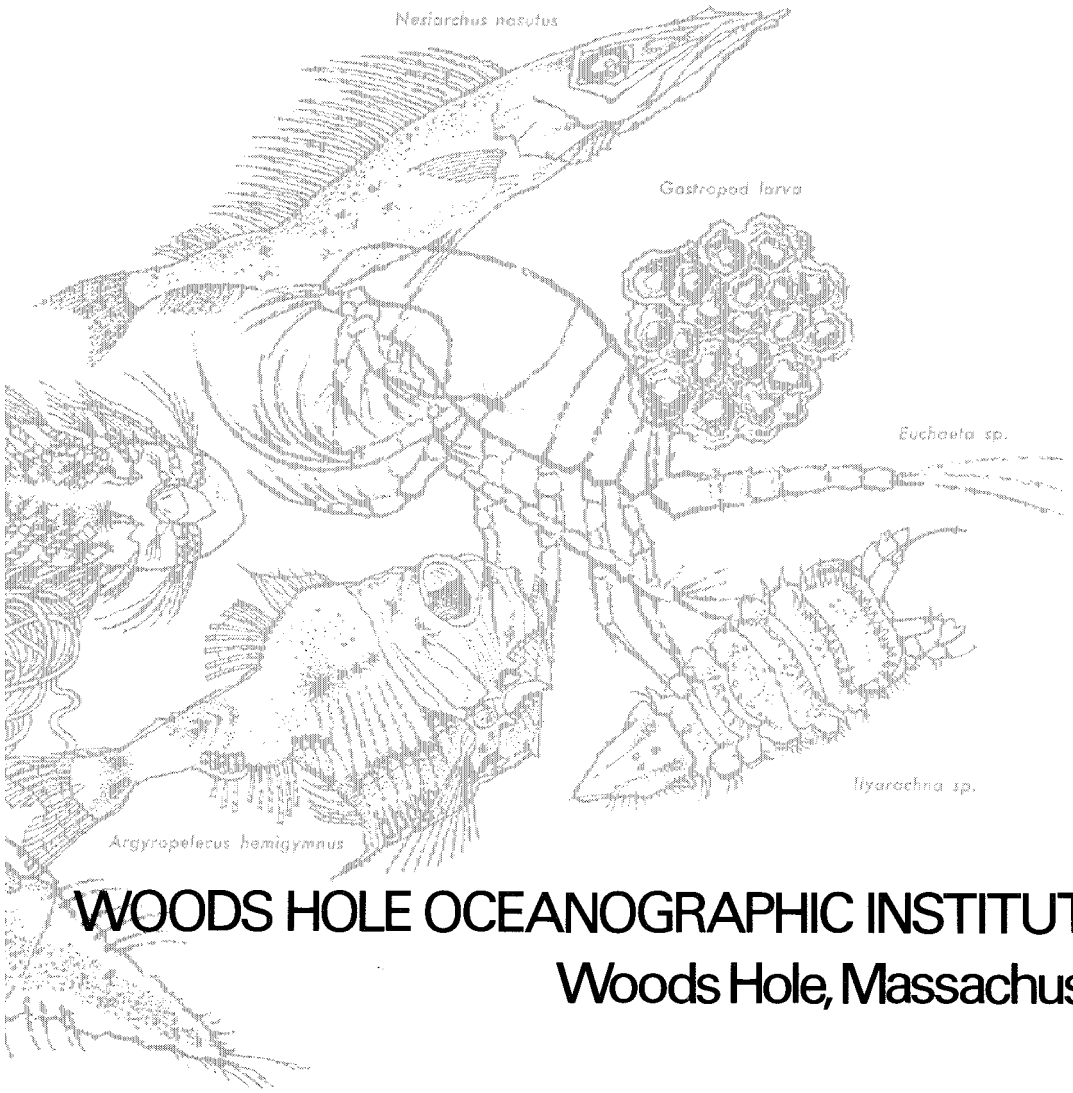

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

Spirorbis borealis

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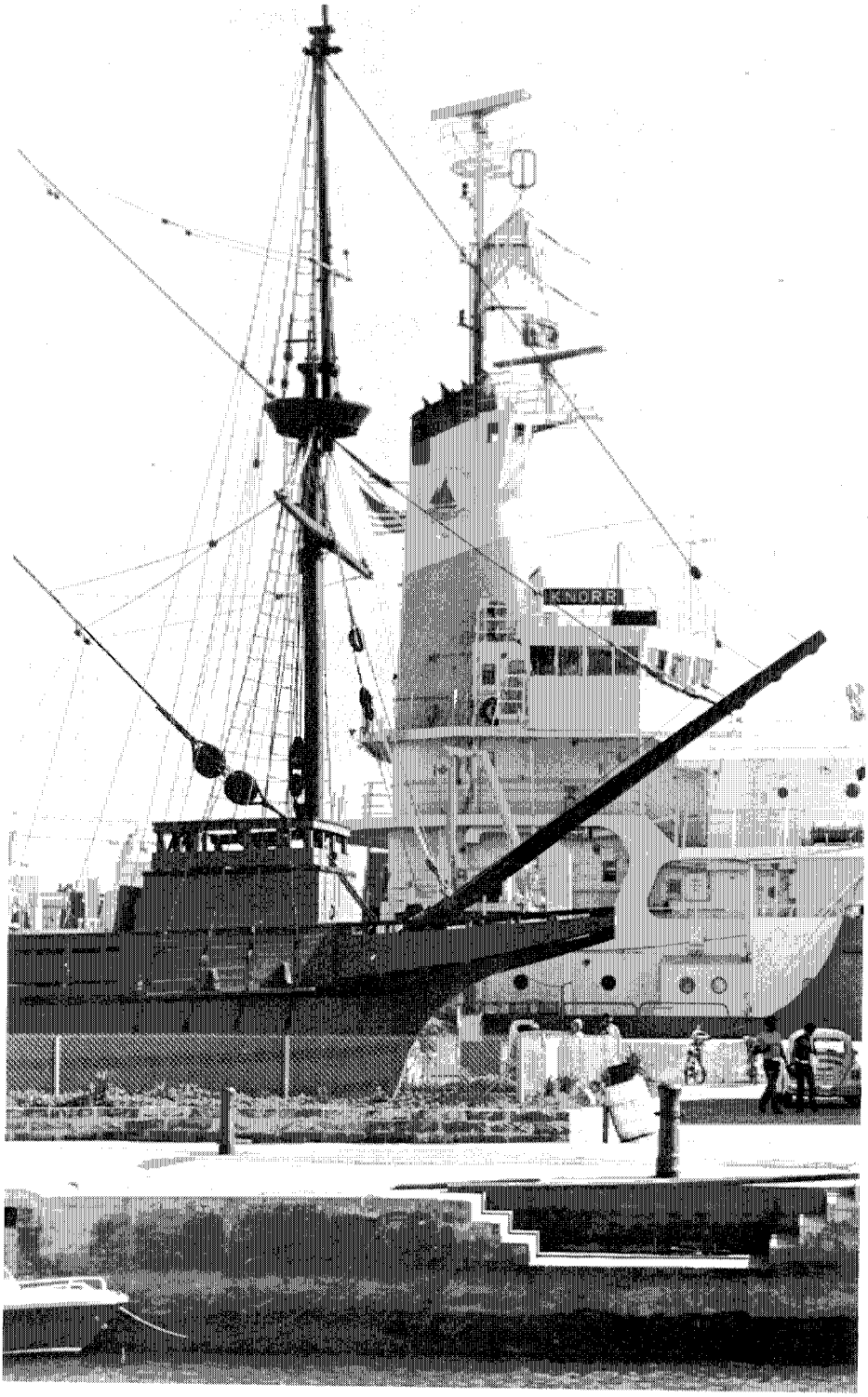

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Selman A. Waksman

22 July 1888-16 August 1973

Although Dr. Waksman's work in marine microbiology was a small part of his professional career, it had a profound influence on the development of the field throughout the world and especially at the Woods Hole Oceanographic Institution. In the early days of the Institution, Dr. Bigelow asked Dr. Waksman to formulate a plan for the study of marine bacteria. It was felt that his previous experience with the interrelationships and interactions of mixed populations of microorganisms in soils would be a firm foundation upon which to build a comprehensive program in another complex environment, the sea. A plan, developed in the summer of 1931 when Dr. Waksman spent a month in Woods Hole, was accepted by the Trustees and implemented by Dr. Waksman and his associates during the next 12 years when he spent one to two months each summer at the Oceanographic Institution. He attracted many students and collaborators and this group embarked on some of the most fundamental studies of bacteria in the oceans; studies which are still being vigorously pursued. Dr. Waksman and his group studied not only the distribution of bacteria in the sea but also the microbial decomposition of various types of organic materials in seawater. He was one of the early scientists to recognize the role of bacteria in maintaining the cycle of life in the sea by their decomposition of organic materials and release of the nutrients essential for phytoplankton production. Although he was physically distressed by the discomforts of ATLANTIS in rough seas, he had the fortitude for work at sea and has stated that it gave him an opportunity to observe the sea at close quarters and to appreciate the significance of some of the problems that he was attempting to solve.

Among the last of Dr. Waksman's marine bacterial experiments was one concerned with the viability of non-marine species in seawater. He had previously turned his attention to the production of antibiotics by soil organisms and was naturally interested in the fact that seawater also killed off bacteria commonly associated with human pollution. Following his discovery of streptomycin, the culmination of a long series of studies of interactions of soil microbes, he became so involved with his work on antibiotics that he could no longer devote the time needed to continue his oceanographic studies as a member of the staff. He continued his association with the Institution, however, by becoming a Trustee and Member of the Corporation in 1946. He and Mrs. Waksman almost always managed to vacation in Woods Hole at the time of the Annual Meetings, staying first at the old Breakwater Hotel and later in their own home on Gardiner Road where he was living at the time of his death. He had as an Honorary Trustee and Member taken an active part at the annual meetings in June.

The scientific world in general remembers him as the co-discoverer of streptomycin, for which he received the Nobel Prize in medicine and physiology in 1952. Most of his work in soil microbiology, and later on antibiotics, was conducted at Rutgers University where he received his Bachelors and Masters degrees in 1915 and 1916 and where, before his retirement, he established the Institute of Microbiology.

Archibald Gowanloch Huntsman

23 November 1883-8 August 1973

Dr. Huntsman had been a member of the Corporation since 1931, a trustee from 1931-1948, and an honorary trustee since 1959. He attended the Annual Meeting this last June. He, like Dr. Bigelow, had a thorough knowledge and broad understanding of the marine sciences. More than any other person, Dr. Bigelow turned to Dr. Huntsman for advice during the formative years of the Institution.

Dr. Huntsman, long a professor at the University of Toronto, was also consulting Director and Editor of the Fisheries Research Board of Canada (and its predecessor, the Biological Board of Canada) and was, for a number of years, Director of the Laboratory at St. Andrews.

He was especially interested in fisheries and fisheries management. In some respects, he was before his time worrying about pollution in Halifax Harbor (1924), promoting aquaculture (1934) and the effects of man on his environment as indicated in his involvement in the International Passamaquoddy Fisheries Commission (ca. 1927). He met with the Executive Committee in June to express his concern for various practical problems affecting progress in the marine sciences (and vice versa). Characteristically, Dr. Huntsman had been hand-seining in the Magaguadavic River the Sunday before he died to ascertain the numbers and location of salmon fry and parr. At the end of this day, Dr. Huntsman wrote a colleague at Toronto that he was very discouraged: he had never seined so long and covered so little ground — in waders in a swiftly running river. He worked almost to the end as he would have wished.

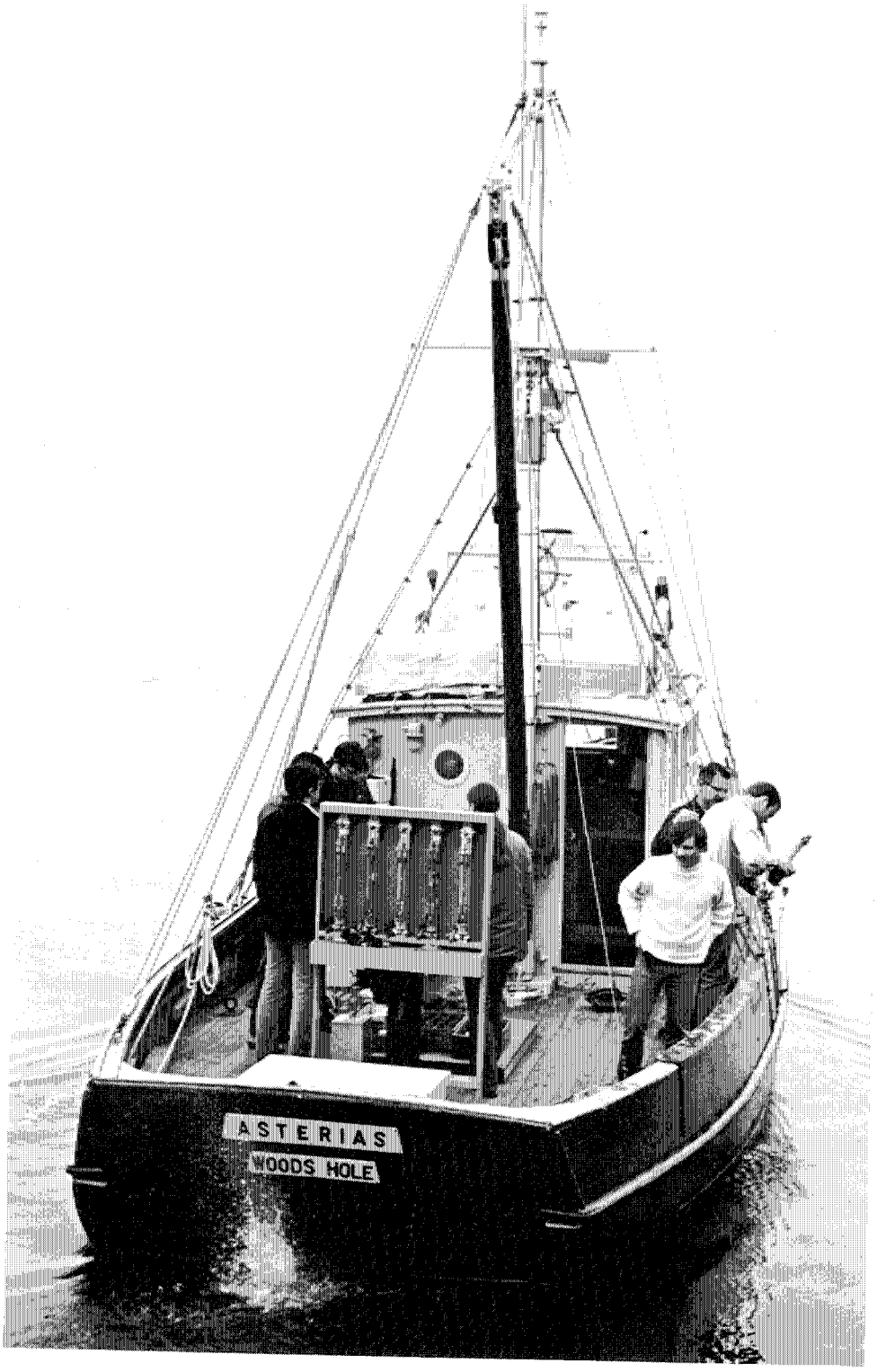
Carl Eckart

4 May 1902-23 October 1973

Carl Eckart was a long-time Member of the Corporation, having been elected on August 15, 1953. A leading authority of hydrodynamics and physical oceanography, he served as Director of our sister laboratory, the Scripps Institution of Oceanography, and also as Vice Chancellor for Academic Affairs of the University of California at San Diego.

Although educated as a physicist, because of his high sensitivity toward mankind, he changed his interest to oceanography in preference to working on the development of the first atomic bomb. This proved to be fortunate for the field of oceanography which benefited greatly from his many scientific contributions, chiefly in hydrodynamics, the properties of sea water, waves and internal waves. A kindly and considerate man, he devoted much attention to students, always finding time for them no matter how busy.

He often visited the Institution in his capacity of Corporation Member and also as a participant of various Visiting Committees, bringing with him great wisdom and a wealth of experience. It is clear the Institution has profited from his forthright opinions and shrewd judgement which he so willingly brought to bear on many of our problems. Both the Institution and the science of oceanography are far richer for the fact Carl Eckart turned to the oceans.


ASTERIAS
WOODS HOLE

DIRECTOR'S REPORT

The multidisciplinary character of oceanography quite naturally leads to cooperative ventures among individuals who are within the same department, in different departments, or at other Institutions both within the United States and overseas. Others who work in relative independence also contribute much to the several major investigations in progress at the Institution. Three of these, upon which much of our work has been focused during the past year, may suffice to provide an appreciation of the great variety and yet the cohesive pattern of our work: (1) The dynamic processes of the ocean characterized by the movement of the waters, (2) the chemical and biological systems on which marine life depends including the effects of man-made pollutants, and (3) the investigations of the structure of the earth beneath the ocean bottom and the resources contained therein. Each of these depends on the skills of our instrumentalists, engineers, and technicians. To summarize all of our work is impossible but a great deal of it contributes to the fuller understanding of these basic themes.

Much is dependent on improving our understanding of water movement. This includes understanding climate and weather, the productivity of our fishing grounds, the dispersal of pollutants and the redistribution of sediments on the ocean bottom. Perhaps a third of our effort in 1973 was devoted to further elucidation of this problem. Indeed this theme has been an essential part of our program since the Institution first sent scientists to sea. Constantly improving technologies for the study of water movement are nevertheless expanding our horizons and capabilities.

Motion in the finite body of fluid covering a large portion of the earth's surface is present at all scales ranging from the dimensions of a whole ocean basin to small scale turbulence of a few centimeters. In order to understand the long term distribution of properties and of organisms, and to evaluate climatic effects resulting from exchanges between the atmosphere and ocean, we must understand the large scale circulation and motions of the open ocean. For pollution and fisheries problems, the coastal circulation, and the exchanges between coastal waters and the deep sea must be known. Within both areas smaller scale circulation and mixing patterns greatly affect local conditions. Thus, we have addressed ourselves to the entire spectrum of motions.

Open sea conditions, especially at depth, change slowly, and this requires periodic measurements of world ocean conditions every few decades. It is fortunate that basic data have been acquired at intervals of roughly twenty-five years as a result of surveys in the Atlantic in 1925 by the German METEOR Expedition, during the International Geophysical Year (IGY) 1957-1958, chiefly aboard R/V CHAIN, R/V ATLANTIS, R/V CRAWFORD and R.R.S. DISCOVERY II (of the then National Institute of Oceanography, Great Britain) and in 1972-1973 the Geochemical Ocean Sections Study (GEOSECS) aboard R/V KNORR. The latter was the most precise chemical survey ever undertaken on a grand scale, from the Arctic to the Antarctic. The ocean was sampled at approximately 2500 points with an average of about ten samples at each spot. These analyses will provide a base iine for monitoring global changes in the future.

Circulation investigations are directed toward describing and understanding motion in many forms: from surface and internal waves, through intermediate scales, such as Rossby waves and mid-ocean eddies, to great currents, such as the Gulf Stream and the

centuries-long turnover of water within the global ocean basins. Computations based especially on IGY data made possible a detailed analysis of the water budget (i.e., the waters flowing into and out of the North Atlantic). For the average parcel of water in this ocean body, the mean "residence time" is 240 years with a range between 4.5 years in the European Basin to 900 years in the Guinea Basin off Equatorial Africa.

Over the years the techniques of measurement have become more complex. Our growing theoretical understanding of the dynamic processes of the ocean has stimulated more challenging experimental investigations. As the scope of our knowledge grows, so too the scale of our experiments has had to grow and become more sophisticated.

Today, arrays of instruments strung between a bottom anchor and a float near the surface can record the direction and magnitude of currents, water temperature, and pressure every few minutes for six months after a single setting. Other instruments are dropped to fall freely to the ocean bottom and return with profiles of the physical properties of the water column, other devices are towed at depths from our ships, while still others move along with the currents at great depths for a year or more, continually sending back information about their location and water conditions. Slow, deep movements may be followed by the chemical analysis of isotopes and other chemical components of the water, as in the GEOSECS program.

Early results of the Mid-Ocean Dynamics Experiment (MODE), a cooperative endeavor with other laboratories including the Institute of Oceanographic Sciences, Great Britain, which explored approximately 100,000 cubic kilometers of ocean southeast of Bermuda and our continuing monitoring of the Gulf Stream, have defined large eddies about one or two hundred kilometers in diameter. These eddies seem to be relatively closely spaced, and may play a major role in the dynamics of the large-scale circulation of the oceans.

New techniques have permitted the measurements of oceanic variability of higher frequencies than the mid-ocean eddies. A highly successful Internal Wave Experiment (IWEX) in which instruments were precisely positioned on a buoyant wire tripod with six kilometer long legs, was completed in December. First results provide a look at the structure, behavior and mechanisms of internal waves within the ocean at great depths to an extent that will allow us to improve significantly our understanding of these phenomena. This in turn should provide the descriptive basis for yet a further theoretical advance in our general understanding of the energetic higher-frequency portion of the spectrum of motions.

In all of this we have not forgotten our first intellectual challenge: the Gulf Stream. Today, through use of satellites and aircraft (unfortunately, not ours) we are much closer to a capability of frequent monitoring of the Gulf Stream. Much of the understanding of the physical oceanography of the western North Atlantic rests upon the growing insight concerning this major ocean current.

