosynthetic green and purple bacteria perform anoxygenic photosynthesis. Both types of photosynthesis rely on light for the generation of energy but differ considerably in other respects.



FREDERICA VALOIS

Stan Watson and John Waterbury adjust "mininet."

preparations for the enumeration of marine bacteria, occasional unstained preparations were examined in an attempt to count small photosynthetic algae. This was possible because the set of excitation and barrier filters employed permitted the visualization of the bright red natural fluorescence of chlorophyll *a*, the primary photosynthetic pigment present in all organisms that perform oxygenic photosynthesis. In addition to eucaryotic algae, many of these unstained preparations contained small spherical bodies, ranging in size between 0.7 and 1.5 microns, which emitted an orange fluorescence quite distinct from that of chlorophyll *a*.

A number of observations suggested that these fluorescent bodies were procaryotic** organisms: cell morphology, size, division by binary fission, uniform fluorescence of the entire cell, and the lack of cell organelles when examined by phase contrast microscopy. Furthermore, these cells were concentrated primarily within the euphotic zone, which suggested that they were photosynthetic and most likely cyanobacteria.

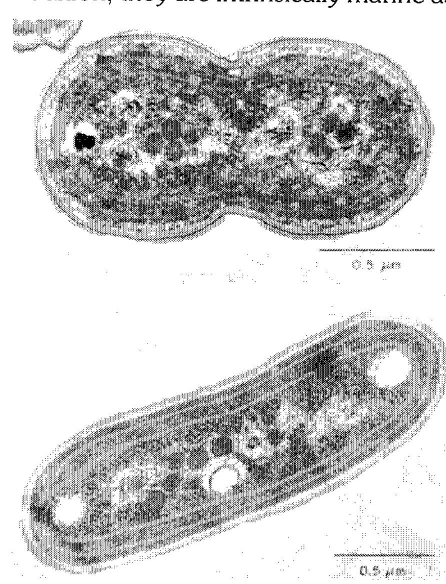
The orange fluorescence of these cyanobacteria was initially puzzling, since one might have expected them to emit the red fluorescence of chlorophyll *a*. However, in addition to chlorophyll *a*, cyanobacteria contain phycobiliproteins as accessory photosynthetic pigments. Since these proteins account for 40 to 60 percent of the total cell protein, it is not surprising that their fluorescence should mask that of chlorophyll *a*. In fact subsequent examination of pure cultures of marine unicellular cyanobacteria revealed that strains containing phycoerythrin fluoresced orange when examined under our experimental conditions while strains containing no phycoerythrin, but rich in phycocyanin, fluoresced red. The fluorescence observed in living cultures corresponds to the natural fluorescence of the purified phycobiliproteins; phycoerythrin and phycocyanin fluoresce orange and red respectively, the red fluorescence of chlorophyll *a* and phycocyanin being indistinguishable in our experimental system.

These unicellular cyanobacteria were first observed by epifluorescence microscopy in the Arabian Sea in January of 1977*** and have been present in virtually all the water samples we have collected subsequently. In surface waters they occur at concentrations of about 10^4 cells/ml, but range from 10^3 cells/ml in nutrient deficient areas such as the southern Sargasso Sea to 5×10^5 cells/ml in nutrient rich areas such as the western Arabian Sea or off the coast of Peru. In Woods Hole Harbor their concentration closely follows the annual water temperature cycle. From May until December their concentration hovers around 10^4 cells/ml with a midsummer peak which may approach 10^5 cells/ml. They rapidly disappear when the water temperature falls below 4°C sometime in late December or January and do not reappear until the water temperature approaches 12°C about the first of May. The pattern of their annual distribution in Woods Hole suggests that in temperate waters their importance may be seasonal and that they may be excluded completely from the polar seas. These two hypotheses are of considerable importance and will be examined in the future.

In collaboration with Robert Guillard and Larry Brand in the Biology Department, we have isolated a number of strains of these unicellular cyanobacteria collected from a variety of oceanic locations. In addition, several strains have been purified and are currently being used in physiological studies.

Cell size and shape accompanied by division in one plane indicate that these cyanobacteria are assignable to the genus *Synechococcus*, an assignment which is further substantiated by their typical synechococcoid ultrastructure (see figure below). The range in cell size among the ioslates now in culture further suggests that they may represent more than one species.

Their pigment system is typical of other cyanobacteria, containing chlorophyll *a* as their major photosynthetic pigment and phycobiliproteins as accessory pigments. They appear red in culture due to a predominance of phycoerythrin, one of the accessory photosynthetic pigments. The strains now in pure culture are obligate photoautotrophs (i.e., they do not have the capability of using organic compounds as sole carbon sources, their cell carbon being derived only from the fixation of carbon dioxide). They also lack the ability to fix nitrogen, a property possessed by many cyanobacteria, and therefore must rely on sources of combined nitrogen (e.g., ammonia, nitrate, urea) to meet their cellular needs. In addition, they are intrinsically marine as



Cyanobacteria *Synechococcus*.

**Two radically different kinds of cells exist in the contemporary living world. They are distinguished by profound differences in both internal cell architecture and function. The more complex *eucaryotic* cell is the unit of structure in animals, plants, protozoa, and fungi. The less complex *procaryotic* cell is the unit of structure in bacteria.

***Subsequently we discovered that Robert Guillard had isolated and still maintains a strain of this organism from a water sample collected off the northeast coast of South America in 1965.

reflected by their elevated growth requirements for sodium, chloride, magnesium, and calcium.

By far the most interesting aspect of the study of these cyanobacteria has been assessing their contribution to total primary productivity. Their small size has made it possible to separate them from larger eucaryotic phytoplankters by sequential filtration through a series of filters of decreasing pore size. A single fraction is thus obtained that contains approximately 50 percent of the *in situ* *Synechococcus* population and that excludes all other phytoplankters. By comparing the amounts of radioactive sodium bicarbonate assimilated by samples of unfiltered seawater, the fraction containing the natural population of *Synechococcus,* and pure cultures of *Synechococcus* diluted to *in situ* concentrations in sterile seawater, it is possible to estimate the proportion of primary productivity attributable to these cyanobacteria. Preliminary results from an *Oceanus* cruise in November 1979 indicated that in the nutrient deficient northern Sargasso Sea *Synechococcus* could be responsible for 15 to 25 percent of the total primary productivity. By comparison, experiments conducted with the relatively rich and productive waters of Woods Hole Harbor in December 1979 indicated that the *Synechococcus* population was responsible for seven to eight percent of the total primary productivity. It is impossible to predict the actual role of these cyanobacteria from the few measurements made to date, but it is probably not unrealistic to suggest that future measurements will verify that they may be responsible for as much as 10 percent of the total primary productivity in the world's oceans.

Instrumentation for *In Situ* Measurement of Marine Phytoplankton Production

Craig Taylor and John Molongoski

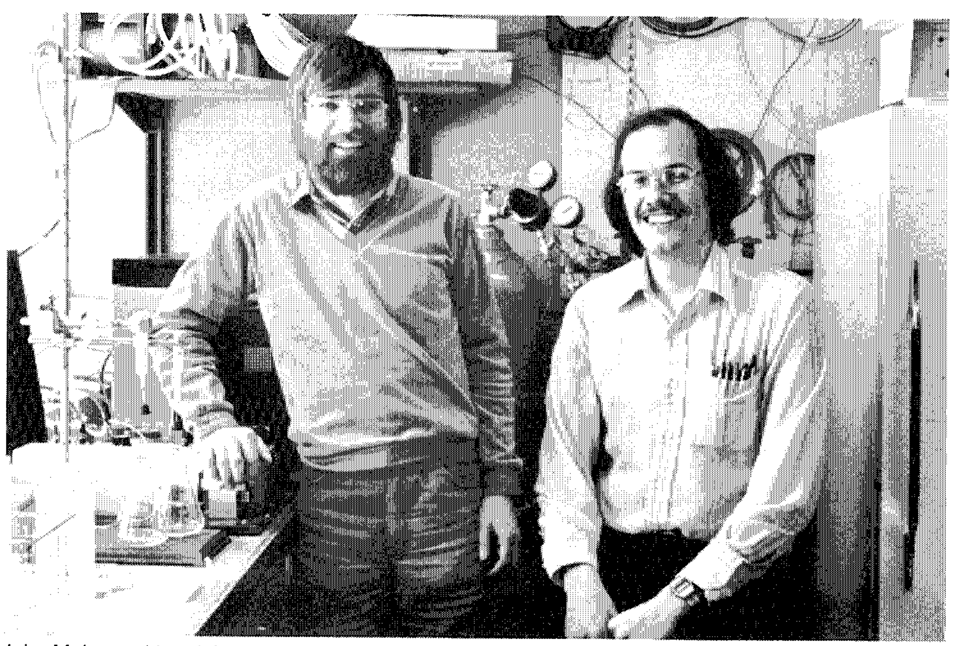
PHYTOPLANKTON occupy an important position in the marine food chain because of their ability to utilize radiant energy for the production of complex organic matter in the form of cell tissue and cell exudates. Since this organic matter subsequently serves as the energy base for much of the marine biosphere, measurements of phytoplankton "primary production" are fundamental requirements of almost any study which is directly or indirectly influenced by the activities of these photosynthetic microorganisms.

Phytoplankton production is typically measured by incubating a seawater sample within an experimental vessel in the presence of radioisotopically labeled carbon dioxide and determining the uptake of labeled carbon into the phytoplankton cells. These measurements are generally end point determinations whereby a single sample is analyzed at the conclusion of the incubation period.

In order for the measurement to be representative of the biological activity naturally occurring within the marine habitat, the sample should ideally be treated such that negligible physical, chemical, or physiological changes occur during incubation. Since some of the nutrients which influence the metabolic activity of phytoplankton are often present in the marine environment in low concentrations and may be in a rapid state of turnover, these idealized conditions may not , in fact, be realized except for short intervals of confinement.

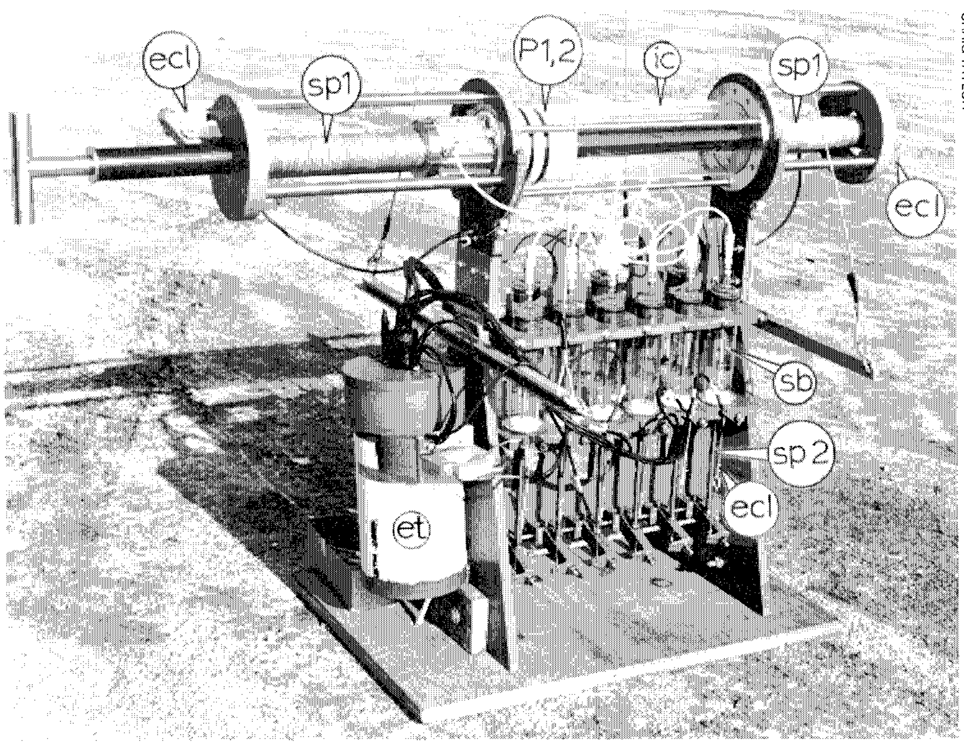
Moreover, in order to quantify changes in phytoplankton activity that may result either from the effects of enclosing the sample or from natural changes in the population, brief sample confinement should be combined with subsampling at frequent intervals.

With the engineering assistance of Kenneth Doherty and Per Ljungdahl, we have developed the sampler-incubation device (SID), an instrument which permits short term, time-course measurements of phytoplankton production to be made directly in the marine environment. The SID shown overleaf has been designed to perform the following operations *in situ:* 1) introduce a one-liter sample from the water column into a syringe-like glass incubation chamber (ic) and simultaneously mix radioactive carbon dioxide with the sample, 2) incubate the radiolabeled water sample at the site of procurement, and 3) at closely spaced intervals, withdraw 50 ml subsamples (sb) from the main incubation chamber and terminate all biological activity within each subsample. The mechanical



VICKY CULLEN

John Molongoski and Craig Taylor



CRAIG TAYLOR

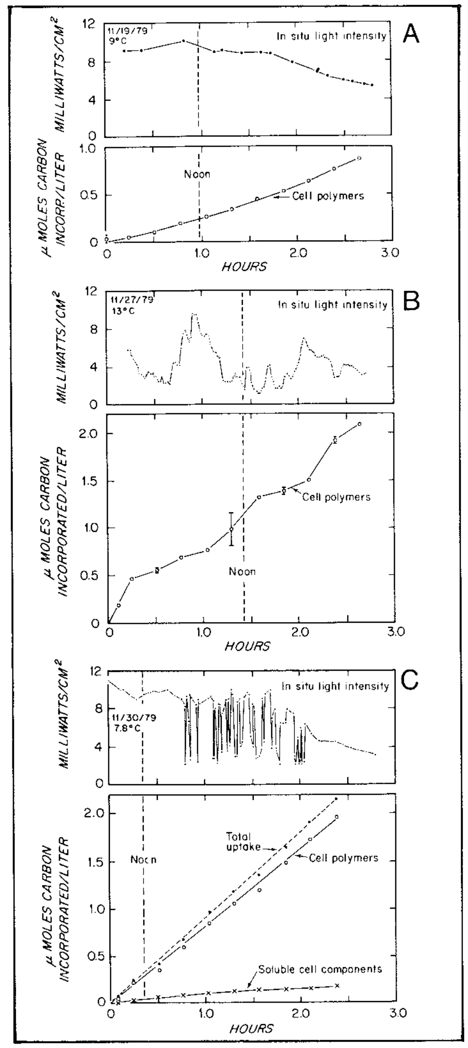
Sampler incubation device ready for deployment into the marine water column. ic-one-liter glass incubation chamber; P1, P2 – ceramic pistons for directing the flow of sample into and out of the incubation chamber; sp1- springs powering pistons P1 and P2; sb – 50 ml subsampling syringes; sp2- springs operating the subsampling syringes; ec l — electrocorrosion links for restraining the incubation chamber springs and subsampling syringe springs; et — electronic timer.

operations of the SID are powered by springs (sp) which are released by the electrocorrosion of thin stainless steel retaining links (ecl). Control of the corrosion events is effected by an electronic timer (et).

Initial testing of the SID has demonstrated its potential for conducting biological rate measurements *in situ*. The figure at right presents the results of three experiments in which the SID was used to measure the incorporation of radiolabeled carbon dioxide into the phytoplankton of Salt Pond, a productive marine basin located in Falmouth, Massachusetts. The experiments were conducted under varying conditions of temperature and light during a period when a bloom of a small unicellular green alga was the predominant phytoplankton in the pond.

Although the results are preliminary, the data illustrate the advantage of *in situ* time-course rate measurements in biological field studies. For example, in instances where a measured metabolic activity is largely a function of a single dominant microorganism as was the case in Salt Pond, time-course data may be compared with theoretically derived equations to provide useful information concerning the organism's rate of growth in nature. Examined in this manner, the data shown in A of the figure indicated that the algal cells in Salt Pond were growing with a generation time of less than three hours. Considering the low temperature of Salt Pond during the experiment, this rapid rate of growth was surprising. Although additional experiments are required to verify these observations, the important feature is that time-course rate measurements are essential to obtain such data in nature.

In situ, time-course measurements can also be utilized to detect temporal variations in primary production in response to changes in environmental parameters such as the intensity of light. The experiment shown in B of the figure was conducted on an overcast day when variations in cloud cover resulted in significant and rapid changes in the observed rates of carbon incorporation. Brief, intermittent periods of shading, on the other hand, did not appear to affect greatly the kinetics of carbon incorporation into algal cells (C of the figure). These results demonstrate the potential for utilizing the SID in field experiments concerning the effect of light or other environmental parameters on natural phytoplankton populations.



Measurement of the incorporation of ^{14}C-carbon dioxide into Salt Pond phytoplankton using the SID. The data shown were obtained by filtering duplicate aliquots of acid fixed subsamples through 0.45 μm pore size filters and analyzing the radioactivity within the retained cells. In panel C, soluble cell components released during acid fixation were also measured in subsample filtrates after removal of radioactive carbon dioxide. Total uptake is the sum of the polymeric and soluble fractions. Except where delineated by the error bars, the analytical error is within the confines of the symbol. Light intensity was continuously measured using a probe from an International Light Model 700 Radiometer that was attached to the SID.

Although we have used measurements of primary production to illustrate the functioning of the SID, this instrumentation is universal in its application and may be employed for the quantitative investigation of many other microbial rate processes in the marine environment. The SID is not restricted to use in aerobic surface waters, but may readily be employed at any depth in the ocean and in regions where oxygen is totally absent from the water column.

Project ROSE

John Ewing and G. Michael Purdy

THE Rivera Ocean Seismic Experiment (Project ROSE) was a major, multi-institutional effort designed to improve our knowledge of the lithospheric structure under a spreading mid-ocean ridge and to determine how, if at all, that structure changes as the lithosphere ages. By studying in a quantitative manner the propagation of seismic waves through the earth's crust and lithosphere, we can place important constraints on its structure and physical properties. In this experiment the sources of seismic energy were both natural earthquakes and explosive charges of various sizes (ranging from 5 to 2,000 pounds). The data (i.e., seismograms) were collected primarily by internally recording seismometer and hydrophone instrument packages emplaced on the ocean floor.

Developing a better model of the young lithosphere may lead to a better understanding of the driving mechanism of plate tectonics. This is not a new problem, and this was not the first effort to solve it — the major difference between this experiment and earlier ones was in scope. Previously, the problem had been attacked by one or two research groups with a limited number of instruments. During the early part of 1979, the seismological community elected to pool resources and deploy instruments in arrays which permit substantially greater resolving power than can be achieved by single instruments, or by a few instruments.

The main reasons for designing the experiment around the Rivera Fracture Zone were:

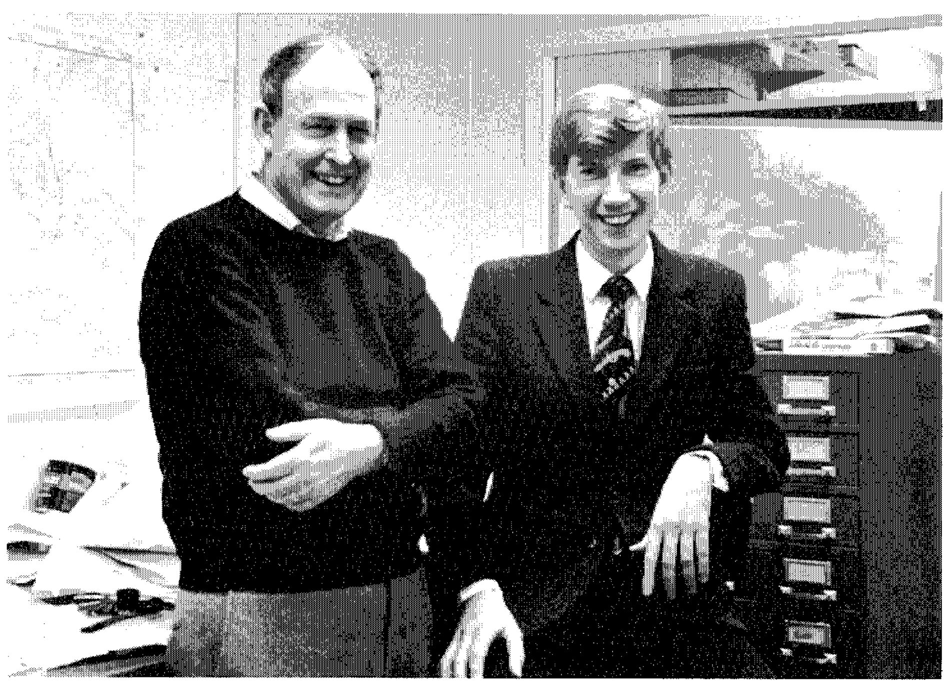
1) Fracture zones are the linear interaction zones between lithospheric plates moving past each other in opposite directions and thus are the major sites of oceanic earthquake generation. The earthquakes can be used as seismic sources for studying lithospheric structure, and the study of the earthquake mechanisms and distribution, particularly as a function of location relative to the mid-ocean ridge crests, offers supporting evidence about the nature of lithosphere at various ages and depths.
2) The Rivera is one of the largest and most active fracture zones, and it is ideally located as far as logistics and weather are concerned (close to port and consistently fair weather).
3) The bathymetry, magnetics, gravity, and sediment distribution were relatively well mapped by previous studies of the area.

