THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

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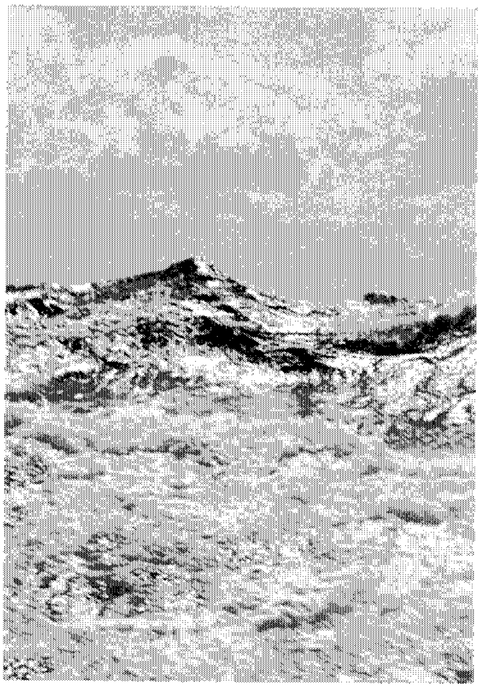

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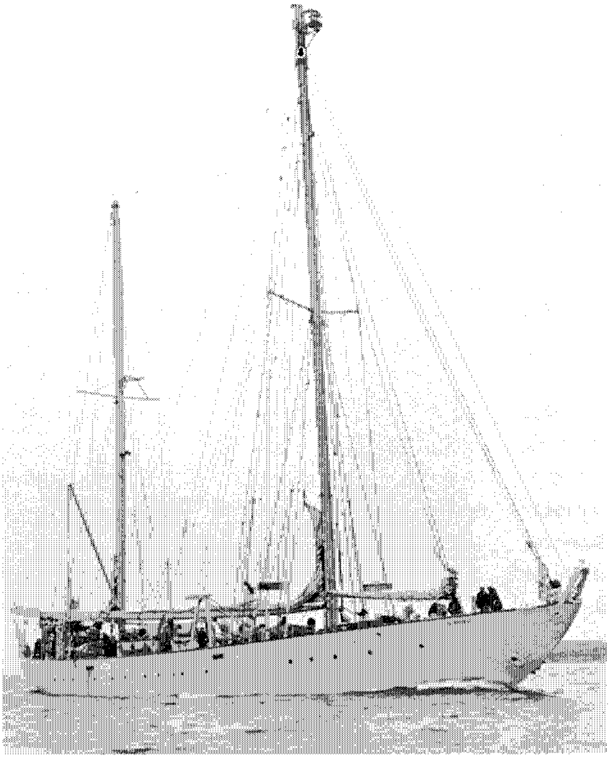

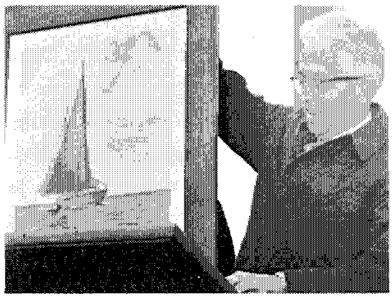

EL AUSTRAL, formerly ATLANTIS (left). Dr. Fye (upper right) presenting picture of ATLANTIS for the wardroom of EL AUSTRAL, Ricardo O. Rennella, Capitan de Corbeta, Argentine Navy, commanding officer of R/V EL AUSTRAL (lower right).

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Award of the Bigelow Medal to Columbus O'Donnell Iselin, 22 June 1966

Sailor, scientist, author, lecturer, administrator, counsellor, teacher, adviser to the U.S. Government and to international bodies, historian, guide to future developments, and above all a "pump primer." Columbus O'Donnell Iselin is to a large extent responsible for the growth and development of oceanography into a major science. He is one of the few people of such accomplishments who has enlarged their subject without enlarging themselves as a public figure.

Just over 35 years ago American oceanography virtually was nonexistent. By good fortune, Columbus Iselin, as a student at Harvard, met Dr. Henry Bryant Bigelow who interested the mathematics major in the problems of the ocean. He (C. O'D. I.) built a 72-foot schooner, the CHANCE, and with a group of fellow students went to study the Labrador Current off Newfoundland, thus proving that valuable work could be done with a small ship — an absolute necessity in those days when little, if any, money was available for oceanography. Soon thereafter (1930) the Woods Hole Oceanographic Institution was founded. Dr. Bigelow became its first Director and Mr. Iselin, the Captain-scientist of the R.V. ATLANTIS which he had helped to design.

During the next ten years he studied the Gulf Stream and wrote a series of classic papers on this current. In 1940, he became the second Director of the Institution. Convinced that the U.S. Navy needed a knowledge of its environment in the coming war, he received his chance by being able to demonstrate that underwater sound location of submarines was influenced by the thermal characteristics of the ocean, thus laying the groundwork for the present-day multi-million dollar anti-submarine warfare

industry. Neither the German nor the Japanese navies were aware of these developments during World War II.

Under Columbus Iselin's guidance the study of ocean waves, air-sea interactions, submarine geology and other programs were actively pursued; programs which today have amassed great stores of knowledge of scientific as well as economic value.

There were no trained oceanographers but Iselin had an uncanny knack of finding and training young men, many of whom have become respected authorities in their fields. Always readily available, he roamed the corridors giving advice and suggestions, often in that indirect way which makes it appear that the resulting developments stem from the recipient's own thoughts.

In the immediate post-war years when government support was difficult to obtain, Columbus Iselin retained the nucleus of his team at low pay but high morale, but also encouraged others to leave for university positions or other marine laboratories, thus spreading talent in many places and by this initial leavening made it possible to interest universities, which had not been notably enthusiastic about the marine sciences.

Imprecise navigation always has bothered oceanography so that the wartime development of Loran greatly interested him. Soon, together with the bathythermograph, a new attack on the Gulf Stream problem was initiated, resulting in a new concept of ocean currents which kept physical oceanographers and mathematicians enthusiastically busy for many years. Iselin's interest in navigation continues. The GEON system and developments in VLF navigation were sparked at Woods Hole, while the ATLANTIS II recently became the first research vessel to employ satellite navigation.

In the lean post-war years, Iselin also encouraged the study of coastal waters which largely had been avoided by oceanographers. These studies led to the first adequate theory on estuarine circulation, a work of great practical importance for pollution, coastal engineering and fishery problems.

In his careful writings, in lecturing, and as a member of many national and international committees, Columbus Iselin's low key suggestions on many aspects of the ocean have received wide acknowledgment and acceptance. He foresaw the great postwar expansion in international fisheries and wrote and spoke extensively on fishery problems which are often more social and economic problems than scientific ones. He initiated the search for new fishery resources in deep water off the New England coast, a "pump priming" which led to a new lobster fishery and extensive searches by other agencies. Years ago he suggested the establishment of the marine equivalent of agricultural experimental stations. This idea seems about to become a reality.

Readily available to anyone, be it scientist, businessman, politician, reporter or layman, he has stated his views thousands of times with the slow voice of reason and has flown more than one million miles to express his ideas as readily to a scientific meeting as to a high school group, Rotarians, or others. A few of his statements have seeped into the national consciousness: "Fishermen remain hunters, not farmers." "A major obstacle to progress is that the old idea of freedom of the seas is diametrically opposed to the wise management of ocean resources." "Our greatest resource is H_2O: we must try to get it on the land more uniformly (through climatic control)." "Acre for acre, the sea is as fertile as good farm land."

Practically no aspect of the ocean, now so widely discussed, has escaped his attention. As early as 1946, he encouraged the development of ocean buoy systems. The coupling of meteorology and oceanography, long-range weather forecasting as well as oceanographic forecasting, the possible moderation of climate and weather, international co-operation in science, education and naval warfare problems all were and are encouraged and discussed.

A most human man, never angry, always reasonable, Iselin also is well aware of the social problems resulting from scientific advances; the difficulties of government support and the lack of sufficient private funds to spur fundamental research and the slow progress from scientific knowledge to practical economic results.

The recipient of many honors, Columbus Iselin has two which cannot be won by professional excellence, the admiration and loyalty of those who are privileged to be associated with him at the Institution. Thus, there is considerable excitement throughout the laboratories that he is the recipient of the Henry Bryant Bigelow Medal, for he has all the qualities that make this award to him most fitting.

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Professor of Chemistry and Chairman of the
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GEORGE VERONIS, *Associate in Mathematics*
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PIERRE WELANDER, *Associate in Physical Oceanography*
Docent, Stockholm University, Stockholm, Sweden

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CARL E. MENNEKEN, U.S. Naval Postgraduate School, Monterey, California

THOMAS C. SMITH, Daystrom, Inc., Poughkeepsie, New York

Department of Biology

HUDSON HOAGLAND, The Worcester Foundation for Experimental Biology, Shrewsbury, Massachusetts

JOHN D. H. STRICKLAND, Institute of Marine Resources, La Jolla, California

KARL M. WILBUR, Duke University, Durham, North Carolina

Department of Chemistry and Geology

WALLACE S. BROECKER, Lamont Geological Observatory, Palisades, New York

L. H. N. COOPER, The Laboratory, Marine Biological Association, Plymouth, England

BERNARD R. PELLETIER, Bedford Institute of Oceanography, Dartmouth, Canada

Department of Geophysics

ANTON L. HALES, Southwest Center for Advanced Studies, Dallas, Texas

FREDERICK V. HUNT, Harvard University, Cambridge, Massachusetts

J. LAMAR WORZEL, Lamont Geological Observatory, Palisades, New York

Department of Physical Oceanography

CLIFFORD A. BARNES, University of Washington, Seattle, Washington

MAURICE RATTRAY, JR., University of Washington, Seattle, Washington

ROBERT W. STEWART, University of British Columbia, Vancouver, Canada

Department of Theoretical Oceanography and Meteorology

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JEROME NAMIAS, U.S. Weather Bureau, Washington, D.C.

P. A. SHEPPARD, Imperial College of Science and Technology, London, England

THE DIRECTOR'S REPORT

A Milepost in Education

For the past several years a Trustees' Education Committee has been looking into the role which graduate education should play at the Institution and the several ways in which a graduate-studies program might best take advantage of the unique character of the Institution. These studies culminated, this past summer, in a final report to the Board of Trustees recommending the establishment of a joint Ph.D. degree program in cooperation with a limited number of universities.

At the Annual Meeting of the Board of Trustees in June, it was unanimously voted to approve the establishment of joint doctoral programs based on the report (June 1966) of the Trustees' Education Committee and to authorize the Director and Executive Committee to formalize agreements with universities and to arrange for the necessary changes in the Institution's charter from the Commonwealth of Massachusetts. The latter half of the year has been devoted to further discussions with representatives from the Massachusetts Institute of Technology about the implementation of such a program and the preparation of the legal documents seeking the necessary change of the Institution's charter from the Commonwealth of Massachusetts. On December 2, 1966, the Corporation of the Massachusetts Institute of Technology approved the establishment of a joint Ph.D. degree program with the Institution, and on January 11, 1967, the Members of the Corporation of the Woods Hole Oceanographic Institution voted the necessary amendment to the Institution's charter.

