WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

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225 Franklin Street (25th floor)
Boston, Massachusetts 02110

Robert R. Shrock
Department of Geology and Geophysics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Athelstan Spilhaus
P.O. Box 3250
West Palm Beach, Florida 33402

H. Burr Steinbach
Woods Hole Oceanographic Institution
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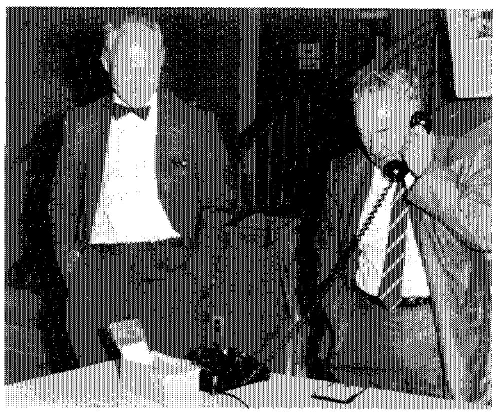

Mr. Townsend Hornor, President of the Associates (left), and Mr. Noel B. McLean, Chairman of the Board of Trustees (right).

THE DIRECTOR'S REPORT
1930-1970 in Retrospect

As we end another year and another decade, we also mark the completion of forty years of oceanographic research at the Institution. It seems appropriate therefore as we cross the threshold of the 70's into the International Decade of Ocean Exploration to reflect about the achievements of the Institution.

Nobody was better prepared or wiser than was Henry Bryant Bigelow to be the first Director of the Woods Hole Oceanographic Institution. On completion of his monumental work on the plankton, on the physical oceanography, and on the fishes of the Gulf of Maine, he had served as secretary to the Committee on Oceanography of the National Academy of Sciences. The report which he prepared was so far-sighted that it might well have been written today. It was that Committee which had recommended the establishment of an oceanographic laboratory on the east coast of the United States. Scientifically, he had won world renown. European oceanographers loved him. One had to be in his laboratory but a short time to appreciate this. Among his visitors there were men such as Sir J. Stanley Gardiner, Bjorn Helland-Hansen, Edouard LeDanois, Johan Hjort and Henry G. Maurice. It was as a result of these friendships that a representative from the Institution has always been warmly welcomed at the meetings of the International Council for the Exploration of the Sea.

The new institution which he was to head was to afford university professors the opportunity to carry on research in the marine sciences. To that end, the Woods Hole Oceanographic Institution had only a part-time staff until towards the beginning of World War II. Dr. Bigelow's genius revealed itself in the selection of staff members. Thus, the Institution soon became a center where scientists with their students came for a summer's work and where at least one visitor from abroad came to work for a season. Among them were H. H. Gran, Kurt Buch, August Krogh, V. W. Ekman, and H. U. Sverdrup.

It was a stimulating time and many of the subsequent reports have become classics in their field, particularly those concerned with the cycles of nutrients, the role of bacteria in the sea, the circulation of the North Atlantic as it focused on the Gulf Stream, and the submarine geology of the continental shelf.

But this was not all. Even before the Institution had opened its doors, support and encouragement was given to Sir Hubert Wilkins' NAUTILUS Expedition (1931) which had hoped to reach the North Pole. The International Passamaquoddy Commission for Fisheries Investigation and the International Ice Patrol were provided with laboratory space. When the ALBATROSS II was laid up as an economy measure, the Institution made it possible to continue the mackerel investigation into July of 1932. All of this was accomplished with a budget of approximately $115,000.

With the onset of hostilities in the early 1940's the Institution under the able guidance of Columbus O'D. Iselin underwent an oceanographic revolution.

The laboratory was busy year-round and soon filled with additional staff. For the first time there were sufficient funds to develop the oceanographic instrumentation needed for modern studies at sea. It had become essential to understand the environment in which a navy operated. Hitherto, all our knowledge of the subsurface layers had been obtained with plankton nets and otter trawls, with reversing water bottles and thermometers (protected and unprotected), and with dredges and primitive corers. Although almost every scrap of information that had been collected in an earlier era could be used, the needs of submarine and anti-submarine warfare were largely met by the use of underwater acoustics. How fortunate we were nevertheless to have a clue to the distribution of the bottom sediments and rock outcrops on the continental shelves of the world and to the temperature and salinity structure of the water masses of the oceans so that we might predict the routes and the distances sound might travel in the subsurface water layers.

Acoustical instruments, underwater photography and other useful tools largely initiated during the wartime era have become much more sophisticated in the two decades since the war. As a consequence a whole new branch of oceanography, ocean engineering, has arisen and is now a sizable business. Oceanography has taken many turns in the past twenty years, some requiring these new approaches in methodology and some the more traditional ones.

Many expeditions in collaboration with other laboratories in the United States and throughout the world have contributed toward the need for more nearly synoptic data of large ocean areas. A multiple-ship survey of the Gulf Stream (1950) was completed through the cooperation of the U.S. Navy Hydrographic Office, Naval Research Establishment, Halifax, Nova Scotia, U.S. Fish and Wildlife Service, Atlantic Oceanographic Group, St. Andrews, New Brunswick, Scripps Institution of Oceanography, U.S. Office of Naval Research, and the U.S. Coast Guard. During the International Geophysical Year (1957-1959) an ambitious program was carried out in conjunction with the National Institute of Oceanography, Great Britain. Traditional methods were particularly effective in obtaining a second "reading" of the North and South Atlantic as a whole, from "top to bottom" along most of the same sections as were traversed by the German Research Vessel METEOR in 1925-1927. The atlas subsequently prepared has given a valuable point of departure for more recent work in these waters. Meanwhile early trials with instrumented buoys in examining inertia currents off Bermuda forecast their usefulness in long-term studies of the oceans. During this same period several important papers on ocean current theory were published which stimulated the hydrodynamicists to produce more elegant theories, and have provided the basis for further work in the field and in the laboratory. The discovery of the deep countercurrent in the Western Atlantic was a direct result of these theories.

Other new developments were the forerunners of the work in the 1960's: an infrared survey of the Gulf Stream from a plane, geological surveys of the Gulf of Mexico and the Peru-Chile Trench, measurements of currents with a geomagnetic electrokinetograph, exploration of anaerobic environments in the Cariaco Trench and Dramsfjord together with studies on the flushing of estuaries and chemical pollution in the New York Bight (essentially the area that has recently been declared "dead"), biological pollution in Great South Bay, Long Island, and the potential effects of radioactive wastes at sea. In this connection, it develops that there is an inexplicably high radioactive fallout on the sea surface, markedly higher than on land, and a higher rate of downward mixing of the radioactive rare earths than might have been anticipated after bomb test series. Even more of an enigma perhaps is the fact that twice as much fallout is found in the Sargasso Sea as in the equatorial regions.

Other precursors to the work of the 1960's have evolved into the work in progress at the present time. With developing techniques in biology and chemistry, it appears that there are great reservoirs of organic material in the deep oceans which do not become involved in the life cycle. Furthermore, it seems that the oxygen minimum layer does not necessarily form *in situ* but rather it may be produced at a site remote from the area where it is found. Older concepts must be changed. Now that organic compounds can be detected in sea water in exceedingly small quantities it has been shown that the planktonic inhabitants of a water mass leave chemical traces behind, which may, for example, provide a more accurate way to trace water masses than with biological "indicator species." Or, again, an olefin first detected in the copepod, *Rhincalanus nasutus,* was subsequently found in a number of algae, in molluscs, in herring and in a shark. Thus, we have a new tool for unravelling the food web. Perhaps more important is the differentiation of the hydrocarbons synthesized by living organisms and those derived from fossil fuels, which may be so destructive to the fauna and flora in local oil spills and which even pollute the surface waters over most of the oceans of the world. It can now be shown that the deleterious effects persist for months, perhaps years, after the original accidents, due to the incorporation of dangerous chemicals into the tissues of shellfish and other marine organisms. The ramifications of this work will continue to improve our understanding of what man is doing to his environment.

At the same time that we have come to derive greater understanding of the chemical medium and the organisms dwelling in the oceans, the instruments have also become available which reveal a greater understanding of our planet and its history. For more than a decade the geophysicists examined the subsurface layers in the area of the Blake Plateau, the "Tongue of the Ocean," the Puerto Rican Trench. Subsequently, the area was extended to the Mid-Atlantic Ridge and on into the Mediterranean. During this interval a location north of Puerto Rico was surveyed with a view to selecting it for the MOHOLE project, which was to have been an attempt to reach the Mohorovičić discontinuity. While that has not yet come to fruition, it has become practicable to obtain long cores in the ocean bottom. This is such a large program (JOIDES) that it has been undertaken by a consortium of five oceanographic laboratories and with the participation of earth scientists from all over the nation. During a period when scientists from Woods Hole were on board cores were taken which demonstrated convincingly the existence of sea-floor spreading.

The physical oceanographers have been developing reliable buoys for synoptic studies on a large scale and even in learning about "oceanography from space." In addition, based in part on theory and in part on observation, a clearer concept of the water budget of the North Atlantic has been achieved by examining the volume transport of water into and out of the northern Atlantic leading to the concept that the Norwegian Sea is a mediterranean basin not unlike the Red and Mediterranean seas. A more detailed description of the shape of the ocean bottom now permits an understanding of its effects on ocean currents. Topographic features may result in current branching or provide barriers which contain currents in a specific ocean basin and which permit overflows between basins at low spots along ridges, as appears to happen in the vicinity of the Romanche Trench.

Partly because oceanography is expensive, it has been found advantageous to pool resources and scientific talent when surveying poorly understood features in remote parts of the world. CHAIN (1964) with geophysicists, ATLANTIS II (late in 1964-1965) with physical oceanographers, and ANTON BRUUN (1963) with biologists all participated in the International Indian Ocean Expedition. Of special interest was the effect of the monsoons on the water masses and currents, but little had been known either of the bottom features or of the productivity of this ocean. *En route* to the Indian Ocean, the DISCOVERY (1964), the METEOR (1964) and the ATLANTIS II (1965) had all found deeps in the Red Sea filled with unusually hot water of a very high salinity (bearing out the earlier observations of the Swedish ALBATROSS in 1948 and the ATLANTIS in 1959). CHAIN was dispatched in 1966 to examine this phenomenon in greater detail. The report of this work is contained in the book, *Hot brines and Recent heavy metal deposits in the Red Sea* (1969). An equally extraordinary environment was explored this year — the Black Sea with its deep anoxic waters. Preliminary findings are quite as exciting as those for the Red Sea and Indian Ocean.

The scientific accomplishments of our staff have been considered as only a part of our responsibilities. In our original charter "instruction in oceanography and allied subjects" was one of the Institution's avowed purposes. In the early years, this goal had been satisfied by offering a number of summer fellowships and by hiring student assistants to work here with their professor. An impressive number of universities were represented. There was a hiatus in this aspect of our program during the wartime years, but by the late 1950's we decided to give it greatly increased emphasis. A goodly number of our year-round staff held appointments to the faculty of one or another university. The numbers of summer fellowships and their stipends were increased; there were nearly a dozen full-time graduate students carrying on work for their theses and several post-doctoral fellows. Members of the staff served as instructors in the Marine Ecology course at the Marine Biological Laboratory, there was a course in Geophysical Fluid Dynamics supported by the National Science Foundation, an M.I.T.-W.H.O.I. seminar on Thermal Convection, and an Institution course in Observational Physical Oceanography. The success of these cooperative ventures made it clear to the Board of Trustees that more formal provisions should be made for graduate education. After studying the possibilities at some length, the change in the charter needed to enable us to grant graduate degrees was obtained on 11 November 1967. By 8 May 1968, the Institution had entered into an agreement for a cooperative program with the Massachusetts Institute of Technology leading to a joint doctoral degree in oceanography. A similar graduate degree program in ocean engineering has also been implemented this year with the Department of Naval Architecture and Marine Engineering of the Massachusetts Institute of Technology.

There are also reciprocal arrangements for the exchange of students with Harvard and Yale universities permitting cross-registration between the two institutions. Less formal understandings will continue in force with other universities whose students may wish to work or take courses at Woods Hole for part of their doctorate requirements. The Institution will when circumstances warrant, award an advanced degree by itself. Thus there is considerable flexibility in the individualized program of the students who intend to make a career in oceanography.

In 1930, it did not seem reasonable to expect that more than the one laboratory building and one sea-going vessel would ever be needed to provide for a viable program in oceanography. Even in the first years, when ATLANTIS was constantly at sea in summer, the ASTERIAS, often operating out of Provincetown, ventured far afield. Henry Stetson's Friendship sloop, NEVA, sailed well offshore into the Gulf of Maine to obtain sediment samples, and Columbus Iselin's RISK underwent many modifications to install specialized gear for science.

Starting in 1943 and later, there was a succession of small craft and larger vessels coming and going at the dock: ANTON DOHRN, MYTILUS, PHYSALIA, RELIANCE, CARYN, BEAR, HAZEL III, BLUE DOLPHIN, ARIES, KEVIN MORAN, YAMACRAW, etc.

During the early days of the war, the Institution installed shops next door in the old Penzance Garage, belonging to the Marine Biological Laboratory. Thus there was room for "welding, brazing, pipe cutting, blacksmith work and tinsmith work" with some space left over for the "repair of boats, engines and automobiles." Wharf facilities were also greatly increased. Next a house for administration was erected in the parking lot (planned for 10 cars in 1930!) behind the laboratory. Other "shacks" soon appeared when space became critical. By 1946, the "Hall property" across the street with a 50-foot frontage on the Eel Pond was acquired. It provided several housing units for a time, until too seriously damaged by hurricane tides to be used for anything but storage and shops.

Not until 1954 was the post-war pressure for increased work in the marine sciences to have additional space in adequate quarters. That year the Laboratory of Oceanography was dedicated. The next year the CARYN was retired for lack of funds, but at the instigation of Admiral Edward H. Smith (then the third Director), the CRAWFORD, an ex-Coast Guard cutter, was obtained. Small as she was she was to make many transects of the Atlantic during the International Geophysical Year.

Pressures for more space had begun to build up just at the end of Dr. Iselin's second term (1956-1958) as Director and these have continued to build during much of my own term. As the following properties, mostly small and in the village, became available, they have been acquired: "Dyer's dock" and parking lots (1957), the old site of the Methodist church, the Fay Homestead estate at the head of Little Harbor (1958), the Woods Hole drugstore (1961), 38 Water Street (1961), the School Street parking lot (Ames property—1962), Edward Swift's hardware store and house (1965), the Sidney W. Lawrence (Winding Lane) property and the Lawrence apartment house on School Street (1966), the DeSorbo house (1966), the Zeigler house (1967) and the Fenno estate of roughly 160 acres (1967). Also, in 1966, through the generosity of the Atlantic Foundation and Mr. J. Seward Johnson, ninety-five acres of land was purchased on the Matamek River, near Sept-Iles, Province of Québec. In an area untouched by man, it is an ideal place for basic ecological studies.

Today, despite the fact that we have rather extensive real estate holdings, that we have excellent quarters for the computer, a Laboratory of Marine Science (1964), a new pier (1968) and a marine facilities building (1969), space ashore particularly for the scientists is still most critical!

The fleet has not limited the work that we can undertake as severely. The CHAIN (T-ARS-20), a converted Navy salvage and rescue ship, was operated the first year (1958) by the Military Sea Transportation Service, but since that time the Institution's own crews have been in charge. The GOSNOLD, a 99-foot Army cargo vessel built in 1949, was purchased by the Institution in 1962. She has been very useful in the cooperative program with the U.S. Geological Survey on the continental shelf off our east coast and more recently in the joint educational program with the Massachusetts Institute of Technology. Now that the CRAWFORD is retired, the GOSNOLD has been even busier. ATLANTIS II, the first of the fleet to circumnavigate the Earth, continues as important to our work as when first launched in 1962. (ATLANTIS departed in 1966, rechristened EL AUSTRAL, for a new career in Argentina.) ALVIN and her "mother-ship," the catamaran LULU, went into service in 1965. Despite time out to search for the A-bomb off Palomares, Spain, ALVIN had proven a very effective tool for the biologists and geologists before she sank in the autumn of 1968 (with recovery in 1969). Before another year is over, the new submersible SEA CLIFF and the R.V. KNORR, to be the largest vessel in our fleet, should have arrived.

With our "catalogue of ships," the odyssey of the Institution's first forty years ends and we now look ahead with great anticipation and expectation to the future. Our cooperative oceanographic programs of the past, both national and international, have paved the way for future efforts in successful ocean exploration. As technology moves ahead with research, as economic benefits accrue to industry and promote greater investment in future ocean exploration, we can only be optimistic about our continuing progress and success.

PAUL M. FYE, *Director*
MARY SEARS

Dean Steinbach in the laboratory

Report of the Dean

It is important to remember, as the Institution enters its fourth decade of leadership in ocean studies, that education, also, has been a major Institution involvement for the past forty years. It is too bad, from the historical standpoint, that we have no precise way of counting the number of ocean scientists who have received primary training at W.H.O.I. However, this lack of historical record is consistent with our priorities: the Institution has always been more concerned with getting on with science than in counting noses or in keeping academic records. This much we are sure of: the number educated at W.H.O.I. in the past is substantial.

Our youngest educational effort, our formal entry into the degree-granting field, has added enormous potential value to the overall educational enterprise. First authorized by the Trustees in 1966, then by the Commonwealth of Massachusetts in 1967, the Woods Hole Oceanographic Institution is now a recognized, operating graduate institution. The success of this Ph.D. program is in no small way the consequence of establishing, at the very outset, a sound partnership with the Massachusetts Institute of Technology. No institution of higher learning can cover all fields in depth. It would be especially unwise for the Institution, regardless of our noteworthiness as a research institution, to attempt to provide all the background aspects of training needed to produce true scholars of the oceans. The joint Massachusetts Institute of Technology-Woods Hole Oceanographic Institution program is truly an invention, an academic amalgamation forming what is certainly one of the world's most exciting opportunities for young people to be trained in the ocean sciences.

Today, the joint program offers specialization in physical oceanography, marine geology, marine geophysics, marine chemistry, and ocean engineering. Here are some of the achievements of the past two years which caused me to evaluate the program as a success so confidently:

. . . The Dean's Office has been established and funded.

. . . In the first year of operation, twenty young scientists applied for the program. That number more than doubled in the second year, and the applicants were top-rated young scientists.

. . . Joint faculty committees function smoothly in maintaining the high standards of admission and performance.

. . . Classes are being held regularly on both campuses, with residents of both institutions attending classes at Woods Hole and the Massachusetts Institute of Technology.

. . . Students in residence at both institutions are participating in seminars and research projects at both institutions.

. . . Financial assistance for students is being maintained at an acceptable level, with Woods Hole supporting eighteen students this year.

. . . One joint degree has been awarded, and it is anticipated that at least four will have been earned by the end of the 1969-1970 academic year.

Our educational activities are good, they are numerous and they are varied. Counting the summer session, in the academic year 1969-1970, at least 150 students participated in educational activities involving more than sixty-five staff members of the Institution. By any set of criteria we are indeed an operating educational institution. Statistical summaries are appended as a part of this report.

The major activity has, of course, related to the joint program with the Massachusetts Institute of Technology. Last fall, counting new entrants, fifty-one students were registered for the program leading to a degree in oceanography, three for the professional degree in ocean engineering. These students took courses, participated in seminars and pursued their research work. By agreement, the courses directly concerned with the ocean environment were conducted on the Woods Hole campus; students whose major residence was in Cambridge came down twice a week by chartered bus. Bussing students, at any level, has inherent difficulties for any educational program. However, the program went off very well and will be repeated. The first Woods Hole courses were rather orthodox in that the course headings followed the classical divisions of chemistry, physics, biology and so forth. As we gain experience, we hope to devise new methods of presenting oceanography as a unified enterprise.

Since founding days, the Institution has maintained high intellectual standards recognized and endorsed by our sister academic institutions. Since developing our own plans more concretely than in the past, discussions have been held, especially with interested units of Harvard, Yale and Brown, which will certainly lead to continued and enhanced cooperative efforts in training scholars of the oceans.

During the summer of 1969, we offered no formal courses. Rather, we instituted a "scholar-in-residence" program. Nine Maury Lane (the Ziegler House) was remodeled to provide a large meeting room, a small but pleasant apartment and a few rooms for students. Following introductory sessions with Institution scientists, each week the students had access to a visiting scientist who was quartered in the apartment and accessible to students for seminars and informal bull sessions. All told, we had about fifty students in residence. The majority of them participated in the visiting scholar sessions. The program was judged a success and we will repeat it this summer, hopefully making it even better because of the experience of last year.

Plans are actively underway to broaden the scope of the joint program. Indeed, the influence of the Woods Hole Oceanographic Institution on the combined operation is clearly evident. Two years ago the majority of students applying to the joint program indicated an interest in physical oceanography. Last fall, a notable proportion registered with a major interest in marine geology and chemical oceanography. Progress is being made towards establishing programs in biological oceanography. The engineering program, without advance advertising, has a notable number of applicants.

Our total Institution effort in educational matters spreads broadly across a wide spectrum of ages and interests. A healthy number of postdoctoral trainees are always in residence, some supported by funds from the National Science Foundation. A somewhat less formal aspect of education is illustrated by the activities this year of Dr. Folger, formerly a member of our staff and now at Middlebury College. Dr. Folger and Dr. John Schlee (U.S. Geological Survey and the Woods Hole Oceanographic Institution) guided the activities of ten science majors of Middlebury during a month residence at the Institution. Field trips, lectures and seminars occupied some of their time but much was spent in analyzing geological samples collected. I consider this program to be a prime example of one way in which the Institution as a unique exciting entity can contribute to a truly regional and national training program without staff always running the show.

Attention should also be called to the informal influence of the Institution by way of the Secondary Schools' Cooperative Effort in Oceanography program. Dr. Richard Haedrich of this Institution acted as guiding angel for this program. Last fall, I had the pleasure of bestowing certificates of achievement on some dozen high school students who had carried out research projects on the oceans.