Our plan was to study the evolution of the lithosphere with explosion seismology which allows the sources, even though narrow band, to be located at will, and to study the same area by measuring its response to earthquake sources. We wanted to use explosives because most of our present knolwedge about the oceanic crust and upper mantle has been acquired from explosion seismology. We wanted earthquakes to take advantage of their broader band spectra and, particularly, to utilize their characteristics as good generators of shear wave energy. The time seemed ripe for this effort because ocean bottom seismographs appeared to be well enough developed and available in sufficient numbers that we could provide hardware adequate for the task. Furthermore, recent work has produced major advances in inversion techniques and synthetic seismogram modeling, so we could expect to derive maximum information from the recorded data.

A complementary part of the project was to instrument the fracture zone region sufficiently to provide both accurate earthquake source locations and source parameters and, from these, develop a more exact description of how the fracture zone operates. A further component of the experiment was to instrument the neighboring regions of Mexico so that propagation across a continental margin could be studied with accurately located sources on each side of the boundary.

The marine community was able to gather about 70 ocean bottom seismographs (OBSs) and ocean bottom hydrophones (OBHs) for the job, and the land seismologists went into the field with about 40 seismographs. At sea, additional measurement capability was provided by two vertical hydrophone arrays, a Naval Research Laboratory array suspended from the surface and a New London Naval Underwater Systems Center array tethered to the bottom. We also had Lamont-Doherty's 24-channel towed seismic array.

Institutions participating in the project included Hawaii Institute of Geophysics, Lamont-Doherty Geological Observatory, Massachusetts Institute of Tech-



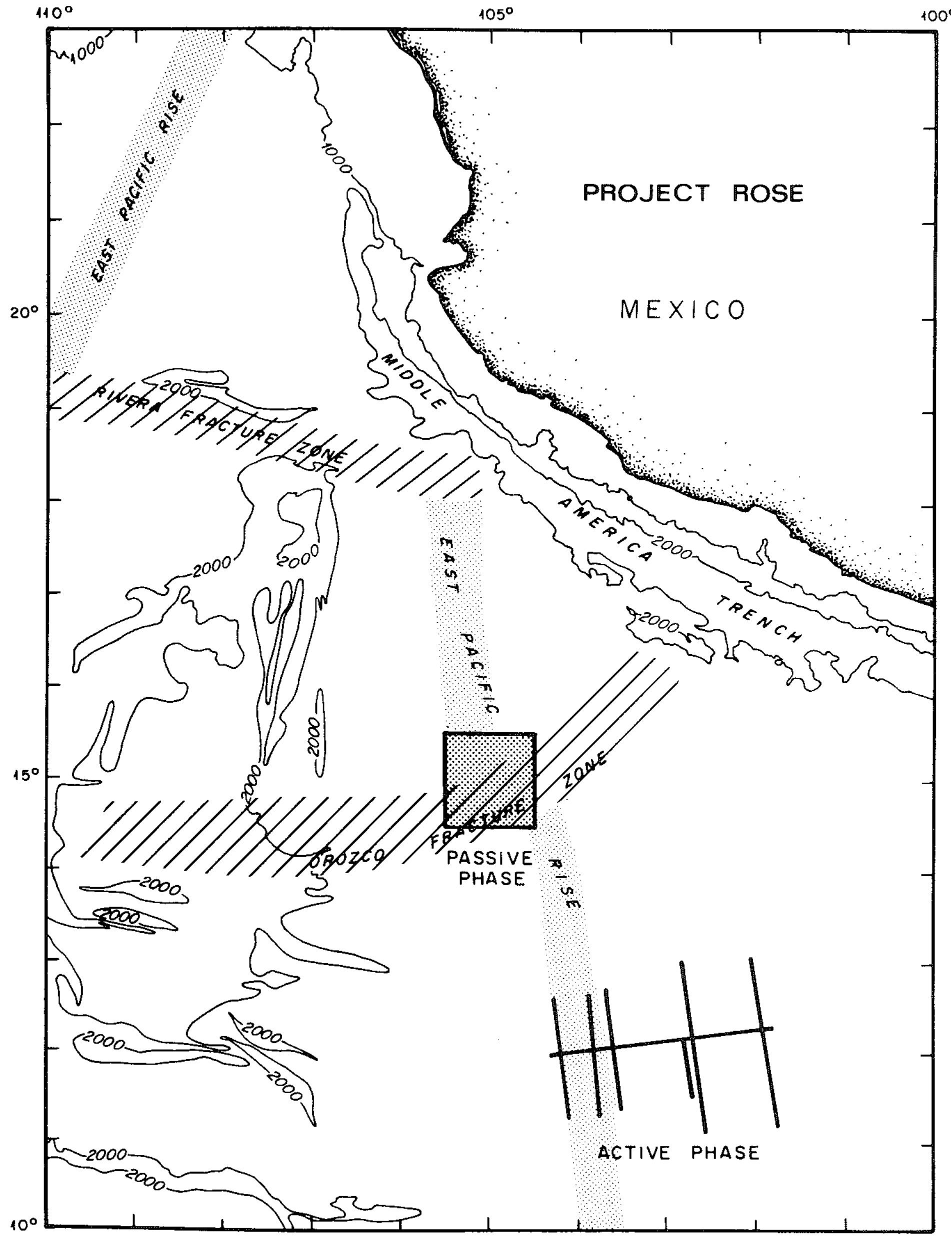
VICKY CULLEN

John Ewing and Mike Purdy

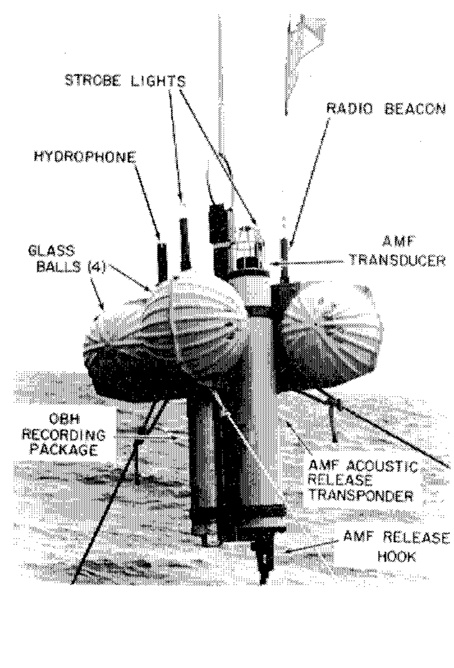
nology, Naval Ocean Research and Development Activity, Naval Research Laboratory, Oregon State University, Scripps Institution of Oceanography, University of California – Santa Barbara, University of Texas – Galveston, University of Washington, Woods Hole Oceanographic Institution, and Instituto Oceanografico – Manzanillo, Mexico. Those participating in the land-based component of the project were University of Wisconsin, Hawaii Institute of Geophysics, and National University of Mexico. Support for the project was provided by the Office of Naval Research and the National Science Foundation.

A map of our operating area is shown in the figure at right. In the north is the Rivera Fracture Zone. This is a long, seismically very active transform fault, with a very reasonably-behaved section of ridge crest north of it and a relatively uncomplicated lithospheric plate east of the ridge crest. The Rivera is where we had intended to work. However, we were unable to get permission from the Mexican authorities to work there, so we had to move the experiment south beyond the 200-mile limit. We made the first deployment (active phase) on the crest and eastern flank of the East Pacific Rise at about 12°N latitude. The second deployment (passive phase) was made in and around the Orozco Fracture Zone (shaded box).

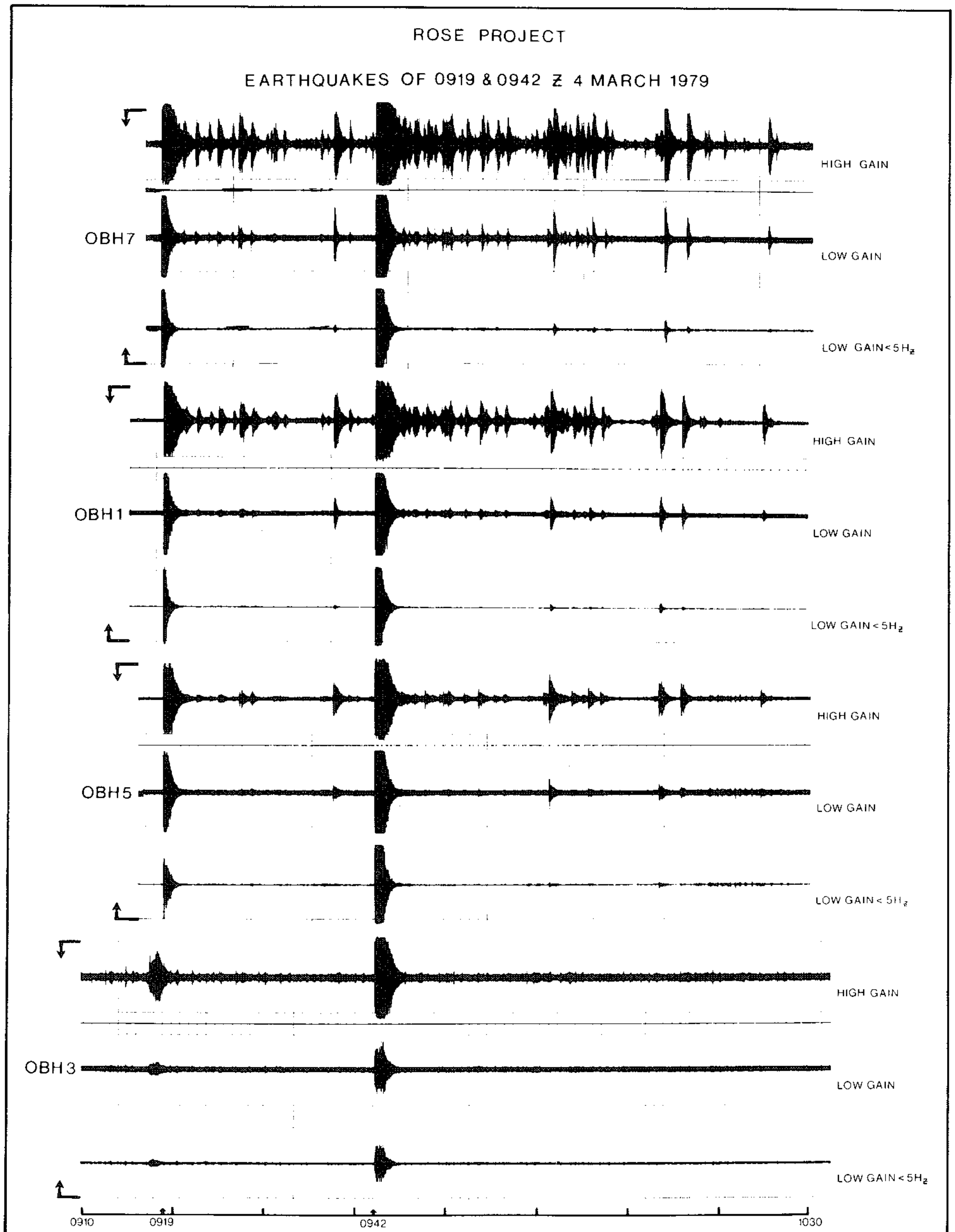
In the active phase the objective was to form linear arrays of detectors, shoot the lines heavily with explosives, and try to determine the variation in crustal and upper mantle structure as a function of lithospheric age. Toward this end we put down 67 OBSs and OBHs along the lines shown in the figure. Average spacing of instruments along the lines was 25 kilometers, with closer subarrays in a few locations. Along these lines we fired 200-pound and 500-pound charges spaced at 10- and 20-kilometer intervals, respectively; then we shot each line again with 5-pound and 25-pound charges spaced at one-kilometer intervals. In addition to these shots, we fired three one-ton charges spaced 20 kilometers apart at the ends of most of the



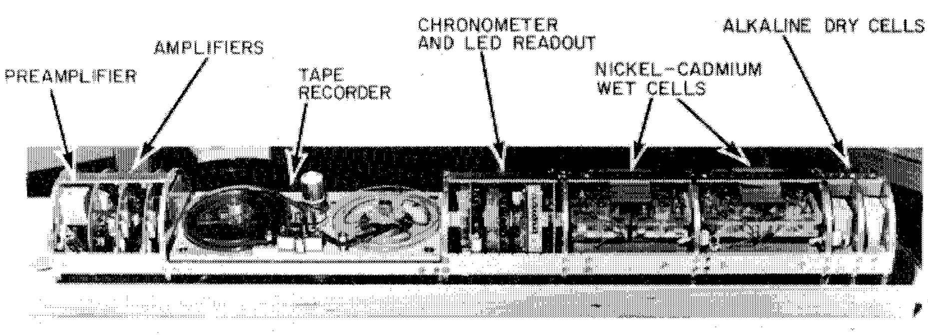
Bathymetric map of the region off the west coast of Mexico showing the two ROSE deployment areas.



The WHOI ocean bottom hydrophone (OBH). Anchor is attached to the AMF release hook by a 3-meter length of line.



Seismograms of two of the larger earthquakes that occurred in the southeastern part of the fracture zone near OBHs 1 and 7. It is evident that many of the aftershocks were of very low magnitude, as they were recorded by only the closest instruments and were undetected by OBH 3, only about 70 kilometers farther away from the epicenters. OBH 5 was located at an intermediate range and recorded most of the aftershocks, but with appreciably lower signal levels.



Interior of OBH is shown with labels indicating major components.

array lines. Altogether, about 1,600 shots were fired to this array of instruments. Even denser spacing of shot points was achieved along the east-west line with a large airgun array fired approximately every 100 meters. Although we have analyzed only a relatively small amount of the data, it appears that we have a data set of sufficient size and quality to enable us to examine details of structural and propagational variations to a degree never before possible in marine seismology.

For the passive phase, the main objectives were to study the seismicity of the Orozco Fracture Zone and to measure the propagation characteristics of the lithospheric plate south of the fracture zone. Accordingly, the deployment pattern was designed to locate approximately half of the instruments within the fracture zone for precise location of earthquake foci, and the other half were located south of the fracture zone to provide appropriate paths for propagation analysis. The eight Woods Hole OBHs were distributed over a substantial part of the area, so their performance gives a reasonable indication of how the whole array was excited by various events. Two of our instruments located within the fracture zone recorded several events per hour during the two-week deployment. This contrasts markedly with instruments only a few tens of kilometers south of the fracture zone which recorded less than one event per hour, indicating that only 20 to 30 percent of the earthquakes are of sufficient magnitude to propagate for appreciable distances (upper figure).

Both the active and passive phases of ROSE were quite successful operationally and have provided us with an enormous amount of data which are now being reduced and organized into a digital format for convenient exchange among the participants. The most serious shortcoming of the experiment stems from our failure to receive permission to work at the Rivera, where the greater number of large earthquakes would have permitted a better comparison of explosive data with natural event data.

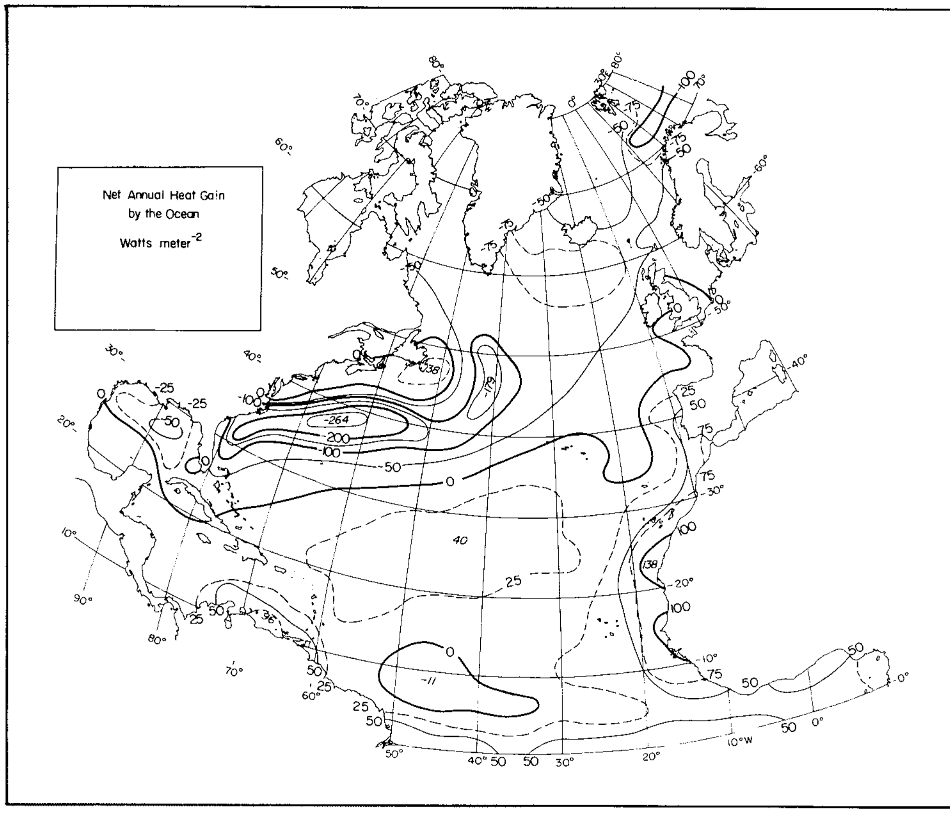
Ocean Heat Transport

Harry Bryden

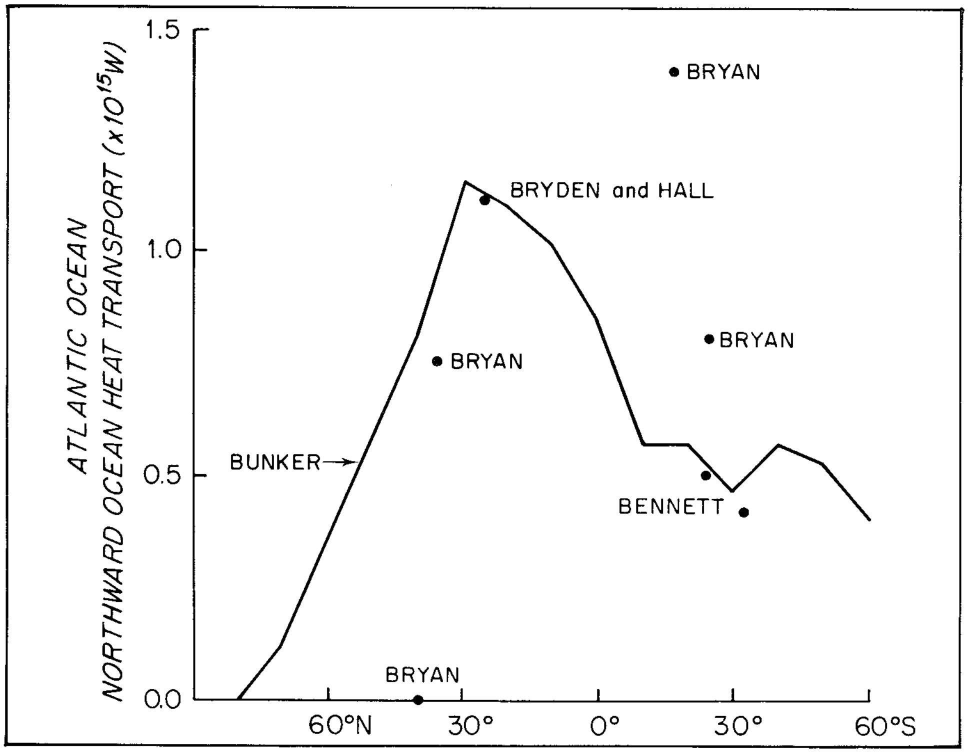
It has been known for a long time that the earth receives most of its radiation from the sun in tropical regions but that it radiates energy back into space nearly uniformly over the globe. To maintain the global heat budget, the ocean and atmosphere must transport heat from the tropics, where there is a net heat gain from radiation, to the polar regions, where there is a net heat loss. Until 1930 there was a general consensus that, owing to its large heat capacity, the ocean must accomplish most of this poleward heat transport. In 1930 meteorologists began making direct estimates of atmospheric heat transport, and from then until 1970 there was a general consensus that the atmosphere accomplished most of the poleward transport. Reconsideration of the problem of heat transport has been undertaken in the last decade, and we now believe that the ocean transports most of the heat in tropical regions while the atmosphere transports most of the heat in regions poleward of 30° latitude. At the Institution, two independent methods are being used to estimate the heat transport by ocean currents.