Thus, all the formal steps within the Institution and at MIT were completed to permit the achievement of a new and unique plan for the training of young people in marine science. This is a milepost of considerable magnitude — one which may well become most significant in the development of the Institution.

Education at Woods Hole — a brief history

The founding of the Institution in 1930 resulted from a recommendation of the first Committee on Oceanography of the National Academy of Sciences.

In their report, its secretary, Henry B. Bigelow, wrote:

> "A single well-equipped oceanographic institution in a central location on the Atlantic Coast is needed to supply necessary facilities for research and education, hitherto lacking, and **to encourage the establishment of oceanography as a university subject.** Such a central institution would contribute to the advancement of oceanographic research not only by the productivity of its staff but also by the impetus that it would give to studies in this field in various universities. The proposed institute would also serve a most important purpose by providing facilities for visiting investigators, and by coordinating the scattered interests of numerous governmental agencies and private organizations already active in parts of the field."

From the day when it first opened its doors, the Institution has provided a common meeting ground and research facilities for faculty and students from many colleges and universities. As early as 1932, the first full year of laboratory operation, the staff, visiting investigators and students came to Woods Hole from eighteen different universities; in the following year, twenty-two universities were represented at the Institution. In subsequent years, these relationships with academic centers have continued to grow. The young Institution thus drew most of its intellectual nourishment from academic soil — from students and their teachers, even though the principal commitments of these individuals were to their parent universities. At the same time, the Institution gave a new impetus to the universities' programs in oceanography. This was indeed a very satisfactory arrangement, for the Institution played a significant role in the academic process even though its educational activities were not formal in nature.

The educational program at the Institution has been based on the philosophy that oceanography is not a unique basic scientific discipline, but rather an interdisciplinary area of research which should draw the attention of investigators trained in each of the fundamental sciences. These investigators, challenged by oceanic problems, use their special knowledge and training to explore the problems of the ocean systems which involve the tools and methods of physics, chemistry, biology and mathematics. Other interdisciplinary areas of research, such as geology, meteorology, and engineering are also drawn upon in the pursuit of oceanographic studies. It would be most unwise, we believe, to disregard the true nature of oceanography in the development of our educational program. The formal education of research oceanographers must not consist of a smattering of each of the basic sciences but rather must be based on a rigorous background in one scientific discipline alone which, it appears to us, provides the most satisfactory basis for a career of original research.

Since its early days, there has been a three-pronged approach to education at Woods Hole: (1) there has been a very substantial scholarship program, which has provided fellowships to over 700 young scientists interested in the marine sciences, (2) faculty members from a large number of universities

(14 at the present time) have been appointed to positions on the non-resident staff, and (3) the regular staff members at Woods Hole have frequently held part-time faculty positions at collaborating universities. Thus, the Institution has successfully fulfilled its assigned role of "encouraging the establishment of oceanography as a university subject."

Current Trends

In recent summers, the Institution's educational program has become in some respects more formal. Summer courses have been offered for which some universities have given credit to their students. The Geophysical Fluid Dynamics course has continued to be a major summer discussion group in the fields of hydrodynamics and theoretical oceanography. Institution staff members, holding joint appointments at cooperating universities, have served as thesis advisers for graduate students pursuing their doctoral research work at sea and in the laboratories at Woods Hole. During the past five years, 25 graduate students have done their doctorate research at the Institution. In order to continue our leading role in oceanography, the Trustees and leaders within the Institution have become concerned with the formulation of new objectives in education and research. These have become increasingly important in maintaining a stimulating environment for the pursuit of significant and exciting new knowledge about the oceans. The pattern of informal participation in universities has become less appropriate today with the development of numerous independent marine programs wholly within university centers.

A formal step in this direction was taken during the summer of 1963 when Dr. Norris W. Rakestraw, then Dean of Graduate Studies at the Scripps Institution of Oceanography, was invited to come to Woods Hole to study in depth the Institution's needs and obligations in education. Dr. Rakestraw's study was followed in June 1964 by the appointment of the Trustees' Committee which was charged with "reporting to the Board of Trustees on the Rakestraw Report and other educational proposals which have arisen . . ."

This Committee consisted initially of Dr. James S. Coles, President of Bowdoin College; Dr. Arnold B. Arons, Professor of Physics, Amherst College, and Professor Carroll L. Wilson of the Massachusetts Institute of Technology, with Dr. Detlev W. Bronk, President of Rockefeller University, and Dr. Jerome B. Wiesner, Provost of the Massachusetts Institute of Technology, added later. They considered at great length the role that educational activities should play within the Institution. Realizing that students are the life blood of basic research, bringing unorthodox ideas, youthful imagination and knowledge of new peripheral fields to bear on yet unsolved questions, the Committee concurred with the Seaborg Report of the President's Scientific Advisory Committee in saying

> "The process of graduate education and the process of basic research belong together at every possible level. We believe that the two kinds of activity reinforce each other in a great variety of ways and that each is weakened when carried on without the other."

They concluded that our educational program must be strengthened to insure the Institution's long-range intellectual health and viability. Continuing to provide opportunities for students from universities to conduct their doctorate research in Woods Hole or at sea is important but not sufficient. In addition, we must attract students to the Institution by actively participating in a full-fledged graduate program leading to doctorates in various branches of oceanography.

Future Plans

The Trustees' Education Committee, in their final report last June, recommended that the Institution establish cooperative Ph.D. programs with one or more universities, and because of the close ties already existing suggested that such programs be explored first with the Massachusetts Institute of Technology and Harvard. Each of these proposed programs would use the facilities and staff both at Woods Hole and at the university and would culminate in a Ph.D. awarded jointly by the Institution and the university concerned. The Institution does not now have, nor do we plan to have, a large diversified faculty such as one might find at a university. It does have, however, a research staff expert in virtually all phases of oceanic studies that can be matched only at one or two other laboratories in the world. An obvious goal is, therefore, to devise a graduate education program in oceanography which would utilize the best that the cooperating university and the Institution could offer jointly. The participating institutions thus should supplement one another in a unique way and the resulting program, we believe, would be second to none in the world. It would offer the staff in Woods Hole the opportunity of actively participating in a graduate studies program with first-rate students, and it would make available to the university staff and students the unsurpassed facilities for oceanic research at Woods Hole.

Excellent progress has been achieved in the planning and development of a joint doctoral program with the Massachusetts Institute of Technology. Having completed all formal internal steps, the necessary charter modifications are now before the General Court and the Board of Higher Education of the Commonwealth. There is every reason to believe that this joint program will come into being during 1967, and it is hoped that one or more additional cooperative programs will be developed in the near future.

The establishment of formal graduate education programs at the Institution will have a profound and positive effect on the Institution. It is quite correct in this instance to say that things will never be the same again, for a major step ahead has been taken.

PAUL M. FYE

Department of Applied Oceanography

The staff of the Department of Applied Oceanography grew in size by about fifty percent between December 1965 and December 1966. The relative increases were largest in the ALVIN Group and smallest in Electronics. Thus, the Institution has been strengthened in the engineering, in information processing and in the technical portions of many programs. Each group is involved quite intimately with the work of one or more of the other departments. This addition, therefore, actually represents an improvement and diversification in the capabilities of the Institution as a whole.

Alvin

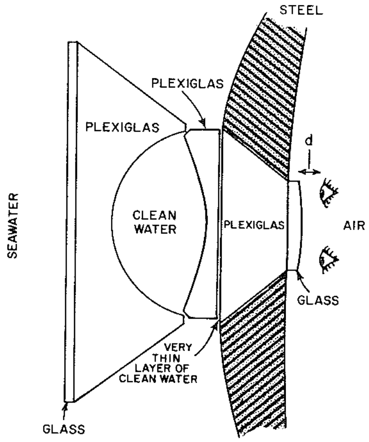
ALVIN had a busy year which must be considered quite successful. Due to unforeseen circumstances there was, however, considerably less time devoted to scientific work for the Institution than had originally been planned and more time was utilized by the Office of Naval Research and its problems than had been intended. About two-thirds of ALVIN's time had been scheduled for Woods Hole scientists and their colleagues with about a month each scheduled for the Office of Naval Research and other Navy oceanographic groups in surveying and in inspection of hydrophones in the Bermuda and Tongue of the Ocean areas where Institution personnel also wanted to work.

The unfortunate collision of the two planes over Palomares, Spain and the subsequent search for the "lost" bomb drastically altered the schedule. ALVIN departed from Otis Air Force Base in early February and finally returned in May. Suffice it to say that ALVIN found the bomb, participated in its recovery and returned to her home port. After some upkeep necessitated by the hard service off the coast of Spain, ALVIN went south. Several weeks were spent at Bermuda where an excellent survey was made on an installation there and where a member of the Biology Department, Robert Hessler, made a first dive. Then the scene of operation was shifted to the Tongue of the Ocean where the other two commitments were completed. There, too, dives were made with Allyn Vine of the Geophysics Department and with John Schlee of the Department of Chemistry and Geology. Coming back to Woods Hole, ALVIN made a dive in Oceanographer Canyon with scientists from the Department of Chemistry and Geology.

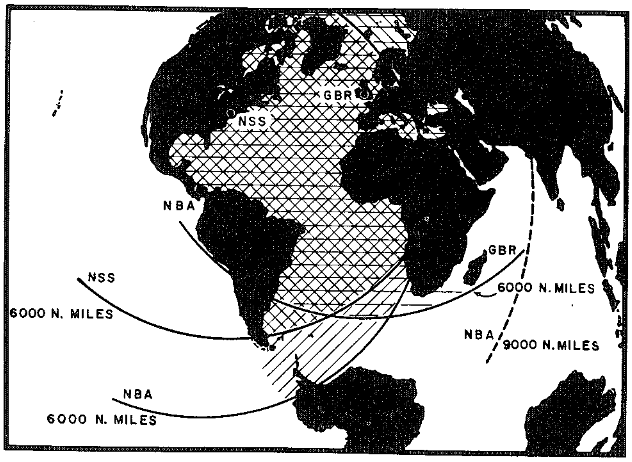
Improvements to ALVIN and extensive modification to the catamaran were made early in 1966, and the operations during the year reflected these changes. A study is still in progress on systems for improving the visibility from ALVIN.