Knowledge of oceanic circulation is essential for the evaluation of marine pollution; a subject of increasing concern to our staff. Thus, the first theme of investigating water motion blends thoroughly into our second theme of chemical and biological processes. In recent years, the oceans have been used increasingly as the final resting place for undesirable industrial and human wastes. Though much remains to be learned of the impact of these materials on the marine ecosystem, we no longer believe that the

oceans' great size eliminates the possibility of substantial damage. Along with other human activities, such as overfishing, the practice of indiscriminate use of the ocean as a dump threatens the marine food production essential for the nutrition of a large share of the world population.

Investigations of pollution are among the most interdepartmental in the Institution. As in the circulation studies described above, staff members of all departments are contributing to the work. The chemists have devised tests to measure petroleum contamination in small amounts (one part per million) in marine organisms and in bottom sediments. The biologists have determined the effect of the aromatic fraction of crude oil on phytoplanktonic diatoms and the genetic characteristics of opportunistic species which invade the site of an oil spill following the disappearance in the area of the normal fauna and flora. Oil is readily trapped in the bottom where it can persist for long times to be released at intervals when storms stir up the sediments. The effects of the polychlorinated biphenyls (PCB's) and other man-made chlorinated hydrocarbons (e.g., DDT) on open-ocean microorganisms, especially bacteria, micro-algae and planktonic protozoa are also under investigation. The toxicity of PCB to the diatom *Thalassiosira pseudonana,* grown in pure and mixed culture, was greatest when it was in competition with other species. Concentrations of PCB as low as one tenth of a part per billion in the medium were toxic to this diatom when interspecific competition occurred. This is one of the lowest chlorinated hydrocarbon levels reported to be toxic to algae and it approaches or equals the PCB concentration found in rivers, coastal waters and the open ocean. These results seem to indicate that in the summer, steady-state phytoplankton communities may well be affected by persistent pollutants because of the constant competition factor.

The chlorinated hydrocarbons do not readily decay in the sea, but other organic pollutants, sewage wastes for example, are quickly incorporated into the marine food chain. Bacteria are responsible for remineralizing organic matter to provide nutrients for plant growth. The organic matter of dead plants and animals (or of sewage) is generally unavailable to plants until bacteria degrade it into simple organic compounds or into such inorganic compounds as carbon dioxide, ammonia, nitrates, sulfates and phosphates, which are essential to plant growth. Thus, the bacteria are essential for the recycling of nutrients which have been incorporated in the organic compounds of living organisms. Bacterial decomposition is affected by pressure, temperature and substrate concentration and thus proceeds at different rates in various parts of the ocean. Our results show a decrease in microbial activity with increasing depth and the associated decreasing temperature and increasing pressure. This work has great relevance to the contemporary debate on the issue of ocean dumping because it suggests that organic materials which have settled to the bottom in the deep sea will decompose more slowly than previously thought and thus will accumulate and be "preserved for posterity".

Theoretically, at least, domestic sewage could be put to beneficial use instead of being considered an obnoxious waste to be thrown away. The essential nutrients it contains, in the right place and in the right amounts, can stimulate plant growth and the biological productivity of the system. Three projects at the Institution are concerned with the combination of this objective and more adequate waste treatment. One of these, an aquaculture system, mixes the effluent from a secondary sewage treatment

plant with sea water as a culture medium for unicellular algae. These are fed to oysters and other shellfish and their wastes nourish polychaete worms and fish, each of which is a useful marine product. The outflow is finally stripped of all but minor traces of nutrients by macroscopic attached algae. The feasibility of the system has been proven in the laboratory, and has moved to a "pilot plant" stage of development.

Another such program uses dried and sterilized sludge from sewage treatment plants to nourish a salt marsh, comparing yields with those produced by application of chemical fertilizers. Plant production on the marsh was increased as much as threefold, and also the marsh removed essentially all the heavy metal contaminants in the sludge.

Also the use of effluent from a treatment plant to stimulate growth of terrestrial plants by spray irrigation and to recharge the water table with drinkable water is being tried in a very new phase of the work. Since the geology of Cape Cod is typical of large areas of the eastern seaboard, this approach may be of great value in coastal zone management plans for the disposal of sewage, growth of trees or fodder crops and replenishment of ground water supplies.

The third theme — the dynamics of the earth beneath the ocean — contributes to an understanding of the history of the Earth from its beginning to the present and perhaps will permit some predictions about its future. Ocean sub-bottom structures provide an insight not only into the formation of the bottom but also into the causes and nature of such submarine phenomena as earthquakes, faulting, and volcanism.

The origin and evolution of the major features of the sea floor, the ridges, trenches, and faults, can be explained in terms of the concept of plate tectonics. The concept is based on the motion of several large plates of the Earth's crust or outer shell, which "float" upon the asthenosphere, a deeper layer of the Earth, whose dynamic characteristics resemble those of a fluid. In some areas the plates are in collision and one will override the other, in other places plates are separating, and at still other localities, the plates may have a transverse movement to each other producing shear. Each type of motion produces a distinctive feature on the sea floor. Trenches are formed when one plate, usually an oceanic one, is thrust under another one, usually a continental one. Mid-ocean ridges, such as the Mid-Atlantic Ridge, are generated by the upwelling of molten magma where the plates are separating. The transverse motion of the plates results in faults and large-scale fracture zones.

According to these concepts, the Atlantic Ocean was a long lake and Brazil and Africa were contiguous about two hundred million years ago. Since that time they have slowly separated and evolved to their present configurations. If ideas about plate tectonics are correct, the features older than the separation on the African side should also be present on the Brazilian side. We are studying the Mid-Atlantic Ridge as an area of separation, the continental margins off the coasts of Africa and Brazil and areas where submerged continental basements are being transformed by oceanic processes.

During the past year, we participated in the first stages of the French-American Mid-Ocean Undersea Study (FAMOUS), which is directed at studying the active geologic processes at the Mid-Atlantic Ridge where plates are being separated, and unique submarine features are being produced. Broad regional surveys were followed by increasingly detailed studies using near-bottom geophysical and geological measurements, monitoring small-scale earthquake activity using sonobuoy arrays and taking

numerous bottom photographs. As many as ten microearthquakes a day have been recorded in the central region of the ridge, an observation that is supported by photographic data which shows extensive faulting and volcanic activity.

Although much of our geologic and geophysical effort have been directed to the deep sea, we have also spent considerable time studying the continental margins, which are adjacent to continents and separate them from the deep sea. Structurally, they are transitional zones between continents and ocean basins and thus provide an important key in understanding the two. To achieve a sound understanding of continental margins requires a knowledge of their topography, geologic structure, rocks, and sediments as well as that of the overlying water and its chemistry and biology.

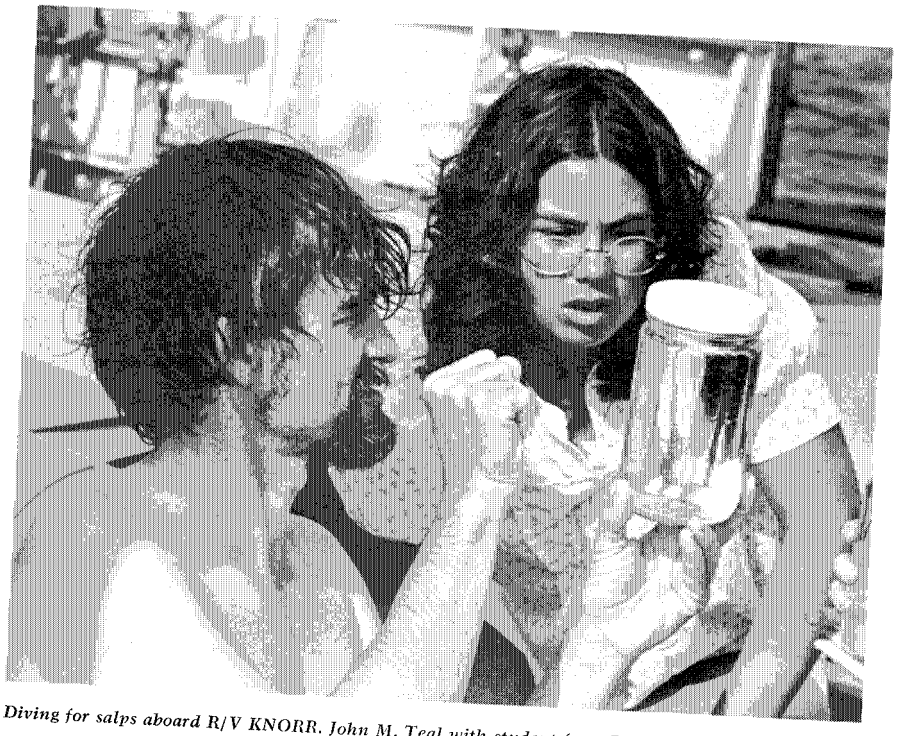
During the past year, we initiated a three-year program in the Gulf of Maine to reconstruct the behavior of this part of the North American margin during the separation of North America and Africa 200 million years ago. It has already been learned that the basement of the North Atlantic continental margin is a product of crustal thinning, crustal collapse, and oceanization of acidic crustal material. Although these processes occurred a long time ago, they supplement the insight obtained concerning the separation of the plates along the Mid-Atlantic Ridge.

On the Eastern Atlantic continental margin along Africa, several large basins containing sediments more than 4 kilometers thick have structural features that could be suitable for oil and gas traps. The position of these basins off major rivers suggests a high content of organic matter, the starting substance for petroleum. One belt of diapiric structures, i.e., dome-like intrusive features, extends onshore to where much of the oil that is produced from Angola, Zaire, Cabinda, Congo, and Gabon occurs. Some of the diapir belts and the basins occur beneath the continental shelf where, after more detailed geophysical surveys have been completed, production is possible. But most of these areas lie in deeper waters and probably will await further technological development before production.

By understanding the concepts and mechanisms of plate tectonics we hope to be better able to determine ways of using the Earth's resources more effectively. The scientific goal of tectonic research is to reconstruct the evolution of the ocean basins and the continents. Also, the continental margin has become an area of increasing interest to marine scientists because of its potential economic value. Nearly one fifth of the total world production of petroleum and natural gas now come from these areas. It is particularly important that contiguous countries be aware of these potential resources. We share the results of our investigations freely with these countries and ultimately they are published in the open literature. This becomes particularly important as resources on land diminish relative to the world's growing rate of consumption. As studies of the continental margins increase, we will learn more about the Earth's history and will be able to define areas of economic potential. However, it will be necessary to understand the total regime of this part of the ocean if we are to use it wisely.

The work at the Institution is described in greater detail in the departmental reports that follow. Eventually the results will be published in various scientific periodicals. Of the two hundred or more papers appearing in 1973 (p. 65) most are based on observations made at sea or in the laboratory a year or more ago.

PAUL M. FYE



Diving for salps aboard R/V KNORR. John M. Teal with student from Boston University.

Report of the Dean of Graduate Studies

In May of 1973 Burr Steinbach stepped out ("retired" would not be the right word) as Dean of Graduate Studies. Burr was the first Dean at the Oceanographic Institution and was responsible for the development of our graduate degree programs from their beginning some six years ago.

Burr not only brought the right kinds of experience to the new Dean's job – research biologist, departmental chairman at Chicago, Director of the Marine Biological Laboratory – but his unique personality ideally matched the challenge. Patience, informality and ingenuity were all required. Most important of all, though, he brought boundless enthusiasm for good science and undiluted optimism in youth. Clearly, he is a hard act to follow.

Burr's accomplishments as Dean were remarkable. Within a period of five years what was little more than an idea was translated into a full graduate program which now has almost seventy students and has already granted twenty-three doctoral degrees. Both the number and quality of the applicants to the program have continually grown, indicating the steadily increasing recognition of the program by the best undergraduates around the country. To Burr's special credit, moreover, the graduate programs were successfully established in a situation where there was little

precedence – namely, a program between two institutions some eighty miles apart, and where one of the institutions had no experience with formalized education.

Beyond Burr's unique influence on the program, the successful establishment of graduate study at the Oceanographic Institution can be attributed to certain other assets which the program possessed from the outset. In retrospect, the decision to base the Institution's initial efforts primarily in a partnership with the Massachusetts Institue of Technology was clearly a wise one. This provided the program with the nucleus of a student body and gave immediate access to the formal teaching strengths of M.I.T. (Our students also now have access to the courses at Harvard, Brown, and Yale universities as well.) The joint undertaking meant that the Institution was not required to make a radical change in its makeup and style in order to start an educational program. Finally, the decision to launch the educational effort only with adequate endowment resources to support it has proved to be a most wise one. It has been essential for the program to have sufficient financial resources in getting started, particularly since other well-established graduate programs have been crippled by diminishing federal support in the past few years.

The graduate programs at the Institution are now a mature and stable undertaking. There are problems, of course, and there are unfulfilled opportunities. We still have not fully infiltrated educational concerns into all aspects of the Institution's life. We still have not captured all the talents or potential interests of the staff in our educational undertakings. We still have not learned all we need to know about administering an educational program in an active research enterprise. These are some of the problems I plan to address in the months ahead. But under Burr we have shown that we can attract excellent students and that they can learn and thrive in our style of operation. Moreover, we can show, if such a test were required, that the educational programs – or, more accurately, our students – have contributed importantly to the research vitality of this Institution.

With respect to the graduate programs in 1973, I call attention to the following facts:

- The number of applications was smaller in 1973 than in 1972 (189 versus 231); the decrease being evident in all fields. This probably reflects a national trend with respect to graduate study. The number of applicants, though, was still more than 1971).
- We are still offering admission to only a small percentage of the applicants (about 15%). The percentage of those offered admission who do in fact enter the program remains high (67%).
- The total number of students in the program continues to grow. In the academic year 1973-74 there were sixty-nine students compared to sixty-two the year before. This continued growth in the total enrollment reflects the fact that the program had not reached a "steady-state" situation. Our experience indicates that the average time in the pro-

gram to obtain a doctorate is 4.2 years. So far our drop-out rate has been small – about 5% per year. If these numbers were to continue in the future, we could expect a steady-state enrollment of about seventy-two for an admission rate of eighteen students per year.

– Since last January nine doctoral degrees and two professional degrees in ocean engineering have been awarded. Ten of these eleven degree recipients entered the Joint Program since it started in 1968. With the exception of one student who did not seek a job, all of the eleven graduates in 1973 have obtained research or teaching positions in oceanography or ocean engineering.

The growth of the Graduate Program has not diminished the other educational activities of the Institution; indeed, the effect has been to strengthen them. Such activities as the Summer Student Fellowship Program and the Postdoctoral Scholars Program continue to flourish. Moreover, the number of visiting graduate students from other institutions who do research here has not diminished significantly.

This was the third year of our Marine Policy and Ocean Management Program. The purpose of this program is to foster an interdisciplinary approach to national and international problems related to the ocean, particularly those in which science plays an important role. It does this by providing research opportunities at Woods Hole for scholars from the social sciences, by giving them an opportunity to learn about oceanography and by encouraging interchange with our scientists on problems of mutual interests. In the academic year 1973-74 there were 4 predoctoral and 5 postdoctoral participants whose professional backgrounds ranged from law to anthropology. In addition, we were fortunate to have the extensive participation of Professor Edward Miles, a political scientist on leave from University of Denver and Dr. Gunnar Randers, a distinguished Norwegian scientist, who recently completed a period as Assistant Secretary General with NATO.

It is very much our intention to continue to emphasize these programs as essential parts of the Institution's educational strategy. Although our facilities and the nature of our research activities prevent any broad involvement in undergraduate education, the Summer Student Fellowship Program allows a limited number of highly selected undergraduates to become directly involved in oceanographic research. The record shows that the program has attracted top talent to oceanography.

At the present time we feel a special urgency in maintaining our Postdoctoral Scholars program. I believe strongly that we, as a nation, face a a grave and not wholly recognized dilemma which threatens to scrap a most precious national asset – namely, the talents of young scholars and scientists. The dilemma is this: as a result of the exceptionally high birth-rate following World War II the number of new Ph.D.'s is now at an all time high; the universities, however, have already expanded in order to meet the increased number of youth and, thus, the universities no longer

have new jobs at the very time when new talent is most available. I believe it is essential for a research institution such as ours to make special efforts to see that research opportunities are provided for the most gifted of these young scientists. This is an obligation not only to the continuing health of science but also to the future vitality of our own Institution. In a limited way we try to meet this obligation through our Postdoctoral Scholars program.

The Postdoctoral program in recent years was funded by the National Science Foundation; however, such federal programs no longer exist. I am happy to say, though, that we have been able to procure sufficient private funds to keep the program going at approximately the same level as in past years.

We are most appreciative of the fact that all of the educational activities described above have been made possible through the generous support of private donors and foundations, both on a current basis and through income from our endowment. These activities, which are vital to the creative life of the Institution, require such commitments.

ROBERT W. MORSE
Dean of Graduate Studies

Joint Woods Hole Oceanographic Institution-
Massachusetts Institute of Technology

DEGREE RECIPIENTS – 1973

Doctor of Philosophy

ZVI BEN-AVRAHAM
B.Sc. The Hebrew University, Israel
Special Field: Marine Geology
Dissertation: *Structural Framework of the Sunda Shelf and Vicinity*

BRIAN D. BORNHOLD
B.Sc. University of Waterloo, Canada
A.M. Duke University
Special Field: Marine Geology
Dissertation: *Late Quaternary Sedimentation in the Eastern Angola Basin*

JOSEPH CHAD MACILVAINE
A.B. University of California, Berkeley
Special Field: Marine Geology
Dissertation: *Sedimentary Processes on the Continental Shelf off New England*

KENNETH MOPPER
A.B. Queens College, New York
Special Field: Chemical Oceanography
Dissertation: *Aspects of the Biogeochemistry of Carbohydrates in Aquatic Environments*

JAMES WRAY MURRAY, JR.
A.B. University of California, Berkeley
Special Field: Chemical Oceanography
Dissertation: *The Interaction of Metal Ions at the Hydrous Manganese Dioxide Solution Interface*

BRIAN E. TUCHOLKE
B.S. South Dakota School of Mines
Special Field: Marine Geology
Dissertation: *The History of Sedimentation and Abyssal Circulation on the Greater Antilles Outer Ridge*

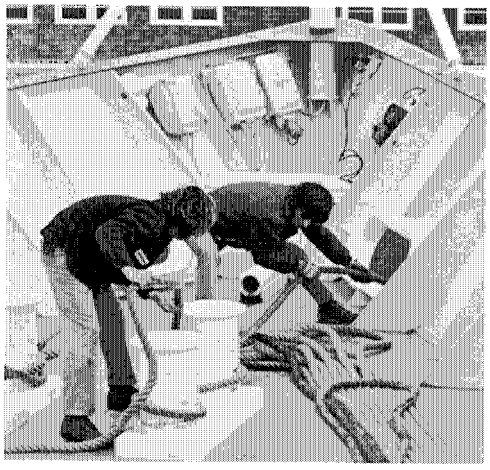
Doctor of Science

BRUCE ARTHUR MAGNELL
B.S.E.E. Massachusetts Institute of Technology
Special Field: Physical Oceanography
Dissertation: *Oceanic Microstructure Observed Near Bermuda Using a Towed Sensor*

Ocean Engineer

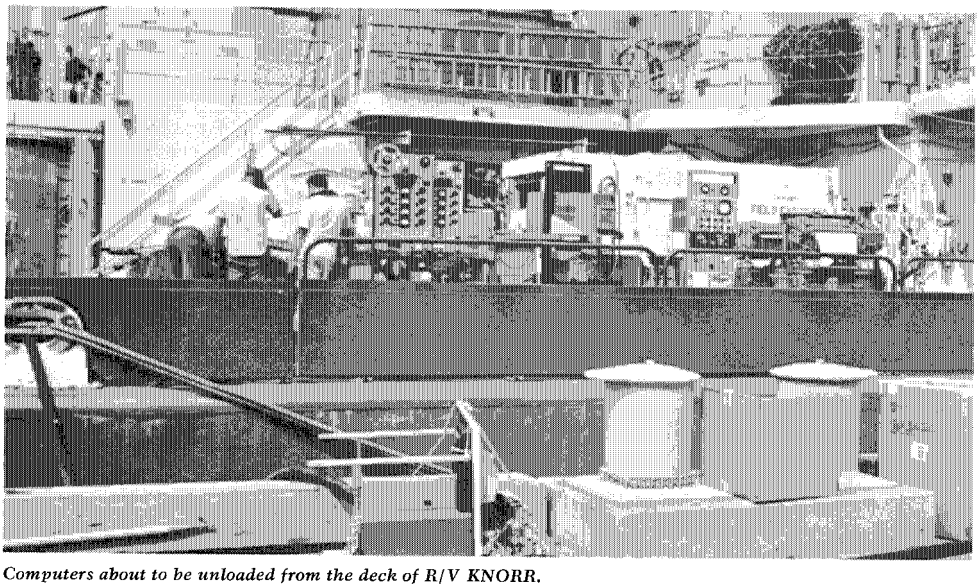
JAMES F. O'SULLIVAN
B.S.M.E. North Carolina State University
Dissertation: *The Design of a Surface Launch and Recovery Fender for DSRV ALVIN*

PAUL JEFFREY SAMONETTI
B.Eng. Stevens Institute of Technology
Dissertation: *An Investigation of Various Forms for a Tuned Oceanographic Platform*



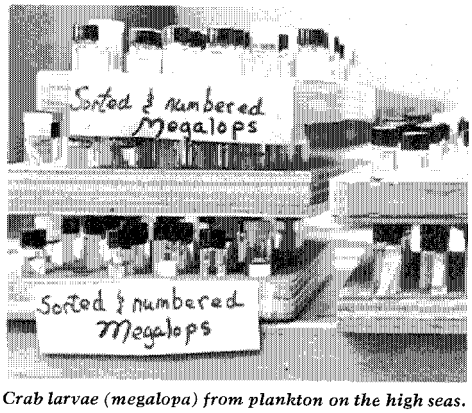
R/V KNORR ties up at dock.