The traditional method of estimating ocean heat transport is to estimate the net gain of heat at the ocean surface due to exchanges of radiative, latent, and sensible heat with the atmosphere. In this method, ship observations of air and water temperature, wind speed, cloudiness, and dew point temperature are put into bulk equations to calculate the radiative heat gain by the ocean, the heat loss due to evaporation, and the sensible heat exchange with the atmosphere. The net heat loss by the ocean in any region must be made up by an equivalent transport of heat by the ocean into that region. The accompanying chart of net heat gain in the North Atlantic, calculated by the late Andrew Bunker,*shows both the large scale features of net heat loss in northern regions and heat gain in tropical regions and the fine-scale features such

*Andy Bunker had been a member of the Institution scientific staff for 33 years when he died in August of 1979.



Andrew Bunker's chart of net heat gain by the North Atlantic Ocean.



Northward ocean heat transport in the Atlantic. The solid curve is obtained by integrating the net heat loss shown in the figure above from the North Pole southward to the given latitude. Point values are derived from the distribution of currents and temperature within the ocean. The values at 36°N and 16°S were calculated by Kirk Bryan, the value at 25°N by Harry Bryden and Mindy Hall, and the values at 24°S and 32°S by Andrew Bennett.

as the huge heat loss near the Gulf Stream south of Cape Cod and the large heat gain in upwelling regions north of Venezuela and west of Africa. Integrating this net heat loss southward from the North Pole enables us to estimate the poleward ocean heat transport across any latitude shown in the second figure.

The second method of estimating ocean heat transport is to use oceanographic measurements to estimate the distribution of northward flowing and southward flowing currents and their temperatures. This method has been used rarely in tropical regions because of the difficulty in measuring accurately the flow of western boundary currents such as the Gulf Stream. A recent calculation using detailed current and temperature measurements in the Florida Straits between Florida and the Bahamas, however, shows that the northward flow of the Gulf Stream of $30 \times 10^6 \, m^3 \, s^{-1}$ in the Florida Straits has an average temperature of 19°C (66°F). The compensating southward return flow across the section between the Bahamas and Africa is found to have an average temperature of 10°C (50°F). The ocean heat transport, which equals the flow multiplied by the temperature difference between northward flowing and southward flowing waters, then is 1.1×10^{15}W and is directed poleward.

Comparison between estimates of ocean heat transport from these two methods, as indicated in the second figure, is good. There is also a third method of estimating ocean heat transport which utilizes satellite radiation measurements to estimate the total ocean plus atmosphere heat transport and subtracts the transport by the atmosphere to derive ocean heat transport as a residual. This third method, however, yields poleward transports which are nearly twice as large as those from the other two methods. Determination of why the satellite-based estimates disagree with the estimates based on ocean-atmosphere exchanges and on distributions of currents and temperatures within the ocean is an active research problem.

During this time when we are debating whether man has affected or will affect adversely the climate of the earth, it is important to determine the mechanisms by which the global heat budget is maintained. For their contribution, oceanographers must not only estimate how much heat is transported by the ocean and by what processes but also determine whether any of the present methods might be used to monitor changes in ocean heat transport which may accompany or even portend changes in the earth's climate.


TERRENCE JOYCE

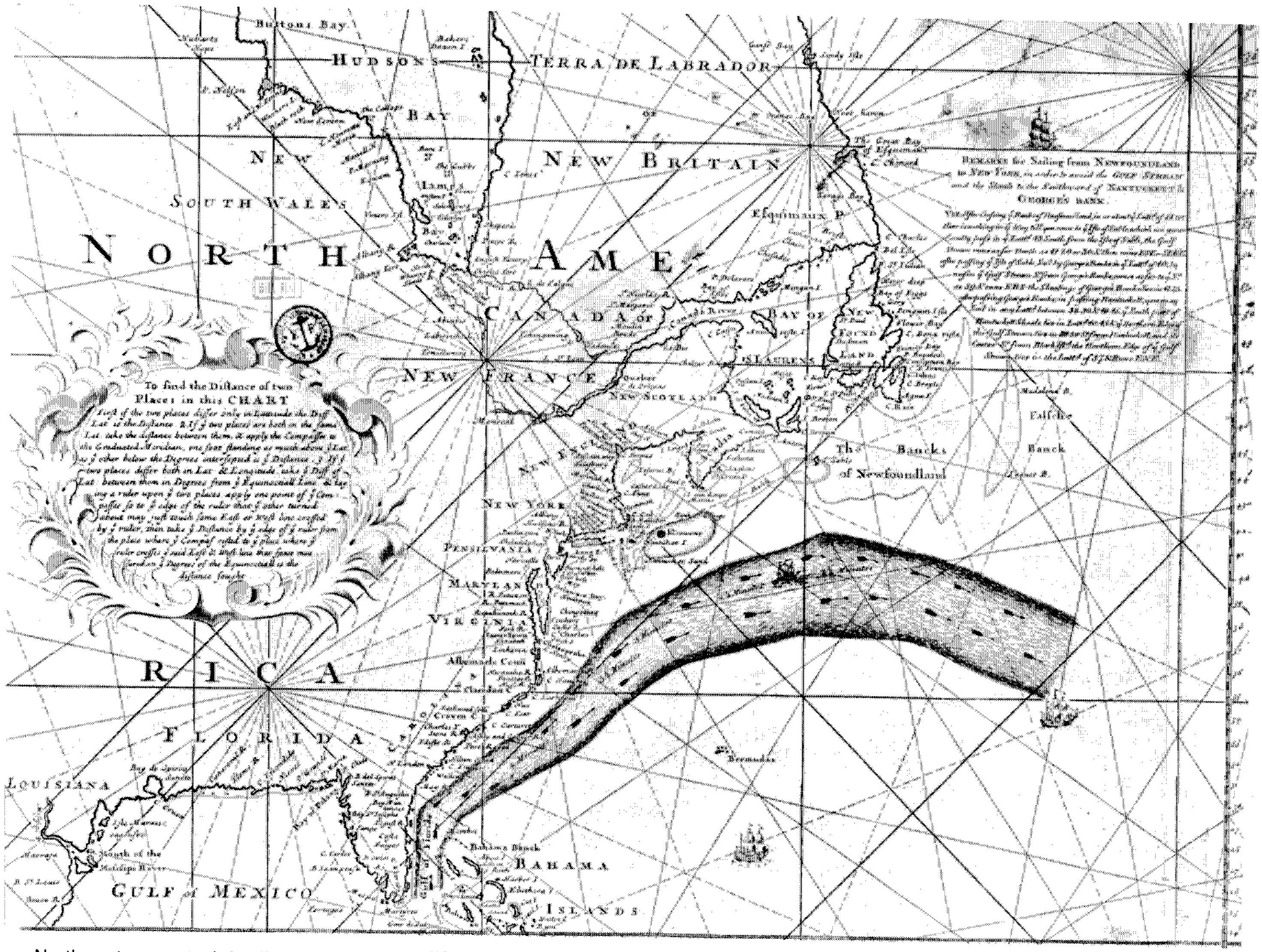
Harry Bryden with CTD/rosette sampler.

Charting the Gulf Stream Then (18th Century) and Now

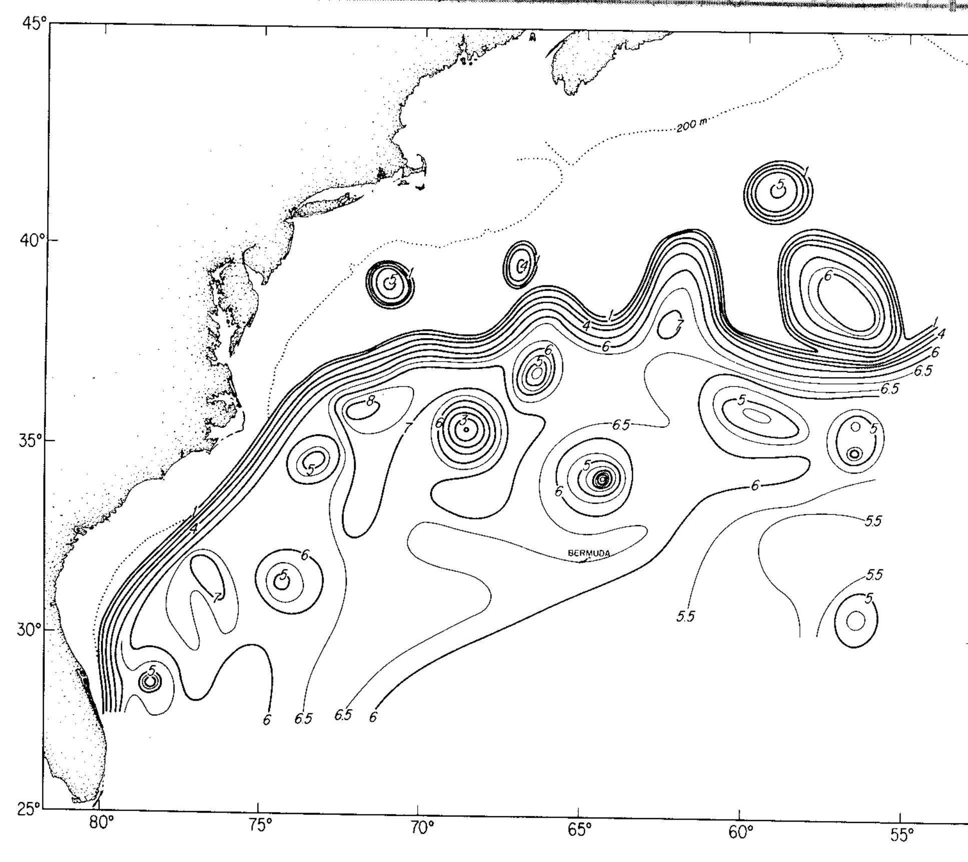
Philip Richardson

As part of my research on the Gulf Stream, I have been studying historical descriptions of this current and accounts of its exploration to rediscover valuable but forgotten or lost information and to learn how our knowledge of the Gulf Stream has evolved with the use of more sophisticated measurement techniques. During a visit to France in 1978, I searched for and was lucky to find a valuable chart — a print of Benjamin Franklin's first chart of the Gulf Stream, all copies of which had been "lost" for over 200 years. It occurred to me that a copy of the chart might have been saved by the French, because Franklin was envoy to France from 1776-1785, and both Franklin and his ideas were highly regarded by the French. My hunch turned out to be right, and I found two prints of the chart in the Bibliothèque Nationale.

In 1769 or 1770, Benjamin Franklin published the first good chart of the Gulf Stream in order to help the captains of the British packets avoid this swift current and speed up their passage to New York. Before 1769, charts showed the most rudimentary pictures of currents; only much later were chronometers used to determine ship drift velocities and maps made of the surface currents. The Gulf Stream was sketched for Franklin by Timothy Folger, a Nantucket ship captain who knew a great deal about ocean currents. Nantucket whalers frequently hunted whales along the edges of the Stream and learned



◆ Northwestern part of the Franklin-Folger chart. There were three versions of this chart. The first version, printed by Mount and Page in London in 1769 or 1770, was copied by LeRouge and printed in Paris about 1778; the Le Rouge version was then copied by Poupard and published by Franklin in Philadelphia in 1786. Only the third version has been widely reproduced and is well known. The photocopy of the chart was provided by the Bibliothèque Nationale.

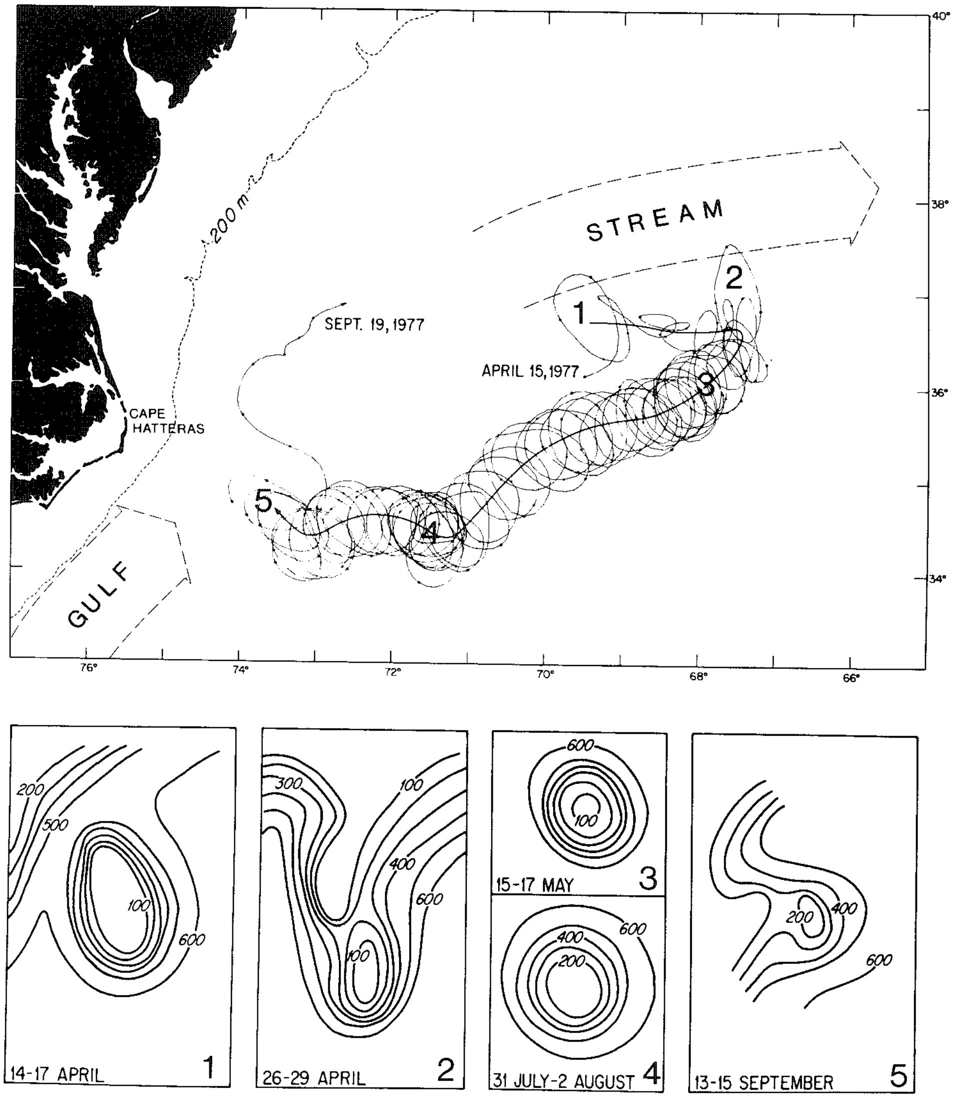


◆ Chart of the topography in hundreds of meters of the 15° isothermal surface showing the Gulf Stream and 9 cyclonic and 3 anticyclonic rings. Rings are eddies which form from large Gulf Stream meanders and separate from the Stream. The chart is based on data from 16 March to 9 July 1975 and represents a quasi-synoptic "weather map" of the Northwestern Atlantic Ocean. Because of the movement of some of the features during this period, the chart is not truly synoptic. However, each of the research cruises made during this period were relatively short and thus there is only slight blurring of the picture where the surveys meet. A comparison of this chart with other, more limited surveys suggests that it is a rather typical picture of the Gulf Stream system.

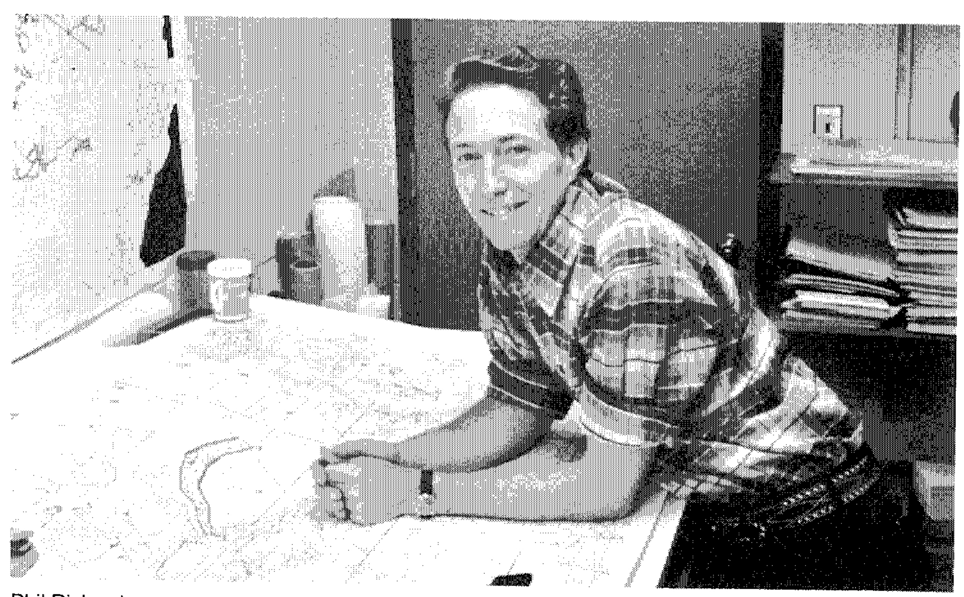
much about its speed, course, and breadth; as this information was seldom written down, the chart provides a rare summary of it. The Franklin chart remains today a good summary of the mean path and width of the Stream and the speeds in its high velocity core.

Partly because the British captains slighted it and partly because of Franklin's role in the confrontation between the American colonies and England, this chart became very rare. Despite considerable effort by many people to find a copy of the Franklin-Folger chart in England and America, not one has been found until now. The chart that most people associate with Franklin was published by him in 1786 in the Transactions of the American Philosophical Society. However, this later chart is really a copy of a copy of the first chart, and the projection is different, the Gulf Stream has been modified, and there are such inaccuracies as that in the location of Bermuda. What may seem surprising is that until now the oldest existing chart of the Gulf Stream was not Franklin's at all but one published by William Gerard DeBrahm in 1772.

Although our idea of the "mean Gulf Stream" has not changed much since the time of Franklin, modern studies of the Gulf Stream have revealed many aspects of its characteristics and variability unknown in the 18th century. Today oceanographers concentrate on studying the time and space variability of the Stream. One method used is to make snapshots or synoptic pictures of the Stream (figure left below) and examine these for energetic features such as meanders and eddies (rings). Modern data-taking techniques for constructing such pictures include satellite infrared images and satellite tracked drifting buoys as well as a full suite of shipboard measurements. By making repeated synoptic charts, we can study the time evolution of the rings and meanders and their interactions within the system. During a recent study, one ring was closely followed from its birth to its death, a span of seven months, and its physical, chemical, and biological properties measured (figure right above). These details provide a better understanding of the Gulf Stream, one of the world ocean's major current systems.



Trajectory of a satellite-tracked free drifting buoy looping around the center of a Gulf Stream ring from 15 April to 15 September 1977. The movement of the ring is given by the shifting center of the loops. Lower panels illustrate the evolving thermal structure of the ring and interactions with the Gulf Stream; contours are the depth in meters of the 15° isothermal surface. During April the ring became connected with the Gulf Stream and moved rapidly (1/2 knot) eastward. In May it separated from the Stream and began its southward drift (1/10 knot) through the Sargasso Sea. In September the ring rapidly and completely coalesced with the Gulf Stream and was lost.



