WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

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Governor Francis W. Sargent presented Dr. Fye with a proclamation of Fortieth Anniversary Celebration Week of the Woods Hole Oceanographic Institution on 12 June 1970.

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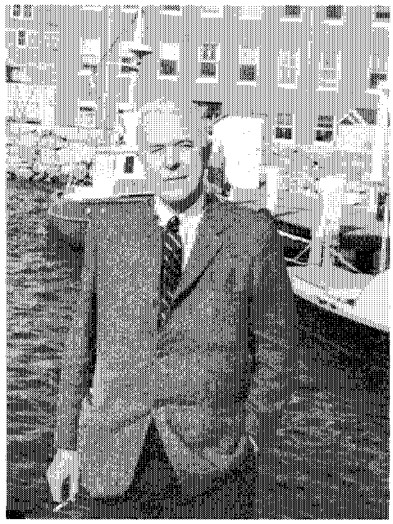
Commemorative Resolution in memory of Columbus O'Donnell Iselin



We, the Trustees and Members of the Corporation of the Woods Hole Oceanographic Institution, at a joint meeting record with great sorrow the death of Columbus O'Donnell Iselin on the fifth day of January, one thousand nine hundred and seventy-one, in his sixty-seventh year.

Sailor, scientist, teacher, oceanographer, statesman, and above all a friend and kind counselor to everyone with whom he came in contact, Columbus Iselin leaves his mark on our Institution and on oceanography all over the world. He was elected a Trustee and Member of the Corporation in 1936, served as Director of the Institution from 1940 to 1950 and again from 1956 to 1958 after which he was appointed to the Henry Bryant Bigelow Chair of Oceanography.

Born into a prominent banking family which had a tradition of yachting as a devoted avocation (his great uncle skippered five successful defenders of the America's Cup between 1893 and 1903), Columbus became interested in the sea at a very early age. Fortunately, he met Professor Henry Bigelow while he was a student at Harvard. Together they formed a team which directed the Institution through the first two decades of its history. As a student he built the CHANCE, a 72-foot schooner, which he used together with a group of fellow students to study the Labrador Current off Newfoundland.

The Institution's history is intimately connected with his personal history starting with the design and supervision of the building of the R/V ATLANTIS in 1930. He served as First Master and Chief Scientist, a combination which has only rarely been repeated in the years to follow. His classic papers on the Gulf Stream system written before 1940 guided the subsequent studies for many years. Above all, his wisdom in guiding the Institution through its rapid growth during World War II and through the lean years immediately following the war did much to lay the foundation for the subsequent growth of oceanography at Woods Hole and elsewhere.

It was largely due to his efforts in 1939 and 1940 that the U.S. Navy became aware of the fact that oceanographic knowledge was vital to its operations. He continued to serve as advisor to the Navy, as well as to NATO. In addition, he encouraged international cooperation in oceanography, particularly during the International Geophysical Year and the International Indian Ocean Expedition.

A trustee and member of many national and international organizations, his advice was sought and was provided in a characteristic low key approach which those who knew him will never forget.

The world-wide eminence of the Woods Hole Oceanographic Institution is in many ways due to his years of service and his ability to appoint members of the scientific staff who remained at Woods Hole or went on to distinguished careers in other Institutions.

His wisdom in foreseeing many aspects of modern oceanography and technology was well recognized. In 1959 at the International Oceanographic Congress he suggested that: "lawyers and statesmen must develop the ground rules within which the vast marine resources can be developed in an efficient and safe manner for the benefit of all mankind." Today such rules are much talked about but not yet settled. It is a tribute to his vision that we are now implementing a program to assist in the training of such policy makers. In many other fields: fishery problems, the possibility of manipulating weather and climate, international cooperation as well as naval problems, his thinking was well ahead of his time.

Few people had the privilege of knowing Columbus Iselin intimately as a man. He was an intensely private person whose life was devoted to oceanography and to his family. Yet, there are many of us whose lives have been changed and influenced by his quiet and indirect guidance.

His many honors included the Agassiz Medal from the National Academy of Sciences (1943), the Medal for Merit from the President of the United States (1948) and the Henry Bryant Bigelow Medal from this Institution (1966). He was a member of the National Academy of Sciences, the American Academy of Arts and Sciences, the New York Academy of Sciences, and many learned societies. He also served as Professor at Harvard University and the Massachusetts Institute of Technology. These are but a few of the honors and positions of distinction he held.

We also record with sorrow the death of his beloved wife Nora only two days ago and less than two weeks after Columbus's untimely death. They were a devoted couple. It is perhaps fitting that these two so completely dedicated to each other in life have now been joined in death.

Every great adventure has had its great leaders. Columbus O'Donnell Iselin was one of the giants of oceanography. An era has ended. We have lost a friend and mentor. Since the early days of Iselin and Bigelow, oceanography in Woods Hole and indeed in the whole nation has had a fair wind. He will be sorely missed by all who knew and loved him.

A resolution presented by Paul M. Fye on January 20th, 1971,
at the Joint Winter Meetings of the Boards of Trustees and Members of the Corporation
of the Woods Hole Oceanographic Institution in Boston, Massachusetts.

THE DIRECTOR'S REPORT
Oceanography and Marine Policy

The continuing purpose of our Institution has been to recruit and retain a staff of highly qualified oceanographers and to provide them with facilities — both on shore and at sea — which enable them to fulfill their innate desire to learn more about the world ocean and to understand more fully the ocean processes. This mission, appropriately simple in concept and gratifyingly productive in execution, has been supported by the governing boards of the Institution with the firm conviction that mankind would benefit from greater understanding of the marine environment.

At our last annual meeting I suggested to our Board Members that as we enter our fifth decade we should broaden our involvement to include the study of man's interaction with the ocean and to emphasize, as a primary goal, the necessity for man to use the oceans wisely. I would like in this report to outline why I believe this step is necessary and to describe the new program in *Marine Policy and Ocean Management* which we are undertaking as a first step in implementing this wider mission.

There are, I believe, three reasons why we must involve ourselves with marine policy. First, oceanographers share with many others throughout the world the strong desire to assist in improving cooperation among nations. Today I think we have an opportunity to do this. The oceans along with Antarctica remain the only portion of the world not claimed by individual nations. As information about the seas expands and as technology grows, governments are increasingly tempted to make claims of ownership or control over large areas of the ocean. The history of world conflict provides many examples wherein conflicting claims and the urge for expansion have developed into major differences among nations.

The international community is now moving to prevent this possibility. Ambassador Arvid Pardo of Malta, in his famous United Nations speech in 1967, claimed that the resources of the deep sea bed are "The Common Heritage of All Mankind." This simple phrase has captured the imagination of peoples throughout the world, especially of those in undeveloped nations where the lack of food and natural resources is felt most keenly. On the 17th of December 1970, the General Assembly of the United Nations incorporated the common heritage concept into its "Declaration of Principles Governing the Seabed — Beyond the Limits of National Jurisdiction." President Nixon's declaration of last May 22nd, in which he called on all nations to renounce all claims of ownership of sea bed resources beyond a depth of 200 meters, was made in this same spirit.

Thus, there exists today an unprecedented opportunity for international cooperation in developing a regime to govern development of the sea bed. At the same time as it approved the "Declaration of Principles" the General Assembly passed a resolution calling for a Conference on the Law of the Sea in 1973 to consider such a regime. The marine sciences will play a prominent role among the many disciplines which must contribute to this conference. Oceanographers throughout the world have been cooperating successfully for many years — through jointly planned international expeditions — to learn about the oceans. It is intriguing to think about the expansion of the methodology which has worked so well in broadening our knowledge of the marine environment to the bigger problem of helping nations work together to make cooperative and peaceful use of this knowledge.

Wise and peaceful use calls for good management which in the oceans means cooperative endeavors rather than unilateral grabs by one big industry or one big nation. Competition for the wealth of the seas is doomed to failure at best and possibly could lead to world disaster. The challenge is immense, even exceeding that of the great age of land development in the last century. The ocean is everyone's backyard — the one physical boundary shared by 121 nations — and is of vital interest to all nations whether landlocked or blessed with some ocean frontage.

A second reason for the Institution to have an interest in the development of marine policy is that we have a unique responsibility to do so. Having contributed significantly to the understanding of the ocean, we share a responsibility that this knowledge is used in the best interest of all mankind. We, more than most, are daily confronted with the evidence that the oceans, although perhaps less visibly affected than the rest of the environment, are already being changed by man's activities. At the same time, we are among the few who can make reasonably enlightened estimates of the impact of these changes. The increasing pressures being generated for development of the sea bed could well lead to man's despoiling the oceans in the same reckless way in which he has denuded large parts of the continents. Thus, it is obvious that a regime for the sea bed cannot be considered apart from the question of the impact of man's present and future activities in the marine environment. Both the United Nations Conference on the Human Environment, to be held in Stockholm in 1972, and the Law of the Sea Conference the following year will be considering specific measures for the control of marine pollution. Knowledge from oceanographers is essential to the success of both conferences.

Third, the Institution is interested in the development of sensible policies for the oceans because bad policy, or the absence of policy, makes oceanographic research very difficult and sometimes impossible. In recent years there have been too many occasions wherein bad policy or unilateral action by one nation has interfered with planned investigations, sometimes preventing them entirely. The present cruise of the CHAIN in the Red Sea has suffered a long series of legal and bureaucratic harassment resulting in the elimination of some of the desired work, in repeated replanning and modification to the point of despairing that the cruise could take place at all. I should emphasize here that our unvarying custom has been to share cruise information with the neighboring states, indeed with the whole world, by open publication. Where possible, we invite nationals of neighboring countries to participate in the cruise, thus assuring them that all the information has been disclosed.

Today nine countries claim territorial seas in excess of twelve miles, and a large international block hopes to use the 1973 conference to extend this limit to 200 miles. Claims for ownership of the sea bed are limited only by the international convention extending title to the "limit of exploitability." It is difficult to compile statistics on the extent to which marine research has been impaired by such expansive claims, since, in most cases, scientists have simply abandoned projects which would require obtaining difficult political clearances. Clearly, the question of the freedom of the seas for research will be a major issue at the 1973 conference and one in which marine scientists must actively participate.

To contribute something to international cooperation; to provide the necessary scientific input to the formation of policy; and to assist in assuring that the seas remain free for scientific research; — these then are the reasons for broadening our mission. I see this expanded effort not as a radical departure from our traditional role, but rather as a logical and necessary step in the evolution of the Institution. Through frequent testimony before legislative bodies, participation in advisory panels, and membership in national and international organizations active in the development of science policy, we perforce have already become intimately involved in the development of policies for the oceans. Since the International Geophysical Year in 1957 when ATLANTIS and CRAWFORD took part in a very extensive international cooperative investigation of the oceans, Woods Hole scientists have played major roles in organizing and participating in (among others) : the Cooperative Investigation of the Caribbean and Adjacent Region, the International Indian Ocean Expedition, several multi-national investigations of the Mediterranean, a cooperative American-German-British investigation of the Red Sea, and a cruise to the Black Sea in which ATLANTIS II carried a scientific party of Russian, American, Turkish and Rumanian investigators. Even now we are highly involved in the plans and programs for the International Decade of Ocean Exploration (IDOE). Indeed, most of the senior scientific staff are now participating in a variety of international (and national) activities.

It has been this exposure that has convinced us that we must improve the avenues of communication between scientists and statesmen, and at the same time must assist in the education of a new breed of science-oriented policy maker who is more familiar with and better able to intepret the information submitted by the oceanographic community. How best to accomplish these objectives has been the subject of innumerable discussions over the past year with staff members, Trustees, and representatives from Harvard, Massachusetts Institute of Technology, and the Fletcher School of Law and Diplomacy at Tufts. From these meetings arose a proposal to the Ford Foundation for launching the program in *Marine Policy and Ocean Management* in which the Institution will:

1. Develop in cooperation with neighboring educational institutions a program of graduate and post-graduate studies for the education of students with backgrounds in relevant fields who are interested in applying their disciplinary training to the solution of marine-related problems.

2. Organize a continuing series of problem-oriented senior level study groups at Woods Hole for the purpose of making the available scientific information about the oceans more accessible (and more comprehensible) to the policy makers who make decisions about issues affecting or affected by the marine environment.

The study groups will deal with marine-related problems of immediate urgency, while the cooperative educational program is designed to contribute to a new generation of policy maker better able to cope with similar problems in the future. The specific cooperative arrangements will vary somewhat with each participating institution, but the basis of this new educational program will be the joint sponsorship by Woods Hole and selected universities of doctoral dissertations and post-doctoral studies by students of law, political science, economics, management, and other relevant fields who have identified marine-oriented theses topics which cannot adequately be treated without scientific input. Representative areas from which such jointly sponsored theses might be drawn include: problems and procedures in implementing an International Regime for the Sea Bed; equitable techniques for establishing the limits of national sovereignty on the high seas and sea bed; equitable and enforceable safeguards for the protection of endangered marine species; the economic impact of the sea bed resources on developing countries; methodologies for assessing in economic terms the ecological stresses created by specific industries and services; and international procedures for guaranteeing the freedom of oceanographic research. Actual thesis work will be jointly supervised by a thesis advisor from both institutions and the student will normally divide his time between Woods Hole and his parent university.

Students will enter the program at about the point in their graduate education when they are prepared to take the general examination in their basic discipline. Their only formal course work here will involve an intensive but loosely structured program of instruction emphasizing the multi-disciplinary aspects of oceanography and consisting of seminars, informal discussions, guest lectures and field experience on our vessels. This will provide a valuable introduction to the marine environment and the language of oceanography, but the real backbone of the program will lie in the working relationship that develops between the students and the scientists who will serve as colleagues and advisors.

We propose to enroll the first six to eight students in the cooperative program during the 1972-73 academic year, and, with their help, to convene the first workshop the following summer. In the interim, as a first step, we are offering three post-doctoral fellowships which have been made possible through the generosity of Mr. J. Seward Johnson. These Fellows will be drawn from disciplines directly relevant to the study of policy, especially political science, economics, law and management, and will be supported by the Institution for a nine, twelve, or fifteen month period while undertaking research and requiring input from the ocean sciences. In addition, they will assist in developing the mechanics of the new cooperative pre-doctoral program.

It is important to note that in devising a mechanism which will enable us to influence marine policy more effectively, we are responding to an often-expressed request from non-science policy-makers. Social scientists who deal with world problems tell us that they urgently require hard scientific facts and reliable interpretations of marine data on which to base their policy decisions. A most important role of the Institution in the formation of marine policy is to help keep the record straight and set forth scientific facts about the world in which we live. We must also be willing to help interpret these facts in relation to policy decisions.

I suspect that the impact of marine science on policy will always be hard to measure. Often, the link between scientific input and non-scientific policy-making is obscured by time and a series of seemingly unrelated events. In the fall of 1969, for example, the Institution initiated a series of events that may have a profound effect on the U.N. Conference on Human Environment which, as already mentioned, will be held in Stockholm in 1972. It began with the Study of Critical Environmental Problems, a conference sponsored by the Massachusetts Institute of Technology under the leadership of Professor Carroll L. Wilson. A number of Woods Hole Oceanographers attended. One of the most important marine requirements identified by this global study was for accurate and current data about the distribution of key pollutants in the marine environment, particularly the deep ocean. Without such data quantitative changes in the amount of these pollutants cannot be measured, much less controlled. Future monitoring is possible only if present distribution and quantities are known. Base measurements are needed, and they are not available. Important questions need to be answered immediately. In the deep oceans, what are the sources and rates of build-up of relevant pollutants from industrial, agricultural and mining wastes? What are the present concentrations of pesticides, of mercury and other heavy toxic metals? In many cases the analytical measurements have never been made. It was not possible, even in the summer of 1970, to state clearly the extent to which such contaminants have been added to the ocean. Hence, it would not be possible to monitor future changes.

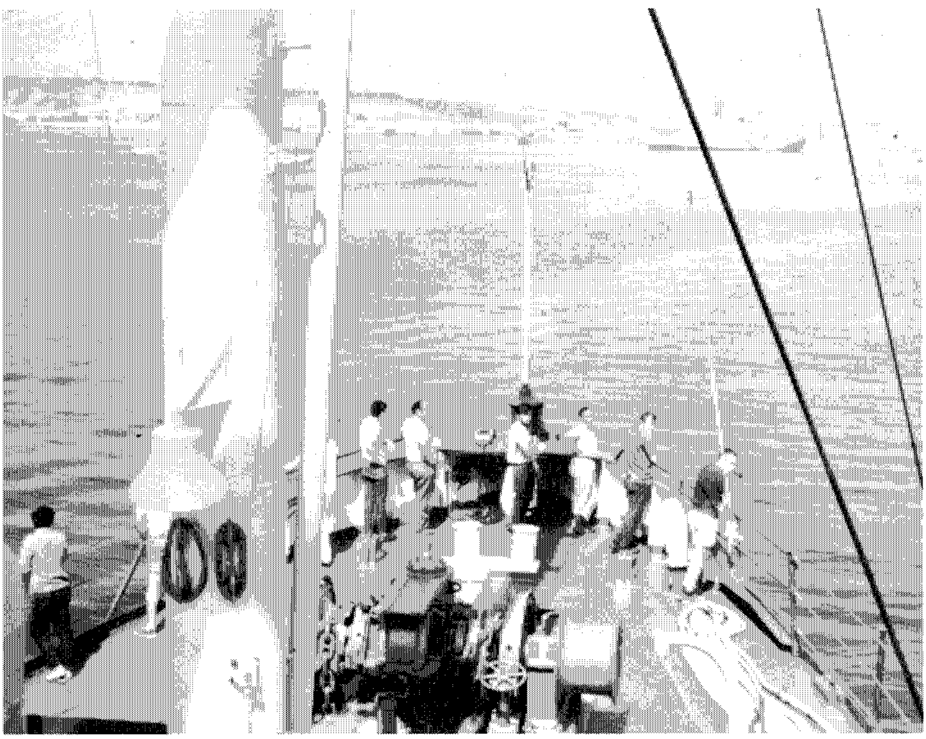
Almost before the last summer's meeting at Williamstown had been held, and well before the report was printed, Woods Hole oceanographers began responding to this need. The ATLANTIS II had long been scheduled by the Biology Department for a cruise from Dakar to Woods Hole, sampling fishes, looking for changes in species, composition and abundance. Out of the Williamstown conference came the stimulus to collect deep-ocean samples and determine whether very minute quantities of various chemicals could be measured. Fishes, plankton and sediment cores were sampled and frozen for transport back to laboratories. Great care was taken not to contaminate the samples, even to quarantining a section of the ship. The results show that with careful precautions the delicate analyses can be carried out.

These data from the ATLANTIS II will become part of a larger collection to be made by the Institution for the International Decade of Ocean Exploration. Between now and November the Institution, together with the University of Rhode Island and the Skidaway Institute, will cooperate with laboratories in Norway, England and Nova Scotia in a survey of contaminants in the North Atlantic. In a world-wide Woods Hole conference, tentatively scheduled for mid-winter, the results of this study will be considered. An avowed purpose of this survey and conference is to establish standards and to inspire other nations to make similar studies. If the work on the ATLANTIS II and the IDOE samples to be collected and analyzed during the coming nine months develops as successfully as I hope, this international meeting of key oceanographers may lay the plan for establishing the world-wide base lines, so essential to any monitoring system.

Coming as it does prior to the U.N. Conference on Human Environment in Stockholm in June of 1972, the information is developing in a timely fashion. We can point with pardonable pride to the fact that Woods Hole work will provide a solid scientific contribution toward the United Nations effort to enhance the human environment. It will be one scientific contribution to the deliberation of world policy makers.

The design and implementation of a global marine monitoring system and the parallel development of international regulatory machinery to insure that safe levels of toxicants are not exceeded are but two examples of the type of policy question on which marine and social scientists must cooperate. There is an impressive range of major marine policy questions which require a similar approach. Through the program in *Marine Policy and Ocean Management,* it is our plan to instigate such studies by post-doctoral and pre-doctoral students of the social sciences and by senior sociologists, legal experts, economists and diplomats who participate in a series of study sessions sponsored by Woods Hole. Scientists from Woods Hole and from other oceanographic institutions will contribute to the thinking of these present and future policy makers as they are examining the problems. I believe that this activity will add an exciting new dimension to the work at Woods Hole. More importantly, the program in *Marine Policy and Ocean Management* provides us with an expanded opportunity to serve.

PAUL M. FYE



CHAIN in Luanda.

Klaus F. Hasselmann, Doherty Professor in the Department of Physical Oceanography.

Report of the Dean of Graduate Studies

The Education Program continues to be centered in the Joint Degree Program with the Massachusetts Institute of Technology. Very heartening progress has been made in the broadening of this effort by the development of programs in ocean engineering and biology. Appropriate joint committees have been established and are functioning. The first students in ocean engineering were admitted a year ago. The first biology students entered in the summer of 1971. There is a continued gratifying trend toward a more even distribution of students' interests as illustrated by the increased enrollment in chemistry and engineering and the addition of biology students. Joint Program students come from 39 different undergraduate institutions. Seven of these are foreign, including four Canadian. The United States institutions are located in twenty different states. Some 40 members of the scientific staff, divided almost equally among Senior, Associate and Assistant Scientists, are involved in teaching, advising, and supervising our degree students.

In the summer of 1970, we continued the scholar-in-residence program as described last year. A rewarding variant in the program was attained by placing the responsibility for planning and management in the hands of two students, H. Michael Byrne and Peter C. Smith. These two young scholars, with the advice and guidance of members of the staff, selected the scholars to be invited and took charge of them upon their arrival. The success of their efforts warrants continued use of students in assisting in the operations of our academic enterprise.

Last year we had a first commencement at Woods Hole. I am sure all who attended agree that it was one of the most dignified, pleasant and appropriate academic exercises ever staged. The first four Ph.D.'s are doing well. Dr. W. Frank Bohlen and Dr. William F. Fitzgerald are both Assistant Professors at the University of Connecticut's new Marine Institute; Dr. Henry T. Perkins is a postdoctoral fellow at the Institut für Meereskunde in Kiel, Germany; and Dr. Albert J. Erickson is a postdoctoral fellow at the Institution. There may be as many as seven new joint degree recipients by this coming June.

As a general policy, we still adhere to the rule that we search for increased quality of students rather than increased numbers. We feel that there will always be places for superior graduates even during times of financial stringency in the research and development world.

Whereas the first two years of our formal program were devoted to establishing the framework of a viable program based on the innovative M.I.T./W.H.O.I. agreement, this past year has been one of consolidation and review. Clearly we have made progress; equally clearly we must continue to reassess our capabilities and our responsibilities.

By action of the Trustees in January of 1970, the Institution is now authorized to accept students for a program leading to the Doctorate conferred by the Woods Hole Oceanographic Institution alone. This authorization is designed to allow us to enroll students whose programs would be best suited by training at the Institution, supplemented by course work as needed at cooperating institutions. To this end, an agreement has been entered into with Harvard University whereby, in appropriate cases, students registered at the Institution may enroll for courses at Harvard, meanwhile continuing the informal arrangement of the past whereby students at Harvard have been able to work at Woods Hole. In a somewhat more restricted sense, a similar agreement is in force with Yale University.