H. BURR STEINBACH,
Dean of Graduate Studies

EDUCATIONAL PROGRAM — ENROLLMENT

1969

Year-Round	*No. of Students*		
M.I.T.-W.H.O.I. Joint Program:			
Resident in Woods Hole	9		
Resident at M.I.T.	42		
Predoctoral Candidates at other Universities	8		
Postdoctoral Fellows	4		
TOTAL YEAR-ROUND		63	
Summer			
M.I.T.-W.H.O.I. Joint Program Fellows	22		
W.H.O.I. Summer Student Fellows	17		
Summer Predoctoral Fellow	1		
Geophysical Fluid Dynamics Seminar Fellows	9		
Guest Student Investigators	15		
Summer Student Employees	42		
TOTAL SUMMER		106	
TOTAL (duplication eliminated)			147

Recipient of Joint Woods Hole Oceanographic Institution-Massachusetts Institute of Technology Doctor of Philosophy–1969

W. FRANK BOHLEN

B.S. Electrical Engineering, Notre Dame

Special Field: Fluid Mechanics

Dissertation: *Experimental Studies of Turbulence in Liquid-Solid Flows.*

Resident Scientific and Technical Staffs

PAUL M. FYE . . . . *Director of the Woods Hole Oceanographic Institution*

H. BURR STEINBACH . . . . *Dean of Graduate Studies*

ARTHUR E. MAXWELL . . . *Director of Research*

BOSTWICK H. KETCHUM . . . *Associate Director*
Associate Member of the Department of Biology, Harvard University

COLUMBUS O'D. ISELIN . . . *Henry Bryant Bigelow Oceanographer*
Professor of Oceanography Harvard University

Department of Biology

RICHARD H. BACKUS, *Senior Scientist*
Associate in Ichthyology, Harvard University
RICHARD T. BARBER, *Assistant Scientist*
FRANCIS G. CAREY, *Associate Scientist*
NATHANIEL CORWIN, *Analytical Chemist*
JAMES E. CRADDOCK, *Assistant Scientist*
J. FREDERICK GRASSLE, *Assistant Scientist*
GEORGE D. GRICE, JR., *Associate Scientist*
ROBERT R. L. GUILLARD, *Associate Scientist*
RICHARD L. HAEDRICH, *Assistant Scientist*
Associate in Ichthyology, Harvard University
GEORGE R. HAMPSON, *Research Associate*
LOUIS A. HOBSON, *Assistant Scientist*
EDWARD M. HULBURT, *Associate Scientist*
HOLGER W. JANNASCH, *Senior Scientist*
Privat Docent in Microbiology,
University of Göttingen
JOHN W. KANWISHER, *Senior Scientist*
ANDREW KONNERTH, JR., *Research Associate*
THOMAS J. LAWSON, JR., *Research Associate*
CARL J. LORENZEN, *Assistant Scientist*
FRANK J. MATHER III, *Associate Scientist*
DAVID W. MENZEL, Assistant Department Chairman, *Associate Scientist*
CHARLES C. REMSEN III, *Assistant Scientist*
GILBERT T. ROWE, *Assistant Scientist*
JOHN H. RYTHER, Department Chairman, *Senior Scientist*
HOWARD L. SANDERS, *Senior Scientist*
Consultant in Marine Ecology
Marine Biological Laboratory, Woods Hole;
Research Affiliate of the Marine Sciences Research Center, State University of New York, Stony Brook;
Associate in Zoology, Harvard University
RUDOLF S. SCHELTEMA, *Associate Scientist*
MARY SEARS, *Senior Scientist*
JOHN M. TEAL, *Associate Scientist*
RALPH F. VACCARO, *Associate Scientist*
STANLEY W. WATSON, *Associate Scientist*
PETER H. WIEBE, *Assistant Scientist*
ASA S. WING, *Research Associate*

Department of Chemistry

MAX BLUMER, *Senior Scientist*
VAUGHAN T. BOWEN, *Senior Scientist*
DAVID B. BOYLAN, *Assistant Scientist*
PETER G. BREWER, *Assistant Scientist*
JOHN C. BURKE, *Research Associate*
EGON T. DEGENS, *Senior Scientist*
WERNER G. DEUSER, *Associate Scientist*
GEORGE R. HARVEY, *Assistant Scientist*
RALPH A. HORNE, *Associate Scientist*
JOHN M. HUNT, Department Chairman, *Senior Scientist*
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PETER L. SACHS, *Research Associate*
JEREMY SASS, *Research Associate*
FRED L. SAYLES, *Assistant Scientist*
DEREK W. SPENCER, *Associate Scientist*
GEOFFREY THOMPSON, *Assistant Scientist*
THOMAS R. S. WILSON, *Assistant Scientist*
KAI M. WONG, *Research Associate*
OLIVER C. ZAFIRIOU, *Assistant Scientist*

Cooperating Scientists U.S. Geological Survey

JOHN C. HATHAWAY   FRANK T. MANHEIM   ROBERT H. MEADE
ROBERT N. OLDALE   JOHN S. SCHLEE

◊As of 31 December 1969

Department of Geology and Geophysics

THOMAS C. ALDRICH, *Research Associate*
LINCOLN BAXTER II, *Applied Physicist*
JOHN C. BECKERLE, *Associate Scientist*
WILLIAM A. BERGGREN, *Associate Scientist*
Visiting Professor, Brown University
Research Associate, Department of Micropaleontology, American Museum of Natural History
STANLEY E. BERGSTROM, *Research Associate*
CARL O. BOWIN, *Associate Scientist*
ROBERT R. BROCKHURST, *Applied Physicist*
ELIZABETH T. BUNCE, *Associate Scientist*
JAMES A. DAVIS, *Assistant Scientist*
WILLARD DOW, *Electronics Engineer*
WILLIAM M. DUNKLE, JR., *Research Associate*
KENNETH O. EMERY, *Senior Scientist*
‡EARL E. HAYS, *Senior Scientist*
JAMES R. HEIRTZLER, Department Chairman, *Senior Scientist*
FREDERICK R. HESS, *Research Associate*
CHARLES D. HOLLISTER, *Assistant Scientist*
HARTLEY HOSKINS. *Assistant Scientist*
‡ELI J. KATZ, *Associate Scientist*
SYDNEY T. KNOTT, *Hydroacoustics Engineer*
PAUL T. MCELROY, *Assistant Scientist*
‡JOHN D. MILLIMAN, *Assistant Scientist*
EDWARD L. MURPHY, *Associate Scientist*
WALTER D. NICHOLS, *Research Associate*
RICHARD T. NOWAK, *Research Associate*
DAVID M. OWEN, *Research Associate*
JOSEPH D. PHILLIPS, *Assistant Scientist*
KENNETH E. PRADA, *Research Associate*
DAVID A. ROSS, *Associate Scientist*
ELAZAR UCHUPI, *Associate Scientist*
ALLYN C. VINE, *Senior Scientist*
RICHARD P. VON HERZEN, *Associate Scientist*
ROGER S. WALEN, *Research Associate*
DAVID WALL, *Associate Scientist*
WILLIAM A. WATKINS, *Research Associate*
WARREN E. WITZELL, *Research Associate*
HOW-KIN WONG, *Assistant Scientist*
EARL M. YOUNG, *Research Associate*
EDWARD F. K. ZARUDZKI, *Seismic Engineer*

Department of Ocean Engineering

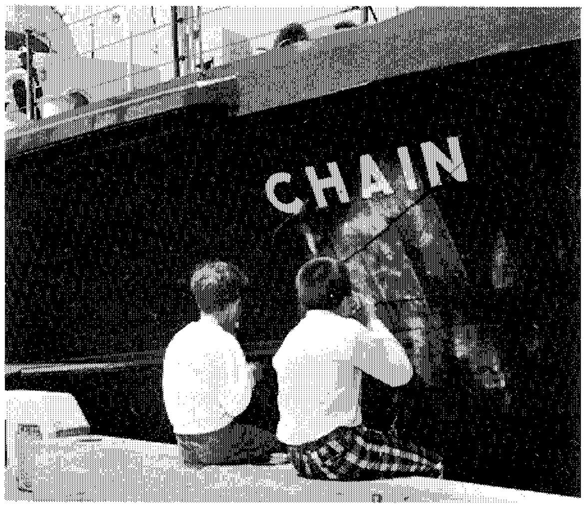
ROBERT D. BALLARD, *Research Associate*
HENRI O. BERTEAUX, *Research Associate*
EDWARD L. BLAND, JR., *Research Associate*
NEIL L. BROWN, *Electrical Engineer*
KENNETH H. BURT, *Research Associate*
SCOTT C. DAUBIN, Department Chairman, *Senior Scientist*
DONALD L. DORSON, *Research Associate*
ROBERT G. DREVER, *Research Associate*
DONNA J. EKSTRAND, *Research Associate*
ERIC H. FRANK, JR., *Research Associate*
CLIFFORD J. HAMILL, *Research Associate*
PETER E. KALLIO, *Research Associate*
RICHARD L. KOEHLER, *Research Associate*
WILLIAM A. MARQUET, *Research Associate*
JAMES W. MAVOR, JR., *Mechanical Engineer*
MARVIN C. MCCAMIS, *Research Associate*
GEORGE H. POWER, *Research Associate*
WILLIAM O. RAINNIE, *Oceanographic Engineer*
MELVIN A. ROSENFELD, Manager, Information Processing Center, *Senior Scientist*
ARNOLD G. SHARP, *Research Associate*
JESS H. STANBROUGH, JR., *Research Physicist*
PAUL B. STIMSON, *Research Associate*
CONSTANTINE D. TOLLIOS, *Research Associate*
ROBERT G. WALDEN, *Electronics Engineer*
DOUGLAS C. WEBB, *Electrical Engineer*
WARREN F. WEBERT, *Research Associate*
‡JACQUELINE WEBSTER, *Research Associate*
VALENTINE P. WILSON, *Research Associate*
CLIFFORD L. WINGET, *Research Associate*

Department of Physical Oceanography

JOSEPH R. BARRETT, JR., *Research Associate*
DEAN F. BUMPUS, *Senior Scientist*
ANDREW F. BUNKER, *Associate Scientist*
ALVIN L. BRADSHAW, *Applied Physicist*
JOHN G. BRUCE, JR., *Research Associate*
MARGARET A. CHAFFEE, *Research Associate*
JOSEPH CHASE, *Associate Scientist*
Visiting Lecturer, State College at Bridgewater
JOHN W. COOPER, *Research Associate*
C. GODFREY DAY, *Research Associate*
CHARLES D. DENSMORE, *Research Associate*
EDWARD A. DENTON, *Research Associate*
GIFFORD C. EWING, *Senior Scientist*
NICHOLAS P. FOFONOFF, Department Chairman, *Senior Scientist*
Gordon McKay Professor of the Practice of Physical Oceanography, Harvard University
FREDERICK C. FUGLISTER, *Senior Scientist*
JAMES E. GIFFORD, *Research Associate*
ROBERT H. HEINMILLER, *Research Associate*
JOHN A. MALTAIS, *Research Associate*
JAMES R. MCCULLOUGH, *Research Associate*
WILLIAM G. METCALF, *Associate Scientist*
ROBERT C. MILLARD, JR., *Research Associate*

‡ On Leave of Absence

Arthur R. Miller, *Associate Scientist*
Robert G. Munns, *Research Associate*
Charles E. Parker, *Research Associate*
Raymond T. Pollard, *Assistant Scientist*
‡F. Claude Ronne, *Photographic Specialist*
Thomas B. Sanford, *Assistant Scientist*
Peter M. Saunders, *Associate Scientist*
Karl E. Schleicher, *Oceanographic Engineer*
William J. Schmitz, Jr., *Assistant Scientist*
Elizabeth H. Schroeder, *Research Associate*
William F. Simmons, *Assistant Scientist*
Allard T. Spencer, *Design Engineer*
Marvel C. Stalcup, *Research Associate*
Robert J. Stanley, *Research Associate*
Foster L. Striffler, *Research Associate*
Gordon H. Volkmann, *Research Associate*
William S. von Arx, *Senior Scientist*
Professor of Physical Oceanography, Massachusetts Institute of Technology
Arthur D. Voorhis, *Associate Scientist*
Bruce A. Warren, *Associate Scientist*
T. Ferris Webster, *Associate Scientist*
Geoffrey G. Whitney, Jr., *Research Associate*
L. Valentine Worthington, *Senior Scientist*



Future oceanographers (?) dream of far places.

Administrative Staff of the Woods Hole Oceanographic Institution

Norman T. Allen	Archivist
Bruce Crawford	Personnel Manager
Richard S. Edwards	Marine Superintendent
Arthur T. Henderson	Procurement Supervisor
Edward J. Hooper	Public Relations
Robert E. King	Industrial Liaison
William D. Lambert	Foundation Liaison
Jonathan Leiby	Naval Architect
Harvey MacKillop	Controller
Frederick E. Mangelsdorf	Assistant Director for Development and Information
James R. Mitchell	Facilities Manager
John F. Pike	Port Captain
John L. Schilling	Public Information
David D. Scott	Assistant Director for Administration
L. Hoyt Watson	Associates Program
Andrew L. Wessling, Jr.	Manager of Services

Non-Resident Research Staff

DAVID L. BELDING, *Emeritus Scientist*

CORNELIA L. CAREY, *Emeritus Scientist*

WILLIAM C. SCHROEDER, *Emeritus Scientist*

ALFRED C. REDFIELD, *Senior Oceanographer (Emeritus)*
Professor of Physiology (Emeritus), Harvard University

ARNOLD B. ARONS, *Associate in Physical Oceanography*
Professor of Physics, University of Washington

GEORGE L. CLARKE, *Associate in Marine Biology*
Professor of Biology, Harvard University

ROBERT R. HESSLER, *Associate in Marine Biology*
Associate Professor of Oceanography,
Scripps Institution of Oceanography

LOUIS N. HOWARD, *Associate in Mathematics*
Professor of Mathematics,
Massachusetts Institute of Technology

GALEN E. JONES, *Associate in Microbiology*
Professor of Microbiology,
University of New Hampshire

ROBERT H. KRAICHNAN, *Associate in Theoretical Physics*
Dublin, New Hampshire

WILLEM V. R. MALKUS, *Associate in Physical Oceanography*
Professor of Applied Mathematics,
Massachusetts Institute of Technology

PAUL C. MANGELSDORF, JR., *Associate in Physical Chemistry*
Associate Professor of Physics, Swarthmore College

GILES W. MEAD, *Associate in Ichthyology*
Curator of Fishes, Museum of Comparative
Zoology, Harvard University

ROBERT L. MILLER, *Associate in Submarine Geology*
Professor of Marine Geophysics,
University of Chicago

ERIC L. MILLS, *Associate in Marine Biology*
Associate Professor, Dalhousie University

JAMES M. MOULTON, *Associate in Marine Biology*
Professor of Biology, Bowdoin College

JEROME NAMIAS, *Associate in Meteorology*
Chief, Extended Forecast Division,
U.S. Weather Bureau,
Environmental Science Services Administration,
Washington, D.C.

GEOFFREY POWER, *Associate in Marine Biology*
Professor of Biology,
University of Waterloo, Ontario

DONALD C. RHOADS, *Associate in Paleoecology*
Assistant Professor of Geology, Yale University

ALLAN R. ROBINSON, *Associate in Physical Oceanography*
Gordon McKay Professor of Geophysical Fluid
Dynamics, Harvard University

WILLIAM E. SCHEVILL, *Associate in Oceanography*
Research Associate in Zoology, Museum of
Comparative Zoology, Harvard University

RAYMOND SIEVER, *Associate in Geology*
Professor of Geology, Harvard University

JOANNE SIMPSON, *Associate in Meteorology*
Chief, Experimental Meteorology Branch,
U.S. Weather Bureau,
Environmental Science Services Administration,
Coral Gables, Florida

EDWARD A. SPIEGEL, *Associate in Astrophysics*
Associate Professor of Physics,
New York University

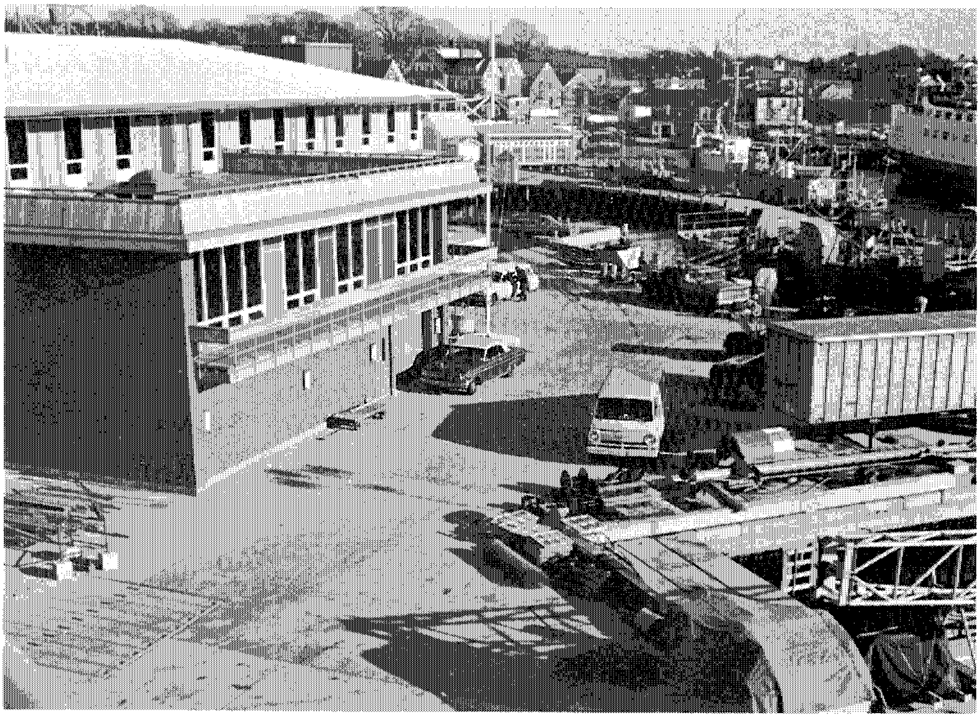
HENRY M. STOMMEL, *Associate in Physical Oceanography*
Professor of Oceanography,
Massachusetts Institute of Technology

THOMAS T. SUGIHARA, *Associate in Geochemistry*
Professor of Chemistry, Texas A. & M. College

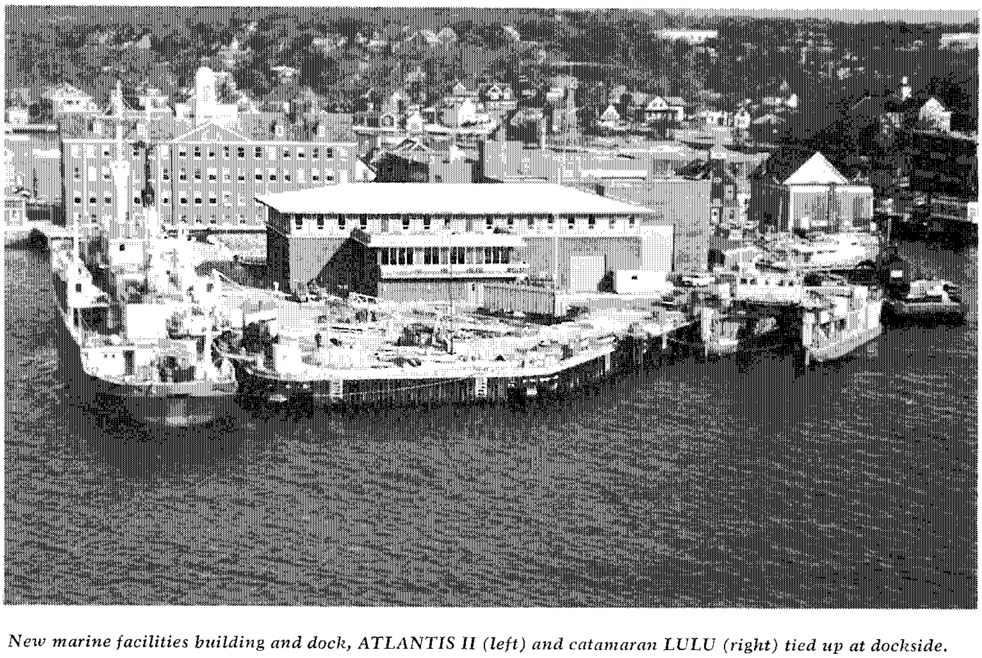
GEORGE VERONIS, *Associate in Mathematics*
Professor of Geology and Applied Science,
Yale University

PIERRE WELANDER, *Associate in Physical Oceanography*
Professor, Oceanographic Institute,
University of Göteborg, Sweden

ALFRED H. WOODCOCK, *Associate in Oceanography*
Research Associate in Geophysics,
Institute of Geophysics, University of Hawaii



The new marine facilities building.



New marine facilities building and dock, ATLANTIS II (left) and catamaran LULU (right) tied up at dockside.

Grants and Fellowships

Year-Round Postdoctoral Fellows

Awarded 1969:

MARY ANN ASBELL
University of Georgia
Enzyme Institute, Wisconsin

EDWARD CARPENTER
North Carolina State University

HAN-HSIUNG KUO
Yale University

BRUCE P. LUYENDYK
Scripps Institution of Oceanography

Predoctoral Fellow

KENNETH HAINES
Rutgers University

M.I.T.-W.H.O.I. Joint Doctoral Program

Recipients of Woods Hole Fellowships and Assistantships

Academic Year 1969-70:

BRIAN ANDRESEN
Florida State

ZVI BEN-AVRAHAM
Hebrew University, Israel

JOHN L. BOWEN
Northwestern University

RICHARD BURROUGHS
Princeton University

DANIEL P. CHARNEWS
New York State Maritime College

THOMAS G. CURTIS
Massachusetts Institute of Technology

WILLIAM F. FITZGERALD
College of the Holy Cross

ROBERT A. FOLINSBEE
University of Alberta

JANICE GLENDE
Winona State College

RONALD C. GULARTE
University of Southern California

EDWARD LAINE
Wesleyan University

HEAU MA
Oregon State University

JOSEPH MACILVAINE
University of California, Berkeley

KENNETH MOPPER
Queen's College, New York

JAMES W. MURRAY
University of California, Berkeley

HENRY T. PERKINS
New York University

BARBARA RAY
University of Hawaii

PETER C. SMITH
Brown University

WILLIAM G. SUNDA
Lehigh University

Summer 1969 Only:

BRADFORD BUTMAN
Cornell University

DONALD W. FORSYTH
Grinnell College

BRUCE GORDON
University of Chicago

JOHN RICKARD
Florida Institute of Technology

BRIAN E. TUCHOLKE
South Dakota School of Mines

CHRISTOPHER WELCH
Wesleyan University

Summer Student Fellows

Awarded 1969:

JUDITH ANDERSON
Radcliffe College

ROGER ANDERSON
University of Oklahoma

EDWARD BELL
Washington & Jefferson College

BARBARA-JO BUCKINGHAM
Miami University

REINHARD FLICK
The Cooper Union

MICHAEL FULLER
Harvard University

BYRON HARTUNIAN
Tufts University

JAMES HULT
Stanford University

CHRISTOPHER JACKSON
University of California, Berkeley

JOHN JOHNSON
Brigham Young University

CHRISTIAN LAMBERTSON
University of Pennsylvania

LEONARD LION
Loyola University

ROBERT PARISER
Princeton University

ANN RANDTKE
Vassar College

RONALD REGAL
Wabash College

RONALD SHERWOOD
Washington University

JEFFREY SPENCER
Williams College

Geophysical Fluid Dynamics Seminar

Staff Members and Lecturers

JAMES L. ANDERSON
Stevens Institute of Technology
GEORGE BACKUS
University of California, San Diego
FRIEDRICH BUSSE
University of California, Los Angeles
B. R. EICHENBAUM
New York University
DOUGLAS O. GOUGH
New York University
EDWARD R. HARRISON
University of Massachusetts
JOSEPH B. KELLER
New York University
ROBERT H. KRAICHNAN
Peterborough, New Hampshire
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Oregon State University
WILLEM V. R. MALKUS
University of California, Los Angeles
LEON MESTEL
Cambridge University, England
KEVIN PRENDERGAST
Columbia University
EDWARD L. REISS
New York University
EDWARD A. SPIEGEL
New York University
ALAR TOOMRE
Massachusetts Institute of Technology
JURI TOOMRE
New York University
JEAN-PAUL ZAHN
New York University

Fellows

JEAN-LUC AURÉ
Institut d'Astrophysique, Paris, France
TERRANCE G. BARKER
Massachusetts Institute of Technology
JOSEPH M. BUSCHI
New York University
RICHARD J. DEFOUW
California Institute of Technology
ROGER F. GANS
University of California, Los Angeles
WILLIAM D. MCKEE
Cambridge University, England
PEDRO MÉSZÁROS
University of California, Berkeley
JEAN PERDANG
University of Liege, Belgium
JOHN D. TRASCO
Columbia University