VICKY CULLEN

Phil Richardson

Ocean Acoustic Tomography

Robert Spindel

THE ocean is an enormously complex, constantly changing system whose impact on our lives is not even yet fully appreciated. As we refine our observational methods we discover ever finer scales of variability, each a major contributor to the complicated fluid dynamics of the sea. Yet the greatest obstacle to achieving an understanding of the ocean is still our ability to observe it properly. We simply cannot measure the vast oceans with all their pertinent time and space scales with the tools and resources available or even conceivably imaginable. A new development in ocean remote sensing, however, holds the promise of providing synoptic maps of the ocean interior on scales ranging from regional to basin-wide. A relatively few instruments can potentially replace a large number of ships and individual instruments.

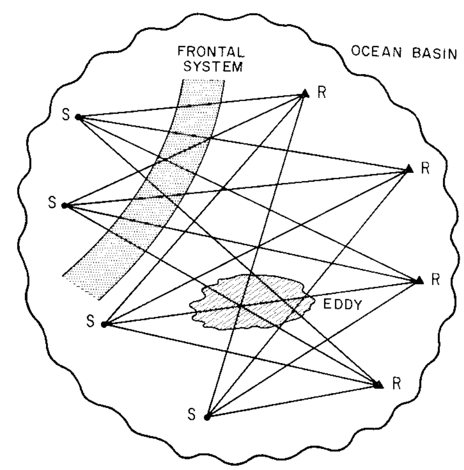
The new technique, known as ocean acoustic tomography, exploits the transparency of the ocean to acoustic energy. Together with scientists at Scripps Institution of Oceanography, MIT, and the University of Michigan we are developing the system to monitor mesoscale (processes with spatial scales of 100-kilometer order) ocean variability. The mean flow of the ocean, its currents and countercurrents, can be regarded as ocean climatology, whereas mesoscale features are akin to storm systems in the atmosphere. Thus, in a sense, the system will monitor "ocean weather."

The word tomography derives from the Greek word *tomo* meaning a section, or a slice; a tomogram is a picture of a slice. In medicine, x-rays are used to image slices of the body in the technique known as x-ray tomography. Computers are used to reconstruct two-dimensional images based on varying absorption of the x-ray energy. In the ocean we will use sound energy to provide images of the interior ocean.

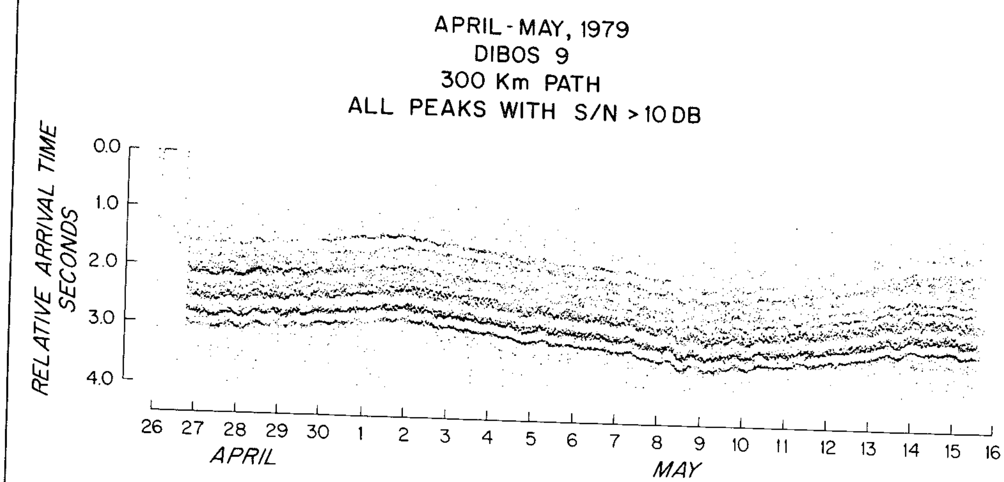
The sound velocity field of the ocean changes continuously in response to temperature, salinity, density, and current variations associated with dynamic ocean processes. Any change in sound velocity will alter the travel time of an acoustic pulse transiting the ocean from source to receiver. Acoustic tomography entails the measurement of time-of-flight between multiple acoustic sources and receivers. This data is inverted (in a mathematical sense) to yield a reconstructed image of the sound speed field. This image can then be related to physical oceanographic quantities.

During the past several years we have perfected the instrumentation required to implement a tomographic monitoring system and have conducted a series of experiments to prove the feasibility of the concept. Self-contained acoustic sources, originally designed as neutrally buoyant floats for tracking subsurface currents, have been designed to transmit pulselike signals. It is interesting to note that these signals have a tone close to the A below middle C. Acoustic receivers containing small computers process these transmissions and extract travel time data. A typical mesoscale eddy will produce travel time changes of 0.05 to 0.1 seconds; an intense frontal system such as the Gulf Stream will produce changes almost ten times as great.

A graphic demonstration of the power of the method was provided by acoustic transmission through a Gulf Stream meander. A source and receiver were each moored at 2,000 meters depth to the northwest of Bermuda about 300 kilometers apart. A single pulse was transmitted every ten minutes for a 19 day period and its travel time was recorded. This single pulse is received as many pulses because sound travels from source to receiver along many different paths, each with slightly different length and thus slightly different net travel time. The arrival time pattern is advanced and retarded as first warm water and then cold water (from north of the Gulf Stream) is moved into the transmission path. The arrival time



Ocean acoustic tomography uses measurements of acoustic travel time between multiple sources (S) and receivers (R) to monitor changes in the sound speed field of the ocean interior. The presence of an oceanographic feature, such as a mesoscale eddy, will alter the travel time along certain paths.



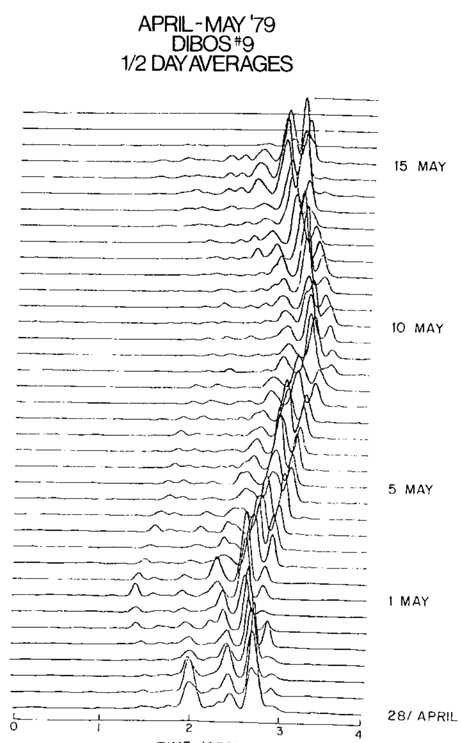
Relative arrival time of received pulses resulting from a single transmitted pulse every 10 minutes. Encroaching warm water first speeds up arrivals, and then cold water delays them. Finally, beginning on 10 May the cold water begins to retreat from the path.

JOSEPH KIEBALA, JR.

Bob Spindel, right, and Paul Boutin inspect acoustic instrument held by Peter Worcester of Scripps aboard *Oceanus.*

wander corresponds directly with simultaneously observed movement of the meander.

Early in 1981 we will proceed with the next step in developing tomography as a viable scientific measuring device. A number of sound sources and receivers will be deployed in the Atlantic in order to monitor mesoscale activity for a six month period. Tomography will then begin to provide long-duration, large-scale observations that until now have proved to be either impossible or extraordinarily difficult.



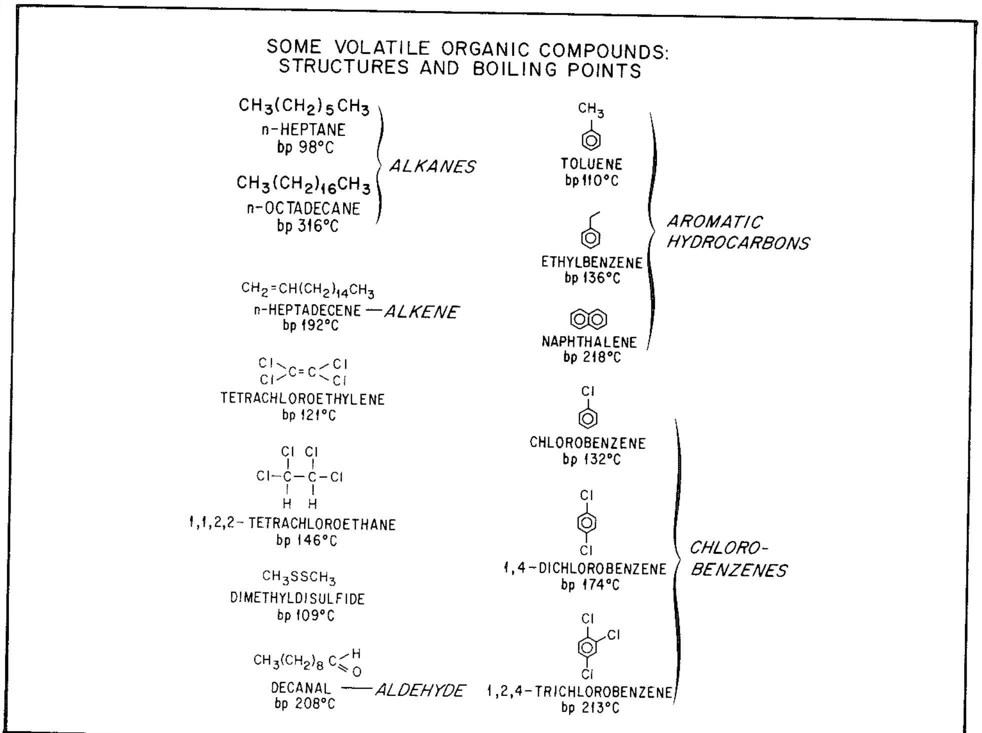
Here we plot only the strong peaks of arriving pulses. The alteration of travel time is quite dramatic — as much as 0.7 seconds.

Volatile Organic Compounds in Narragansett Bay and MERL

Stuart Wakeham

SEAWATER contains a very complex, diverse, and poorly characterized mixture of organic compounds. Historically, most studies of seawater organic matter have focused on "bulk" properties, such as concentration and distribution, molecular size distribution, and adsorbance spectrum as an indicator of molecular structure. Recent efforts have been directed to structural characterization of this organic material, initially simply as compound classes (e.g., hydrocarbons, fatty acids, sterols, amino acids, and sugars), but most recently in greater detail as individual organic molecules within specific structural groups. Although only a minor portion of the organic matter in seawater has been characterized at present, the temporal and spatial information becoming available is valuable in obtaining a better understanding of the sources, sinks, transport, and transformation of organic matter in the oceans.

As part of a major effort at the Institution to better define the biogeochemistry of organic matter in seawater at the molecular level, we have been involved in a study of volatile organic compounds. Seawater compounds falling into the "volatiles" category are little-investigated, being too volatile to be handled by conventional extraction techniques, such as those used for hydrocarbons and fatty acids, and yet not volatile enough to be analyzed by procedures designed for very light organic compounds, such as gaseous hydrocarbons and fluorocarbons. Our analytical methodology yields information about a variety of low to medium polarity organic compounds in the volatility (boiling point) range bracketed by n-heptane and n-octadecane (see figure below). The major compound classes are: alkanes and alkenes; aromatic hydrocarbons; halogenated alkanes, alkenes, and ben-

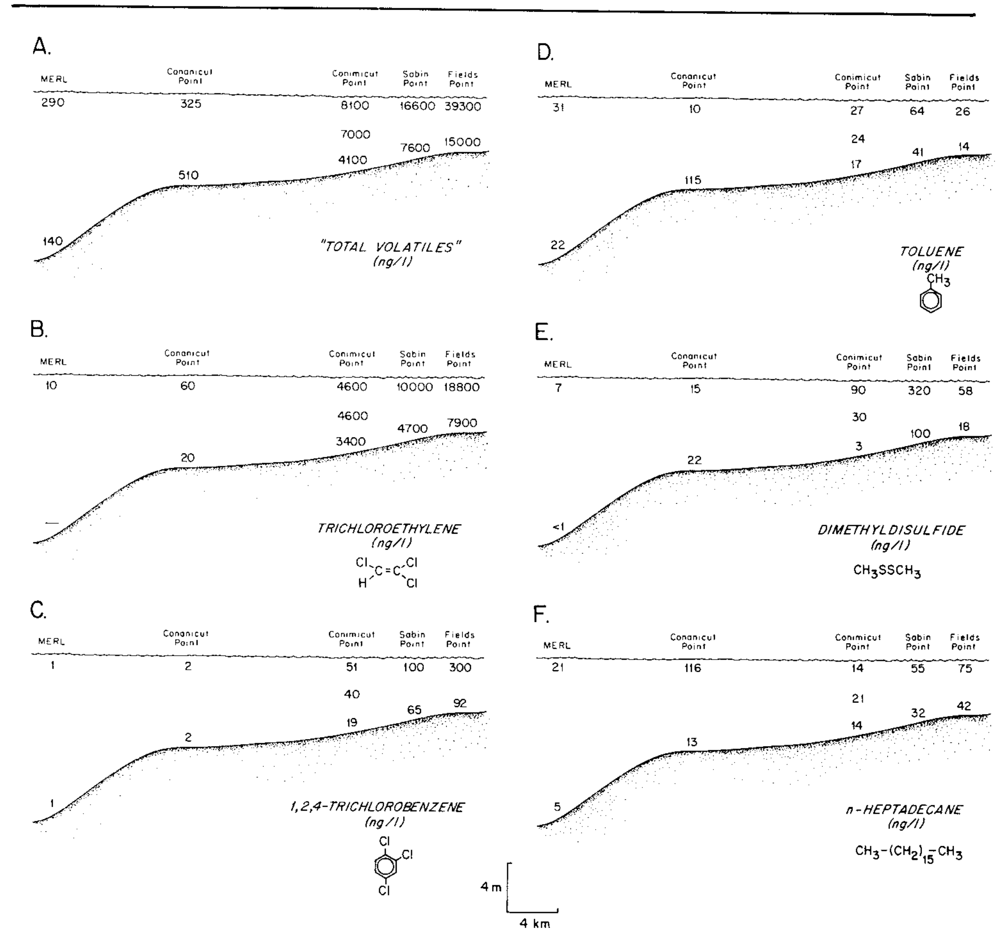


Structures and boiling points of representative volatile organic compounds bracketed by n-heptane and n-octadecane. By comparison, gasoline generally boils between about 100 and 200°C and contains such compounds as heptane, toluene, and ethyl benzene. Tetrachloroethylene is commonly used as a dry-cleaning and industrial solvent. Naphthalene and 1,4-dichlorobenzene are used in moth balls. 1,2,4-trichlorobenzene is an insulator.

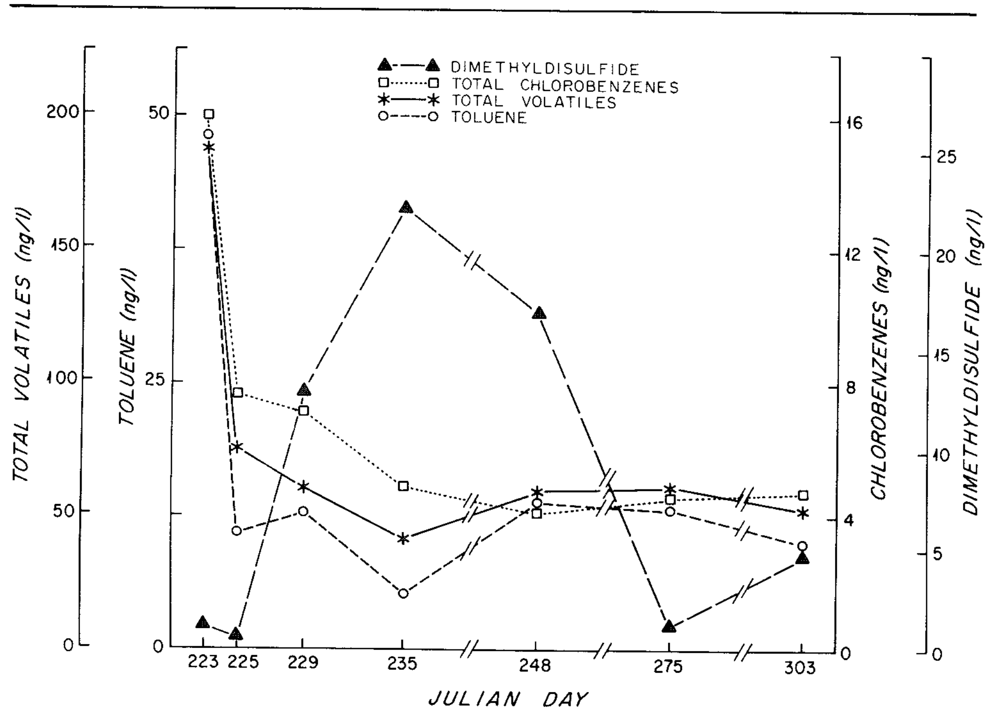
zenes; aldehydes; alkyl sulfides. A few of these compounds have biosynthetic origins and are of biochemical significance to marine organisms. Many other volatiles are strictly anthropogenic, and some are toxic, often identified by the U.S. Environmental Protection Agency as "priority pollutants."

Previous studies of volatile organic compounds in natural waters have shown that lakes and rivers in densely populated and industrialized areas contain relatively high concentrations of pollutant compounds. On the other hand, coastal seawater and the open ocean generally contain much lower volatiles levels. These data indicate that some processes act to reduce concentrations of volatile organic compounds in water masses as they are transported away from source areas, through estuaries and the coastal zone and into the open ocean. Furthermore, the combination of high concentrations in rivers and low concentrations in seawater means that most of the removal of volatiles occurs in estuaries. What processes are responsible (evaporation, sedimentation, degradation, etc.) and the extent to which each is important for a given organic compound are poorly understood at present. Our volatiles studies are designed to begin to provide answers to at least part of this complex question, and we are approaching the problem from two directions: 1) field measurements in Narragansett Bay, Rhode Island, and 2) controlled experiments in the large microcosms of the Marine Ecosystems Research Laboratory (MERL) at the University of Rhode Island.

Volatile organic compounds in Narragansett Bay show a strong concentration gradient as distance from the city of Providence increases (toward Fields Point in the upper figure). Simple dilution of water from the Providence River, containing high volatiles levels, with "cleaner" seawater flowing in from the mouth of the bay cannot account for the observed concentration change. Some volatile compounds must evaporate preferentially from the bay water, while other molecules probably preferentially degrade or accumulate in the sediments. Rates for these respective processes remain to be determined. Nevertheless, volatiles in the bay fall into three general groups: 1) *Chlori-*



Volatile organic compounds in Narragansett Bay 1 August 1979.



Temporal variation in selected voltiles in a MERL tank during the sediment gradient experiment 11 August to 30 October 1979.

nated ethylenes and chlorobenzenes (e.g., trichloroethylene and 1,2,4-trichlorobenzene in the figure), widely used as industrial solvents and chemical intermediates, most likely enter Narragansett Bay as industrial sewage effluents in the area of Fields Point. 2) *Aromatic hydrocarbons* (e.g., toluene) are more uniformly distributed throughout the bay and probably have dispersed sources related to gasoline and fuel usage, such as the atmosphere, boat traffic, sewage effluents, and stormwater runoff. 3) *Substances of natural origins* produced by microbial activity (e.g., dimethyldisulfide) and/or planktonic productivity (n-heptadecane) are usually most abundant in surface waters where these compounds are generated.