The extent to which the Institution avails itself of this authorization will, of course, depend on the needs of the students. Up to now, the needs of the majority of students seem well served by the M.I.T.-W.H.O.I. degree program and this mechanism will, without doubt, remain the major focus of our efforts.

The general operating philosophy has been set forth in the booklet *Education Programs 1970-71*. The mechanics of the operations of the programs continue to be formulated and monitored by the Joint Committees (three now exist) with the advice and assistance of the Education Advisory Committee of the Institution and the Staff Council. The review of a new group of applicants may well present us with our first instances of applicants whose interests may be best served by Woods Hole registration using cooperative facilities of other institutions. Whether there will be such instances is hard to tell until the applications have been scrutinized in detail. Meanwhile, there is general enthusiastic acceptance of the principle that we give preference to the Joint Degree program whenever appropriate.

I characterized this last year as one of assessment and consolidation. This process will, I trust, continue and certainly there are many questions that need year to year examination. The Woods Hole Oceanographic Institution is primarily devoted to the advancement of knowledge of the oceans and by applying the knowledge gained for the benefit of mankind. Student training must continue to be integrated into the evolving patterns of science — we must not become hardened into a fixed educational structure. All this has a familiar ring in these days of general review by all institutions of learning as to the suitability of their patterns of education. It is indeed refreshing to note that as new plans of other institutions are announced, especially for graduate education, the general recommendations are those which are clearly consistent with our objectives.

In 1970, the Fellowship Committee selected 17 Summer Student Fellows, the extent of our fiscal ability, and guided the overall summer program of these exceptional young men. The same committee makes recommendations for recipients of the Institution's postdoctoral fellowships, which are funded primarily through a grant from the National Science Foundation. Seven awards were made in 1970. The Fellowship Committee also reviews the recommendations for participants in the Geophysical Fluid Dynamics Summer Seminar. Last summer nine fellowship awards were made. This same committee is responsible for maintaining standards and recommending awards under the Institution's Employee Education policy. In the past year, seven awards were made and payments on 11 outstanding awards were approved.

As competition for our summer fellowships has grown, selection based upon demonstrated quality tends to favor advanced undergraduates and graduate students. Therefore, we especially welcomed the Jake Hornor Traineeship to be awarded to a deserving high school student or young college student with sincere interests in the natural sciences. In 1970 this Traineeship was awarded to Mr. William Potter, a high school student with an expressed interest in biological studies, but who otherwise probably would not have had an opportunity to pursue his interests.

Through the interest and advice of individual staff members of the Institution, a number of educational activities are carried out in which we may take pride as a part of our contribution to the public welfare. Staff members continue to be involved in the Secondary Schools' Cooperative Effort in Oceanography. Andrew Konnerth carried a primary responsibility here. St. George's School inaugurated in 1970 a summer practice school in oceanography in Newport. Dr. Haedrich and Mr. Peirson serve as advisors to this program which was very successful indeed. As noted in last year's report, through the efforts of individual staff members, select groups of students are sometimes brought to Woods Hole to study special aspects of marine science. Such short term programs, several of which are being planned for the coming January interim period, I should note, are measured in terms of the intellectual contribution made by involved staff members, not in dollars spent.

H. Burr Steinbach
Dean of Graduate Studies

EDUCATIONAL PROGRAM — ENROLLMENT

1970

Year-Round		*No. of Students*	
M.I.T.-W.H.O.I. Joint Program:			
Resident in Woods Hole	20		
Resident at M.I.T.	34		
Predoctoral Candidates at other Universities	4		
Postdoctoral Fellows	7		
Special Students	5		
TOTAL YEAR-ROUND		70	
Summer			
M.I.T.-W.H.O.I. Joint Program Fellows	33		
W.H.O.I. Summer Student Fellows	17		
Geophysical Fluid Dynamics Seminar Fellows	9		
Jake Hornor Traineeship	1		
Summer Student Employees	60		
TOTAL SUMMER		120	
TOTAL (duplication eliminated)			168

Recipients of Joint Woods Hole Oceanographic Institution-
Massachusetts Institute of Technology
Doctor of Philosophy—1970

DAVID A. CACCHIONE
A.B., Geology, Princeton University
Special Field: Marine Geology
Dissertation: *Experimental Study of Internal Gravity Waves Over a Slope*

ALBERT J. ERICKSON
B.S., Physics, Brown University
Special Field: Marine Geophysics
Dissertation: *The Measurement and Interpretation of Heat Flow in the Mediterranean and Black Seas*

WILLIAM F. FITZGERALD
B.S., Chemistry, Boston College
M.S., Chemistry, College of the Holy Cross
Special Field: Chemical Oceanography
Dissertation: *A Study of Certain Trace Metals in Sea Water Using Anodic Stripping Voltammetry*

HENRY T. PERKINS
B.S., Mathematics, Massachusetts Institute of Technology
M.S., Mathematics, New York University
Special Field: Physical Oceanography
Dissertation: *Inertial Oscillations in the Mediterranean*

The

Henry Bryant Bigelow Medal

awarded to

Frederick John Vine

In recognition of his imaginative
and sound contributions to
man's understanding of the formative
processes active within the earth

by the

Board of Trustees of the Woods Hole Oceanographic Institution

17 June 1970

The ticking of a clock often notes the passage of time. With each moment a man grows older, dreams become reality, or visions fade. As the seconds of their lives inexorably creep past, many strive for wealth. Others, of a breed called scientists, compete and collaborate to lay another stone upon the cairn of knowledge. The small stones are usually and paradoxically the most complex; the giant stones invariably are exceedingly simple in structure.

The man we honor today with the Henry Bryant Bigelow Medal is Frederick John Vine — born in 1939, by the reckoning of our clocks. And we honor him for simply showing us where lies the record of the ticking of another clock, one that lies buried near the center of our planet earth. The ticking of this clock is the polarity changes of the earth's magnetic field, and the record is frozen into the volcanic rocks that make up the crust of the ocean floor.

Unlike our present time-keeping that counts 24 hours in a day, or the eight bells of counting time aboard ships, the earth's magnetic clock has only two conditions of state — with the north pole where it is now (called the normal state), and with the north magnetic pole at the earth's south pole (called the reverse state). Rather than beating regularly, the magnetic clock is quite irregular in the length of time that it remains in any one state. This last aspect of the reversals in magnetic polarity is fortunate: certain patterns of change may be rather unique, serving to identify particular periods of time in the past.

When Frederick Vine was a graduate student at Cambridge University in England, as the story goes, it was suggested that he become involved in studies of magnetic anomalies at sea. At that time, magnetic anomalies were considered the most ambiguous of the geophysical parameters, and therefore most appropriate as interpretation assignments for the junior members of a department.

Among the important findings that had preceded Vine's involvement were the discovery by Mason and Raff of unexplained large-amplitude magnetic anomalies off the western coast of North America. These puzzling anomalies described a lineated pattern more than a thousand kilometers long. The large anomalies required magnetic susceptibilities much higher than could be expected in the rocks of the oceanic crust. Cox and Doell had proved from a study of a succession of lava flows that reversals of the magnetic field had occurred over the past few million years. And, Hess had proposed the astounding concept that the floor of the oceans is young, being formed at the crests of the mid-ocean ridges and being moved outward at an estimated rate of about one centimeter per year.

Vine, together with his dissertation supervisor, D. H. Matthews, made the magnificently simple suggestion that the large-amplitude magnetic anomalies result from the juxtaposition of normal and oppositely polarized rocks, and that their linearity is caused by their having been implaced in a long crack that occurs along the crest of mid-ocean ridges. As the intruded magma cools, it becomes magnetized in the prevailing direction at that time, thus yielding, as the rocks move away from the crust, a striped pattern of magnetic anomalies.

Frederick Vine very ably meets the special consideration of the Bigelow Medal towards an outstanding contribution by a younger scientist. He was 25 years of age when the Vine/Matthews hypothesis was published in 1963. This hypothesis, which is now virtually considered a law, provided a key that has furnished three major contributions to the quantitative understanding of processes active within the earth. It has allowed the rate to be determined at which continents move apart from one another. It has allowed the relative ages of different parts of the ocean floor to be determined. And, it has permitted a definition of the width of the zone in which magma intrudes, cools, and forms new oceanic crust. This zone has proved to be remarkably narrow, no more than a few kilometers wide.

FREDERICK JOHN VINE—*Assistant Professor, Department of Geological and Geophysical Sciences, Princeton University.*

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*
deceased 5 January 1971
Professor of Oceanography, Harvard University

KLAUSS F. HASSELMANN . . . *Henry L. Doherty Professor*

Department of Biology

RICHARD H. BACKUS, Department Chairman, *Senior Scientist*
Associate in Ichthyology, Harvard University
FRANCIS G. CAREY, *Associate Scientist*
EDWARD J. CARPENTER, *Assistant Scientist*
NATHANIEL CORWIN, *Analytical Chemist*
JAMES E. CRADDOCK, *Research Associate*
WILLIAM M. DUNSTAN, *Assistant Scientist*
J. FREDERICK GRASSLE, *Assistant Scientist*
GEORGE D. GRICE, JR., *Associate Scientist*
ROBERT R. L. GUILLARD, *Associate Scientist*
RICHARD L. HAEDRICH, *Associate Scientist*
Associate in Ichthyology, Harvard University
GEORGE R. HAMPSON, *Research Associate*
JOHN E. HUGUENIN, *Research Associate*
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*
CHARLES C. REMSEN III, *Assistant Scientist*
GILBERT T. ROWE, *Assistant Scientist*
JOHN H. RYTHER, *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, *Senior Scientist*
PETER H. WIEBE, *Assistant Scientist*
ASA S. WING, *Research Associate*
CARL O. WIRSEN, *Research Associate*

Department of Chemistry

JELLE ATEMA, *Assistant Scientist*
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*
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JEREMY SASS, *Research Associate*
FRED L. SAYLES, *Assistant Scientist*
DEREK W. SPENCER, *Associate Scientist*
GEOFFREY THOMPSON, *Associate Scientist*
JOHN H. TODD, *Assistant Scientist*
LEE S. WATERMAN, *Research Associate*
THOMAS R. S. WILSON, *Assistant Scientist*
KAI M. WONG, *Research Associate*
OLIVER C. ZAFIRIOU, *Assistant Scientist*

**As of 31 December 1970*

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 W. Bergstrom, *Research Associate*
Carl O. Bowin, *Associate Scientist*
Robert R. Brockhurst, *Applied Physicist*
Wilfred B. Bryan, *Associate Scientist*
Elizabeth T. Bunce, *Associate Scientist*
James A. Davis, *Assistant Scientist*
James A. Doutt, *Research Associate*
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*
Susumo Honjo, *Associate Scientist*
Hartley Hoskins, *Assistant Scientist*
Eli J. Katz, *Associate Scientist*
Sydney T. Knott, *Hydroacoustics Engineer*
Bruce P. Luyendyk, *Assistant Scientist*
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*
Virginia B. Peters, *Research Associate*
Joseph D. Phillips, *Associate 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*
Visiting Professor of Archaeological Geophysics, Brandeis University

Cooperating Scientists U.S. Geological Survey

John C. Hathaway
Frank T. Manheim
Robert H. Meade
Robert N. Oldale
John S. Schlee

Department of Ocean Engineering

Robert D. Ballard, *Research Associate*
Henri O. Berteaux, *Research Associate*
David S. Bitterman, Jr., *Research Associate*
Edward L. Bland, Jr., *Research Associate*
Neil L. Brown, *Electrical Engineer*
Kenneth H. Burt, *Research Associate*
Clayton W. Collins, Jr., *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 M. Marquet, *Instrumentation Engineer*
James W. Mavor, Jr., *Safety Engineer, Mechanical Engineer*
Marvin J. McCamis, *Research Associate*
George H. Power, *Research Associate*
William O. Rainnie, Jr., Manager, Deep Submergence Engineering & Operations Section, *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*
Barrie B. Walden, *Research Associate*
Robert G. Walden, Manager, Buoy Engineering Section, *Electronics Engineer*
Douglas C. Webb, Manager, Instrument Section, *Electrical Engineer*
Jacqueline Webster, *Research Associate*
Valentine P. Wilson, *Research Associate*
Clifford L. Winget, *Electromechanical Engineer*

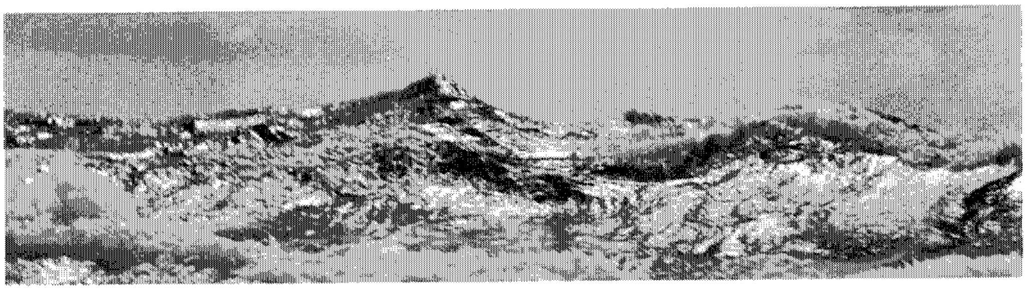
Department of Physical Oceanography

Joseph R. Barrett, Jr., *Research Associate*
Alvin L. Bradshaw, *Applied Physicist*
John G. Bruce, Jr., *Research Associate*
Dean F. Bumpus, *Senior Scientist*
Andrew F. Bunker, *Associate Scientist*
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*

‡On Leave of Absence

Department of Physical Oceanography (continued)

JEROME P. DEAN, *Research Associate*
C. DANA 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*
ARTHUR R. MILLER, *Associate Scientist*
ROBERT G. MUNNS, *Research Associate*
CHARLES E. PARKER, *Research Associate*
F. CLAUDE RONNE, *Photographic Specialist*
THOMAS B. SANFORD, *Assistant Scientist*
PETER M. SAUNDERS, *Associate Scientist*
ROBERT J. STANLEY, *Research Associate*
FOSTER L. STRIFFLER, *Research Associate*
RORY THOMPSON, *Assistant Scientist*
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, *Senior Scientist*
GEOFFREY G. WHITNEY, JR., *Research Associate*
L. VALENTINE WORTHINGTON, *Senior Scientist*
W. REDWOOD WRIGHT, *Assistant 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*



Administrative Staff of the Woods Hole Oceanographic Institution

HENRY G. BEHRENS	Deputy Controller
BRUCE CRAWFORD	Personnel Manager
RICHARD S. EDWARDS	Marine Superintendent
JAN HAHN	Editor, *Oceanus*
DWIGHT F. HAMBLET	Port Engineer
ARTHUR T. HENDERSON	Procurement Supervisor
EDWARD J. HOOPER	Public Relations
CHARLES S. INNIS, JR.	Supervisor, Graphic Arts
ROBERT E. KING	Industrial Liaison
WILLIAM D. LAMBERT	Foundation Liaison
JONATHAN LEIBY	Naval Architect
HARVEY MACKILLOP	Controller
FREDERICK E. MANGELSDORF	Assistant Director
JAMES R. MITCHELL	Manager of Facilities
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

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

Richard M. Goody, *Associate in Meteorology*
Mallinkrodt Professor of Planetary Physics and Director, Blue Hill Meteorological Observatory
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 and Director, Jackson Estuarine Laboratory, University of New Hampshire

Joseph B. Keller, *Associate in Mathematics*
Professor of Mathematics and Director, Electromagnetic Division, Courant Institute of Mathematical Sciences, New York University

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*
Professor of Physics, Swarthmore College

Giles W. Mead, *Associate in Ichthyology*
Director, Los Angeles County Museum of Natural History

David W. Menzel, *Associate in Marine Biology*
Director, Skiddaway Institute of Oceanography, University System of Georgia

Robert L. Miller, *Associate in Submarine Geology*
Professor of Marine Geophysics, University of Chicago

Eric L. Mills, *Associate in Marine Biology*
Associate Professor of Biology, Dalhousie University

James M. Moulton, *Associate in Marine Biology*
Professor of Biology, Bowdoin College

Jerome Namias, *Associate in Meteorology*
Chief, Extended Forecast Division, National Weather Service, National Oceanic and Atmospheric Administration
Washington, D.C.

Geoffrey Power, *Associate in Marine Biology*
Professor of Biology, University of Waterloo, Ontario

Donald C. Rhoads, *Associate in Paleoecology*
Associate Professor of Geology and Research Affiliate in Invertebrate Paleontology, Peabody Museum, 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, National Weather Service, National Oceanic and Atmospheric Administration
Coral Gables, Florida

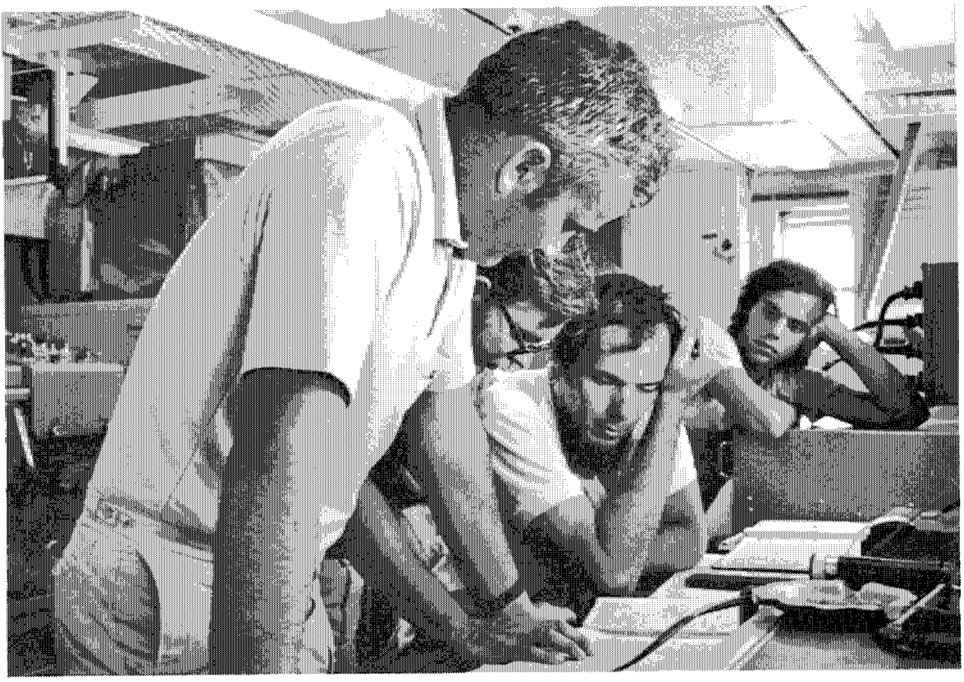
Edward A. Spiegel, *Associate in Astrophysics*
Professor of Physics, New York University

Henry M. Stommel, *Associate in Physical Oceanography*
Professor of Oceanography, Massachusetts Institute of Technology

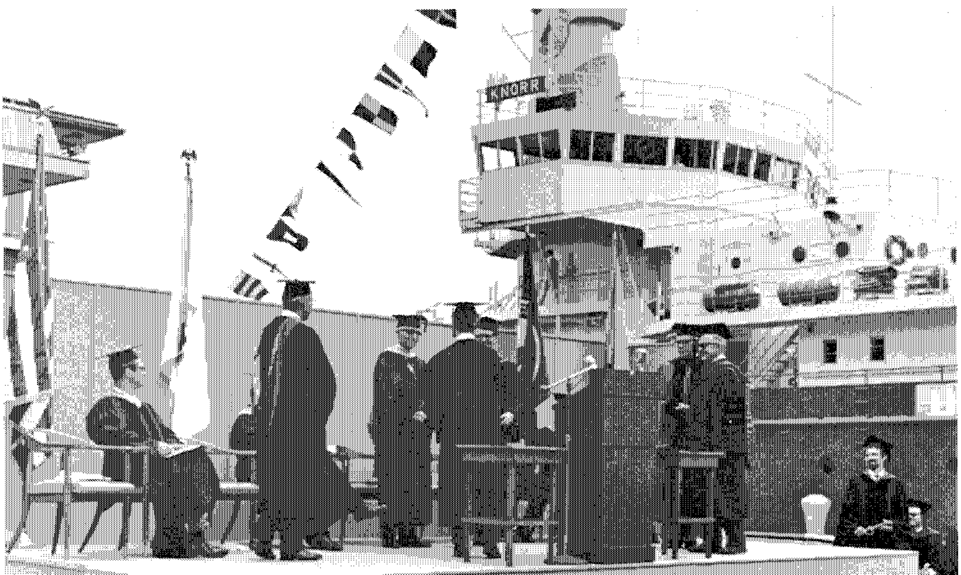
George Veronis, *Associate in Mathematics*
Professor of Geology and Applied Science, Yale University

Pierre L. Welander, *Associate in Physical Oceanography*
Professor of Oceanography (Visiting), Massachusetts Institute of Technology

Alfred H. Woodcock, *Associate in Oceanography*
Meteorologist, Institute of Geophysics, University of Hawaii



George T. Needler (left) the Rossby Fellow for 1970, and shipmates (left to right), Robert C. Millard (WHOI), Peter Rhines (M.I.T.) and Eric J. Brown (Harvard), aboard ATLANTIS II.



After the First Graduation.