Buoys

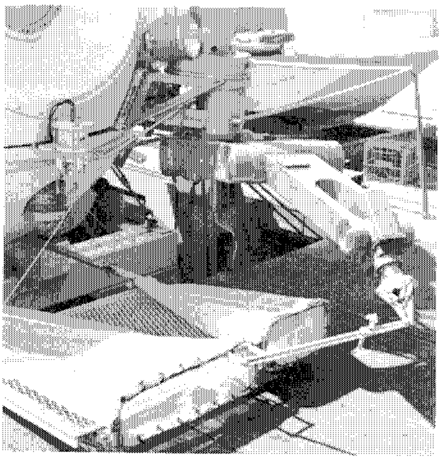
The Buoy Group is working very closely with members of the Department of Physical Oceanography in the processing and analysis of data obtained from the buoy sets (page 42). During 1966, buoys were anchored at five stations, at latitudes 39°20′, 38°30′ 38°00′, 37°30′, 36°00′N all along longitude 70°W. Each set contained current meter and temperature sensors with mechanisms to accumulate such data over a period of months. The northern and southern extremes were instrumented from surface to bottom, but the inner three had bottom instruments only. The strong currents in the Gulf Stream still present a formidable problem in obtaining measurements from surface to bottom. Although an overall sensor recovery of 64 per cent was reached during the year, this is not considered satisfactory and studies of the design and technique of the mooring system



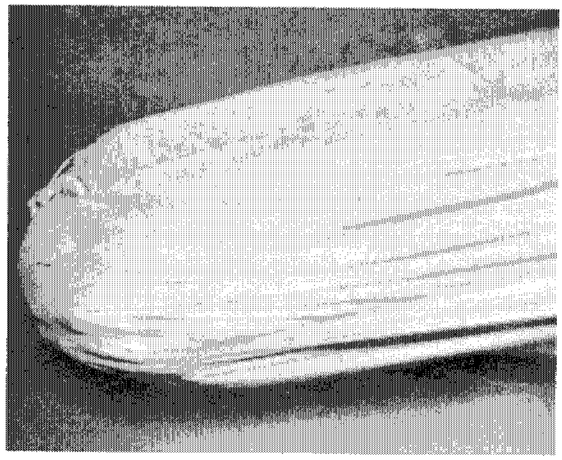
A promising design for correcting the distortion of ALVIN ports.



North and South Atlantic coverage by VLF navigational stations NSS, NBA and GBR.



ALVIN's plankton nets.



Parachute-shrouded H-bomb.

continue as an important part of the program. The high incidence of "fish bite" losses has been reduced by using a combination of cable and synthetic line. Cable terminations, rates of corrosion and cable failure are now the major causes of loss. A measurement program of tensions experienced by the mooring is underway and is leading to some design changes. The major improvements in the instruments themselves has been the change from recording on film to recording on magnetic tape. This will be a more efficient and economical way to obtain the data. The use of location pingers on the submerged units was initiated and is becoming standard operating practice.

Computers

The Information-Processing Center is continuing to expand its influence throughout the Institution. Although the greatest amount of time for the computer is devoted to the analysis of data from the buoy line, a large number of investigators are now using it to their advantage. Many of these programs require small amounts of time, but they eliminate hours and hours of hand computation by assistants.

To facilitate use of the computer by the staff a course in beginning Fortran was given at four different times during 1966. In addition a course in statistics for scientists was given by one staff member from the Center and one from the Chemistry and Geology Department.

A start has also been made in applying the computer to the business and administrative data of the Institution. Property control records, programs for allocation of payroll costs to projects and certain summaries are now processed more efficiently at the Center.

The physical equipment of the Information-Processing Center was essentially unchanged during 1966. The GE 225 has served well as the first medium class computer for the Institution. Although not used appreciably in second or third shift operations it does lack the capability to process certain data economically as compared with larger machines. The recognition of this restriction has caused a reduction in the scope of some investigations to fit the computer. As a result a study has been made to determine the next logical step for the improvement of computer facilities at Woods Hole.

The "at sea" computer has also been active. In the Geophysics Department the magnetics-gravity-bathymetry-navigation system (IBM 1710) has operated many hours aboard ship. Also a real-time sounding velocity profiler system using the PDP-5 was operational on ATLANTIS II during the summer. An "at sea" computer committee has been struggling valiantly to ascertain the sort of system that should be installed to improve the capabilities aboard ship.

Electronics

The Electronics Group has two functions: one concerns the maintenance of a large percentage of the instruments aboard the ships and in the laboratories, the other new instrumentation and the development of measuring techniques. The present size of the group is so limited that all personnel become involved in both types of work. The variety and complexity of the equipment to be maintained and the small percentage of "down time" reflects their effort and success.

In new instruments the emphasis has been on a beacon navigation system for ALVIN, on an isotherm follower, and on long range (1600Km) Swallow floats. Significant progress has been made and important field tests have been conducted on all of these, but none are as yet considered as finished.

The Electronics Group has worked closely with the Buoy Group in problems associated with medium frequency (3.8 KHz) beacons for locating subsurface and bottom moorings by acoustic methods, and "call-up" release mechanisms.

Rational components have been developed and assembled for the long-range Swallow-float program and a series of tests were successfully conducted from Bermuda aboard CHAIN. Operationally useful attenuation data at 780 Hz out to 500 Km were obtained.

The evolution of a simple precise acoustic recorder for use in finding and locating drifting or anchored buoys has been satisfactory.

Sound Transmission

Two investigators are concerned with sound transmission problems. One involved the diffraction effect in long-range refracted sound in the Mediterranean Sea. This effect resulted in a spreading of the expected focusing regions and is of interest in the prediction of long-range sound intensities. In addition, there has been a study of the seasonal and spatial variation of sound velocity in the North Atlantic and Mediterranean, as measured directly and as obtained from physical oceanographic data from many sources.

EARL E. HAYS, *Chairman*

Department of Biology

Biochemistry and Microbiology

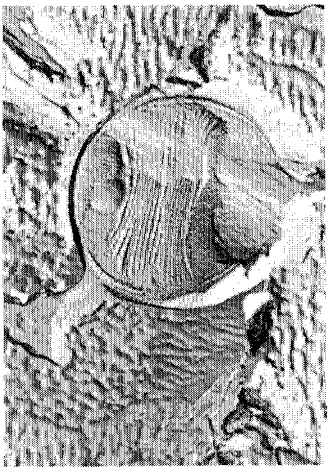
During March-April, 1966, an opportunity was provided through the ANTON BRUUN Program sponsored by the National Science Foundation to study plankton growth and related chemical and microbiological activities in the highly-productive waters of the Peru Coastal Current. Due to the rapid biological changes which occur as the result of the upwelling of nutrient-rich waters along the Peruvian coast, it was possible by following a given parcel of water to measure organic production and decomposition directly, by short-term changes in particulate organic carbon, phosphorus, and chlorophyll, and indirectly through related changes in oxygen, phosphate, and nitrate.

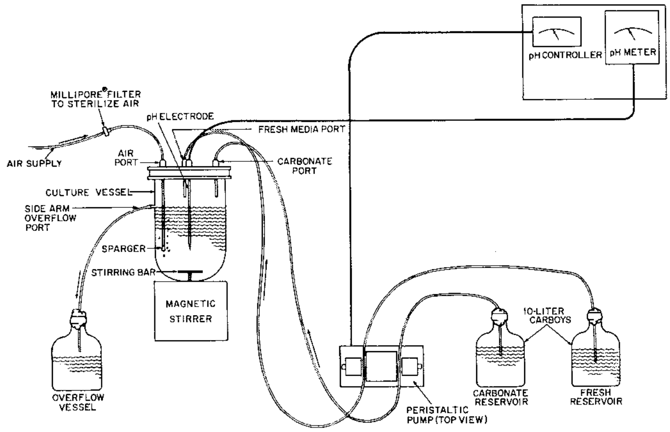
Rapid growth during the first three days following upwelling, with rates of organic production exceeding 10 g carbon/m^2/day, were followed by an equally rapid decline in the population. The latter probably resulted from zooplankton grazing since no nutrient regeneration accompanied the population decrease. Excretion of dissolved organic compounds was extremely low during the growth and decline of the population, amounting to no more than 5% of the organic matter fixed during photosynthesis.

Despite the rapid biological-chemical changes and the relatively high populations of plankton algae which developed and disappeared in the surface layers, no changes were observed in the levels of particulate organic carbon below about 50 m. These, and other observations made in the North Atlantic during 1966, confirm the earlier hypothesis that the levels of organic carbon in the deep-sea are extremely low, are constant geographically and at all depths below the mixed layer, and are not dependent upon or affected by the level of organic production or the biomass in the overlying surface water.

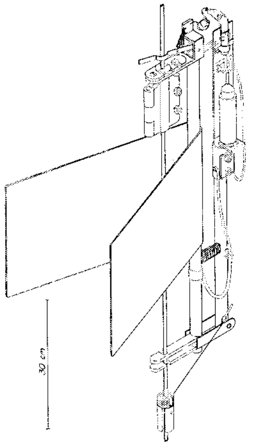
The kinetics of the heterotrophic uptake of tagged organic substrates by natural populations of microorganisms from the Peru Current and adjacent waters appear to differ from those studied from the Atlantic Ocean. In the latter region, uptake at various substrate levels showed a saturation-type curve with a linear reciprocal plot typical of the uptake kinetics of pure enzyme systems, as described by the Michaelis-Menton equation. In the Pacific, on the other hand, the usual uptake response to different substrate levels plotted as a sigmoid curve suggesting mixed populations with differing uptake kinetic constants. It is possible that these differences reflect differences between the populations of microorganisms in the stable waters of the western Atlantic and those characteristic of the newly upwelled and relatively unstable waters of the Peru Current.

The earlier concept of minimum population densities of certain species of marine bacteria and threshold concentrations of a limited substrate was confirmed. The fact that high growth rates and high population densities produce lower threshold concentrations suggests a positive feedback mechanism which is ineffective below a certain minimum population density, resulting in a drastic drop in growth rate and leaving a corresponding concentration of limiting substrate. The high levels of dissolved organic matter in seawater may be explained on the basis of those observations: i.e., that the compounds involved are

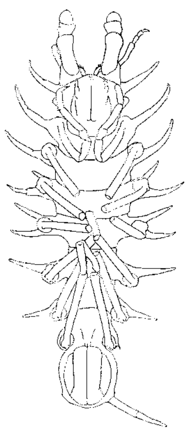




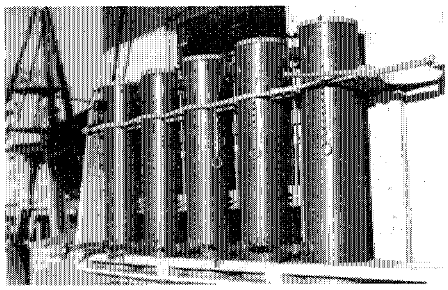
Frozen-etched preparation (left) of Nitrosocystis oceanus *showing extensive cytomembranes as viewed with an electron microscope. Automatic growth chamber (right) for ammonia oxidizing bacteria.*



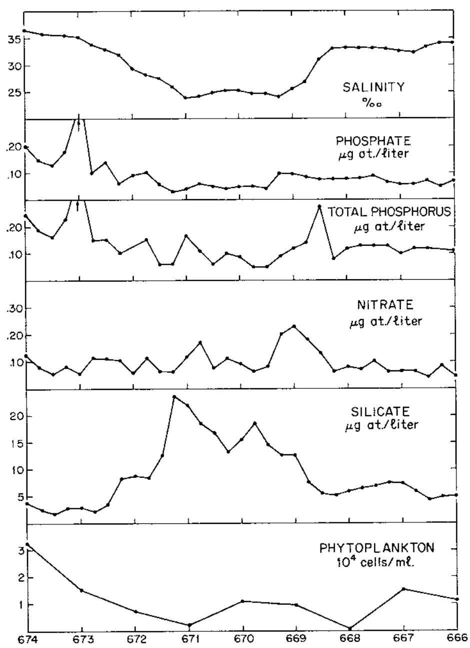
Bacteriological sampler. The prominent vanes keep the instrument heading into current ahead of the hydrographic wire to avoid contamination.