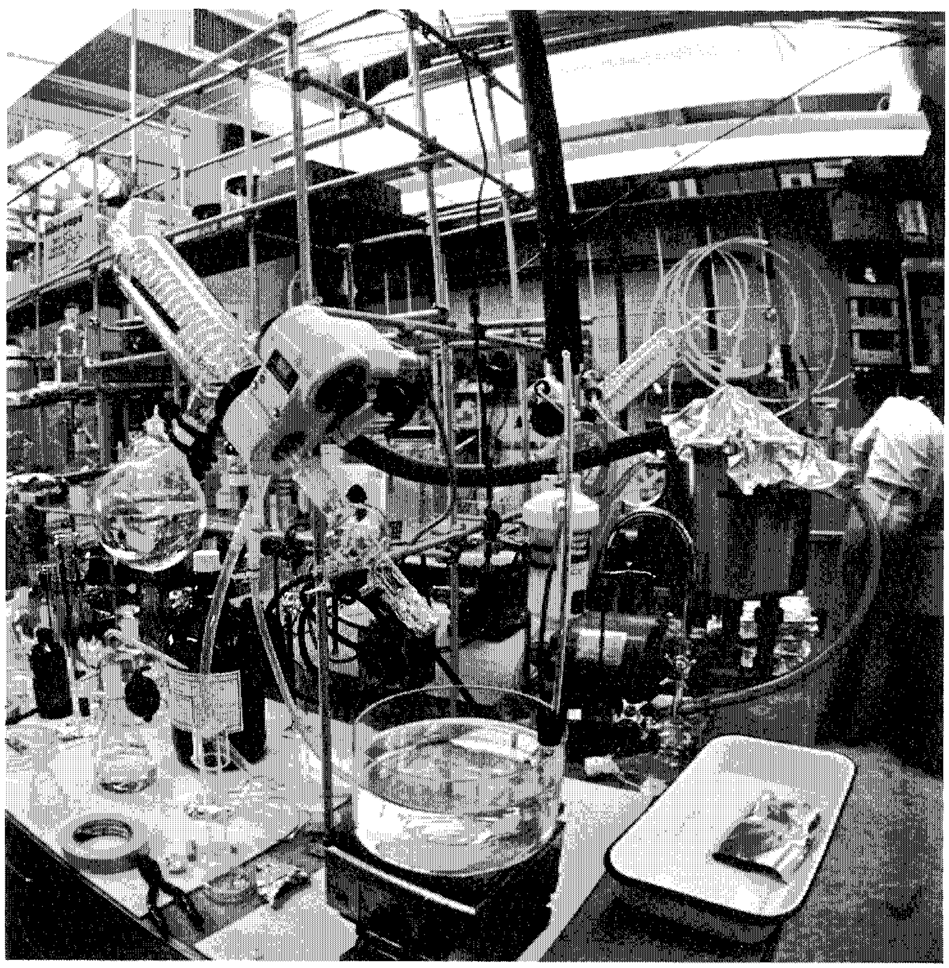
Experiments in the 13,000 liter tanks at MERL are designed to acquire a detailed quantitative understanding of processes affecting chemical transfer and also an understanding of biological effects of volatile and other pollutants in nature in controlled and well-monitored (physically, biologically, and chemically) experimental conditions. The MERL microcosms simulate Narragansett Bay to a surprising degree and complement the field measurements. An experiment in progress for several months involves a multi-disciplinary study of remobilization and release of pollutant materials, both organic and inorganic, out of a contaminated sediment from the Providence River and into overlying seawater. Knowledge of the extent to which this process occurs is critical in understanding the release of toxic chemicals from contaminated sediments even after the source of contamination is removed.

Concentrations of most volatile organics which can be classed as anthropogenic were high at the beginning of the experiment (figure at left). This probably reflects an initial resuspension of particulate matter containing volatile compounds which were then desorbed into the water. Within several days, however, concentrations generally decreased, perhaps as particles settled out, and have remained relatively constant. No significant differences have been observed between tanks containing highly contaminated Providence River sediment and tanks with less polluted "control" sediment. In contrast to the general trend for the anthropogenic compounds, dimethyldisulfide shows a very different pattern (see figure). The concentration of this alkyl sulfide peaks several days after the experiment began, and the Providence River tanks apparently produced more than the control tanks. More than likely, the concentration maximum for dimethyldisulfide reflects blooms in bacterial or phytoplankton biomass in response to unknown processes occurring at this time and occurring to a greater extent in tanks containing the more polluted sediment.

Our research into volatile organic compounds in estuaries and coastal seawater is just beginning. Additional field measurements are needed, with an emphasis on elucidating sources in greater detail. Our experiments in MERL will also continue and will address the question of removal processes and their rates, and will look into distinguishing dissolved from particulate volatiles.

VICKY CULLEN

Stu Wakeham



VICKY CULLEN

Rotary evaporator concentrates organic extracts of water and sediment in chemistry lab of Bob Gagosian.


FRANK MEDEIROS

Paul Fye presides as Phil Gschwend receives his WHOI Ph.D. at a special ceremony during the Associates' Day of Science. Charles Hollister, the new Dean, is at left.

1979 Degree Recipients

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

Doctor of Philosophy

JAMES A. AUSTIN, JR.
B.A., Amherst College
Special Field: Marine Geology
Dissertation: *Geology of the Passive Margin off New England*

YONATHAN EREZ
B.S., M.S., Hebrew University of Jerusalem
Special Field: Marine Geology
Dissertation: *The Influence of Differential Production and Dissolution on the Stable Isotope Composition of Planktonic Foraminifera*

ROBERT W. HOWARTH
B.S., Amherst College
Special Field: Biological Oceanography
Dissertation: *The Role of Sulfur in Salt Marsh Metabolism*

HSIEN WANG OU
B.A., National Tsing Hua University
M.S., Florida State University
Special Field: Physical Oceanography
Dissertation: *On the Propagation of Free Topographic Rossby Waves Near Continental Margins*

CHRISTOPHER R. TAPSCOTT
B.A., Swarthmore College
Special Field: Marine Geophysics
Dissertation: *The Evolution of the Indian Ocean Triple Junction and the Finite Rotation Problem*

Doctor of Science

PAUL W. MAY
B.S., Southern Missionary College
Special Field: Physical Oceanography
Dissertation: *Analysis and Interpretation of Tidal Currents in the Coastal Boundary Layer*

Oceanographic Engineer

JAMES R. BROOKS
A.B., B.S., University of Southern California
Special Field: Oceanographic Engineering
Dissertation: *Intake Flow Fields for a Zooplankton Pump Sampling System*

MATTHEW N. GREER
B.S., Stanford University
Special Field: Oceanographic Engineering
Dissertation: *Development and Application of a Field Instrumentation System for the Investigation of Surf Zone Hydrodynamics*

DAVID R. MARTINEZ
B.S., New Mexico State University
Special Field: Oceanographic Engineering
Dissertation: *Algorithm for Computation of the Acoustic Plane-Wave Reflection Coefficient of the Ocean Bottom*

JOHN D. ZITTEL
B.S., Pennsylvania State University
Special Field: Oceanographic Engineering
Dissertation: *Ocean Basin Reverberation*

Woods Hole Oceanographic Institution Doctoral Program

Doctor of Philosophy

PHILIP M. GSCHWEND
B.S., California Institute of Technology
Special Field: Chemical Oceanography
Dissertation: *Volatile Organic Compounds in Seawater*

Dean's Comments

VICKY CULLEN

Dean Hollister

THIS brief report comes at a transition period in the Education Office and follows last year's complete review by my predecessor, Robert W. Morse, of our first decade of formal education.

The graduate program continued at a healthy pace during 1979. Our applicant pool was up slightly over the previous year and the acceptance ratio was very close to our usual three to one. Total graduates of the Joint Program and the Woods Hole Doctoral Program reached 97 with the awarding of six joint doctoral degrees, four joint engineer's degrees, and one WHOI Ph.D.

Thanks to the enthusiastic response to our Summer Student Fellowship Program by the Institution's Associates, we were able to reach a new high of 20 Summer Fellows. The Associates provided the financial support for nearly three-quarters of the fellowships granted to these advanced and highly qualified undergraduate students.

Our second year of providing 12-week traineeships to undergraduate members of minority groups was again successful, though possibly too small in size to be as effective as we would like. We hope to continue and expand this modest program of exposing minority students to marine science and will be seeking financial support from both private and Federal sources during the coming year.

We continue to support a healthy postdoctoral fellowship program in oceanographic sciences, engineering, and marine policy.

We feel particularly pleased with the appointment of Joseph Pedlosky as the Henry and Grace Doherty Professor of Oceanography. He brings to the Institution a strong commitment to graduate education and a distinguished record of contributions to the field of dynamical oceanography.

Also in 1979, a Joint Program Review Committee was initiated by the Provosts of both MIT and Woods Hole in order to reassess the joint educational efforts of these institutions. This group, whose report will be complete in the spring of 1980, consists of Professors Arthur B. Baggeroer and John B. Southard of MIT, Drs. Richard H. Backus and Geoffrey Thompson of WHOI, and is cochaired by the writer of this report and Kenneth R. Wadleigh, the Dean of the Graduate School at MIT.

Over the next year we plan to complete a review of the Joint Program and issue the final report. Nearly 50 of the staff from both institutions, all of the current 87 students, and all department heads involved in the Joint Program have been interviewed by joint teams, and the nearly 100 alumni were polled by mail.

Even at this early stage, there are some clear signals emerging from this review. Most important, there is strong support within both institutions for the Joint Program in its present form, a relatively small yet prestigious and select program. The students are unanimous in their desire to keep the program flexible enough to allow for individual treatment and freedom of choice of research programs.

In May of 1980 the Deans from the nine major oceanographic institutions most involved in Ph.D.-level education will meet in Woods Hole to discuss some of the many mutual problems in this expensive field of education. Graduate student support, job placement, and the asymmetry in numbers of qualified applicants among the different disciplines will be included as discussion topics.

I am very excited about the potential that lies ahead for Woods Hole's unique educational programs and, naturally, quite agree with President Carter who recently stated that . . . "The Woods Hole Oceanographic Institution has become a leading center of worldwide oceanographic research and education".

Charles D. Hollister
Dean of Graduate Studies

Ashore & Afloat

ONE of the major considerations at the winter meeting of the Corporation, held 9 January at the American Meteorological Society Headquarters in Boston, was planning for oceanography in the 1980s and attendant development needs. Director John H. Steele discussed scientific directions for the 1980s, and Trustees' Development Committee Chairman Noel B. McLean announced a development goal of $51 million.

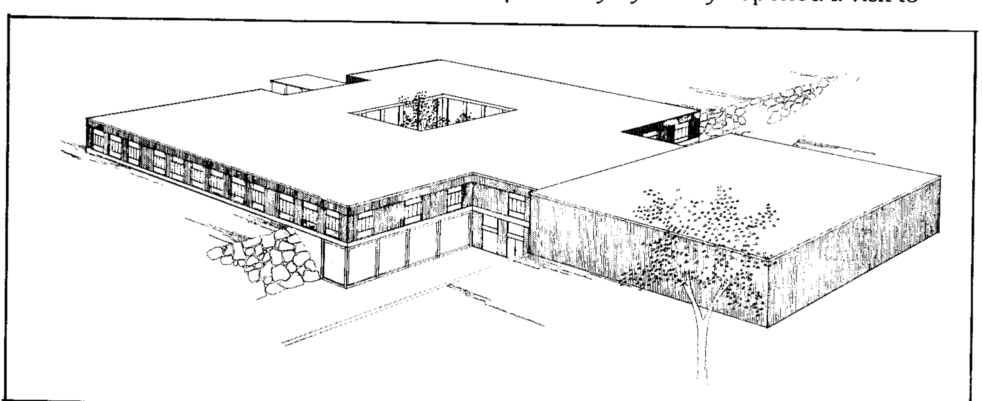
A grant of $1,550,000 from the Fleischmann Foundation was announced by President of the Corporation Paul M. Fye toward construction of a Geosciences Research Center on the Quissett Campus. Ground was broken for the new building in June, and construction was begun later in the year by Wescott Construction Company. The building will house the deep-sea sample collection, laboratories, and the Institution archives.

Atlantis II was towed 16 January to a Fall River shipyard for a major overhaul and conversion from steam to diesel power. The conversion kept the ship out of service until early October when she embarked on a 15-month voyage for work largely in the southern Atlantic.

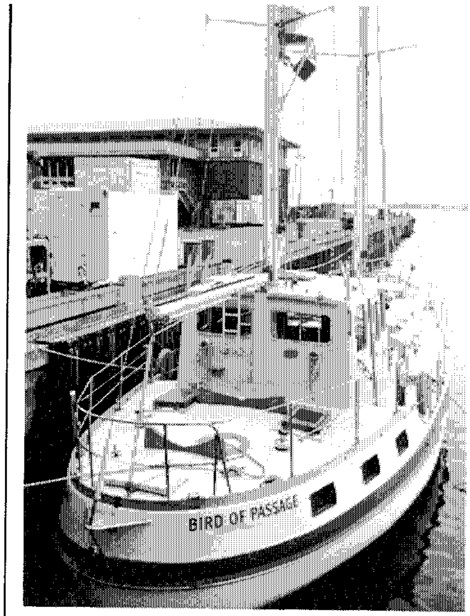
A February announcement from the National Aeronautics and Space Administration revealed that the four space shuttles planned for construction over the next few years would be named for exploration and research vessels. The fourth name listed was *Atlantis,* for the Institution's first research vessel, and the other three were *Columbia, Challenger,* and *Discovery.*

"Poster session" displays introduced Institution research vessels and several scientific projects to Associates attending the three annual spring dinners in Boston, New York, and Woods Hole. A new National Geographic film entitled "Our Dynamic Earth" and featuring work with *Alvin* at deep ocean spreading centers was shown after dinner.

Among the many visitors to the Institution during 1979 were Rear Admiral Albert J. Baciocco, Jr., Chief of Naval Research; Richard A. Frank, Administrator of the National Oceanic and Atmospheric Administration (NOAA); and Dr. Dirk Frankenburg, Division Director of the Ocean Sciences Division of the National Science Foundation. U.S. Representative Gerry Studds, Chairman of the Subcommittee on Oceanography of the House Committee on Merchant Marine and Fisheries, visited several laboratories and met with Marine Policy staff members in August. Russian, Japanese, and Chinese delegations visited at various times during the year, and the Ambassador to the United States from the Government of the Ruandiase Republic came to discuss work done by Institution staff several years ago on Lake Kivu's methane gas potential. Semi-annual presentations were organized for members of the Institution's Ocean Industry Program and the Naval Staff College foreign officers' course. Meetings on aquaculture and mariculture were held in Woods Hole under the auspices of the International Federation of Institutions for Advanced Study. A welcome and overview of the Woods Hole scientific community by Dr. Fye opened a visit to



Drawing of the new Geosciences Research Center.



SHELLEY LAUZON

Bird of Passage at the Woods Hole pier.

Woods Hole village by some 500 delegates attending the World Council of Churches World Conference on Faith, Science, and the Future held at MIT.

R/V *Oceanus* rescued two sailboat crews in distress during June. On 21 June, two young Canadian dentists were taken aboard north of Bermuda along with their 24-foot sloop *Solace* which had been severely damaged by lightning. On 26 June, two young men were rescued as they abandoned the 36-foot sloop *Troll-Fjord* which was taking on water 300 miles southeast of New York.

R/V *Chain* left Woods Hole harbor for the last time 2 June, when she was taken under tow to the U.S. Navy Inactive Ship Facility in Portsmouth, VA, and the 26-foot motorboat *Nobska* was sold by auction in August.

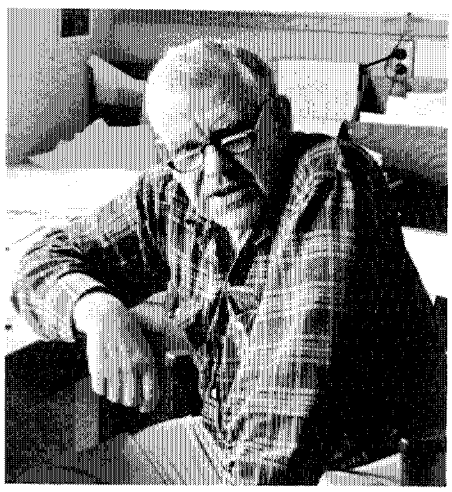
Associate Percy Chubb II, a well-known yachtsman, donated the 50-foot ocean cruising motor yacht *Bird of Passage* to the Institution in late summer. The sail-assisted vessel was used for several whale observation trips during the year.

Replacement for the nearly 50-year old *Asterias* was delivered 21 November. The boat is expected to be in use by mid-1980. At 46-feet, the new boat is a bit larger than the old *Asterias* (40 feet). She has a 15-foot beam, 5-foot draft, cruises at 12 to 14 knots, and has a maximum speed of 17 knots.

Senior Scientist Henry M. Stommel received the 1979 Alexander Agassiz

Medal from the National Academy of Sciences for his "major advances in the understanding of ocean circulation and of distribution of water masses." Senior Scientist John H. Ryther received an honorary doctor of science degree at spring commencement exercises of Plymouth State College in New Hampshire. One of the world's leading aquaculture experts, Ryther was honored for his outstanding contributions to production of food from the sea. Senior Scientist Peter Rhines received the medal of the University of Liege in 1979.

Senior Scientist David A. Ross was named to the Advisory Committee on Law of the Sea by the U.S. State Department and was assigned to the Freedom of Scientific Research Subcommittee.



VICKY CULLEN

Henry Stommel received 1979 Agassiz Medal.

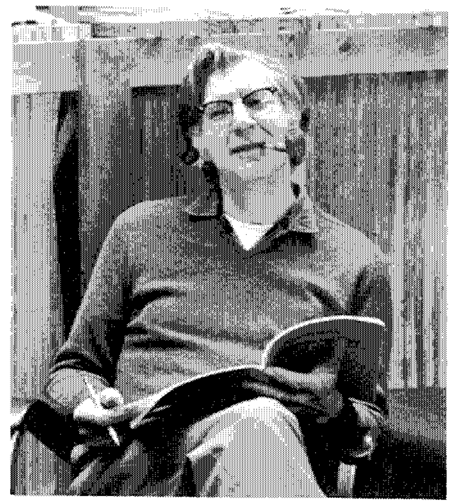
Dr. Charles D. Hollister was named Dean of the Institution's graduate education program replacing Dr. Robert W. Morse, who joined the staff of the Ocean Engineering Department and continues as Director of the Marine Policy and Ocean Management Program.

Members attending the Annual Corporation meeting 21 June heard discussions of plans for organizing coastal studies and marine systems analysis centers within the Institution and of the need for new facilities to meet the demands of sophisticated biogeochemical studies.

June 1979 marked the 15th anniversary of the dedication of DSRV *Alvin*. The 4,000-meter sub just missed also making her 1,000th dive in 1979 — that event happened 15 January 1980 on the Galapagos Rift during a series of dives for NOAA scientists.

Andrew F. Bunker

30 October 1916 – 28 August 1979



VICKY CULLEN

Andrew F. Bunker, Meteorologist in the Department of Physical Oceanography, died Tuesday, August 28, in Boston, of leukemia. His pursuit of his first interest, astronomy (in which he published two papers), was interrupted by World War II and training as a meteorologist as a Captain in the U.S. Army. In 1946 he came to Woods Hole to work with Jeffries Wyman on the results of fundamental field study of cumulus convection in the tropics, and there followed six papers on various aspects of this problem. Andy's interest then turned to development and use of airborne instrumentation to measure turbulent fluxes of heat, water, and momentum from WHOI operated aircraft, beginning with a PBY and ending with a DC-3. In the years 1955-1972 he carried out a series of pioneering studies of air-mass modification observations, using these instruments, in cold outbreaks over the Gulf of Maine, in the monsoons of the Indian Ocean, over the tropical Pacific, and during the mistral of the Northwest Mediterranean. Beginning about 1973 Andy began a comprehensive program of computation, from the complete historical archives of individual marine weather reports, of surface energy flux of the world oceans. His five published papers on this subject, which today is of considerable social concern, were, it seems, only the beginning of a long series of systematic studies which he had planned for this material.

Henry Stommel

Ambassador Elliott Richardson, Special Representative of the President to the Law of the Sea Conference, presented the 11th J. Seward Johnson Marine Policy Lecture 1 June. He discussed "Marine Scientific Research and the Law of the Sea: The Fight for Freedom of Inquiry."

Retiring Senior Scientists Kenneth O. Emery and Allyn C. Vine were honored at a June reception in the Clark Laboratory. Their combined active service totaled 56 years. Both were named Scientist Emeritus.

With bands playing and banners waving, R/V *Knorr* returned to home port in August at the completion of a 19-month Pacific voyage. The ship traveled 55,820 nautical miles in 571 days on this research cruise. Captain Emerson Hiller compiled a set of birthday statistics when the ship passed the nine-year

BRADFORD BRAYTON, FALMOUTH ENTERPRISE

R/V *Knorr* comes home after long Pacific research voyage.

milestone 15 April, and noted she had traveled 263,977 miles — like steaming to the moon at 10 knots, he said, and already 25,000 miles along the route back to Woods Hole. He noted that *Knorr* had visited 28 foreign ports and noncontiguous territories and been host to 2,211 scientists.