Richard S. Edwards and Robert G. Weeks dive to examine cycloid of R/V KNORR.



Computers about to be unloaded from the deck of R/V KNORR.

The "new" ALVIN.



Crab larvae (megalopa) from plankton on the high seas.

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ROBERT W. MORSE . . . . . *Dean of Graduate Studies and Associate Director*
FERRIS WEBSTER . . . . . *Associate Director for Research*
BOSTWICK H. KETCHUM . . . . *Associate Director*

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Professor of Physiology (Emeritus), Harvard University

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*As of 31 December 1973.

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VIRGINIA B. PETERS, *Research Associate*
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DAVID WALL, *Associate Scientist*
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N. N. PANICKER, *Assistant Scientist*
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FOSTER STRIFFLER, *Research Associate*
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BARRIE B. WALDEN, *Research Associate*
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ROGER S. WALEN, *Research Associate*
DOUGLAS C. WEBB, Manager, Instrument Section, *Electrical Engineer, Senior Research Specialist*
JACQUELINE WEBSTER, *Research Associate*
ALBERT J. WILLIAMS III, *Assistant Scientist*
VALENTINE P. WILSON, *Research Associate*
CLIFFORD L. WINGET, *Electromechanical Engineer*

‡On Leave of Absence

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MELBOURNE G. BRISCOE, *Assistant Scientist*
JOHN G. BRUCE, JR., *Research Associate*
DEAN F. BUMPUS, *Senior Scientist*
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MARGARET A. CHAFFEE, *Research Associate*
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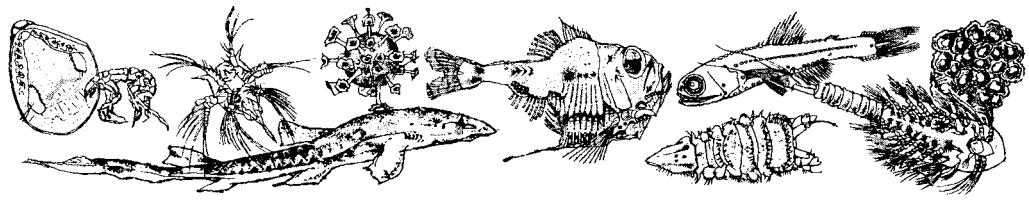

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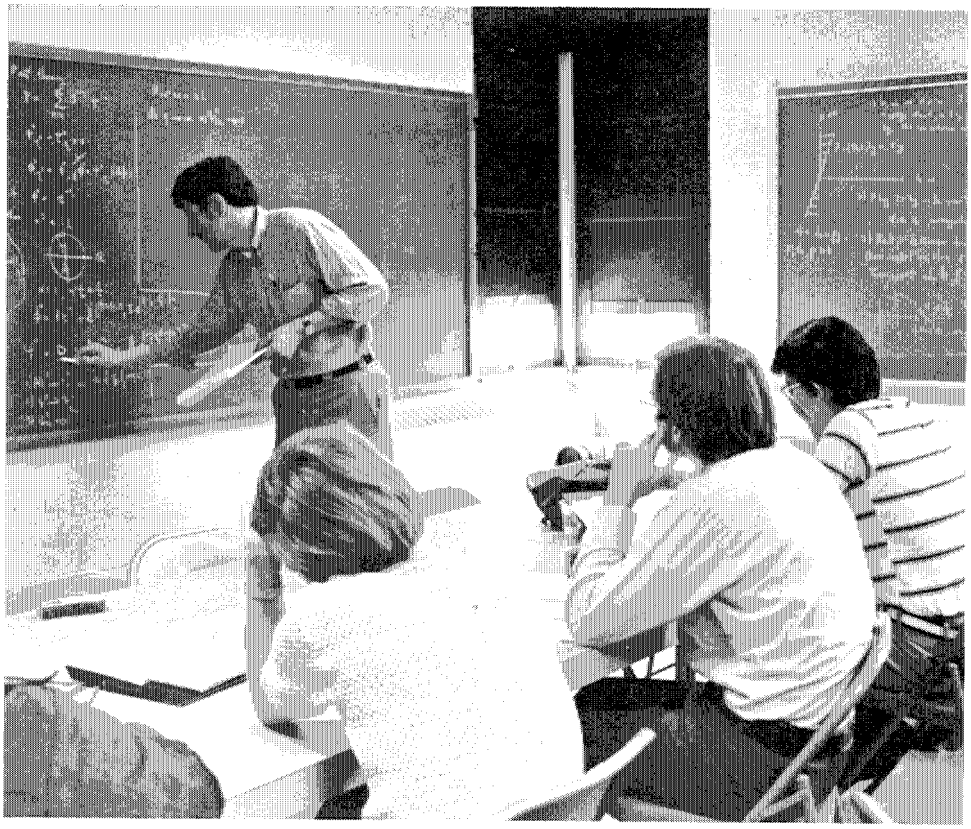


Watching the depth recorder (PGR) for the moment when it hits bottom.

Department of Biology

Noteworthy in 1973 was the beginning of a project to be carried out wholly away from the sea — perhaps the first in the Institution's history — one to determine the effectiveness of spray-irrigation as a method for tertiary sewage treatment for communities living on the sandy coastal plain. The spray irrigation system not only removes nutrients from wastewater, thus preventing their indiscriminate disposal, but also applies them as fertilizer to cropland or forest. This could be an alternative to disposal of secondarily treated sewage into coastal waters via outfall.

Several years old are an aquaculture experiment using secondarily-treated sewage to grow phytoplankton as food for shellfish, which has moved into a new complex of laboratories and waterways and an investigation of a salt marsh as a converter of excess nutrients, which has expanded to include a mangrove swamp.

Of the hundred or more other programs underway some like those just mentioned will contribute to an understanding of efficient and beneficial recycling of nutrients in the marine environment, to the long term effects of oil pollution, to potential food resources at some level in the food chain. The work on such problems is in some instances an advance for that reported a year ago, in others, it has been completed and in still others it is in the early stages of development. Consequently, in the report that follows, samples have been selected to indicate the scope and diversity of the work at the Institution, much of it in collaboration with other departments and other laboratories.

Microbiology

As an outgrowth of work in the Black Sea, the marine microbial sulfur cycle was studied in another anerobic basin, the Cariaco Trench. Water samples were incu-

bated *in situ* for eight days to measure the reduction rate of ^{35}S-labeled sulfate at various depths. Photosynthetic and heterotrophic fixation of carbon dioxide was determined in order to assess the intricate relationships between the carbon and sulfur cycles.

In the ultrastructure of purple sulphur bacteria the membrane surrounding the sulfur granules is derived from that of the chromatophore which in turn originates from the plasma membrane. To examine this evolution, the protein components of the two systems are to be compared with those present in the plasma membranes. The localization of enzyme activities on the membranes may reveal functional assymmetry in the chromatophore membrane.

When a lysate from horseshoe crab blood reacts with Gram-negative bacterial endotoxins, a clot forms. The lysate can detect as little as 10^{-12} grams of endotoxin. Improved methods have been developed to extract its active constituents, the biochemical events involving clot formation were examined, and the potential application of the lysate tests in medicine and ecology further explored. The test has now been used by clinicians at the children's hospitals of Washington and Los Angeles for a rapid determination of the etiological agent of spinal meningitis. It also proved successful in measuring the horizontal and vertical distribution of bacteria in the ocean. Thus, over 99% of the bacteria in offshore waters are confined to the upper 200 meters where they may comprise 10% of the biomass.

In situ measurements of rates of nitrification has not solved the problem of how and where nitrate is produced in the ocean. Far too few nitrifying bacteria appear to exist in the ocean to account for the amounts of nitrate. Nitrogen-fixing bacteria occur in waters and sediments of the continental shelf, but have not been detected in offshore waters except in association with *Sargassum*. Evidently the latter derive their nutrients from algal excretions, but they fix less than 1% of the nitrogen required for the growth of the *Sargassum*.

Phytoplankton Ecology

Phytoplankton species counts off West Africa revealed a large increase south of Dakar in the upwelling region, but south of Newfoundland in September-October there was no floristic difference, though Coastal Water, Slope Water, and Sargasso Sea Water were crossed. In summer counts in western Long Island Sound were higher and flagellates were preponderant, but in fall they were lower and had a preponderance of diatoms.

An obligate silicate requirement for growth has been found for the first time for an organism other than a diatom. The growth rate of the fresh water flagellate *Synura petersoni* is reduced to half when the silicate supply is limited.

In seawater exposed aseptically and without agitation to No. 2 fuel oil or crude oil, dissolved substances, chiefly aromatics, enter the water. Of 15 species of planktonic algae, a sufficiently high concentration of dissolved substances stops growth entirely in most species, a lower concentration inhibits, but does not stop growth, and a still lower concentration stimulates growth rate and final yield slightly.

Functional relationships between copper activity in the external growth medium, cellular uptake of copper, and growth inhibition in batch cultures of *Thalassiosira pseudonana* indicate that growth inhibition depends on copper activity, not its total concentration. Activity of copper in the medium is partially under control of the algae through the production of extracellular complexing agents.

The productivity of *Dichothrix*, a blue-green epiphyte on drifting *Sargassum*, was

determined along with that of its host. The carbon turnover rate of *Dichothrix* was four times that of *Sargassum*. Indeed, *Sargassum* contributes no more than 0.5% to the total primary productivity of the Sargasso Sea.

Mats of photosynthetic bacteria and benthic blue-green algae fix a significant amount of nitrogen in the Great Sippewissett Marsh. The salt marsh exports relatively large amounts of combined-nitrogen compounds to Buzzards Bay, some derived from nitrogen fixation by marsh organisms.

An *Azotobacter* capable of fixing nitrogen lives on the recently-introduced green alga *Codium fragile*. Of the several local algae surveyed *Codium* was the only one with associated nitrogen-fixing ability, and its relationship with *Azotobacter* may account in part for its rapid spread.

Wood is a major part of shipworm diet, but the carbon/nitrogen ratio of wood is low (300-500 to 1). Thus shipworms require an additional source of combined nitrogen, and it appears that a bacterium living in association with the shipworms provides this.

Pelagic Animal Ecology

A characteristic of temperate-boreal neritic copepods, for which there is no generally accepted explanation, is their seasonal appearance and disappearance. Thus, *Labidocera aestiva,* a large predatory species, is absent from our winter plankton. Eggs laid in late fall (1972) hatched only after a lapse of five months were similar in size and ornamentation to those laid in summer, but had thicker shells. Their prolonged period of dormancy and their thick shells suggests that they are resting eggs. Those laid in June, July and August (1973) hatched within 72 hours, but beginning in mid-September they again failed to hatch. The latter were identical to those previously observed to undergo diapause.

Five thousand candaciid copepod individuals have been identified from 339 stations taken during the International Indian Ocean Expedition (1961-65). Species distribution and their relationship to the hydrographic data are underway. Maps have been constructed by computer for all species and distributional patterns are discernible in most.

Atlantic and Pacific populations of the copepod, *Acartia clausi,* did not interbreed successfully in the laboratory, although each had produced many successive generations. This is evidence that the Atlantic and Pacific populations even though morphologically almost identical have diverged and are in reality distinct species.

The sampling by midwater fishing on RRS DISCOVERY in the "Ocean Acre" near Bermuda in March will allow a three-way comparison of the mesopelagic fish fauna of the Northern Sargasso Sea — conclusions based on the DISCOVERY mode of mid-water sampling, on the Ocean Acre sampling program, and on our own sampling in this same region. Likewise, on the German FFS WALTHER HERWIG Isaacs-Kidd midwater trawl collections along a transect from west Iceland to Portugal permit a comparison of IKMT catches with those obtained with the much larger Engels midwater trawl.

Midwater fishes of the family Myctophidae from the South Atlantic are being examined for the distributional phenomenon of "bipolarity". Of more than seventy-five species, eight appear to be indistinguishable from species inhabiting comparable latitudes north of the equator. Bipolarity is also indicated by similar, but distinct species, which have apparently evolved from two identical but separated populations. The Gulf of Guinea contains a well-developed oxygen minimum layer and adjacent waters are upwelling sites. While most midwater fishes are widespread, the

Guinean Region interrupts the distribution of most myctophids at the same time providing an environment for a few species which are essentially restricted to it. Thus the Guinean region resembles the eastern tropical Pacific where similar hydrographic conditions occur and a somewhat similar distributional pattern is apparent.

The decapod crustaceans from about 350 midwater trawl collections have been identified. In the St. Lawrence system are boreal species usually associated with waters over the continental shelf, but in the Mediterranean, temperate-boreal and subtropical species are mixed. Most subtropical species in the adjacent Atlantic do not enter the Mediterranean. In the Caribbean and Gulf of Mexico there are primarily species occurring in the western equatorial Atlantic. The Sargasso Sea decapods, like the mesopelagic fishes there, appear to be divided into northern and southern assemblages. In the eastern equatorial Atlantic the species are identical or very closely related to those below 40°S in the South Atlantic.

In order to ascertain whether the Gulf Stream is simply a faunal boundary, or whether it is a third and separate faunal region in the Slope Water-Gulf Stream-Northern Sargasso Sea complex, three sets of existing fish collections were chosen from the area north of 32°N and west of 59°W. A biomass (displacement volume) ratio of 8-3-1.5 for the Slope Water-Gulf Stream-Northern Sargasso Sea "transect" agrees well with a literature value of 8-3-2 for zooplankton for the same three regions. From a similarity analysis the faunal composition of the Slope Water appears distinct from those of the Gulf Stream and northern Sargasso Sea and the Gulf Stream and northern Sargasso Sea sets are faunistically rather similar.

Gulf Stream rings forming to the south or east of the Gulf Stream enclose water and organisms of Slope Water origin. Many slope species are distinct from those in the northern Sargasso Sea although they occupy similar ecological niches. Thus the formation of a ring constitutes the invasion of one oceanic community by another. This with the ring's subsequent decay is a natural ecological experiment which may separate the effects of the physical-chemical environment from those of biological interactions on the structure and function of an oceanic community. Physical, chemical, and biological observations have now been made inside and outside three cold-core rings of various ages.

The Cooperative Game Fish Tagging Program at the Institution has now joined with the National Marine Fisheries Service in a cooperative project. With the Southeast Fisheries Center, Miami, and Southwest Fisheries Center, La Jolla, analyses have continued of data for certain pelagic species, especially the bluefin tuna. A heavy fishing pressure is exerted on those off the eastern United States in summer to the detriment of the stock as reflected by the catches.

Robert B. Campenot works on equipment for high pressure electrophysiology of deep-sea animals.

Bregmaceros nectabanus, a midwater codlet, migrates diurnally into the hydrogen sulfide waters of the Cariaco Trench. Preliminary measurements in fish collected at various times of day suggest a decrease in respiration and an increase in lactic acid concentration when in the anoxic water.

The observed dispersal of larvae of the nearshore worms, *Chaetopterus* and *Spiochaetopterus,* may explain not only the very wide geographical range of the adults, but also the possibility for restricted but regular gene flow between populations separated by ocean basins. However, more data are needed in order to understand the relationship between larval dispersal, natural selection, and genetic variation between populations. Investigations of mortality and dispersal of benthic larvae in and out of a small estuary and the genetic differences between geographically separated populations of marine gastropods have already been initiated toward this end.

One of the Pacific spinner porpoises, *Stenella* sp., and the sperm whale, *Physeter catodon,* were tracked and recorded as sound-producing animals swam within acoustic range of a three-dimensional, four-hydrophone array. These cetaceans appear to have voluntary control of the level of their sounds, just as do terrestrial animals. Level variations of as much as 16 dB were noted in the lower frequency sounds of individual porpoises and as much as 26 dB in those of individual sperm whales.

Benthic Animal Ecology

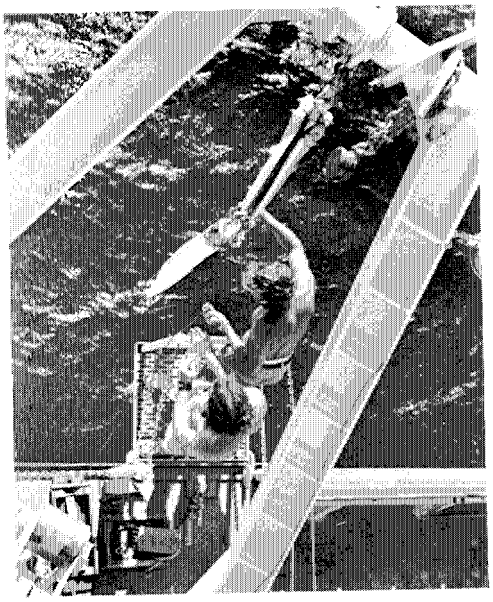
The fauna of Hudson Canyon between 200 and 2800 m is quite similar to that on the nearby continental slope. Biomass in the Canyon, however, is four or five times that of the slope at similar depths with an abrupt change in its fauna between 200 and 350 meters. On the slope, each species seems to have its preferred depth range, and, for fishes, larger individuals occur in the deeper portions of that range. Enzyme polymorphism of echinoderms from Hudson Canyon is without any clear correlation of degree of polymorphism with depth.

Deep-sea bottom animals may affect erosion and other mass physical properties of sediments. In Mona Canyon, northwest of Puerto Rico, where the benthic fauna is less abundant than in the canyons off the northeastern United States, the animals were no less important in catalyzing erosion.

Species of benthic invertebrates with the most opportunistic life histories increased, then declined at the two stations most heavily oiled by the West Falmouth oil spill of 1969. At stations intermediately affected there were increases and declines of somewhat less opportunistic species. Electrophoretic studies of the malate dehydrogenase loci of the most opportunistic species, *Capitella capitata* showed short-term selection for a single genotype in Wild Harbor following the oil spill. Temporal changes in genotypic frequencies have been followed at four localities. In azoic sediment placed at two localities in a salt marsh at intervals, *Capitella* did not increase the way it had in West Falmouth.

The amount of oxygen dissolved in the bottom water has an important effect on the structure of benthic invertebrate communities. Where the oxygen concentration varies widely, species diversity is low. Where it is constant, even though low, benthic communities have greater diversity.

The respiration of sediments and benthopelagic fishes was determined *in situ* in the San Diego Trough at a depth of 1230 m. That of the rattail *Coryphaenoides acrolepis* was two orders of magnitude less than that of a phylogenetically related shallow-water cod (*Gadus morhua*) and that of the hagfish *Eptatretus deani* was significantly less than that of a shallow-water congener, *E. stouti.* Total oxygen uptake by the sedi-



A plankton sample.

ments had values an order of magnitude greater than comparable measurements on the continental slope off Cape Cod.

For *in situ* measurements on naturally enriched sediments under the California Current the total oxygen demand was significantly higher than in control areas. Both the biological and chemical oxygen demands were significantly increased by organic enrichment. Comparison of the effects of natural enrichment (upwelling) with sewage enrichment in the New York Bight (outwelling) revealed no significant difference in the total oxygen uptake at comparable temperatures.

As an effect of pressure on the neuromuscular junction of lobsters, there is a diminution of excitatory junction potential at pressures above 50 atmospheres. In *Geryon,* a moderately deep-living crab, there is little diminution up to 200 atmospheres, an indication that its mechanism of adaptation may be presynaptic.

Aquaculture

During the first four months of 1973, the growth and nutrient uptake kinetics of several species of marine phytoplankton were tested in chemostats to determine the optimum combination of sewage effluent and seawater in the medium, algal yield, and nutrient utilization consistent with the concept of a combined tertiary-treatment aquaculture system. Output from the continuous algal cultures was fed to juvenile oysters to determine their growth as a function of particular algal food species. The effect was tested on the concentration of a single diatom, *Phaedactylum tricornutum,* on the rate and efficiency of food assimilation, deposition (as feces and pseudofeces) and growth of juvenile oysters. The feeding, growth, and reproduction of the small worm, *Capitella capitata,* and the large bait worm, *Nereis virens,* were examined in order to ascertain their suitability as consumers of the deposits of the oysters and its meiofauna. The growth of abalones and their feeding on algae (*Ulva lactata, Chondrus crispus, Rhodymenia palmata,* and *Laminaria* spp.), the nutrient-uptake and growth rate of these seaweeds and the effects of temperature, light, and other factors on their growth and reproduction were determined preparatory to using these plants in the final cleanup of the tertiary treatment process.

In March, 1973, a new pilot-scale system was designed, constructed and operated on the dock until October (when it was discontinued on completion of the Environmental Systems Laboratory). Up to 1600 liters per day of secondary sewage effluent was trucked from Otis Air Force Base. The treated effluent and filtered seawater were pumped into head boxes, and mixtures of the two added at different ratios and rates to two 400-liter phytoplankton growth tanks. For the first time, a complete continuous-flow, gravity-feed system was operated. Overflow (yield) from the continuous phytoplankton cultures was fed into rectangular tanks each containing 2000 juvenile oysters. Overflow from the oyster tanks was in turn fed into

400-liter seaweed tanks containing either *Ulva* or *Chondrus*. The *Ulva* was then fed to juvenile abalone, which were maintained in separate tanks. The polychaete worms *Capitella capitata* and *Nereis virens* were stocked in the bottoms of the oyster tanks.