Dactylostylis acutifrons
Richardson 1911
(Isopoda: Asellota)



Van Dorn water samplers.



Surface chemistry determined from hourly bucket samples and phytoplankton—all counts taken along a section northeast of the Guianas, May-June 1965.

Variety of fin whale (Balaenoptera sp.) *from the Indian Ocean.*

not resistant to bacteriological degradation *per se* but are probably present at concentrations which are individually below threshold levels.

Some promising headway was made during the year on the problem of assaying for minute concentrations of specific organic substrates by enzymatic analysis. Sensitivity of the method has been increased to the point where it can be used for the direct determination of glucose at a level of 10^{-8} M without prior concentration or extraction. Since the high salt concentration of natural seawater inhibits the reactions, samples must be diluted 1:2 with distilled water giving a final sensitivity of 3×10^{-8} M.

Ecological, morphological, and biochemical studies have continued on specific groups of marine microorganisms including the nitrifying, sulfate reducing, and sulfide oxidizing bacteria. Organisms have been cultured from a variety of coastal and offshore locations, several new species of each group have been isolated, and comparative studies are now in progress. The latter are soon to be facilitated through the installation of a Phillips-300 electron microscope.

Comparative physiological studies have also been undertaken with strains of plankton algae which appear morphologically to be the same species but which have been isolated from markedly different environments (e.g., tropical vs. temperate, estuarine vs. oceanic). Relative growth rates of the different isolates as a function of such environmental variables as temperature and salinity have revealed several examples of physiological races of algal species.

Floristic studies of marine phytoplankton during the past year have extended observations in the Eastern Tropical Pacific, the Caribbean, the Gulf of Mexico, the Gulf Stream, and the Gulf of Maine. A seasonal study of the dinoflagellates of the Woods Hole region in relation to bioluminescence has been initiated.

Chromatographic and spectrophotometric studies of phytoplankton pigments and their decomposition products have included both laboratory cultures and natural populations. The former have provided a basis for reevaluating the taxonomic position of several species of nannoplankton. The latter have been greatly facilitated by the development of a submersible batch filtration unit which permits the *in situ* filtration of large volumes of water thus insuring an adequate quantity of natural material for pigment fractionation.

Invertebrate Zoology

The role of pelagic larvae in the transatlantic distribution of benthic invertebrates may be demonstrated by the presence of such larvae in the surface plankton of the major current systems of the North Atlantic Ocean. Furthermore, these larvae must intrinsically have long pelagic lives or possess mechanisms for delaying metamorphosis to enable them to survive the oceanic crossing. To date 450 plankton samples from twelve major and twelve additional shorter North Atlantic cruises have been sorted. Long distance larvae have been identified for about forty species of molluscs, fifteen to twenty species of sipunculids, and two brachipods. The data for Crustacea and annelids are not complete, but larvae of both groups are well represented in the plankton samples. Estimates of the frequency with which larvae are likely to be distributed across the Atlantic are roughly the same as the proposed rates of natural mutation, suggesting that larval transport provides an important genetic link between widely-separated populations of the same species.

Techniques have been improved during the past years for obtaining deep-sea bottom

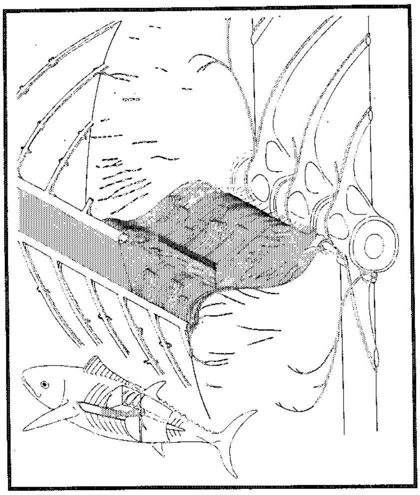
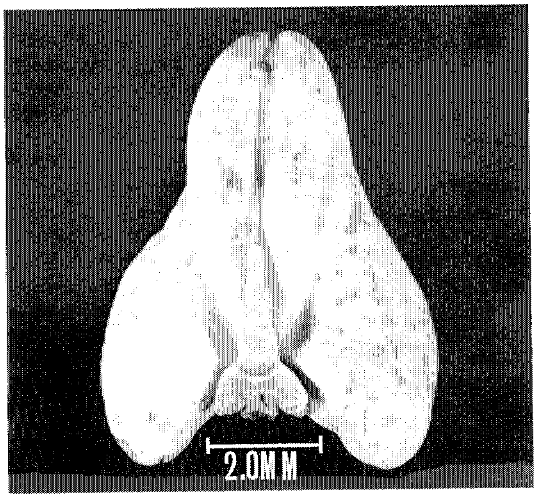
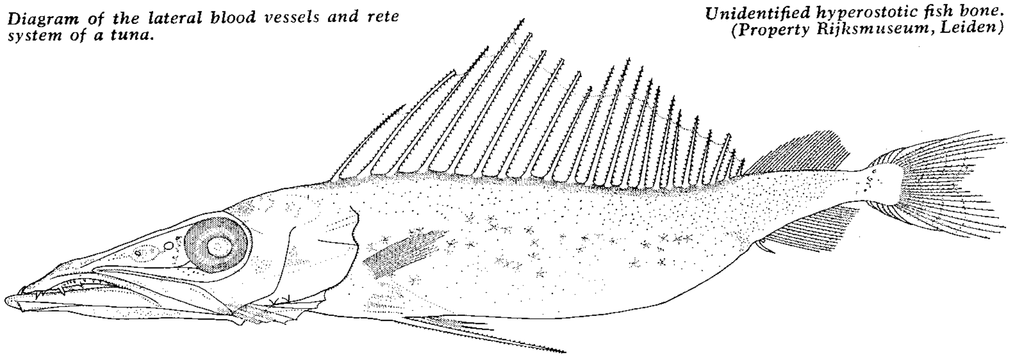


Diagram of the lateral blood vessels and rete system of a tuna.



Unidentified hyperostotic fish bone. (Property Rijksmuseum, Leiden)



Nesiarchus nasutus, *a pelagic fish akin to the snake mackerel which may reach a length of several feet. This specimen was collected in the Anegada Passage and is about an inch long.*

samples with the new epibenthic sled. Samples were taken in the Sohm Abyssal Plain and near Bermuda to permit testing of the hypothesis concerning the homogeneity of the deep-sea fauna and to make comparisons of bathyal island fauna with that of the continental slope. These samples show a remarkable diversity but, at the same time, contain large numbers of closely related species. The latter is in contrast to the oft-quoted ecological theory which states that, because the requirement of related species are similar, they are to be found in different habitats.

Analysis of deep-living copepods from the western Indian Ocean has been completed. Of 269 species encountered, 241 are also common to the North Atlantic Ocean. No significant decrease in the so-called "North-Atlantic species" was found in progressively more northern Indian Ocean samples. These observations provide evidence of the effective inter-oceanic dispersal of copepods by the deep-sea currents and may also indicate a slow rate of speciation among bathypelagic Crustacea which may be typical of deep-sea faunas in general.

Experiments with euphausids taken from the oxygen-minimum layer of the Eastern Tropical Pacific showed that these animals were able to maintain normal respiration rates in water containing less than 1% of the level of oxygen saturation and were perfectly normal after exposure to such water for periods of several hours. This behavior suggests a special adaptation to living under near-anoxic conditions, as most animals show a sharp decrease in respiration when oxygen pressure falls below 10-30% saturation.

Previous studies of euphausids taken from the deep scattering layer indicated that pressure has little or no effect on their respiration. Preliminary experiments with decapods, however, show that higher pressures increase metabolic rates, at least partially compensating for the opposing effects of decreasing temperature with depth.

For the first time in many years, plankton investigators at the Institution have included a study of the ecology and life history of salps. An attempt was made to assess the geographical and vertical distribution of a swarm of *Thalia democratica,* to determine the number of individuals comprising a salp swarm, to relate changes in relative abundance of solitary (oozooid) to aggregate (blastozooid) forms, and to record any environmental changes which could be associated with the swarming.

Vertebrate Zoology

During January-February, forty-two collections of bathy- and mesopelagic fishes were made from ANTON BRUUN off the coast of Chile. Identification of the fishes is nearly complete and has revealed a rich and varied fauna including some 125 species of open-ocean fishes, several encountered for the first time outside of the North Atlantic.

Continued emphasis on the tagging of oceanic fishes resulted in 1966 in the release of over 7,000 marked individuals and 663 returns. Major effort was placed on bluefin tuna, based largely on the New Jersey-Cape Cod seine fishery, which produced 590 returns from 4,200 releases. Catch and effort and size-frequency data were gathered concurrently. Returns from 1965 releases of young bluefin included 46 local recaptures and 13 from the Bay of Biscay. These and earlier observations indicate that the transatlantic migration of the bluefin does not occur annually or involve the entire stock. First evidence of a trans-equatorial migration was provided by a return from 140 miles southeast of Recife, Brazil, of a tuna tagged in 1963 off the Bahamas.

Physiological experimentation with giant bluefin (and certain species of sharks) have shown them to be warmer than the water they inhabit by as much as 12°C. This is accomplished by means of a complex system of countercurrent heat exchangers formed from masses of intermingled arteries and veins in the fish's gills, the so-called *rete mirabile,* which provides an effective thermal barrier in the circulatory system between the muscles, where heat is produced, and the gills, where it is lost. It is of some interest that two such unrelated groups of fast-swimming fishes as the tuna and the isurid sharks have evolved almost identical heat-conserving anatomical structures.

Acoustic telemetry of physiological data has been developed on free-swimming SCUBA divers as an outgrowth of earlier methods worked out for porpoises and seals. With a unit one and one-half inches in diameter and ten inches long it is now possible to transmit electrocardiograms, temperature, breathing, and speed of a diver from a distance of up to one kilometer through the water. Depth may be included in the measurements by increasing the diameter of the case to three inches. The primary purpose of this technique is to permit study of the exercise physiology of man in the sea compared to that of marine mammals. A secondary use of the device is as a safety feature for surface monitoring of the physiology of deep divers.

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Department of Chemistry and Geology

Organic Compounds

Previous investigators have found that the straight chain paraffin hydrocarbons in recent, nearshore sediments contain in the C_{18}-C_{32} range predominantly odd carbon number chains. Generally, these exceed the even carbon number chains by a factor of about four. The hydrocarbons in terrestrial plant waxes show a similar odd carbon predominance and plants — terrestrial or marine — are considered the sources of the hydrocarbons in marine sediments.