Grants and Fellowships

Rossby Memorial Fellow

GEORGE T. NEEDLER
Atlantic Oceanographic Laboratory
Bedford Institute, Dartmouth, Nova Scotia, Canada

Year-Round Postdoctoral Fellows

Awarded 1970:

WEN M. CHANG
Virginia Polytechnic Institute

ALBERT J. ERICKSON
Massachusetts Institute of Technology
Woods Hole Oceanographic Institution

KURT R. GEITZENAUER
Florida State University

RICHARD S. SCOTTI
University of California, Berkeley

KENNETH L. SMITH, JR.
University of Georgia

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

Recipients of Woods Hole Oceanographic Institution Fellowships and Assistantships

Academic Year 1970-71:

CARL S. ALBRO
University of Massachusetts

ZVI BEN-AVRAHAM
Hebrew University, Israel

BRIAN BORNHOLD
Duke University

KATHRYN A. BURNS
Michigan State University

RICHARD BURROUGHS
Princeton University

H. MICHAEL BYRNE
Boston College

DANIEL P. CHARNEWS
New York State University

REINIER A. COURANT
Northeastern University

ROBERT A. FOLINSBEE
Massachusetts Institute of Technology

RONALD C. GULARTE
University of Southern California

GEOFFREY G. HALLOCK
Massachusetts Institute of Technology

RICHARD J. JAFFEE
Brown University

ANDREW E. JAHN
University of California, Davis

JOSEPH C. MACILVAINE
University of California, Berkeley

KENNETH MOPPER
Queen's College, New York

JAMES W. MURRAY
University of California, Berkeley

JEAN A. NICHOLS
Pomona College

CHARLES G. PARIS
Rensselaer Polytechnic Institute

PETER F. PORANSKI
Newark College of Engineering

BARBARA RAY
University of Hawaii

PETER C. SMITH
Brown University

WILLIAM G. SUNDA
Lehigh University

BRIAN E. TUCHOLKE
South Dakota School of Mines
and Technology

CHRISTOPHER WELCH
Wesleyan University

ROBERT A. YOUNG
Brooklyn College

Summer 1970 Only:

BRIAN ANDRESEN
Florida State University

TERRENCE L. BURCH
Swarthmore College

BRADFORD BUTMAN
Cornell University

T. GRAY CURTIS
Massachusetts Institute of Technology

DONALD W. FORSYTH
Grinnell College

ROSS M. HENDRY
University of Waterloo, Canada

EDWARD LAINE
Wesleyan University

CHI-YUAN LEE
National Central University, Taiwan

HEAU S. MA
University of Oregon

RONALD R. REGAL
Wabash College

KURT SCHNEBELE
University of Washington, Seattle

DANIEL H. STUERMER
University of California, Santa Barbara

Summer Student Fellows

Awarded 1970:

ROBERT E. BARLETTA
University of Rhode Island

ERIC J. BROWN
Harvard College

LOUIS R. D'ABRAMO
Assumption College

ROBERT S. DETRICK
Lehigh University

ROBERT H. K. ENG
University of Washington, Seattle

DON E. HARRISON
Reed College

ALAN HOENIG
Yale College

JOHN W. LEFFLER
Albright College

HECTOR J. MARCHAND
John Carroll University

CHARLES B. MILSTEIN
University of Puerto Rico

BERL R. OAKLEY
Duke University

MICHAEL A. REX
Harvard University

JAMES G. RICHMAN
Harvey Mudd College

DENNIS W. SCHMIDT
University of Cincinnati

SETH TYLER
Swarthmore College

THOMAS J. WEILER
Stanford University

CHARLES H. WOERNLE
Franklin & Marshall College

Geophysical Fluid Dynamics Seminar

Staff Members and Lecturers

FRIEDRICH H. BUSSE
Max-Planck Institute, Munich, Germany

JACKSON HERRING
Goddard Space Flight Center, National Aeronautics and Space Administration

RAYMOND HIDE
Meteorological Office, Berkshire, England

LOUIS N. HOWARD
Massachusetts Institute of Technology

ANDREW P. INGERSOLL
California Institute of Technology

ROBERT H. KRAICHNAN
Dublin, New Hampshire

MARTEN LANDAHL
Massachusetts Institute of Technology

CECIL E. LEITH
National Center for Atmospheric Research, Boulder, Colorado

WILLEM V. R. MALKUS
Massachusetts Institute of Technology

BERNARD MATKOWSKY
Rensselaer Polytechnic Institute

TONY MAXWORTHY
University of Southern California, Los Angeles

STEVEN A. ORSZAG
National Center for Atmospheric Research, Boulder, Colorado

JOSEPH PEDLOSKY
University of Chicago

ELLIOTT E. SCHULMAN
National Center for Atmospheric Research, Boulder, Colorado

RICHARD C. J. SOMERVILLE
Courant Institute, New York University

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Columbia University

MELVIN E. STERN
University of Rhode Island

WILLIAM STREETT
U.S. Military Academy

HENRY STOMMEL
Massachusetts Institute of Technology

GEORGE VERONIS
Yale University

CARL WUNSCH
Massachusetts Institute of Technology

Fellows

YVES J. DESAUBIES
University of California, San Diego

WILLIAM B. HEARD
Yale University

E. JOHN HINCH
University of Cambridge, England

JOEL E. HIRSH
Harvard University

NELSON G. HOGG
Massachusetts Institute of Technology

PAUL F. LINDEN
University of Cambridge, England

FRANK M. RICHTER
University of Chicago

D. RANDOLPH WATTS
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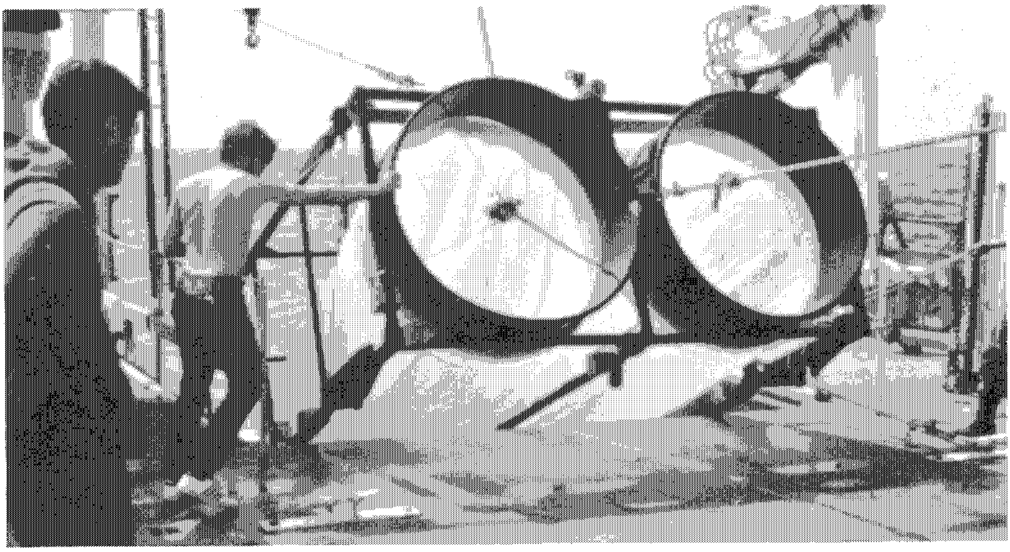


Longhurst-Hardy Recorder System for sampling zooplankton from very small spatial intervals. (See also figure, page 37, for detail of collection device in the tail of the nets.)

Department of Biology

One way to represent the diverse activities of the Department of Biology is in terms of the organic cycle itself. The growth of phytoplankton produces organic matter that is consumed by herbivorous zooplankters. Some of the energy and material passes up through successive levels of carnivores. Dead organisms of all sorts and their wastes are reduced by bacteria to the elemental constituents used in plant growth. These processes of the organic cycle are under study at almost all levels by department scientists, and the morphology, physiology, and biogeography of a great variety of organisms from diatoms and nitrifying bacteria to porpoises and tunas are of present concern. Almost all of this work is properly described as ecology; that is, it concerns interactions between living things and living things and their surroundings. Much of the work mentioned here has immediacy in terms of pollution and other "environmental" problems. This is not because of any great redirection of our work, but rather is simply due to the fact that our basic research in the ocean has always been "ecological" by choice and so is "environmental" by definition.

Microbiology

Experiments completed during the year show that the remarkable preservation of the food which sank with ALVIN to 5,000 feet and was exposed to the sea for 10 months was no happenstance. Additional samples have been lowered to about 5,000 m and exposed for 2 to 5 months. These were degraded from about 10 to hundreds of times more slowly than others held in the laboratory at comparable temperatures. The reasons for the difference are little understood, but the implications are great so far as waste disposal in the deep ocean goes.

The successive degradation of an organic substrate in seawater by different bacteria indicate that fatty acids represent intermediate products of the microbial oxidation of hydrocarbons. These compounds were thus specifically selected for further investigation. Enrichments from decomposition products of the fatty acids have been obtained in multi-stage chemostats. It is hoped that a system will yield isolates that can be grown commensally in single-stage chemostats in order to ascertain the energetic relationships during the breakdown.

In examining the morphology and growth kinetics of a typical aquatic bacterium, *Spirasoma* sp., the morphological variability of the cells appears to be dependent on the growth rate. The saturation coefficient for growth decreases with decreasing temperatures. This implies a relatively fast growth rate of these organisms at low temperatures and an advantage in the competition for organic substrates at the low levels occurring in natural waters.

A large number of colorless sulfur bacteria from various marine environments have been isolated and grown in pure culture. In contrast to earlier work on marine sulfur bacteria, most isolates grew readily on organic substrates. Our data on productivity and the microbial transformation of sulfur compounds in the Black Sea give conclusions not in agreement with those of Russian microbiologists in that the photosynthetic production of organic carbon is sufficient to account for the amount of hydrogen sulfide produced by bacterial sulfate reduction.

The activity of nitrifying bacteria was examined in a local body of water with the hope of explaining seasonal and yearly fluctuations in their numbers. It was shown that: (a) As water temperature and amounts of urea and ammonia increased, the numbers of urea, ammonia, and nitrite-oxidizing bacteria also increased; (b) expected trends of these bacteria occurred after seasonal blooms when nutrient levels were high; (c) peaks in the numbers of ammonia-oxidizing bacteria always occurred after peaks in the number of urea-oxidizers. Among forty cultures of nitrifying bacteria originally isolated on urea, some prefer urea to ammonia as an energy source in nitrification. Two advances in the biochemistry of nitrification, namely, cell-free ammonia oxidation by *Nitrosocystis oceanus* and *Nitrosomonas europaea,* and cell-free nitrite oxidation by *Nitrococcus mobilis* have also been reported.

Examination of the fine structure of the nitrifying bacteria has continued. The structure of the cell wall of *Nitrosocystis oceanus* is by far the most complex viewed to date. Variations in the basic arrangements of macromolecular subunits in the cell walls of marine autotrophic bacteria have been observed. It appears that common cultural or environmental factors may account for morphological similarities.

Using urea as a substrate for nitrification, the average population of nitrifying bacteria in the lower Mississippi River (from New Orleans to Pilottown) was determined. Despite their presence, most of the inorganic and organic compounds present in the river at New Orleans entered the Gulf of Mexico in a relatively unchanged state. The little microbial activity that does occur in the river, is inhibited by salt water intrusion.

The Mediterranean Sea has been continuously exposed to the waste products of sizable civilizations since early recorded time. Thus, it offers a unique opportunity to learn about the long-term effects of organic enrichment on an entire marine ecosystem. A recent cruise there permitted an evaluation of the biochemical activity characteristic of some representative off-shore locations. In view of the prevailing tendency for isolated natural waters to become overfertilized with organic residues, we were especially anxious to assess the level of heterotrophic activity of microbial populations. Previously, it had been shown in the Atlantic that where organic degradation is relatively complete, i.e., at locations in mid-ocean, heterotrophic activity is minimal and often unmeasurable. Conversely, where relatively rapid turnover rates for organic carbon obtain, i.e., in organic-rich estuaries and coastal waters, heterotrophic activity is relatively intense. Offshore Mediterranean waters showed little evidence of over-exposure to organic matter. Excepting for certain harbors and coastal areas, the level of heterotrophic activity in the Mediterranean is not unlike that previously encountered within a broad oligotrophic area of the western Atlantic.

The distribution of urea was determined in surface waters off the shelf between Panama and Callao, Peru. Non-upwelling water areas had lower concentrations than upwelling ones. On the continental shelf between Cape Cod and Cape May concentrations at the 1,000-fathom line were one-fortieth of those in New York Harbor. Absolute values in the upper twenty-five meters south of Callao, Peru, were higher than those off New York, but the amount relative to the measured nitrogen was considerably lower. High values in upwelling waters seem to be a consequence of excretion by marine organisms. High values observed at the mouth of the Hudson and Raritan Rivers and in the lower Mississippi River are most certainly a consequence of pollution with a terrestrial source. However, relatively low values were found immediately seaward so that it appears that urea is rapidly diluted, broken down or assimilated.

Other investigations of nutrients between Cape Cod and Cape Hatteras showed high levels for all within New York Harbor. However, a short distance outside, where sewage sludge and dredging spoils are dumped, and elsewhere on the continental shelf, inorganic nitrogen compounds occurred only in traces. Nitrogen concentrations in coastal waters in general were lower than those offshore. On the other hand, the concentration of inorganic phosphorus was higher on the shelf than at the offshore stations. Further, a gradient was observed, from high in heavily-polluted coastal waters to low in oceanic waters. Growth of the coastal diatom, *Skeletonema costatum,* added to water enriched with ammonium-nitrogen and phosphate-phosphorus respectively, was compared to that in unenriched control samples. In most cases, growth was greatly enhanced when ammonium-nitrogen was added, but in the phosphate-enriched samples it was no better than or worse than that in the controls. It was concluded that eutrophication of the coastal marine environment, unlike that of many fresh water situations, is normally limited by the amount of available nitrogen rather than by available phosphorus. Removal of the phosphates from household detergents, which accounts for about half the phosphate in domestic wastes, will therefore not alleviate the problem of marine eutrophication. If the phosphate in detergents is replaced with NTA (nitrolotriacetic acid), which contains nitrogen and presumably breaks down to amino acids and, eventually, to ammonia, the net effect may be an enhancement of algal growth in the coastal marine environment.

Plant Physiology, Ecology, and Distribution

Since urea can serve as a substrate for nitrification it was felt that it might sometimes serve as a nitrogen source for phytoplankton. Six diatoms were isolated into bacteria-free culture from urea-enriched seawater. These phytoplankters grew with urea as the sole nitrogen source. Moreover, the diatoms were able to use urea at concentrations normally found in the sea.

A continuous-flow culture system has been used to determine the effects of secondary-treated sewage on natural phytoplankton populations. Tested were: (1) the potential toxicity of sewage effluents; (2)

the productivity of plants in seawater-sewage continuous culture; (3) changes in species structure in sewage-enriched natural phytoplankton populations. Secondary-treated sewage diluted in seawater proved to be an excellent growth medium for marine phytoplankton and the toxic effects were slight. Using 15-liter innocula of natural populations from Vineyard Sound and various amounts of sewage, a concentration of sewage equivalent to 100 μg A NH_4-N gave optimal production. Maximum cell-density and carbon production per liter were maintained at turnover rates of over 50% of the culture volume per day. A laboratory system is in operation which uses the output from continuous sewage-enriched algae cultures for the feeding of oysters and other bivalve molluscs.

In a separate study, the effects, on brackish water phytoplankters, of a long-term temperature increase (5°C over ambient) and the addition of domestic sewage were determined. A temperature increase and the sewage addition significantly altered the species composition and concentration of phytoplankters.

Clones of three species of phytoplankton from offshore had lower half-saturation constants for nitrate uptake than the clones from inshore. Thus, the offshore ones are more efficient in the uptake of nitrate at low concentrations than the inshore ones.

Facultative heterotrophy in the economy of certain diatoms recently isolated by procedures that select for heterotrophic potentials is under investigation. The nature of suitable carbon sources, definition of the kinetics of uptake, the effects of superposition of heterotrophic growth upon autotrophic growth, and the effects of organics on survival in darkness are being examined.

A preliminary analysis showed that the major factor associated with variations in the phaeo-pigment content of cores were variations in the surface chlorophyll concentration, not the water column depth. This would indicate that deposition of these pigments is probably a rapid process, perhaps by the sinking of large particles (a few hundred microns) or even by an active transport wherein animals engaged in large vertical migrations defecate at great depths.

Shipboard studies were made of natural phytoplankton populations between Malta and Woods Hole via the Canaries and Cape Verdes. Changes in the phytoplankton were correlated with changes in hydrographic conditions. Noted were floral changes in an upwelling area of northwest Africa and a biogeographic boundary at about 20°N near the Cape Verde Islands and a 10-fold increase in cell-count in crossing from the southern to northern Sargasso seas along the meridian 47°W.

A method has been developed for the measurement of ocean color from aircraft. The method makes possible the delineation of different water masses; conditions beneficial or harmful to biological production may be detectable. Among biological materials exhibiting characteristic spectral signatures, chlorophyll is the most important, since it is an index of the abundance of phytoplankton. Concentrations of chlorophyll ranging from 0.05 to 4 mg/m^3 were detected. A great range of ocean color conditions was viewed ranging from bright blue, through various shades of green and brown, to the bright salmon pink of red tide patches. Over 3,000 spectra of backscattered light are now on hand.

A study of salt marsh production under the influence of artificial fertilization was begun in cooperation with the Marine Biological Laboratory. Grasses in the fertilized areas showed little increased growth, but they were greener and produced more seeds. Diatoms on the marsh surface showed increased growth as well as changes in species. Although analysis is incomplete, there seemed also to be an increase in soil fauna in the fertilized areas. The only deleterious effect noted was an increased mortality of fiddler crabs in late fall.

We also measured production at the Wild Harbor marsh oiled by the barge accident of a year ago. The grass (*Spartina*) was completely killed wherever oil reached the roots of the plants. *Spartina,* whose roots were flooded with water during the period when the oil settled, survived as did *Spartina* above the oil level.

Animal Ecology and Distribution

The logarithms of biomass and density of the macrobenthos from samples in the Gulf of Mexico, off Peru, on the shelf and slope south of Gay Head, and in the Hudson Submarine Canyon have been regressed on depth. It was concluded that there is approximately a ten-fold decrease in the abundance of life with every 2,000-meter increase in depth. A comparison of the Gulf and Peru indicates that there was approximately 100 times more benthos off Peru than in the Gulf, even though primary productivity appeared to be only 10-50 times greater off Peru. This suggests that primary production was of great significance in controlling the deep-sea biomass. Minimum biomass off Peru, was at 319 m, where the core of the oxygen-minimum layer contacted the bottom and the community was composed almost entirely of nematode worms. Record densities for sublittoral macrobenthos were observed at the head of the Hudson Submarine Canyon. The organic-rich, fine mud in the Canyon trough contained from 50,000-100,000 animals/m^2 ($>$ 0.42 mm), mostly various polychaete worms, whereas in adjacent fine to coarse sand estimated ranged from about 1,500-5,000 animals/m^2. It is not now possible to say whether the dense populations in the shallow canyon survive in spite of or because of the nearby dumping of wastes.

The habits and statistical parameters characterizing populations of macroscopic epifauna in photographs have been used to differentiate canyon versus non-canyon environments at various depths. We are now able to describe certain faunal characteristics of the Hatteras, Wilmington, Hudson, Atlantis, Veatch, Hydrographer, and Oceanographer canyons. There appear to be species which can be considered "canyon indicators" because they have not been seen outside these topographic anomalies. On the other hand, many species which dominate the typical continental slope were absent from the canyons or occurred in significantly reduced densities.

The recovery following an oil spill off West Falmouth has been documented by taking monthly samples over most of the Wild Harbor and Wild Harbor River areas. The most sensitive indicator of oil pollution is the amphipod family Ampeliscidae, which are eliminated by even low concentrations of oil. The kill of amphipods and other species continues to occur as they attempt to settle in heavily oiled areas. The sequence of species coming into the oiled areas is useful in classifying animals according to their ability to survive in very strictly regulated environments.

Using a new coring device designed for deep-sea benthos, a number of samples have been taken at 1,500 m on the Gayhead-Bermuda transect. Initial results indicate numbers of individuals and species similar to those obtained at this station with an anchor-dredge. Positions of individual species in a large number of cores will provide information on differences in scale of patchiness of deep-sea animals.

The "long-distance" larvae of shoal-water bottom-dwelling organisms of the shelf that are caught in the surface-waters of the open sea have been designated *teleplanic* larvae or *teleplanos*. These larvae have a development of long duration and are most commonly found among tropical and warm temperate species. Because very few taxonomic investigations have been made on the larvae of the tropical benthos, their adult affinities are largely unknown. Approximately twenty species of gastropods can now be identified to species and a number of others to family or genus. Likewise progress has been made in identifying the teleplanic larvae of sipunculids using characteristics of the larval cuticle.

A comparison of five species of tropical prosobranch gastropods with wide geographical distributions shows that species estimated to have a high frequency of larval dispersal display little or no consistent morphological difference between eastern and western Atlantic populations. Conversely, species having lower rates of dispersal are represented by different subspecies on either side of the Atlantic Ocean.

The stability and nutritive value of particulate organic carbon (POC) concentrated from shallow and deep oceanic waters off South West Africa was examined. The carbon in samples of concentrated POC stored for not less than 90 days at 20°C decreased 68 and 43% for shallow (< 300 m) and deep (< 300 m) samples respectively. However, newly hatched nauplii of *Artemia* given concentrated POC as food survived no longer than control animals maintained without food.

A preliminary test on the effects of passage through the heat exchangers of a nuclear power plant has shown that zooplankton nauplii are reduced by about 50%. Chlorination at 0.2 ppm (done intermittently to reduce fouling) reduces the nauplii by about 90%. A similar reduction was shown for six diatom species, but twelve other species were unaffected.

A Longhurst-Hardy Plankton Recorder System was field tested in the Mediterranean Sea and used to obtain profiles of the distribution of zooplankton in the upper

Zooplankton entering in water at lower right is entrapped on gauze tape which is then wound onto spool.

1,000 meters of water off northwest Africa. It was used in a continuing effort to assess the standing crop of zooplankton in high and low-production areas and the flux of living carbon from surface to depths resulting from vertical migration.

Mediterranean zooplankton collected between Rhodes, Greece, and Gibraltar contained bathypelagic copepods, but the species were few in comparison to those taken at comparable depths in the North Atlantic Ocean. Twenty-five deep zooplankton samples collected in the Red Sea did not contain a single bathypelagic copepod species. Studies on the zoogeography and speciation of the calanoid copepods of the family Candaciidae are continuing. Species from 150 plankton stations in the Indian Ocean have been identified, counted and measured.

The fishes taken in 125 midwater trawls from the Mediterranean Sea and eastern Atlantic in 1969 (ATLANTIS II Cruise 49) have been identified. Eastern basin-western basin differences are marked in the Mediterranean collections. A number of mesopelagic species not inhabiting the Mediterranean occur just west of the Strait of Gibraltar. Some of these move upward at night into waters as shallow as 100 meters. This is an indication that the Strait is not acting purely as a mechanical filter in keeping these species out of the Mediterranean. The analysis of Gulf of Mexico and Caribbean Sea collections (about 40,000 specimens in about 230 species; CHAIN Cruise 60) is nearing completion.

The Gulf and the Caribbean fish faunas differ somewhat from one another and both are significantly richer than those from the adjacent Atlantic. Collections taken in 1968 on CHAIN Cruise 85 across the Sargasso Sea on a north-south axis show that the region of thermal fronts is as significant a faunal boundary in the early winter as an earlier cruise showed it to be in early summer. About 120 midwater trawls were made on ATLANTIS II Cruise 59 between Madeira and Woods Hole via the Cape Verdes in November and December. All of these are a part of a long-range one to understand mesopelagic fish distribution in the Atlantic Ocean and to divide the Atlantic pelagial into faunal regions.

The 1970 season, with more than 2,000 releases and 200 returns in the Atlantic to date, brought the respective totals for our Cooperative Game Fish Tagging Program to over 37,000 and nearly 2,700. Results for bluefin tuna included the first proof of east-west transatlantic migration of a school of bluefin tuna, the first recapture in the western North Atlantic of giant bluefin tagged in the Straits of Florida, and the highest return rate ever realized in the Atlantic for small bluefin. Tag returns for white marlin, sailfish, and greater amberjack gave much additional information on the movements of these species.

Animal Physiology and Behavior

Direct observations showed that planktonic animals were immobilized by pressures of 500 atmospheres whether collected at the surface or between 1,000 and 1,500 meters depth. On return to lower pressures, the deep-living forms recovered but the surface forms did not. In contrast, some animals from intertidal and shallow waters showed as much pressure tolerance as some of the deepest forms tested. Respiration was measured mostly in species other than those used for the direct observations. Oxygen uptake typically continued during the high pressure exposure, but ceased when pressure was reduced by fifty atmospheres.