The amount of nitrogen (as urea, ammonia, nitrite, and nitrate) removed from the sewage by the phytoplankton averaged about 40%, but removal from the system as a whole, including the final seaweed stage, averaged over 90% and often was virtually complete. Under the best conditions, phosphate removed by the complete system was about 50%.

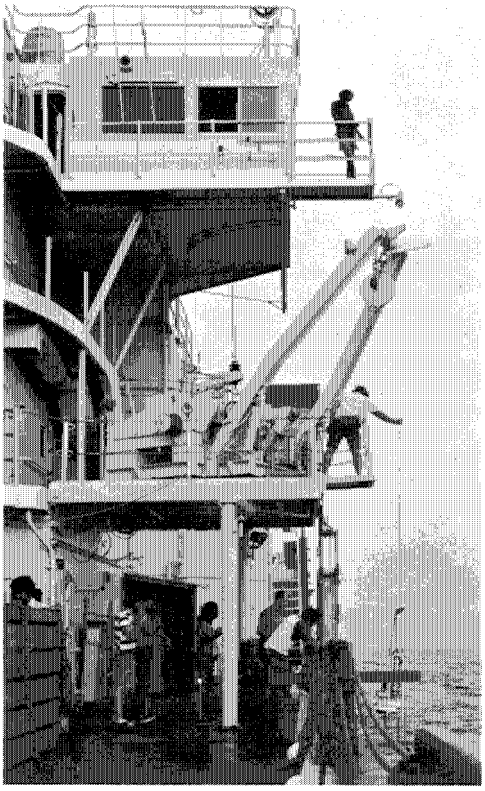
A major risk in a sewage-based aquaculture system is that human enteric pathogens may be concentrated in the cultivated organisms. Enteric viruses are therefore monitored throughout the system from sewage to final discharge, as well as in the shellfish and other cultured species. Assessment has begun on the effects of high-energy electron bombardment on survival of virus and other microorganisms of human origin in sewage.

A groundwater recharge project is evaluating alternative means of wastewater treatment and developing design criteria for the recharge of water of potable quality to the groundwater reservoir of the coastal outwash plains of Cape Cod and the Islands. Investigated will be the *in situ* performance of (1) an existing sand filter bed, (2) a rapid infiltration system designed to enhance biological denitrification, and (3) a spray irrigation-cropping program. The quantity and quality of the treated water, the receiving water, and the character of the soil is being examined to project eventual water condition after years of operation.

In the fourth year of enrichment of Great Sippiwissett Marsh, the salt-marsh grass on fertilized plots became more and more like that on the most productive parts of the unmodified marsh — the creek banks. The grass is taller and thicker, but there are fewer of the larger plants so that production per unit area is about the same. Budgets for the lead, cadmium and zinc added to the plots with the sewage sludge fertilizer were worked out. Lead is almost entirely retained in the marsh. Cadmium on the other hand was exported in significant amounts.

Domestic wastewater frequently contains a higher load of dissolved metals than the original source water. While nutrient-rich secondarily-treated wastewater can serve as a fertilizer for the culture of commercially valuable algae and shellfish, excessive levels of dissolved metals pose problems. To determine acceptable levels of heavy metals in a wastewater treatment-aquaculture system, the original levels of metal in the wastewater were supplemented with simultaneous progressive increases in the concentration of copper, zinc, nickel, chromium, lead and cadmium. Elevation of metal concentration caused an increase in the metal content of phytoplankton cells, but little change in cell numbers, and an increase in cadmium, nickel, chromium, and lead content in oysters. No accumulation of copper was noted; the level of zinc decreased with increasing concentration in the wastewater.

In two populations of oysters differing in lipid content which were exposed to petroleum hydrocarbons, the rate of oil uptake slowed with time and after 50 days approached equilibrium. The concentration of hydrocarbons in the populations then differed when calculated on a wet-weight basis, but not on a lipid basis. The initial rate of uptake was directly related to the hydrocarbon concentration in the water. Oysters exposed to 100 g/liter for 50 days and then transferred to clean water lost 90% of the accumulated hydrocarbons in two weeks. Thus, it appears the total toxicological potential of such oysters is slowly yet continually changing.



Lowering pinger and corer.

The lamprey *Petromyzon marinus* and the hagfish *Myxine glutinosa* have been examined for the presence of genetically distinct multiple molecular forms of the pentose shunt enzyme glucose-6-phosphate dehydrogenase (G6PD), one with restricted substrate specificity and one which reacts with several substrates including unsubstituted glucose. The gene for the enzyme with the broader substrate specificity does not seem to occur in the hagfish. Lampreys have an enzyme which oxidizes glucose.

Larvae and eggs of twenty-two species of fishes are entrained in the cooling water of a nuclear power plant on Long Island Sound. The most numerous are *Pseudopleuronectes americanus* (winter flounder), *Tautoga onitis* (tautog), *Anchoa mitchilli* (anchovy), and *Tautogolabrus adspersus* (cunner). About 70% of the larvae that pass through are killed. The temperature rise accompanying entrainment increases the activity of phytoplanktonic nitrate reductase about 25% with each 3°C increase to about 24°C. Above this, the activity decreases.

A reef constructed of ten tons of baled, shredded urban refuse continues to be under observation in Great Harbor, Woods Hole. Gas generation, a result of microbial activity, reached a maximum in warm weather, but the microbial decomposition has had no noticeable effect on the physical character of the bales. The bales wrapped in polyethylene appear as they did when first deployed in the summer of 1972.

Biological Instrumentation and Techniques

Devices and techniques used to further various projects within the department may be complicated and time-consuming to construct and test preparatory to their use at sea or in the laboratory. A few representative examples are: (1) an *in situ* particle counter for monitoring spatial and temporal variations of animals in a more detailed manner than nets allow, (2) a flow sensor to use in tandem with the counting cell, which also shows promise as a current meter in its own right, (3) a technique of continuous zonal centrifugation applied to the collection of marine phytoplankters from cultures with an ultimate application for harvesting large-volume natural samples, (4) a recovery vessel for returning animals and water at ambient pressure and temperature to the surface with consideration of a combined recovery-experiment vessel (as has been done for bacteria), and (5) a trap to measure the flux of particulate organic matter to the deep-sea floor.

RICHARD H. BACKUS,
Chairman

The extraction of hydrocarbons.

Department of Chemistry

The first major cruise of the Geochemical Ocean Sections Study was completed in April when R/V KNORR arrived in Woods Hole following a nine month cruise in the Atlantic. During the cruise, 121 stations were occupied between 75°N and 55°S, and about 100,000 shipboard analyses were made. In addition, about 400,000 liters of water samples were taken which are being analyzed by universities and research institutions all over the world. The cruise was very successful and is now being followed by the Pacific portion of the program, with R/V MELVILLE working from the tip of the Aleutian Islands to Antarctic waters. Details on this and other programs follow.

Geochemistry

For a better understanding of the diffusion of ions into and from sediment pore waters, a unique *in situ* sampling device has been developed. The "Harpoon", as it is known, enters the sediment and then withdraws six filtered pore water samples of approximately 20 ml. from the top two meters. In spite of their small size, several quantitative analyses are performed on each of the samples. These have been obtained from more than 35 stations in both the North Atlantic and the Caribbean. Preliminary examination of the data obtained in this way reveals a widespread uptake of potassium, magnesium and sulfate by the sediments. On the other hand, from virtually all the samples, there was a release of calcium, bicarbonate and silicate. If the concentration gradients of magnesium and potassium are typical of the sea floor, diffusion of these components into the sediment will account for a large portion of the quantity of these elements supplied to the oceans by the rivers.

The JOIDES Deep Sea Drilling Program continued in 1973, and in cooperation with scientists from other institu-

tions, we have examined basalts from seven drilling sites in the North and South Atlantic, with ages ranging from 18 to 67 million years. Since these were recovered far from the present ridge axis and are not from oceanic islands or seamounts, they provided us with a unique opportunity to ascertain the characteristics of the old Atlantic sea floor. Of the seven sites, only one (Leg 2, Site 10) has basalt that differs from that of the present ridge axis. The basalts from this site are more alkaline and are enriched in elements such as lanthanum, strontium, barium and zirconium in comparison to mid-ocean ridge basalts.

Igneous rocks from the Indian Ocean Ninety-east Ridge were also studied this year. The petrography and chemistry of the lavas support the hypothesis that they represent fractionated magmas that have cooled and crystallized in shallow magma chambers before extrusion.

In October on an R/V ATLANTIS II cruise, basalts were systematically dredged on a traverse from the ridge crest to the flanks. These were progressively altered with distance from the crest of the ridge. In terms of sea-floor spreading age they span from 0 to 50 million years. This collection will permit a better definition of genesis, composition and history of the oceanic lithosphere.

Organic and Biochemistry

Investigations have continued of the place and extent of oxidation of organic carbon in the water column by measuring δC^{13} and ΣCO_2 profiles and determining δC^{13} of organic phases in the system. In the western North Atlantic a significant difference was detected between the carbon-13 content of organic matter formed in the euphotic zone and that remineralized in the uppermost kilometer of the water column. Since different groups of organic compounds generally have different carbon-13 contents, this information can be used in identifying the principal depth ranges of oxidation for the different types of organic matter.

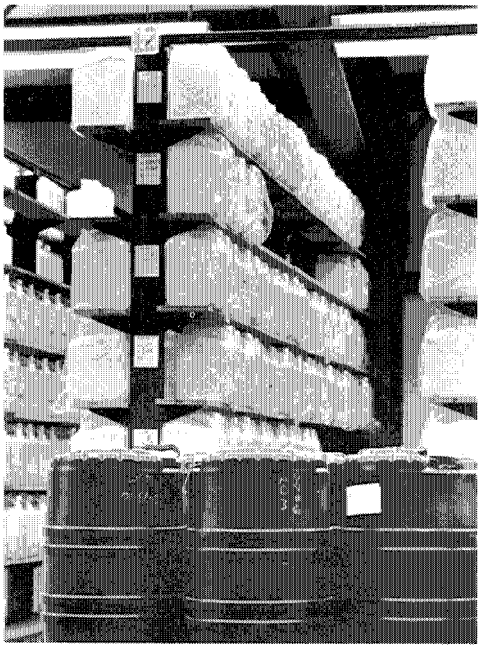
Stable-isotope studies of Deep Sea Drilling cores from the Red Sea and Gulf of Aden should determine the relationships between pluvial periods in low latitudes and glacial periods in high latitudes. At Red Sea Site 228 there were five intervals of abnormal δO^{18} values from the analysis of 250 single-species samples of planktonic foraminifera between recent deposits and the middle Pleistocene. The δO^{18} variations indicate density variations in the water in which the foraminifera lived which were caused principally by changes in the precipitation-evaporation ratio. Future work on time-equivalent samples from the Gulf of Aden will yield information on the contemporaneous changes in the open ocean due to fluctuations in ice abundance in the high latitudes.

One of our long-term projects is to delimit hydrocarbon distributions in marine organisms, the water column and the sediments in order to determine the fate of these compounds and how they differ from fossil hydrocarbons such as petroleum. Analysis of the saturated and olefinic hydrocarbons in benthic algae showed only normal alkanes and alkenes to be present, with two minor exceptions. The hydrocarbon spectrum differs greatly from petroleum in its simplicity and predominately unsaturated nature. Young plants, or the rapidly growing tissues of older plants contain the highest hydrocarbon concentrations and alkene to alkane ratios.

Total hydrocarbons were determined in sediments from 15 stations between Bermuda and Woods Hole. The concentrations increased by three orders of mag-

nitude between the Abyssal Plain and the New York Bight. Normal alkanes had an odd carbon predominance at all stations except three in the New York Bight, where the data indicate that the area is polluted with fossil fuels. The odd carbon predominance in the Abyssal Plain suggests some contribution of land or marsh derived hydrocarbons.

A program has been initiated to explore the quantity and types of aromatic hydrocarbons in the marine environment. A method has been developed for the selective recovery of aromatics from complex lipid extracts obtained from sea water, marine sediments or biological materials. To date a water sample, several sediments and benthic marine algae have been analyzed. The complexity of composition of the polynuclear aromatic hydrocarbon mixture appears to be far greater than previously known. The principal hydrocarbon series extend over a wide molecular weight range and are accompanied by minor series that are interpreted as the naphthenologs and thienologs of the major series.



Water "library" acquired during GEOSECS cruises.

One group of hydrocarbons not formed by living marine organisms is the alkanes, cycloalkanes and aromatics in the C_1 to C_7 range. Consequently, their presence in sediments indicates preliminary decomposition of organic matter leading to petroleum. In some 50 Deep Sea Drilling cores in the Atlantic, Pacific and Indian oceans these hydrocarbons are more widely distributed than had been believed previously, although the concentrations were low. Yields varied from 0.5 to over 6,000 parts per billion in the depth ranges from 120 to 770 meters, involving a time interval from the Cretaceous to the present. Most appear to be forming indigenously through low temperature cracking of larger molecules, with some diffusion from deeper horizons.

Concentrations of polychlorobiphenyl (PCB) in the atmosphere, water and sediments of the North Atlantic are being measured to determine the routes and possible mechanisms of input of such compounds in the marine environment. The delivery of chlorinated hydrocarbons to the ocean appears to be greatest in the coastal zones. PCB concentrations in the atmosphere decrease exponentially seaward. This input is buffered by the higher particulate load and sedimentation rate in the nearshore ocean, causing the PCB concentrations in the water and organisms not to show a meridianal gradient. The delivery does appear to be reflected in the surface sediments of the ocean. Samples collected in the summer of 1972 indicate that the mixed layer of the North Atlantic contained about 20,000 tons of PCB at that time. Since then concentrations have decreased and we believe some of this has penetrated the deep Atlantic.

Bacteria collected from the water column of the North Atlantic, mid-Atlantic and Caribbean Sea are being cultured in the laboratory and tested for their sensitivity to PCB and DDT, and in some cases, their ability to concentrate these chlorinated hydrocarbons within the cell. We are also studying the growth responses of phytoplankton algae in pure and mixed culture when exposed to environmental levels of PCB. The toxicity of PCB to *Thalassiosira pseudonana* was greatest when this diatom was in competition with other species.

Steroids are important in regulating the growth, respiration and reproduction of marine organisms, yet little is known about their origin, distribution, concentration and fate in sea water and sediments. A relatively simple method has recently been developed for isolating and elucidating the structures of sterols in sea water. Coastal waters of Vineyard Sound have sterol concentrations in the range of 2.6 to 7.4 μg/l., with cholesterol, campesterol and β-sitosterol being the major constituents. Total sterols in the Gulf Stream range between 1-2 μg/l. with cholesterol and β-sitosterol the major constituents. Sargasso Sea samples had the lowest sterol concentration, approximately 0.5 to 1 μg/l., with cholesterol dominant. The source of β-sitosterol in sea water appears to be terrestrial runoff of land-plant detritus. Its concentration decreases in going from Gulf Stream water to the Sargasso Sea. Lobsters and shrimp have wet weight sterol contents of 0.075% and 0.13% respectively. Cholesterol constitutes about 95% of the total sterols in both organisms.

The molting hormone from the lobster *Homarus americanus* has been isolated and identified. This compound, ecdysterone, has the same structure as the molting hormone in insects. It constitutes about 6 μg/kg wet weight of the lobster. The biosynthetic precursor of ecdysterone, as in insects, appears to be cholesterol.

Various aspects of lobster behavior are examined in order to learn more of the effects of natural chemicals and pollutants on aquatic animals. The behavior patterns of ten lobsters were observed in a 200,000 gallon tank in the New England Aquarium in Boston, where, with a low population density, there was no staking out of territories and very little aggression between the lobsters themselves. Aggressive and defensive behavior was directed more often against fishes and turtles in the same tank.

In small tanks, lobsters can discriminate different foods by odor. Furthermore, they can be trained to pull different targets, using food as a reward for correct responses. Thus, they appear to exhibit an invertebrate intelligence just below that of the octopus.

In Little Sippewissett Marsh the mud snail, *Nassarium obsoletus,* has been found to release an alarm pheromone when it is crushed or otherwise damaged. The pheromone causes other mud snails to burrow in the mud or move away from the area of pheromone release. Damage to any part of the snail's body appears to cause release of the pheromone.

The two major problems preventing the mass culture of lobsters from larvae to marketable size are cannibalism and aggression. In the behavioral development of young lobsters there is increased aggressive behavior during their development from stage 4 to stage 8, with a peak occurring at stage 7. Excess food and shelter, and a reduction in population density all favor a reduction in the amount of cannibalism and aggression. Thus, in community situations involving

four lobsters in a fifty-five gallon tank, there was significantly less aggression than in paired encounters of lobsters in small tanks. This is partly due to the fact that differential growth in the large tank results in the smaller individuals avoiding interactions with the larger animals whenever possible.

Radiochemistry

Sedimenting particles do not appear to affect the ratio of cesium^{137} to strontium^{90} in ocean water columns. In a large series of samples of over ocean precipitation from the North Atlantic the mean ratio of cesium^{137} to strontium^{90} was 1.47±0.2. In open ocean surface water the mean ratio was 1.43±0.4 and in subsurface samples having at least 5 dpm cesium^{137} per hundred liters the ratio was 1.44±0.4. The latter samples represented depths down to 2,000 meters. In deep water samples having cesium^{137} of less than 5 dpm per hundred liters, the mean ratio was 1.64±0.7. No clear trend of the ratios correlated over a seven year period with either depth or ocean area. In contrast, water samples from nearshore ocean areas in many parts of the world agree in being significantly depleted in cesium^{137}; the mean ratio being about 1.05. Sediment analyses in such areas do not show enough cesium^{137} to account for that lost from the water column. The low ratio appears to be due to a combination of processes, such as cesium^{137} sedimentation, low cesium^{137} to strontium^{90} ratios in river and runoff supplies of fresh water, and high strontium^{90} in ground water supply of salt water.

Measurements of strontium^{90} in water samples taken from the North Atlantic in 1972 confirm earlier data with an excess of strontium^{90} over that that would be predicted by extrapolation of various delivery measurements over land. The amount of excess appears to correlate with latitude, passing from 500% at about 75°N in the Greenland Sea to only about 35% near 19°N in the Antilles Outer Basin. Plutonium^{239} does not show this same excess over prediction.

Our interest in the biogeochemistry of plutonium has expanded to other transuranic elements, such as neptunium, curium and americium. New technologies in nuclear power production will soon begin to result in large amounts of these nuclides as radioactive wastes. Last year we developed a method for separating americium^{241} in marine environmental samples and more recently a similar method has been used to measure curium^{242}. Americium^{241} is formed by the decay of plutonium^{241} which has a much shorter half-life than plutonium^{239}. Consequently, the ratio of americium^{241} to plutonium^{239} would be expected to increase with depth. At one North Atlantic station this ratio increased smoothly from 0.16 at 200 meters to 0.38 at 2,900 meters, both nuclides showing maximum concentration at 675 meters. This increase greatly exceeds that to be expected because of decay of plutonium^{241}. Further analyses are needed to determine the geochemical process causing this increase.

The quantity of iron^{55} in a Buzzards Bay core was about five times that expected from direct fallout. This compares with a six-fold excess reported from a core in the Santa Barbara Basin. We are now investigating the mechanism causing concentration of iron^{55} in shallow water coastal sediments.

A continuation of our Lake Ontario work indicates that plutonium^{239} concentrations continued to be highest in the deeper waters, although vertical gradients were less steep in 1972 than in 1971. There appears to be a significant input of plutonium^{239} via the Niagara River. Surface

sediments at the southwestern end of the lake contained as much as 460 dpm plutonium^{239} per kilogram of dry sediment. Concentrations decreased rapidly to 0.5-7 dpm per kilogram in the first five centimeters of depth, with some plutonium being detected to depths of 60 centimeters in the most westerly core. The guts and liver of lake fish exhibit significantly higher plutonium than the meat, bones and roe, although levels are generally less than one dpm per kilogram wet weight. Higher levels have been detected in several bottom feeding fish.

Among the naturally occurring radionuclides, lead^{210} and polonium^{210} are known to be concentrated by marine particulate matter. Hence, their distribution should be useful in determining whether scavenging and transport by particles is important in controlling the concentration of similar trace metals in sea water. Methods have been developed for analyzing the particulate matter and a number of samples have been collected from the Atlantic and Caribbean with further sampling being planned for the Pacific.

Sea Water Chemistry

The GEOSECS (Geochemical Ocean Sections Study) program, which began in 1972, continued in 1973. In April, the R/V KNORR finished a nine month cruise in the Atlantic, collecting data and water samples from 75°N to 55°S. The Pacific portion of the program is now underway, with the R/V MELVILLE working its way down to Antarctic waters, first going north from San Diego to Adak at the tip of the Aleutian Islands. During the Atlantic cruise, 121 stations were occupied and literally tens of thousands of water samples were taken. These are being analyzed by the various participating universities and research institutions from all over the world. Our part of the program involves the study of trace and major elements present in the ocean particulate matter. Recently, in cooperation with the University of Rhode Island, using their irradiating facilities, we have been able to do some neutron activation analyses of short-lived isotopes in suspended matter. Samples that were previously analyzed for concentrations of manganese, magnesium, mercury, copper, antimony, scandium, iron, zinc and cobalt, were analyzed for calcium and aluminum. These two elements have particular importance because they are major constituents in the detrital terrigenous clays and biogenic carbonate fractions of oceanic suspended material.