The studies of hydrocarbons in marine benthic and pelagic algae collected from their natural environment and in planktonic algae grown in pure and uncontaminated cultures, show little or no odd carbon predominance in the C_{18}-C_{32} range. All algae show a major concentration maximum at C_{15} or C_{17} and a secondary maximum between C_{27} and C_{30}. Recent sediments from local nearshore environments show the same odd carbon number predominance previously reported from other areas. This suggests that the normal paraffins of Recent sediments are largely derived from sources other than the benthic or planktonic organisms studied. A possible application of this work may lie in the determination of the relative contributions of terrestrial and marine organic matter to the sediments of the shelf, slope and deep sea.

Different genera of algae have different hydrocarbon distribution patterns especially in the C_{15} to C_{17} molecular weight range. This finding confirms and extends that of the great variability of the hydrocarbon distribution pattern found earlier in zooplankton and further suggests the use of hydrocarbons as biochemical and geochemical tracers. The isoprenoid hydrocarbon pristane, isolated earlier from zooplankton, occurs in several planktonic and benthic algae while phytane was not detected. This substantiates the earlier interpretation that pristane is a biochemical product while phytane appears to be formed during diagenesis of sediments.

A study of the accumulation of plankton derived hydrocarbons in the liver of the basking shark, *Cetorhinus maximus* (Gunnerus), has been completed. The hydrocarbons incorporated with the planktonic food pass through the digestive system of the shark and eventually are deposited unaltered in the liver. There is no fractionation or hydrogenation of the olefinic hydrocarbons. This and earlier work indicates that the half-lives of hydrocarbons in marine organisms are sufficiently long to trace their dispersal through several stages of the food chain.

Red Sea

A detailed geophysical and geochemical study of the hot brines and associated mineral deposits in the Red Sea was made on CHAIN in the fall of 1966. A hundred stations were made in the Red Sea, taking about sixty cores, twenty-five hydrocasts, thirty heat flow measurements, and fifty-seven continuous temperature depth profiles. The hot brine together with associated heavy metals is apparently periodically ejected from the subsurface due to some magmatic event. The minerals are deposited over a wide area; bottom currents disperse the hot water except in the deeper restricted areas where the high salt content causes stratification of the water. The concept of periodic injections is clearly indicated by the layering of highly colored iron rich sediments from cores taken on the flanks of the holes above the present hot water levels. The major iron deposits are in the ATLANTIS II hole which is approximately twelve kilometers long and six kilometers wide. A small channel extends south-southwest from the ATLANTIS II hole to the DISCOVERY hole. Between these a new brine pool, the CHAIN hole, was discovered which contained water with a maximum temperature of 34°C as compared to maximum temperatures of 56°C and 44°C found in the ATLANTIS II and DISCOVERY holes. The brine pools of the three holes appear to be separated by sills at the northern and southern end of the CHAIN hole, although they were undoubtedly in communication during periods of ejection of the hot water. Two new instruments were successfully tested on this cruise; the first a temperature telemetering pinger which takes a continuous recording of water temperatures during its lowering. This instrument takes advantage of a dual pinger system, with the time difference between the pings being temperature dependent. This enabled detailed temperature profiles to be made in all three holes. The second instrument, a German Kasten corer obtained relatively undisturbed cores twenty-five centimeters square and four meters in length. These combined with free fall, piston and gravity cores, gave a fairly complete picture of the sedimentation pattern along the twenty kilometer length of the rift valley where the holes are located.

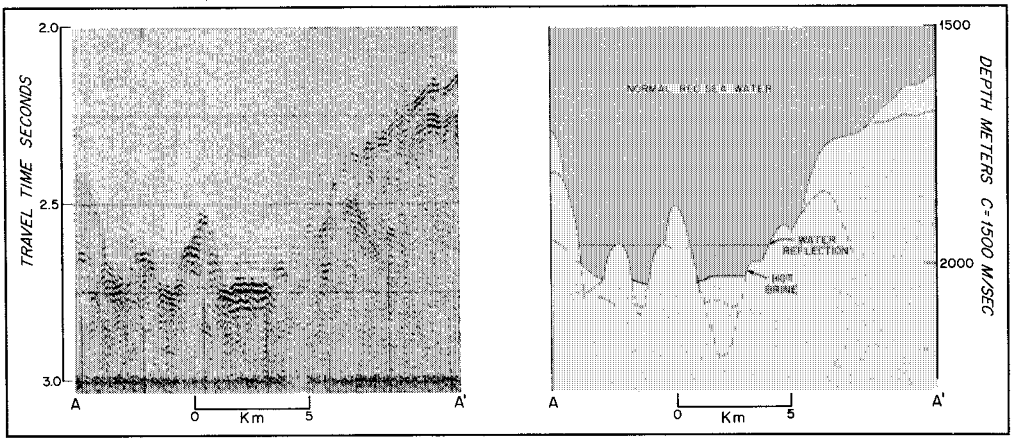
Continuous Seismic Profiling showed a second strong reflection about one hundred and fifty meters below the sediment surface on the flanks but not in the hot hole areas. Faulting was also observed on both flanks of the rift zone. Reflections were also obtained from the hot saline water in the ATLANTIS II and DISCOVERY holes, but none were observed in other deep holes north of 19°N in the Red Sea. The temperature pinger indicated no hot water in deeps of the Red Sea except in the known hot hole area.

Sea Water Chemistry

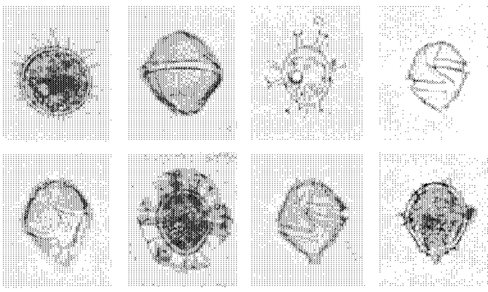
The solubility of naphthalene in various salt solutions was determined as part of our continuing studies on electrolyte-nonelectrolyte interactions. Naphthalene salting by five two-salt mixtures was found to be additive and from this it was possible to predict naphthalene salting in an artificial sea water. Several natural waters also had predictable salt effects thereby proving that any natural solubilizers present are not contributing to the solubility of non-electrolytes such as naphthalene.

The Ligand exchange method, previously reported for concentrating the dissolved organic matter from sea water has been further tested. The Gulf of Maine contains about forty per cent more free amino acids than Buzzards Bay, although the relative amounts of amino acids are essentially the same. The method has been extended to the extraction of polymeric, non-dialyzable humic acid-like compounds in sea water. Butanol and acetone extracts of this material gave infra-spectra comparable to the yellow organic products that had been obtained in freshwater streams. The results show that the resin extraction procedure will concentrate large as well as small molecules from sea water. Studies of the nature of the bonding between the chelex resin and the copper have revealed the presence of two types of bonding, one of a chelating nature and very strong, and the other very weak.

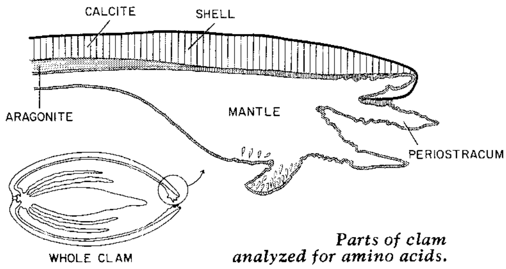
Techniques were developed for the routine analysis of Fe, Pb, Li, Mg, Sr, Zn, Ca, Cr, Ni, Co, Mn and Cu in sea water by atomic absorption spectrophotometry. Li, Sr and Mg are determined directly by aspirating normal or diluted seawater and using artificial brine standards. Other metals are being analyzed through extraction with a chelating agent, ammonium pyrroli-



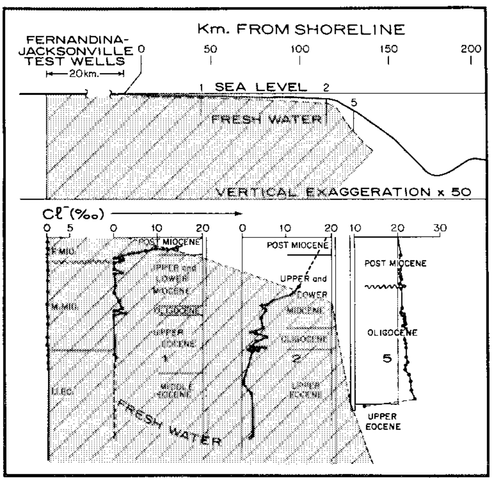
Continuous seismic reflection profile record from the ATLANTIS II Deep. Actual record is on the left, a line indicating the interpretation on the right. Dashed lines represent uncertainties. Travel time is two way time.



Dinoflagellates and their cysts.



Parts of clam analyzed for amino acids.



Geological section showing fresh water (shaded area) from sediments beneath the Atlantic shelf off Florida.

dine dithiocarbamate and dissolution in methyl-isobutyl ketone.

Radio Isotopes

Particulate material collected on air filters at sea was analyzed for seven gamma emitting radioisotopes: Cs^{137}, Ce^{144}, Sb^{125}, Ru^{106}, Mn^{54}, Zr^{95} and Be^{7}. The concentration of these isotopes in the air over the sea decreases from northern to southern latitudes. Concentration fluctuations by factors of 2 to 4 were found in samples collected at the same latitude only a few days apart. The Ce^{144} to Cs^{137} ratio for all latitudes sampled showed a decrease from November 1964 to May 1966 which corresponds to that expected from radioactive decay during this period. This indicates very little fractionation between Ce and Cs on reaching the sea surface from the atmosphere and no measurable introduction of new Ce^{144} to the atmosphere during this period. Fallout radioisotope concentrations in sea-level air over the Atlantic from 5° to 35°N are in the same range as those measured over land at similar latitudes. It is planned to correlate surface water data with air filter data from the same location to determine how rapidly the isotopes are distributed in the upper layers and what fractionation occurs between isotopes in surface water compared to those in the air above.

Analyses of Sr^{90} in ocean surface water show that current movements considerably smear the north to south gradients evident in land-based measurements of fallout delivery rates. Integration of vertical profiles of concentration continues to support the concept that the rate of delivery of fallout is much higher to the ocean surface than to the land surface. Analyses in Lake Michigan show it has received as much as double the fallout typical for its latitude zone. It is not yet known if water surfaces have a higher collecting efficiency or if meteorological differences are responsible for higher over-ocean fallout.

Samples of *Sargassum* from the Western North Atlantic were found to have little Cs^{137} or Sr^{90} in contrast to fairly large amounts previously reported from analyses of *Sargassum* from the Gulf of Mexico. The North Atlantic samples did contain large amounts of Fe^{55} and Mn^{54}. From the analyses of Fe^{55} in the *Sargassum* and published estimates of the standing crop of *Sargassum* and the expected delivery of Fe^{55} to the Sargasso Sea, it was calculated that about one per cent of the total bomb test Fe^{55} in this area is now in *Sargassum* tissues.