Visiting Investigators

JOEL P. BRAINARD
Talladega College
KJELL EIMHJELLAN
Tekniske Universitet, Trondheim, Norway
KLAUS GRASSHOFF
Institut für Meereskunde
U. Z. BILAL UL HAQ
University of Stockholm
ELROY U. LACASCE
Bowdoin College
YUAN-HUI LI
Harvard University
SEEYLE MARTIN
University of Washington
ERNEST E. NICHOLS
University of New Hampshire
GREGORIO PARRILLA
Instituto Español de Oceanografia, Spain
ALFRED C. PINCHAK
Case Institute of Technology
BRYCE PRINDLE
Babson Institute
SHIRLEY RUBINOW
University of Chicago
MICHAEL HANS RUEFF
Universität Heidelberg, Germany
ALDIN L. WINN
University of New Hampshire

Guest Investigators

JOHN A. ALLEN
University of Newcastle-upon-Tyne, England
RICHARD S. ARMSTRONG
University of Michigan
HENYO T. BARRETO
Petrobras, Brazil
RICHARD BARTHA
Rutgers University
ALAN W. BERHEIMER
New York University Medical School
ERCOLE CANALE-PAROLA
University of Massachusetts
SNEED B. COLLARD
Harvard University
KAROLYN J. MARTIN
Massachusetts Institute of Technology
EDWARD MONAHAN
University of Michigan
RALPH MITCHELL
Harvard University
RODERICK E. MCKENZIE
University of Washington
CARL A. PRICE
Rutgers University
SAMUEL RAYMOND
University of Pennsylvania
JACK E. OLIVER
Lamont-Doherty Geological Observatory

Guest Investigators (continued)

TOMO GAMULIN
Bioloski Institut, Dubrovnik, Yugoslavia

THOMAS R. P. GIBB
Tufts University

JAMES M. KENNEY
U.S. Naval Academy

J. E. DOUGLAS KERR
University of Miami

THOMAS L. MALUMPHY
College of the Holy Cross

PHILIP B. ROBERTSON
University of Miami

FRANCIS J. SCHMITZ
University of Oklahoma

ELIJAH SWIFT
Johns Hopkins University

J. STEWART TURNER
University of Cambridge, England

AUGUST P. VAN GOOL
University of Louvain, Belgium

Guest Student Investigators

DONALD F. ALLEN
Yale University

FRANK W. BARVENIK
University of New Hampshire

THOMAS BRUSHART
Harvard University

ELLEN DANIELL
Swarthmore College

ANN MARIE DENORME
University of Louvain, Belgium

CARL A. DONOVAN
Carnegie-Mellon University

ROBERT C. ECKHARDT
Harvard University

JOHN HALL
University of North Carolina

RONALD HEDBERG
Harvard University

DAVID G. KERSEY
Harvard University

JEFFREY LIVINTON
Yale University

DOUGLAS E. MOORE
Johns Hopkins University

FLOYD W. McCOY, JR.
Harvard University

RICHARD REYNOLDS
University of Colorado

DOROTHY G. SWIFT
Johns Hopkins University

EMILIENNE VAN CAULEWAERT
University of Louvain, Belgium

ALLAN WHITE
Harvard University

Lawrence High School Scholarships

THOMAS CHASE
Oberlin College

RICHARD PANTON
Worcester Polytechnic Institute

LEON TURNER
Lowell Technological Institute

SANDRA WATKINS
Wheaton College

Visiting Scholars - Summer 1969

JELLE ATEMA
Research Associate
School of Natural Resources,
Department of Psychiatry
University of Michigan

JOHN E. BARDACH
Professor of Zoology and Fisheries
School of Natural Resources,
Department of Zoology
University of Michigan

RICHARD COOPER
Bureau of Commercial Fisheries
Boothbay Harbor, Maine

JOHN I. EWING
Senior Research Associate
Lamont-Doherty Geological Observatory
Columbia University

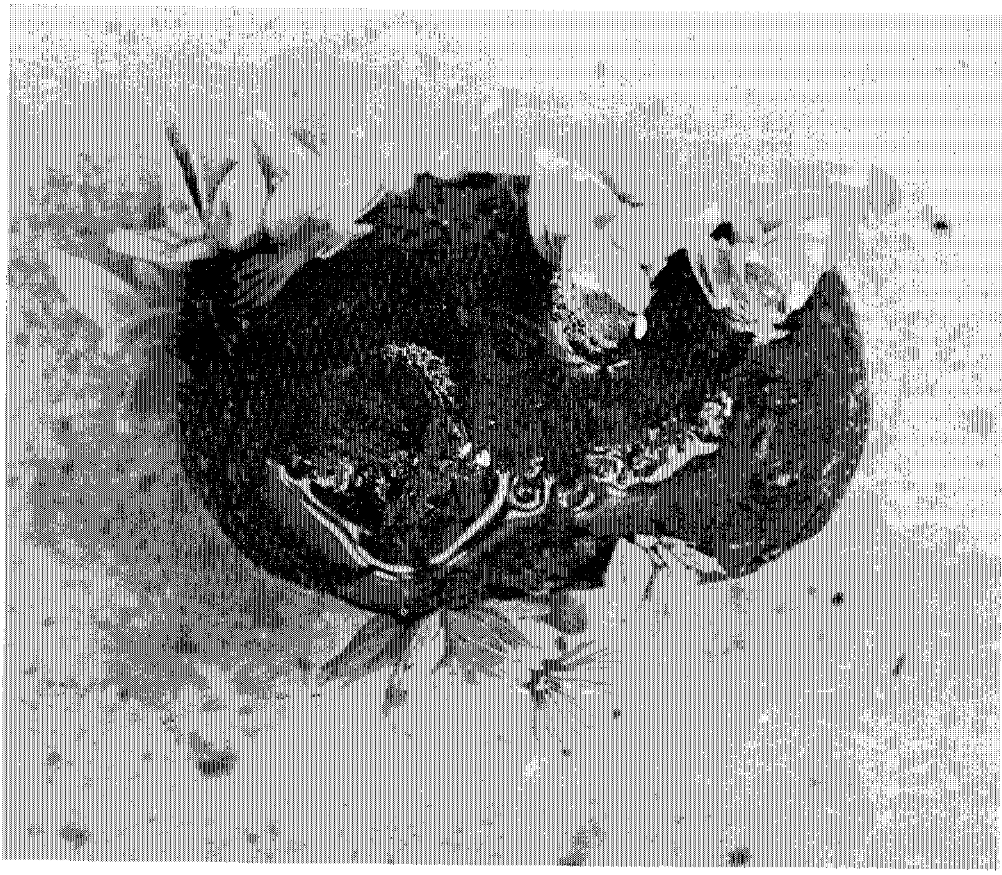
EDWARD D. GOLDBERG
Professor of Chemistry
Scripps Institution of Oceanography
University of California, San Diego

MYRL C. HENDERSHOTT
Professor of Oceanography
Scripps Institution of Oceanography
University of California, San Diego

CLAES ROOTH
Professor of Oceanography and Meteorology
Institute of Marine and Atmospheric Sciences
University of Miami, Florida

WALTER STARCK
Research Associate
Institute of Marine and Atmospheric Sciences
University of Miami, Florida

JOHN H. TODD
Assistant Professor of Zoology
San Diego State College



Lepas pectinata, a goose barnacle, growing on lumps of crude oil

Department of Biology

Microbiology

A new technique has been developed for measuring growth characteristics of heterotrophic bacteria in natural seawater. This technique is based on the calculation of actual growth rates from kinetic parameters and the dilution rate during transient state of a continuous culture using unsupplemented seawater as a medium. Continuous growth at extremely low rates has been demonstrated including mean generation times of more than four days.

Multi-stage continuous culture methods have been used to examine the step-by-step degradation of dissolved hydrocarbons, separating the sequence of intermediate breakdown products in reactors run at different dilution rates. The study includes the effects of various environmental factors (pH, temperatures, and concentrations of oxygen, nitrogen compounds, and phosphate) on the types of organisms engaged in the breakdown process and the rates of the reactions.

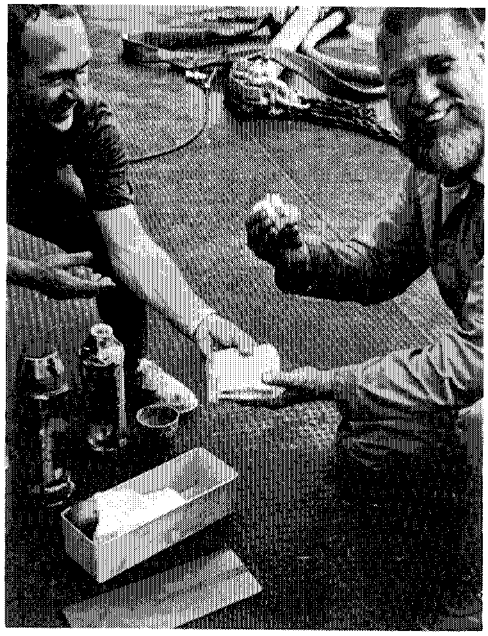
The observation that food materials carried in ALVIN were not visibly decomposed or denatured after 10 months of exposure to seawater at 5000 ft. has stimulated bacteriological investigations of the *in situ* decomposition of a variety of simple and complex organic materials in the deep sea.

From the small numbers of marine nitrifying bacteria that can be proven to exist in the deep sea (usually less than one cell per liter), it seems unlikely that any appreciable amount of nitrification occurs *in situ* in this environment. The thinking along these lines now parallels that of others for the formation of the oxygen minimum and nutrient maxima layers of the sea, that is, that most of the nitrification occurs in shallow coastal regions of high biological productivity, such as regions of upwelling. The nitrate produced in this way is then distributed in the sea by advective and mixing processes.

Comparison of ammonia- and nitrite-oxidizing bacteria from both the marine and terrestrial environment indicate that the nitrate oxidizers from both sources are morphologically and physiologically similar and may be identical. The ammonia oxidizers from the two environments on the other hand, appear to be quite distinct taxonomically and apparently cannot tolerate the conditions of both habitats, as can the former group. Three new strains of nitrifying bacteria have been isolated which appear to be capable of completing the entire oxidation of ammonia through nitrite to nitrate.

The fine structure, electron microscope work on marine nitrifying bacteria, particularly *Nitrosocystis oceanus,* has continued with the objectives to define (1) the cultural conditions which control the production of the various cell wall and membrane structures, (2) the ecological significance of such structures, (3) the molecular mechanisms responsible for the aggregation of these macromolecular subunits into such regular arrangements, and (4) the structural arrangement and composition of the layers.

Open-ocean heterotrophic bacteria have been found to be remarkably inefficient in attacking and decomposing the normal pool



"Food materials carried in ALVIN were not visibly decomposed or denatured after 10 months of exposure to sea water at 5000 ft."

of organic substrates that occur in such waters. Littoral populations occurring in coastal waters and estuaries, on the other hand, participate much more actively in the organic cycles. The relative inactivity of the former group may reflect an unavailability of the oceanic substrate or fractional inhibition of the enzyme systems of bacteria existing under sub-optimal conditions. Attempts are being made to test this latter possibility by adapting, through enrichment amplification, naturally occurring oceanic populations and thereby exploiting the diverse natural enzyme pools for the bioassay of various dissolved organic species in the open ocean.

Physiology, Ecology, and Distribution of Phytoplankton

A mutualistic interaction has been shown *in vitro* between marine bacteria that produce vitamin B_{12} and certain species of phytoplankton that require B_{12} and that excrete dissolved organic matter, which is used as a substrate for the bacteria. The most active bacteria in this symbiotic relationship are now known to be those isolated from coastal upwelling regions, regions which support dense diatom blooms. In continuing studies of the vitamin B_{12}-requirements of marine phytoplankton, some species of algae do not have an absolute requirement but their growth is markedly stimulated by the vitamin. This phenomenon may be peculiar to cold-water species of phytoplankton. Ecologically, and with respect to such phenomena as dominance and succession, the growth-stimulating property may be equivalent to an absolute requirement, a possibility that suggests care in the interpretation of experiments purported to show the presence or absence of growth-factor requirements.

The stimulatory effects of deep (nutrient-rich) water on the growth of phytoplankton have been compared with those of enrichment with artificial media of various compositions. It has been found that the availability of essential metals is altered by the presence of organic compounds synthesized and excreted by phytoplankton. Deep-ocean water apparently does not contain adequate quantities or kinds of this organic matter and must be "conditioned" by the phytoplankton organisms themselves before it acquires its growth-stimulating properties. Inorganically-enriched surface water can be rendered unsuitable for phytoplankton growth by oxidative removal of its organic fraction and deepwater can be made immediately stimulatory to growth by adding a variety of organic ligands.

The taxonomic position of several species of small greenish algae is being reexamined on the basis of their pigment composition. The presence or absence of chlorophylls "b" and "c" and xanthophyll pigments has helped to elucidate the position of these microorganisms and necessitated revision of the classification of some of those commonly used in our physiological and biochemical experiments.

In an extension of the work done at this Institution two years ago, the effects of the chlorinated hydrocarbons DDT, endrin and dieldrin were tested on the photosynthesis and growth of several species of marine phytoplankton. The results were highly variable with respect both to the pesticide and the species of phytoplankton used. In general, open-ocean species were more sensitive than inshore forms. The estuarine green alga, *Dunaliella tertiolecta,* was unaffected by all three hydrocarbons at concentrations up to 1000 ppb, while the oceanic diatom, *Cyclotella nana* (clone 13-1), showed inhibition of both photosynthesis and growth at levels of 0.1-1.0 ppb.

A new study has been initiated on the effects of nutrition on the growth and succession of phytoplankton populations, using a continuous or flowing culture system to maintain constant nutrient levels. This has included the enrichment of seawater with sewage. Steady-state populations, identical in species composition to those initially present in the seawater in nature, can be developed and maintained in the continuous culture system. The possibility of adding a herbivore (a bivalve mollusc) to the system will next be investigated in a preliminary evaluation of a possible sewage treatment-aquaculture system.

Statistical analysis of data from several oceanographic cruises has shown a close and predictable relationship between chlorophyll concentration at the sea surface, the total quantity contained within the euphotic layer, the depth of the euphotic layer, and the rate of primary productivity. These relationships have increased the value of surface chlorophyll monitoring, now possible from a ship while underway and from the air. The latter technique has been developed as a part of the Institution's "Oceanography from Space" program.

Phytoplankton distribution patterns have been determined during the past year between Panama and Peru, between Montauk Point and Cape Hatteras, and in the coastal waters of Maine. The sporadic occurrence and abundance of diatoms in these coastal areas appears to be indicative of both cold water and relatively high nutrient levels which, in turn, result from localized vertical mixing or advection.

Animal Ecology and Distribution

Detailed taxonomic identification of copepods collected by epibenthic samplers operated from ALVIN in 1968 were continued. These small crustaceans are true bottom-living calanoid copepods. Several are undescribed, others are of uncertain systematic position, and none were previously known to be restricted to a benthic habitat.

Two species of calanoids, *Eurytemora americana* and *E. herdmani,* have been successfully cultured in the laboratory and their entire life cycles and developmental stages described. Preliminary experiments indicate that DDT at concentrations of 0.01 to 1.00 ppb do not affect the hatching of eggs but induce a high mortality in the early naupliar stages of *Pseudodiaptomus coronatus* and in the copepodid stages of *Eurytemora herdmani.* In all cases toxicity was due not to DDT transfer through the food but by direct exposure to the pesticide in the water.

Veliger larvae are the dispersal stages of tropical and warm-temperature shoal-water gastropod species. The effectiveness of veligers as genetic links between geographically separated gastropod populations depends upon the frequency of long-distance larval dispersal (d) in the expression

$$d = pt$$

where p equals the probability of long-distance dispersal and t, the number of larvae from the originating population. From estimates of these variables, it can be concluded that the frequency of dispersal across the Atlantic Ocean is at least as great as the natural mutation rate.

The hypothesis that the diversity of benthic organisms is low beneath the highly-productive upwelling regions of the ocean was tested and confirmed by analysis of samples collected along a transect through the upwelling region of Walvis Bay, Southwest Africa. The extremely low diversity observed in the immediate vicinity of the upwelling is attributed to the severe stress conditions resulting from the heavy organic load and the associated low oxygen concentrations in the sediment and the overlying water. Moving away from this zone, benthic diversity increased with rising oxygen concentrations.

The shallow water benthic communities off southern New England were compared with those occurring in similar depths and bottom types in Puget Sound, Washington. The benthic diversity of the former, ex-

Susan Garner collects a daily plankton sample posed to a vigorous continental climate with high summer and low winter temperatures, was greatly reduced in comparison with that of the latter, where there is a maritime climate of appreciably less seasonal temperature variability.

Some preliminary data are available from a new study to relate the water depth and surface productivity to the biomass of the benthic fauna. In the Gulf of Mexico, an order of magnitude reduction in biomass was observed roughly for each increase of 2000 m in depth. While biomass (as wet weight, dry weight, or organic carbon) showed a linear regression on the depth of the water, the numbers of animals to depth were not quantitative. Primary productivity at the sea surface also had a direct quantitative relationship to the biomass of benthic organisms, but it was of secondary importance. The latter relationship breaks down in regions of exceptionally high productivity, where there is upwelling and where the low oxygen concentration in the underlying waters and in the bottom sediment restricts the diversity of life and reduces its total quantity.

Collections of mesopelagic fishes from the eastern Atlantic were made for the first time by our staff. These collections will contribute to the continuing study of distribution patterns in this group of fishes in the North Atlantic. Certain species of the more important mesopelagic fishes have been singled out for extensive study. These include *Gonichthys coccoi,* the most abundant fish taken in the neuston collections. In addition to the more conventional approaches, the fish parasites will be investigated in the hope that different parasitic assemblages will reveal the existence of separate breeding populations of the species.

A now familiar part of the catch in neuston (surface) net hauls is lumps of crude oil. These occur free-floating in every part of the ocean that has been sampled and are also frequently found in the stomach contents of a wide variety of fishes. Attempts are now being made to estimate quantitatively the occurrence of this pollutant in the sea surface.

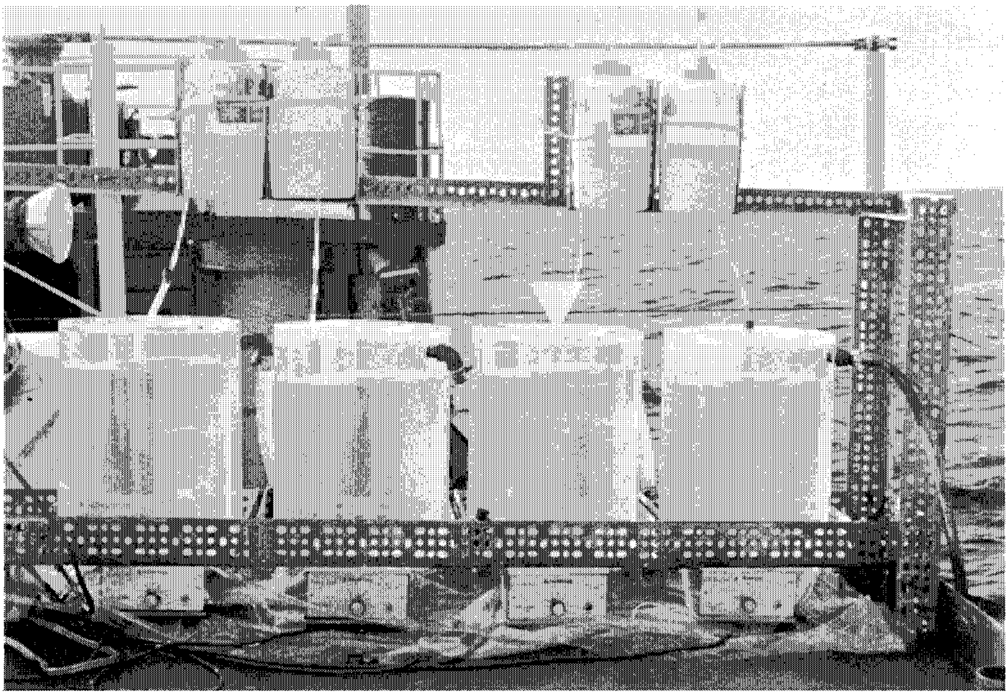
By an examination of stomach contents, predators and prey of mid-water fishes can be ascertained. One promising approach to this problem is the identification of species in the stomachs of their predators from otoliths, the hard earstones that remain long after all else has been digested.

The Institution's fish tagging program has continued to provide new information on the distribution, migration, and life history of the large pelagic game fishes, including bluefin tuna, white marlin, Atlantic sailfish, blue marlin, and greater amberjack. New records of the transatlantic migration of bluefin tuna were obtained. The greatest progress was made in understanding the habits of white marlin. Record numbers of tagged releases and their returns further defined the migratory pattern of the stock that summers off our Middle Atlantic Coast.

Physiology and Behavior

Thermoregulation in various species of fish was further documented the past year. New data on the muscle and visceral temperatures of the mako shark make it seem likely that this species can regulate its body temperature to some degree. Experiments were continued on the oxygen-binding properties of fish blood, showing that the warm-blooded species have blood whose affinity for oxygen changes little with temperature, in contrast to the normal cold-blooded species.

Direct measurements were made of the metabolic rates of small tuna swimming in a tank, both by their carbon dioxide production and their heat-loss. The two methods gave comparable results and agreed favorably with other data on fish metabo-



Comparison of deep water and sewage as enrichment for phytoplankton growth off the Bahamas aboard GOSNOLD.

lism, thus encouraging further work along such lines as an additional approach to the thermoregulation problem.

Field experiments with bluefin tuna were continued using acoustic telemetry, the attached instrument broadcasting both water and body temperature. Five fish were tracked for six to eight hours and unique records of the body temperature of normal, actively-swimming (in one case actively-feeding) fish were obtained. The water temperature data, used in conjunction with bathythermograph records, provided additional information on the depths to which the fish swam between surface excursions, these ranging from 20 to 30 meters and in one case, 50 meters.

The migrations of local herring gulls were followed during periods of low visibility. Although only a few birds were tracked, the preliminary results revealed their ability to locate their nests from considerable distances in dense fog.

Through cooperation with NASA and use of the Spandar radar at Wallops Island, Virginia, and the tracking radar at Bermuda, birds flying over the ocean were observed during both the spring and fall migration periods. During the spring most birds flew over land though many larger birds headed northeast out over the coastal waters. In the fall, many more traveled over water at considerable distances from land, large flocks leaving Wallops Island in an easterly direction and flying over and beyond Bermuda without changing course. These latter observations suggest, other than mass suicide, that the fall migration commonly involves a flight pattern much farther to the east and farther out at sea than had been previously believed.

John H. Ryther, *Chairman*
David W. Menzel, *Assistant Chairman*

R/V ATLANTIS II at Yalta in the shadow of a U.S.S.R. passenger liner built in East Germany.

Department of Chemistry

In 1969, we began a modest increase in our capability to handle the expanding programs of the early seventies — marine pollution, chemotaxis, and the Geochemical Ocean Section study of the International Decade. We now have six Ph.D. organic chemists on our staff, probably the largest group at any oceanographic facility in the country. Their expertise covers most organic chemicals entering the marine environment such as hydrocarbons which come from oil pollution and natural sources, ectometabolites which are chemicals released by marine animals into the surrounding water, pesticides and herbicides from terrestrial runoff, and organometallics from industrial wastes.