A Special Advisory Committee made up of Corporation Members and individuals from business, government, and academia was convened in the fall to discuss Institution plans for the next decade. Their advice was sought on a range of questions encompassing basic research and educational objectives, social implications of science, and access to funding. Following two days of meetings with management, department chairmen, senior and junior staff, and representatives of the Graded and Marine Personnel Committee, the advisory committee prepared a report summarizing their recommendations.

The annual Associates' Day of Science brought more than 200 people to Woods Hole 5 October to hear four lectures in Redfield Auditorium, have lunch in yellow and white striped tents on the waterfront, and watch the presentation of the third WHOI Ph.D. to Dr. Philip Gschwend.

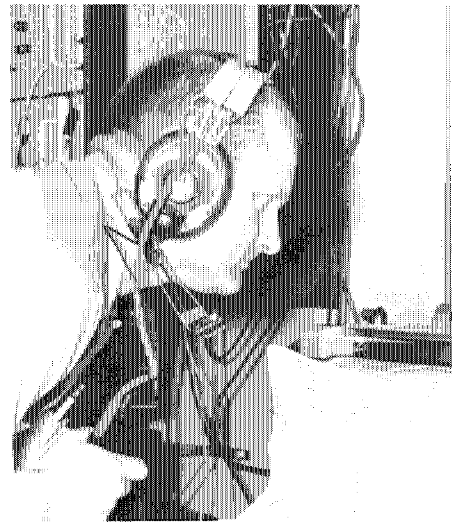
Thirty-year pins were presented 7 December to Senior Scientist Elizabeth Bunce and former Port Captain John Pike. Fifteen retirees were also recognized at the ceremony.

The Graded and Marine Employees Committee sponsored a float in the Falmouth "Christmas by the Sea" parade. Following the theme "Home for Christmas," a variety of sea creatures ranging from an octopus and a seaweed monster to mermaids and scuba divers rode or skipped along beside an ancient dory dubbed R/V *Noel*. The float took a first place trophy.

As the year ended, Institution staff and friends were looking forward to a variety of 50th anniversary events planned and organized during 1979 for a festive 1980.

Sydney T. Knott

9 August 1922 – 15 March 1979



CARL HIGH

Sydney T. Knott, Jr., 'Bud' to all who knew him, Research Specialist and Hydroacoustics Engineer in the Geology and Geophysics Department, died in March 1979, at age 56, following a long illness.

Bud was initially employed at the Institution on J. B. Hersey's project B-16 in 1946. He started college at Bowdoin, went into the Navy V-12 program and spent four years in the Pacific as a naval officer in destroyers, then returned to the Cape to build boats with his brother Dan. He attended Tufts and Massachusetts Teachers' Colleges, accumulating more than enough credit hours for a bachelor's degree but never was (in his own words) able to take a year away from work to satisfy the residence requirement.

He is considered to be the father of modern echo sounding at WHOI, having held primary responsibility for the concept of the Precision Graphic Recorder (PGR), developed with Whitey Witzell in the early fifites.

With others of the 'Hersey Group,' Bud responded to the Navy's request for assistance in searching for the submarine *Thresher*. Using the high resolution capabilities of the PGR and "towed" pinger-camera assemblies, the team made the first photos of debris associated with the wreck.

As a direct result of the *Thresher* search, in April of 1964, Paul N. Nitze, then Secretary of the Navy, awarded Bud the Navy Meritorious Public Service Citation for his valuable contributions to the Department of the Navy in the field of scientific investigation. This is one of the highest honors which the Navy can grant a civilian.

As an engineer, his attention to detail was legendary. He would work for hours (and days) on problems of design to insure their stability, durability, and accuracy. For all who worked with him or around him, he was an excellent teacher, always willing to take the time to explain a given situation and to work out the eventual solution. As a hydro-acoustics engineer, he not only designed equipment to gather data, but went to sea with it and then worked up the data. His knowledge of geology and geophysics went far beyond that of an engineer.

Bud's meticulous attention to the needs of underwater acoustics/geophysics is not easily replaced.

Betty Bunce

JOHN SHECKLE STANDARD-TIMES

Roger Mann discusses shellfish research with C.C. Woo (USGS), left, and other Chinese visitors.

SHELLEY LAUZON

The new *Asterias* in Eel Pond.

VICKY CULLEN

R/V *Knorr* was one of the main attractions during the 1979 Associates' Day of Science.

SHELLEY LAUZON

Jim Sanders introduces visitors to the work of the Environmental Systems Laboratory during Day of Science.

Publications

Publications of record as of 10 March 1980. Institution contribution number appears at end of each entry.

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TOM BOLMER

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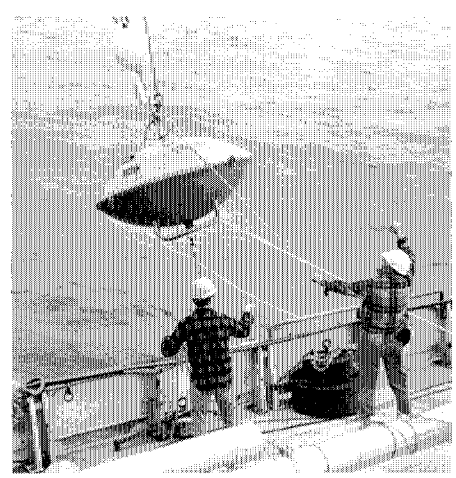

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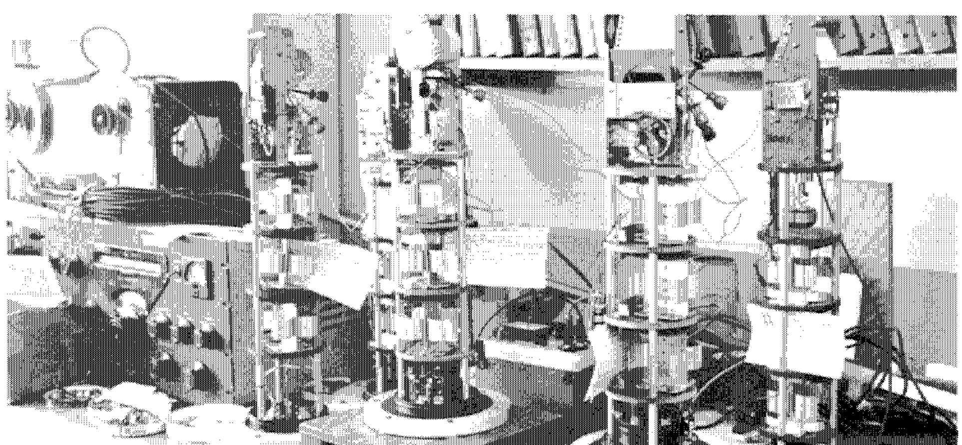
Marine Policy & Ocean Management

K. O. Emery and R. D. Catchings. Exports of Nations. *Geoforum*, 10:141-149. 1979. No. 4467

John H. Steele. Some Problems in the Management of Marine Resources. In: *Appl. Biol.*, T. H. Coaker, ed., Academic Press, IV:103-140. 1979. No. 4073



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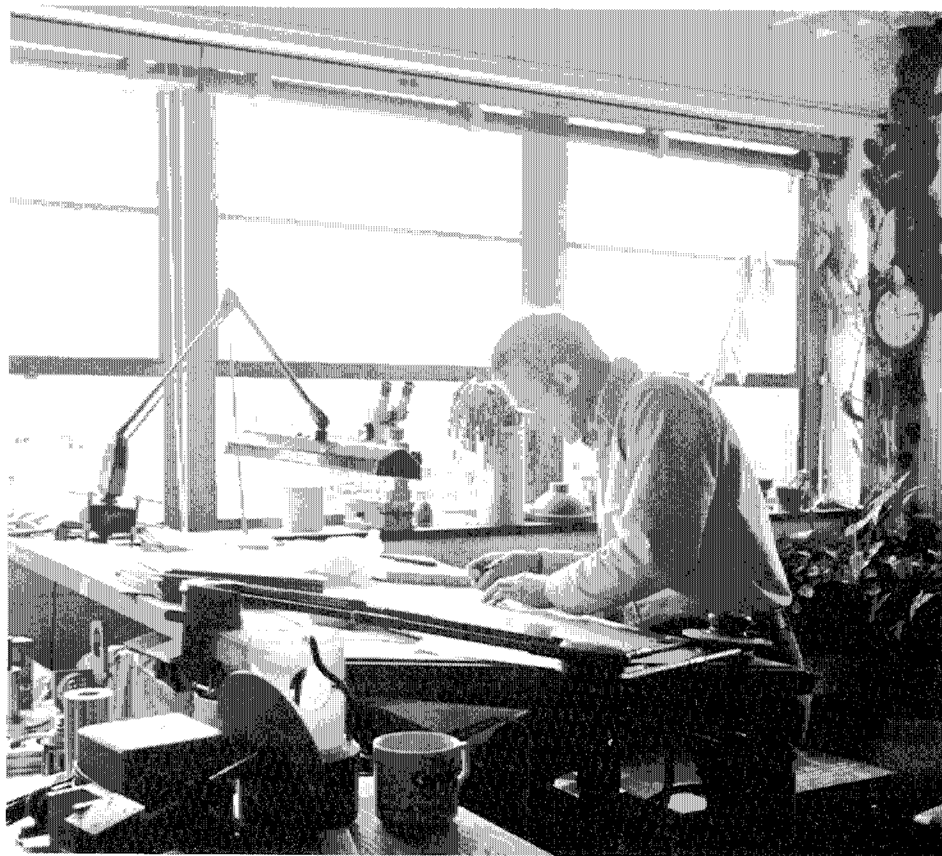
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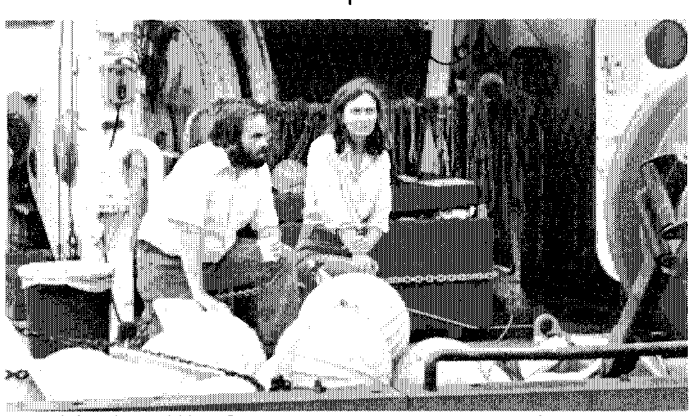
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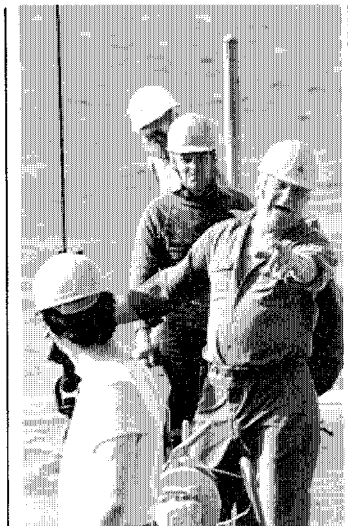
William G. Gubbins
Carol A. Gunter
Mark V. Hickey
Robert J. Hindley
Howard A. Holland
Mary Jane Januszkiewicz
Lawrence M. Johnson
Robert F. Kelley
Percy L. Kennedy, Sr.
Donna H. Keyser
Andrea F. Lawson
Lonnie Lewis
Stella J. Livingston
Samuel J. Lomba
Donald J. Martin
Roland G. Masse
Edwin McGuire
Clarence R. McNiel
Frank Medeiros
Dorothy Meinert
Juanita A. Mogardo
Patricia A. Mogardo
Cynthia Moor
Beverley Morrison
Joseph F. Motta
Jay R. Murphy
Michael S. Murphy
Kim M. Oliver
Charles E. Pacheco
Kenneth A. Pacheco
James P. Philbrick
#Eugene A. Pineault
John M. Ranney
Laurie A. Raymond
John E. Rice
Eben A. Sage
Albert Santiago, Sr.
Mark A. Servis
Roland R. Simmons
Donald P. Souza
John W. Stimpson
#James A. Swan
Jean D. Walker
Robert Wichterman
John C. Williams
Ronald E. Woods
Jeffrey A. Zwinakis

#Disability Leave of Absence
+Leave of Absence

Facilities and Marine Operations Staff

Robertson P. Dinsmore	*Chairman, Facilities and Marine Operations Department*
John P. Bizzozero	*Chief Engineer, R/V ATLANTIS II*
Edward L. Bland, Jr.	*Research Associate*
David F. Casiles	*Master, R/V ATLANTIS II*
Richard H. Dimmock	*Port Engineer*
John D. Donnelly	*Manager, ALVIN/LULU Operations*
Richard S. Edwards	*Marine Superintendent*
George G. Ellis	*Pilot, DSRV ALVIN*
Emerson H. Hiller	*Master, R/V KNORR*
Ralph M. Hollis	*Pilot, DSRV ALVIN*
Paul C. Howland	*Master, R/V OCEANUS*
Bernard E. Kilbreth	*Chief Engineer, R/V LULU*
David G. Landry	*Master, R/V LULU*
Jonathan Leiby	*Naval Architect*
Barrett H. McLaughlin	*Chief Engineer, R/V KNORR*
Paul R. Mercado	*Chief Engineer, R/V OCEANUS*
James R. Mitchell	*Manager, Facilities*
Donald A. Moller	*Marine Operations Coordinator*
David M. Owen	*Diving Supervisor*
J. Paul Thompson	*Assistant Facilities Manager*



JAMES DOUTT

Oceanus Bosun Whitey Warecki gives orders; others, left to right, are Fred Schuler, Dick Nowak, and Rick Simpkin.

KEITH BRADLEY

Bobby Weeks

Facilities Personnel

Edward F. Acton
Ernest E. Baker
Richard W. Bowman
Frederick A. Brauneis
Gustaf A. Carlson
Ernest G. Charette
Charles Clemishaw
Arthur Costa
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John P. Romiza
Thomas H. Smart
William R. Tavares, Jr.
Barbara M. Vallesio
David M. Ward
Robert G. Weeks
Haskel E. White
Carleton R. Wing
Martin C. Woodward
Carleton F. Young

Marine Operations

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Kittie E. Elliott
Carole R. Merson
Stephen G. Page

ALVIN/LULU Operations

Steven W. Allsopp
+Stephen S. Bates
+George F. Brady
George Broderson
Robert S. Brown
Wayne D. Cable
Lawrence P. Costello
#Keith A. Francis
Kevin C. Grady
Marc A. McAllister
Jack W. McCarthy
#William O. Monnick
Dariusz Nachtman
William F. Page
Joseph Ribeiro
Theodore W. Rubel
Margaret P. Stern
Jack T. Terry
#Gary J. Witty

Marine Personnel

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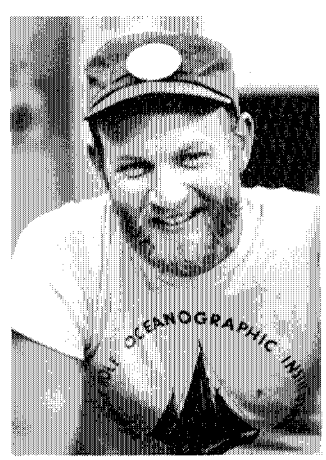
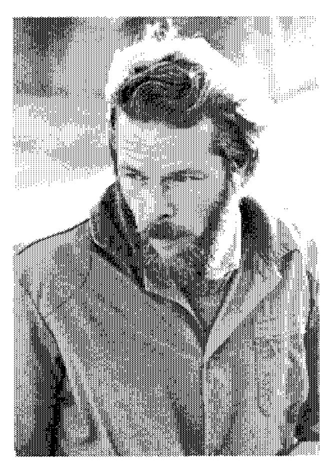
Mitchell G. Barros
Kenneth E. Bazner
Edward J. Brennan
Edward R. Brodrick
+Harry F. Clinton
Arthur D. Colburn, Jr.
Martha A. Coneybear
Jerome M. Cotter
Shane P. Crosby
+Arthur J. Dunn
Aaron W. Edwards
William A. Eident
Ellen R. Farris
#Eugene Fortes
Gilberto B. Garcia
John M. Gassert
Robert L. Gordon
Richard M. Hanley
David L. Hayden
Henry P. Hirschel
John S. Hurder
Albert C. Jefferson
John P. Kamataris
John K. Kay
John J. Kennedy
Millard Klinke
John T. Lobo
Tomas M. A. Macedo
Mark T. Maloof
John W. Martin
Robert P. Martin
David H. Megathlin
Robert G. Munns
George E. Murphy
Harry E. Oakes
#Conrad H. Ocampo
+Thomas F. O'Neil
John A. Osburn, Jr.
Michael Palmieri, Jr.
George E. Pierce
Samuel F. Pierce
Jason M. Polsky
Harry Rougas
Thomas C. Sheeran
Janice M. Simmons
Richard F. Simpkin
Charles E. Small
Ernest G. Smith, Jr.
Emilio Soto
Harry H. Stanton
John K. Sweet, Jr.
Frank D. Tibbetts
Steven F. Tomkiewicz
Joseph Warecki
+Michael J. Zukovich



KENNETH HINGA, LDGO

Tom Sheeran



JAMES DOUTT

Don Moller

Fellows, Students & Visitors

Postdoctoral Scholars 1979-80

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Joint Program Students Bill Dewar and Teri Chereskin, left and right, and MIT student Yun Chi Tseng attend class in Surface and Internal Gravity Waves.