Continued work on the vertical distribution of fallout isotopes in marine sediments indicates that different mechanisms are causing variations in the vertical movement of fallout isotopes from the surface down. As expected, vertical profiles of Ce^{144} and Eu^{155} correspond to movement only by mechanical mixing by organisms; profiles of Sr^{90}, Cs^{137} and Mn^{54} all appear more or less modified by physiological processes, and Sb^{125}, surprisingly, is very similar in distribution to Mn^{54}.

Preliminary studies of the uptake from sea water of Ce^{141} indicates that on an equal weight basis some copepods can remove as much cerium as can clay particles. Continued studies of the interactions of lanthanide elements with clay particles has proven that the lanthanides interact as ions in solution and not as colloid particles. The distribution coefficient shows no correlation with the measured total base exchange capacity of pure clay because the reactions are at concentration levels far below those required to saturate the clays.

Shell Morphology

About two hundred specimens of molluscs, largely from marine environments, were analyzed for the amino acid composition of mineralized and unmineralized tissues. In addition, the spatial conformation of the molecular network of proteins in the shells was determined by gel-filtration, electrophoresis and solubility studies. The objective of this work was to relate molecular biological changes in terms of amino acid composition and spatial conformation of proteins to (1) molluscan phylogeny and (2) environmental variations, such as salinity, water depth and temperature. The analytical data was subjected to Factor Analysis and from this it was possible to construct a phylogenetic tree of Mollusca from the amino acid data. This biochemical model agrees in general with conventional biological taxonomy. It also demonstrates that shell morphology and the molecular biology of the organism are inter-related.

The protein chemistry of the molluscs also showed the presence of cystine, amino sugars, phenolic amino compounds, quinones and hydroxylysine, the latter of which may provide cross links in the shell tissues.

The molecular weight of the individual protein units range from 20,000 to 80,000. The chemical work plus X-ray and electron-micrograph studies showed that the proteins are fibrous in nature and resemble the so-called keratin-myosin-epidermin-fibrin groups of proteins.

Carbon Isotopes

A detailed study was made of the ratio of C^{13} to C^{12} in the organic matter from bottom sediments of rivers, lakes, estuaries, bays and the open sea along the Atlantic coast of the United States. Data from about thirty rivers showed the samples furthest upstream to be the lightest with increasing C^{13} going downstream into the ocean. C^{13}/C^{12} ratios of organic matter from sediments taken across the shelf and on the continental slope were essentially the same as those on the seaward side of the outermost sand bars. Since the terrestrially derived organic matter has about six per mil less C^{13} than the marine organic matter it is apparent that the terrestrial effect does not extend much beyond the nearshore areas. If terrestrial organic matter is finding its way farther out to sea its effect is being diluted by much greater amounts of the heavier marine organic matter. Two samples of peat found on Georges Bank had C^{13}/C^{12} values of –25.9 and –26.3 respectively, relative to the PeeDee belemnite. This means there has been no fractionation in the peat bog since the last ice age when this land was emergent.

Studies of laboratory cultured marine plankton grown under controlled environmental conditions, showed that the plant material became enriched in C^{12} as the temperature decreased. There also appeared to be a five per mil enrichment by plants left in darkness for twelve days. These results are complicated by the fact that the major biochemical fractions of the plankton show as wide variation between each other as occurred in the total organism during these experiments.

Continental Margin

Field work for the initial five year joint Woods Hole Oceanographic Institution – U.S. Geological Survey Program for geological studies of the continental margin was finished in the fourth year. Ship time totaled 634 days including time involved in underwater dives of ALVIN. Laboratory studies and final reports will be completed during the coming year, after which the program will be directed toward investigation of details of processes, local topographic problems, and extension of work to new areas such as the continental rise between the Grand Banks and Florida. Greater emphasis will also be placed on subsurface studies with ALVIN, side-scanning sonar, and details of the third dimension through offshore drilling.

Submarine canyon extensions off the east coast were surveyed during 1966 beyond the 2000-meter contour. Canyons related to the major drainage areas on the East Coast show deep sea extensions, many of which have a high levied right bank and most, like the Washington, bend toward the left where they enter the continental rise. Others like the Hudson and Wilmington canyons bend sharply to the right and deepen about seventy miles down the rise, suggesting that they are partly erosional in that area. Two cycles of canyon formation appear to have occurred off the East Coast with the deeper canyons, such as the Hudson, involved in both cycles. These topographic studies of the submarine canyons were supplemented by a month of dredging their side slopes from GOSNOLD. In addition, ALVIN was used to collect rock and sediment samples, to trace rock outcrops, and to photograph the floor and the western side of Oceanographer Canyon (southeast of New England) and the precipitous eastern side of the Tongue of the Ocean (near New Providence Island, Bahamas).

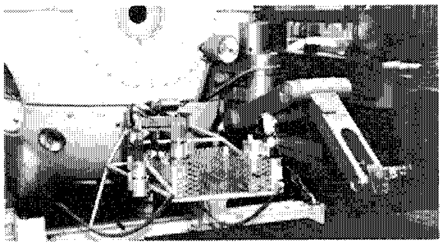
About twenty-five hundred kilometers of continuous seismic profiling were recorded during 1966 over several submarine canyons and their seaward extensions on the continental rise, and over the junction of the continental slope and rise south of Block Island. The profiles indicate that the base of the slope from Cape Fear to Halifax, Nova Scotia, is characterized by massive slump structures. Slumps off Block Island are more than one kilometer thick and nine kilometers wide. Continuous Seismic Profiling traces in the Gulf of Mexico show that the Florida Escarpment is located along a former coral reef and that the sediments of the continental margin west of the Mississippi Delta are disrupted by salt or mud intrusions.

Similar records in Long Island, Block Island, and Rhode Island sounds and Buzzards Bay, reveal a prominent reflecting horizon ranging from 16 to 200 meters below sea level; it probably delineates the top of pre-Cretaceous basement rocks in some areas and the top of Cretaceous sediments in others. The survey indicates that the topography of the reflecting horizon below the seafloor was formed by preglacial fluvial erosion and that the Pleistocene glaciers simply deepened existing troughs into flat bottomed, broad, U-shaped valleys characteristic of glaciated areas.

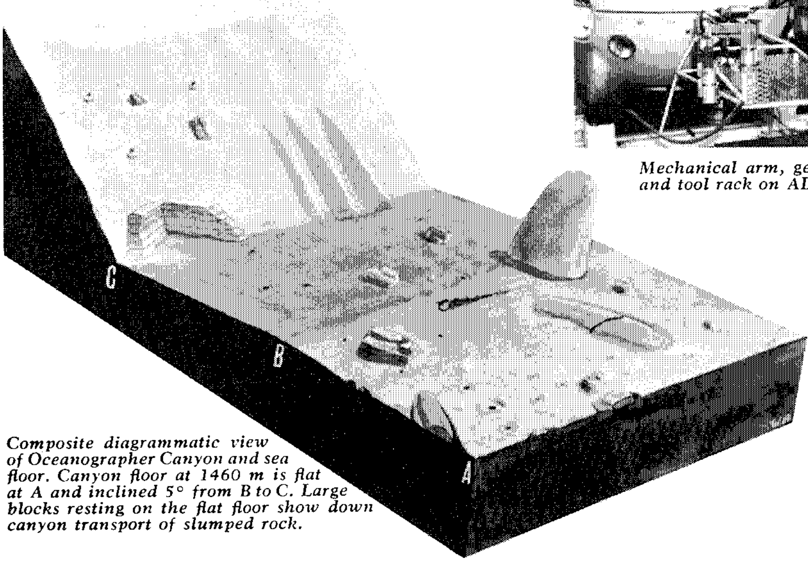
Gravel dispersal patterns and topography of the Gulf of Maine indicate that Pleistocene glaciers moved southward in two principal lobes, (1) into Great South Channel, (2) from the Bay of Fundy into the Jordan Basin area and continued thence into the northeast channel with ice rafting of some erratics along the slopes and rise and out into the deep ocean basin as far south as Hudson Canyon. Absence of shoals, rounded gravel and resistant minerals on Browns Bank and the southwestern Scotian Shelf indicates that the glacier terminated over the deep sea with little opportunity for modifying the gravel through river transport.

Textural patterns of total bottom sediment on the continental margin east of New England reflect Pleistocene glacial sedimentation and post-Pleistocene reworking and deposition. South of New England the shelf is covered with fine to medium-grained sand associated with minor amounts of gravel and sandy silt. Lack of a gradient in sediment texture across the shelf supports the idea that the deposits probably originated as fluvial and beach sands during lower stands of sea level. The skewness of sediment from the continental slope indicates that it was deposited by two mechanisms: by tractive currents and by subsequent settling from the water column. Silty clays on the lower slope and continental rise are probably pelagic in origin.

Heavy minerals having densities greater than 2.9 gm/cm^3 in the sand-sized fraction of sediments from the continental margin appear to have three major sources. One source is modern rivers such as Penobscot, Kennebec, and Merrimack which deposit their heavy minerals close to shore. A second was the glaciers that distributed minerals along Long Island Sound, Cape Cod, and generally seaward of the river deposits. The third of heavy mineral assemblages is a coarse-grained lag type of deposit that has been reworked by waves and currents from coastal-plain sediments underlying Georges Bank. Dispersal of sediments is generally in an offshore direction except on Georges Bank where some material is carried landward into the Gulf of Maine.



Mechanical arm, geological sampling gear and tool rack on ALVIN's bow.



Composite diagrammatic view of Oceanographer Canyon and sea floor. Canyon floor at 1460 m is flat at A and inclined 5° from B to C. Large blocks resting on the flat floor show down canyon transport of slumped rock.

Suspended matter in surface waters of the open shelf and slope consists predominantly of organic matter, whereas inshore waters along the coast and in estuaries commonly contain less than forty per cent organic matter. Plankton species having mineralized tests are common in nearshore waters off Florida and Georgia but are relatively rare farther offshore. Both industrial and domestic pollutants such as soot, ash, iron aggregates, and cellulose products are common in coastal areas adjacent to major centers of population. Recognizable mineral grains make up less than ten per cent of the total suspended matter in most samples. Size distributions of the grains suggest that the suspended mineral matter in estuaries and nearshore waters is derived and deposited fairly locally. Very little suspended sediment appears to be transported across the shelf in surface waters under normal conditions. Moreover, studies of circulation in estuaries and on the continental shelf suggest that the net movement of water along the bottom is landward, thereby minimizing any seaward transport of fine grained sediments except possibly during intense storms.

Sediment cores from the six holes drilled off eastern Florida by the Joint Oceanographic Institutions Deep Earth Sampling program were examined for organic constituents. Sediments from the Blake Plateau contained over 80% calcium carbonate from the Eocene through the post-Miocene and less than 0.2% and 0.02% respectively, of organic carbon and nitrogen. In contrast, the shelf holes which generally contained less than 80% calcium carbonate from Oligocene through post-Miocene had organic carbon and nitrogen contents around 1.0% and 0.06% respectively. This decrease in organic matter with increasing calcium carbonate content has been observed in recent sediments of other coastal areas.