This group is closely integrated with our staff of ocean going radio-chemists, geochemists, physical and inorganic chemists. From this total staff we can now build teams to study the burgeoning problems associated with man's increasing use of the oceans both as a dumping ground, and as a source of food and minerals.

Pollution in the Marine Environment

For many years, we have carried out a program at Woods Hole on the origin and distribution of natural organic compounds in the sea with special emphasis on the stable hydrocarbons. These years of work, which have been purely basic research, have built up a valuable backlog of data which is finding extensive use in the growing concern over pollution. Obviously, we cannot understand the effects of man-derived contaminants entering the sea unless we know the nature of the compounds that are already there.

A systematic study of a C_{21} polyunsaturated hydrocarbon in the marine food chain has again demonstrated the surprising stability of hydrocarbons. Some time ago, we isolated this hydrocarbon from sea water and from the copepod *Rhincalanus nasutus*. This olefin has now been found in a large variety of marine algae. Feeding experiments with *Rhincalanus* show a direct proportion between the olefin content of the ingested algae and that of the copepod lipids. The hydrocarbon also has appeared in higher members of the marine food webs, molluscs and larger fishes such as the herring and the basking shark. This is a harmless, natural hydrocarbon. The same process, however, could pick up the stable toxic aromatic hydrocarbons now entering the sea through wide-spread oil pollution. In order to build up a more complete background picture, in advance of the anticipated increased pollution of the ocean, we are analyzing the hydrocarbon chemistry of twenty-five species of planktonic algae of the North Atlantic. Many species appear to have a unique hydrocarbon composition, possibly a sufficient marker to recognize the presence of particular algae in a mixture, or in its contribution to feeding a higher organism.

We are also analyzing the organic matter of marine bacteria since they are believed to be major contributors to organic substances in the ocean. Palmitic and palmitoleic acids account for 95% of the total fatty acids in the lipids of ammonia oxidizing bacteria. Nitrite oxidizing bacteria contain fatty acids in the range from C_{14} to C_{19} with two of them accounting for more than 80% of the total. Branched iso- and anteiso-acids are present in traces of two of the nineteen types of bacteria. Studies are continuing with the hope of establishing a base for possible chemotaxonomic distinction between different species of bacteria.

The quantity of oil carried at sea has been increasing logarithmically with a corresponding increase in spillage. Present estimates are that the 10,000 or so annual spills introduce at least a million metric tons of oil into the ocean annually. These pollutant hydrocarbons are introduced predominantly inshore and in shipping lanes. They differ from natural biogenic hydrocarbons in having a much higher concentration of toxic and carcinogenic substances. Many of these hydrocarbons have very long half-lives and tend to be concentrated in the fatty fractions of the marine food chain. So far, the public reaction to oceanic oil spills has been confined to the short-term effects of polluting recreational areas and localized biological communities. The long-term effects such as the gradual buildup of carcinogens and other toxic materials in the marine food chain are receiving less publicity. Yet, it is these effects that may render food from the sea unusable to future generations. In the fall of 1969, a spill of 700,000 liters of #2 fuel oil in Buzzards Bay, Massachusetts, demonstrated the extreme persistence of hydrocarbon compounds. The oil polluted the sediments so thoroughly over a wide area that several months after the spill, the shellfish still contain high percentages of toxic hydrocarbons that render them unfit for human consumption.

Chemotaxis

Chemotaxis is the science of communication between marine organisms and their environment by means of chemical cues. Natural chemicals in the water and those released by fish under various stress conditions (ectometabolites) are recognized through the senses of taste and smell. This activates a whole series of behavior patterns such as food-finding, avoidance of injury, social communication, migration and sexual behavior. In addition, the marine chemosensory systems are affected by the introduction of man-derived pollutants. Consequently, the overall program involves the isolation, analysis and biological testing of (1) natural chemicals, (2) ectometabolites and (3) man-derived pollutants.

The common sea-star *Asterias vulgaris* is known to approach intact oysters (*Crassostrea virginica*) rapidly, when placed downstream from them in a flow tank. During the past year, we have concentrated the chemicals from oyster tissue which are causing the attraction of sea-stars. Most of the attractiveness is in a group of highly polar heat-stable organic compounds with a molecular weight of under 700. We are currently isolating the most potent chemicals in this group with the intent of determining the structure and then exploring the attractiveness of structurally related compounds.

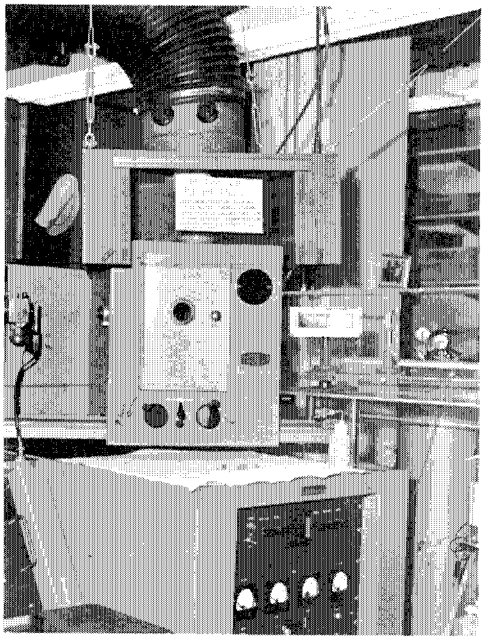
Cat fish are known to set up a rigid social system based on recognition by chemical odors. Initial studies indicate that the active chemicals are polar and extractable with butanol. They originate partly in the skin mucous material. Olfactory discrimination also causes the silver hake to move toward water conditioned by another hake and to move away from water conditioned by a toad fish. Another experiment concerns the attraction of the flat worm *Bdelloura,* to its host *Limulus,* the horseshoe crab. When the worm is allowed to choose between two sources of water, one being water which contained the crab, and the other being the same untreated water, the worm invariably moves towards the crab-conditioned water. The ectometabolite released by the crab is heat-stable, acidic, and has a molecular weight under 1,000.

In studying the effects of pollution on behavior, it has been found that the branched chain and cyclic hydrocarbons in kerosene are strong attractants to lobsters. This fraction in crude oil is one of the more resistant to biodegradation. Its presence in the marine environment may well lead to false feeding reactions that could upset the normal food finding habits of the lobsters.

Organic Matter in Sediments

Vanadyl porphyrin complexes of approximately 1100 molecular weight have been isolated from a Triassic and a Pennsylvanian oil shale. The pigments were separated into two homologous groups, one consisting of tetrapyrrole ring monomers with long chain alkyl substitution and the other porphyrin dimers. These high molecular weight porphyrins are not present in organisms or in Recent sediments. Consequently, they may provide a tool for indicating the extent of diagenesis. The more complex forms are indicative of extensive diagenesis compared to the relatively simple forms of porphyrins found in Recent sediments.

A cooperative program has been initiated with four other research laboratories to study the organic compounds in selected JOIDES cores. The purpose of this study is to survey the quantity and types of organic matter in deep sea cores and to determine their possible contribution in forming deep sea petroleum deposits.



Emission spectrometer showing excitation chamber set up to deliver light to two instruments simultaneously.

Geochemistry, Geology and Geophysics of the Black Sea

The most successful cruise carried out by the department in 1969 was a seven-week interdisciplinary study of the Black Sea. This area has long been of interest to oceanographers because of its unusual history and environment. The Black Sea is believed to be a remnant of the old Tethys Sea which existed prior to the splitting and separation of continents some two hundred million years ago. Consequently, the sediments in the Black Sea may represent a more continuous section of deposition through geologic time than can be found in the younger ocean basins such as the North and South Atlantic. The environment of the Black Sea is also unique in that it is the largest body of anoxic water in the world. From about 100 meters depth to the bottom at 2200 meters the water contains hydrogen sulphide which is deadly to all forms of life except anaerobic bacteria.

The major programs carried out on the cruise involved acoustic geophysics, gravity, magnetics, coring, heat flow, hydrochemistry, trace metals, particulate matter, stable isotopes, organic geochemistry, microbiology and bottom photography. Over fifty stations were made at which more than 1,000 water samples and 60 cores of various types were obtained. Scientists from fourteen universities and research institutions including many from abroad, participated in the cruise along with those from Woods Hole.

The geochemical program involved detailed salinity, oxygen and temperature profiles at all stations. In addition, we had on board a six-channel chemical analyzer loaned through the generosity of the Technicon Corporation. This analyzer enabled us to determine phosphate, nitrate, nitrite, ammonia, silica and total carbon dioxide. Other techniques were used to determine alkalinity, pH, and hydrogen sulphide at most stations.

At Istanbul, we visited the Hydrographic Office of the Turkish Navy under the direction of Commander Ozturgut. Later, we put into Novorossiysk and Yalta, USSR, where we visited with Dr. Ovchinnikov, Director of the Gelendzhik Institute, and Dr. Polikarpov, Director of the Biological Institute at Sevastopol, and their associates.

The preliminary analysis of the data has turned up several interesting results. The surface of the hydrogen sulphide water appears to be convex with a depth of about 75 meters in the center of the sea and of up to 250 meters along the rim. Surface and subterranean rivers and mountain streams appear to cause the increase in coastal oxygenated waters. At the interface of the oxic-anoxic waters, there is suspended particulate matter containing ten times as much manganese as iron. Apparently, manganese is going through a cycle of precipitation and re-solution as it is transported by turbulent mixing from the anoxic to the oxic layer and back. Most heavy metals have concentrations in the oxygenated surface waters comparable to open ocean values. In the deep anoxic waters, however, metals such as zinc and copper are being removed as sulphides.

Analyses of the C^{13}/C^{12} ratio of total carbon dioxide as a function of depth, showed a good correlation of δC^{13} with dissolved oxygen in the surface waters and an inverse correlation with dissolved hydrogen sulphide in the deep anoxic waters. The results suggest that some organic matter continues to be oxidized in the deep waters despite the absence of free oxygen. Presumably, this oxidation is the by-product of the bacterial reduction of sulphate to hydrogen sulphide. The results suggest that over 90% of the hydrogen sulphide in the Black Sea comes from the reduction of sulphate with the remainder from the putrefaction of organic matter. It is not yet known whether the sulphate reduction is occurring primarily in the sediments with diffusion into the water, or whether it is being initiated in the water.

Several cores taken in the Black Sea showed a remarkable alternation of grey and black sediments which appeared to be related to differences in salinity and oxidation during deposition. The Black Sea has only a 40-meter sill at the Bosporus. Consequently, it has been cut off from the Mediterranean several times in the past during sea level lowerings. Throughout most of its history, the Black Sea has been fed by several rivers which apparently converted it to a fresh water lake during periods of sea water lowerings. Significant variations in the δC^{13} of organic matter in the sediments appears to confirm the cyclic salinity changes. A rather dramatic change in the organic content of the sediments appears to accompany some of the salinity changes. For example, in the areas of slow deposition (about 10 centimeters per 1,000 years), there is a sudden increase from about 1% organic carbon to as high as 20% organic carbon occurring 7,000 years ago. Apparently, this represents a change from fresh water conditions to periods of increasing salinity. The sudden appearance of coccolithophorids about three thousand years ago, coincided with the establishment of marine conditions. An interesting part of the core studies is that the anoxic environment resulted in the almost complete preservation of organic structures. Many types of membrane structures, which are almost never found in other environments, are now being studied in detail by electron microscopy.

A comprehensive bibliography is being compiled to assist the scientific program on the Black Sea. To date, over 4,000 references have been collected and contacts are being made with the East European countries to obtain the most recent pertinent literature. A draft of the bibliography will be circulated during the August 1970 meeting on the Black Sea at which scientists from the United States and abroad will compare their results.

Radioelement Studies in the Oceans

The depth of penetration of Sr^{90} and Cs^{137} and the times of arrival of these elements at various depths in the North Atlantic, continue to fit a pattern of down-movement by both convection and mixing at high latitudes and penetration to lower latitudes principally by horizontal movement along isopycnal surfaces. An interesting contrast in penetration depth is seen by comparing a northern hemisphere station at 32° N. in the Sargasso Sea with a southern station at 28° 31′ S. in the Cape Basin in late 1968. The former showed a subsurface Sr^{90} maximum at 100 meters and about half surface value at 700 meters. The latter showed a subsurface maximum in Cs^{137} at 100 meters with about half surface value at 317 meters.

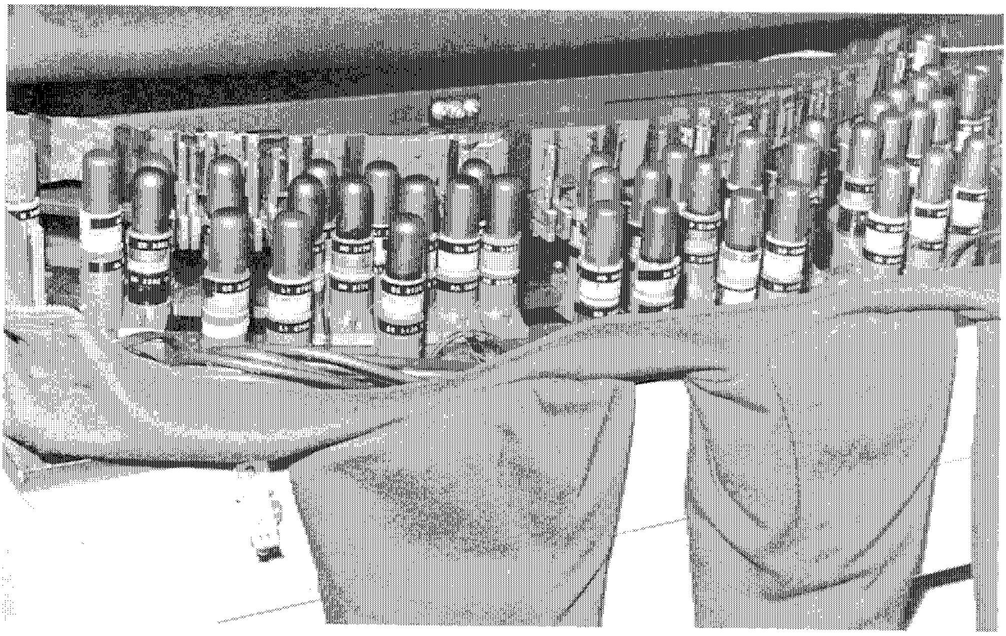
We had expected deeper fallout penetration in the southern station and are awaiting additional analyses to verify this.

A series of samples taken across the Equator from about 50° W. to 06° E. in early 1968 showed a large change in surface concentrations in Sr^{90}. Samples west of 14° W. have Sr^{90} values about twice as high as those east of the area. We believe this pattern is a reflection of an east-west difference in the rate at which deep water is brought to the surface by the interaction of the Equatorial Undercurrent and the South Equatorial Current.

Vertical profiles in the Western Mediterranean show an increase in Cs^{137} concentration from a minimum around 2,000 meters to about twice this value in the 2700-meter bottom water. Similar concentrations were observed by H. Kantsky of the German Hydrographic Office, at two western Mediterranean stations taken late in 1966.

A cooperative program involving the collection and interlaboratory calibration of three large sets of surface samples, has been initiated with the U.S. Atomic Energy Commission Health and Safety Laboratory in New York and the International Atomic Energy Agency in Vienna. The program will test both radio-analytical methods and the effect of container materials particularly for the elements Sr^{90}, Cs^{137}, Ru^{106}, Zr^{95} and Nb^{95}.

Interesting information on inter-hemispheric mixing and other fallout dispersal processes was obtained from radio-isotopes collected from over-ocean aerosols in late 1968 and throughout 1969. Sample coverage of the Atlantic Ocean has increased considerably through the generosity of the officers and crew of the Farrell Lines vessel AFRICAN COMET. It routinely collects air-filter samples between New York and South Africa. Fallout from a series of French tests carried out in mid-1968 around 22° S., 140° W., was found to have penetrated as far north as 38° N. over the Atlantic in less than three months. Such rapid inter-hemispheric dispersal of fallout debris has not



Internal view of emission spectrometer revealing exit slits and photo-multiplier tubes.

been noted in the past. Fresh fallout debris, from a southern hemisphere source was also detected in India, mid-central United States and other North American sites during this period. Apparently, these local deliveries are tied in with a complex system of synoptic conditions related to the development and deterioration of the Indian southwest monsoon system.

Beryllium 7 which has a natural source in the atmosphere, is constant throughout the year in aerosol samples at all latitudes analyzed and does not appear to have changed between 1966 and 1968.

We are investigating the possibility of using silver to trace either water or particle movements in the ocean. Background concentrations of silver in sea water are low (about 0.3 micrograms per liter). Localized increases are occurring due to the use of silver iodide crystals in cloud seeding. For example, about one ton of silver iodide was used to seed Hurricane "Debbie" in August 1969. As over-ocean cloud seeding programs increase, it may be possible to measure the dispersal and removal of silver iodide from given areas.

Our new high resolution lithium-drifted silicon, alpha detector allows us to determine plutonium (Pu^{239}) in sea-water to a concentration level of 0.00005 picocuries/liter. During the past year, we have analyzed over a hundred sea-water samples. The Pu^{239} concentration ranged from 0.4% to 1% of the Sr^{90} concentration in sea water, or about half that previously found in aerosols. We plan to evaluate its usefulness as a tracer compared with other fallout isotopes.

Trace Elements in Oceanic Rocks and Organisms

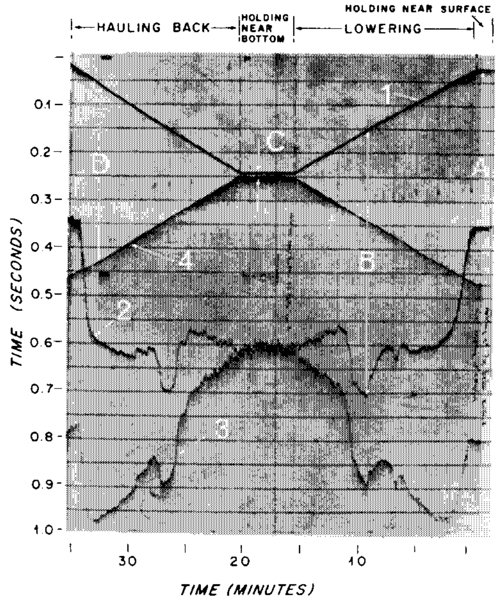
Our studies of trace elements in submarine rocks have allowed us to better understand the fractionation that can occur in layered basic intrusions in the oceanic crust. We can also speculate on the nature of hydrothermal solutions in the oceanic crust based on our analyses of serpentinized peridotites and metabasalts. For example, we believe that boron-containing juvenile solutions have been responsible for serpentinization of ultramafic rocks. Such solutions could provide replacement of the boron that is being lost by clay minerals entering the oceans, and by basaltic rocks weathering on the sea floor.

Our investigation of trace element distributions in modern scleractinian corals showed the elements Sr, Ba, U, B, Cu, Li, Zn, and Zr to be predominantly in the carbonate skeleton, while the elements Si, Al, Ga, Ti, and Cr were mainly in the detrital phases. The elements Fe, Mn, Co, Ni, Sc and Pb and the lanthanides were distributed in varying amounts between these two phases. The strontium concentration in the coral aragonite did not show the temperature dependence postulated for aragonite on thermodynamic grounds.

Dolomites Containing Organic Carbon

Variations in the stable isotope C^{13} have been used to follow natural processes involving carbon. Normally, the quantity of C^{13} is highest in oxidized forms of carbon and lowest in reduced forms. The δC^{13} values of marine carbonates normally cover a fairly narrow range near $0°/_{oo}$ relative to the PDB standard.

Dolomite samples dredged from submarine canyons off the northeastern United States were found to have δC^{13} values ranging from -64 to $+21°/_{oo}$. This range spans almost the entire breadth of carbon isotope variations in terrestrial materials. Variations in δC^{13} of more than $40°/_{oo}$ were found among samples from the same canyon. The low C^{13} content is characteristic of carbon of an organic origin and the extreme variations are most likely a consequence of differences in the extent and pathways of utilization of the organic carbon which was



Telemeter record of a deep submersible instrument which measures variations in light intensity due to scattering by minute particles suspended in clear ocean water.

incorporated into the carbonate. Dolomite formation appears to have taken place at a time of lowered sea-level when evaporation in shallow lagoons produced waters having high magnesium content.

The Electrolytes of Sea Water

We still do not know the factors that determine the relative proportions of the major salt components in sea water. Are they in equilibrium with the earth's crust or in a non-equilibrium steady state or is the composition of sea salt slowly changing with time? What are the sources and sinks of electrolytes entering the sea? Conventional analytical methods are not well suited to answering these questions because of the small variations in ionic composition (usually less than 0.5%) and the difficulties in analyzing large numbers of samples. The difference chromatograph analysis, which has been previously discussed, is a rapid precise technique for electrolyte analyses that was developed to answer these questions. The technique is capable of determining cations such as potassium in fifteen minutes with a precision that is ten times greater than that of other published methods. During 1969, we extended this technique into the anion field and made preliminary studies of ion pairing in sea water. Initial experiments indicate that the sulphate to chloride ion ratio can be determined with a precision about an order of magnitude smaller than the previous best method. A regional survey in the Gulf of Mexico showed calcium variations which appear to be related to the temperature structure. Studies of the Baltic Sea clearly showed the composition of the "fresh" and saline waters which, mixed in various proportions, form Baltic Water. We are also studying ion exchange equilibrium in deep sea sediments and in fresh water sediments of the eastern United States. We expect to learn more about the interaction of suspended matter with dissolved electrolytes as the material passes from the fresh water river environment to its ultimate destination in the ocean.

A membrane salinometer is being developed for routine use both in the field and in the laboratory. A simple modification will allow it to be used for continuous *in situ* measurement of the pore waters of estuarine sediments and other aqueous biological micro-environments. We expect the instrument to find wide application particularly in estuarine pollution studies.

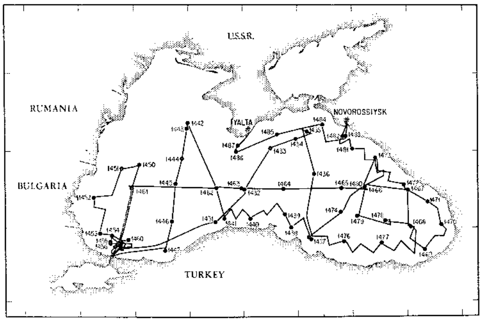
Traditional estimates of the ionic strength of sea water are in error due to the incorrect assumption of complete dissociation of all the principal sea-water electrolytes. We are recalculating the ionic strength of sea water as a function of salinity, temperature and pressure on the basis of colligative properties and the Garrels-Thompson chemical equilibria model of sea water.

We also have initiated a study on the mechanism of ionic fractionation at the air/sea interface. It is known that the ratio of ionic constituents in the marine aerosol differ considerably from those in its sea-water source, so we are planning to set up experiments aimed at understanding this phenomenon.

Geochemical Ocean Sections

Our department is cooperating with oceanographers in other institutions in planning and organizing the Geochemical Ocean Section study which is to be carried out under the auspices of the International Decade of Ocean Exploration, starting in 1970. The objectives and plans of the GEOSECS program have been outlined in a brochure and a series of reports which are available on request from the Department of Chemistry at the Woods Hole Oceanographic Institution. Briefly, the objectives are to analyze for a whole series of chemical entities in vertical profiles through the North and South Atlantic, Indian, and North and South Pacific oceans. The data obtained will be valuable in helping physical oceanographers design better models of ocean systems and thereby improve their understanding of air/sea interaction and weather prediction. The data also will provide needed background information to interpret the increasing effect of man's pollution of the oceans, and to understand the inter-relationship between chemical variations in the sea and the known variations in biota.