The Cariaco Trench has always been of special interest to oceanographers; it is one of a few anoxic basins of the world. It has been shown previously that a trend of warming of the bottom water is occur-

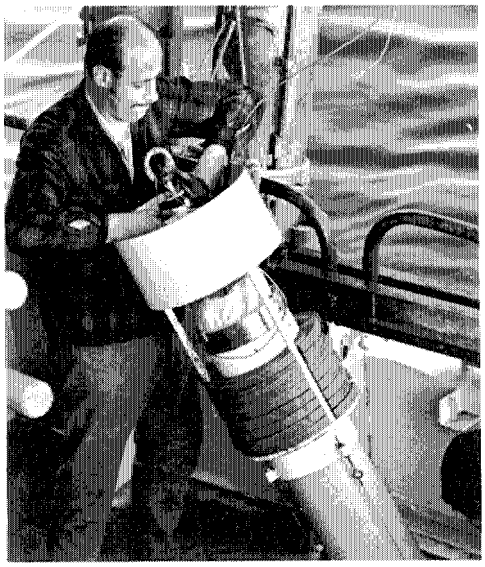
Helen P. Miklas testing for PCBs.

ring (approximately 0.002°C/year) with no corresponding change in salinity. A visit in 1973 indicated that this unexplained trend is continuing and has resulted in a density decrease of 0.0209 σ_t units in the deep water in 19.7 years.

The analyses of sea water for major elements by difference chromatography continued. Successful usage of the previously mentioned *in situ* "Harpoon" sampler provided samples that we could not previously obtain. These filtered pore water samples have a composition significantly different from the "ordinary" pelagic sea water. The presence of NH_4^+ ion in them required modification of our procedure since it interfered with determination of magnesium to sodium ratios. By placing a copper-chelex resin ahead of the regular cation resin the NH_4 peak could be sufficiently delayed to prevent interference.

Efforts have continued to develop accurate methods for measurement of lead in sea water. Natural lead levels are extremely low, less than 50 nanograms per kilogram, and a major effort has been directed toward eliminating laboratory sources of contamination during sample processing. Lead measurements of samples from two stations in the North Atlantic indicate strong depth gradients decreasing from 150 nanograms of lead per kilogram near the surface to about 35 nanograms of lead per kilogram per 2,000 meters. The deep water concentrations are comparable to earlier measurements by Chew and Patterson near Bermuda, but surface concentrations are about twice as high. This suggests that the atmospheric input of lead has increased the burden of open ocean surface waters considerably since 1966.

Solar photolysis of nitrate and nitrite occurs at a significant rate in surface waters in the tropics. For nitrate the process

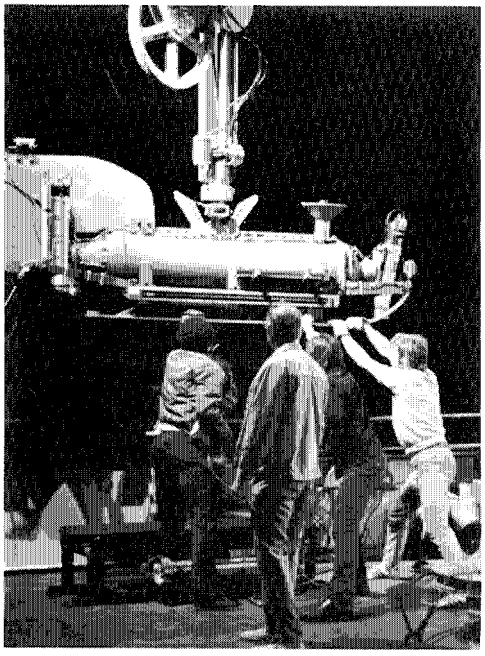


John W. Farrington readies sphincter corer.

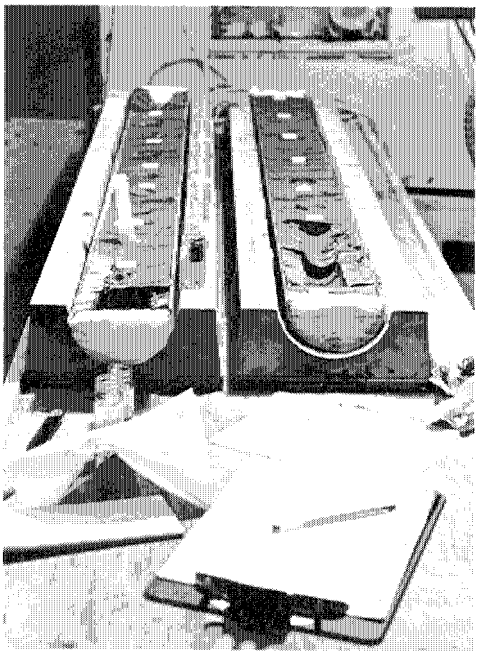
is limited to the upper few meters, but nitrite may be photolyzed at significant rates down to at least 25 meters. Both the nitrate and nitrite photolysis produce the extraordinarily reactive radical O^- (oxygen minus an electron). Flash photolysis-kinetic spectroscopy is being used to assess the effects of this product in sea water. It appears to form a light-absorbing transient on a microsecond time scale which subsequently decays on a millisecond scale. The decay is faster in real sea water than in artificial sea water mixtures.

This transient may be a free radical which disappears by reacting with the dissolved organic matter in sea water. The halogen gases are also rapidly dissociated to free atoms by sun light. The resulting iodine atoms react with ozone to yield iodine oxide whose ultimate fate is unclear. The photochemical decomposition of organic compounds such as thiamine is also under investigation.

JOHN M. HUNT, *Chairman*



DEEP-TOW apparatus for near bottom magnetic, photographic sediment thickness and side scan observations.



Core obtained with the Hollister corer, split and ready for sampling.

Department of Geology and Geophysics

The major scientific projects of the Department were large international ones relating to the continental margins of the eastern Atlantic and Brazil, to the Mid-Atlantic Ridge south of the Azores, to the JOIDES Deep-Sea Drilling Project, especially in the Indian Ocean, and to the initiation of the SOUTHLANT cruise to the far South Atlantic Ocean. Less extensive, but still significant was the work carried out in the North Atlantic with the Scripps Deep-Tow instrument package, in completing reports on the Red Sea and Samoan Passage data, on micropaleontological biostratigraphic syntheses, in examining lunar samples, and in obtaining new gravity measurements in the Bay of Bengal and magnetic measurements in the Greenland and Norwegian seas. Extensive analyses of coccolithophorids and other suspended matter were also made with the electron microscope. To support these programs there were instrumental developments with gravity meters, giant piston corers, rock drills, digital processing of seismic reflection data and precisely located deep sea photographs. Data reduction and the archiving of data, photographs, and geological samples have kept pace with the scientific programs.

The Larger Programs

The cruises to the eastern Atlantic continental margin extending from 45°S to 40°N were completed. While still at sea, all the major sediment basins were delineated and their age and thickness of the sediment approximated. In all, 95,000 kilometers were steamed about half in 1972 and half in 1973. In addition to the regular Institution staff, there were also participants from Africa (19), from Europe (13) and from North and South

America (12). From the vast amount of data accumulated (gravity anomalies, magnetic anomalies, depths to structural discontinuities, the thickness of the sediment between the major acoustic reflection horizons, etc.), four sections are to receive special emphasis. The first, already completed, is that off southwestern Africa, where the chief structural features are the Agulhas Fracture Zone, the ancient Orange River delta, and the Walvis Ridge. In this latitude, the date of separation between Africa and South America appears to have been about 165 m.y. ago. Most of the sediment atop the continental margin was deposited during the Mesozoic Era; the lesser amount deposited during the Cenozoic is attributed to a possible change in climate.

Project FAMOUS is an American-French project to examine, in detail, a portion of the Mid-Atlantic Rift Valley about 350 miles southwest of San Miguel in the Azores Islands. Since the project started in late 1971 about twenty cruises have been made. In 1973 the Institution's R/V ATLANTIS II cruise 77 recorded microearthquakes, took many accurately positioned heat flow measurements, dredge samples, bottom photographs and obtained other geophysical data. The R/V KNORR used the Scripps Deep-Tow apparatus to make near bottom magnetic, sediment thickness, photographic and side scan observations. Our personnel joined a USNS MIZAR cruise to take large area photographs and emplace current meters and a USNS LYNCH cruise to recover the meters. One member of the staff participated in the preliminary dives of the French Bathyscaphe ARCHIMÈDE on the Mid-Atlantic Ridge during the summer. These and other cruises yielded a great amount of information on the bathymetry, magnetics, and bottom forms in an area of about 10 by 30 miles. Thus it became possible to formulate plans for the joint U.S.-France submersible program for 1974.

The Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) developed a proposal for deep sea drilling in the post-1975 period; new project orientation and new international participation will further increase our understanding of the earth's formation, in a way which will add to the significance of that already obtained from cores taken aboard the D/V GLOMAR CHALLENGER. Members of the staff at Woods Hole participated in formulating this proposal. In addition to providing advisory services for that project the staff at the Institution completed much of the work based on data obtained from earlier drilling, especially in the Indian Ocean. Four staff members were co-chief scientists on Legs 23, 24, 26 and 27. Hence, they have been greatly involved in the preparation of the four *Initial Reports* summarizing the preliminary results, in addition to more formal reports. Northwest of Australia, the age of the sea-floor basement was estimated to be 155 million years, as old as any part of the sea floor now known (Leg 27). Sediments overlying this old sea floor provided an opportunity to examine the paleomagnetic record of the Mesozoic Era and the history of the initial breakup of Gondwanaland in the Indian Ocean.

From the petrography and chemistry of rocks from the Ninety-east Ridge, it does not appear to have been an old spreading center or an inactive island arc. It is more likely that the ridge may have been formed by passage of the Indian plate over a mantle plume near the southern end of the ridge.

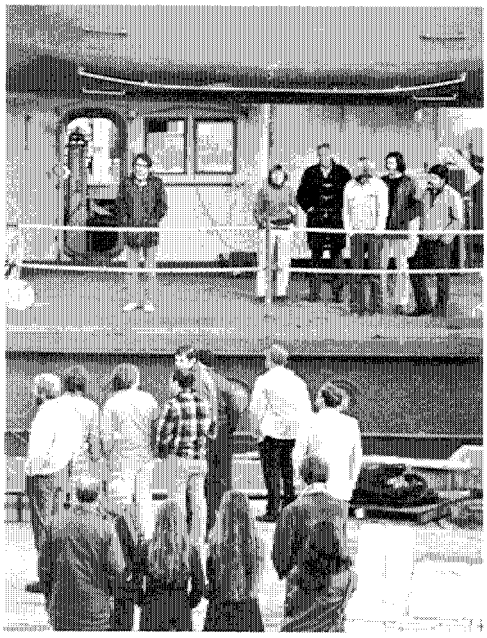
Regional hiatuses during the Oligocene, early Tertiary and late Cretaceous best defined in the western boundaries of the Indian Ocean (Leg 25) and southwest

Pacific (Leg 21) suggest that their origin is related to a western boundary undercurrent. The Oligocene and early Tertiary hiatuses seem to have been caused by climatic deterioration in Antarctica during the late Cretaceous and early Oligocene, which resulted in an increased flow of Antarctic Bottom Water.

The Red Sea developed in two main stages. In early or pre-Miocene times an uplift and lateral extension resulted in crustal thinning and eventual formation of the Red Sea Basin. During the Miocene, the Sea was isolated from the Indian Ocean but possibly connected with the Mediterranean. In the Pliocene, connection with the Indian Ocean was re-established and the opening to the Mediterranean closed. Sea-floor spreading which first started in Pliocene-Pleistocene time resulted in the axial zone of the Red Sea. The volcanic features of the axial trough are typical of those on mid-ocean ridges. Many of the lavas appear fresh and unweathered. Although reworked by bottom currents and bioturbation, in hot brine areas, the sediments are smooth, but they may, it seems, be reworked into ripples and dunes by internal waves where brines of different densities intersect the sea floor. Sediments from the Red Sea collected on Leg 23 have four distinct lithologic units which have been tentatively correlated with land stratigraphy.

In November the R/V CHAIN departed on a cruise called SOUTHLANT which will take it to Dakar and the high latitudes of the southern Atlantic. On the first leg the flow of bottom water in the gap of the Sierra Leone Rise was determined with geological, geophysical and oceanographic techniques.

The Scripps Deep-Tow instrument was very successfully deployed from R/V KNORR and in the FAMOUS area, in the



Geophysicists sail on R/V CHAIN.

southwest North Atlantic, and again around Mytilus Seamount. The first magnetic transition was found for basement rocks in the Mid-Atlantic Ridge. What appear to be minor trenches were located off the Blake Plateau and outcrops were identified near the top of the Mytilus Seamount. On this cruise giant piston cores were also taken in an attempt to compare the lithology and physical properties of the sediments with the 3.5 kHz acoustic bottom reflections.

In the Atlantic, an aeromagnetic survey over the Greenland and Norwegian seas across their entire width was completed between 70° and 83°N latitudes. As there are almost no magnetic anomalies in many oceanic areas, an inventory of global magnetic data was made in an attempt to identify a common cause of these anomaly free regions. The exact cause is still not determined but they occur frequently near continental margins and over a sea-floor created when geomagnetic reversals were thought to be absent.

A gravity anomaly map for the Caribbean made it possible to consider the structure and tectonics of that area in relation to topography, volcanoes, seismicity and terrestrial heat flow. A similar map is in progress for the Sunda Arc of Indonesia.

Thousands of miles of seismic reflection data have been acquired and submitted to digital signal processing. As in the eastern Atlantic a record of this sort together with other types of data proves invaluable in learning about the geology of shallow water areas. A preliminary analysis of 525 sonobuoy stations has been completed. Further treatment of these data will facilitate interpretation of such phenomena as shear-wave supported propagation in basement and lithified sediments. On some portions of the cruises the output pulse of the airgun source and the received signal were monitored to permit quantitative measurements of the seafloor reflectivity and possibly to identify the nature of the seafloor.

Our first measurements of geomagnetic time variations from the seafloor were made in the North Atlantic in depths of more than five kilometers during MODE I (p. 62). Continuous magnetometer records for two sequences of about 44 days indicate several periods of magnetic storm activity and/or "bay disturbances". These data, when processed, can be compared with simultaneous horizontal electric field recordings.

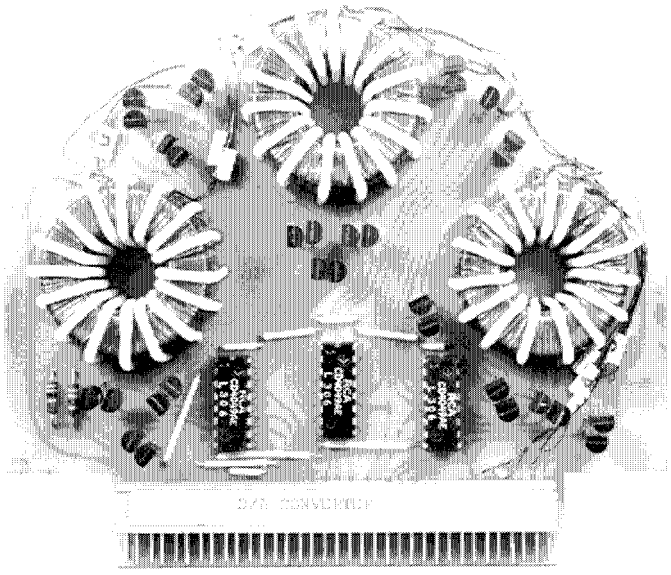
Several sorties to the seafloor were made with submersibles accompanied by observations from surface ships off the east coast of the United States. A review of 26 DRV ALVIN dives in the Gulf of Maine and other geophysical data there permit speculation about the deformation of that region during the early rifting of the North Atlantic. Somewhat similar techniques were used to detect the physical processes that control sedimentation and/or erosion in the Hudson Canyon.

Micropaleontologists at the Institution have in a number of instances turned their attention to living forms to determine life histories of dinoflagellates by culturing cysts from recent sediments. Such knowledge then will facilitate later work in biostratigraphy. Or again the complexities of the genus *Ceratium,* long a challenge to biologists, may be unravelled by an examination of fossil relatives. The electron microscope has in recent years caused a revolution in coccolithophorid taxonomy. Now with the superb electron microscope outlay at the Institution the development of coccoliths can be seen to change under the influence of different temperatures, salinities and other variables in the environment. In time, such observations will aid in the interpretation of the fossil record.

Wide-ranging cumulations of cores, many obtained aboard the D/V GLOMAR CHALLENGER contain foraminifera which can be related to calibrated biostratigraphic datum levels. Some are in such an excellent state of preservation that certain taxonomic points can be clarified. All this mass of information in conjunction with data on paleomagnetism and radiometric dating make it possible to decipher in part certain details about climate and currents in past geologic ages and to improve our concept of glacial chronology.

Another first for the Institution, which may in time contribute to our understanding the past on the earth has been a preliminary examination of volcanism on the moon, most of which seems to have occurred 3.0 to 3.8 billion years ago.

JAMES R. HEIRTZLER, *Chairman*



D/A Converter in Brown CTD Microprofiler (pp. 52, 63)

Department of Ocean Engineering

Three activities that stand out in 1973 are (a) the testing of DRV ALVIN while manned to a pressure equivalent to 12,000 feet in the Navy facility at Annapolis (b) the deployment and tracking of 20 SOFAR floats over long distances during the MODE experiment and (c) the setting and recovery of a deep sea "Trimoor" in collaboration with the Physical Oceanography Department. Perhaps these stand out because they were large programs; other activities of the department may be more important to the future of oceanography.

Instrument Section

Better measurements usually reveal that a phenomenon is more complex than previous measurements have demonstrated, but they also often lead to a better understanding of that phenomenon. The SOFAR floats which are free-drifting and neutrally buoyant are tracked over long distances by acoustic methods. Twenty floats deployed at 1500 meters depth during the MODE-I experiment in an area south of Bermuda were followed for a period of several months (eleven floats are expected to continue signaling well into 1974) over an area with dimensions of hundreds of kilometers. Their paths, displayed in a movie, resemble water bugs on the surface of a pond; sudden spurts, circling, hesitation and slow transits. Water motion at 1500 meters is not simple (p. 63).

These floats designed and constructed at Woods Hole have opened up a new avenue for study of deep water motion over long periods of time. For those which were designed to be recovered, data can also be obtained on salinity, temperature, depth and vertical motion as a function of time. Several long range experiments are currently contemplated, and the acoustic signaling sub-system is being explored as a sound source for acoustic experiments.

The microstructure CTD (conductivity, temperature, depth) system development is drawing to a close. Its acceptance by the oceanographic community is shown by the facts that ten units now exist and that three more are under construction at Woods Hole by personnel from Yale University, the University of Miami and the Institute of Oceanographic Sciences (U.K.), even before the instrument is considered developed.

The Self-Contained Imaging Micro-Profiler (SCIMP) was launched aboard an "Autoprobe" in the Tyrrhenian Sea and in the Mediterranean Outflow in 1973. This instrument sinks slowly while it records temperature and salinity and photographs the effects of optical inhomogeneities in the water column. The latter reveals microscale structure, the scale at which molecular diffusion mixes salt and heat from one parcel of water into another. In the Tyrrhenian Sea, in the deep water, layers about 50 meters thick with weak temperature and salinity gradients were separated by layers about 6 meters thick with strong gradients. Only faint traces of microstructure were recorded in the optical system. In the Mediterranean Outflow, on the other hand, the weak gradient layers were characteristically much thinner (10 m) and were separated by strong gradient layers about 30 cm thick. Here there was substantial optical evidence of inhomogeneities with many cases appropriate to salt finger structure.

An experiment is underway to track surface drifting buoys by the relative phase shifts between precision oscillators in the buoys and shore stations, using a high frequency radio communication link. Initial tests using one shore station and one buoy package in a truck are promising. This system, if it proves feasible, will be useful in coastal studies required for anticipated offshore installations of the next decade. The ordinary drift bottle which merely gives the starting and end points, though inexpensive, does not give the information required for future work.

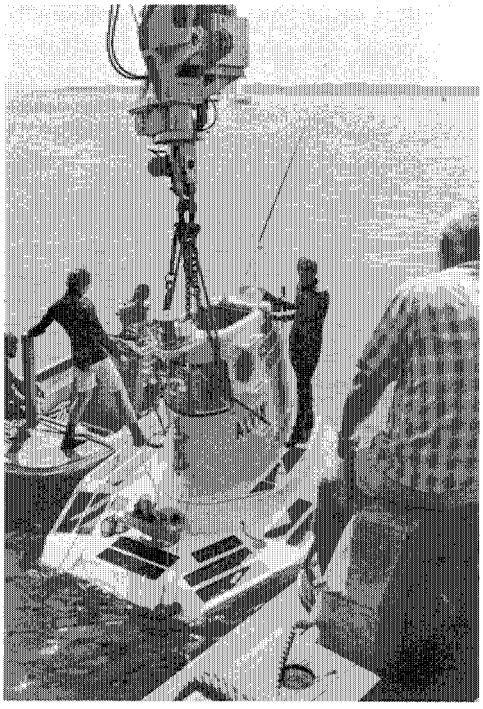
Deep Submergence Engineering and Operations

DRV ALVIN is getting to be like great grandfather's axe; 'it has had 4 new handles and two new heads but is still a good axe'. The titanium hull which had earlier undergone tests at the Navy facility at Carderock to depths of 13,200 feet, was installed during the spring. An identical hull is to be tested exhaustively during 1974 to define its properties with respect to fatigue, creep, and the ultimate failure point which is expected to be in excess of 18,000 feet.