Analyses of interstitial waters of the JOIDES cores show that fresh and brackish waters characterize submarine strata as far as 120 km from land. The major cationic composition of the interstitial waters in cores 40 and 100 km from the Florida coast indicates that they are related to waters found in the Floridan aquifer on the mainland, but that they have been in longer and more intimate contact with subsurface high magnesium carbonate sediments. Estimates of flow rates on land and comparison of water compositions suggests that the waters were introduced into the underground aquifers more than ten thousand years ago, possibly when the present sea bottom was exposed.

Manganese and phosphorite concretions occur both separately and as complex intergrowths on the Blake Plateau. The purest manganese concretions are found in water deeper than 750 m, whereas intergrowths and relatively pure phosphorite generally occur at shallower depths. The phosphorite appears to be a lag deposit left by erosion of phosphatic sediments in coastal plain strata. Although manganese and phosphate had several episodes of reworking and resolution, the manganese concretions are younger and are currently being deposited at a rate of 0.01 mm per thousand years (by C^{14} dating).

Mid-Atlantic Ridge

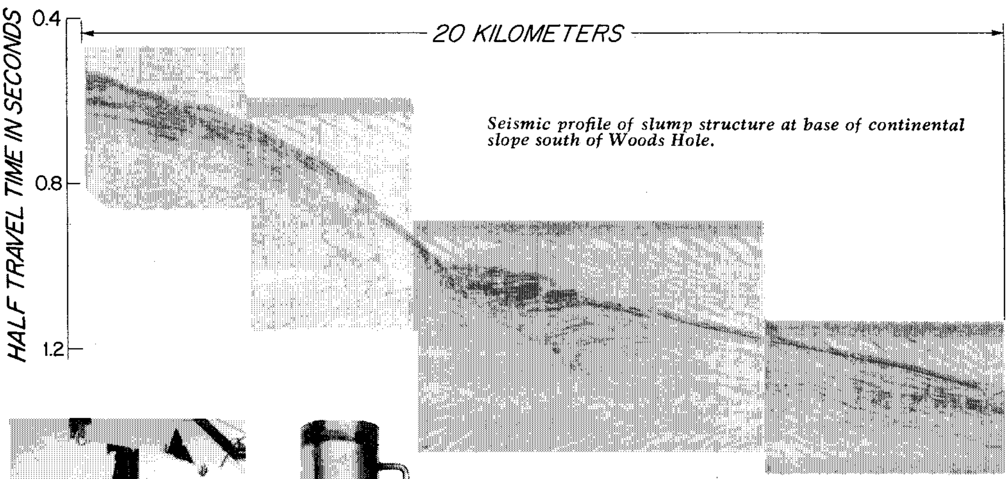
A detailed geological and geochemical study has been made for four areas of the Mid-Atlantic Ridge: about 22°-23° N; about 10°-11°N (the Vema Fracture Zone); the Romanche Trench and Fracture Zone; St. Paul's Rocks. A complex suite of metamorphosed basalts and tuffs, of metamorphic grades up to the greenschist facies, was found along the median valley around 22°N. In the 11°N area there is evidence of volcanic activity along the crest of the Ridge, offset by an older complex set of fractures, the valleys containing thinly bedded, little disturbed sediments deposited since the Paleocene. In the Romanche Trench, a surprising series of dolerites, hornblendites, gabbros, clastics, schists and lithified sediments were dredged from a single, deep basin observed below 7400 m. St. Paul's Rocks were found to top a massif isolated on all sides from the Ridge and largely surrounded by a shallow moat which acts as a sediment trap. The massif includes rocks which crystallized at quite different levels in the mantle, and were afterward incorporated and mylonized during intrusion of the hot, but solid massif. A highly vesicular very fresh alkali basalt was found on the northeast flank of the massif about 3000 m deep.

Dinoflagellates

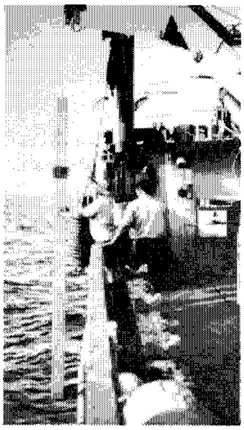
The encysted stage in the life history of neritic dinoflagellates is being investigated in order to (1) correlate cysts with their better known motile stages and thus establish the cyst cycle for numerous species and (2) to correlate the cyst stage with fossil dinoflagellates and hystrichospheres. The ultimate objective is to establish a systematic correlation between fossil and modern dinoflagellates, trace the phylogeny of the group and use the fossils in stratigraphic and paleoecological interpretations, especially in epicontinental and totally marine Pleistocene and Holocene sediments. The importance of the cyst mechanism as a factor in the survival and localization of dinoflagellate populations is also being investigated.

Over five hundred experiments were carried out to isolate and incubate marine cysts and restore the motile phase. These experiments showed that the resting cysts of a large number of dinoflagellates were typical hystrichospheres and fossil dinoflagellates. Some were found to produce calcitic cysts previously known only as fossils and some produced cysts that are yet unknown as fossils.

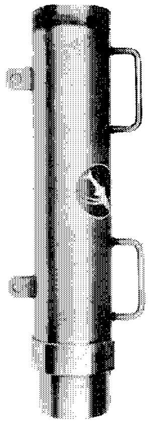
The following observations were made from these studies: (1) The taxonomy of

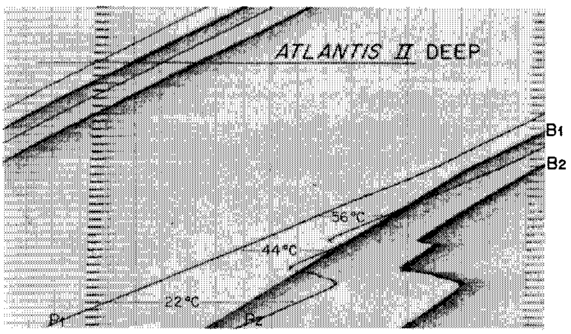


Seismic profile of slump structure at base of continental slope south of Woods Hole.



Square box corer used in Red Sea to obtain large sediment samples.





Precision Graphic Recorder record of the temperature on lowering the telemetering pinger into the ATLANTIS II Deep. Pinger is shown to the left.

modern dinoflagellates as well as the fossil scheme should be revised to attach more importance to the cyst phase of the life history. (2) In fossil systematics the single most reliable criterion for establishing a phylogenetic scheme is the nature and position of the excystment aperture or archeopyle. (3) The cyst mechanism is a factor of considerable influence in the seasonal and geographic distribution of numerous neritic dinoflagellates. (4) The most primitive form of dinoflagellate organization may be a uniflagellated condition which is found briefly after excystment rather than a naked biflagellate as had been formerly believed.

Coastal Hydrodynamics

A correlation of beach erosion profiles and sea state was made from field data of beaches of the East and Gulf Coasts. It was generally found that the steeper slopes faced the rougher seas with the inner slope generally having several times the angle of the outer slope.

Preliminary wave observations at Highland Light on Cape Cod indicate stronger seas and far greater percentages of waves from the northeast than would be predicted from published hindcasts. Additional work is expected to show that more open ocean swell reaches the coast, and local winds build high waves at a faster rate, than is predicted by hindcasting theories.

The role played by tidal currents in longshore transport of sand and the effects of tidal flow on nearshore morphology is being investigated by determining the tidal component of the nearshore fluid movement from the surf zone to depths of about sixty feet. Recording current meters were mounted in sixty feet of water at Nauset Light and Cape Cod Light on outer Cape Cod with the assistance of the U.S. Coast and Geodetic Survey. Tidal heights were also supplied at the two stations. The cross section of tidal flow between the recording current meter stations and the beach was accomplished by means of tracking subsurface drogues and surface flares. Analysis of the data is underway.

Bottom sand ripples interacting with the oscillatory fluid motion under shoaling waves have been recorded as important agents in placing sand in suspension. Since this interaction may be responsible for much of the selective sorting in the nearshore zone it is important to determine ripple stability on tidal beaches. Last summer several tidal cycles were monitored at a subtidal location. Wave height, period and near bottom horizontal velocity were recorded while SCUBA divers measured ripple parameters. Preliminary examination of the data indicates that the low tide ripple forms are fairly stable with relatively small changes in ripple parameters during periods of high tide.

Trace Elements

The accuracy and precision of trace element analyses in a variety of matrices with the direct reading emission spectrometer has been greatly improved from an investigation of the various parameters affecting the analysis. Background corrections for each element are being made for high precision work and improvements in burning techniques have cut background variations from about twenty-five per cent to less than ten per cent. A computer program has been developed to process the data from the direct reader and incorporate the necessary corrections. Currently trace elements are being analyzed in the ashes of planktonic organisms, basalts and greenstones from the Mid-Atlantic Ridge, and dredge samples from St. Paul's Rocks massif in the equatorial Atlantic. The latter rocks are also being studied petrographically as part of a more detailed study of the structure and composition of the massif.

Wet chemical and radiochemical analyses show there are significant variations in North Atlantic water columns in both the strontium and barium ratios to salinity, and of the lanthanide elements to salinity and to each other.

Statistics

Three multivariate statistical programs were developed principally for use with geochemical data from sea water and sediments although the techniques themselves have a far wider applicability. Computer programs have been written and are now operational for three procedures: Factor Analysis, Canonical Correlation and Multiple Regression. During the past year the Factor Analysis technique was used in studying trace elements in sediments and amino acids in shell proteins. Currently under study are chlorophyll and nutrient concentration data from past cruises, trace element data from Indian Ocean cores, fish populations in the Central Atlantic, and transition metal distribution in particulate and dissolved fractions of water samples from the Gulf of Maine. The Canonical Correlation program has not yet been used although it could be quite useful in examining the relationship between the distribution of various organisms and certain physical and chemical parameters of the environment. The Multiple Regression Program was used to examine the relationship of amino acid and amino sugar contents of crab shells to the degree of classification.

JOHN M. HUNT, *Chairman*

Department of Geophysics

A five-month cruise of CHAIN to the Mediterranean and the Red Sea was one of the major sea-going activities, but others of shorter duration were made: to the Outer Ridge north of the Puerto Rico Trench from 16 February until 21 April and to the Caribbean from 18 May to 30 June both aboard CHAIN and south of Bermuda from 10 June until 6 August on ATLANTIS II. Preliminary equipment tests were made on several other short trips. Using geological and geophysical techniques, the features of the Outer Ridge were studied in relation to the Puerto Rico Trench and the Greater Antilles. In the region south of Bermuda the rather complex water structure near 30°N and the larger scale variations to the south of that region were examined acoustically. The cruise to the Caribbean was made to delimit the distribution of pelagic fish and sound scatterers. One cruise, primarily for a geological survey of the Eastern Mediterranean, included participation in a North Atlantic Treaty Organization acoustical exercise west of Ireland, a detailed geophysical, geological and geochemical examination of the hot brine holes in the Red Sea, and a geophysical examination of a section of the Mid-Atlantic Ridge.