In September 1969 the initial GEOSECS intercalibration cruise was held off the coast of Southern California. Our part in the cruise involved the analyses of heavy metals in filtered and unfiltered sea-water samples from the surface to a depth of 4,000 meters. Initial results show that the concentrations of Fe, Ni, Cu, and Zn do not vary greatly with depth, although the deep water does have higher concentrations.



ATLANTIS II stations in the Black Sea, 1969

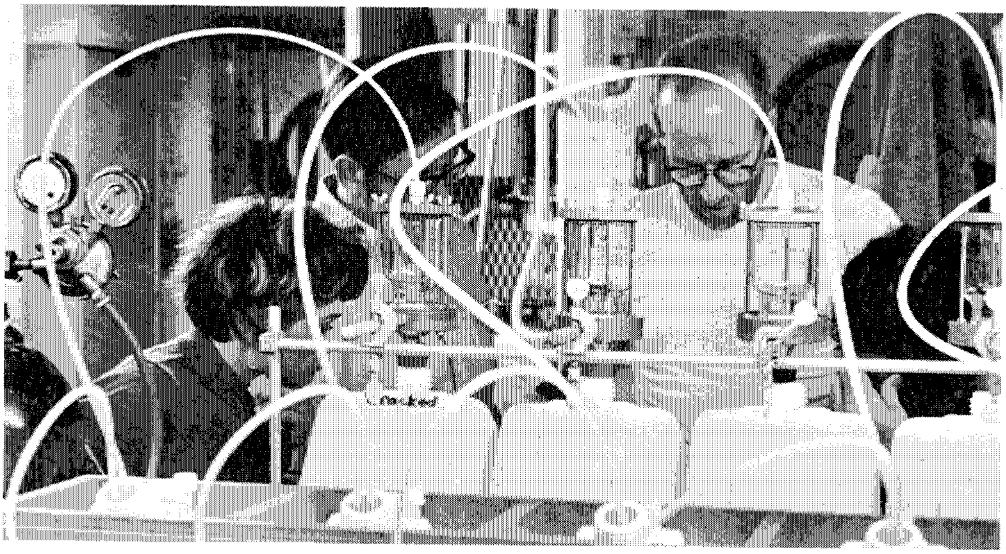
Suspended Matter in the Sea

We have developed and tested a shipboard laser nephelometer which can be used for making continuous real-time *in situ* measurements of light scattering material in the sea. To date, this instrument has been lowered at several stations from Cape Hatteras to the Gulf of Maine. A beautifully detailed profile of the variation in small angle forward scatter was obtained at each station. Large volume water samples were taken in conjunction with the scatterance measurements to obtain gravimetric data on suspended particulate matter. In general, there was good agreement between the gravimetric analysis and the light scattering measurement with the laser beam.

On the continental margin between Cape Cod and Cape Hatteras, concentrations of suspended matter were found to be relatively high at the surface, decreasing rapidly with increasing depth in the range from 20 to 200 meters. The near surface maxima appeared to be related to plankton concentrations, and to terrigenous material contributed by rivers and estuaries. This material is mostly organic. A major increase in suspended matter near the bottom was noted in most northerly deep stations. This is probably associated with bottom sediment transport in deep water since it is largely inorganic.

John M. Hunt, *Chairman*

Electron microscope view of a marine photosynthetic bacterium



Filtration of suspended matter from sea water aboard ATLANTIS II.

Department of Geology and Geophysics

Deep Sea Drilling

In 1969 the Joint Oceanographic Institutions Deep Earth Sampling (JOIDES) program completed four legs each in the Atlantic and in the Pacific. It consisted of drill holes to sample the sediments and upper volcanic rocks of the deep ocean floor. A. E. Maxwell and R. P. Von Herzen were Co-chief Scientists for Leg 3 on the GLOMAR CHALLENGER in the equatorial Atlantic between Africa and South America. The principal geomorphic provinces traversed were the Sierre Leone Rise, the Rio Grande Rise and the Mid-Atlantic Ridge. Not only did these observations further substantiate the sea-floor spreading hypothesis, but also they confirmed a spreading rate of about two centimeters a year from the Ridge axis for the past seventy million years.

The general results thus far have been (1) the verification of the age of the ocean basement as indicated by magnetic anomalies, (2) dating the age of major buried acoustic reflectors in the ocean bottom, (3) finding pre-Cretaceous ocean basement in the western Atlantic and Pacific, and (4) the collection of samples for chemical, geological, and paleontological studies.

Funds for a 36-month extension of the JOIDES program were provided by the National Science Foundation in 1969. It is expected that there will be about equal time for drilling in the North Atlantic (including Gulf of Mexico and Mediterranean Sea), in the Pacific Ocean and in the Indian Ocean. The capability will be available shortly to re-enter a drill hole. This will permit drilling through some very hard chert layers that have prevented drill penetration on previous legs. Special heat flow equipment is being developed for use in drill holes. The Institution has members on advisory panels for the Gulf of Mexico, the Atlantic, the Mediterranean, the Indian Ocean, on the panel for paleontology and paleomagnetism, and on the executive committee for the project.

Continental Margins and Marginal Seas

Largely through continued support from the U.S. Geological Survey considerable progress has been made in understanding the eastern continental margin of the United States. Broad regional reviews have been completed of the texture and mineralogy of the bottom sediments, the role of bottom current dynamics in sediment transport, the tectonic framework and how it relates to adjacent continental and oceanic structures. New 1:1,000,000 (16 miles to the inch) bathymetric maps on five sheets have been prepared for the east coast of North America extending as far north as Georges Bank and as far south as Mexico.

Recognizing the importance of the coastal shelf as a zone of increased use and interest, an examination of the sea-floor geology has been focused on the Jeffreys Quadrangle in the western Gulf of Maine. Data collected on cruises of the R/V VERRILL, the R/V DOLPHIN and the R/V GOSNOLD have allowed a finer scale delineation of sediment thickness, texture, and structure through use of the depth recorder, 3.5 kc profiler, air gun seismic profiler, magnetometer, and the collection of bottom samples.

Less extensive special surveys have also been made of the sediment types of the continental margin south of Long Island, of cores from the Grand Banks, of source of sediments in the Gulf of Panama, of contour currents in the Weddell Sea, of the shelf off Florida with the submersible BENJAMIN FRANKLIN, of bathymetry, sediments and structure in the Black Sea. Geophysical data were obtained in the Caribbean off the north coasts of Panama and Columbia on ATLANTIS Cruise 54 in December.

In the past year a book, *Hot brines and Recent heavy metal deposits in the Red Sea,* was published. It is an up-to-date and thorough compendium of the geology, geophysics, geochemistry, and oceanography of the Red Sea area based largely on the survey made in 1965.

A cooperative undertaking with groups in Italy to last several years was initiated to explore the geology and geophysics of the Mediterranean. A survey of the Tyrrhenian Sea over a period of four months was the first step. Most of the equipment, personnel, and the ships were supplied this past year by our Italian colleagues.

Foraminifera and Dinoflagellates

The distribution of the planktonic Foraminifera have been helpful in delimiting the zonation in the Cenozoic and the development of a micropaleontological time-scale for this geologic time. This time-scale has already been of great value in dating the long cores obtained on the GLOMAR CHALLENGER. Similarity of benthonic foraminiferal patterns for North Africa and for the Gulf of Mexico, Caribbean, central and northern South America during different geologic periods contributed greatly to our understanding of sea-floor spreading and continental drift in the North Atlantic. This paleontological evidence strengthened that obtained by geophysical methods. It is difficult to overestimate the importance of the Foraminifera in the reconstruction of paleo-oceanographic, paleo-ecological and paleo-geographic conditions for the last 200 to 300 million years of the earth's history.

The basic problem of the relationships that exist between fossil dinoflagellates (and hystrichospheres) and their living representatives was examined with reference to *Spiniferites, Leptodinium,* and *Tuberculodinium.* In 1965 several modern dinoflagellates were found that secreted a mineralized calcareous cyst. Prior to that time only fossil calcareous dinoflagellates had been known. Now new examples of calcareous cysts have been identified and germinated *in vitro*. The general distribution of dinoflagellate cysts will be established as a result of recent sampling in the Mediterranean Sea and in the North Atlantic off Africa. Other samples have been collected off the coast of Peru and in the Black Sea.

The acquisition of a scanning electron microscope within the year will be a valuable facility to further the work in micropaleontology and for the Institution as a whole.

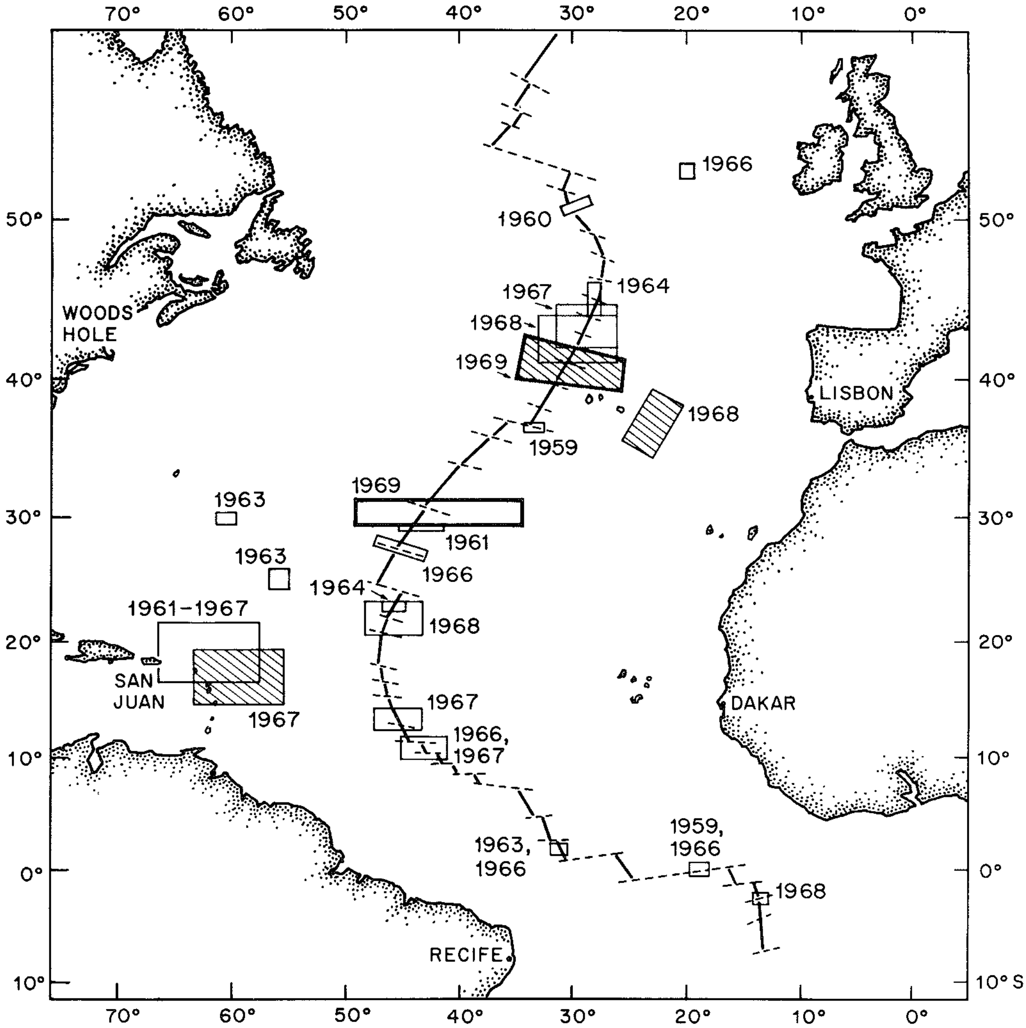
Tectonics of the Ocean Floor

The concept of sea-floor spreading has continued to dominate the work of the ocean basins and the mid-ocean ridges. A special magnetic survey over the Mid-Atlantic Ridge was made by the C54Q aircraft, just north of the Azores, in June. On CHAIN Cruise 96, in December, the entire array of geological-geophysical instruments was used in examining an area of the Mid-Atlantic Ridge crest at about 30°N. Less dense magnetic data over the Ridge crest, between 8°N and 24°N, was the basis for an attempt to determine the nature of spreading in this important area opposite the Caribbean Island Arc.

Aeromagnetic traverses of the North Atlantic east of the Caribbean Lesser Antilles had been completed earlier by the C54Q aircraft. Now these data, added to those gathered aboard ship, yield the first comprehensive structural knowledge of this little known part of the Atlantic. The Barracuda Rise, an east-west trending feature at 17°N, separates two structurally different sections of the oceanic crust. South of the Rise the linear magnetic anomaly pattern is not very distinct. In this area, however, continuous seismic profiler records reveal the Atlantic basement underthrusting the island arc on the east. The Aves Swell appears to be structurally similar to the Antilles Arc and may be a remnant island arc. To the north of the Rise the magnetic anomaly pattern nearly parallels the Mid-Atlantic Ridge axis 1200 kms to the east. From 1968 CHAIN and other data it has been possible to examine the structure of the Puerto Rico Trench and the Antilles Outer Ridge. Although the Trench has been the subject of many geophysical investigations it is now known that this area north of Puerto Rico has a different structural origin from that north of the Barracuda Rise.

In November on ATLANTIS II Cruise 54 important geothermal traverses were made of the East Pacific Rise crest near 7°S latitude to explore the variability of the thermal flux over area's size. With other values previously obtained in the same region, it is now known that the entire region southwest from Panama to the Rise crest is one of generally high heat flow, ranging from 1.5 to 6 times that normally encountered. Detailed measurements at some localities indicated a large variability over small (i.e., a few kilometers) horizontal distances superimposed on this generally high background. While the high average values have their source in the earth's mantle, much of the local variability is correlated with local topographic and sediment distribution.

For the North Atlantic a reconstruction of bordering coastlines has been made and a history of the opening of the North Atlantic Ocean has been illustrated. A rotation of plates is described which is in agreement with continental paleomagnetic, marine geophysical and marine micropaleontological evidence. Marine geophysical and continental paleomagnetic data are now sufficient in the southern hemisphere to describe the breakup of the super-continent called Gondwanaland. The evolution of the southern oceans, previously outlined only for South America and Africa, can now be described in its entirety.



Areas recently studied on or near the Mid-Atlantic Ridge. Cross-hatched areas were the sites of aeromagnetic surveys.

Gravity Field in the Black Sea

The general bathymetry of the Black Sea indicates a single deep located in the approximate center of the sea, but the free-air anomaly and the simple Bouguer anomaly contours suggest separate structures for the eastern and western portions. An east-west trending Bouguer high across the southern tip of the Crimean Peninsula is not revealed on either bathymetric or free-air anomaly charts. A comparison of the Bouguer anomaly contours with Russian results from deep seismic sounding suggests a correlation of 25 mgal change for 6 km relief of the Mohorovičić discontinuity. This implies a density contrast of slightly less than 0.1 gm/cm^3 between the lower crust and upper mantle. A dense lower crust is also indicated by the agreement between depths to "Moho" obtained by deep seismic sounding and those derived from an empirical curve. This agreement seemingly suggests that the high density lower crust compensates in part for the overlying thick section of low density sedimentary rock.

The coastal portions of the greater Caucasus mountains and the marginal portions of the Black Sea have lower anomalies than do regions in isostatic conditions. The areas of gravity highs in the Black Sea are closest to being in isostatic equilibrium. An uplift by a thrust fault may have carried the Crimean mountains to the south over the northern margin of the Black Sea. Thus the axis of a negative free-air anomaly south of the Soviet Union may be the site of a thicker accumulation of sediments due to a downwarping of the crust in front of a thrust fault. Consequently, the free-air anomaly lows near the margin of the Black Sea may be indicative of deformation of the Black Sea Basin in its early stages, a deformation which will probably continue as this region undergoes compression.

Marine Acoustics and Related Studies

The major at-sea acoustics experiment was a cooperative one with the Naval Research Laboratory and with the Admiralty Underwater Weapons Establishment of Great Britain in the eastern North Atlantic. Long range sound is usually transmitted at the depth of the minimum in the vertical sound velocity profile. However, in the eastern North Atlantic this profile has two minima. The acoustic experiment was designed to ascertain how this unusual situation affects long range sound transmission. Data were processed on board with digital and analog computers. There were accompanying theoretical studies to sort out the various sound arrivals and sound-field regimes from impulsive type sources. Other theoretical investigations considered the frequency dependent ray theory especially as it relates to the turning point phenomena of rays.

Analysis of the data acquired, in 1968, on shallow-water sound transmission in the

Elizabeth T. Bunce, as Chief Scientist aboard CHAIN

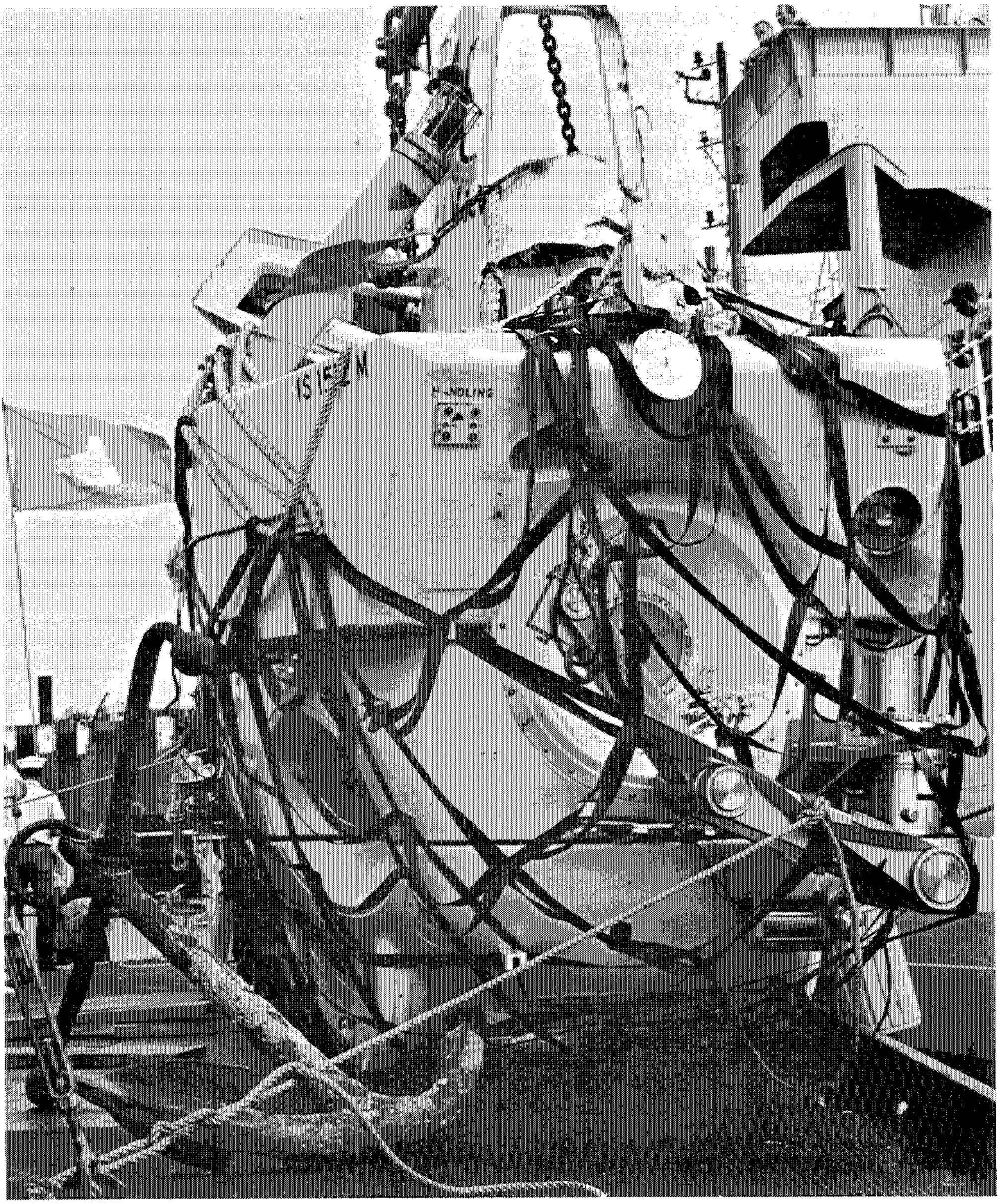
English Channel and on bottom reflectivity is nearing completion.

In May and June measurements were made of acoustical scattering due to biological origin. These measurements taken along with mid-water biological trawls are being examined to relate acoustic scattering at various frequencies and various ranges to the appropriate distribution of marine organisms at any time.

In March and April sound velocity measurements were made over a large portion of the Sargasso Sea with a very accurate digital velocimeter. These together with simultaneous measurements of the temperature distribution are being used to learn about the dynamics and eddy circulation of oceanic water masses. Other questions in the Sargasso Sea area concern the passage of weather fronts and hurricanes (Hurricane ALMA, in 1966) as they affect the air and sea water temperatures with time.

In April and May, near Japan, the calls of a coastal porpoise, *Neophocaena,* and other animals were recorded against a heavy background of diesel-powered small boat noises. An analysis has also been made of the radiated sound field from the Antarctic seal *Leptonychotes.* This is significantly different from that of some porpoises.

JAMES R. HEIRTZLER, *Chairman*



ALVIN returns after wintering at 5000 ft.

Department of Ocean Engineering

This was a year of beginnings, of progress, and of success. ALVIN was recovered from the sea, a SOFAR Probe was successfully deployed, and engineered buoy moorings proved themselves in tests at sea. These are examples from many projects in which the department has supported science and furthered engineering at the Institution. In the spring the Joint Graduate Education Program in Ocean Engineering with the Massachusetts Institute of Technology was ratified and three students were admitted in the fall. This was a beginning, one that will have far-reaching consequences for the Institute and the profession.

Information Processing and Analysis

The past year was a period of consolidation and operational smoothing for the on-shore computing activities and one of greatly increased activities for sea-going computer efforts. For the shore computer, system modifications were more important than hardware changes; for the sea computers, hardware changes were the outstanding features. The first full year of Sigma 7 use was marked by continual improvement in the operating systems. The original monitor supplied with the system was changed three times: each new monitor furnished an improvement in the speed with which programs operate, better diagnostic output for programmers and much better control by operators. Hardware changes included the elimination of the paper tape input unit to the Sigma 7 and the replacement of the six million character capacity with disks of twelve million character capacity. Paper tape input is now accomplished by a conversion to magnetic tape through the PDP/5 computer. This computer also drives the Calcomp plotter and is used for reading current meter tape cassettes and converting the data to computer tape.

Construction of a high-speed, analog-to-digital converter was completed and is on-line with the Sigma 7. It was built in response to needs for acoustical analysis but is applicable to other work. Magnetic tape cleaning equipment was added and a new system for routine maintenance of magnetic tapes was initiated.

Scientific computing accounted for about ninety-five per cent of the effort with the moored buoy project still being in the lead. Institution business use continued to grow with additional accounting, personnel and purchasing applications. For the first time, student computer use has become an appreciable factor as a result of the increased educational activity at the Institution.

Three major cruises were equipped with computers and satellite navigation receivers. A new shipboard computer was acquired and the memory increased on another. There are now two 16,000-word and one 8,000-word general-purpose sea-going Hewlett-Packard computers on hand. The Institution has one Magnavox 702-CA satellite receiver and shortly expects delivery of two 706 receivers with internal computers. As the complement of available equipment increases, the capability for on-line data acquisition and for shipboard scientific computing will become standard for all cruises.