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Phyllis M. Hayes
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Sharonetta L. McIntyre
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Elijah White
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Jackson State University

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Wim Twight
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Peter Worcester
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Denise M. Boyle
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Michael E. Carneglia
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Richard Grosberg
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A. Michelle Wood
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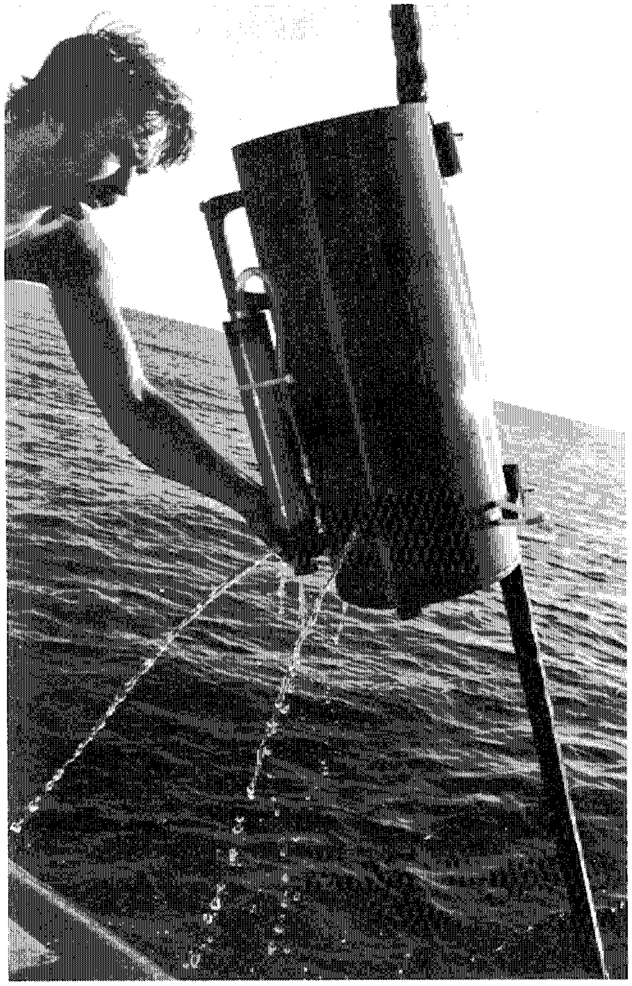
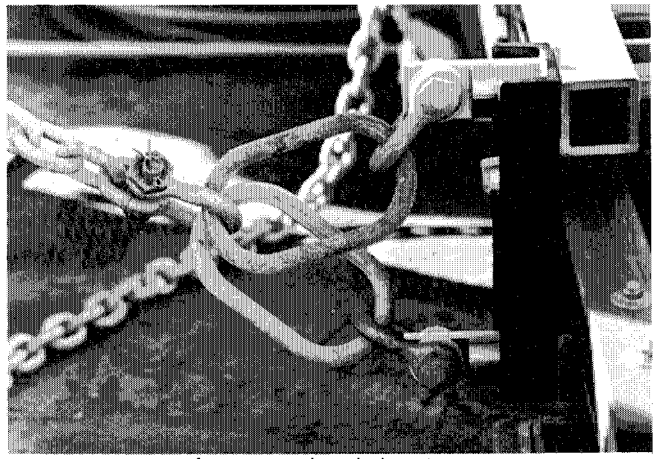
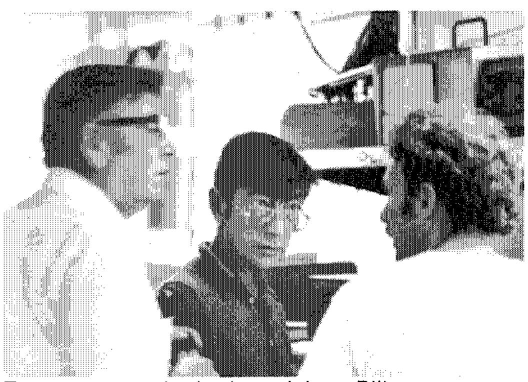

GEORGE TUPPER

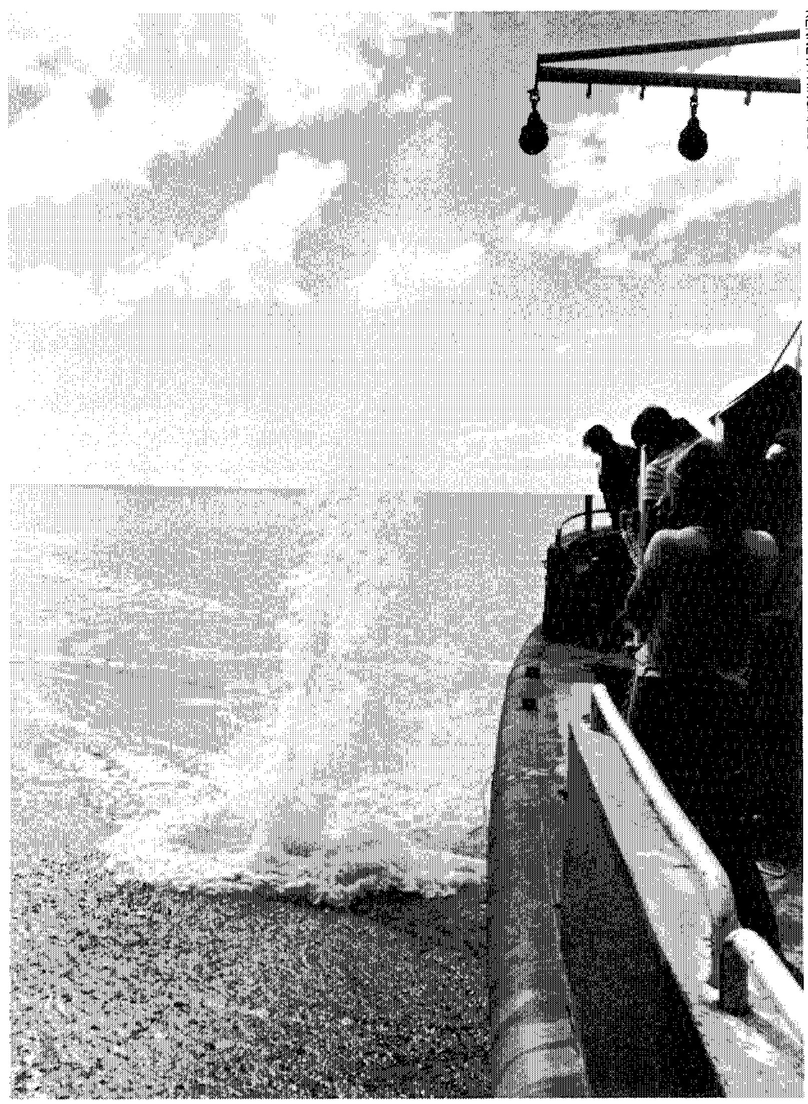
Scott Worrilow brings sediment trap aboard *Oceanus.*


KENNETH HINGA, LDGO

Bridle arrangement for a moored nephelometer.


KEITH BRADLEY

Tense moment in the buoy lab — Bill Horn, Joe Poirier, and Al Ciesluk.


KENNETH HINGA, LDGO

Mooring anchor makes a spectacular splash.

Voyage Statistics

R/V Atlantis II

Total Nautical Miles for 1979 — 10,933
Total Days at Sea — 84

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call	Chief Scientist
	16 Jan	Fall River, MA, Shipyard for conversion from steam to diesel power		
	23 June-24 June	Jersey City, NJ, Shipyard for continuation of conversion		
	9 Aug-10 Aug	Return to Woods Hole for continuation of conversion		
	18 Sep	Sea Trial	Woods Hole	
106	23 Sep-26 Sep	Sea Trial	Woods Hole	Edwards
	2 Oct	Coast Guard Trial	Woods Hole	
	5 Oct	Coast Guard Trial	Woods Hole	
107-I	9 Oct-5 Nov	Beta Spiral Survey to obtain more representative measurements of isopycnal slopes near 30°N, 30°W for absolute velocity calculation	Fortaleza, Brazil	Stommel
107-II	14 Nov-3 Dec	Moored and hydrographic observations in Vema Channel to measure the flux of Antarctic bottom water and the dynamics of flow through passages	Mar del Plata, Argentina	Hogg
107-III	10 Dec-12 Jan	Study of intense frontal zone forming at the confluence of the Brazil and Falkland Currents	Punta Arenas, Chile	Gordon (LDGO)

R/V Knorr

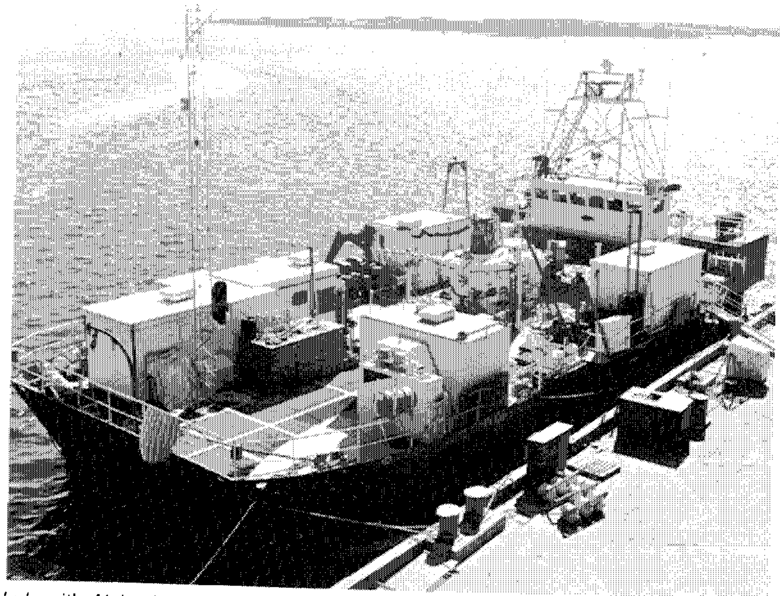
Total Nautical Miles for 1979 — 26,366
Total Days at Sea — 208

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call	Chief Scientist
73-XIII	15 Jan-8 Feb	Transit from New Zealand to Hawaii with study of long-distance dispersal of the pelagic larvae of benthic species and gravity sections	Wellington, NZ Honolulu, Hawaii	Goldsborough
73-XIV	1 May-30 May	IDOE Manganese Nodule Program: Investigation of transition metal fluxes at the sea floor using bottom instrument arrays in the central eastern Pacific	Honolulu	Lyle (Stanford) Lowenstein, Rossen (SIO)
73-XV	4 Jun-26 Jun	Manganese Nodule Program continued, participation in Global Weather Experiment	Balboa, Panama	Dymond (OSU)
73-XVI	1 Jul-22 Jul	Acquisition of data on rates of vertical transport and boundary adsorption of certain trace metals and naturally occurring radionuclides, geochemistry of sediment interstitial waters, and oceanic carbon dioxide system	Balboa, Panama	Brewer
73-XVII	25 Jul-9 Aug	Sediment Trap Intercomparison Experiment	Balboa, Panama	Spencer
73-XVIII	12 Aug-21 Aug	Transit to Woods Hole with underway sampling	Woods Hole	
74	7 Sep-3 Oct	Detailed reconnaissance of temporal and spatial variability of high-energy fluid events and the resulting sedimentary bedforms on the Scotian Continental Rise (High Energy Benthic Boundary Layer Experiment)	Woods Hole	Hollister
75	12 Oct-7 Nov	Recover POLYMODE Clusters A and B on the Mid-Atlantic Ridge and deploy 8 moorings for Gulf Stream Extension/Norwegian Sea Outflow Intrusion Experiment	Woods Hole	Tupper
76	3 Dec	Perth Amboy, NJ, Shipyard		
	18 Dec	Return to Woods Hole		

R/V Oceanus

Total Nautical Miles for 1979 — 31,183
Total Days at Sea — 232

Voyage	Cruise Period	Principal Objectives, Area of Operations	Ports of Call	Chief Scientist
53	23 Jan-26 Jan	Sample collection for work on metabolism, effects of pressure, and swimbladder structure in fishes and radionuclide and heavy metal content of seawater	Woods Hole	Clifford
54	29 Jan-1 Feb	Buoy and mooring recovery in Great South Channel	Woods Hole	Vermersch
55	6 Feb-26 Feb	Study of mid-water fish distribution and their interaction with circulation in cold-core rings, warm eddies, slope water, and Gulf Stream	Woods Hole	Backus
56	6 Mar-15 Mar	Mooring deployment and recovery, various measurements for a continuing study of currents and sediment transport on the U.S. east coast continental shelf	Woods Hole	Butman (USGS)
57	17 Mar-22 Mar	Mooring deployment	Woods Hole	Vermersch
58	27 Mar-29 Mar	Mooring deployment	Woods Hole	Butman (USGS)
59	11 Apr	Newport, RI, Shipyard		
	19 Apr	Return to Woods Hole		
60	22 Apr-28 Apr	Acoustic work in and around the Gulf Stream	Woods Hole	Spindel
61	1 May-7 May	Atlantic coastal ecosystems study	Woods Hole	Walsh (Brookhaven)
62	8 May	Benthic chamber recovery	Woods Hole	Tripp
63-I	14 May-29 May	Acoustic/hydrographic studies in the Gulf Stream, around Bermuda, and around 28°N, 70°W	St. George, Bermuda	Price (URI), Bradley
63-II	1 Jun-15 Jun	Continuation of acoustic work, mooring recovery	Woods Hole	Schmitz, Bradley
64	25 Jun-6 Jul	Microbiological deep water sampling using conventional and high pressure sampling gear in the northwest Atlantic	Woods Hole	Jannasch
65	9 Jul-13 Jul	Equipment testing and measurement of velocity structure in western boundary undercurrent	Woods Hole	Williams
66-I	17 Jul-26 Jul	Recovery of 10 moorings in POLYMODE Local Dynamics Experiment	Woods Hole	Tupper
66-II	1 Jun-15 Jun	Mooring recovery	Woods Hole	Tupper
67	6 Aug-13 Aug	Recovery and deployment of moorings for current and sediment transport studies	Woods Hole	Butman (USGS)
68	17 Aug-30 Aug	Measurement of factors controlling the color of the sea surface as related to satellite imagery (with brief stop at West Boothbay Harbor, ME)	Woods Hole	Yentsch (Bigelow)
69	4 Sep-13 Sep	Microbiological deep water sampling	Woods Hole	Wirsen
70	17 Sep-21 Sep	Field operations for Nantucket Shoals experiment	Woods Hole	Vermersch
71	28 Sep-2 Oct	Deep water drop tests of air deployed oceanographic moorings	Woods Hole	Walden
72-I	6 Oct-11 Oct	Underwater acoustics experiment near Bermuda	St. George, Bermuda	Spindel
72-II	12 Oct-25 Oct	Continuation of underwater acoustics work	Woods Hole	Frisk
73	29 Oct- 9 Nov	Determination of the concentration, distribution, and activity of cyanobacteria in the Sargasso Sea	Woods Hole	Watson
74	16 Nov-25 Nov	Sediment and interstitial water sampling for geochemical studies	Woods Hole	Farrington
75	29 Nov-4 Dec	Sampling for studies of the environmental physiology of oceanic phytoplankton	Woods Hole	Guillard
76	7 Dec-11 Dec	Hydrographic and XBT stations across Gulf Stream at 68°W	Woods Hole	Worthington
77	13 Dec-19 Dec	Mooring recovery and deployment for Georges Bank sediment transport studies	Woods Hole	Butman (USGS)



VICKY CULLEN

Lulu with *Alvin* aboard in home port.

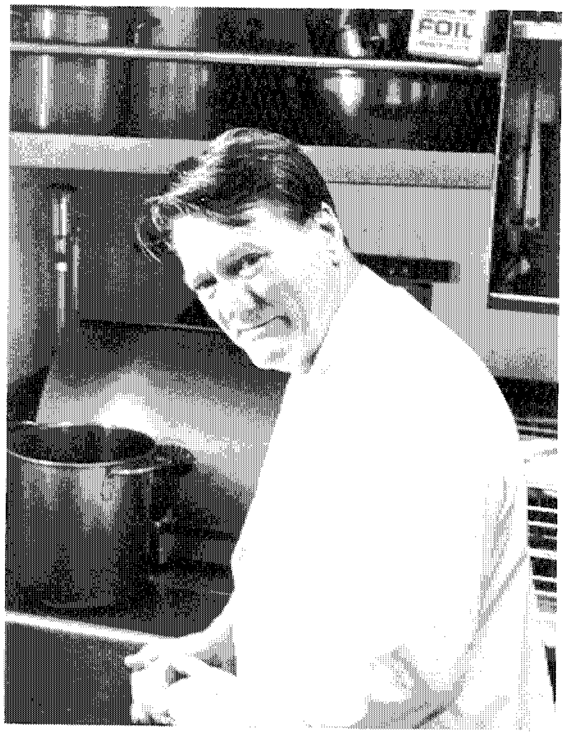
DSRV Alvin and R/V Lulu

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 1979 — 17,409

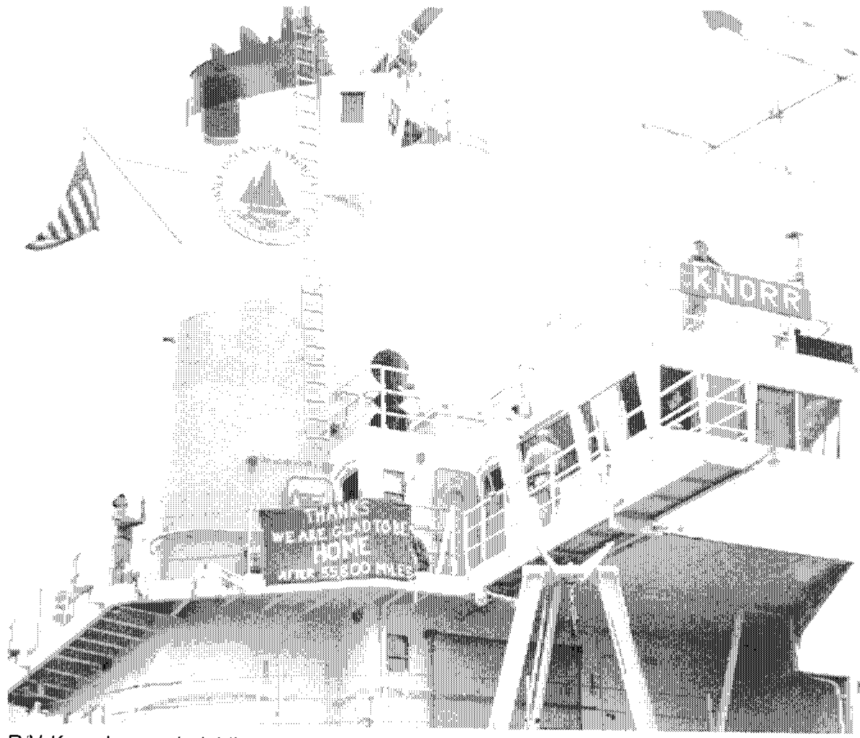
Total Days at Sea — 228
Total Dives — 117

Lulu Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Port of Call*	*Chief Scientist*
102-VII	3 Jan-10 Jan	Transit from Roosevelt Roads, Puerto Rico	Balboa, Panama	
102-VIII	14 Jan-31 Jan	9 dives for biological work in the warm-water vent areas on the Galapagos Rift	Balboa, Panama	Grassle
102-IX	6 Feb-26 Feb	11 dives for geological work on the Galapagos vents	Balboa, Panama	Ballard
102-X	3 Mar-21 Mar	9 dives for geochemical work on the Galapagos vents	Balboa, Panama	Edmond (MIT)
102-XI	23 Mar-6 Apr	Transit from Balboa, Panama	Mazatlan, Mexico	
102-XII	10 Apr-27 Apr	13 dives for geophysical work including magnetic, seismic, and gravity investigations on the East Pacific Rise; discovery of hot vents	Mazatlan, Mexico	Spiess (SIO)
102-XIII	2 May-13 May	7 dives continuing work of previous leg	Mazatlan, Mexico	Macdonald (SIO)
102-XIV	15 May-21 May	Transit from Mazatlan, Mexico	San Diego, CA	
102-XV	12 Jun-14 Jun	1 dive in the Catalina Basin for work on metabolism of benthic organisms	San Diego, CA	Smith (SIO)
	16 Jun-29 Jun	13 dives continuing work in Catalina Basin	San Diego, CA	Smith (SIO)
	24 Jul	1 training dive	San Diego, CA	Donnelly
102-XVI	27 Jul-3 Aug	7 dives to study geological characteristics off California coast and survey potential terminal site	Port Heuneme, CA	Kennedy (State of CA) Greene (USGS)
102-XVII	7 Aug-14 Aug	8 dives for benthic organism studies, equipment testing	San Diego, CA	Childress (UCSB) Takahashi (LDGO)
102-XVIII	21 Aug-31 Aug	5 dives for NOAA's Deep Ocean Mining Environmental Survey	San Diego, CA	Swift (NOAA)
102-XIX	4 Sep-10 Sep	9 dives for studies of mid-water gelatinous zooplankton	San Diego, CA	Harbison Madin
102-XX	13 Sep	Transit from San Diego, CA	Long Beach, CA	
103-I	5 Oct	Transit from Long Beach, CA	San Diego, CA	
103-II	13 Oct-28 Oct	8 dives for work on the geology of the Tamayo Fracture Zone	Mazatlan, Mexico	Fox (SUNY)
103-III	30 Oct-8 Nov	5 dives for geochemistry on the East Pacific Rise hot vents	Manzanillo, Mexico	Edmond (MIT)
103-IV	13 Nov-21 Nov	Transit from Manzanillo, Mexico	Puntarenas, Costa Rica	
103-V	25 Nov-~~15~~ 14 Dec	11 dives for biological work on the Galapagos Rift vents	Balboa, Panama	Grassle



JOSEPH KIEBALA, JR.

Sammy Pierce at work in the *Oceanus* galley.



SHELLEY LAUZON

R/V *Knorr* bears glad tidings of coming home from the Pacific.

VICKY CULLEN

Two WHOI ships tied up at the Woods Hole pier.

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VICKY CULLEN

Institution President Paul Fye addresses group assembled at ground breaking for the new Geosciences Research Center on the Quissett Campus. From left, John Heyl, Noel McLean, Dr. Fye, John Steele, Charles Adams, and Bob Dinsmore.

Eric G. Ball
12 July 1904 — 4 Sept. 1979

DR. Eric G. Ball became a Member of the Corporation in 1953 and served as a Trustee from 1953 to 1957. In 1954 and 1955, he also served as a member of the Executive Committee. He became an Honorary Trustee in 1976.

A well-known and highly regarded biological chemist, Dr. Ball was an Associate Professor at Johns Hopkins Medical School in the 1930s and led a distinguished career which culminated in his becoming the Edward S. Wood Professor Emeritus at Harvard Medical School in 1971. At the time of his death, he was still active in research, working on the isolation and identification of pigment in the eggs of horseshoe crabs in his laboratory at the Marine Biological Laboratory in Woods Hole. Dr. Ball had been a Member of the Corporation of the Marine Biological Laboratory since 1933 and served as a Trustee there from 1953 to 1957.