After shallow water testing DRV ALVIN, without the conning tower, was placed in a large pressure vessel at Annapolis, Md. and taken to a pressure equivalent to 12,000 feet. Strain gages were placed at important points to verify results of the previous tests. Then personnel from Woods Hole and the Navy boarded DRV ALVIN and made a manned 'dive' to 12,000 feet. The strain gage measurements were converted to stress by a nearby computer and a plot was kept to confirm the linearity of the stress/strain relation. Everything worked well, except for one external light bulb which imploded. (This bulb had been tested to over 15,000 feet ten times during component testing.)

On return to Woods Hole a series of working and training dives were begun and early in November R/V LULU transported DRV ALVIN to Fort Pierce for a winter of diving off Florida and near the Bahamas.

The underwater acoustic navigation system developed by the Deep Submer-



ALVIN with new titanium hull.

gence Group has been so successful that the Physical Oceanography and Geology and Geophysics departments have constructed two more. With the three groups working together, rapid advances and improvements were made and by the end of 1973 the systems had added considerable capability to our ability to navigate underwater.

Engineers from the Deep Submergence Group also took an active part in rebuilding a winch for a Deep-Tow system aboard R/V KNORR, in the rebuilding of the KNORR's forward shafting, in the design of a plant for tertiary sewage treatment for the Biology Department and in the evaluation of a habitat for diving to 100 meters.

Information Processing and Analysis

How busy is a computer? Unless one becomes personally involved in the use of a computer, it remains a marvelous device that does all sorts of computations very rapidly, makes plots and diagrams, and prints pages and pages of things. The following statistics show what has happened on the Sigma 7 (the largest computer at the Institution) during 1973.

	1973
Number of jobs processed	58,847
Total hours used	2,849
Central processor hours	2,151
Cards read	9,139,707
Pages printed	1,343,202
Cards punched	754,210
Tape mounts	44,453
Average CPU time/job	2.19 mins.
Average number cards read/job	155.31
Average number pages/job	22.83
Average number cards punched/job	12.82
Average number tape mounts/job	.76

The term 'job' may mean a rearrangement of an assembly of computer cards or a cross correlation of two time series; it may be a simple or a complex problem, each one asked for by an individual. When one considers that the Sigma 7 is only part of the computing facilities at the Institution, it becomes obvious that computers are an important part of our daily business.

Improvements have been made to the Sigma 7 and to the shipboard systems. A high speed electrostatic printer/plotter for the Sigma 7 has decreased the time required to output several types of information. Addition of some peripherals has made the three ship-board systems nearly equal in computing power with the shore-based ship system.

Navigation received a fair share of attention during the year. Aboard ship the output from LORAN-C (a radio wave navigating system) receiver was used in computer programs that gave plots of the position. Fixes from the satellite navigation system are used to verify the LORAN-C numbers. LORAN-C reception is not good world-wide, but in many areas of interest it is excellent. A large programming effort went into the DRV ALVIN system for precise navigation by acoustic means in a local area.

Corrosion and "Microfouling"

In order to increase our understanding of the complex relationship between the initial stages of marine corrosion and microbiological fouling the scanning electron microscope is being used to determine the influence of marine bacteria on the nucleation of micro-anodic areas on metallic surfaces such as stainless steels, 90-10 copper-nickel and aluminum alloys. The effect of surface free energy of various metals and nonmetals on the rate and location of microbiological attachment is being examined. Such observations may eventually allow us to control fouling by manipulating the surface energy of engineering materials.

A Woods Hole intermediate mooring set in October 1972 in the Sargasso Sea was recovered in December 1973. Test samples of copper nickel alloys, commercial cuprous oxide and inorganic tin antifouling paints and two experimental 90-10 copper nickel flake paints on special modules were recovered from depths of 500, 1000, 3000 and 5000 meters. Their performance is being evaluated for use on long-term deep-sea instruments. Data were collected on the severity, the time constant of fouling and the species of fouling microorganisms encountered at various depths down to 5000 meters in the Sargasso Sea.

Ocean Structures, Moorings and Materials Section

With members of the Physical Oceanography Department, the Section was involved in the design and analysis of the Internal Wave Experiment "Trimoor", which was set in October and recovered in December. With a computer simulation of the tripod mooring the sensitivity of mooring excursions to line buoyancy, apex float buoyancy, wire diameter and slope, with different current speeds and directions was determined. The final design was based on these results considering the realities of launch and recovery. During studies on flow-induced oscillations of current meters and cables, calculations indicated that there would be appreciable oscillations when current meters were suspended vertically on the inclined legs of the tripod moorings in the anticipated current field. Experimental measurements in a towing tank confirmed these calculations. Nylon line wrapped in a herring-bone pattern about the current meter reduces the oscillations drastically, a scheme that was used for the "Trimoor" set.

The dynamics of a single point taut wire mooring (W.H.O.I. mooring #290, CHAIN 90) were analyzed and compared with experimental measurements. The agreement between the calculated and experimental values was encouraging but we have much to learn about mooring motion.

A 53-foot spar buoy with a natural "heave" period of 27 seconds was constructed. It was used in October, tethered to a surface taut wire mooring. Unfortunately the weather remained calm and the buoy did not have an opportunity to demonstrate its value in near surface measurements.

Acoustics in Oceanographic Research

The phase and amplitude of low frequency acoustic signals received at a range of 210 km have been analyzed. The data represents an initial foray into (a) the study of spatial and temporal variations of phase and amplitude of long range transmissions, and (b) the relationship between observed variations .and causal environmental factors. A fixed bottom mounted acoustic source was used in conjunction with free-drifting receiving hydrophones suspended at mid-water depths to eliminate bottom, and most surface reflection paths. Phase variations due to hydrophone drift were removed by a bottom-moored Doppler tracking system especially designed for these experiments.

Maximum phase fluctuations over continuous four-hour intervals amounted to as much as 15 cycles, but the rates of phase change were relatively slow; the phase fluctuation spectrum fell off with a slope of -2 between 0.4 and 40 cycles/hour. On the other hand, amplitude fluctuations were extremely rapid. Comparison of phase fluctuations with hydrophones at various depth reveals a depth dependence. It has been postulated that internal waves, which produce maximum sound velocity fluctuations in the main thermocline, are responsible for the major portion of the phase fluctuation. Rays which spent a larger percentage of their total source-receiver travel time in the main thermocline were most affected by internal waves and exhibited maximum phase fluctuations. For the particular sound velocity profile encountered during these experiments deeper hydrophones (1500 m) intercepted rays spending a larger fraction of their travel time in this region than do shallow hydrophones (300 m). As a consequence, phase fluctuations were greater in the deeper phones.

A theoretical ray model, based on an internal wave spectrum postulated by Garrett and Munk (1972) indicated that the spectrum of the acoustic phase for both fixed and drifting hydrophones is proportional to the spectrum of the internal wave field and that the internal wave field produces high-frequency, random amplitude variations. Comparison of these predictions with the data supported the conclusion that internal waves do indeed account for a considerable fraction of the total phase variation observed. The model may, in addition, predict phase variations as a function of range, frequency and source and receiver location.

Preparatory to the investigation in 1974 of the Mid-Atlantic Ridge (Project FAMOUS) the pulsed acoustic navigation system originally developed for the tracking of DSRV ALVIN was modified to permit tracking free-drifting sonobuoys with an accuracy of roughly 10 meters. Sonobuoy arrays were deployed near the median valley of the ridge to detect and localize microearthquakes acoustically. Of the 112 seismic events detected in 74 hours of listening, twenty-nine were sufficiently strong to permit their geographic location to within about 400 meters. Most seismic activity near 36°30'N apparently occurs on the eastern wall of the median valley. Spectral analysis of close events (<5 km) revealed a strong energy peak in the neighborhood of 20-25 Hz.

The signals from the SOFAR floats, which are received at shore stations, are used to determine the floats' positions. The amplitude and shape of the signal contain information about the transmission path. The variation in the average amplitude of the signals received are being analyzed for characteristic frequency behaviour. Whether it will be possible to relate the spectra to environmental effects remains to be seen.

In the summer of 1972 volume reverberation data were collected at 34 stations on Cruise 105 of R/V CHAIN from Newfoundland to the Azores, and thence to Portugal and Ireland. This year the data were fully reduced to give column strength spectra from 1 Khz to 31.5 Khz and each pair of spectra were compared quantitatively using a new measure called the cross-standard deviation (σ cross). Low values indicated that the spectra were similar; high values, that they were dissimilar. It was noted that spectra for nearby stations were similar and could be classed in geographically-based groups called the pelagic region. This is reasonable since much volume reverberation is sound scattered from animals which in turn are distributed in pelagic faunal regions. The regions have been identified on the basis of physical-oceanographic features, such as the polar front and subdivisions of the Gulf Stream system, which are used in defining boundaries for these regions. This is the first quantitative demonstration that volume reverberation spectra may be grouped in a meaningful way. These results will be compared with the analysis of the fish trawls made during that same cruise.

On Cruise 59 of R/V ATLANTIS II between the Cape Verde Islands and Woods Hole (November-December 1970), measurements were made of the volume scattering strength of a scattering layer while that same layer was being fished with the Isaacs-Kidd midwater trawl. Scattering strength was determined at 12 kHz for the water at the trawl depth. The biological and acoustic data have been compared for the 35 nighttime and 6 daytime trawls. Specimens per hour correlate highly ($r=.84$) with volume scattering strength, a far better correlation than had been expected. The correlation is lower between volume scattering strength and volume of fish per hour.

The analysis is continuing using other variables. Depth and temperature of the water at trawl depth are parameters with significant correlations. Interestingly, geographic position, the temperature at 200 meters, and the measurement error of the trawl depth determination have far less statistical significance. If the high correlation is confirmed using the CHAIN 105 data, it will appear that single frequency measurements are a better predictor of scatterer density than had been thought likely.

Development began in December 1972 on a complete sonar suite for DRV ALVIN to provide the scientist/user of ALVIN with a set of acoustic tools for many different investigations. The completed system will contain the following components: (1) a precisely controllable signal-generating system (Synthesizer) in three separate bands covering the range of 2-45 kHz. (2) A display and recording system for various displays of sonar information by oscilloscope and for permanent recording by camera film and magnetic tape recorder. (3) A programmable training mechanism which permits pointing the sonar transducer in any direction and scanning any bearing interval. The training mechanism is coupled to the display for presentation of sonar data versus bearing angle. (4) A general-purpose digital computer capable of performing all control and data processing functions as well as providing faster and more complex sonar modes than are possible in a purely manual system. This system will provide an instrument base for studies of topography, volume reverberation and sediment layers.

EARL E. HAYS, *Chairman*

Peter M. Saunders and an associate discuss Gulf Stream data.

Department of Physical Oceanography

Introduction

During 1973, two major operations were carried out at sea. One, the field work of the Mid-Ocean Dynamics Experiment (MODE-I), involved an extensive array of moorings, free floating instrumental floats, towed sensors, and dropped free-falling recoverable instruments. The Woods Hole Oceanographic Institution contribution to MODE-I was part of a multi-university cooperative endeavor. The other, the Internal Wave Experiment (IWEX), carried out in the same region of the Sargasso Sea as MODE-I centered on a subsurface tripod in five kilometers of water. By year's end, both had reached the stage of extensive data interpretation. In addition to these innovative experiments, other extensive programs directed to an understanding of ocean circulation and oceanic processes continued. A small but growing component of the effort in the Department is devoted to coastal and nearshore oceanography.

Ocean Circulation

The meridional circulation of the North Atlantic was determined using a five-layer model. In such a "box model", water entering and leaving each of the five layers is budgeted to the nearest million cubic meters per second. Together with maps of the circulation in these layers, the transports of the major current systems of the North Atlantic have been defined to the nearest five million cubic meters per second for each of the layers. The net meridional circulation of the North Atlantic has been found to be one million cubic meters per second to the south. This amount enters the North Polar Sea from the Pacific and an equal amount must therefore cross the equator into the South Atlantic. However, there is a much stronger meridional circulation consisting of deep and bottom water formed in the north flowing toward the equator and warmer water drawn northward to replace it.

Using the volume of water in each of the layers, the mean residence time of a given particle of water was determined for each of the layers and in each of six major basins in the North Atlantic. The deep water residence times vary between 4.5 years in the European Basin to more than 900 years in the Guinea Basin off equatorial Africa. The North Atlantic, as a whole, contains 137 cubic kilometers of water and the total amount entering and leaving the ocean is 18 million kilometers per second. Thus, the mean residence time for the North Atlantic as a whole is 240 years.

A significant component of the North Atlantic circulation is the Gulf Stream. The variable nature and complexity of the Gulf Stream system in the area just south of the Grand Banks of Newfoundland was demonstrated on a month-long cruise in September and October, where long north-south meanders were found extending over several degrees of latitude. North of the Stream is a region of shifting Slope-Water Current and just to the west, the rugged bottom topography of the Newfoundland Rise. This complicated hydrographic and topographic regime explains in part why it has been so difficult to interpret the results of a single line of measurements across this region.

Furthermore, measurements using tracked drifting buoys in the Gulf Stream give results which are complex and difficult to interpret. Circulation patterns in this area are influenced by bottom topography, especially to the west of the Newfoundland Rise. If the relationship between currents and bottom topography is to be explored effectively, improved bathymetric charts for the area are needed.

The inflow of water to the Caribbean Sea has been under continued investigation during the past year. Across the sill of the Jungfern Passage there is a relationship between temperature and direction of flow. An interpretation is that cold Atlantic Water flowing into the Caribbean sinks below sill depth. When the current reverses, it is warmer Caribbean Water which flows out into the Atlantic.

In November, a bathymetric survey was made of the Windward Passage in preparation for a similar survey in that region during 1974.

Beyond the confines of the Atlantic, analysis continued of data collected in the Indian and Southern oceans. A water-mass census of the Indian Ocean will ultimately define its basin structure in terms of temperature and salinity. Already the deep western boundary current of the South Indian Ocean predicted by deep circulation theory, has been identified and reported upon. The existence of such a current just east of Madagascar at depths greater than three kilometers was demonstrated in the distributions of temperature and of dissolved oxygen. Estimates of the magnitude of the current give a volume transport of about 4-5 million cubic meters per second with maximum speeds of 4-6 cm per second. The current is believed to be of Antarctic origin and the source of deep water for the Western Indian Ocean.

The distribution of dissolved silicon in the world oceans is consistent with near-zero Antarctic Bottom Water foremen-tioned in the present century. If silicon-rich Antarctic Bottom Water flows northward in large quantities, it must return to Antarctica as thermocline and surface waters. These waters, however, are devoid of silicon.

Coastal Oceanography

An increasing interest in the Physical Oceanography Department is directed to

continental shelf, coastal, and nearshore studies, in part due to the growing awareness of the importance of this region to many national and even international problems. This trend will probably continue in the years to come.

A review of all available physical oceanographic information from Massachusetts Bay has included temperature and salinity cycles as well as tidal, residual and high frequency oscillations. Together with an annotated bibliography on the hydrography, chemistry and sea level of Massachusetts Bay, it will serve as a basis for further work in this region.

In the same vein, during the past year an extensive examination was made of existing hydrographic data in Institution files from the continental shelf east of Cape Hatteras and in the Slope-Water region. On the shelf edge south of Cape Cod, there is a sharp interface between relatively fresh Coastal Water and the saltier Slope Water offshore. Data extending back more than 30 years have been examined for evidence of seasonal and long-term variation in this interface and for an indication of the production of parcels of Coastal Water within the Slope Water. A clear seasonality has been found: the occurrence of these parcels reaches a peak in August. Similarly, in the Slope Water region, anomalies of fresh water in the upper 100 meters were taken as indicators of Coastal Water bubbles. These also have a marked seasonal pattern with the peak in August. These early results will serve as a basis for a more extensive series of field observations to be carried out in the coming years.

With certain limitations, one may legitimately regard the Great Lakes as "model oceans". During 1973, an analysis of the circulation of Lake Ontario has provided some insight into such mechanisms. The manner in which storms set up circulation gyres was related to a simple dynamic theory, according to which the depth of distribution in the lake is the key to the water transport pattern. During the summer, under stratified conditions, winds also set up intense nearshore currents called coastal jets. These jets may reverse and begin to flow upwind under some circumstances. Since Lake Ontario is large enough for the earth's rotation to affect water movements, the results should therefore be valuable for the understanding of nearshore oceanic phenomena.

In a cooperative effort with the Instituto Español de Oceanografía Spanish coastal waters were examined to determine why the Ría de Arosa region is more productive than other estuaries along the Atlantic coast of Galicia. It appears that the terrain in the region controls the airflow down the valley in the summer. This results in a high frequency of northwest winds flowing out of the Ría de Arosa, which, together with water run-off is an important environmental factor affecting the water quality in the Ría. The other estuaries in the region are not so favorably situated for flows of this type.

Oceanic Processes

A variety of laboratory models are used to study physical processes in the ocean affecting currents and waves. Flows through narrow openings in a rotating frame have provided a clearer understanding of oceanic flow through straits and over sills and are in agreement with direct observations in the Strait of Gibraltar and in the Denmark Strait. Other experiments concerned with the motion between a thin layer of fluid lying above or below a deep layer indicate that in cases of instability the thin layer forms spouts down into the deep liquid. Such spouts are common in the winter when

cold and still centers of high pressure in the atmosphere move out over the ocean. The mixed layer of the ocean then is cooled from above and is seen to have such convection.

In the field of marine thermodynamics several equations of state for sea water were examined in order to evaluate their stability for use in processing oceanographic data. The equation presently in wide use does not yield estimates of compressibility of sea water with acceptable precision, particularly at pressures below 2000 decibars (one decibar is approximately equivalent to a depth of one meter) or above 6000 decibars. The goal for an internationally acceptable equation of state for sea water is to achieve precision of 3 ppm (parts per million) at atmospheric pressure and 10 ppm at higher pressure up to 10,000 decibars. Before this goal can be achieved, systematic differences in the specific volume of sea water as derived from the velocity of sound must be resolved.

During the Internal Wave Experiment (IWEX) a multi-dimensional array of simultaneous temperature and velocity measurements were collected in the Sargasso Sea in an attempt to measure the spectrum of motions in the main thermocline of the ocean over those space and time scales appropriate to internal gravity waves. Between 600 and 1000 meters depth, instruments were spaced logarithmically along the inclined legs of a subsurface tripod anchored in five kilometers of water. The modified current meters each carried two thermistor pods in order to measure currents, temperatures and vertical temperature gradient. A variety of other instruments were also attached to assess the motion of the "Trimoor" (p. 54) for engineering purposes. All this equipment was recovered successfully after a 6-week deployment.

The IWEX project required extensive planning both in preparation for the design of the mooring and for the large task of data processing and interpretation that was to follow. The coherence properties of internal waves based on previous moored-array experiments in the western Atlantic and Mediterranean were analyzed. Numerical studies of the effect of temperature fine-structure upon the ability to infer vertical motion using temperature sensors suggest that for IWEX, the fine-structure should play a small role in masking internal waves and that it can be reduced if the sensors measure both the vertical temperature gradient and the temperature. The IWEX data reveal the dominance of internal-wave dynamics over the frequency range appropriate to internal gravity waves. There is also indication that the wave field is modulated by currents.

Fantail of R/V KNORR about to sail on IWEX cruise.

In another part of the spectrum of variability, low-frequency fluctuations in the flow and mass field were studied in the vicinity of the Gulf Stream. Series of long moored-current-meter records from Sites D (39° 10'N, 70°W) and J (36°N, 70°W) had a characteristic variabiity with amplitudes of 5-10 cm per second and time scales of 5-10 days. The motions are consistent with the interpretation of a field of topographic waves radiating energy away from the Gulf Stream between the two sites.

Current meter observations from Site J indicate energetic variability at time scales of about 30 days. These events are infrequent and are similar to others seen in the Gulf Stream region near the tail of the Grand Banks. An experiment designed to investigate these phenomena and their relations to the flow between the Gulf Stream and Site D is planned for the spring of 1974.

A small array of current meter sensors around Site D continued with three moorings and two levels of measurement. The results are in good agreement with theory and show westward propagating motions with north-south wavelengths of about 150 kilometers and east-west wavelengths of about 250 kilometers. Motions trapped to the bottom are also evident. In agreement with theory, the axes of these motions rotate as the period of the motion varies.

Other effects of the ocean bottom on currents and sedimentation were examined theoretically as a basis for field observations. Such features as seamounts, ridges, islands, and trenches may have significant influences on currents and their corresponding density field. Steady flow past a seamount generates long waves that can have a distant influence throughout the water column. The altered flow past a seamount may affect the associated sediment deposition. Theoretical considerations of the rate of deposition suggests that the predicted streamline patterns should give asymmetric sediment distributions similar to many observed sediment patterns.

For the other major oceanic boundary, the air-sea interface, the results of the JASIN (Joint Air-Sea Interaction) experiment in September 1972, have given some insight into the relationship between sea-surface temperatures and atmospheric effects. During this period, an energetic anticyclonic oceanic eddy of about 150 kilometers diameter and a free circulation of about 30 cm per second, influenced the region in the vicinity of Ocean Weather Station J for the entire month. This eddy, which progressed slowly northward with a speed of about 2-8 cm per second, was vertically coherent throughout the thermocline and the currents associated with it penetrated to a depth of 1500 meters.

A new program initiated during the year involves the energies in various geophysical, astronomical, biological and botanical processes. In each of these, the routes, rates and reservoirs of energy were outlined and those points in each natural system where it is technically feasible to divert energy continuously for social applications were defined. In addition, the ecological consequences of large-scale intervention in these natural processes were estimated. The energies involved in some fifteen natural processes were examined and arranged in order of total power. Solar sea power which employs the thermal contrast of the world ocean may represent an "energy ceiling" unless some practical and economically feasible methods are found for using solar energy directly, as an alternative for fossil and nuclear fuels.