Continuing the investigations of warm-bodied fishes, temperature measurements were made and experiments carried on with acoustic telemetry of temperature from free-swimming fish. Acoustic transmitters were of two types. One was implanted in muscle with a thermistor harpoon and telemetered water and muscle temperatures. The second was forced down the fish's throat and telemetered stomach and water temperatures. There were fourteen experiments on thermoregulation in free-swiming bluefin tunas. In one, a bluefin with a stomach transmitter swam from the surface water into depths as much as 11°C colder and remained there for four hours before returning to warmer water. During this sharp and prolonged change in water temperature the stomach temperature remained essentially constant. This is a clear demonstration that this species can regulate its deep body temperature to a constant value during abrupt changes in the external water temperature.

In cooperative work with scientists of the U.S.N. Undersea Research and Development Laboratory, use was made of a porpoise trained to dive to a given depth, return to the surface, and breathe out under a funnel. Analysis of the expired air shows that the lungs collapse as the animal goes down. This allows the porpoise to spend time at depth without subsequent danger of the bends. Back at the surface the animal takes 10 to 15 rapid breaths during which carbon dioxide in the expired air is higher than normal. The heart rate does not show the usual slowing. Apparently circulation is kept at a maximum so the carbon dioxide can be transported to the lungs for unloading. By telemetry of heartbeat and "commanding" individual breaths from the porpoise we have been able to detail the course of this process. Further, a temperature transmitter was placed in the porpoise's stomach. This allows monitoring of the frequency of eating and sea water swallowing and some inference on the sea water load to the kidneys.

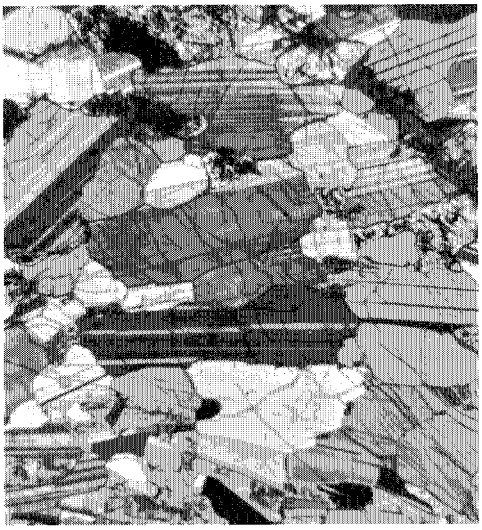
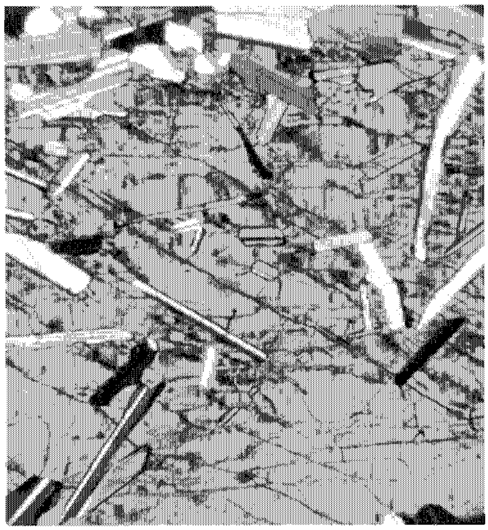
Work on diver instrumentation for the coming lock-out dives with the Link-Smithsonian submarine has been in three parts. First are instruments to monitor the diver physiologically. Transmitters relay information on heart beat and breathing including the partial-pressure of oxygen in the closed-circuit breathing device. Second, we have built single side-band acoustical devices which allow the diver to keep in communication with the surface. Helium speech difficulties place an added burden on intelligibility and bandwidth. Last has been the problem of keeping track of the diver and also of his keeping track of the boat. A transponder on the diver answers an interrogating ping from the surface (or submarine) and gives distance and direction. For the diver we have tried a Doppler wand. This is a receiver which the diver can wave in a circle. The corresponding frequency shift of an audio tone tells the direction to the transmitter.

From September 28 through October 16 simultaneous radar observations were made at the following stations: St. Margarets (New Brunswick)*, Sydney (Nova Scotia)*, Barrington (Nova Scotia)*, North Truro (Massachusetts), Otis Air Force Base (Massachusetts), Wallops Island (Virginia), Bermuda, Antigua, and San Juan (Puerto Rico). Movements of birds leaving the coast of the U.S. and heading east or southeast were recorded. This easterly movement continued at Bermuda. Movements at San Juan were along the chain of the West Indies. Movements at Antigua were from west to east across the island. Preliminary analysis of the data from Bermuda and Wallops Island indicates that the eastward moving targets may be flocks of small shore birds. Their flight destination remains a mystery. Radar data indicates that birds are able to maintain orientation over the open ocean without reference to land marks, that birds flying over land do not need landmarks if they can see the sky, but that birds do use landmarks, such as coastlines, if the sky is overcast. Timing of flights between the mainland and Bermuda indicates that even small birds such as sandpipers are able to fly for more than 30 hours without rest.

After a short period of initial disorientation blindfolded gulls were able to take off and land successfully on the water and make sustained flights of more than ½ hour at altitudes of at least 800′. Flight without vision in herring gulls strengthens our conclusions concerning the ability of birds to migrate without visual reference points. Fifteen herring gulls with 400-MH_3 radio transmitters were released during the 6-week nesting season. Under clear skies the birds flew toward their home colony unless they faced strong headwinds in which case they flew a compromise course between the homeward direction and the course to nearest land. When released in heavy fog, birds wander in a disoriented fashion until they reach some land area; they then reorient their flight towards home. Birds released during heavy rain did not fly more than ¼ mile from the release point.

RICHARD H. BACKUS, *Chairman*

*In cooperation with the Canadian National Research Council.

Photomicrographs of laminated gabbro.

Department of Chemistry

During 1970, we expanded our program in hydrochemistry and biochemistry with increased emphasis on the problems of pollution and its effect on marine organisms. Our studies of chemical communication in aquatic animals and the effects of both chemical and thermal pollution were strengthened through the additions to the staff of a neurophysiologist, a fish behaviorist and an ecologist. As in the past, several projects were carried out in cooperation with members of other departments, primarily, biology and geology. Increased efforts have been given to two major programs with other institutions: the Geochemical Ocean Sections Study (GEOSECS) of the International Decade of Oceanographic Exploitation and the porewater and organic chemistry studies of the Deep Sea Drilling Project. Late in 1970, we cooperated with the Biology Department in initiating an interdisciplinary survey of the effects of pollutants on marine organisms which will also be supported by the International Decade of Oceanographic Exploitation. The projects of the department are divided into four major categories: hydrochemistry, radiochemistry, organic and biochemistry, and geochemistry.

Hydrochemistry

In the Black Sea the dissolved trace metals in the water column can now be classified into three groups based on their reaction with the oxygenated surface waters and the deeper hydrogen sulfide waters. Metals such as zinc and copper, which form insoluble sulfides, are markedly depleted in the deep water. The presence of low levels of these metals in many water samples indicates that some of them are complexing with organic materials in a manner which prevents their complete precipitation as sulfides. The second group includes metals such as iron and manganese which undergo oxidation-reduction reactions while diffusing from the hydrogen sulfide zone to oxygenated waters and back. For example, manganese reaches a maximum concentration 30 meters below the oxygen-hydrogen-sulfide interface due to the fact that the metal precipitates as manganese dioxide in the surface waters and then redissolves in the hydrogen-sulfide waters. The third group of metals are those unaffected by the change in oxygen such as nickel and cobalt.

A calculation of the organic carbon budget of the Black Sea indicates that 80% of the primary carbon production is recycled in the upper 200 meters (the oxic zone) and 4% is permanently fixed in the sediments. About four-fifths of the organic carbon falling into the anoxic zone is either oxidized by bacteria or rendered soluble. Detailed analyses of the carbon and oxygen isotope ratios of the sediments have defined the hydrographic history of the past 17,000 years. From that time to about 8,000 years ago the Black Sea was essentially a freshwater body whose waters were supersaturated with calcium carbonate. During the last 8,000 years salt water has entered through the Bosporus in increasing amounts as a consequence of the world-wide rise of sea level. This influx caused density stratification leading to anoxic bottom condition. The anoxic layer rose to its present level about 3,000 years ago and has resulted in an extremely high fixation of organic matter in the sediments, in some cases exceeding twenty percent.

A 280-page bibliography of the scientific literature on the Black Sea was compiled in the fall of 1970 to assist participants in the program and to provide a reading list for future studies of the area. It was distributed to Black Sea collaborators in Russia, Turkey and other countries.

Another program has involved sampling for trace elements and particulate matter in Antarctic intermediate waters. This was carried out in the Drake Passage aboard the C.S.S. HUDSON of the Bedford Institute. The samples were taken on a line south of Cape Horn to the Antarctic continent in the Bransfield Strait. Water in the Drake Passage was remarkably free of particulate matter except for plankton in the upper 200 meters. Trace metal analyses are now being carried out with the hope of determining whether the Antarctic region is a source of dissolved trace metals from continental weathering or a sink for metals from fixation by biological productivity.

Particulate matter in surface waters of the ocean is largely organic consisting of living and dead plankton plus some mineral matter. The mercury content of this material in coastal waters from Long Island to the Gulf of Maine varies from about 0.1 to 20 ppm on a dry weight basis. This is higher than was expected since similar samples from the Antarctic region have about 1 ppm mercury. We are now trying to determine if these higher values are due to pollution or if some areas have a naturally high content of mercury in the particulate matter. We have also developed a method for the determination of arsenic in sea water using neutron activation.

Inter-laboratory calibrations for trace elements, carbon isotopes and other chemical parameters are being carried out in preparation for the Geochemical Ocean Sections Study which is to start in 1972. Intercalibration of carbon isotope measurements showed excellent agreement between two of the three participating laboratories, and it appears that it will be possible to compare profiles from different laboratories on deep-sea samples. A total of twenty-one trace elements analyzed by twenty laboratories, however, showed wide disagreement even though most variances were small at any one laboratory. The errors appear to be due to variations in the quality of the standards, as well as to difficulties in determining some metals that exist in very low concentrations. Further intercalibrations are planned between those laboratories that will participate directly in the GEOSECS program.

The difference chromatography method of analyzing for small differences in the major ions of sea water is being applied to 810 samples collected during the circumnavigation of the Americas by C.S.S. HUDSON early in 1970. Preliminary results indicate that significant regional variations in the calcium-depth profile appear to be related to the carbonate ion concentration. In contrast, the relative concentrations of sodium to potassium and magnesium show less than a 0.1% variation. In considering the influence of salt fingering on ionic composition in a simple two-layer laboratory model system, it appears that the upper hot layer is enriched by the more mobile potassium ion at the expense of the lower cooler layer.

A portable salinometer suitable for field and laboratory use has been designed and tested to show an accuracy of 1% of the salinity reading over the range 1 to 40 ‰ salinity. The instrument is lightweight, simple in design and unaffected by suspended material in the water. These advantages make it particularly useful for investigations of estuarine circulation and salt marsh ecology. An *in situ* salinometer based on the same principle has been designed and is under construction. This instrument should enable us to obtain salinity profiles with depth more rapidly and at a lower cost than is currently possible.

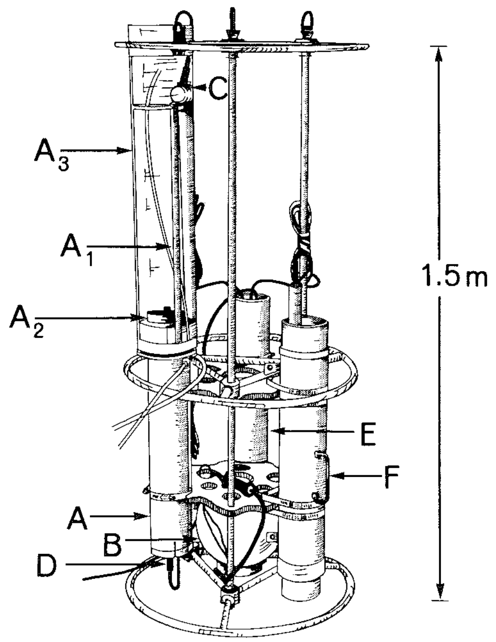
An accurately scaled two-dimensional diagram of the structure of liquid water has been constructed based on the Frank-Wen cluster theory. This model is being used to help resolve some of the controversies on the continuity of water structure. It is also helping us to understand the relation of chemical species in solution to water structure. Structural effects appear to offer an explanation for the observed difference in the relative amounts of ionic solutes in a marine aerosol as compared to its sea-water source. Water seems to be structured at the air-water interface with the exclusion of ionic solutes. In contrast, the molecules of non-polar solutes tend to concentrate near the interface.

During the summer, an Environmental Pollution Information Center (EPIC) was established where some eight thousand references on the environment were catalogued. A major part of this bibliography was related to waters of the New York Bight as part of a grant from the U.S. Army Corps of Engineers to prepare a report on the marine disposal of sewage sludge and dredge spoils in this area.

Radiochemistry

Our fallout radioactivity investigations continued to emphasize strontium-90, cesium-137, and plutonium-238 and 239. Mean concentrations of strontium-90 in the Atlantic between 10°N to 70°N have hardly diminished since the first half of 1968. This is in marked contrast to the rapid reduction in the concentration observed from late 1963 through 1967. Since about 1968, concentrations of strontium-90 and cesium-137 in nearshore and estuarine waters have been higher than in either rivers or the open seas. One explanation for this is that the radionuclides are being released by ion displacement from sediments carried into the estuaries. This appears to apply more to cesium-137 than to strontium-90. The cesium-137/strontium-90 ratios are always highest in the open ocean and less as any coastline is approached. The latitude band showing the maximum mean strontium-90 in ocean surface water has remained unchanged now for several years and the gradient from 0° northward of higher strontium-90 concentration seems not to have changed its shape. This indicates that homogenization of these values by the known surface circulation of the Atlantic is not occurring.

In sub-surface waters concentrations of strontium-90 and cesium-137 are measur-



Telemetering laser nephelometer to measure scattering of light.

able much deeper at high and low latitudes than in the equatorial Atlantic where the maximum depth ranges about 300 meters from 5°S to 23°N. Measurable concentrations reach to at least a thousand meters on the eastern side of the North Atlantic and on the western side of the South Atlantic to around 8°S. The cesium-137/strontium-90 ratios are much more variable below about 500 meters than in near surface samples, with many of the deeper ratios being one or less. This is difficult to explain in terms of particle transport of either nuclide.

Comparison of the ratios of plutonium-239/strontium-90 and plutonium 239/cesium-137 in Atlantic waters shallower than 500 meters indicates that about two-thirds of the plutonium-239 has been removed from the mixed layer at a rate much faster than the other two radionuclides. We have not yet determined the mechanism causing this removal but present data indicate biological processes play only a minor role. Plutonium-239 is concentrated by factors of up to 9,000 in sargassum, 2,400 in plankton, and 1,000 in fish above the average North Atlantic surface sea water. In general the ratios of plutonium-239 to strontium-90 and cesium-137 are higher in the organisms than in their environment. Since plutonium is an alpha emitter, it appears to be contributing more to the artificial radiation exposure of some marine organisms than do either strontium-90 or cesium-137. The procedures for plutonium analysis in sea water, sediment, and organisms have been considerably improved in the past year to yield better recovery of the element and improve reliability of the analysis. Two complete alpha spectrometry systems utilizing low background, high resolution, lithium drifted silicon detectors have been assembled for this work and two more are under construction.

Organic and Biochemistry

Our extensive background on the fate of hydrocarbons in the marine environment is now having a direct application to the problems of oil pollution. We are continuing to look at the distribution of hydrocarbons in marine algae and have found in general that these natural hydrocarbons can be readily distinguished from those in oil pollutants entering the sea. For example, 24 species of green, brown, and red benthic marine algae from the Cape Cod area contained saturated and olefinic hydrocarbons with chain lengths predominantly of 15, 17, 19, and 21 carbon atoms: C_{15} hydrocarbons were dominant in the brown and C_{17} in the red algae. Two species of green algae had a C_{17} alkylcyclopropane which has never been reported in crude oil. In fruiting *Ascophyllum nodosum,* the olefinic hydrocarbons occur exclusively in the reproductive structures while the rest of the plant contains saturated alkanes.

The hydrocarbons in 22 species of planktonic marine algae were found to be highly unsaturated, with C_{21} chains containing six olefinic bonds predominating in most diatoms; however, *Rhizosolenia setigera* contained the saturated C_{21} hydrocarbon and C_{17} olefins occurred in the green algae. The work to date indicates that the hydrocarbon composition of both benthic and planktonic algae is unique for many algal species or classes.

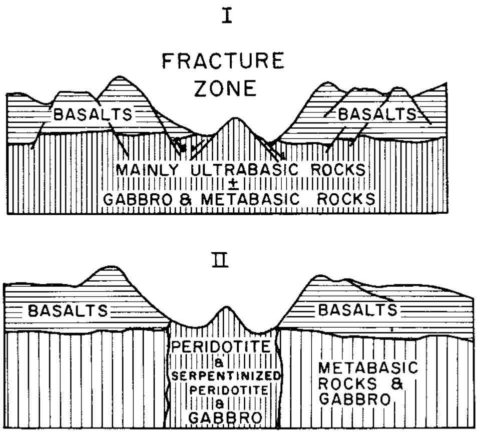
We are continuing to follow the long-term effects of the oil spill in Buzzards Bay of September, 1969. By early 1970, the oil had spread in the sediments to more distant offshore regions. In the less polluted areas there was evidence of bacterial degradation of the oil which depleted the saturated hydrocarbons and left the more toxic aromatic hydrocarbons. The 1970 crop of shellfish in the area was as heavily polluted as the 1969 crop. Oil-contaminated oysters that were transplanted to unpolluted water for as long as six months retained the oil in their tissues without change in composition or concentration. It has thus been clearly demonstrated that oil on the sea bottom can persist and remain toxic long after the visual evidence of the oil has disappeared from the surface. The oil can be incorporated into fisheries products and destroy their value for human nutrition; our findings of the pollution of shellfish are supported by other investigations that have shown petroleum derived hydrocarbons in the flesh of teleosts. We are also looking at the aging of spilled oil by physical, chemical, and biological alteration in the environment. From periodic sampling of several oil spills on Martha's Vineyard it appears that oils can still be correlated with their source for time periods as long as one year.

In our investigation of the organic chemicals that are involved in the communication between marine organisms and their environment we have noted that migrating alewives have a definite preference for water from the streams to which they return to spawn. The materials in the water causing this preference have not yet been identified. Studies on lobster mating have shown that the male is attracted to the female by a chemical released into the water immediately after she molts. The anatomy of the brains, and olfactory and taste centers of mid-water fish are being examined to determine how fish utilize chemical information from the environment. Methods of shipboard neurophysiology have been developed for monitoring the effects of chemical stimulation on the smell and taste centers of living mid-water fish.

The effects of kerosene and kerosene fractions on the social organization and behavior of lobsters are also under scrutiny. Several fractions in low concentrations appear to disrupt their social behavior and to damage the chemosensory receptor tissue. Other fractions are highly attractive and induce feeding.

The effects of thermal pollution on the organization and social behavior of several species of aquatic animals seems to be important. Preliminary studies have shown that the fresh water catfish, *Ictalurus nebulosus,* is unable to maintain a stable, social community at about 8°C below its lethal temperature. This disruption may be due to inability to communicate the information between individuals that is necessary to maintain a stable community. Similar tests are now in progress on lobster communities.

In our work on the origin of living things, we have succeeded in synthesizing some biological building blocks on clay mineral surfaces at room temperature. The objective of this experiment was to determine whether or not organic structures can be formed under normal geological conditions without requiring high energy such as a lightning discharge. Using glycerol, palmitic acid and calcium phosphate as starting materials, both lipids and phospholipids were synthesized on kaolinite covered with phos-



Alternative explanations for the abundance of ultrabasic and basic rocks in fracture zones.

phate mono-layers as a template. The phospholipids formed membrane sheets with a 40 Å periodicity. This is exactly the same structure observed in biological membranes. Sugars can also be synthesized on clay minerals from paraformaldehyde. Some inter-conversion of sugars likewise occurs on mineral templates. For example, arabinose, a 5-carbon sugar, is partly altered to rhamnose and glucose, a 6-carbon sugar.

Geochemistry

We are examining the major ion composition of the interstitial water in deep-sea sediments in order to understand the diagenetic processes in the sediments and to evaluate the transport of ions between sea water and sediment. Several general trends are apparent from the data collected to date. Sodium and chlorine behave as conservative constituents with little change with depth or age of the sediment whereas calcium, magnesium and potassium fluctuate widely in concentration. The latter changes may be linear with depth or erratic. The magnitude of the change varies with environment and deposition rate. Potassium, magnesium and sulphate are invariably depleted in rapidly deposited sediments of terrigenous detritus whereas calcium is generally enriched by factors of two to eight as compared with sea water. Biogenic deposits usually show only slight changes except for enrichment of calcium and depletion of magnesium. Concentration gradients for most ions are nearly constant over depths of hundreds of meters in biogenic deposits whereas there are erratic variations in terrigenous material. This suggests that diffusion effects are more important than chemical reactions in biogenic deposits than in clastic sediments.

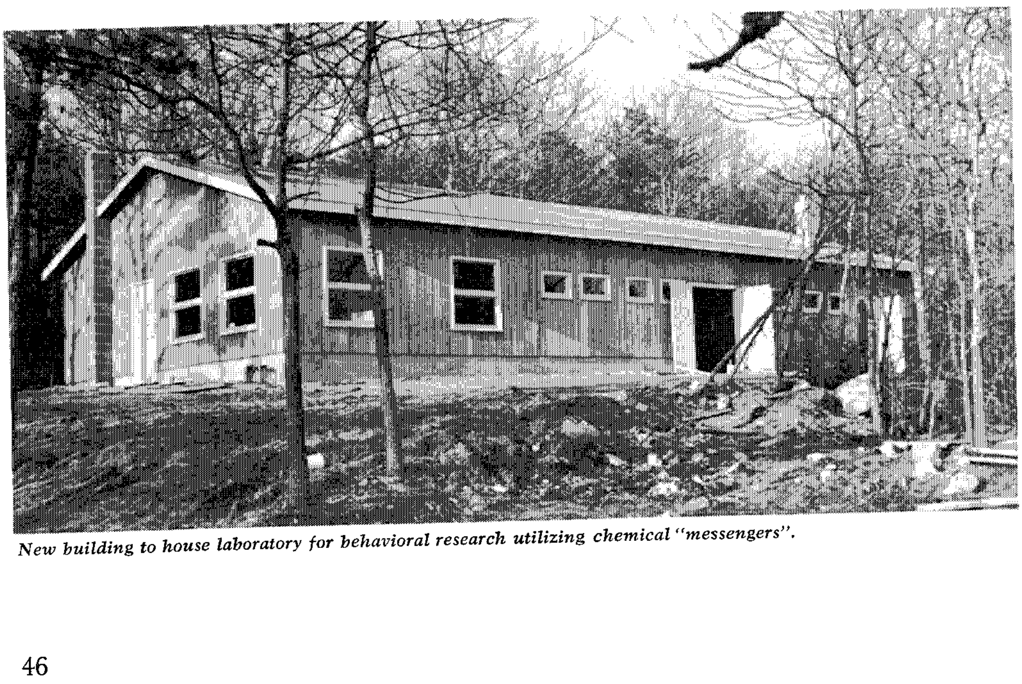
Unusually high concentrations of heavy metals were detected in three cores of amorphous sediments from the East Pacific. In six analyses the average iron content was 14.5% and the manganese content, 4.3%. The sediments are also enriched in lead, nickel, copper and zinc with low values for aluminum and titanium relative to normal pelagic sediments. The analyses indicate that these sediments were precipitated from mineralized hydrothermal solutions. The process was probably similar to that which formed the Red Sea mineral deposits.