Deep Submergence Engineering and Operation

When the year opened, ALVIN rested on the bottom of the ocean at a depth of 1520 meters, 190 kilometers southeast of Cape Cod and R/V LULU was moored at the institution. Exhaustive tests were conducted to determine the cause of the failure of LULU's hoisting system which had resulted in the loss of ALVIN. These tests pointed to corrosion of the lift cable from exposure to salt water over a long period of time as the chief reason for the break. There was no evidence to indicate that a concurrent hydraulic failure was directly related to the cable break. The report of a special investigating committee on the loss of ALVIN containing this finding was delivered to the Institution and to the Chief of Naval Research in July.

ALVIN disassembled outside the warehouse.

At the Institution's request the Naval Research Laboratory conducted a photographic reconnaissance of the ALVIN loss site with U.S.N.S. MIZAR in an attempt to learn more about the condition of the "lost" submersible. An excellent set of pictures obtained by MIZAR's unique camera system showed ALVIN intact on the bottom as anticipated. Subsequently the decision was made to attempt a recovery. In July, the Office of Naval Research asked the Supervisor of Salvage to carry out the difficult task. The Supervisor assembled a task force consisting of MIZAR, CRAWFORD, and DSV ALUMINAUT supported by M/V STACEY TIDE. After pinpointing ALVIN's location with towed cameras, MIZAR planted a buoyed recovery "clump" within 200 feet of ALVIN. After an unsuccessful attempt on August 17, ALUMINAUT placed the recovery toggle bar inside ALVIN's pressure hull on the 28th. ALUMINAUT surfaced and MIZAR lifted ALVIN to within 80 feet of the surface. Navy divers subsequently placed a lift bridle around ALVIN and she was towed toward Cape Cod. At Menemsha Bight, Martha's Vineyard, the submersible was lifted from the water and taken to Woods Hole on September 1st. ALVIN has since been completely disassembled and preserved. It has been impossible to rebuild ALVIN immediately due to funding limitations, but a slow restoration is proceeding awaiting delivery of SEA CLIFF. There is an indication that a titanium hull from the Navy's project TITANES will be installed by 1972.

A major modification of R/V LULU, funded by the Office of Naval Research, will enable her to support heavier submersibles. Her new submarine-handling system is rated for a 50,000-pound submersible.

In March an agreement was signed by the Office of Naval Research with the Naval Ship Systems Command for the joint use of R/V LULU as operation and logistic support for SEA CLIFF and TURTLE through June 1970. The Institution will be responsible for the surface support of both submersibles and for the initial operational training of the Navy crew for TURTLE. Under the sponsorship of the Office of Naval Research, the Institution will operate SEA CLIFF for the advancement of ocean science and engineering. A temporary facility has been established in West Palm Beach, Florida, to support these operations. Much of the activity in deep submergence has thus been directed toward the receipt and operation of SEA CLIFF and the carrying out of our responsibilities in the joint operations with TURTLE. At present, LULU is undergoing preparations for the cruise to southern waters to tend the Navy's new submersibles.

Instrument Engineering

Advanced instrument development moved forward along many lines. Important was the initiation of a successful program for the accurate, *in situ,* fine-scale measurement of the physical variables of ocean water, the design, construction, and trials at sea of a free-fall electromagnetic current meter, and the tracing of the trajectory of a neutrally buoyant Swallow float transmitting via the deep sound channel to shore-based stations. Exploitation of the vertical current measurement technique continued in the Mediterranean and a new internally recording instrument was readied during several cruises in 1969. A new design of the Autoprobe was likewise completed, and will be used in the field in 1970. An inverted echo sounder and recording system was built and operated near Bermuda to monitor continuously variations in the depth of the main thermocline. The trajectory of the path of a falling mooring line and anchor was obtained with an existing array of submerged hydrophones. Significant improvements were made in the data handling and recording system of the Richardson current meters, the plotting of VLF navigation data, and the analog input to the Sigma 7 computer.

Buoy Engineering

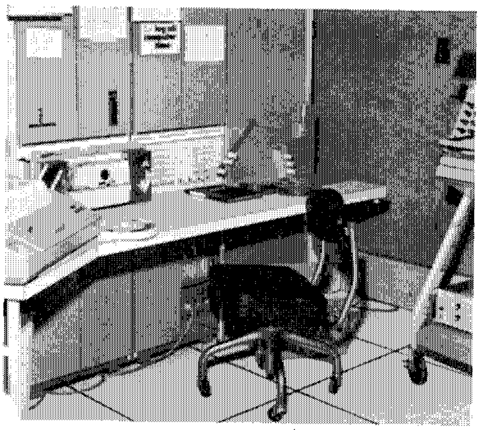
The objective of the buoy engineering program is to provide a more reliable, long-life anchored buoy system in support of the scientific work. The systematic evaluation of buoys and mooring components during the past year revealed deficiencies in certain elements. In the laboratory significant information was gained on the operational properties of wire rope as a mooring-line element. The forces acting on the moorings experienced in the deep-sea were measured by recording tension and acceleration at several points along the line. Measurements of tension during deployment and anchor drop provided data useful for future designs.

Twenty test moorings were deployed at an unprotected site seven and one-half miles south of Cuttyhunk, Massachusetts. Two identical samples of ten different wire-rope specimens were exposed. From these tests, important data on fatigue and corrosion resistance were obtained. Fifteen of the more satisfactory lines were then anchored in the open ocean at sites D and L in regular compound moorings. Two additional lines were set near Bermuda. With the exception of three moorings presently at sea, all were recovered after two to four months on location. Emphasis in the coming year will be on an extension of the useful life of the moorings from four to six months.

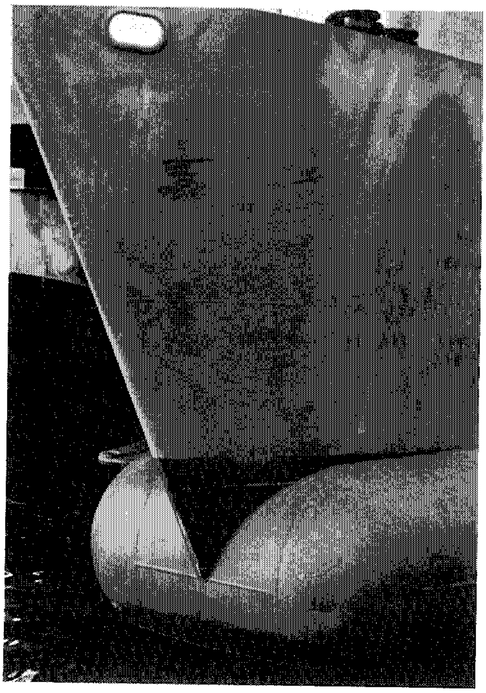
Analysis programs were refined for the computer which simulate the environmental forces, the resulting strain and the displacement of the deep-sea moorings. These programs have enabled us to improve the designs and to determine the resulting safety factor of the system.

A telemetry buoy anchored at Station D for two months transmitted environmental data including mooring tension every four hours. Over 400 transmissions were received at Woods Hole during this period. Telemetry tests from Site L indicated that our present frequency and transmitter power is satisfactory during the night hours for this range.

Intensified efforts have been made to determine the extent and severity of fishbite damage to our mooring lines. Special moorings have been set south of the Gulf Stream,



Computer center



One of LULU's new bows.

where such damage has occurred, to record its severity as a function of depth. Various armoring materials for synthetic ropes were evaluated and the investigation is continuing.

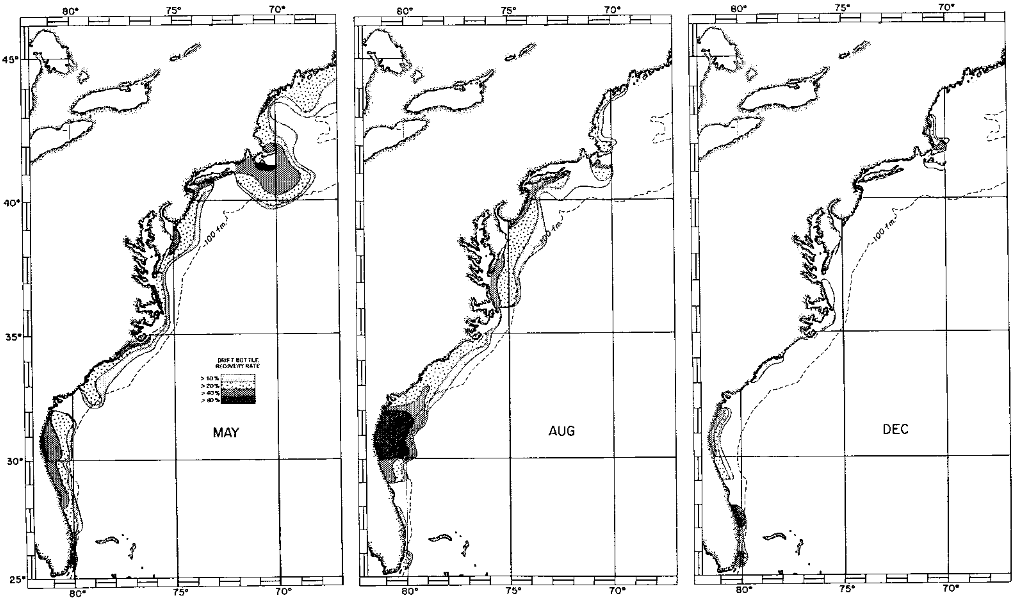
VLF/Omega/Satellite Navigation

VLF/Omega provides coverage throughout most of the world, either in circular or hyperbolic mode systems, and true continuous navigation may be achieved when the VLF/Omega is coupled with Satellite navigation as an up-date system. The satellites pass at specific intervals with approximately fifteen per day having good elevations. An essential element to the Satellite navigational system is the proper input of ship speed and course which is readily obtainable from VLF/Omega. Long-range navigation is essential to world-wide oceanographic research work and meaningful scientific measurements for the most part depend on precise navigation. VLF/Omega appears to satisfy more nearly the requirements; hence, the goals of this investigation are to provide continuous navigation in longitude and latitude to 0.5 nautical mile for oceanographic vessels, direct plotting of ship track in X-Y recording from VLF/Omega for station keeping and surveys, and geographical positions from Omega with the shipboard computer.

During the past year, several significant developments have been accomplished in the VLF/Omega and Satellite navigation systems used on aircraft and ships of the Institution. In June 1969 the C54Q made six flights out of Terceira, Azores, conducting a survey of magnetic anomalies of the Mid-Atlantic Ridge area; this required precision navigation. A hybrid VLF/Omega/Satellite system which continuously gave latitude and longitude readouts at one second intervals was used operationally for the first time on any aircraft. This system was a joint program of the Applied Physics Laboratory, Johns Hopkins University (APL/JHU) and Woods Hole Oceanographic Institution. A ground monitor was operated during each flight to obtain sky wave corrections. The APL/JHU Satellite navigator provided periodic automatic updates to the navigation during the flights.

On R/V CHAIN cruise 96 as a part of Project NEAT, Omega and VLF were separately used with an AN/SRN-9 Satellite navigator which was on loan from the Applied Physics Laboratory of Johns Hopkins University. The navigational achievements on this cruise were (1) continuous Omega navigation having a manual update with the satellite system, (2) digital presentation of Omega centicycles within two lanes, (3) computation geographic position from the Omega readings using the shipboard computer, and (4) direct plotting of ship's track from two VLF stations by a small analog computer.

SCOTT C. DAUBIN, *Chairman*



Drift bottle recovery rate along the eastern seaboard of the United States.

Department of Physical Oceanography

Several major cruises were undertaken in 1969 in a continuing effort to increase understanding of the circulation and dynamics of the oceans. Members of the Department participated in the cooperative international program "MEDOC '69," to study the formation of bottom water in late winter in the northwestern Mediterranean. Shipboard measurements were made from R/V ATLANTIS II and six other participating research vessels supplemented by flights of the Institution's C54Q aircraft to measure fluxes in the atmosphere over the region of bottom water formation. Retirement of C54Q in December 1969 because of funding curtailments represents a significant loss of research capability within the Department. Two cruises in summer were devoted to an intensive examination of the spatial structure and short-term variations of the Gulf Stream. These, together with aerial surveys of the Stream, were carried out cooperatively with scientists from the U.S. Naval Oceanographic Office and from Harvard University. Further evidence for the abyssal flow east of New Zealand and the Tonga-Kermadec Ridge was gathered aboard the U.S.N.S. ELTANIN in October and November. A series of short trips to deploy instrumented buoys were made at regular intervals throughout the year.

North Atlantic

The deep circulation of the North Atlantic is fed by five major sources. The deepest and coldest water originates from the Antarctic and the Denmark Straits overflow. Further contributions are made from the Norwegian Sea and the surface waters of the Labrador Sea. The fifth is the saline outflow from the Mediterranean. Studies of water types and magnitudes of these deep water sources have stimulated investigation of the formation of other, shallower water masses, such as the 18°C water of the

Central North Atlantic. Estimates of the heat budget suggest that as much as twenty-five percent of the 18°C water may be replaced in an average year. A census of the volume of water types in six subregions of the North Atlantic is being prepared as an atlas to be printed by the American Geographical Society. A second atlas describing the average thermal structure of the upper layers of the North Atlantic, as determined by many years of bathythermograph observations, is to be printed in color by the U.S. Naval Oceanographic Office.

Analysis of the data collected in 1968 and earlier off the coasts of Brazil and Guiana is still in progress in an attempt to understand the tropical circulation in these waters. A cruise scheduled for 1969 to this region had to be postponed to 1970 because of the retirement of R/V CRAWFORD from active service in 1968. Interest in the area stems from the fact that it is a source of water for the Caribbean and ultimately for the Gulf Stream itself.

The circulation over the continental shelf along the eastern coast of the United States is being gradually delineated through an accumulation of time series measurements at lightship stations and observations of drift bottles and seabed drifters. Five major circulation systems have been identified from the Gulf of Maine to Florida. Factors controlling these include wind, coastal run-off and tidal mixing.

The Gulf Stream

Repeated surveys of a short segment of the Gulf Stream south of Cape Cod were carried out over a period of one month to examine the short-term changes in both space and time. The segment, about 180 km in length, was traversed at two-day intervals to examine the variations for high-frequency content. In addition, sixteen flights were made by personnel from the U.S. Naval Oceanographic Office to track the Stream with an infrared radiation thermometer. Current meters suspended 200 meters above the ocean bottom were used to relate the deep water motion to the surface Stream. Later, a second cruise was made to track drogues over an 1800 kilometer segment downstream. Analysis of the data is in process to determine the characteristics of the changes. Preliminary indications are that significant variations are to be seen at all time scales that can be resolved.

Volume transports of the Gulf Stream were estimated in 1968 and 1969 using the horizontal displacement of free-fall instruments as measured by relative VLF navigation. Estimates varied from 120 to 180 million cubic meters per second for sections between Cape Cod and Bermuda. A large variability was found for depths below 3,000 meters. The marked variations were also observed in current measurements near the bottom: changes in speed from zero to one knot with a time scale of the order of one month were obtained on the current records. These were reflected in the near-bottom currents at Site "D" about 300 kilometers to the north. It appears that a strong time-dependent flow field much broader than the Stream itself is associated with meandering of the Gulf Stream.

Mediterranean Sea

An international cooperative program "MEDOC '69" involving seven ships from four countries was carried out during February and March 1969 to describe the formation of bottom water in the Ligurian Sea. In addition to standard hydrographic observations, measurements of the vertical component of the current were made using neutrally buoyant floats. Vertical speeds of 25 centimeters per second were found during the period of active formation. Turbulent fluxes of momentum, heat and water vapor were measured in several flights over the formation region. A long series of current measurements were obtained off the Algerian coast to explore the mechanism of excitation of inertial currents. These revealed highly coherent inertial motion at all depths examined.

South Pacific

In 1967, two transpacific sections were made along 28° S. and 43° S. latitudes on the U.S.N.S. ELTANIN, a research vessel of the U.S. Antarctic Program, to explore the gross features of the South Pacific. Evidence was found for an abyssal current flowing northward to the east of New Zealand and along the Tonga-Kermadec Trench. In 1969, three hydrographic sections were made to examine the deep western boundary current in greater detail. Neutrally buoyant floats were placed across the current to estimate its speed. These floats were released in two groups which showed an average northward movement of 1 to 2 centimeters per second, although individual floats quickened to 10 centimeters per second. The spread in direction was large, indicating a complex spatial structure for the current. The data failed to show significant development of the East Cape Current off New Zealand.

Ocean Variability

Continued improvement in the techniques and instrumentation of moored buoy experiments has opened new possibilities for detecting a wide range of variable phenomena in the ocean. In 1969 a total of thirty-four deep-sea moorings were deployed in a variety of scientific and engineering experiments. A number of simultaneous wind and surface current measurements collected in 1969 and earlier were analyzed to determine the relationship between local wind variation and the generation of inertial currents in the mixed surface layer. Good agreement was obtained between measured and computed currents under strong generating conditions. Inertial currents as high as one knot have been observed at Site "D". The deep water at this same locality contains current fluctuations with time scales of about one week that appear to be related to the sloping bottom. Tests are being planned to examine the effects of bottom topography in more detail.

Electromagnetic effects induced by ocean currents flowing through the earth's magnetic field can be used to estimate the vertical profile and total transport of currents in the ocean. Free-fall and fixed instruments are under development to sense the horizontal electric field. A free-fall instrument has been tried with very encouraging results. Detailed vertical profiles of the horizontal current in the Gulf Stream were obtained during field trials.

Laboratory experiments on resonant internal wave interactions have progressed in 1969. An unexpected result is the simultaneous generation of many resonant triads with single mode forcing. The result suggests the ease with which energy is transferred among internal waves. These studies aid in understanding the mechanisms by which energy is supplied and distributed among the continuum of internal waves observed in the ocean.

Air-Sea Interaction

The small and medium scale structure of the temperature field in the surface layers of the ocean has been examined with an airborne radiation thermometer for the Shelf and Slope Water south of Cape Cod. Persistence of the temperature structure ranged from one day for length scales of fifteen kilometers to ten days for 100 kilometers. Data are being collected to compare the spatial variability to temperature and current measurements made from a mooring at Site "D". It is also hoped to determine the parameters that affect the absorption of solar radiation and to examine its spatial and temporal distribution.

A series of thirteen flights were made in the trade wind region east of Barbados in support of the multi-agency program "BOMEX". Measurements included turbulent fluxes of momentum, heat and water vapor as well as solar radiation, clouds and sea surface temperatures.

Marine Geodesy

The work in marine geodesy is motivated by the basic need in physical oceanography to know the gravity potential of the sea surface and its changes with time. Such knowledge would not only improve understanding of the general circulation but provide an approach to the problem of eustatic change in sea level. Present efforts have been directed toward the measurement of the figure of a marine equipotential datum by astrogeodetic and gravimetric techniques. Special equipment for measuring the magnitude and direction of gravity at sea has been developed for this purpose.

"Measurements of the vertical component of the current were made using neutrally buoyant floats" (p. 55).

Techniques are also being devised which permit the slope of the physical sea surface to be distinguished from that of the equipotential surface. These techniques include direct optical measurement from shipboard — a slow and difficult method — and the possible use of Very Long Base Line Interferometry. Either or both of these shipboard techniques can provide the "ground truth" needed for the orbiting altimeter proposed to the NASA as an effective means for the study of the dynamical and radiative regimes of the world ocean.

Aerospace Oceanography

Observations of the distribution patterns of phenomena in the upper layers of the world ocean are rapidly becoming available due to development of more sophisticated remote sensing instruments mounted in earth-orbiting satellites. During the next decade these efforts are scheduled to be much expanded by several government agencies. In order to evaluate these methods fully it is necessary to compare the data on a quasi-real time basis to data acquired by more conventional means such as ships, buoys and aircraft. This is a prime objective of the air program which combines a number of interrelated projects.

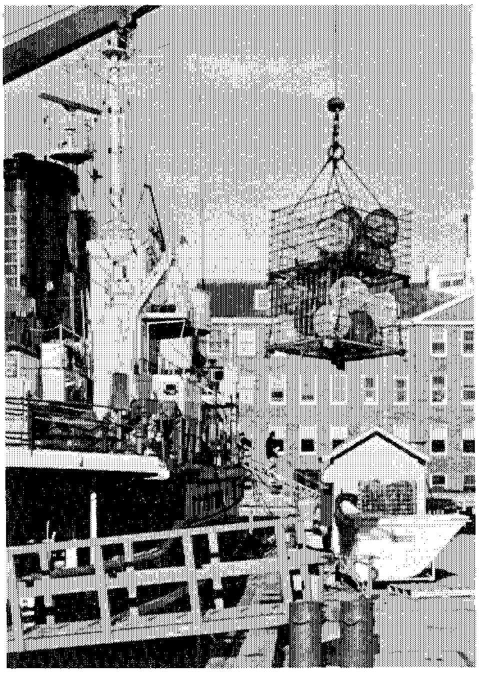
A Data Center has been established to acquire synoptic oceanographic data from all available sources. At present, this is limited to that provided by the U.S. Naval Environmental Data Net of the Fleet Weather Service. Analysis of ship reports are received over a telephone data link from the Fleet Numerical Weather Facility, Monterey, California. This information includes many oceanographic products in addition to world-wide meteorological reports.

Sea surface temperatures, currently being measured by infrared radiometers mounted in operational satellites, give daily coverage of the cloud free areas of the world ocean.

Unfortunately, many of the most significant areas, such as storm centers and regions of strong upwelling, are usually obscured by clouds. Two alternative methods for filling in these lacunae are being pursued. One method utilizes passive radiometers operating on the S-band in the microwave frequencies which, as in the case of active radar, can receive signals through shallow stratus in the absence of heavy rain or hail. This system, being developed in collaboration with North American Rockwell Corporation, has undergone preliminary ground and flight test. The results are sufficiently encouraging so that the project has been assigned by NASA to their Langley Field facility for development and evaluation. The other approach uses the clouds themselves as indicators of areas of unusual sea surface temperatures. This method was explored in the region of the strong upwelling associated with the Peru Current using cloud imagery from the ATS-111 (Applications Technology Satellite). Results are strikingly successful in delineating upwelling areas and correlate well with results of conventional ship surveys carried out by Peruvian oceanographic vessels.

A means of discriminating water masses by differences in chemical constituents is being developed. This capability will supplement measurements of the temperature parameter now routinely measured by airborne radiation thermometry. Results obtained by means of a spectrophotometer suggest that this technique can be extended to include observations from earth orbiting satellites. It should be particularly useful in locating areas of high biological productivity when temperature contrast is not observed. It may also be useful in locating the world-wide distribution of pollutants.