Mid-Ocean Dynamics

The first phase of the multi-institution Mid-Ocean Dynamics Experiment (MODE-I) was carried out from March to July, 1973. Its objective was to obtain a description of mesoscale eddy motions during this period and over the prescribed range between Bermuda and the Bahamas. An array of 16 moorings with 83 current meters and 60 temperature recorders was set out to map currents as a function of time and space for comparison with the current field inferred by neutrally buoyant floats and from the density field. Data returns from the moored array fell below expectations: the overall recovery for the velocity data was only about 50%, but in contrast, the temperature data were good, exceeding 80% return. In spite of the problems encountered with instruments, a large body of usable data was obtained. The currents and temperature fields depict a clockwise eddy in the region moving slowly westward.

An extensive neutrally buoyant float experiment was carried out successfully as part of MODE-I. Eighteen large floats were launched, 600 kilometers southwest of Bermuda and were tracked acoustically for 4 months as they drifted at a depth of 1500 meters. At the end of the experiment, all surviving floats were relaunched for an extended drift of at least a year. At year's end, 12 floats were still being tracked. The preliminary results of the float measurements are consistent with those obtained from the moored array. In addition, 10 of the floats were instrumented to sense vertical current, which, it appears, may be as high as one centimeter per second due to internal waves with periods of nearly 90 minutes.

On several occasions during MODE-I, a density surface in the main thermocline was mapped by continuously towing sensors behind the ship to resolve the vertical displacement of the surface over horizontal scales of from 10 meters to 100 kilometers. The spatial spectrum of the internal wave field was defined: it is nondirectional and has a continuous energy distribution over scales from a fraction of a kilometer to 200 kilometers. By comparing the shape of a density surface with the horizontal currents above and below that surface as recorded by moored current meters, it appears that the currents roughly parallel the contour lines of the density surface, as predicted.

With the extensive use of free-fall instruments over 70 velocity and density profiles were obtained during MODE-I in a variety of locations. These reveal a striking difference between the velocity structure over a ridge on the sea floor and that

W. G. Metcalf returns from the Caribbean.

seen even a short distance out onto a smooth abyssal plain. A series of profiles over a 5-day period in the center of the MODE-I array reveal that the low-frequency structure has large vertical extent. Velocity variations of small vertical scale are the result of short-period internal waves. From theoretical considerations it seems that a nearby coast and the bottom topography affected the results significantly, but in other respects, the observed eddies agree in time scale, intensity, and horizontal wavelengths with theoretical models.

The MODE-I float data was used as a basis for what may be the first moving picture of deep ocean currents spanning about 1 year or several oscillations of the eddies. Thus, the restoring effect of the earth's curvature becomes strikingly visible and the notion that the fluid undergoes excursions typical of an eddy-diameter seems verified. The wavelike character of the motions prevents the floats from dispersing rapidly, suggesting gradual mixing of Mediterranean Water at a depth of 1500 meters (see p. 51).

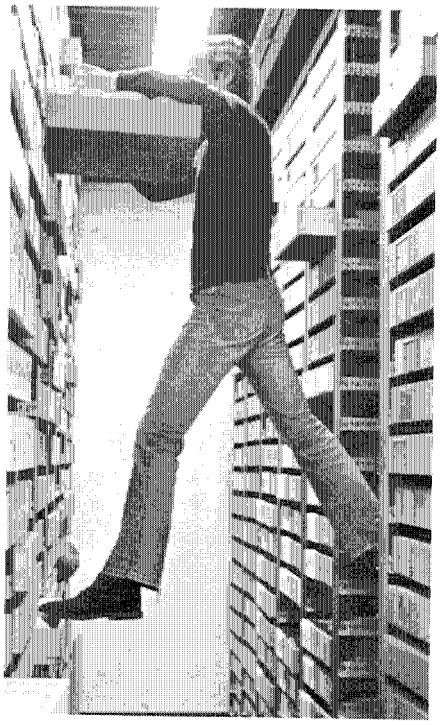
Other studies of waves and turbulence in the ocean interior have the goal of understanding the physics of ocean variability at length scales from 2 to 5000 kilometers and at time scales greater than a day. It is hoped to determine the generation, decay, and interaction of such motions with the mean oceanic circulation.

By considering an idealized 'flat-bottom' ocean without rough bottom topography or coastal boundaries, both in theory and with a computer, closely packed eddies in the model evolve according to simple laws toward a horizontal length scale of between 40 kilometers and 70 kilometers. This range gives a 'natural' scale such as may be expected of the dominant oceanic eddies. There is also an evolution toward larger vertical scales. The currents at different depths thus become more and more alike as time goes on. There is a tendency for potential energy to be converted into kinetic energy and for east-west currents to have greater magnitude than north-south currents. It is hoped that fully turbulent flow may be inferred from these linear theories and thus the role of eddies in the long-term ocean circulation might be simply represented.

Vertical profiles of temperature and salinity were taken using a Brown CTD Microprofiler, during both MODE-I and IWEX. This new instrument has great potential, but it necessitates an extensive effort for calibration, data processing, archiving, and interpretation. Vertical spectra of temperature fine-structure computed from the MODE-I measurements have a similarity in spectral shape throughout the entire water column. Thus, a single number, for example, the amplitude of the temperature fluctuations, can characterize the spectrum at any depth. The fine-structure observed in water of Mediterranean origin in the MODE-I region is due to lateral mixing along density surfaces. There are variations in the temperature-salinity characteristics of water in this area, but there is no evidence there for local generation of these variations.

FERRIS WEBSTER, *Acting Chairman*

Labeling recently dredged rocks.



Samples from the rock "library".

Loading.

Analysis of geophysical data, D.E.S.C. building.

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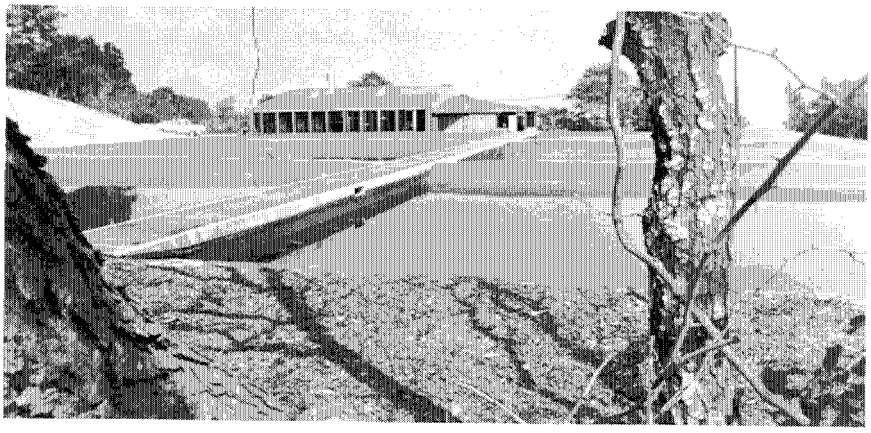

Environmental Systems Laboratory from across the algae ponds.

Ashore and Afloat

Culminating several years' planning, a contract was signed in early December with Peterson Builders, Inc. of Sturgeon Bay, Wisconsin, for the construction of R/V OCEANUS. A sister ship will be constructed at the same time and assigned to another laboratory by the National Science Foundation, the funding agency. Displacing 962 tons, the vessels will have variable pitch propellers and bow thrusters for the control and maneuverability needed for oceanographic research tasks. The 177-foot ships will carry a crew of 13 and a scientific party of 12. They will include 1,350 square feet of laboratory space and have a range of 8,000 miles. Delivery is scheduled for late 1975.

On 15 October, R/V GOSNOLD sailed for a year's assignment with the Harbor Branch Foundation in Fort Pierce, Florida. LULU and ALVIN (with the new titanium hull — see p. 53) also spent the winter months working in the warmer southern waters out of Fort Pierce doing biological and geological research as well as preparing for Project FAMOUS deep diving work on the Mid-Atlantic Ridge in the summer of 1974.

Despite heavy schedules for the larger vessels (p. 77) 1973 ship operations went smoothly. While on station for MODE-I southeast of Bermuda in early May, R/V CHAIN hit a 50-foot log and damaged her port propeller. Two blades were repaired and the tail shaft replaced in drydock at Norfolk, Virginia, and she was quickly back at work. R/V KNORR operated at reduced speeds for part of the summer Geology and Geophysics cruise because of a broken pinion on the after cycloid. Underway repairs were supplemented by later drydock work in Savannah, Georgia.

An *ad hoc* committee of Trustees was appointed at the June Corporation meeting to review Institution safety procedures with particular attention to marine operations (including submersibles) and to Federal regulations imposed by the Occupational Safety and Health Act. On the recommendation of this committee, an Institution Safety Office has been established and a Staff Engineer and a Staff Safety Coordinator have been appointed.

The Institution has hosted and operated the University-National Oceanographic Laboratory System (UNOLS) since its inception in 1971 under a

funding grant from the National Science Foundation with the Office of Naval Research, National Oceanic and Atmospheric Administration, and the Environmental Protection Agency.

UNOLS grew out of the 1969 Stratton Commission report which in part recommended a more effective system for the use of and planning for resources for oceanographic research. It is a joint effort by the academic community and federal funding agencies, to review and coordinate utilization of and access to oceanographic research facilities. Its members come from seventeen major laboratories in the United States who operate the 32 seagoing research vessels comprising our nation's academic research fleet.

The functions of UNOLS are to coordinate the scheduling of research ships and seek opportunities for scientists to go to sea who do not have direct access to ships. It also serves as a forum for institutions to work together in the effective use, assessment and planning for oceanographic facilities.

The Chairman of UNOLS is Dr. Arthur E. Maxwell and its Executive Secretary is Captain Robertson P. Dinsmore, U.S.C.G. (ret.).

The new Central Laboratory on the Quissett Campus was nearing completion structurally by the end of the year with occupancy scheduled for the late spring of 1974. This $8,000,000 project will provide about 60,000 square feet (a net gain of about one third) of assignable space for portions of all departments and the principal administrative offices. The four floors, topped by a multi-purpose conference room, will provide much-needed laboratory and office space to relieve the crowded conditions in the existing buildings in Woods Hole village. The Institution population has grown approximately 10% just since the building was started in mid-1972, at which time the need for more space was already glaringly apparent. Thus, the new facility will be a welcome addition when it is completed.

The Environmental Systems Laboratory was completed and occupied by biology staff members in late October, 1973. After a few weeks of debugging, common to all new buildings, the salt water system was providing filtered and heated water to approximately 300,000 systems, clams, worms, and seaweed. It has operated successfully through the cold winter weather. The shellfish have shown definite signs of growth from feeding on the food "grown" in the algae ponds. The growth of the algae in these ponds has initially at least exceeded even the most optimistic predictions; however, it will be at least another year before plant operation on this scale can be fully evaluated.

Ground is to be broken early in 1974 for a new laboratory next to the Data and Earth Sample Center (D.E.S.C.) on the Campus. This building will house 25-30 scientists and staff of the U.S. Geological Survey, providing permanent quarters on a long-term lease basis. The structure and architecture as well as the use of the building will be similar to the D.E.S.C. nearby. This fact played a large part in choosing the location. Plans of the Survey include installation of wet laboratories, fume hoods, miscroscopy equipment, photo developing facilities, an electron microscope, core storage racks and other support equipment in addition to the office spaces required. It is expected that occupancy will take place next summer.

Cruises-1973

KNORR

Sea/Use Days – 292

Total Nautical Miles for Year – 30,046

VOYAGE NO.	DATES	AREA OF OPERATIONS	DAYS	CH. SCIENTIST
30 Leg VII	30 December–5 February	GEOSECS — South Atlantic		Craig
30 Leg VIII	10 February–7 March	and Antarctic	94	Reid
30 Leg IX	10 March–1 April			Takahashi
	3-4 April			
31 Leg I	7 May–1 June	Mid-Atlantic Ridge	80	Luyendyk
31 Leg II	9-24 June			
31 Leg III	26 June–14 July			Hollister
31 Leg IV	17-25 July			
	2-3 August	To shipyard	2	
31 Leg V	11-27 August	Western North Atlantic	24	Hollister
	27 August–3 September			
32	6-7 September	To shipyard		
	8 September	and return	3	
33 Leg I	13-24 September	Sargasso Sea	25	Teal
33 Leg II	27 September–7 October			
34	13 October–8 November	Woods Hole-Bermuda		
		buoy line	27	Moller
35 Leg I	12-20 November	Hudson Canyon-		Haedrich
35 Leg II	22 November–3 December	Continental Shelf	21	Wiebe
36	6-21 December	Woods Hole-Bermuda		
		buoy line	16	Moller

CHAIN

Sea/Use Days – 278

Total Estimated Nautical Miles for Year – 41,800

VOYAGE NO.	DATES	AREA OF OPERATIONS	DAYS	CH. SCIENTIST
110	30 January–3 February	Continental Shelf	5	Backus
111 Leg I	6-18 February	Sargasso Sea	26	Vaccaro
111 Leg II	20 February–3 March			Haedrich
112 Leg I	6-19 March	MODE area Southwest		
112 Leg II	25 March–5 April	of Bermuda	14	Heinmiller
112 Leg III	8-29 April			Katz
	1-4 May	To shipyard		
112 Leg IV	11-27 May		41	Wunsch
112 Leg V	30 May–21 June			Robinson
112 Leg VI	24 June–9 July		60	Heinmiller
113 Leg I	16-29 July	Eastern North Atlantic		Hays
113 Leg II	3-15 August			
113 Leg III	15-29 August			
113 Leg IV	31 August–12 September		59	
114	20 September–20 October	Gulf Stream	31	Fuglister
115 Leg I	20 November–10 December	West Coast of Africa	42	Bunce
115 Leg II	14 December			Summerhayes

ATLANTIS II

Sea/Use Days – 341

Total Nautical Miles for Year – 41,518

VOYAGE NO.	DATES	AREA OF OPERATIONS	DAYS	CH. SCIENTIST
74	7-8 January	To shipyard		
	9-10 January	and return	4	
75 Leg I	20 January–7 February	West African Continental		
75 Leg II	10 February–6 March	Slope		Emery
75 Leg III	12-27 March			
	27 March–4 April			
75 Leg IV	8-9 April			Uchupi
	12 April–2 May			
75 Leg V	5-23 May			
75 Leg VI	28 May–19 June			
75 Leg VII	23 June–9 July			
76	13-30 July	Mediterranean Outfall area		Deuser
77	4-16 August	Mid-Atlantic Ridge		Phillips
	16-31 August			Bryan
78 Leg I	3-30 September	South West Atlantic and		Bowen
78 Leg II	4 October–1 November	Caribbean		Thompson
79 Leg III	5-19 November			Livingston
	19-29 November			
79	3-20 December	Cariaco Trench	335	Jannasch
80	26-27 December	To shipyard	2	

Department of Physical Oceanography

Aldrich, Thomas C.
Alexander, Robert M.
*Allen, Ethel B.
Anderson, Edward R. III
Armstrong, Harold C.
Bauchmann, Nancy J.
Bailey, Phyllis T.
Barbour, R. Lorraine
Bradshaw, Alvin L.
Breivogel, Barbara B.
Briscoe, Melbourne G.
Bruce, John G., Jr.
Bruen, Alan T.
**Bryden, Harry L.
Bumpus, Dean F.
Bunker, Andrew F.
Chaffee, Margaret A.
Chase, Joseph
Chausse, Dolores H.
Csanady, Gabriel T.
Daly, Kathleen
Day, C. Godfrey
Dean, Jerome P.
Ewing, Gifford C.
Fofonoff, Nicholas P.
Ford, Edwin F.
Frank, Winifred H.
Frazel, Robert E.
Freeland, Howard J.
Fuglister, Frederick C.
Gaffron, Barbara P.
Gifford, James E.
Guillard, Elizabeth D.
Harlow, Caroline
Hayes, Stanley P.
Heinmiller, Robert H.
Hogg, Nelson G.
Horn, William H.
Jordan, Robert S.
Joyce, Terrence M.
Katz, Eli J.
**Kim, Kuh
Knapp, George P. III
LaRochelle, Roderigue A.
*Lawday, Laura M.
Luyten, James R.
Maltais, John A.
McCartney, Michael S.
McCullough, James R.
Metcalf, William G.
Millard, Robert C., Jr.
Miller, Arthur R.
Moller, Donald A.
Moore, Douglas E.
Parker, Charles E.
Payne, Richard E.
Poirier, Joseph R.
Reese, Mabel M.
Rhines, Peter B.
**Ruddick, Barry
**Sambuco, Edmund
Sanford, Thomas B.
Saunders, Peter M.
Scharff, John M. III
Schleicher, Karl E.
Schmitz, William J., Jr.
Schroeder, Elizabeth H.
Simmons, William F.
Simoneau, R. David
Soderland, Eloise M.
Spencer, Allard T.
Spencer, Ann
Stalcup, Marvel C.
Stanley, Robert J.
Stratton, Joyce B.
Tarbell, Susan A.
Thompson, Rory
Tupper, George H.
Volkmann, Gordon H.
von Arx, William S.
Voorhis, Arthur D.
Warren, Bruce A.
Webster, Ferris
Whitehead, John A., Jr.
Whitney, Geoffrey G., Jr.
Williams, Audrey L.
Worthington, L. Valentine
Wright, W. Redwood
Zemanovic, Marguerite E.
Zenk, Walter
‡Ziegler, Evelyn L.

Department of Ocean Engineering

Adams, James M.
Aldrich, Thomas B.
Bardsley, Brian L.
Barrs, Andrew F.
Bartlett, Arthur C.
Baxter, Lincoln II
Benoit, Raymond R.
Bento, Joseph, Jr.
Bergstrom, Stanley W.
Bitterman, David S.
Bland, Edward L., Jr.
Boutin, Paul R.
Brereton, Richard S.
Broderson, George de P.
Brown, Neil L.
Burt, Kenneth H.
Butler, James
Chute, Edward H.
Clay, Peter R.
Cole, Bruce R.
Collins, Clayton W., Jr.
Connell, William L.
Cook, Alden H.
Crook, Thomas
Curtis, Philip R.
Davis, James A.
Deane, Stanley R.
Densmore, C. Dana
Denton, Edward A.
Dexter, Stephen C.
Doherty, Kenneth W.
Donnelly, John D.
Dorson, Donald L.
‡Doutt, James A.
Dow, Willard
Drever, Robert G.
Dunworth, Jane A.
Eggleston, Fred S., Jr.
Eliason, Andrew H.
Evans, Emily
Fairhurst, Kenneth D.
**Fletcher, Susan
Foster, Dudley B.
Frank, Eric H., Jr.
Freund, William F., Jr.
Gibson, George W.
Glass, Gordon K.
Goff, William E.
Goldsmith, Roger A.
Goutal, Kenneth G.
Graham, Russell G.
Gunderson, Allen C.
Hardy, Carl C.
Hays, Earl E.
**Hendricks, Peter
Hess, Frederick R.
Hilliard, Channing N., Jr.
Hosom, David S.
Hunt, Mary M.
**Jaffee, Richard J.
*Jones, Maxine M.
Kallio, Peter E.
Koehler, Richard L.
**Kreider, John R.
Kucharski, William M.

Robert L. Gordon lengthens the anchor chain for R/V CHAIN.