Investigations of the geochemical cycles of stable elements in the marine environment have concentrated on submarine igneous rocks, pelagic sediments and marine organisms. In co-operation with the Smithsonian Institution we have begun an examination of the petrology and geochemistry of lavas from Iceland in the vicinity of Hekla. This is a region where the Mid-Atlantic Ridge is inferred to underlie Iceland and where sea-floor spreading should be active. Our studies of the trace element distributions in basalts from the Mid-Atlantic Ridge this past year reveal that we can define differences and distribution trends in early stages of fractional crystallization of different basalt magmas in terms of such trace elements as cobalt, chromium, nickel, barium, strontium, gallium, lithium and vanadium. We have also started to work on the weathering of igneous rocks exposed on the sea floor. It appears that as these rocks react with sea water, they take up some elements such as potassium, rubidium, cesium, boron and lithium. Chlorite commonly forms in the weathered zone. The lithification of carbonate sediments on the deep ocean floor is not usually accompanied by major chemical changes except for strontium which decreases as the sediments lithify.

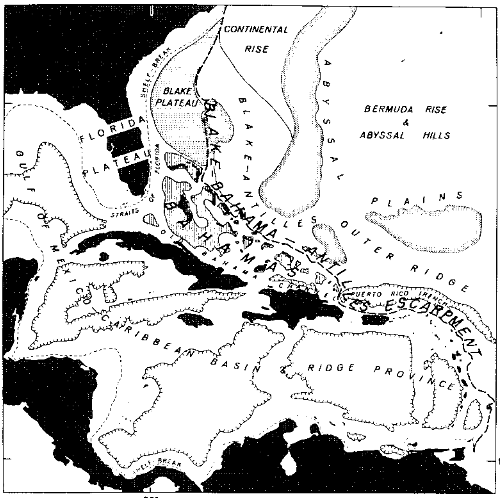
The chemical composition of the cast plates of coccolithophorids appear to vary slightly between the Indian, Pacific and Atlantic oceans. All species analyzed to date are low in magnesium and contain relatively small concentrations of transitional metal ions. An examination of benthic foraminifera, begun this year, indicates their tests to contain more magnesium and strontium but less of most other ions when compared to planktonic foraminifera. In late 1970 we initiated a somewhat similar endeavor on the chemical composition of sponges.

A detailed hydrochemical, sedimentological, and geophysical survey of Lake Tanganyika was carried out in the spring of 1970 as part of an overall program to study the evolution of the rift system of eastern Africa. The water chemistry of the lake is uniform except for the nutrient minerals, ammonia, nitrate, phosphate, and silica, the distribution of which is depth controlled. Sediment fill may reach thicknesses of several kilometers. Because the top sediments are almost entirely composed of skeletal remains of diatoms and other biological debris, changes in the fossil inventory may be linked to the chemical and in turn biological evolution of the lake. Rates of depositions are about 30-50 centimeters per 1,000 years in the deep basins and five centimeters per 1,000 years in the sill areas separating the southern and northern basins. Seismic profiles indicate graben-type structures. Magnetic observations reveal no magnetic lineation typical of rifting. Free air and simple Bouguer anomalies suggest that the lake and land structures are grossly similar. Low heat flow and similarity with surrounding values in Africa is consistent with a lack of active volcanicity and sea-floor spreading in Lake Tanganyika. These data will eventually be integrated with those from Lake Kivu (to be obtained in the spring of 1971).

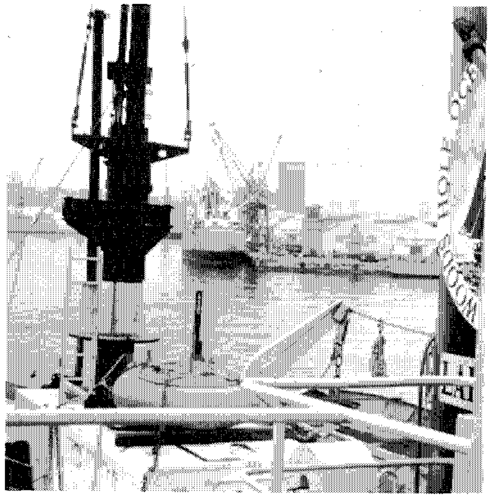
JOHN M. HUNT, *Chairman*



New building to house laboratory for behavioral research utilizing chemical "messengers".



Physiographic diagram of the continental margin south of Cape Hatteras, North Carolina. The hatchured areas represent carbonate platforms.



CHAIN in Luanda, Angola, first African port-of-call following work on the Mid-Atlantic Ridge. June 1970.

Department of Geology and Geophysics

Geological Studies off the Eastern United States

A significant portion of the work of the Department was concerned with the continuing investigation of the continental shelf off the eastern United States, especially in the Gulf of Maine. The surveys of the western Gulf of Maine, Nantucket Sound, Vineyard Sound and Buzzards Bay are part of the cooperative program with the U.S. Geological Survey (as are a number of our other geological programs). There are linear Triassic (?) structural features north of Georges Bank and a Triassic-Carboniferous (?) basin beneath Nantucket Sound. Structural and isopach maps of the sediment thickness in the western Gulf of Maine were compiled, which delineate an ancient drainage system.

A detailed seismic profiler study was also made of Corsair Canyon. Several hundred bottom sediment samples which have been collected in the area off Massachusetts, from Cape Ann to Cape Cod, provided the basis of a series of maps of physical and chemical characteristics. Two traverses of the Miami Terrace east of Miami, Florida were made aboard the submersible BENJAMIN FRANKLIN to examine structure there.

An investigation of suspended matter in the Gulf of Mexico indicated that organic aggregates with mineral detritus were common and that the concentration of suspended matter decreased seaward.

In 6,000 surficial sediment samples taken between northern Maine and southern Florida, the composition of calcium carbonate skeletons especially coralline algae and serpulids were given special attention. The occurrences of certain species of fossil Ostracoda were used to determine the temperatures of the Atlantic continental shelf during the upper Miocene, lower Pliocene and late Pleistocene ages.

Other Geological Studies

The distribution and mass physical properties of sediments from the Middle America Trench were determined. Shear strength, porosity, density, etc. indicate that these are stable except on the landward side of the trench.

From cores taken during the ATLANTIS II Cruise 49 to the Black Sea, it has been possible to reconstruct the sedimentological history of the Black Sea before and after its connection with the Mediterranean Sea some 10,000 to 20,000 years ago.

Some 1,500 sediment samples were obtained from the continental shelf off West Africa, from Morocco to Nigeria. It appears that on the Guinea-Senegal shelf, relict fluvial sands occur while on the continental slope shallow water carbonates together with glauconite and phosphorite are common.

Institution scientists and scientists of other countries, working with the United Nations Economic Commission for Asia and the Far East (ECAFE), have completed a geophysical study off eastern Asia and in the South China Sea, between the Malay Peninsula, Borneo and the Philippine Islands. The structure of the basins there as delimited by seismic and geomagnetic profiles is such that petroleum reservoirs may be expected to occur in this region.

Closer to home geologists assisted the Town of Falmouth with the plans for a new sewage disposal system. The effect of such disposal on the ground water on land and the water quality of Vineyard Sound were evaluated.

Bottom photographs, cores, and echograms provided the basic information to ascertain the effects of ocean bottom currents on the distribution of bottom sediments in the western North Atlantic and over the Greater Antilles Outer Ridge. These bottom contour currents are believed to be one of the most important means of sediment deposition on the continental rise. More than 10,000 photographs were examined in order to locate the distribution of tracks, trails or fecal coils left by benthic animals. In an experimental project a flume is being used to follow the various processes in the erosion of fine deep-sea carbonate ooze. The initiation of erosion is being observed for cohesive marine clays as a function of the fluid shear stress at the bed and as a function of shear strength of the sediment.

Much of the micropaleontological work was centered around the material obtained on leg 12 of the drilling ship GLOMAR CHALLENGER. Biostratigraphic studies from this leg in the North Atlantic dated the first appearance of icebergs in the Labrador Sea about 3 million years ago, a decrease in the diversity of planktonic foraminiferal faunas from older to younger sediments, the appearance of cooler water in the Tertiary agreeing with present theories for the opening of the North Atlantic. Examination of material from earlier legs of the drilling ship have confirmed a major change in the microfaunal population at the Cretaceous-Tertiary boundary.

Cores containing the Pliocene/Pleistocene age boundary are being analyzed following the method of Imbrie to estimate average winter and summer temperatures and salinity of the sea in past geologic time. Nannoplankton and paleomagnetic stratigraphies have been compared in a number of cores. The place of origin of the benthonic foraminiferal genus *Uvigerina* was apparently in the eastern Mediterranean and its migration can now be followed westward to the U.S. Gulf Coast and California provinces.

Studies of the morphology of planktonic foraminifera have been emphasized by the addition of Dr. Susumo Honjo to the staff. A new Scanning Electron Microscope has been obtained and is temporarily housed at the Marine Biological Laboratory.

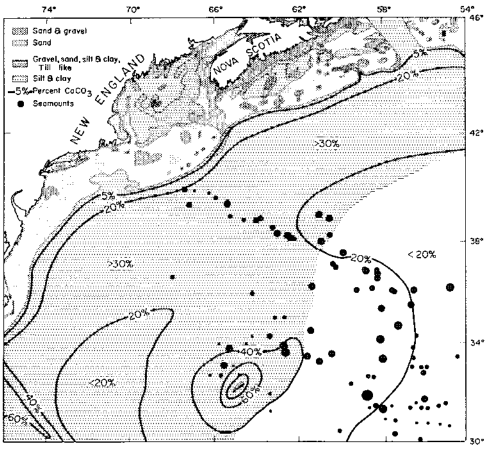
Dinoflagellate investigations of the relationship of fossil specimens and their living counterparts which were thought, heretofore, to be separate forms have been definitely established. The first incubation of a fossil cyst, a specimen obtained from the Bahamas, has been successfully cultured. Paleontologic changes in dinoflagellates from Black Sea sediments have been examined.

CHAIN Cruise 99

Much of the work of the department during 1970 was centered around CHAIN Cruise 99 which left Woods Hole in March and continued through the North and South Atlantic and into the Indian Ocean. On the first leg the structural framework of the southeastern Bahamas was investigated. This area seems to be located along a fracture zone that was formed as the Atlantic opened. The thickness of the crust appears to be about 20 km, a value intermediate between that of continents and oceans.

From San Juan to Dakar an additional survey of the Atlantis Fracture Zone was made to supplement the one made on Cruise 96 of CHAIN. It was found that two poles of rotation were required to separate the American and African plates along this fracture.

Diapiric structures off the Angola continental rise were also located. On the third leg, a profile of geophysical measurements was obtained from the crest of the Mid-Atlantic Ridge near Ascension Island down the east flank to Luanda, Angola, where heat-flow and coring stations were interspersed at close intervals. The heat-flow measurements over these structures gave higher values than surrounding areas. This implies higher thermal conductivity than adjacent material and suggests that the diapirs may be salt.



Bottom sediments of region off eastern North America based on samples collected during the joint study of sea floor by the Woods Hole Oceanographic Institution and other organizations.

On the next leg, there was a concentrated investigation of the Walvis Ridge off southwest Africa before reaching Lourenço Marques in southeast Africa. The data from both the third and fourth legs are being worked up with similar data acquired by the Scripps Institution and the Lamont-Doherty Geological Observatory on their recent cruises.

During November-December the CHAIN, after leaving Mombasa, surveyed two sites for the Deep Sea Drilling Project and the northern portion of the Mozambique Channel between Madagascar and Africa and then returned to Mombasa. In the Channel, a major ridge was detected near the African side. It trends north-south and is probably related to the separation of Madagascar from the mainland.

Deep-Sea Drilling Project

Leg 11 of the GLOMAR CHALLENGER was between Miami, Florida and Hoboken, New Jersey: eleven holes were drilled. The age of material recovered from Hole 105, beyond the continental margin off New York, permits an age of 170 to 180 million years to be assigned to the initial formation of the North Atlantic Ocean. Polished thin sections of basalt from this hole have been examined within our new petrology program: new methods of thin sectioning have been applied with advantage to this material.

Leg 12 of the Drilling Project was between Boston and Lisbon. Thirteen holes were drilled in the Labrador Sea, the Reykjanes Ridge south of Iceland, the Rockall Bank west of Ireland and the Bay of Biscay. Rich subtropical microfauna and flora of Pliocene age were obtained beneath the glacial sediments in the Labrador Sea. A history of vertical tectonic movements was evident for the Rockall Plateau.

In addition to the two members of the staff who served as chief scientist on these two segments two members of the Department participated on Leg 14 westward across the North Atlantic to test temperature and heat flow instruments now under development. These will be used inside the drill hole.

Other Geophysical Studies

A number of projects were completed in the Mediterranean and northeast Atlantic, during the second year of our cooperative program with the Laboratory of Marine Geology of Bologna and with the Experimental Geophysical Observatory at Trieste. Seismic work in the Tyrrhenian Basin indicates that the bottom structure is the result of crustal collapse. The central part of the basin appears to be underlain by Paleozoic and Triassic rocks. Off western Sardinia on the other hand there is a group of diapiric structures. Older records have provided the basis for our understanding of the East Mediterranean Ridge.

Seismic reflection profiles off the northwest Africa continental margin provided important information for interpreting recent results of the JOIDES drilling program. The basement is seemingly younger than it is at corresponding drill sites in the western North Atlantic. The Azores-Gibraltar lineation forms part of the boundary between the European and African lithospheric plates. The stress patterns in this area are being determined from seismic, gravity and magnetic data. Over the Mid-Atlantic Ridge at about 44°N concentrated reflection-refraction profiles have revealed an anomalously low velocity for a layer with velocities which were about 2 km/sec less than expected. Other types of geophysical data are now being examined to try to explain this situation.

As part of a continuing program of the rift lakes of East Africa geophysical-geochemical observations were carried out in Lake Tanganyika. The work included gravity (with the vibrating string accelerometer), magnetic, seismic and heat-flow measurements. The minimum for the free-air gravity anomalies was much less than expected from nearby land measurements. The heat-flow results can be compared to those for the temperate lakes of Switzerland, also surveyed this year.

The Caribbean area was another focus of attention during the year. Earlier it had been demonstrated that the Lesser Antillean Island Arc was being underthrust by the Atlantic lithospheric plate. A compilation of gravity data along this plate edge gives a clearer picture of the nature and extent of this underthrusting. The gravity field of Venezuela was the object of another undertaking in order to delineate active faults and stress patterns along northern South America. The southwest margin of the Caribbean plate, north of Panama and Colombia, was crossed by the ATLANTIS II in December 1969. Data from that cruise has provided a history of the deformation of this area. These endeavors plus many earlier years of work in the Caribbean were reviewed in a general seminar on the geology and geophysics of the Caribbean Sea.

Aboard a Scripps Institution of Oceanography research vessel deep-tow magnetic measurements were made in the Gulf of Alaska. Two traverses were made over the same major magnetic anomaly with the traverses being separated by 200 km. Many small scale magnetic features seem to be similar on the two records.

As a natural consequence of an understanding of the relationship between physical oceanographic and geophysical phenomena as they occur today, it should be possible to ascertain the ocean water motions for specific continental configurations during past geological ages. A careful review of past configurations for the borders of the Atlantic Ocean has been completed, and scale models of the continents have been made and mounted in a rotating tank for model oceanographic circulation experiments. These should start shortly.

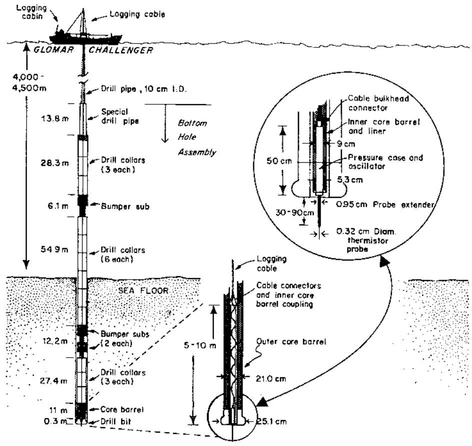
A new dating technique was investigated for marine sediments. This work, done jointly with the Department of Geological Sciences of Harvard University, shows that the racemization (change from optically active to inactive) of amino acids may be used as an age indicator.

The dip of the Benioff Plane (plane on which earthquake epicenters lie beneath island arcs) was found to be related to the relative speed of overthrust of lithospheric plates. This fact suggests that a gravitational effect may be responsible for the downgoing plate and that the heat-flow regimes over various Benioff Planes may be quite similar.

Geophysical Instruments and Data Processing

A Vibrating String Gravity Meter passed an initial test for use in a helicopter in trials made with the U.S. Army Topographic Command. Work has in addition been nearly completed on a second vibrating string gravity meter and on a data acquisition van.

For seismic investigations a new compressor system for the air gun has been constructed and checked. This is a self-contained unit for mounting on deck and weighs about six tons. A complete manual



Schematic view of drill string, bottom hole assembly and temperature-measuring information.

for operating the seismic profiling system was issued. It contains numerous tips acquired after many years of practical experience at sea for obtaining high quality records. Digital programs for processing sonobuoy reflection-refraction records have been improved and a feasibility study of real-time digital shipboard processing was undertaken.

A new effort this year was the comprehensive digital processing of navigation, bathymetric, magnetic, gravity and station data with Hewlett-Packard 2114 and 2116 and the SDS Sigma 7 computing system. This results in the graphic plots for the cruise reports and edited geophysical data ready for interpretation. It should be recalled that oceanographic, geological, geophysical, biological and acoustical data are regularly filed with the various data centers. This year, data from 95 local and 42 extended cruises will be included. A special summary report on major cruises to the Caribbean was prepared in support of the international "CICAR" project.

Underwater Acoustics Studies

Ambient noise measurements were made at six sites in the Mediterranean Sea during the summer of 1970 at various depths and at various frequencies while an aircraft assisted by monitoring the noises of surface vessels in the vicinity. Sound velocity profiles were also drafted for the area.

A modified ray theory has been developed using a WKB solution to the wave equation for a medium in the presence of boundary. With the formulation of a computer program, the method applies to propagation in regions of sound velocity maxima such as occur at depth in winter when the surface waters are cold, and for rays reflected or refracted away from the sea surface when the velocity profile decreases monotonically away from the surface as in summer when the surface waters are warm.

For a period of approximately one week at sea a test was made of long range explosive echo ranging against topographic features. Although ranges approaching 100 miles were obtained, they were not obtained with the consistency achieved earlier in calmer seas further south.

Volume scattering measurements from an explosive sound source were taken on the maiden voyage of the R/V KNORR through the Great Lakes and St. Lawrence River and on the R/V ATLANTIS II Cruise 59. A biological program to identify the nature of the scatterers was undertaken on the same cruises. While exact analyses are not completed differences were immediately recognized. For example, there was a 4kHz return at 200 fathoms to the east but not to the west of Gibraltar.

Following a comprehensive report of eddy circulation in the Sargasso Sea, an attempt is now being made to apply Ertel's Circulation Theorem to an explanation of these large scale motions.

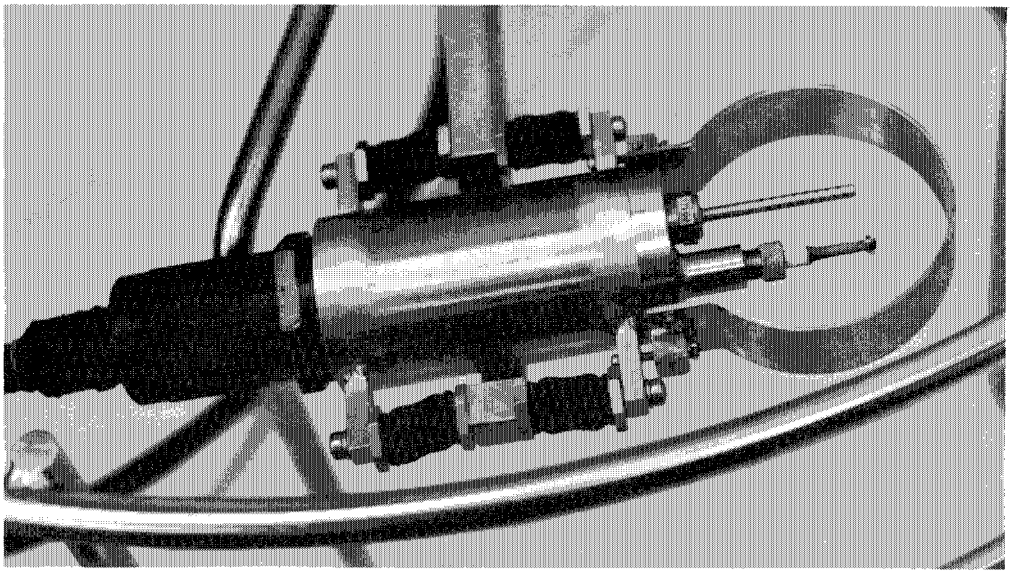
Measurements of salinity and temperature with depth in the Mediterranean revealed an appreciable change in the profiles at about 7°E, where a highly saline mass of Levantine Water existed 200 to 500 meters below the surface.

Tests for animal noises were undertaken with a four-hydrophone array in Cape Cod Bay with whale and porpoise sounds. The array can be used to determine range and therefore obtain an estimate of source strength. The sounds of various Arctic and Antarctic species have been analyzed for their frequency content and compared to those made by ice in polar latitudes.

Acoustic Instrumentation

An extensive modification and calibration effort was required for sonobuoys to use in sound transmission and ambient noise projects. These included altering the frequency response, the dynamic range and the life-time characteristics. Leaks have occurred in some of the deeper deployed sonobuoy hydrophones. A calibrator now provides a 30-second signal to the entire recording system at each of several frequencies. A 200-element towed array was developed to be used at depths of up to 5,000 feet and towed on 25,000 feet of cable. A modification of a seismic profiling array, it contains preamplifier and depth measuring circuits. This was used in the long-range explosive echo-ranging tests mentioned above. In an earlier analysis of flow noises around a towed array, power spectral and coherency measurements between the individual hydrophone elements were calculated. The noise was related to speed and acoustical and mechanical resonances in the design. To obtain quieter hydrophone measurements for instruments suspended from a ship on station a new suspension system has been devised, constructed and tested in a water-filled flume. A salinity, temperature, depth (STD) instrument, normally used only for vertical lowerings has been modified for towing. With this instrument bodies of anomalous water of limited horizontal extent can be more accurately defined. Nearly 300 miles of towing have been logged at speeds as fast as seven knots.