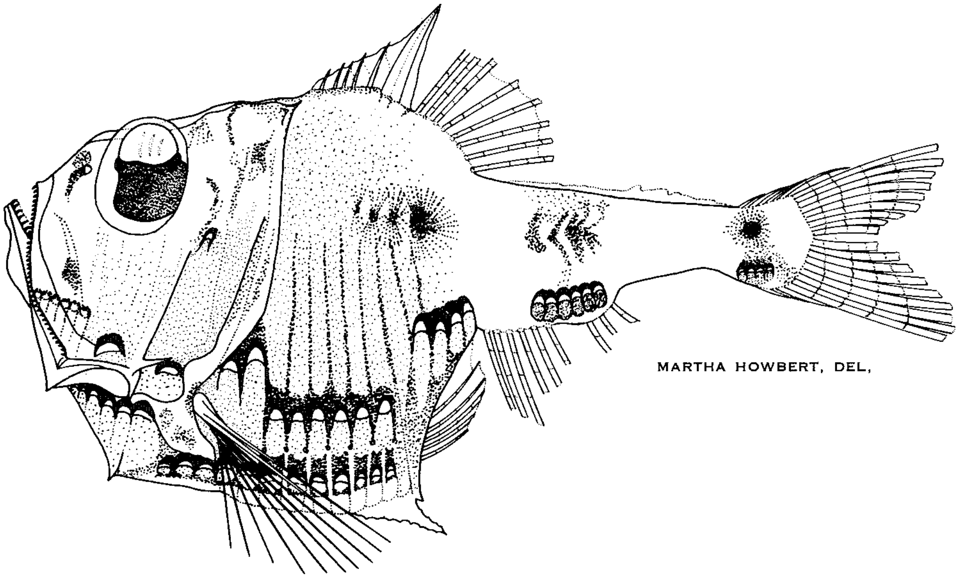
The NIMBUS II and III satellites include an IRLS (Interrogation, Recording and Locating Subsystem) which can locate and acquire oceanic data from drifting or moored buoys. A prototype buoy has been built and tested. Three more buoys are being made ready to deploy in the Gulf Stream and on the fishing banks during the next spring spawning season.



Glass spheres used in "back-up" recovery system for buoyed instruments being loaded aboard CHAIN.

Two methods were tested for direct sampling of ocean parameters from low aircraft flight altitudes. This capability is needed to increase the efficiency of flight operations by releasing the aircraft from dependence on slow surface vessels for "ground truth". One system consists of trailing a long wire from the airplane while circling. The line, properly weighted and equipped with sampling devices, stabilizes at the apex of an inverted cone in the center of the circle, the aircraft track forming a trace of the conic base. The second method consists of air dropping expendable radio transmitters which telemeter optical data. This latter system worked well and proved more suitable for operational use.

NICHOLAS P. FOFONOFF, *Chairman*



Argyropelecus hemigymnus *Cocco 1829 (30 mm standard length)*

The Helio-Courier comes in for a landing.

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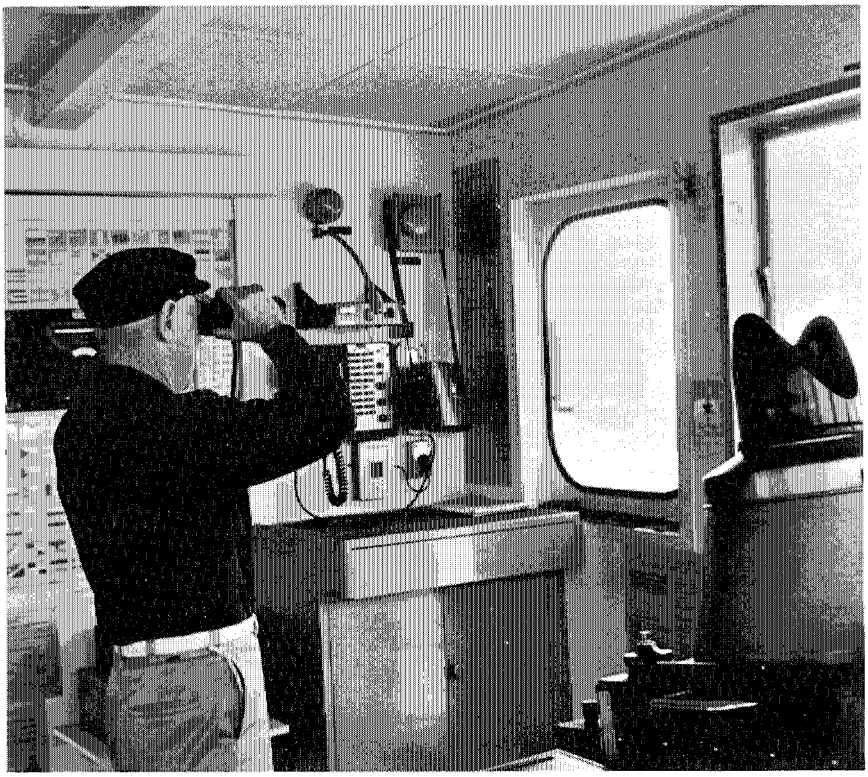
No. 2440. W. A. Berggren. Cenozoic Foraminiferal Faunas. *Initial Repts., Deep-Sea Drilling Project,* U.S. Govt. Printing Office, Vol. 1, pp. 594-607. 1969.



Edward J. Tully, Chief Mate on bridge of ATLANTIS II.

Ashore and Afloat

The Marine Services Building was occupied in the fall, marking completion of expansion plans for the pier. Marine offices were moved from the "White House" to the new building. The old frame building was then removed, and the area has been cleared and tidied so that it is no longer a fire hazard. The Marine Services Building now contains the offices of the Marine Superintendent, the Marine Electrician, the Port Engineer, the Naval Architect, the Port Captain, the acoustics group, electronics group, and the shop. It also houses a transit area for loading and unloading research vessels, and a high bay with traveling cranes for large engineering projects.

Despite the apparent spaciousness on the dock, overcrowding is now so acute that seven trailers have been acquired to relieve some of the strain until a new building now being planned can be erected.

The Carriage House and to a lesser extent the Fenno House on the Quisset Campus were suitably converted to house the summer study groups of the National Academy of Sciences, under the terms of a five-year lease negotiated early in the year.

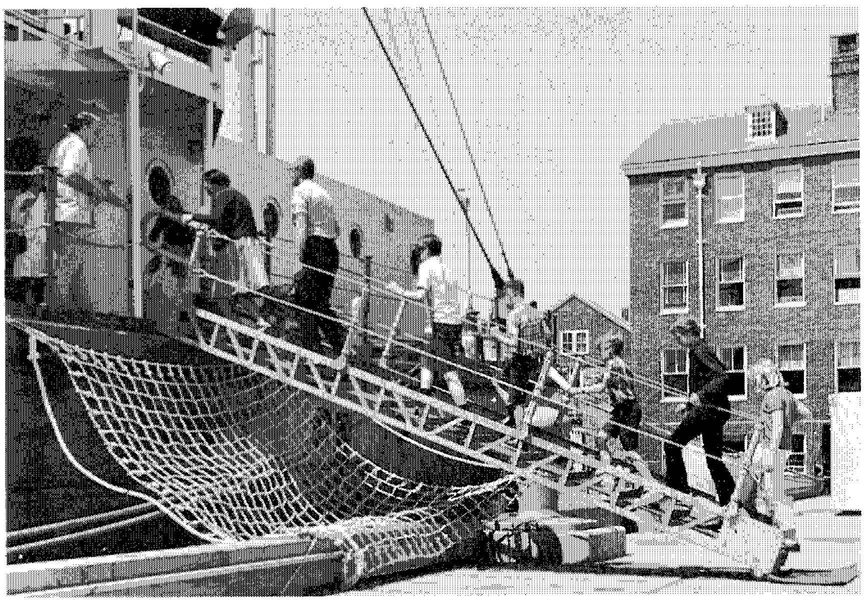
The work on salmon fisheries at the Matamek Research Station, Province of Quebec, continues to function smoothly under the guidance of colleagues from the University of Waterloo, Ontario. The first published reports are in press.

Construction on the Research Vessel KNORR (AGOR-15) continued and neared completion at the Defoe Ship Building Company, Bay City, Michigan. Although delivery was expected in the late fall, it has now been postponed to April 1970. Similar delays have plagued the completion of the new submersible SEA CLIFF.

The 65 foot VIP FLYER, belonging to Mr. Roger R. Noble of Norwell, Massachusetts, was presented to the Institution as a gift. The FLYER, rather similar to the VERRILL owned by the Marine Biological Laboratory, is certified to carry 49 passengers and a crew of three. She has an 18.6 foot breadth and is powered by a 335 horsepower GM diesel. Her hull is of steel and the deckhouse is of aluminum. She has a cruising speed of ten knots. Thus, this addition to the fleet should prove very useful.

Due to a reduction of funds it was necessary at the end of the year to dispense with the C54Q. Accordingly, certain field work in meteorology, physical oceanography, geophysics, biology, etc., will have to be indefinitely postponed. Over the years, the plane has ranged as far as the Indian Ocean, the Line Islands in the Pacific, the Mediterranean, the West Indies, etc.

For the first time in two years, an open house for the community was held in May, bringing visitors into the laboratories, the display center, and aboard the R/V CHAIN. Twenty-six states and three foreign countries were represented among the visitors.



Open house aboard CHAIN.

At the meeting of the Consultative Council of the Intergovernmental Oceanographic Commission, UNESCO, Dr. G. W. Heath (left) and Dr. A. J. Lee (right).

Visitors from Far and Near

Forty years ago, visitors from abroad were welcomed less frequently, but on the whole their visits were longer. Now almost weekly there are one or more guests from overseas arriving to discuss topics of mutual interest, such is the cooperation among oceanographers. Conferences of various kinds are almost commonplace. Perhaps the most outstanding in 1969 was the ninth meeting of the Bureau and Consultative Council of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). This was the first such meeting in the United States. There were discussions on the future development (expansion) of the Commission (IOC), especially as it will be affected by recent decisions of the General Assembly of the United Nations and other bodies. From a scientific point of view the most important and far-reaching matters discussed both formally and informally may well be the International Decade of Ocean Exploration and such services as the Integrated Global Ocean Stations Systems (IGOSS). Already the advantages of the World Oceanographic Data Centers have become evident.

The American Assembly a year ago held a conference on the *Uses of the Sea.* This year sectional meetings were held on the same subject. The New England Assembly met at the Institution from May twenty-second to twenty-sixth. The eighty-one participants came from "the worlds of science and engineering, business, law, government, communications," etc. Problems were discussed that will arise as national policies are developed for the utilization of marine resources.

In October, representatives of the Corporate Associates and other interested friends in the business world spent a day at the Institution to be briefed on the work presently in progress at the Institution. Such reports have become increasingly important as indicated by a visit to Woods Hole of the Japan Marine Technology Team representing various industries in their native country.

The R/V MELVILLE, sister ship of the KNORR, stopped over at Woods Hole for five days in September to undergo sea trials in local waters before proceeding to her home port, San Diego, as the most recent addition to the fleet of the Scripps Institution of Oceanography. The French R/V THALASSA, a fisheries research vessel working on the Grand Banks, spent several days at the Woods Hole dock while making repairs. Finally, more than 100 scientists and members of the crew from the Russian R/V AKADEMIK KURCHATOV came down from Boston, where their ship was docked, for a day at the Institution. After lunch at the MBL Club, they toured the laboratories and the vessels that happened to be in port. Some even found time to visit in private homes and to take trips about the town. After a New England clambake on the Quisset Campus, the visitors returned to their ship that same evening. The welcome was particularly warm as the Russians had been so cordial to those aboard ATLANTIS II when in the Black Sea earlier in the year.

A New England clam bake for visitors from the AKADEMIK KURCHATOV of the U.S.S.R.

Professor Maria Klenova, U.S.S.R., with Mrs. Fye

KNORR winters in the ice, Bay City, Michigan, 1969

Cruises - 1969

ATLANTIS II — Days at Sea – 272 — Total Miles Sailed – 39,037

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
49 Leg I-V	6 January–11 July	Mediterranean Sea	152	H. Stommel A. Miller, J. Hunt, R. Backus, V. Bowen
50	13 July–6 August	Munro's Shipyard		
51	9-31 August	Halifax	23	F. Fuglister
52	5-28 September	Norfolk	24	J. Ryther
53	3 October–12 October	Station D (Buoy Line)	10	J. Gifford
54 Leg I-III	20 October–21 December	Eastern Pacific Rise	63	H. Wong, R. von Herzen, C. Bowin
		Total	272 days	

CHAIN — Days at Sea – 249 — Total Miles Sailed – 29,598

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
87	6-12 February	Slope Waters (Site D)	7	N. Fofonoff
88 Leg I-II	17 February–7 March	Gulf Stream	19	H. Sanders, J. Teal
89	11 March–9 April	Bermuda Area	30	T. Whalen
90	15–30 April	Site D	16	R. Heinmiller

CHAIN (continued) Total Miles Sailed – 29,598

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
91	5–27 May	Gulf Stream	23	T. Sanford
92	5–15 June	Station D (Buoy Line)	11	J. Gifford
93	24 June–22 July	Gulf Stream	29	F. Fuglister
94	23 July–5 August	Bethlehem Steel Shipyard		
95	8–21 August	Buoy Line	14	R. Heinmiller
96 Leg I-III	8 September–16 December	Eastern North Atlantic	100	R. Nowak, J. Phillips, J. Stanbrough
		Total	249 days	

GOSNOLD Days at Sea – 272 Total Miles Sailed – 22,814

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
140	11 February–28 May	Peruvian Current	107	C. Lorenzen
141	29 May–6 June	Munro's Shipyard		
142	9–13 June	Hudson Canyon	5	G. Rowe
143	18–24 June	Hudson Canyon	7	F. Striffler
144	2 July–6 August	Bermuda Islands Waters	37	C. Wunsch
145	13–28 August	Georges Bank	16	C. Lorenzen
146	2–13 September	Gulf of Maine	13	E. Uchupi
147	17–22 September	Local Area	6	J. Craddock
148 Leg I-II	24 September–10 October	Block Canyon	17	J. Teal
149	13 October	Local Area	1	G. Clarke
150	17 October–21 October	Local Area	5	P. Sachs
151	27–30 October	Hudson Canyon	3	P. Wiebe
152 Leg I-III	7 November–31 December	Gulf of Mexico	55	L. Hobson, C. Remsen, G. Rowe
		Total	272 days	

C 54 Q Aircraft Flights – 1969

FLIGHT NO.	DATE	AREA OF OPERATION	DAYS	SCIENTIST
1	6 January	Wilmington, Del.	½	- - - - -
2	14 January	Test flight out of Wilmington	½	- - - - -
3	15 January	Wilmington to Otis	½	- - - - -
4	25 January	Local test flight	½	- - - - -
5	27 January	Otis to Nomansland	½	G. Ewing
6	31 January	Local test	½	A. Bunker
7	4 February	Cape May	½	A. Bunker
8	4 February	Return from Cape May	½	A. Bunker
9	6 February	Otis to Bermuda	½	A. Bunker
10	7 February	Bermuda to Azores	1	A. Bunker
11	8 February	Lajes to Rota	1	A. Bunker
12	10 February	Rota to Hyeres	1	A. Bunker
13	13 February	Local Hyeres	1	A. Bunker
14	16 February	Local Hyeres	1	A. Bunker
15	18 February	Hyeres to Pisa, Italy	1	A. Bunker
16	21 February	Pisa to Hyeres	1	A. Bunker
17	24 February	Local Hyeres	1	A. Bunker
18	26 February	Local Hyeres	1	A. Bunker
19	28 February	Local Hyeres	1	A. Bunker

FLIGHT NO.	DATE	AREA	DAYS	SCIENTIST
20	2 March	Hyeres to Rota, Spain	1	A. Bunker
22	5 March	Lajes to Sidney, N.S.	1	A. Bunker
23	5 March	Sidney to Otis	1	A. Bunker
24	12 March	LaGuardia, N.Y.	½	- - - - -
25	12 March	LaGuardia to Otis	½	- - - - -
26	25 March	Otis to Miami	½	- - - - -
27	14 May	Local test out of Miami	½	- - - - -
28	16 May	Local test out of Miami	½	- - - - -
29	17 May	Miami to Otis	1	- - - - -
30	19 May	Otis to Wilmington, Del., & return	½	G. Ewing
31	22 May	Otis to Wilmington, Del.	½	G. Ewing
32	23 May	Return from Wilmington	½	G. Ewing
33	26 May	Otis to Azores	1	J. Phillips
34	30 May	Local Azores	1	J. Phillips
35	5 June	Local Azores	1	J. Phillips
36	8 June	Azores to Otis	1	J. Phillips
37	18 June	Otis to Wilmington, Del.	½	- - - - -
38	18 June	Return from Wilmington	½	- - - - -
39	20 June	Otis to Barbados	1	A. Bunker
40	23 June	Local Barbados	1	A. Bunker
41	25 June	Local Barbados	½	A. Bunker
42	26 June	Local Barbados	1	A. Bunker
43	29 June	Local Barbados	1	A. Bunker
44	2 July	Local Barbados	1	A. Bunker
45	5 July	Local Barbados	1	A. Bunker
46	8 July	Local Barbados	1	A. Bunker
47	13 July	Local Barbados	1	A. Bunker
48	15 July	Local Barbados	1	A. Bunker
49	18 July	Local Barbados	1	A. Bunker
50	21 July	Local Barbados	1	A. Bunker
51	23 July	Local Barbados	1	A. Bunker
52	25 July	Local Barbados	½	A. Bunker
53	28 July	Local Barbados	1	A. Bunker
54	30 July	Barbados to Otis	1	A. Bunker
55	12 August	Local test flight	½	- - - - -
56	13 August	Local flight	½	G. Clarke
57	14 August	Local flight	½	G. Clarke
58	18 August	Local flight	½	G. Clarke
59	19 August	Local flight	½	G. Clarke
60	20 August	Local flight	½	G. Clarke
61	21 August	Local flight	1	G. Clarke
62	22 August	Local flight	1	G. Clarke
63	27 August	Local flight	1	G. Clarke
64	28 August	Local flight	1	G. Clarke
65	11 September	Test flight	1	- - - - -
66	15 September	Local area	1	P. Saunders
67	2 October	Local test flight	½	- - - - -
68	6 October	Local area	1	P. Saunders
69	7 October	Local area	½	P. Saunders
70	21 October	Local area (Gulf Stream)	1	P. Saunders
71	17 November	Local area	1	P. Saunders
72	25 November	Gulf Stream	1	P. Saunders
73	4 December	Local area	1	P. Saunders

Scientific Departments and Supporting Services Personnel

PAUL M. FYE	Director
H. BURR STEINBACH	Dean of Graduate Studies
ARTHUR E. MAXWELL	Director of Research
BOSTWICK H. KETCHUM	Associate Director
FREDERICK E. MANGELSDORF	Assistant Director for Development and Information
DAVID D. SCOTT	Assistant Director for Administration

The following were in the employ of the Institution on December 31, 1969:

Department of Biology

Backus, Richard H.
Barber, Richard T.
*Brown, Anna
Carey, Francis G.
Clark, H. Lawrence
*Clarke, George L.
Clarner, John P.
Clifford, Charles H.
Collins, Barbara Ann
Corwin, Nathaniel
Craddock, James E.
Dunstan, William M.
Eimhjellen, Kjell E.
Graham, Linda B.
Grassle, J. Frederick
Grice, George D., Jr.
Guillard, Robert R. L.
Gunning, Anita H.
Haedrich, Richard L.
Hampson, George R.
Hobson, Louis A.
Hulburt, Edward M.
Jannasch, Holger W.
Kanwisher, John W.
Konnerth, Andrew, Jr.
Krieger, Diane L.
**Laue, Peter K.
Lawson, Kenneth D., Jr.
Lawson, Thomas J., Jr.
Lorenzen, Carl J.
Masch, David W.
Mather, Frank J. III
Mayhew, Mary S.
Menzel, David W.
Mogardo, Juanita A.
Pritchard, Parmely H.
Remsen, Charles C. III
Rogers, M. Dorothy
Rowe, Gilbert T.
Ryther, John H.
Sanders, Howard L.
Sawtelle, Cynthia A.
Scheltema, Rudolf S.
Schroeder, Brian W.
Sears, Mary
Shores, David L.
Stanley, Helen I.
Teal, John M.
Tuttle, Jon H.
Vaccaro, Ralph F.
Valois, Frederica W.
Watson, Stanley W.
Wiebe, Peter H.
Williams, Isabel P.
*Wilson, Esther N.
Wing, Asa S.
Wirsen, Carl O., Jr.

Department of Chemistry

Bankston, Donald C.
Blumer, Max
Bowen, Vaughan T.
Boylan, David B.
Brewer, Peter G.
Burke, John C.
Courant, Reinier A.
Degens, Egon T.
Deuser, Werner G.
Fitzgerald, William F.
Gordon, Allan G.
Harvey, George R.
*Hess, Marilyn R.
Horne, Ralph A.
Kadar, Susan
Laking, Phyllis N.
Langley, Louise R.
Lawson, Charlotte M.
McAuliffe, Julianne
McNulty, Patrick S.
Noshkin, Victor E., Jr.
Pasley, Susan M.
*Richards, Heidi
Ross, Edith
Sachs, Peter L.
Sass, Jeremy
Sayles, Fred L.
Smith, C. LeRoy
Spencer, Derek W.
*Steudler, Paul A.
Surprenant, Lolita D.
Thompson, Geoffrey
*Tollios, Harriet M.
Tripp, Bruce W.
Wilson, T. R. S.
Wong, Kai M.
Zafiriou, Oliver C.

Department of Geology and Geophysics

Abbott, Stanley S.
Aldrich, Thomas C.
Allison, Donna F.
Baxter, Lincoln II
Beckerle, John C.
Berggren, William A.
Bergstrom, Stanley W.
Boutin, Paul R.
Bowin, Carl O.
Brockhurst, Robert R.
**Bruhweiler, Fred C.
Bunce, Elizabeth T.
Church, William J.
Cole, Bruce R.
Collins, Anne C.

‡On Leave of Absence *Part-time Employment **Temporary Employment

Department of Geology and Geophysics (continued)

*Coppenrath, Agnes I.
Dale, Barrie
Davis, James A.
Doutt, James A.
Dow, Willard
Dunkle, William M., Jr.
Emery, Kenneth O.
Fiske, Royce John III
Franklin, Denise
*Gallagher, Gloria S.
Grant, Carlton W., Jr.
Guild, Ritchey L.
‡Gurney, Elaine B.
‡Haq, Bilal U.
†Hathaway, John C.
*Hayes, Carlyle R.
‡Hayes, Earl E.
Hays, Helen C.
Heirtzler, James R.
Hemenway, Elizabeth D.
Hess, Frederick R.
Hilliard, Channing N., Jr.
Hollister, Charles D.
Hoskins, Hartley
*Jones, Maxine M.
‡Katz, Eli J.
Knott, Sydney T., Jr.
†Manheim, Frank T.
McElroy, Paul T.
†Meade, Robert H.
Mellor, Florence K.
‡Milliman, John D.
Miner, Arnold W.
Morehouse, Clayton W.
Mosier, Gatha A.
Murphy, Edward L.
Nichols, Walter D.
Nowak, Richard T.
Owen, David M.
†Oldale, Robert N.
Phillips, Joseph D.
Pine, Denise
Poole, Stanley E.
Prada, Kenneth E.
Riley, Anne S.
Ross, David A.
Ruiter, Robert G.
*Schevill, William E.
†Schlee, John
Scott, Carl W., Jr.
Simkins, Samuel T.
Stetson, Thomas R.
Stone, Louise D.
Sutcliffe, Thomas O.L.
Toner, Lois G.
Uchupi, Elazar
Vine, Allyn C.
Von Herzen, Richard P.
Wall, David
Watkins, William A.
‡Wertheimer, Alice M.
*Weston, Edith A.
Witzell, Grace M.
Witzell, Warren E.
Wolfe, Jack C.
Wong, How-Kin
Wooding, Christine R.
Wooding, Frank B.
Young, Earl M., Jr.
Zarudski, Edward F. K.