Dr. Ball's education included bachelor's and master's degrees from Haverford College and a doctoral degree in physiological chemistry from the University of Pennsylvania. He also held honorary degrees from Harvard University and Haverford College. In 1940 he received the Eli Lilly Award in Biochemistry, and in 1963 he was a Guggenheim Fellow at the Scripps Institution of Oceanography.

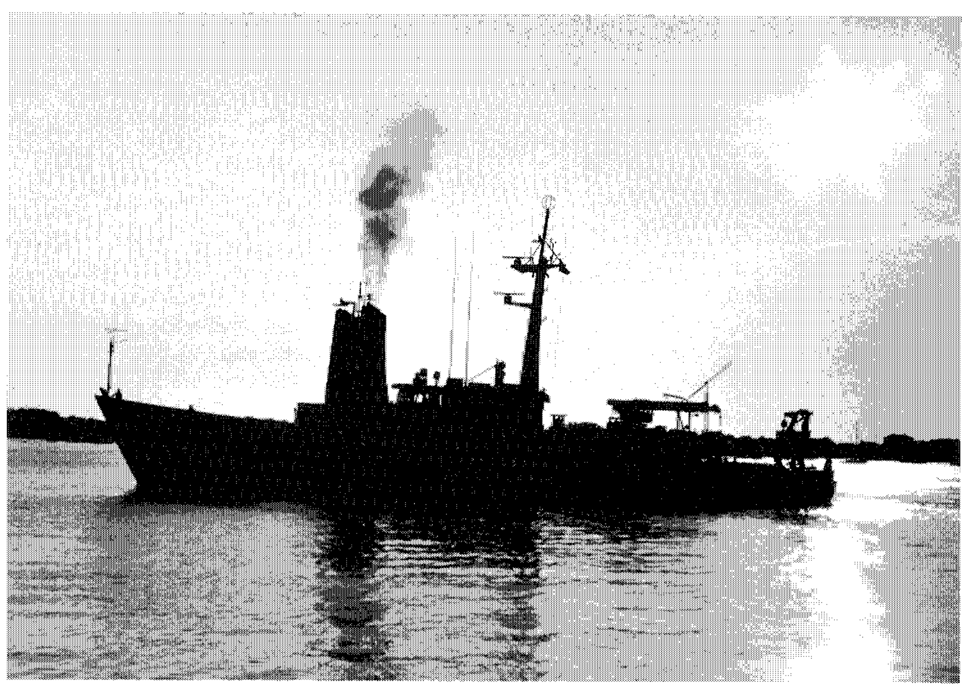
Gerard Swope, Jr.
13 Dec. 1905 — 27 Sept. 1979

GERARD Swope, Jr., was elected a Trustee and Member of the Corporation in 1952. He served four terms as a Trustee and was elected an Honorary Trustee in 1979.

In 1952 Mr. Swope was instrumental in establishing the Associates Program of the Woods Hole Oceanographic Institution. He became the organization's first president and served until 1955. His interest in Institution activities over the years was further manifested by active and faithful attendance at meetings and years of service on various committees.

Mr. Swope was educated at the Horace Mann School in New York and at Dartmouth College. After earning a law degree at Harvard University, Mr. Swope worked for the New York law firm of Cotton, Franklin, Wright and Gordon. He later moved to Washington, DC, to work for the Securities and Exchange Commission, and he served in the Navy at the Bureau of Personnel during World War II, attaining the rank of Commander. After military service, he joined the General Electric Company, where he retired as International Counsel in 1968.

Mr. Swope was President of the Marine Biological Laboratory from 1953 to 1963 and Chairman of the Board from 1963 to 1971. He was instrumental in the planning and design of new laboratories at MBL as well as the dormitory and dining hall that became the Swope Center, dedicated to him and his wife, Marjorie Park Swope, in 1971.



KEITH BRADLEY

Oceanus makes a handsome silhouette in Woods Hole harbor.

Sources of Support for Research & Education

University of Alaska
Alcoa Foundation
Alden Electronic & Impulse Recording Equipment Company, Inc.
George I. Alden Trust
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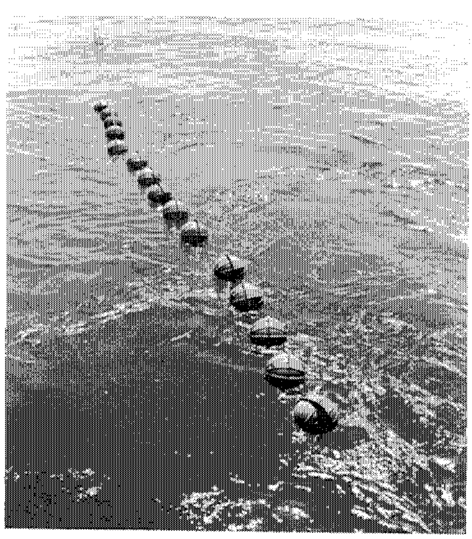

Mooring floatation extends to a radio float during buoy operations.

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- National Science Foundation
- Department of the Navy
  - Naval Research Laboratory
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The Warner-Lambert Foundation
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Plans were laid in 1979 for a major 50th anniversay fund-raising campaign for support of staff, students, new research directions, development of exploratory technology, and construction and endowment of research centers for work on the frontiers of oceanography. Noel B. McLean, former Chairman of the Board, is Chairman of the Development Committee.

There are lots of goodbyes in oceanography — Maxine Jones sees *Oceanus* off on a cruise.

Financial Statements

Financial Highlights

The Institution's total operating revenue increased 12% in 1979, compared with a 14% increase in 1978. Unrestricted income increased 39% in 1979, compared with 1% in 1978 and 11% in 1977. Gifts and short-term investment income accounted for nearly all of the 1979 increases.

In 1979, excess current unrestricted funds of $250,000 were transferred to Unexpended Plant Funds. In 1978, transfers of $314,000 to Plant and $25,000 to Quasi-Endowment were made from unrestricted current funds.

Funding for sponsored research was derived from the following sources:

	1979	1978	Increase (Decrease)
National Science Foundation	$14,364,000	$13,066,000	10%
Office of Naval Research	6,822,000	5,703,000	20%
Department of Energy	1,233,000	1,424,000	(9%)
National Oceanic and Atmospheric Administration	1,188,000	819,000	5%
Other Government	2,022,000	2,187,000	(9%)
Restricted Endowment Income	332,000	259,000	28%
Other Restricted Gifts and Grants	1,350,000	1,465,000	(8%)
	$27,311,000	$24,923,000	10%

Other statistics of interest are:

	1979	1978	Increase (Decrease)
Full-time Equivalent Employees	762	784	(3%)
Total Compensation (including overtime & employee benefits)	$16,223,000	$15,474,000	5%
Retirement Trust Contribution	1,680,000	1,504,000	12%
Endowment Income	1,997,000	1,820,000	10%
Additions to Endowment Principal	47,000	74,000	(36%)
Endowment Principal (year-end, at market value)	36,457,000	35,033,000	4%

Gifts and grants from private sources including the 1,171 Institution Associates totaled $3,851,000 in 1979 of which $2,971,000 was restricted as follows:

Laboratory Construction	$1,625,000
Coastal Studies Center Support	750,000
Marine Policy & Ocean Management	365,000
Biomedical Utilization of Sea Resources	62,000
Benthonic Foraminifera Studies	50,000
Addition to Endowment Principal	47,000
Education Program Support	21,000
Congress on the History of Oceanography	20,000
Benthic Boundary Layer Studies	20,000
Other Research Programs	11,000
	$2,971,000

Funds availed of in support of the Education Program were derived principally from endowment income received in 1979 totaling $947,000. In addition to funds restricted for education program support, unrestricted funds of $151,000 were utilized along with $311,000 in student support provided from research contracts and grants.

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

Joseph Kiebala, Jr.
Assistant Director for Finance and Administration
Edwin D. Brooks, Jr.
Treasurer
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 31 December 1979 and 1978, and the related statements of changes in fund balances, and of current fund revenues, expenses and transfers for the years then ended. Our examinations were made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the aforementioned financial statements present fairly the financial position of Woods Hole Oceanographic Institution as of 31 December 1979 and 1978, 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
4 April 1980

Balance Sheets: 31 December 1979 and 1978

ASSETS	1979	1978
Current Fund Assets (Note A):		
Cash	$ 699,191	$ 188,742
Short-term investments, at cost which approximates market	5,635,000	3,305,000
Reimbursable costs:		
Billed	1,269,388	1,385,961
Unbilled	2,658,842	1,486,109
Other receivables	183,397	169,518
Deferred charges supplies and prepaid expenses	564,036	546,815
Due to plant fund	(2,855,761)	(1,089,330)
Due (to) from endowment and similar funds	(140)	(1,622)
	8,153,953	**5,991,193**
Endowment and Similar Fund Assets (Notes A and B):		
Separately invested, at market	17,844,663	17,184,372
Pooled investments, at market	18,612,151	17,913,674
Accounts receivable — sale of investments	—	8,454
Due (to) from current fund	140	1,622
	36,456,954	**35,108,122**
Annuity Fund Assets (Note A):		
Investments, at market (cost $70,528 in 1979 and $73,654 in 1978)	73,752	73,275
Cash	3,396	1,654
	77,148	**74,929**
Plant Fund Assets (Note A):		
Land, buildings and improvements	15,941,206	15,551,647
Vessels and dock facilities	7,356,418	7,176,910
Laboratory and other equipment	2,669,031	2,609,471
	25,966,655	25,338,028
Less accumulated depreciation	8,566,609	7,813,104
	17,400,046	17,524,924
Due from current fund	2,855,761	1,089,330
	20,255,807	**18,614,254**
	$64,943,862	**$59,788,498**
LIABILITIES AND FUND BALANCES		
Current Fund Liabilites and Balances:		
Accounts payable and other accrued expenses	$ 1,467,792	$ 922,707
Accrued vacation	813,320	799,962
Deferred revenue	770,862	601,184
Unexpended balances of restricted funds	2,061,908	1,495,353
Unrestricted balances designated for:		
Income and salary stabilization	2,114,040	1,941,446
Ocean Industry Program	191,632	132,966
Fiftieth Anniversary Fund	412,207	—
Working capital	322,192	97,575
Total unrestricted balances	3,040,071	2,171,987
	8,153,953	**5,991,193**
Endowment and Similar Fund Liabilities and Balances:		
Accounts payable — purchase of investments	—	74,780
Endowment:		
Income restricted	21,358,092	20,587,010
Income unrestricted	2,875,237	2,725,366
Term endowment	3,552,904	3,391,914
Quasi-endowment:		
Restricted	5,615,524	5,349,861
Unrestricted	3,055,197	2,979,191
	36,456,954	**35,108,122**
Annuity Fund Liabilities and Balance:		
Annuities payable	27,838	29,065
Fund balance	49,310	45,864
	77,148	**74,929**
Plant Fund Balances:		
Invested in plant	17,400,046	17,524,924
Unexpended:		
Restricted	1,504,515	176,056
Unrestricted	1,351,246	913,274
Total unexpended balances	2,855,761	1,089,330
	20,255,807	**18,614,254**
	$64,943,862	**$59,788,498**

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

Statement of Current Fund Revenues, Expenses, and Transfers for the years ended 31 December 1979 and 1978

	1979	1978
Revenues		
Sponsored research:		
Government	$25,629,474	$22,411,236
Nongovernment	1,681,927	2,512,083
	27,311,401	24,923,319
Education funds availed of	1,121,145	953,367
Total restricted	28,432,546	25,876,686
Unrestricted:		
Fees	230,117	194,291
Endowment and similar fund income	517,781	465,916
Gifts	880,601	420,028
Tuition	316,338	296,156
Investment income	440,653	176,283
Other	238,703	341,099
Total unrestricted	2,624,193	1,893,773
Total revenues	**31,056,739**	**27,770,459**
Expenses and Transfers		
Sponsored Research:		
Salaries and benefits	8,173,696	7,525,727
Ships and submersibles	5,083,090	5,448,887
Materials and equipment	2,978,553	3,680,555
Sub-contracts	2,724,305	742,444
Laboratory overhead	1,657,499	1,545,853
Other	3,542,674	2,997,456
General and administrative	3,151,584	2,982,397
	27,311,401	24,923,319
Education:		
Faculty expense	280,307	260,806
Student expense	469,620	408,730
Postdoctoral programs	273,547	67,754
Other	128,405	109,235
General and administrative	119,766	106,842
	1,271,645	953,367
Unsponsored research	592,276	739,249
Other activity	653,048	524,685
General and administrative	110,285	192,279
	1,355,609	1,456,213
Total expenses	**29,938,655**	**27,332,899**
Nonmandatory transfers:		
To quasi-endowment fund	—	25,000
To plant fund, unexpended	250,000	314,400
Total expenses and nonmandatory transfers	**30,188,655**	**27,672,299**
Net increase in unrestricted current fund	**$ 868,084**	**$ 98,160**
Designated for:		
Income and salary stabilization	$ 172,594	$ 155,305
Ocean industry program	58,666	(38,509)
Fiftieth Anniversary Fund	344,949	—
Working capital	291,875	(18,636)
	$ 868,084	$ 98,160

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

Statement of Changes in Fund Balances for the years ended 31 December 1979 and 1978

	Current Fund					Plant Fund		
	Restricted	Unrestricted	Total	Endowment and Similar Funds	Annuity Fund	Invested in Plant	Unexpended	Total Funds
1979								
Increases:								
Gifts, grants, and contracts:								
Government	$25,629,474		$25,629,474					$25,629,474
Nongovernment	2,012,992	$ 835,101	2,848,093	$ 46,598			$1,625,000	4,519,691
Endowment and similar funds investment income	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	29,044,909	2,578,693	31,623,602	1,423,304	3,446	—	1,625,000	34,675,352
Decreases:								
Expenditures (including $586,213 of funded depreciation)	(28,583,046)	(1,355,609)	(29,938,655)				586,213	(29,352,442)
Depreciation (Note A)						$ (819,660)		(819,660)
Total decreases	(28,583,046)	(1,355,609)	(29,938,655)	—	—	(819,660)	586,213	(30,172,102)
Net change before transfers	461,863	1,223,084	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 education funds	105,000	(105,000)	—					—
Transfers to plant fund		(250,000)	(250,000)				250,000	—
Plant asset additions						694,782	(694,782)	—
Total transfers	104,692	(355,000)	(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 31 December 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 31 December 1979	$ 2,061,908	$ 3,040,071	$ 5,101,979	$36,456,954	$49,310	$17,400,046	$2,855,761	$61,864,050
1978								
Increases:								
Gifts, grants and contracts:								
Government	$22,411,236		$22,411,236					$22,411,236
Nongovernment	2,266,198	$ 420,028	2,686,226	$ 48,834			$ 75,000	2,810,060
Endowment and similar funds investment income	1,280,268	465,916	1,746,184					1,746,184
Other		1,007,829	1,007,829		$ 703			1,008,532
Total increases	25,957,702	1,893,773	27,851,475	48,834	703	—	75,000	27,976,012
Decreases:								
Expenditures (including $501,863 of funded depreciation)	(25,876,686)	(1,456,213)	(27,332,899)				501,863	(26,831,036)
Depreciation (Note A)						$ (765,091)		(765,091)
Net decrease in realized and unrealized appreciation				(321,247)				(321,247)
Total decreases	(25,876,686)	(1,456,213)	(27,332,899)	(321,247)	—	(765,091)	501,863	(27,917,374)
Net change before transfers	81,016	437,560	518,576	(272,413)	703	(765,091)	576,863	58,638
Transfers — additions (deductions):								
Transfers to endowment and similar funds	(413)	(25,000)	(25,413)	25,413				—
Transfers to plant fund		(314,400)	(314,400)				314,400	—
Plant asset additions						823,616	(823,616)	—
Total transfers	(413)	(339,400)	(339,813)	25,413	—	823,616	(509,216)	—
Change in fund balance for the year	80,603	98,160	178,763	(247,000)	703	58,525	67,647	58,638
Fund balance 31 December 1977	1,414,750	2,073,827	3,488,577	35,280,342	45,161	17,466,399	1,021,683	57,302,162
Fund balance 31 December 1978	$ 1,495,353	$ 2,171,987	$ 3,667,340	$35,033,342	$45,864	$17,524,924	$1,089,330	$57,360,800

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 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, 3⅓% on Atlantis II and 5% to 33⅓% on equipment. Depreciation expense on Institution-purchased plant assets amounting to $586,213 in 1979 and $501,863 in 1978 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.

The 1979 asset balances include $294,225 of construction in progress. No depreciation is provided until the assets are placed in service.

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 1978 Balances
Certain balances in the 1978 financial statements have been reclassified to conform with the 1979 presentation.

B. ENDOWMENT AND SIMILAR FUND INVESTMENTS:

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

	31 December 1979 Cost	31 December 1979 Market	31 December 1978 Cost	31 December 1978 Market
Separately invested:				
Government and government agencies	$ 2,520,228	$ 2,177,000	$ 2,894,349	$ 2,652,250
Bonds	3,308,747	2,999,000	2,063,048	1,884,500
Common stocks	11,785,518	12,602,100	12,264,211	12,127,500
Savings deposits	—	—	524,267	524,267
Cash	66,563	66,563	46,099	46,099
Call options written	—	—	(41,225)	(50,244)
Total separately invested	**$17,681,056**	**$17,844,663**	**$17,750,749**	**$17,184,372**
Pooled investments:				
Pool A				
Government and government agencies	$ 2,209,548	$ 2,023,000	$ 2,079,711	$ 1,957,250
Bonds	2,060,573	1,837,000	2,310,773	2,162,500
Preferred stocks	—	—	59,704	22,000
Common stocks	8,556,255	9,328,403	8,484,052	8,521,977
Savings deposits	—	—	28,115	28,115
Real estate	42,775	42,775	42,915	42,915
Cash	139,229	139,229	113,862	113,862
Call options written	—	—	(29,112)	(36,006)
	13,008,380	13,370,407	13,090,020	12,812,613
Pool B				
Government and government agencies	1,719,969	1,528,000	1,661,463	1,519,000
Bonds	596,573	523,000	1,370,298	1,253,200
Common stocks	2,981,382	3,157,848	2,299,094	2,310,100
Savings deposits	—	—	22,035	22,035
Cash	32,896	32,896	4,914	4,914
Call options written	—	—	(6,791)	(8,188)
	5,330,820	5,241,744	5,351,013	5,101,061
Total pooled investments	**$18,339,200**	**$18,612,151**	**$18,441,033**	**$17,913,674**

C. POOLED INVESTMENTS UNITS:

The value of a pooled investment unit was as follows:

	Pool A	Pool B
31 December 1978	$.8328	$.8147
31 December 1979	$.8724	$.8329

The pooled investment income per unit was as follows:

	Pool A	Pool B
1978	$.0410	$.0459
1979	$.0450	$.0522

D. ENDOWMENT AND SIMILAR FUND INCOME:

Income of endowment and similar funds consisted of the following:

	1979	1978
Dividends	$1,020,275	$ 866,912
Interest	973,277	949,906
Other	2,994	2,994
	1,996,546	1,819,812
Investment management costs	(76,322)	(73,628)
Net investment income	$1,920,224	$1,746,184

E. RETIREMENT PLAN:

The Institution has a noncontributory trusteed retirement plan covering substantially all full-time employees. The Institution's policy is to fund pension cost accrued which includes amortization of prior service costs over a 30-year period. Retirement plan costs charged to operating expense amounted to $1,765,000 in 1979 and $1,535,000 in 1978, including $85,000 and $31,000, respectively, relating to expenses of the retirement trust. As of the most recent valuation date, (1 January 1979) the unfunded prior service costs, which will be funded through future annual accruals, approximated $7,164,000.

F. CALL OPTIONS WRITTEN:

In 1978 the Institution began writing covered call options on the endowment fund's investment securities. The call option gives the holder of the option the right to purchase the underlying security at a specified price at any time until the option expires. Call options are valued at their market value as reported on the last business day of the year, and presented as a reduction in the market value of the underlying securities. At 31 December 1979 there were no options outstanding.


TOM BOLMER

Nephelometer/CTD/rosette sampler array is readied for launch on *Knorr* Voyage 74.