JAMES R. HEIRTZLER, *Chairman*



Probe sensors of new microdigital STD system for measuring salinity, temperature and depth.

Department of Ocean Engineering

Our field of specialization is oceanographic engineering, for the advancement of the science of oceanography. In 1970 we developed and deployed several new and revolutionary instruments. For the first time a long endurance SOFAR probe was successfully used and for the first time the vertical overturn of water in the Mediterranean was directly measured by a vertical current meter. Both instruments were designed and built in our laboratory. We are extending capability in three directions: in resolution and accuracy with the microstructure Salinity-Temperature-Depth digital system (STD), in time with the vector averaging current meter and the Acoustic Data Capsule (ACODAC) and in depth with the ALVIN rebuilding program including preparations for the installation of a titanium hull. Closely integrated with these activities is the joint ocean-engineering degree program with the Massachusetts Institute of Technology. Six students were enrolled in 1970.

Instrument Engineering

We have developed new and advanced instruments to achieve a greater capability for oceanic measurement than was hitherto possible. Notable results have been obtained from the vertical current meters, the SOFAR Probe, and the free fall electromagnetic current meter. AUTOPROBE has been rebuilt to be more reliable and versatile. The new microdigital Salinity-Temperature-Depth (STD) system is nearing completion and will be tested at sea early in 1971. The SOFAR Probe yields long-time series observations of abyssal circulation through long-range acoustical tracking; the instrument telemeters at a frequency of 380 Hz. The first completely successful probe was launched at 25°N, 69°W on October 26, 1969 from R/V ATLANTIS II, and was tracked until February 28, 1970, a period of 125 days during which it traversed a net distance of approximately 160 miles in a WNW direction.

Major improvements have been made to

the free-fall electromagnetic current meter by adding temperature and direction measurements of the electric field. Two field experiments encompassing forty "drops" demonstrated that it can be used in the deep sea in regions where the flow is as low as 10 cm/sec (0.2 knots). The data from these tests have supplied the necessary information to design and build a new model which will be able to record digitally on magnetic tape the horizontal field and the conductivity of the sea water; the maximum operating depth is 6,000 meters.

AUTOPROBE is a general purpose autonomous undersea observational platform that can be programmed to stabilize at a constant pressure, to follow a constant temperature, and to make vertical excursions. In November six successful dives were made from R/V KNORR in an area south of the continental shelf; the longest dive was 8½ hours. The instrument was programmed to follow the 10°C isotherm which was located at approximately 200 meters and to telemeter temperature and pressure data to the ship for recording.

Exciting results have been achieved in a new technique for studying vertical flow with a vertical current meter. This is essentially a neutrally buoyant float fitted with vanes diagonal to the vertical axis in such a way that vertical translation of water causes the instrument to rotate. The data are recorded internally and long time series of measurements may be recorded. A total of seventeen successful launches were made during the year near Bermuda and in the Mediterranean, the latter from the French N/O JEAN CHARCOT.

The microstructure Salinity-Temperature-Depth digital system (STD) is under development; its goal is to resolve temperature to .0005°C, salinity to .001 ‰ and pressure to .0015%: absolute accuracies will be somewhat less. During the year, most of the components have been completed in the laboratory and will undergo trials at sea early in 1971. The underwater unit measures conductivity, temperature and pressure. Each sensor is sampled thirty times per second resulting in a sixteen bit binary output from each. These are transmitted in serial teletype format using frequency shift keying (FSK) via a cable to the shipboard system which consists of a demodulator and a computer; the interface between the computer and the demodulator is a standard teletype I/O card. The shipboard computer calculates the salinity from conductivity, temperature and pressure.

A display system having a digital output in engineering units and analog d.c. outputs has been designed and constructed. These displays permit the system to be calibrated in the laboratory or at sea and to be monitored during data acquisition without having a computer on line.

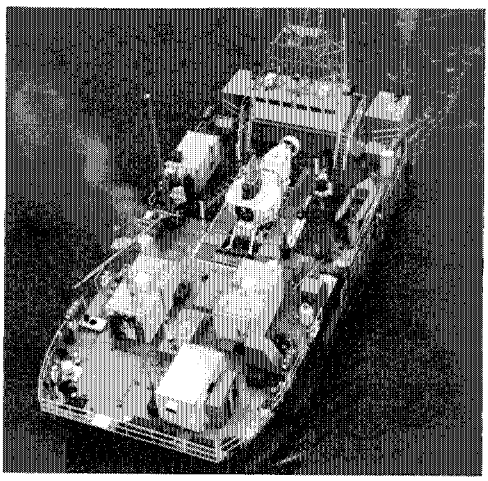
Other work has been done on the development of the techniques for salt finger detection, i.e., the detection of nascent convective cells. There is an indication that salt fingers operate to intensify layering in the thermocline in many areas of the ocean; however, this has not yet been proven. Studies for an instrument which will make *in situ* measurements are in progress.

A vector averaging feature has been added to the Richardson Savonius rotor and vane current meter. The internal computer calculates and averages the N-S and E-W components of currents with a typical integration time of fifteen minutes. The result along with average temperature is recorded on magnetic tape. Electronic parts and the recording system will last for a period of at least one year.

The long term *in situ* measurement and recording of sound in the deep ocean has long been a problem. Early in 1970 a program was initiated to accomplish this with an instrument called the Acoustic Data Capsule (ACODAC). The acoustic field in the 20-300 hertz band will be recorded in a fixed location simultaneously at seven different depths down to more than 6,000 meters for a period of up to a month. Five such systems are to be constructed, and the first two will be employed in the Mediterranean in late 1971 to obtain the long term statistics, depth dependence, and vertical coherence. The shipboard data processing will reduce the statistical data in one third octave bands and the Sigma 7 will be used to examine the narrow band spectra, vertical coherence, and vertical directionality.

Deep Submergence Engineering and Operations

At the beginning of the year R/V LULU was at the dock completing modifications that had not been done at the shipyard the previous year. ALVIN was in sections and pieces at the warehouse being slowly rebuilt. SEA CLIFF was finally reaching completion and preparing to depart Groton, Connecticut for the Bahamas to conduct builders sea trials and acceptance certification. The displacement of R/V LULU was increased from 250 tons to approximately 470 tons. As a result of strain gauge tests



R/V LULU with DRSV TURTLE aboard.

at sea, the arches were reinforced with welded plate. As a part of the post-overhaul sea trials two successful geophysical cruises proved that it is possible to do seismic and other scientific work from a catamaran.

SEA CLIFF and TURTLE departed Groton in early February for Nassau on the support ship MAXINE "D": after the trials both arrived at Woods Hole in late September. One trip was made to Provincetown with TURTLE on board. The new hoist system on R/V LULU was used for the first time to launch and recover a submersible, and it worked well although it has not yet been tested in significant sea states. Because of budgetary austerity SEA CLIFF, which had been intended for Woods Hole operation, was turned over to the Navy (Commander Submarine Development Group One) on November 1, 1970 by direction of the Office of Naval Research. SEA CLIFF and TURTLE were shipped overland by truck to San Diego, California. The primary goal of our effort was then turned to the recommissioning of ALVIN.

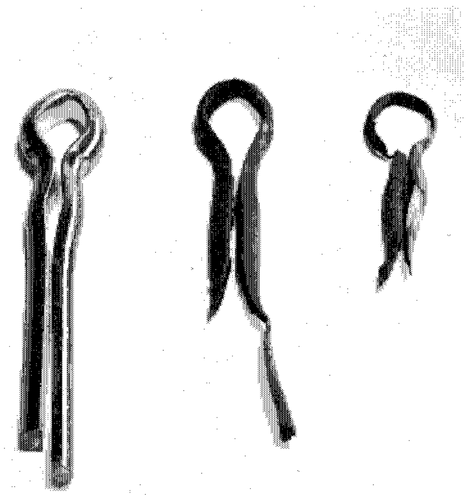
The major tasks required to rebuild ALVIN were the in-house fabrication of all of the fiberglass skin damaged during the loss and recovery, the reclamation of the main motors, pumps and other machinery, assembly of the variable ballast system for pressure testing and rebuilding of the internal panels and distribution centers. Full attention was directed toward having a 6,000-foot version of ALVIN for operations starting in the spring of 1971.

Other activities have included participation in the program for the construction of the titanium hulls (Project TITANES), assignment of the procurement of the electrical penetrators for TITANES and participation in the Deep Ocean Technology program primarily with the Naval Ships Research and Development Laboratory, Annapolis, Maryland. It is hoped that ALVIN will be operational in late spring for a full diving program in the summer of 1971 and extending into the fall if funding permits. Development of an improved submerged navigation system will be a major task under the Advanced Research Project Agency. Continued work with the Deep Ocean Technology program is anticipated and it is expected that the titanium hull will be installed in ALVIN in the fall and winter of 1971-72, thus providing a deeper capability for 1972 and later years.

Buoy Systems Engineering

Progress has been made in routinely maintaining moorings at sea for from two to four months. Through tests at sea, in shallow water and in the laboratory we have been able to determine the forces experienced by moorings, and in most cases, have been able to supply components capable of withstanding these forces. Damage due to fishbite and corrosion continue to be a significant deterrent to deployments of six months or more.

A deep-sea mooring was designed and tested to make measurements, uncontaminated by the effects of surface buoy excitation at intermediate depths (from the bottom to 1,000 meters below the surface) using distributed buoyancy (16-inch glass spheres) at several levels. Samples of glass rope and strand are being evaluated at the buoy test "farm," seven and one-half miles south of Cuttyhunk. One sample of glass rope has been moored for over one year. The dozen or so presently on station will be left until failure, at which time the failed specimens will be analyzed.



Deterioration of cotter pins.

Long range telemetry has been employed to monitor the mooring cable tension of the deep-ocean moored buoys at Site D and Site L, 149 nautical miles and 450 nautical miles respectively from Woods Hole.

Safety Program

Research with safety is the theme of a program codified at the close of 1970 in an Institution policy statement. Safety considerations are a part of every engineering process but safety engineering in this context is an activity quite distinct from project engineering. Consultations on the design of equipment for safety have been provided to all departments. These include design of hoisting slings for permanent use with particular vans, ship crane capabilities, pressure vessel design, hydrodynamics of towed bodies, materials properties, fire protection, electrical safety, core handling gear and specification of marine fittings for stockroom supply.

Information Processing and Analysis

This is the first full year of operation of both the Sigma 7 and four shipboard computer systems. Both have shown considerable increase in usage and a great deal of change in the method of operation. By the end of 1969 most of the equipment was performing with reasonable stability and more attention could be directed to improving the systems operationally. A number of software changes were made to the Sigma 7 system of controlling computer usage; these improved existing hardware reliability and increased transfer speeds. The shipboard computer centers were at sea for a record number of months and are now well established as part of the sea-going scientific equipments. A new area of data gathering was opened with a DATAGRID digitizer which has been installed and is in daily use.

The major sea-going activity during the first of the year was the preparation for cruises on the ATLANTIS II and the CHAIN. The consolidation of Hewlett-Packard computer equipment made possible the installation of a computer system on each ship for scientific instrumentation and shipboard data processing. The long cruise of the CHAIN to the Red Sea required extensive preparations in computer program development as well as logistic support. The top laboratory of the CHAIN was converted to a computer processing center for geological and geophysical requirements in gravity and magnetic data processing. Navigation requirements, including satellite tracking, were also added. Data processing for science and navigation has been conducted continuously on CHAIN since April. New computer equipment was received during the year to support data processing on R/V KNORR. This consisted of a Hewlett-Packard computer with 16K memory and peripheral equipment similar to that on CHAIN and ATLANTIS II. A new Magnavox 706 satellite receiver was delivered in November; it will be installed on KNORR when on-shore testing is completed. Also, a cassette read-write magnetic tape recording system was introduced as a new peripheral device for the computer system.

The major computer users were projects supported by the Office of Naval Research (61.8%) and the National Science Foundation (16.2%). The first payroll of 1970 was processed on the Sigma 7 and every two weeks thereafter. Business use accounts for 9.1% of the total usage. In 1970 there were 27,845 jobs processed on the Sigma 7 under the monitor. The total job time was 1,381 hours and the average time per job was 2.98 minutes. Much of the programming time in the past year has been spent in work done for the Physical Oceanography Department and on general purpose programs and utility routines. Programming for the Geology and Geophysics Department included a real-time shipboard acquisition system for gravity and magnetic data.

Four classes were given to Institution employees and to summer students. These classes were an introduction to the Sigma 7 computing facilities, Basic, Fortran IV, and the use of Batch Processing Monitor control cards. For the second year of a three year grant period student and unsponsored research computer use were supported by the National Science Foundation. As in the past year, this grant allowed summer and year-round students to use the computer facilities as part of their research and in conjunction with courses.

Oceanographic Engineering Academic Development

Under Sea Grant support with matching funds from our education account we have been developing the oceanographic engineering graduate education program. During the summer of 1970 a course, "Oceanographic Systems," was presented as part of the joint Woods Hole/Massachusetts Institute of Technology program in Ocean Engineering from June 22 until September 3, with six graduate students participating. Seminar topics were presented by each student after independent library research. In groups of two, they conducted either a field or laboratory experiment and reported the results. During the fall term two courses, "Buoy Engineering" and "Oceanographic Systems Analysis I," were given and two more are planned for the spring term.

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determine the structure and history of these rings after formation. In addition, the historical file of bathythermograms has been searched for evidence of occurrence of rings over a wider geographical region. A total of 62 rings have been identified along a broad arc of the western boundary of the Sargasso Sea. The region of most likely occurrence appears to lie between 60°W and 70°W.

Anticyclonic eddies in the Slope Water north of the Gulf Stream have also been observed to form from the Stream and then to drift slowly westward along the continental shelf. These northern eddies are the counterpart of the Gulf Stream rings, injecting warm, saline water into the Slope Water region.

Measurements near the bottom beneath the Gulf Stream have yielded currents as high as 50 cm/sec that vary slowly over periods of a month or more. It is probable that these strong currents are associated with the lateral displacements of the Stream that constitute the meandering rather than the Stream itself. A two-dimensional array of bottom moorings was installed in December to determine the deep velocity field on the scale of the meanders. These moorings, scheduled for recovery in May, 1971, will help to define the relationship of the vigorous abyssal currents to the Gulf Stream.

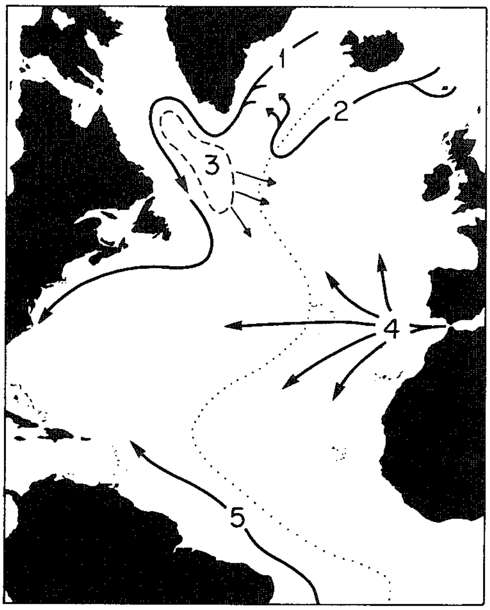
The Mediterranean Sea

In February and March, 1970, a return visit aboard the French Research Vessel JEAN CHARCOT was made to the sinking region of the northwestern Mediterranean to measure the strength of the vertical convection. The neutrally buoyant vertical current meters had been redesigned to record temperature as well as currents. A two-week record, obtained in the convecting region, indicated a net upward motion of about 1500 meters of water past the sensor. On two occasions, intense downward flow (500 meters in two hours) was detected. Peak vertical speeds were about 10 cm/sec. One period of downflow was accompanied by a significant drop in temperature. The downward flow is the more intense and is probably more limited horizontally than the upward flow.

An atlas of the physical oceanography of the Mediterranean is nearing completion and work is progressing on construction of a map of the temperature and salinity in the surface layers based on data obtained in recent years.

The Indian Ocean

Deep circulation theory indicates that bottom water in all three oceans of the southern hemisphere must enter from the Antarctic in the form of deep western boundary currents. One such current has been known for many years from the METEOR Expedition in the South Atlantic. The abyssal current in the South Pacific was detected in 1967 and 1969 during cruises of U.S.N.S. ELTANIN.



Schematic diagram of chief sources of deep water in the North Atlantic Ocean. 1. Denmark Strait Overflow. 2. Iceland-Scotland Overflow. 3. Labrador Sea Surface Water (which cools and sinks in winter). 4. Mediterranean Outflow. 5. Antarctic Bottom Water.

In July, 1970, hydrographic sections were occupied along 12°S and 23°S latitudes east of Madagascar. The abyssal current was clearly indicated in both sections flowing northward along the deep western boundary. These new data provide support for the theory for all three oceans. Preliminary estimates indicate that the volume transport in the Indian Ocean is about half that of the South Pacific.

The cruise was continued to occupy a network of 130 hydrographic stations and to take other observations extending from the Somali coast to 61°E and from the equator to the island of Socotra. The purpose of these was to verify the existence of an anticyclonic circulation in the western part of the Indian Ocean as suggested on earlier surveys. Although analysis of the data is still in progress, evidence for a southward flow was found in the upper 200 meters about 300 miles east of the Somali coast. This southward flow could be traced to within 5° of the equator.

Ocean Variability

Most of the kinetic energy observed in the open ocean is associated with variable components of flow. The time and spatial scales of these motions need to be defined by measurements to develop an understanding of their dynamics. A number of experiments, using instrumented moorings to measure currents, were carried out during 1970. A north-south array of six moorings, extending 1200 kilometers from the axis of the Gulf Stream over the Hatteras Abyssal Plain was set to determine the magnitude and variation of the deep-water currents. The influence of Gulf Stream meanders could be recognized for several hundred kilometers south of the axis. The variable flow field associated with the meanders appears to be much wider than the Stream itself. Currents at the southern end of the array (28°N) were weaker and varied more slowly than the currents in the vicinity of the Stream.

Previous success in correlating surface inertial currents with local winds encouraged attempts to examine phase differences of the currents over short horizontal intervals. A three-mooring array with fifty kilometer spacing between moorings was set in the Slope water near Site "D" to record wind and currents at each location.

Analysis of the twenty simultaneous time series obtained in the experiment is still in progress. However, significant differences in both magnitude and phase of the currents were detected during the two-month period of the test.

In another experiment, a seven-mooring array was deployed along the continental slope for a period of four months. The objective was to determine the influence of bottom topography on the flow components parallel and perpendicular to the bottom slope. Low-frequency variations were found to be significantly weaker in the component perpendicular to the slope. However, tidal components were not suppressed by the sloping bottom.

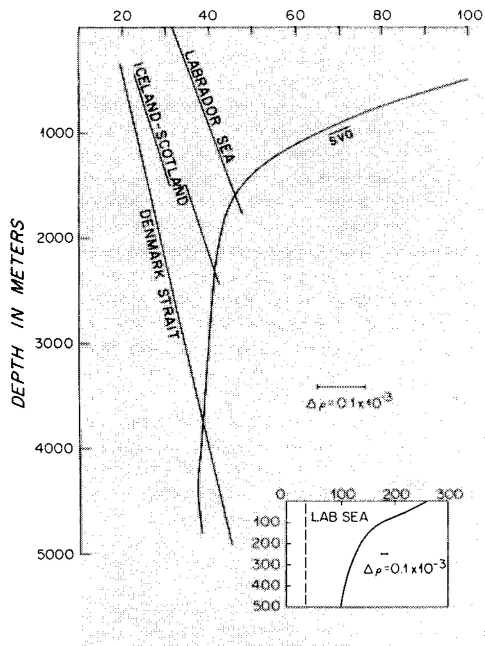
Kinetic energy estimates from neutrally-buoyant float measurements were found to be similar to those obtained from fixed moorings. Comparisons from widely separated regions such as the Sargasso Sea, the Bay of Biscay and the Mediterranean Sea yielded surprisingly similar levels of total kinetic energy. A notable exception to the yield of high kinetic energies occurred in a set of measurements northeast of Bermuda, apparently because of the presence of a Gulf Stream meander.

The development of a free-fall instrument to determine the horizontal electric field induced by motion of sea water through the earth's magnetic field provides a unique method for inferring the vertical structure of ocean currents. Extensive tests of the free-fall current meter were conducted in 1970. Useful data were obtained even in regions of weak current (<10 cm/sec).

Marine Geodesy

A knowledge of the topography of the sea surface relative to a geopotential surface would provide oceanographers with a more precise method for estimating geostrophic currents and the related transports of mass, heat and salt. The necessary measurements could be made with the GEON system, but it now seems possible and more efficient to use an orbiting altimeter. A satellite altimeter in near-earth polar orbit could provide a coarse-grained topographic map of the sea surface every 12 hours and examine every degree square about once a week. Time series of such maps would provide oceanographers with the distribution and changes of ocean currents on a global scale.

The geometrical height resolution to provide information about ocean currents must be at least ±0.1 meters. This is beyond the capability of present technology but appears attainable. Through the cooperation of a number of federal agencies, a radar altimeter is being designed for installation in the GEOS-C geodetic satellite to be launched in 1972. As part of the effort to develop the techniques required, theoretical studies have been made on the problem of downward continuation of gravity from satellite altitudes to the sea surface. Direct measurements of gravity and geoid topography were made in 1970 with the cooperation of the Canadian Bureau of Energy, Mines and Resources. It was possible to run a gravimetric arc along the 150°W meridian from 63°S to 57.5°N latitude. Similar arcs are planned from the Weddell Sea to Iceland and for circumnavigation of the Earth along the equator. These measured great circles must necessarily be crossed



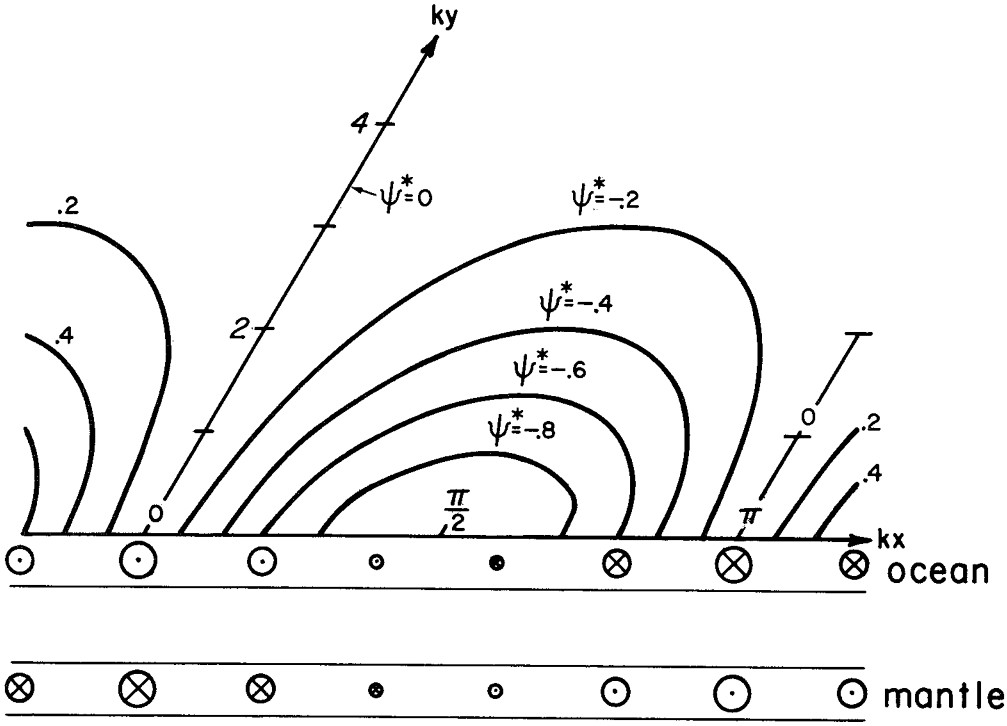
Specific volume anomaly of the northern deep water sources in relation to the average specific volume.

by every oceanographic satellite and will provide a succession of check points for altimeter calibration and drift correction.