Department of Ocean Engineering

Aldrich, Thomas B.
Ballard, Robert D.
Barstow, Elmer M.
Bartlett, Arthur C.
Berteaux, Henri O.
Blair, Joseph P.
Blanchard, Rudolph G.
Bland, Edward L., Jr.
Broderson, George DeP.
Brown, Neil L.
Burt, Kenneth H.
Chute, Edward H.
Collins, Clayton W., Jr.
Crook, Thomas
Daubin, Scott C.
Davison, Allan R.
Deane, Stanley R.
Dorson, Donald L.
Drever, Robert G.
Eggleston, Fred S., Jr.
Ekstrand, Donna J.
Eliason, Andrew H.
Evans, Emily
Fairhurst, Kenneth D.
Frank, Eric H., Jr.
Freund, William F., Jr.
Gibson, George W.
Graham, Russell G.
Hamill, Clifford J.
Hunt, Mary M.
Kallio, Peter G.
Koehler, Richard L.
Lackey, Martha E.
Lenart, Alice L.
Lyon, Thomas P.
Machado, Richard A.
Marquet, William M.
Mavor, James W., Jr.
McCamis, Marvin J.
McLeod, John W.
Medeiros, Alfred F., Jr.
Muzzey, Charlotte A.
Olmstead, Ellen K.
O'Malley, Patrick
Page, William F.
Polloni, Christopher
Porembski, Chester R.
Porteous, John
Power, George H.
Rainnie, William O., Jr.
Roberts, William P.
Rosenfeld, Melvin A.
Roy, Pamela A.
Sharp, Arnold G.
Shultz, William S.
Stanbrough, Jess H., Jr.
Stegenga, Melendy
Stern, Margaret P.
Stimson, Paul B.
*Sullivan, James R.
Tollios, Constantine D.
Walden, Robert G.
Weaver, Roger D.
Webb, Douglas C.
Webert, Warren F.
‡Webster, Jacqueline
Williams, Albert J. III
Wilson, Valentine P.
Winget, Clifford L.
Woods, Donald E.

Department of Physical Oceanography

Alexander, Robert M.
*Allen, Ethel B.
*Anderson, Nellie E.
Armstrong, Harold C.
Bailey, Phyllis T.
Barbour, Rose L.
Barrett, Joseph R., Jr.
Bowen, Derwent C.
Bradshaw, Alvin L.
Breivogel, Barbara B.
Bruce, John G., Jr.
Bumpus, Dean F.
Bunker, Andrew F.
Chaffee, Margaret A.
Chase, Joseph
Cooper, John W.
Cornell, Sidney
Daniels, Dolores H.
Day, C. Godfrey
*Dennis, Joan B.
Densmore, C. Dana
Denton, Edward A.
Ewing, Gifford C.
Fofonoff, Nicholas P.

‡On Leave of Absence *Part Time Employment **Temporary Employment
†Member of U.S. Geological Survey assigned for work at the Woods Hole Oceanographic Institution.

Department of Physical Oceanography (continued)

Frank, Winifred H.
Frazel, Robert E.
Fuglister, Frederick C.
Gifford, James E.
Guillard, Elizabeth D.
Harlow, Caroline
Heinmiller, Robert H.
Houston, Leo C.
*Kahler, Yolande A.
Knapp, George P. III
Ma, Heau Sen
Mason, David H.
McCullough, James R.
Metcalf, William G.
Millard, Robert C., Jr.
Miller, Arthur R.
Moore, Douglas E.
Mullen, Carolyn G.
Munns, Robert G.
Parker, Charles E.
Payne, Richard E.
**Perkins, Henry T.
Pollard, Raymond T.
Reese, Mabel M.
‡Ronne, F. Claude
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Saunders, Peter M.
Scharff, John M.
Schleicher, Karl E.
Schmitz, William J., Jr.
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Shodin, Leonard P.
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Simoneau, R. David
Soderland, Eloise M.
Spencer, Allard T.
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Tupper, George H.
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von Arx, William S.
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Warren, Bruce A.
Webster, T. Ferris
Whitney, Geoffrey G., Jr.
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**Winget, Katherine
Worthington, L. Valentine
Wright, W. Redwood
Zemanovic, Marguerite P.
Ziegler, Evelyn L.
‡Zwilling, Avron M.

Department of Administrative and Service Personnel

Aiguier, Edgar L.
*Allen, Norman T.
Anders, Wilbur J.
Andrews, Josephine A.
*Banay, Barbara B.
Battee, Janice A.
Behrens, Henry G.
Benttinen, Dave D.
Bjorklund, Mark L.
Bowman, Richard W.
Brienzo, Karen A.
Brown, Joseph C.
Busa, Kathryn
Callahan, Sharon L.
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Carlson, Gustav A.
Carlson, Ruth H. E.
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Davis, Ruth H.
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°Erwin, Clarence
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Fielden, Frederick E.
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Hooper, Edward J.
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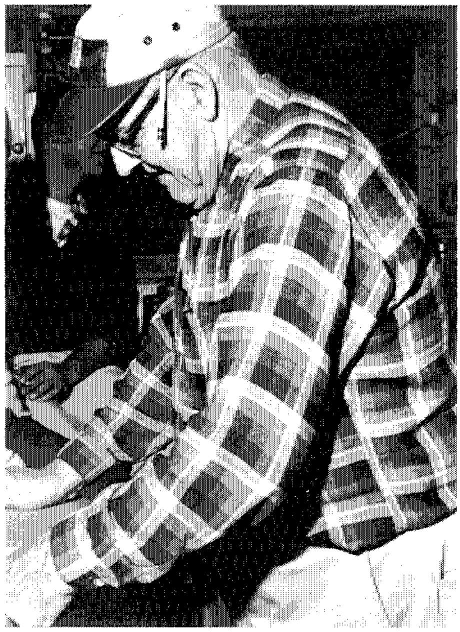
Jenkins, Delmar R.
Johnson, Harold W.
Joseph, Charles R.
Kelley, Robert F.
**Kempton, Edward E.
King, Robert E.
Lajoie, Therese S.
Lamarre, Adrien J.
Lambert, William D.
LeBlanc, Donald F.
Leonard, Susan
Lewis, Ellen S.
Lizotte, Richard
Lohr, Donald H.
Macaulay, Marianne
MacKillop, Harvey
Mahut, Odette A.
*Mahut, Raymond
Manni, Janice
Martin, Olive
Mayberry, Ernest
McCamis, Martha L.
McDermott, Maud Ann
McGilvray, Mary K.
Medeiros, Frank
Meinert, Dorothy
Mitchell, James R.
Motta, Joseph F.
Muller, John T.
Ortolani, Mary
Page, Stephen G.
Peirson, A. Lawrence III
Perry, Lawrence N.
Peterson, Judith A.
Phares, Edward
Picard, Eleanor P.
Pires, Joseph L.
Quigley, Ralph W.
Ramsey, William S., Jr.
Reeves, Stanley A.
Rennie, Thomas D.
Robbins, Charles C.
Roberts, Harry A.
Ross, David F.
Rudden, Robert D., Jr.
Schilling, John L.
Shave, Charlet E.
Smart, Thomas H.
Souza, Donald P.
Souza, James H.
Souza, Thomas A.
Staltare, Michelle E.
Stimpson, John W.
Sullivan, Gerard E.
Tometich, Louis J.
Vallesio, Barbara M.
von Dannenberg, Carl A.
Walker, Jean D.
Watson, L. Hoyt
Weeks, Robert G.
Wessling, Andrew L., Jr.
White, Haskel E.
Williams, Sally A.
Wing, Carleton R.
Woodward, Fred C., Jr.
Woodward, Martin C.
Woodward, Ruth F.

‡On Leave of Absence
°Deceased 4 February 1970
*Part Time Employment
**Temporary Employment

Marine Personnel

Aiguier, Edgar L., Jr.
Babbitt, Herbert L.
Baugh, Jess D.
Bazner, Kenneth E.
Bizzozero, John P.
Breault, Robert H.
Brereton, Richard S.
Brodrick, Edward R.
Brown, John W.
Bumer, John Q.
Butler, Dale T.
Cabral, John V.
Caranci, Donald H.
Casiles, David F.
Clarkin, William H.
Colburn, Arthur D., Jr.
Cook, Alden
Cook, Robert J.
Cornell, Jack W.
Cotter, Jerome M.
‡Coughlin, Brooks W.
‡Crocker, John D.
Davis, Charles A.
DeTerra, George
Dimmock, Richard H.
Dunn, Arthur J.
Eastman, Philip L.
Edwards, Richard S.
Farnsworth, Donald C.
Field, Michael J.
Gabbett, Leo F.
Gordon, Robert L.
Halverson, Leonard C.
Hamblet, Dwight F.
Hansen, H. Morgan
Hartke, David L.
Hartke, Richard A.
Henton, H. Dean
Hiller, Emerson H.
Howland, Paul C.
Jefferson, Albert C.
Johnston, Alexander T.
Jones, William E.
Knight, Olin T.
La Porte, Leonide
Leiby, Jonathan
Lind, Gordon W.
Lobo, Wayne F., Jr.
Manahan, Paul S.
Manley, Thomas F.
Martin, John W., Jr.
Martin, Ralph S.
Matthews, Francis S.
McLaughlin, Barrett J.
Mendez, Florencio
Merrill, Raymond A.
Millikan, James D.
‡Moller, Donald A.



Stanley N. Eldridge, Chief Carpenter, nearing his second retirement

Helen Franklin Phillips 1903-1969. For nearly forty years, she made the Institution her life. In her devotion to duty, faithful service and loyalty to her associates in magnificent proportions, she expressed her love for it. For the greater part of the time she was research assistant and secretary to Columbus Iselin, including the periods he served as Director. More recently she had assisted William S. Von Arx with the drafts of the typescript for his book, "Introduction to Physical Oceanography", and Dean F. Bumpus, in his work with drift bottles.

Moroney, Paul R.
Morse, Joseph C.
Moye, William E.
Mysona, Eugene J.
Ocampo, Conrad H.
O'Reilly, Peter P.
Palmieri, Michael, Jr.
Pierce, George E.
Pierce, Samuel F.
Pike, John F.
Porrata, Carlos F.
Ribeiro, Joseph
Rioux, Raymond H.
Roy, Alfred J.
Russell, Lee T.
Seibert, Harry H.
Seifert, Charles T.
Sorenson, Donald M.
Stack, William M.
Stires, Ronald K.
Sture, Armas B.
Sutcliffe, Leonard C.
Szymanski, Theodore J.
Tully, Edward J.
Walden, Henry A.
Wheaton, Gary W.
White, William A.
Wiebe, Judith D.
Young, Stephen K.

‡On Leave of Absence

The Institution and the Town of Falmouth

A Committee to Study Tax-Exempt Property was authorized by the annual Falmouth Town Meeting of 1969. As a consequence, the tax status of the real estate property of the Institution has been reviewed. The usual policy has been to pay taxes on all properties from which income is realized and to remove from the tax rolls only such properties as are used directly for research and education. Taxes have been paid on residential quarters behind Challenger House, on the former Sidney W. Lawrence estate, etc., as well as on the drugstore — two-thirds of which is used for Institution purposes — and on Dyer's parking lot — which is open to the public at Institution expense on summer weekends without charge. Thus, the untaxed acreage has amounted to less than 0.002% of the total tax-exempt real estate within the township. The voluntary payments ($17,496.66 in 1969) have, however, reached such proportions that the long-standing policy needs to be carefully reviewed. The Trustees are obligated to use the limited endowment for the purposes specified in the Charter and the government contracts and grants strictly forbid applying public funds toward real estate taxes.

At a special Town Meeting in April, it was "voted-----to negotiate a lease with the W.H.O.I. to allow the Town to use a portion of the Beach acquired by the W.H.O.I. from the Fenno estate for Beach purposes and to raise and appropriate the sum of $1.00 for said purpose. Said beach to be restricted to Falmouth residents and guests." To date, the Selectmen have not entered into such negotiations.

Local Waters and Sewage Disposal

With the need for a domestic sewage system in Falmouth more urgent than at any time in the forty years it has been under consideration, a report was prepared late in 1968 for the Falmouth Department of Public Works by a Boston engineering firm. They had recommended a secondary outfall system to empty off Jupiter Point not very far from the present Woods Hole outlet. In the belief that some of the hydrographers and biologists on the staff might contribute to the planning, the Director placed the services of various members of the staff at the disposal of the Selectmen to prepare a supplemental report (or reports). After preliminary considerations, it appeared that the effluent, even though greatly diluted, might be carried up into Great Harbor on an ebbing tide and around Nobska Point towards the Falmouth beaches on a flooding tide. Subsequently, a better location was found in ninety feet of water 0.375 miles south of Nobska Point where the currents and a shoal would tend to deflect the treated effluent away from Woods Hole Passage and the beaches.

A second report was concerned with the possible consequences of inland sewage disposal at two sites selected as alternates by the engineering firm. In this case also neither the Institution nor the individuals concerned made any recommendation as to the preferred plan. Rather they presented the facts to serve as a basis for the decision to be made by the townspeople.

An Oil Spill and its Consequences

During September, an oil spill in Buzzards Bay off Wild Harbor (North Falmouth) from a grounded barge was examined immediately by interested members of the staff. As a consequence, the details of massive initial mortality that occurred within the first few days was well documented. Since the soft-bodied organisms rot and disappear within a week, there would have been little obvious evidence of


Evidence of kill in the oil spill, North Falmouth

the disaster even one week later. A secondary more insidious mortality was still occurring several months after the original spill. This may be related to the anaerobiosis that has developed over much of the bottom. Even in the upper reaches of the Wild Harbor River few species of metazoans persist. The polychaete *Capitello capitatata,* a known indicator of pollution, has, however, increased in great numbers. Below the low water mark, there is evidence that the affected zone is enlarging.

Aside from these gross biological indications, the chemists have demonstrated that the oil has impregnated into the sediments and that it has remained there for more than three months. Furthermore, the oil has been incorporated in the soft tissues of oysters and in the adductor muscles (the edible portion) of the scallop. The hydrocarbon content of these polluted shellfish is many times higher and entirely different from that in shellfish from an unpolluted bottom. In "clean" areas, the hydrocarbon source is derived from such biochemical sources as the algae, the food of molluscs.

The evidence gathered by the staff indicates that the contamination and the destruction of a shellfishery persists for many months after the accident. The results are so well documented by members of the staff with the cooperation of the Falmouth Shellfish Warden that the Town of Falmouth can present an unusually strong case for damages in the courts.

Treasurer's Report

The accounts for the year 1969 have been audited by Lybrand, Ross Bros. & Montgomery.

Some of the principal changes during 1969 are shown below:

	1969	1968	Increases (Decreases)
Direct Costs of Research Activity	$8,692,235	$8,755,825	$(63,590)
Educational Operations	243,100	145,420	97,680
General & Administrative Costs	1,171,404	1,143,186	28,218

During 1969 gifts from individuals, foundations and corporations increased Endowment Fund assets and income as shown below:

	1969	1968	Increases
Endowment Assets, Book Value	$13,938,214	$5,772,428	$8,165,786
Endowment Assets, Market Quotation	17,462,661	8,519,762	8,942,899
Endowment Income	314,437	277,179	37,258

Of major significance was a most generous gift from J. Seward Johnson which has been added to the endowment investments to establish a fund to provide future support for the graduate studies program.

The Development Program shows gratifying progress, with gifts and pledges now totalling $16.5 million.

	1969	1968	Increase
Contribution to the W.H.O.I. Retirement Trust	$405,089	$367,557	$37,532

The Institution's plant assets increased $857,843 principally due to the completion of the new waterfront building funded by the National Science Foundation.

Woods Hole Oceanographic Institution

Woods Hole, Massachusetts

We have examined the balance sheet of Woods Hole Oceanographic Institution as at December 31, 1969 and the related statements of changes in funds and of operating expenses and resources used to meet operating expenses 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. It was not practicable to confirm receivables from United States Government departments, but we have satisfied ourselves as to such accounts by means of other auditing procedures.

In our opinion, the accompanying statements (with investments stated at cost) (pages 85 and 86 and Notes to The Financial Statements on page 87) present fairly the financial position of Woods Hole Oceanographic Institution at December 31, 1969 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

The supplemental schedules included in this report (pages 87 and 88) although not considered necessary for a fair presentation of the financial position and results of operations, are 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 19, 1970

Lybrand, Ross Bros. & Montgomery

BALANCE SHEET

December 31, 1969

ASSETS

Current Fund Assets:		
Cash	$ 1,643,009	
Short-term investments, at cost which approximates market	1,062,317	
Reimbursable research costs:		
Billed	120,961	
Unbilled (note A)	1,229,799	
Supplies, prepaid expenses and deferred charges	189,640	
Plant funds advanced to current	(1,617,926)	
	2,627,800	
Endowment Fund Assets:		
Investments:		
Marketable securities, at cost, market value $17,408,149 (note B)	13,834,441	
Real estate	54,512	
	13,888,953	
Cash	49,261	
	13,938,214	
Plant Fund Assets:		
Laboratory, plant and equipment	5,074,153	
Atlantis II, contingent title (note C)	4,831,130	
Other vessels, equipment and property	3,733,224	
	13,638,507	
Less accumulated depreciation	3,117,059	
	10,521,448	
Plant funds advanced to current	1,617,926	
	12,139,374	
	$28,705,388	

LIABILITIES

Current Liabilities and Reserves:	
Accounts payable and accrued expenses	$ 592,379
Contribution payable to employees' retirement plan and trust	405,089
Unexpended balances of restricted gifts and grants	639,696
Reserves	990,636
	2,627,800
Endowment Funds (note B):	
Restricted as to principal and income	8,000,400
Restricted as to principal	2,521,420
Unrestricted as to principal; restricted as to income	816,856
Unrestricted as to principal and income	171,951
Accumulated net gain on sales of investments	2,427,587
	13,938,214
Plant Funds:	
Expended for plant, less retirements	13,638,507
Less accumulated depreciation	3,117,059
	10,521,448
Unexpended	1,617,926
	12,139,374
	$28,705,388

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

Statement of Operating Expenses and Resources Used to Meet Operating Expenses

Year Ended December 31, 1969

Operating Expenses		
Direct costs of research activity:		
Salaries and wages		$3,303,286
Vessel and aircraft operations		2,049,453
Materials, equipment and services		2,005,065
Laboratory costs		479,390
Travel		204,364
Service departments		263,899
Computer center		386,778
		8,692,235
Direct costs of educational operations		243,100
Indirect costs:		
General and administration		1,171,404
Total depreciation (note E)	$431,949	
Less amount funded in direct and indirect costs above	186,656	245,293
Miscellaneous		186,176
		$10,538,208
Resources Used to Meet Operating Expenses		
Income for sponsored research (including $2,577,290 gifts and grants expended):		
For direct costs		8,530,531
For indirect costs		1,106,801
Fees for use of facilities		239,713
		9,877,045
Endowment income availed of (note D):		
For institution research	161,704	
For education	4,609	
For institution indirect costs	21,713	188,026
Development program contributions		103,776
Revenue from educational operation:		
Gifts availed of	222,838	
Tuition income	41,546	264,384
Miscellaneous		52,917
Working capital and contingency reserve availed of		52,060
		$10,538,208

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

Statement of Changes in Funds

Year Ended December 31, 1969

	Endowment Funds (note B)	Plant Funds: Invested in Plant	Plant Funds: Unexpended: Acquisition of Capital Assets	Plant Funds: Unexpended: General Plant and Equipment Reserve	Unexpended Balances of Restricted Gifts and Grants	Reserves: Income and Salary Stabilization	Reserves: Working Capital and Contingency
Balance at beginning of year	**$5,772,428**	**$10,067,157**	**$ 877,044**	**$427,726**	**$310,103**	**$900,671**	**$111,300**
Restricted gifts and grants received	8,129,293	50,000	682,014		3,096,251		
Endowment income (note D)					40,979	273,458	
Net gain on sales of investments	36,493						
Working capital and contingency reserve availed of							(52,060)
Provision for depreciation (note E):							
Funded		(186,656)		186,656			
Unfunded		(245,293)					245,293
Availed of for research and education costs (note D)					(2,800,128)	(188,026)	
Transferred to acquisition of capital assets fund from working capital and contingency reserve			300,000				(300,000)
Invested in plant		859,664	(685,731)	(173,933)			
Miscellaneous		(23,424)	3,717	433	(7,509)		
	$13,938,214	$10,521,448	$1,177,044	$440,882	$639,696	$986,103	$ 4,533

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

Summary of Investments

As at December 31, 1969

	Book Amount	% of Total	Market Quotation	% of Total	Endowment Income
BONDS:					
Government and government agencies	$1,459,615	10.5	$1,340,430	7.7	$ 79,933
Railroad	288,183	2.1	204,848	1.2	13,371
Public utility	529,780	3.8	396,563	2.3	22,342
Industrial	773,381	5.7	595,869	3.4	28,404
Financial and investments	476,283	3.4	407,784	2.3	20,066
Total bonds	3,527,242	25.5	2,945,494	16.9	164,116
STOCKS:					
Preferred	176,661	1.2	144,425	.8	7,810
Common:					
Public utility	531,419	3.8	1,049,435	6.0	42,061
Industrial*	9,446,159	68.0	13,059,858	74.8	98,666
Miscellaneous	152,960	1.1	208,937	1.2	6,309
Total common stocks	10,130,538	72.9	14,318,230	82.0	147,036
Total stocks	10,307,199	74.1	14,462,655	82.8	154,846
Total marketable securities	13,834,441	99.6	17,408,149	99.7	318,962
REAL ESTATE	54,512	.4	54,512**	.3	(4,525)
Total investments	$13,888,953	100.0	$17,462,661	100.0	$314,437

*See note B to the financial statements.
**At book amount.

Notes to The Financial Statements

A — Unbilled reimbursable research costs include December costs of $438,058 and costs of $600,890 for which a contract amendment was received in March 1970.

B — Endowment funds include securities, received in 1969, which are restricted as to public sale. Such securities were valued at the current market valuation ($8,000,400) of unrestricted securities of the same class, on the date of gift.

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

D — Total endowment income in 1969 of $314,437 was allocated to the following:

To meet operating expenses	$188,026
Income and salary stabilization reserve	85,432
Unexpended balances of restricted gifts and grants	40,979
	$314,437

E — Depreciation is provided at annual rates of 2% on buildings, 3⅓% on Atlantis II and 5% to 33⅓% on equipment. Depreciation expense for 1969 totaling $431,949 includes $245,293 of depreciation on Atlantis II, Laboratory for Marine Science and the dock facility.

Direct Costs of Research Activity

Year Ended December 31, 1969

	Salaries and Wages	Vessel and Aircraft Operations	Materials, Equipment and Services	Laboratory Costs	Travel	Service Departments	Computer Center	Total
U.S. Government:								
Contracts	$2,347,214	$1,360,707	$1,523,599	$ 338,773	$128,105	$202,703	$324,397	$6,225,498
Grants	802,258	671,358	340,002	116,108	64,903	38,593	55,668	2,088,890
Other sponsored research	46,686	446	133,433	7,164	4,496	17,537	6,381	216,143
Total direct costs of sponsored research	3,196,158	2,032,511	1,997,034	462,045	197,504	258,833	386,446	8,530,531
Institution research	107,128	16,942	8,031	17,345	6,860	5,066	332	161,704
Total direct costs of research	$3,303,286	$2,049,453	$2,005,065	$479,390	$204,364	$263,899	$386,778	$8,692,235