*Part Time Employment **Temporary Employment ‡Leave of Absence

Department of Ocean Engineering (continued)

Lenart, Alice L.
Leslie, H. David
Liberatore, Stephen P.
Little, William S., Jr.
Lyon, Thomas P.
Machado, Richard A.
Marquet, William M.
Mason, David H.
Mavor, James W., Jr.
McCamis, Marvin J.
McElroy, Marguerite K.
McElroy, Paul T.
McLeod, John W.
Meier, George A.
Morton, Alfred W.
Murray, Paul C.
Muzzey, Charlotte A.
Nowak, Richard T.
O'Brien, Thomas F.
O'Malley, Patrick
**O'Sullivan, James F.
Page, William F.
Panicker, Narayana N.
Peal, Kenneth R.
Penton, Ronald D.
Pires, Clara Y.
Pires, Karen
Polloni, Christopher F.
Porteous, John
Porter, Robert P.
Power, George H.
Reynolds, William A., Jr.
*Ronne, F. Claude
Rosenblad, Stanley G.
Rosenfeld, Melvin A.
*Sass, Warren J.
Sharp, Arnold G.
**Schmidt, Dennis W.
**Schott, Walter E. III
**Schultz, Susan M.
Shumaker, Lawrence A.
Simkins, Samuel T.
Smith, Woollcott K.
Spindel, Robert C.
Stanbrough, Jess H., Jr.
Stern, Margaret P.
Striffler, Foster L.
Stuermer, Elizabeth A.
*Sullivan, James R.
Thayer, Robert J.
**Tochko, John S.
Tollios, Constantine D.
Wagner, Kenneth N.
Walden, Barrie B.
Walden, Robert G.
Walen, Roger S.
Webb, Douglas C.
Webster, Jacqueline H.
Williams, Albert J. 3rd
Wilson, Valentine P.
Winget, Clifford L.
Witzell, Warren E., Jr.
Woods, Donald E.
Yang, Chen Yi

Department of Administrative and Service Personnel

Aiguier, Edgar L.
Anders, Wilbur J.
Babitsky, Ellen J.
Barnes, Susan M.
Battee, Howard
Battee, Janice R.
Behrens, Henry G.
Berteaux, Henri O.
Botelho, Eleanor M.
Botelho, Linda J.
Bourne, Wallace T.
*Bowden, Bruce
Bowman, Richard W.
Brauneis, Frederick A.
Breivogel, Richard J.
Briscoe, Vicky C.
Brown, John W.
Brown, Norma H.
Burt, Sandra J.
Busa, Kathryn
Campbell, Eleanor N
Carlson, Gustaf A.
Carver, Kenneth W.
Casiles, Phyllis
Chalmers, Agnes C.
Charette, Ernest G.
Christian, John A.
Clemishaw, Charles W.
Clough, Auguste K.
Coneybear, Edna W.
Conway, George C.
Corr, James P.
Costa, Arthur
Crawford, Bruce
Creighton, James E.
Crocker, Marion W.
Croft, Donald A.
Croft, Harold E.
Crouse, Porter A.
Dastous, Roland L.
Davis, Francis L.
*Davis, Ruth H.
Davis, Robert C.
Dean, Mildred J.
DeLisle, Homer R.
DeSanti, Judith C.
Dimmock, Richard H.
Dinsmore, Robertson P.
Dodge, William B.
Drew, Roberta E.
Eastman, Arthur C.
Edwards, Richard S.
Fennelly, Cyril L.
Ferreira, Anthony
Fernandes, Alice P.
Fisher, Stanley O.
Flanagan, Christine M.
Frederiksen, Mauritz C.
*Fuglister, Cecelia B.
*Gallagher, William F.
Gandy, Curtis
Gibson, Laurence E.
Glista, Anthony G.
Goodspeed, Eileen M.
Green, Nancy H.
Gunter, Carol A.
Halbert, John R., Jr.
Hampton, Carolyn S.
Hatzikon, Kaleroy L.
Henderson, Arthur T.
Hindley, Robert J.
*Hodgman, Elizabeth R.
*Hulburt, Joan B.
Ingram, Ruth C.
Innis, Charles S., Jr.
Jenkins, Delmar R.
Jenney, Philomena
Johnson, Harold W.
Joseph, Charles R.
Kelley, Robert F.
Kinchla, Susan
King, Lauriston R.
Koval, Frank
Lajoie, Therese S.
Laking, Phyllis N.
Lamarre, Adrien J.
LeBlanc, Donald F.
Leiby, Jonathan
Livingston, Stella J.
Long, Shirley-Anne
Lowe, Robert G.
Lumsden, George W.
MacKillop, Harvey
MacLeish, William H.
Martin, Donald J.
Martin, Loretta M.
Martin, Olive
Matthews, Francis S.
Mayberry, Ernest H.
McClung, Philip E.
McGilvray, Mary K.
McMurray, Robert H., Jr.
Medeiros, Frank
Meinert, Dorothy
Mello, Michael A.
Mendousa, Anthony G.
Mendousa, Tina C.
Merson, Carole R.
Mikolajczyk, Walter C.
Miller, Carolyn B.
Miller, Cynthia A.
Mitchell, James R.
Moore, Karen E.
Motta, Joseph F.
Muller, John T.
Oakes, Harry E.
Ortolani, Mary
Page, Stephen G.
*Payne, Sheila T.
Peirson, A. Lawrence III
Peters, Charles J., Jr.
Phares, Edward
Picard, Eleanor P.
Pike, John F.
Pocknett, Marie P.
*Porter, Janet
Price, Nancy G.
Pucci, Joseph F.
Pykosz, Patricia A.
Quigley, Alexsandra
Rainnie, William O., Jr.
Ramsey, William S., Jr.
Reeves, Jeannette W.
Reeves, A. Stanley
Rennie, Thomas D.
Rice, William T.
Robinson, Christine C.
Robitaille, W. H.

*Part Time Employment **Temporary Employment

Department of Administrative and Service Personnel (continued)

Ross, David F.
Rubino, Barbara J.
Rudden, R. David, Jr.
Ruffen, Kenneth T.
Schilling, John L.
Schneider, Frederic W.
Schneider, Gloria F.
Schofield, Michael G.
Scott, David D.
Sharpe, Michael S.
Simmons, Nancy S.
Simmons, Roland R.
Singer, Joseph M.
Smart, Charlotte M.
Smart, Thomas H. M.
Souza, Carol J.
Souza, Donald P.
Souza, Thomas A.
Sprague, Evelyn M.
Steinbach, H. Burr
Stimpson, John W.
Stone, Louise D.
Swan, James A.
Taylor, Mildred L.
Thayer, Mary C.
*Thomas, Patricia A.
*Thompson, Leslie C.
*Thompson, Patricia E.
Vail, Stanley F.
Vallesio, Barbara M.
Walker, Jean D.
Watson, L. Hoyt
Weeks, Robert G.
Wege, Jane P.
Wessling, Andrew L., Jr.
White, Haskel E.
White, Ralph W.
Whitmore, Wendy
Wildes, Nancy K.
Wing, Carleton R.
Winling, Irene C.
Woodward, Fred C., Jr.
Woodward, Martin C.
Woodward, Ruth F.
Young, Carleton F.
Zentz, Bernard L.
Zingale, Douglas A.
Zwinakis, Jeffrey A.

Marine Personnel

Allsopp, Steven W.
Babbitt, Herbert L.
Bailey, James A.
Baker, William R.
Bauerlein, Gunter
Baugh, Jess D.
Bazner, Kenneth E.
Bizzozero, John P.
Bluestein, Keith
Brennan, Edward J.
Brill, Arnold C.
Broderick, Edward R.
Bumer, John Q.
Butler, Dale T.
Casiles, David F.
Chamberlin, J. Mark
‡Chretien, Alfred J.
Clark, John M.
Clarkin, William H.
Cochran, Patrick F.
Colburn, Arthur D., Jr.
Cotter, Jerome M.
Cottell, Paul H.
Cycz, Paul S.
‡Davis, Charles A.
**DeTerra, George
Dunn, Arthur J.
‡Elderkin, Donald R.
Farnsworth, Donald C.
Field, Michael J.
Flaherty, Peter M.
Flegenheimer, Richard C.
Fortes, Eugene B.
Frawley, John M.
Gassert, John M.
Genther, James A.
Gordon, Robert L.
‡Graca, Francisco T.
Hanlon, Robert A.
Hartke, David L.
**Hill, Henry J.
Hiller, Emerson H.
Howland, Paul C.
**Huckabee, Walter G.
Hume, Anthony
Jefferson, Albert C.
Johnston, Alexander T.
Kaminski, Lech J.
Kilbreth, Bernard E.
Knight, Olin T.
LaPorte, Leonide
Lineaweaver, Toby T.
Lobo, John T.
Lobo, Wayne F.
Loftfield, Eric B.
Madison, William J., Jr.
Mallery, Lawrence R.
Manley, Thomas F.
‡Martin, John W.
**McArdle, Frederick C.
McDaniel, Stanley O.
McLaughlin, Barrett H.
Medeiros, Alfred F., Jr.
Metzger, Donald J., Jr.
Mortens, Marvin A.
Moss, George G.
Moye, William E.
Munns, Robert G.
Murphy, Steven D.
Mysona, Eugene J.
Nicoll, David J.
Ocampo, Conrad H.
O'Connor, Michael M.
O'Neil, Thomas F.
O'Reilly, Peter P.
Ott, Theodore F.
Palmieri, Michael
**Patton, Gordon G.
Peck, Jeffrey F.
Pierce, George E.
Pierce, Samuel F.
Pope, Christopher M.
Ribeiro, Joseph
Rioux, Raymond H.
Roderick, John P.
Rogers, Richard D.
Rougas, Harry
Sainz, Alfonso B.
Seibert, Harry H.
Sequeira, Jorge A.
Sheak, Robert E.
Smith, Kenneth M.
Smith, Martin G.
Smith, Robert E.
Soucy, Trefton A.
Stack, William M.
‡Stires, Ronald K.
Sture, Armas V.
Sweet, John K., Jr.
Szymanski, John J.
Thatcher, Brett W.
Trombley, Alan B.
Turton, Alden D.
Van Solkema, Bradshaw A.
Vogel, Carl E.
Warecki, Joseph
Wheaton, Gary W.
‡Whitehouse, Arnold A.
Williams, Robert M.

Safety inspection in a lifeboat aboard R/V ATLANTIS II.

*Part Time Employment **Temporary Employment ‡Leave of Absence

Notes to Financial Statements

A. Summary of Significant Accounting Policies

Fund Accounting

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

Investments

Endowment fund investments are stated at cost except for securities restricted as to public sale which are valued for book purposes at the market valuation of unrestricted securities of the same class, on the dates of the gifts. The book value of these restricted securities amounted to $1,880,000 at December 31, 1973 ($5,750,649 at December 31, 1972). Endowment fund assets also include securities for which a readily determinable market value cannot be established. Such securities are included at a nominal value of $1, in accordance with the existing policy of the Institution.

Gifts and Grants

Gifts and grants are generally recorded as 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.

Depreciation

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 $365,071 in 1973 and $394,361 in 1972 has been charged to operating expense. Depreciation on certain government furnished equipment (Atlantis II, Laboratory for Marine Science and the dock facility) amounting to $263,228 in each year has been accounted for as a direct reduction of the plant asset and invested plant funds.

Title to the ship Atlantis II is contingent upon its continued use for oceanographic research.

Endowment Funds

The Institution maintains a pooled investment account for all endowment funds except for funds restricted as to principal and income which are separately invested. Current year income of the pooled investments is distributed on the unit method as follows:

a. Actual income earned to funds unrestricted as to income.

b. At a fixed annual rate (5% of a three year moving average of the unit value of the Fund) to funds unrestricted as to principal, restricted as to income. The annual income distribution to these funds will be provided first from the current investment income of the Fund and then from the gains on investments. The Institution's investment policy is to maximize the endowment fund's long-term total return (any combination of interest, dividends and capital appreciation).

Current year income earned on the separately invested securities of funds restricted as to principal and income is distributed directly to the funds to support the purpose of the donation.

B. Endowment Fund Assets

The changes in the market value of endowment fund assets were as follows:

	1973	1972
Market value beginning of year	$38,684,718	$32,150,574
Net gain (loss) in investment market value:		
Unrealized	(8,931,881)	971,498
Realized	4,979,477	5,592,954
Less investment gains availed of for restricted purposes	(70,353)	(46,684)
	(4,022,757)	6,517,768
Gifts	1,006,009	12,900
Transfers	11,154	3,476
	$35,679,124	$38,684,718

C. Endowment Income

Total endowment income, including investment gains of $70,353 and $46,684 availed of for restricted purposes in 1973 and 1972 respectively, was allocated as follows:

	1973	1972
To meet operating expenses	$ 282,240	$286,694
To restricted gifts and grants accounts	905,207	443,152
	$1,187,447	$729,846

D. Retirement Plan

Effective January 1, 1973, the Institution amended its trusteed noncontributory retirement plan to provide for improved retirement benefits to its employees. Under the amended plan, annual contributions are actuarially computed using the "entry age normal with frozen initial liability" cost method and it is the intention of the Institution to fund this expense as accrued. Under the previous plan the annual contribution was based on 12% of compensation paid by the Institution to plan members during the year. The amended retirement plan covers substantially all of the Institution's employees. Past service costs are to be amortized over a 30-year period commencing in 1973. At the most recent valuation date (January 1, 1973), the actuarially computed value of vested benefits exceeded the assets of the trust and balance sheet accruals by approximately $850,000.

Retirement plan costs charged to operating expense amounted to $719,015 in 1973 and $633,892 in 1972. The effect of the amendment of the plan did not materially change the cost of the plan in 1973. At December 31, 1973 the liability for contributions payable to the employees' retirement plan and trust has been reduced by partial payments made to the plan during 1973.

E. Commitments

As of December 31, 1973, the Institution is committed under construction contracts to spend an additional $1,400,000.

Supplemental Schedule

Summary of Endowment Assets

as at December 31, 1973

	Book Amount	% of Total	Market Quotation	% of Total
SEPARATELY INVESTED (FUNDS RESTRICTED AS TO PRINCIPAL AND INCOME):				
BONDS	$ 7,165,710	36.3	$ 7,081,130-	32.6
COMMON STOCKS**	12,365,914	62.7	14,463,195	66.5
CASH (INCLUDING $100,000 CERTIFICATE OF DEPOSIT)	206,681	1.0	206,681*	.9
TOTAL	**19,738,305**	**100.0**	**21,751,006**	**100.0**
POOLED INVESTMENTS:				
BONDS	6,142,983	46.9	5,736,420	40.6
COMMON AND PREFERRED STOCKS**	6,766,410	51.7	8,167,848	58.0
REAL ESTATE	51,023	.4	51,023*	.4
CASH	122,435	.9	122,435*	.9
OTHER ASSETS	14,227	.1	14,227*	.1
TOTAL	**13,097,078**	**100.0**	**14,091,953**	**100.0**
ENDOWMENT FUNDS DUE TO CURRENT FUNDS	(163,835)		(163,835)*	
TOTAL ENDOWMENT ASSETS	**$32,671,548**		**$35,679,124**	

*At book amount.
**See Note A to the financial statements.

Treasurer's Report

Total Operating Expenses of the Institution increased 7% in 1973 over the previous year, the major cost categories increasing as follows:

	1973	1972	Increase
Direct Costs of Research	$14,999,000	$14,274,000	5%
Graduate Studies Program	736,000	639,000	15%
General & Administration	2,026,000	1,710,000	18%

A comparison of the Endowment Fund activity for the years 1973 and 1972 is as follows:

	1973	1972	Increase (Decrease)
Assets at Book Value	$32,672,000	$26,745,000	22%
Assets at Market Quotations	35,679,000	38,685,000	(8%)
Additions to Principal	1,017,000	16,000	—
Total Income Received	1,117,000	683,000	64%
Unit Value of General Fund	.9568	1.0382	(8%)
Income per Unit	.0390	.0396	(2%)

Other statistics of interest are:

	1973	1972	Increase
Gross Payroll	$ 8,852,000	$ 7,960,000	11%
Retirement Trust Contribution	725,000	634,000	14%

Gifts and grants received from private sources including Foundations, Industry and the 652 Individual, Corporate and Club Associates totalled $5,207,000 in 1973.

Contributions for the Quissett Campus Development Program through the end of 1973 increased to $3,733,000 while expenditures for planning and construction of the Central Laboratory amounted to $4,460,000. During the first three months of 1974 an additional $400,000 has been received while expenditures increased by $1,236,000 to $5,696,000 with the total cost of this construction project expected to reach $8,000,000 when completed. Outstanding pledges currently total $4,000,000.

Audited Financial Statements appear on the following pages.

Edwin D. Brooks, Jr.
Treasurer

COOPERS & LYBRAND

CERTIFIED PUBLIC ACCOUNTANTS

To the Board of Trustees of

Woods Hole Oceanographic Institution.

We have examined the balance sheet of Woods Hole Oceanographic Institution as of December 31, 1973, and the related statements of current fund revenues, expenses and transfers, and changes in funds for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances. We previously examined and reported upon the financial statements for the year ended December 31, 1972.

In our opinion, the aforementioned statements (with investments stated at cost) (pages 85 to 87 inclusive) present fairly the financial position of Woods Hole Oceanographic Institution at December 31, 1973 and 1972, its current fund revenues, expenses and transfers for the years then ended, and the changes in funds for the year ended December 31, 1973, in conformity with generally accepted accounting principles applied on a consistent basis.

The supplemental schedule included in this report (page 88), although not considered necessary for a fair presentation of the financial position and results of operations is presented primarily for supplemental analysis purposes. This additional information has been subjected to the audit procedures applied in the examination of the basic financial statements and, in our opinion, is fairly stated in all material respects in relation to the basic financial statements taken as a whole.

Boston, Massachusetts
March 29, 1974

Coopers & Lybrand

BALANCE SHEETS

December 31, 1973 and 1972

ASSETS

	1973	1972
Current Fund Assets:		
Cash	$ 108,232	$ 397,389
Short-term investments, at cost which approximates market	3,100,000	3,100,015
Reimbursable research costs:		
Billed	401,358	705,945
Unbilled	1,584,474	1,126,563
Supplies, prepaid expenses and deferred charges	486,256	383,265
Plant funds advanced to current funds	(1,236,175)	(2,427,195)
Endowment funds due to current funds	163,835	37,260
	4,607,980	**3,323,242**
Endowment Fund Assets (Notes A and B):		
Investments:		
Securities, at cost (market value $35,448,593 in 1973 and $38,295,202 in 1972)	32,441,017	26,355,745
Real estate	51,023	52,440
	32,492,040	26,408,185
Cash (including certificates of deposit of $100,000 in 1973 and $250,000 in 1972)	329,116	363,298
Other assets	14,227	11,038
Endowment funds due to current funds	(163,835)	(37,260)
	32,671,548	**26,745,261**
Plant Fund Assets (Note A):		
Laboratory, plant and equipment	7,051,048	6,328,426
Atlantis II, contingent title (Note A)	4,831,130	4,831,130
Other vessels, equipment and property	3,575,404	3,587,167
Construction in progress	4,883,789	1,041,698
	20,341,371	15,788,421
Less accumulated depreciation	4,994,952	4,389,613
	15,346,419	11,398,808
Plant funds advanced to current funds	1,236,175	2,427,195
	16,582,594	**13,826,003**
	$53,862,122	**$43,894,506**

LIABILITIES AND FUNDS

	1973	1972
Current Fund Liabilities and Balances:		
Accounts payable and other accrued expenses	$ 894,516	$ 339,606
Accrued vacation	561,806	501,261
Contribution payable to employees' retirement plan and trust (Note D)	175,000	633,892
Unexpended balances of restricted gifts and grants	1,565,664	560,535
Current fund balance designated for:		
Income and salary stabilization	1,354,509	1,260,556
Working capital and contingency	56,485	27,392
	4,607,980	**3,323,242**
Endowment Funds (Note A):		
Restricted as to principal and income	9,140,400	9,140,400
Restricted as to principal	2,523,095	2,522,696
Unrestricted as to principal; restricted as to income	7,209,692	6,255,551
Unrestricted as to principal and income	224,474	161,851
Accumulated net gain on sales of investments (including gains relating to funds restricted as to principal and income of $10,598,496 in 1973 and $5,201,383 in 1972)	13,573,887	8,664,763
	32,671,548	**26,745,261**
Plant Funds (Note E):		
Invested in plant, less retirements	20,341,371	15,788,421
Less accumulated depreciation	4,994,952	4,389,613
	15,346,419	11,398,808
Unexpended	1,236,175	2,427,195
	16,582,594	**13,826,003**
	$53,862,122	**$43,894,506**

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

Statement of Current Fund Revenues, Expenses and Transfers

for the years ended December 31, 1973 and 1972

	1973	1972
Revenues		
Income for sponsored research:		
For direct costs	$14,784,512	$14,149,572
For indirect costs	1,853,573	1,738,885
Fees for use of facilities	239,959	174,895
	16,878,044	16,063,352
Revenue from educational operations:		
Grants expended for fellowships	83,465	99,755
Gifts availed of	681,216	535,698
Tuition and rental income	177,925	151,495
	942,606	786,948
Unrestricted endowment income availed of (Note C)	282,240	286,694
Development program contributions for unrestricted purposes	62,741	80,787
Other — principally interest income	308,776	98,693
	18,474,407	17,316,474
Operating Expenses		
Direct costs of research activity:		
Salaries	5,396,211	4,899,912
Vessel operations	3,684,150	3,414,312
Materials, equipment and services	3,586,584	3,863,249
Laboratory costs	837,888	807,985
Travel	429,093	393,981
Service departments	370,025	377,348
Computer center	694,594	516,898
	14,998,545	14,273,685
Direct costs of educational operations:		
Fellowships	361,166	336,856
Other operating costs	404,940	362,273
	766,106	699,129
Indirect costs:		
General and administrative	2,026,472	1,709,524
Miscellaneous	196,951	205,494
	17,988,074	16,887,832
Transfers		
Transferred to unexpended plant funds	363,287	391,129
Net increase for the year	**123,046**	**37,513**
Current fund balance, beginning of year	**1,287,948**	**1,250,435**
Current fund balance, end of year	**$1,410,994**	**$1,287,948**

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

Statement of Changes in Funds

year ended December 31, 1973

	Endowment Funds (Note A)	Invested in Plant	Unexpended Plant Funds	Unexpended Balances of Restricted Gifts and Grants	Current Fund Balance: Income and Salary Stabilization	Current Fund Balance: Working Capital and Contingency
Balance at beginning of year	**$26,745,261**	**$11,398,808**	**$2,427,195**	**$ 560,535**	**$1,260,556**	**$ 27,392**
Restricted gifts and private and public grants received	1,006,009		2,646,032	8,988,337		
Restricted endowment income including investment gains of $70,353 availed of (Notes A and C)	(70,353)			905,207		
Net gain on sales of investments	4,979,477					
Current fund revenues						18,474,407
Current fund operating expenses						(17,988,074)
Allocation of current fund increase to income and salary stabilization reserve					93,953	(93,953)
Depreciation expense — operations (Note A)		(365,071)	365,071			
Depreciation expense — Atlantis II and others (Note A)		(263,228)				
Availed of for research and education costs				(8,866,761)		
Transferred from working capital and contingency reserve to unexpended plant funds			363,287			(363,287)
Transferred from restricted gifts and grants to unexpended plant funds			10,500	(10,500)		
Transferred from restricted gifts and grants to endowment funds	11,154			(11,154)		
Invested in plant		4,575,910	(4,575,910)			
Balance at end of year	**$32,671,548**	**$15,346,419**	**$1,236,175**	**$1,565,664**	**1,354,509**	**56,485**
						1,354,509
						$1,410,994

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