Aerospace Oceanography

Interest in observations of the ocean from aircraft and space is increasing as familiarity with the potential of remote sensing is shared by a wider circle of investigators. The interest is spurred by the plans of the National Aeronautics and Space Administration to launch instrumented satellites and orbiting manned space laboratories starting in 1972. The remote methods of sensing the ocean must be evaluated by direct measurements by more conventional means. Progress has been made on several fronts to provide this "ground truth."

The spectral distribution of backscattered light from the ocean was determined in a series of flights in the Florida Straits and Gulf of Mexico. These flights to measure the



Large-scale horizontal electric current induced in the ocean and in the mantle for a low frequency ocean wave moving in the earth's magnetic field.

color of the ocean were coordinated with observations from the USC&GS DISCOVERER. At each station, a spectrophotometric sounding was made at several levels between 1,000 and 15,000 feet altitude. In addition, sea surface temperature was recorded by airborne infrared radiometer and sounding to 1,000 feet depth were made with air expendable bathythermographs and bathyphotometers. Shipboard observations of biological productivity and chlorophyll concentration were made at several depths below the surface. These data will permit a closer evaluation of the relationship between the spectra of backscattered light and the biological activity within the ocean.

Work is in progress to evaluate the use of passive microwave radiometers for measurement of temperature at the sea surface. The ability of thermal radiation of the ocean to penetrate shallow stratus clouds at these wavelengths affords the possibility of greater coverage than infrared techniques. Tests will be made by installing microwave sensors under the railroad lift bridge over the Cape Cod Canal that can be raised to 130 feet above the water surface.

Successful interrogation and location of a free-drifting buoy was achieved in tests over Georges Bank. The buoy was outfitted with an Interrogating, Recording, Locating System (IRLS) designed to transmit data from known locations via the interrogating satellite. The ability of the IRLS system to telemeter oceanographic data makes it a primary candidate for acquiring ground truth for remote systems.

NICHOLAS P. FOFONOFF, *Chairman*

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No. 2542. William J. Schmitz, Jr., A. R. Robinson and F. C. Fuglister. Bottom Velocity Observations Directly under the Gulf Stream. *Science,* Vol. 170, No. 3693, pp. 1192-1194. 1970.

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40th Anniversary Week

There have been days of open house in previous years, but in 1970, the two days (June 15-16) when guests and the public were welcomed to inspect the buildings and sea-going vessels marked a special occasion, the celebration of the 40th anniversary of the founding of the Woods Hole Oceanographic Institution, part of a week of ceremony and festivity.

The Anniversary Convocation (June 17) included the first commencement ceremony of the Woods Hole Oceanographic Institution-Massachusetts Institute of Technology Joint Program in Oceanography with the awarding of degrees of Doctor of Philosophy to four recipients (p. 21) which was held in the courtyard of the Iselin Marine Facility. The degrees were conferred by Howard W. Johnson, President of the Massachusetts Institute of Technology, and by Paul M. Fye, President of the Woods Hole Oceanographic Institution. The Commencement address was delivered by Julius A. Stratton, Chairman of the Board of the Ford Foundation, a former President of the Massachusetts Institute of Technology and Chairman of the Commission on Marine Science, Engineering and Resources.

Next followed the dedication of the Columbus O'Donnell Iselin Marine Facility, consisting of the marine services building, the new Institution pier and courtyard. Columbus Iselin was one of the earliest to be appointed to the scientific staff as physical oceanographer, the first master and chief scientist of the Ketch ATLANTIS, a Trustee and Member of the Corporation, the second Director of the Institution: scientist, sailor, educator, administrator, colleague and friend (p. 10). Dr. Iselin reminisced about the early days and was followed by three speakers, Dr. Fye, Mr. McLean and Dr. William D. McElroy.

Following a buffet lunch in the marine services building, Dr. Alfred C. Redfield gave the Anniversary Address and dedicated the Bigelow Laboratory, the first Institution building erected in 1930, with an unveiling of the plaque which has been mounted on the wall of the main entryway.

Next, the Henry Bryant Bigelow Medal, which was established in 1960 to be awarded "to those who may make significant inquiries into the phenomena of the sea," was given to Frederick J. Vine (p. 22). In conclusion of the ceremonial day, William D. McElroy, Director of the National Science Foundation, gave the Keynote Address.

That evening the Bigelow Dinner was held in a tent on the Quissett campus in honor of the Bigelow "colleagues" who had been at the Institution during the first decade when Henry Bryant Bigelow was Director. Those who had returned for the dinner (or other event) were:

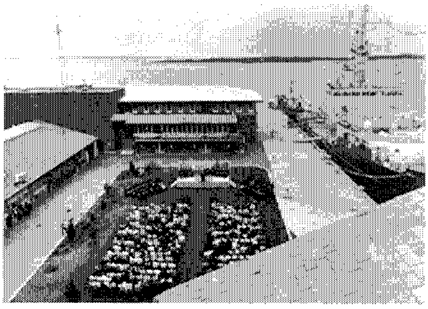
Eliot F. Beach
Dean F. Bumpus
Frank A. Brown, Jr.
George L. Clarke
Charles J. Fish
Marie P. Fish
Erik F. B. Fries
T. Nathan Kelley
Bostwick H. Ketchum
James B. Lackey
Henry E. Mahnke
Mildred Mahnke
Daniel Merriman
Raymond B. Montgomery
Rudolph F. Nunnemacher
Albert E. Parr
Alfred C. Redfield
Herbert W. Reuszer
Marshall Schalk
Irving I. Schell
Mary Sears
Frederick K. Sparrow
Athelstan F. Spilhaus
Edmond E. Watson
Allyn C. Vine
Selman A. Waksman
Charles M. Weiss
Louise Palmer Wilson

In addition to recognition of these special guests, Carleton R. Wing who joined the Institution's marine staff on 19 February 1940 was presented with a 30-year Service Award. The dinner address was given by Dr. Detlev W. Bronk, President Emeritus of the Rockefeller University, an Honorary Trustee and Member of the Corporation of the Woods Hole Oceanographic Institution.

On 18 June the usual Associates lectures were held in the morning and the R/V KNORR was dedicated at a ceremony in the early afternoon. The Invocation and Benediction were offered by the Reverend William D. Henderson, St. John's Episcopal Church, Roanoke, Virginia, a grandson of Ernest R. Knorr (p. 75). The Knorr family presented an oil portrait of their illustrious ancestor for the wardroom. The Honorable Robert A. Frosch, Assistant Secretary of the Navy for Research and Development, gave the address. Music was furnished by the Seabee's Band from Davisville, Rhode Island. The remainder of the afternoon was spent in Vineyard Sound for demonstration of the scientific equipment.


(Left) Dr. Selman A. Waksman, Marine Bacteriologist 1931-1946 (Bigelow "Colleague"), Honorary Trustee and Member of the Corporation. (Right) Dr. Alfred C. Redfield, Senior Physiologist 1930, Senior Biologist 1938 (Bigelow "Colleague"), Senior Oceanographer 1954, Senior Oceanographer (Emeritus) 1957, Associate Director 1942-1950, Honorary Trustee and Member of Corporation.

Graduation in the courtyard of the Iselin Marine Facility with R.V. KNORR at dock.



Ashore and Afloat

The Institution has dispensed with the two aircraft which have seen considerable service in the past decade. The Helio-Courier single-engine float plane acquired in 1959 for use in tracking marine mammals at sea was sold on 20 May. The C-54Q aircraft which had been fitted especially for meteorological observations in the Caribbean, the Indian Ocean, Mediterranean Sea and to the Line Islands, was returned to the Navy in January and is now in storage in Litchfield Park, Arizona.

The CRAWFORD, a converted Coast Guard cutter acquired in 1955, was sold on 11 December to the University of Puerto Rico. She will continue work in oceanography and it is understood that the name will be retained.

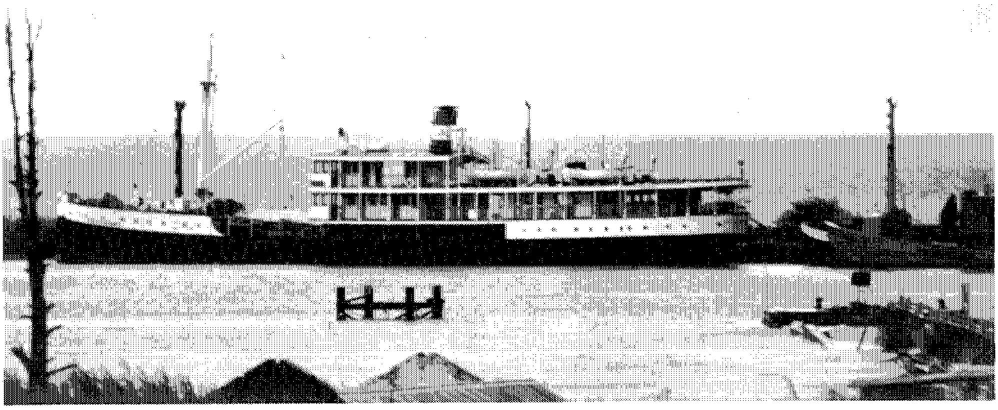
The KNORR was turned over to the Institution by the U.S. Navy on 15 April under a charter agreement. On the voyage in mid-May from the builder's yard in Bay City, Michigan, scientific observations were made in the Great Lakes and in the Gulf of St. Lawrence en route to Woods Hole. For the remainder of the year KNORR spent 106 days working at sea in nearby waters. R/V KNORR (AGOR-15) is named in honor of Ernest R. Knorr, an outstanding early hydrographic engineer and cartographer, who was appointed senior civilian and Chief Engineer Cartographer of the U.S. Navy Hydrographic Office in 1860. Mr. Knorr was largely responsible for the success of the Navy's first systematic charting and surveying effort from 1860 to 1885.

The ALVIN's tender LULU underwent extensive modification to its hoisting installation and its underwater body to enable it to handle the heavier submersible SEA CLIFF. However, SEA CLIFF has now been assigned to the Pacific and will be operated out of San Diego. ALVIN, when restoration now under way is complete, will rejoin the fleet at Woods Hole.

CHAIN at year-end was half way through a twenty month around-the-world cruise. She has been working in the western part of the Indian Ocean and Red Sea. During December she underwent overhaul in a shipyard at Mombasa, Kenya.

On July 27, forty acres of undeveloped land adjoining the Quissett campus to the east was purchased from the estate of the late Mrs. Edwin S. Webster. This will round out the property known as the Quissett campus.

A small wooden frame building has been erected on the water front through a grant from the Scaife Foundation to provide quarters specifically for those concerned with behavioral research utilizing chemical "messengers."



DUC DU BRABANT served as research vessel on Lake Tanganika (page 46) for a combined chemical-geophysical survey by Egon T. Degens, Richard P. Von Herzen and How-Kin Wong.

Cruises - 1970

ATLANTIS II — Days at Sea – 244 — Total Miles Sailed – 32,889

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
54	12-21 Jan.	Gulf Stream	9	V. T. Bowen
55	21-26 January	Shipyard	–	- - - - -
56	4 February–28 March	Caribbean	55	W. G. Metcalf
57	8-20 May	Buoy Line	12	J. E. Gifford
58	22-30 May	Shipyard	–	- - - - -
59 Leg I	9 June–3 July	Mediterranean	24	J. R. Heirtzler
59 Leg II	8-29 July	Mediterranean	21	E. L. Murphy
59 Leg III	2-30 August	Mediterranean	28	E. F. K. Zarudzki
59 Leg IV	1-13 September	Mediterranean	12	P. M. Saunders
59 Leg V	18-26 September	Mediterranean	8	G. D. Grice
59 Leg VI	26 September–6 October	Mediterranean	10	G. D. Grice
59 Leg VII	10 October–16 November	East and North Atlantic	37	J. H. Ryther
59 Leg VIII	19 November–17 December	Mid-Atlantic Ridge	28	R. H. Backus
		Total	244 days	

CHAIN — Days at Sea – 227 — Total Miles Sailed – 38,655

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
97	5-12 January	Buoy Line	7	H. H. Heinmiller
98	16 March–26 February	Site "D"	18	G. H. Volkmann
99 Leg I	1-14 April	Mid-Atlantic	38	E. Uchupi
99 Leg II	17 April–9 May	Mid-Atlantic	22	J. D. Phillips
99 Leg III	13 May–7 June	Mid-Atlantic	25	R. P. Von Herzen
99 Leg IV	11 June–2 July	Indian Ocean	21	H. Hoskins
99 Leg V	7-29 July	Indian Ocean	22	J. G. Bruce
99 Leg VI	2-29 August	Indian Ocean	27	J. G. Bruce
99 Leg VII	4-29 September	Indian Ocean	25	J. G. Bruce
99 Leg VIII	24 November–16 December	Indian Ocean	22	J. R. Heirtzler
		Total	227 days	

GOSNOLD — Days at Sea – 180 — Total Miles Sailed – 15,788

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
152 Leg III	4-12 January	Gulf of Mexico	8	G. T. Rowe
153	17 January–18 February	Gulf of Mexico	32	J. H. Ryther
154	24 February–3 March	East Coast	7	B. Dale
155	9-13 March	Gulf of Maine	4	D. W. Spencer

GOSNOLD (continued)

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
156	6-8 April	Gayhead–Bermuda Transect	2	J. F. Grassle
157	11-14 April	Gulf of Maine	3	W. E. Schevill
158	15-17 April	Gulf of Maine	2	J. F. Grassle
159	24-28 April	Gulf of Maine	4	P. G. Brewer
160	30 April–20 May	South of New England	20	F. G. Carey
161	22 May	Vineyard Sound	1	D. C. Rhoads
162	26 May–6 June	Shipyard	–	- - - - -
163	8 June	Great Harbor	1	P. H. Wiebe
164	10-16 June	Gulf of Maine	6	J. S. Schlee
165	18-20 June	Gayhead–Bermuda Transect	2	J. F. Grassle
166	25-30 June	New York Bight	5	R. F. Vaccaro
167 Leg I	1-13 July	Vicinity Bermuda Islands	12	J. W. Cooper
167 Leg II	16 July–5 August	Vicinity Bermuda Islands	20	D. C. Webb
168	12-17 August	Gulf of Maine	5	P. L. Sachs
169	19-21 August	Local Waters	2	H. W. Jannasch
170	24-28 August	Continental Shelf	4	G. T. Rowe
171	2-11 October	Block & Hudson Canyons	9	F. G. Carey
171A	12 October	Naushon Island & Witches Glen	1	G. L. Clarke
171B	19-25 October	Block & Hudson Canyons & Nantucket	6	F. G. Carey
171C	27 October–1 November	Block & Hudson Canyons & Nantucket	5	F. G. Carey
172	4-6 November	Gayhead–Bermuda Transect	2	J. F. Grassle
173	10-13 November	Gayhead–Bermuda Transect	3	J. F. Grassle
174	27 November–3 December	East Coast to Georgia	6	B. Dale
174 Leg I	5-8 December	Coast of Georgia	3	D. W. Menzel
174 Leg II	11-14 December	Cont. Shelf off Georgia Coast	3	D. Howard
174 Leg III	16-18 December	Cont. Shelf off Georgia Coast	2	J. Henry
		Total	180 days	

KNORR Days at Sea – 108 Total Miles Sailed – 15,455

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
1	15-29 May	In transit from Great Lakes	14	R. H. Backus
2	10 June	Trial Run	1	- - - - -
3	17 June	Trial Run	1	- - - - -
4	18 June	Associates Cruise	1	- - - - -
5	26 June–10 July	Buoy Line	14	R. H. Heinmiller
6	17 July	Trial Run	1	- - - - -
7 Leg I	21-25 July	Continental Shelf	4	T. B. Sanford
7A	26 July	President of Finland	1	- - - - -
8	28 July–4 August	Sargasso Sea	7	T. B. Sanford
9	11-20 August	Buoy Line	9	J. E. Gifford
10	24 August–3 September	Gulf Stream	10	D. W. Spencer
11	15 September	America's Cup Race	1	- - - - -
12	21 September–1 October	North West Atlantic	10	D. W. Spencer
13	5 December–15 October	Continental Shelf	10	D. Moller
14	18-26 October	Shipyard	–	- - - - -
15	9-17 November	Gulf Stream & Nova Scotia	8	L.V.Worthington
16	23-24 November	Gulf of Maine	2	C. D. Hollister
17	3-17 December	Buoy Line	14	R. H. Heinmiller
		Total	108 days	

LULU Days at Sea – 23

CRUISE NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
31	12-17 March	Nantucket Sound	5	R. N. Oldale
32	6 July–4 August	Shipyard	–	- - - - -
33	9-19 September	Georges Bank & Nantucket	10	E. Uchupi
34	1 October	Vineyard Sound	1	Test Run
35	14 October	Vineyard Sound	1	Test Run
36	16-22 October	Provincetown	6	Trial of Subs
		Total	23 days	

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, 1970:

Department of Biology

Anderson, Susan J.
Andrews, Robert G.
Backus, Richard H.
Bowman, Pamela E.
*Brown, Anna
Burnette, Donald W.
**Burns, Kathryn A.
Carey, Francis G.
Carpenter, Edward J.
*Clark, H. Lawrence
*Clarke, George L.
Clarner, John P.
Clifford, Charles H.
Collins, Barbara Ann
Corwin, Nathaniel
Craddock, James E.
Dunstan, William M.
Franklin, Denise
Garner, Susan P.
Graham, Linda B.
Grassle, J. Frederick
Grice, George D., Jr.
Guillard, Robert R. L.
Gunning, Anita H.
Haedrich, Richard L.
Hampson, George R.
Huguenin, John E.
Hulburt, Edward M.
Jannasch, Holger W.
Kanwisher, John W.
*Knapp, Cynthia A.
Konnerth, Andrew, Jr.
Lawson, Kenneth D., Jr.
Lawson, Thomas J., Jr.
Lorenzen, Carl J.
Masch, David W.
*Mason, John M., Jr.
Mather, Frank J. III
Mogardo, Juanita A.
Peck, Bradford B.
Polloni, Pamela A.
Pritchard, Parmely H.
Remsen, Charles C. III
Rogers, M. Dorothy
*Rossello, Richard C.
Rowe, Gilbert T.
Ryther, John H.
Sanders, Howard L.
Scheltema, Rudolf S.
Schroeder, Brian W.
Sears, Mary
Shores, David L.
Stanley, Helen I.
Teal, John M.
Tenore, Kenneth R.
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.

*Part-time Employment **Temporary Employment

Department of Chemistry

*Antonellis, Blenda
Atema, Jelle
Bankston, Donald C.
Blumer, Max
Bowen, Vaughan T.
Boylan, David B.
Brewer, Peter G.
Brezin, Paul
Burke, John C.
Degens, Egon T.
Deuser, Werner G.
Ehrhardt, Manfred
*Fennelly, Olga
Gordon, Allan G.
**Hancox, Stephanie
Harvey, George R.
Hess, Marilyn
Horne, Ralph A.
Hunt, John M.
Kadar, Susan
Laking, Phyllis N.
Lawson, Charlotte M.
McAuliffe, Julianne G.
McKenzie, Susan M.
McLarney, William
‡Noshkin, Victor
Olson, Charles
Patten, Linda E.
*Richards, Heidi
Ross, Edith
Sachs, Peter L.
Sass, Jeremy
Sayles, Fred L.
Smith, Clarence L.
Spencer, Derek W.
Stein, Lauren
Steinhauer, William C.
Suprenant, Lolita D.
*Taylor, Carol
Thompson, Geoffrey
Todd, John
Tripp, Bruce W.
Tucholke, Anita
Uhlitzsch, Irene
Waterman, Lee
Wilson, T. R. S.
Wong, Kai M.
Zafiriou, Oliver

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

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.
Bowin, Carl O.
Brockhurst, Robert R.
Bryan, Wilfred B.
Bunce, Elizabeth T.
Collins, Anne C.
*Coppenrath, Agnes I.
Dale, Barrie
Davis, James A.
Doutt, James A.
Dow, Willard
Driscoll, Alan H.
Dunkle, William M., Jr.
Emery, Kenneth O.
*Gallagher, Gloria S.
Grant, Carlton W., Jr.
Haq, Bilal U.
†Hathaway, John C.
‡Hays, Earl E.
Hays, Helen C.
Heirtzler, James R.
Hess, Frederick R.
Hill, Frank M. II
Hollister, Charles D.
Honjo, Susumo
Hoskins, Hartley
*Jones, Maxine M.
Katz, Eli J.
Knott, Sydney T., Jr.
Luyendyk, Bruce P.
**Mahoney, John W., Jr.
†Manheim, Frank T.
McElroy, Paul T.
†Meade, Robert H.
Mellor, Florence K.
Milliman, John D.
Morehouse, Clayton W.
Mosier, Gatha A.
Murphy, Edward L.
**Murray, Paul C.
Nichols, Walter D.
Nowak, Richard T.
Owen, David M.
†Oldale, Robert N.
*Peters, Virginia B.
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.
Serotkin, Nancy G.
Simkins, Samuel T.
Stetson, Thomas R.
Stone, Louise D.
Sutcliffe, Thomas O. L.
Toner, Lois G.
**Tucholke, Brian E.
Uchupi, Elazar
Vine, Allyn C.
Von Herzen, Richard P.
Walen, Roger S.
Wall, David
Watkins, William A.
*Weston, Edith A.
Witzell, Grace M.
Witzell, Warren E.
Wong, How-Kin
Wooding, Christine R.
Wooding, Frank B.
Young, Earl M., Jr.
Zarudzki, Edward F. K.

Department of Ocean Engineering

**Agen, Louise M.
Ballard, Robert D.
Barstow, Elmer M.
Bartlett, Arthur C.
Berteaux, Henri O.
Bitterman, David S., Jr.
Bland, Edward L., Jr.
Boutin, Paul R.
Breen, Mary L.
Broderson, George DeP.
Brown, Neil L.
Burt, Kenneth H.
**Charnews, Daniel
Chute, Edward H.
Cole, Bruce R.
Collins, Clayton W., Jr.
*Connell, William L.
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.
**Gularte, Ronald C.
Hamill, Clifford J.
Hilliard, Channing N., Jr.
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.
Morton, Alfred W.
Muzzey, Charlotte A.
O'Brien, Thomas F.
O'Malley, Patrick
Page, William F.
Picard, Ronald E.
Polloni, Christopher
Porteous, John
**Potts, Sherrill S.
Power, George H.
Rainnie, William O., Jr.
Roberts, William P.
Rosenfeld, Melvin A.
Sharp, Arnold G.
Shultz, William S.
Stanbrough, Jess H., Jr.
Stern, Margaret P.
Stimson, Paul B.
*Sullivan, James R.
Tollios, Constantine D.
Walden, Barrie B.
Walden, Robert G.
Weaver, Roger D.
Webb, Douglas C.
Webster, Jacqueline
Williams, Albert J. III
Wilson, Valentine P.
Winget, Clifford L.
Woods, Donald E.

‡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

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.
**Bowen, John L.
Bradshaw, Alvin L.
Breivogel, Barbara B.
Bruce, John G., Jr.
Bumpus, Dean F.
Bunker, Andrew F.
Chaffee, Margaret A.
Chase, Joseph
Chausse, Dolores H.
Cooper, John W.
Day, C. Godfrey
Dean, Jerome P.
Densmore, C. Dana
Denton, Edward A.
Dunlap, John H.
Ewing, Gifford C.
Fofonoff, Nicholas P.
Frank, Winifred H.
Frazel, Robert E.
Fuglister, Frederick C.
Gifford, James E.
**Gonella, Joseph
Guillard, Elizabeth D.
Hardy, Carl C.
Harlow, Caroline
**Hasselmann, Klaus F.
Heinmiller, Robert H.
Houston, Leo C.
Kelley, Michael D.
Knapp, George P. III
Maltais, John A.
Mason, David H.
McCullough, James R.
Metcalf, William G.
Millard, Robert C., Jr.
Miller, Arthur R.
Moller, Donald A.
Moore, Douglas E.
Munns, Robert G.
Parker, Charles E.
Payne, Richard E.
Reese, Mabel M.
Ronne, F. Claude
Sanford, Thomas B.
Saunders, Peter M.
Scharff, John M.
Schleicher, Karl E.
**Schmidt, Dennis W.
Schmitz, William J., Jr.
Schroeder, Elizabeth H.
Shodin, Leonard P.
Simmons, Charles F.
Simmons, William F.
Simoneau, R. David
Soderland, Eloise M.
Spencer, Allard T.
Stalcup, Marvel
Stanley, Robert J.
Striffler, Foster L.
Tarbell, Susan A.
Thayer, Mary C.
Thompson, Rory
Tupper, George H.
Volkmann, Gordon H.
von Arx, William S.
Voorhis, Arthur D.
Warren, Bruce A.
Webster, T. Ferris
**Welch, Christopher S.
Whitney, Geoffrey G., Jr.
Williams, Audrey L.
Worthington, L. Valentine
Wright, W. Redwood
Zemanovic, Marguerite P.
Ziegler, Evelyn
Zwilling, Avron M.

Department of Administrative and Service Personnel

Aiguier, Edgar L.
Anders, Wilbur J.
Andrews, Josephine A.
*Banay, Barbara B.
Barabe, Richard L.
Barabe, Roland E.
Battee, Howard
Battee, Janice
Baxter, Lincoln A.
Behrens, Henry G.
Bowman, Richard W.
Bragel, Ida A.
Brienzo, Karen A.
Brown, John W.
Busa, Kathryn
Cadwalader, George
Campbell, Eleanor N.
Carlson, Alfred G.
Carlson, Gustav A.
Carlson, Ruth H. E.
Carver, Kenneth W.
Chalmers, Agnes C.
Christian, John A.
Clough, Auguste K.
Conway, George E.
Corr, James P.
Costa, Arthur
Crawford, Bruce
Creighton, James E.
Crocker, Marion W.
Croft, Donald A.
Crouse, Porter A.
*Dalton, George A.
Dastous, Roland L.
Davis, Frances L.
Davis, Ruth H.
Dean, Mildred J.
Eastman, Arthur C.
Fagan, Peter D.
Fernandes, Alice P.
Ferreira, Anthony
Ferreira, Linda A.
Fielden, Frederick E.
Fisher, Stanley O.
Fredriksen, Mauritz C.
*Fuglister, Cecelia B.
Gallagher, William F.
Gibson, Laurance E.
Govoni, Arthur A., Jr.
Gross, Karen M.
*Hahn, Jan
Halle, Rene C., Jr.
Hampton, Carolyn S.
Hatzikon, Kaleroy L.
Henderson, Arthur T.
Hindley, Robert J.
Hodgson, Sloat F.
Hooper, Edward J.
Hunting, Judith E.
Ingram, Ruth C.
Innis, Charles S., Jr.
Jenkins, Delmar R.
Johnson, Harold W.
Joseph, Charles R.
Kelley, Robert F.
Kempton, Edward E.
Koval, Frank
Kvaraceus, Rose A.
Lajoie, Therese S.
Lamarre, Adrien J.
Lambert, William D.
LeBlanc, Donald F.
Lewis, Ellen S.
Macaulay, Marianne
MacKillop, Harvey
Mahut, Odette A.
Manni, Janice
Marks, Cynthia A.
Martin, Olive
Mayberry, Ernest H.
McGilvray, Mary K.
Medeiros, Frank
Meinert, Dorothy
Mitchell, James R.
Motta, Joseph F.
Mullen, Carolyn G.
Muller, John T.
Ortolani, Mary
Page, Stephen G.
Peirson, A. Lawrence III

*Part Time Employment

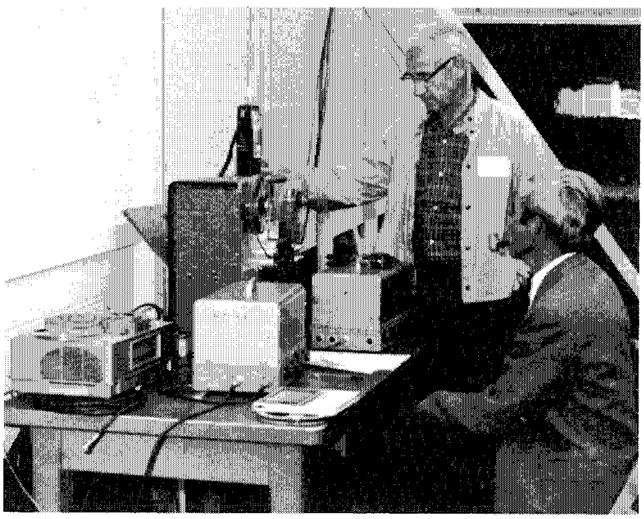
**Temporary Employment

Department of Administrative and Service Personnel (continued)

Perry, Lawrence N.
Peterson, Judith A.
Phares, Edward
Picard, Eleanor P.
Pires, Joseph L.
Pykosz, Patricia A.
Quigley, Alexsandra
Quigley, Ralph W.
Ramsey, William S., Jr.
Reeves, Stanley A.
Rennie, Thomas D.
Robbins, Charles C.
Ross, David F.
Rudden, Robert D., Jr.
Schilling, John L.
Smart, Thomas H.
Souza, Donald P.
Souza, James H.
Souza, Thomas A.
Staltare, Michelle E.
Stimpson, John W.
Vallesio, Barbara M.
von Dannenberg, Carl R.
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.
Young, Carleton F.

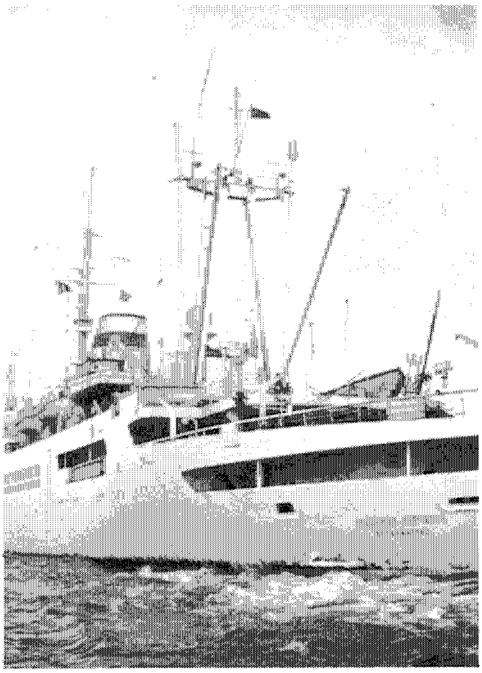
Marine Personnel

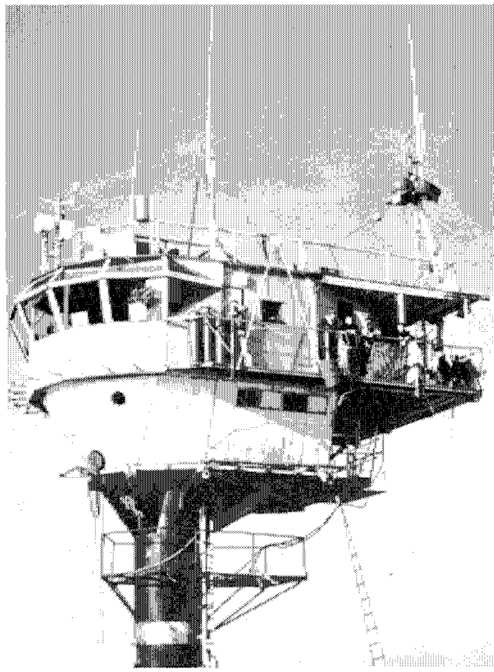
Anderson, David S.
Anderson, Thomas L.
Babbitt, Herbert L.
Baker, William R.
Barnes, David A.
Bazner, Kenneth E.
Benttinen, David D.
Bizzozero, John P.
Brodrick, Edward R.
Bumer, John Q.
Butler, Dale T.
Caranci, Donald H.
Casiles, David F.
Clark, Richard B.
Clarkin, William H.
Colburn, Arthur D., Jr.
Cook, Alden
Cotter, Jerome M.
‡Coughlin, Brooks W.
Davis, Charles A.
Day, C. Godfrey
Dimmock, Richard H.
Dunn, Arthur J.
Edwards, Richard S.
Ellsworth, Harvey A.
Ewing, Barry E.
Fairfield, Edward E.
Farnsworth, Donald C.
Field, Michael J.
Frank, Donald S.
Gabbett, Leo F.
Gallivan, Christopher
Gassert, John M.
Gassett, Kenneth
Gordon, Robert L.
Hamblet, Dwight F.
Hansen, H. Morgan
Hartke, David L.
Hartke, Richard A.
Hiller, Emerson H.
Howland, Paul C.
Jefferson, Albert C.
Johnston, Alexander T.
Johnston, Ronald
Jones, William E.
Karalekas, Theodore
Knight, Olin T.
La Porte, Leonide
Leiby, Jonathan
Linde, John H.
Lobo, Wayne F., Jr.
Manley, Thomas F.
Martin, John W., Jr.
McLaughlin, Barrett J.
Melson, Carroll L.
Merrill, Raymond A.
Morse, Joseph C.
Moye, William E.
Mysona, Eugene J.
Oakes, Harry E.
Ocampo, Conrad H.
O'Neill, Thomas F.
O'Reilly, Peter P.
Palmieri, Michael, Jr.
Pierce, George E.
Pierce, Samuel F.
Pike, John F.
Rand, Kenneth W.
Ribeiro, Joseph
Rioux, Raymond H.
Roderick, Alfred C.
Samp, Michael W.
Seibert, Harry H.
Sheak, Robert E.
Smith, Robert E.
Sorenson, Donald M.
Soucy, Trefton A.
Stires, Ronald K.
Sture, Armas B.
Tully, Edward J.
Webert, Warren F.
White, William A.
Wood, Robert C.
Woodworth, Michael S.
Wordell, Ralph



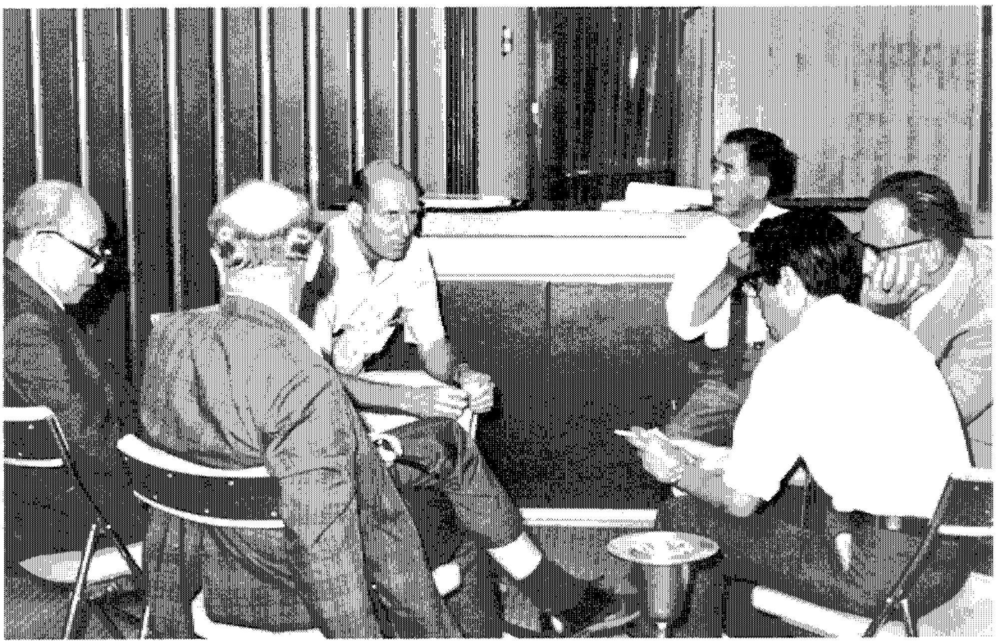
Sound control, behind the scenes, at graduation. Edward H. Chute (seated). Elmer M. Barstow (standing).

‡Leave of Absence





(Left) Robert H. Heinmiller (W.H.O.I.) participated in SCOR-sponsored experiments aboard R.V. AKADEMIK KURCHATOV. Woods Hole current meters were attached to Russian buoys to compare current measurements made by several groups. (Right) T. Ferris Webster joined the scientific team aboard the Bouée Laboratoire of Marseille for two weeks in February 1970.



Last planning session before the Joint Oceanographic Assembly in Tokyo 13-25 September 1970. From left to right: Drs. Michitaka Uda, Warren S. Wooster, Arthur E. Maxwell, Ken Sugawara, Kozo Yoshida and Günter Dietrich.

Treasurer's Report

The accounts for the year 1970 have been audited by Lybrand, Ross Bros. & Montgomery.

Some of the principal changes during 1970 are shown below:

	1970	1969	Increases
Direct Costs of Research Activity	$10,175,388	$ 8,692,235	$1,483,153
Education Operations	408,995	243,100	165,895
General and Administrative Costs	1,345,141	1,171,404	173,737

During 1970 gifts from individuals, foundations and corporations increased Endowment Fund assets and income as shown below:

	1970	1969	Increases
Endowment Assets, Book Value	$16,086,055	$13,938,214	$2,147,841
Endowment Assets, Market Quotation	19,211,923	17,462,661	1,749,262
Endowment Income	368,219	314,437	53,782

"Total gifts and pledges to the Development Campaign now exceed $18.5 million. Of particular significance during 1970 were an additional gift by Mr. J. Seward Johnson, a payment on the earlier pledge by the Edna McConnell Clark Foundation and a gift by John M. Olin."

	1970	1969	Increase
Contributions to W.H.O.I. Retirement Trust	$504,249	$405,089	$99,160

Woods Hole Oceanographic Institution

Woods Hole, Massachusetts

We have examined the balance sheet of Woods Hole Oceanographic Institution as at December 31, 1970 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.

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, 1970 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 schedule included in this report (page 87) although not considered necessary for a fair presentation of the financial position and results of operations, is presented primarily for supplemental analysis purposes. This additional information has been subjected to the audit procedures applied in the examination of the basic financial statements, and in our opinion, is fairly stated in all material respects in relation to the basic financial statements taken as a whole.

Boston, Massachusetts

March 15, 1971

Lybrand, Ross Bros. & Montgomery

BALANCE SHEET

December 31, 1970

ASSETS

Current Fund Assets:	
Cash	$ 697,250
Short-term investments, at cost which approximates market	1,672,866
Reimbursable research costs:	
Billed	990,940
Unbilled	811,492
Supplies, prepaid expenses and deferred charges	265,870
Plant funds advanced to current	(1,702,053)
	2,736,365
Endowment Fund Assets (note A):	
Investments:	
Securities, at cost, market value $18,161,653	15,035,785
Certificate of deposit	900,000
Real estate	54,512
	15,990,297
Cash	56,776
Receivable on investments sold	38,982
	16,086,055
Plant Fund Assets:	
Laboratory, plant and equipment	5,301,878
Atlantis II, contingent title (note B)	4,831,130
Other vessels, equipment and property	3,572,843
	13,705,851
Less accumulated depreciation	3,280,664
	10,425,187
Plant funds advanced to current	1,702,053
	12,127,240
	$30,949,660

LIABILITIES

Current Liabilities and Reserves:	
Accounts payable and accrued expenses	$ 579,558
Contribution payable to employees' retirement plan and trust (note E)	504,249
Unexpended balances of restricted gifts and grants	494,393
Reserves	1,158,165
	2,736,365
Endowment Funds (note A):	
Restricted as to principal and income	9,140,400
Restricted as to principal	2,521,420
Unrestricted as to principal; restricted as to income	1,808,856
Unrestricted as to principal and income	157,952
Accumulated net gain on sales of investments	2,457,427
	16,086,055
Plant Funds:	
Expended for plant, less retirements	13,705,851
Less accumulated depreciation	3,280,664
	10,425,187
Unexpended	1,702,053
	12,127,240
	$30,949,660

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, 1970

Operating Expenses:		
Direct costs of research activity:		
Salaries and wages		$ 3,638,204
Vessel and aircraft operations		2,702,564
Materials, equipment and services		2,237,157
Laboratory costs		562,598
Travel		311,827
Service departments		348,540
Computer center		374,498
		10,175,388
Direct costs of educational operations		408,995
Indirect costs:		
General and administrative		1,345,141
Total depreciation (note D)	$465,677	
Less amount charged to direct and indirect costs above	220,384	245,293
Miscellaneous		269,203
		$12,444,020
Resources Used to Meet Operating Expenses:		
Income for sponsored research (including $3,847,681 gifts and grants expended):		
For direct costs		10,056,944
For indirect costs		1,260,127
Fees for use of facilities		241,161
		11,558,232
Revenue from educational operation:		
Gifts availed of	$206,922	
Tuition and rental income	86,271	293,193
Endowment income availed of (note C)		185,493
Development program contributions for unrestricted purposes		117,535
Miscellaneous		119,056
Working capital and contingency reserve availed of		170,511
		$12,444,020

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

Statement of Changes in Funds

Year Ended December 31, 1970

	Endowment Funds (note A)	Invested in Plant	Unexpended Plant Funds	Unexpended Balances of Restricted Gifts and Grants	Reserves: Income and Salary Stabilization	Reserves: Working Capital and Contingency
Balance at beginning of year	**$13,938,214**	**$10,521,448**	**$1,617,926**	**$ 639,696**	**$ 986,103**	**$ 4,533**
Restricted gifts and grants received	2,107,001		70,194	3,995,563		
Endowment income (note C)				89,979	92,747	
Net gain on sales of investments	29,840					
Working capital and contingency reserve availed of						(170,511)
Provision for depreciation (note D):		(465,677)	220,384			245,293
Availed of for research and education costs				(4,054,603)		
Transferred from restricted gifts and grants to unexpended plant funds and endowment funds	11,000		162,965	(173,965)		
Invested in plant		369,416	(369,416)			
Miscellaneous				(2,277)		
Balance at end of year	**$16,086,055**	**$10,425,187**	**$1,702,053**	**$ 494,393**	**$1,078,850**	**$ 79,315**

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

Summary of Endowment Assets

As at December 31, 1970

	Book Amount	% of Total	Market Quotation	% of Total	Endowment Income
BONDS:					
Government and government agencies	$1,155,549	7.2	$1,135,190	5.9	$ 69,195
Railroad	288,152	1.8	208,860	1.1	12,212
Public utility	775,702	4.8	683,940	3.6	27,498
Industrial	774,500	4.8	621,860	3.2	39,774
Financial and investments	370,472	2.3	327,790	1.7	22,366
Total bonds	3,364,375	20.9	2,977,640	15.5	171,045
STOCKS:					
Preferred	176,661	1.1	140,400	.7	6,355
Common:					
Public utility	456,422	2.8	991,826	5.2	42,228
Industrial*	10,876,648	67.7	13,865,412	72.1	141,936
Miscellaneous*	161,679	1.0	186,375	1.0	6,732
Total common stocks	11,494,749	71.5	15,043,613	78.3	190,896
Total stocks	11,671,410	72.6	15,184,013	79.0	197,251
Total securities	15,035,785	93.5	18,161,653	94.5	368,296
CERTIFICATE OF DEPOSIT	900,000	5.6	900,000	4.7	
REAL ESTATE	54,512	.3	54,512**	.3	(77)
CASH AND ACCOUNTS RECEIVABLE	95,758	.6	95,758**	.5	
Total endowment assets	**$16,086,055**	**100.00**	**$19,211,923**	**100.00**	**$368,219**

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

Notes to Financial Statements

A — Endowment fund assets include securities which are restricted as to public sale. Such securities were valued at the current market valuation ($9,140,400) of unrestricted securities of the same class, on the dates of gifts.

Endowment fund assets also include securities received in 1970 for which a readily determinable market value could not be established. Such securities are included at a nominal value of $1, in accordance with the existing policy of the Institution.

The changes in the market value of endowment fund assets were as follows for the year ended December 31, 1970:

Market value, beginning of year		$17,511,922
Net (loss) in investment market value:		
Realized	$ 29,840	
Unrealized	(447,840)	(418,000)
Gifts		2,107,001
Transfers		11,000
Market value, end of year		$19,211,923

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

C — Total endowment income in 1970 of $368,219 was allocated to the following:

To meet operating expenses	$185,493
Income and salary stabilization reserve	92,747
Unexpended balances of restricted gifts and grants	89,979
	$368,219

D — Depreciation is provided at annual rates of 2% to 5% on buildings, 3⅓% on Atlantis II and 5% to 33⅓% on equipment. Depreciation expense for 1970 totaling $465,677 includes $245,293 of depreciation on Atlantis II, Laboratory for Marine Science and the dock facility which is not charged to the costs of research activity or educational operations.

E — For its noncontributory retirement plan, the Institution charged $504,249 to operating expenses for the year ended December 31, 1970. Under the terms of the retirement trust, the amount of the Institution's annual contribution shall be 12% of compensation paid or accrued by the Institution to plan members during the year.