Submarine Geophysics and Geology

A program in submarine geophysics and geology has been carried out in the North Atlantic Ocean, in the Caribbean, in the Mediterranean, and in the Red Sea. Attention was chiefly focused on the structure and composition of the sediment and shallower rocks of the sea floor to ascertain the nature, origin, and development of the earth's crust. Each of the major cruises has yielded gravimetric, magnetic, seismic reflection, and bathymetric profiles useful in evaluating such concepts as sea-floor spreading and continental drift, which have recently dominated ideas about the evolution of the earth's surface. Sea-floor spreading, an intriguing possibility, is believed to be caused by convection cells in the earth's mantle resembling conveyor belts which move the continents across the earth's surface. Mid-ocean ridges are thought to be the locus of such upwelling. The investigations of the Mid-Atlantic Ridge and Red Sea aboard CHAIN have provided information which supports this hypothesis. Symmetrical patterns of intense magnetic anomalies, high heat-flow, geologic evidence of faulting and folding of Recent sediment strata and volcanic activity, especially in the Red Sea area, suggest that these areas are sites of active ocean-floor spreading.

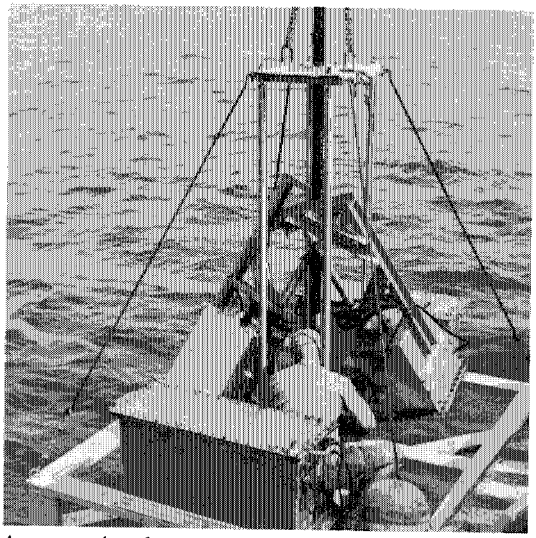
The geophysical and geological investigations of the Caribbean area have continued. The recent CHAIN cruise attempted to determine the structure of the Antilles Outer Ridge, and its relation to the Puerto Rico Trench to the south and the deep ocean basin to the north. While our general interest is directed toward relating the trench system to the geologic history of the North Atlantic Basin and the Antilles Island Arc, during this cruise special emphasis was placed on determining the nature of the acoustically transparent sediment layer which lies over much of this area. Specifically, it was hoped to determine the extent of this layer and its relation to the complex underlying basement rocks. A study of modern submarine valleys in the layer suggests that the processes which formed it in the past are still active today. Further, a latitudinal submarine rise appears to have controlled the areal deposition of the sediments of the transparent layer. An isopach map of the transparent layer shows that the thickest accumulation is north of the rise.

In addition to current research in the Caribbean area analyses of previous geophysical data from the Cayman Trough to the west of the Puerto Rico Trench suggests that this deep ocean basin, although similar in depth and extent to the Puerto Rico Trench, is of different origin. Unlike the Trench which is believed to have resulted from compressive forces depressing the crust to great depth, the Cayman Trough appears to have resulted from tensional forces which have rifted the oceanic crust apart. Gravity profiles from the Trough suggest that the structure is not contiguous with the structure producing the Puerto Rico negative gravity anomaly of the Antillean Arc. It appears that the Cayman Trough was developed on the gently sloping northern flank of the Nicaraguan Rise by extension of the crust. Geologic data from southern Cuba suggests the initiation of the extension began in the Paleocene. From geological and gravity information it is concluded that the Enriquillo-Cul de Sac Trough of southern Hispaniola is a young extension of the Cayman Trough structure, and that the latter is extending eastward at the present time.

The sea floor in the Mediterranean Sea may have special significance in our understanding of such broad geophysical concepts as continental drift. Here the continents of Africa and Europe are separated by the relatively narrow Mediterranean Sea. Preliminary results from the investigations aboard CHAIN showed the sea floor to be complexly faulted and folded. Evidence for the recent deformation of the beds of the Eastern Mediterranean was clear in seismic reflection profiles and sediment cores from that area. Southwest of the Peloponnesus, strata have been folded into anticlines and synclines which trend roughly east-west. The synclines form valleys which are filled with younger, flat-lying sediments. North of the submarine fan of the Nile lies the Herodotus Abyssal Plain. The flat-lying strata of this plain, when followed north, become part of the folded southern flank of the Central Mediterranean Ridge. Deformation of these sediments only a few meters below the sea floor on the Ridge itself is indicated by displacements of several centimeters along steeply dipping planes in sediment cores.

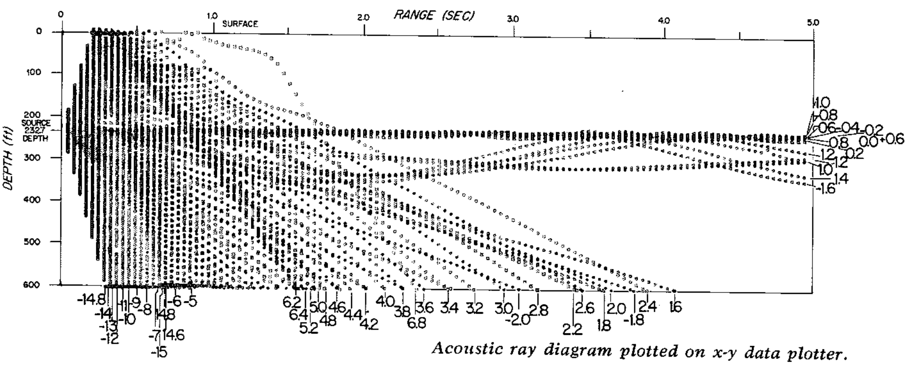
In support of the sea-going geological and geophysical investigations land-based facilities have been added for examining rock and sediment samples. A micropaleontology laboratory has been established for the study of fossil shells of minute Foraminifera and Radiolaria, commonly found in sea-floor rocks and sediments. Such animal remains can provide valuable evidence for determining the age of a sample and the environmental conditions under which it was formed. Another phase of this work will be a collaborative undertaking with scientists at Hokkaido University on the morphology of the shell structures using electron microscopy techniques.

The long-standing interest in the physical properties of oceanic rocks was broadened considerably with the development of a rock magnetism laboratory. The magnetization of sea-floor rocks and sediments is believed to have recorded the Earth's magnetic-field direction in the distant past. By measuring this "fossil" magnetism it is hoped to trace the history of the ancient geomagnetic field. Detailed knowledge of the epochs when the geomagnetic field reversed its polarity is especially useful in determining the age of sea-floor rocks. In addition such information can provide important clues about the nature and origin of the geomagnetic field itself and its curious reversal mechanism.



A near surface box sediment sampler to provide geologists with an undisturbed mud sample from the surface of the ocean floor.

Photomicrograph of typical serpentinized peridotite.



Acoustic ray diagram plotted on x-y data plotter.

Oceanic Acoustics

Acoustics is an important tool of the marine geophysicist. Coupled with magnetic, gravimetric and sea-floor sample information, it enables him to probe far beneath the sea-floor.

Continuous seismic reflection profiling, the primary acoustical tool of marine geophysics today, provides information about the depth of the geologic structure in the oceanic crust. Low-frequency sound waves periodically emitted by a ship are reflected from sub-bottom reflectors and received on a hydrophone towed astern of the ship. The continuing success of this technique has encouraged the geophysicist to examine in more detail the crustal structures. However, in order to detect the very weak signals which return to the surface in presence of the high-noise environment associated with a moving ship special efforts are required. To increase the signal-to-noise ratio of the system, linear arrays of hydrophones have usually been employed. These arrays provide greatest sensitivity to signals returning vertically from the sea-floor whereas they tend to reject flow and ship noise. A further improvement of this technique has resulted from recent development of a continuous-line hydrophone. It consists of a flexible hose-like coaxial capacitor which is rugged and inexpensive compared to the spaced, multiple hydrophone arrays. Also since the complete length is sensitive, it eliminates the undesirable side-lobe properties of spaced-hydrophone arrays. Prototype models have been used and have given excellent results on several cruises.

Sound traveling in the ocean is analyzed by considering sound as rays or waves depending upon the physical situation. The ray picture is an approximation to the exact wave solution, and when applicable over a large portion of the path but does not apply over the complete path. This condition is met in water that contains multiple sound channels. A theoretical analysis of this problem has been undertaken and a method is evolving for calculating the behavior of sound under such conditions.

Programs have continued in the analysis of previous experiments in sound transmission and bottom reflectivity, and preparations are being made for a cruise to study sound transmission in the Baltic Sea.

Internal Waves and Thermal Fronts

As part of a long-range sound transmission project, detailed examinations of the thermal and sound velocity structure were made in the area southwest of Bermuda. It was discovered that a rather strong horizontal thermal gradient in a north-south direction existed near latitude 30° North. This has been designated as a thermal front region and has been studied each year for several years. Towed thermistor arrays, sound velocity profiles, and air-borne radiometer measurements have been used in this work. The picture that has evolved has interesting possibilities for our understanding of large-scale water movements and their effects on sound propagation.

In a horizontal plane near the ocean surface about 200 miles south of Bermuda, contours that define horizontal thermal gradients meander along a general east to west line with a characteristic wavelength larger than several hundred miles. Superimposed on this large-scale wave are shorter waves that are about twenty-four miles in length. These meandering near-surface thermal fronts are evidence for Rossby waves in the Atlantic Ocean. The scales and periods of the horizontal waves are so long that it is difficult to define their motion and to select appropriate measurement techniques.

Further observations have established that these meandering waves extend to great depths in the deep ocean. Their role in the overall motions of the ocean and the Gulf Stream is of interest. Short-period internal gravity waves have also been shown to be associated with the surface thermal front. Studies of these waves have been undertaken in an attempt to understand how they are generated in the frontal region, why they appear to exhibit different spatial wavelengths on each side of the frontal zone, and the part they play in sound transmission in this and similar areas.

Mesopelagic Fish

Sixty-eight midwater trawl collections were made in the Caribbean Sea and the Gulf of Mexico. A typical haul nets several hundreds of individual fish representing twenty to thirty species. Twenty-four collections were made between the Lesser Antilles and Africa. Sorting, identification, and measuring of these and unfinished portions of the previous collections progressed during the year. An attempt is being made to delineate faunal boundaries throughout the North Atlantic. Acoustic measurements of the strength of the scattering layer were continued on these cruises as an integral part of the program. The use of the computer facility was found to aid in the statistical analysis of the data on mesopelagic fish.

EARL E. HAYS, *Chairman*

Department of Physical Oceanography

In recent years, extensive physical-oceanographic observations have been made in the Atlantic and Indian Oceans, and a large body of raw data has been accumulated. During the past year, therefore, the emphasis in the research of this department has been placed on digestion of this material rather than on ambitious new observational programs. Of particular interest has been greater attention to variability in the ocean, on several time scales, and more refined descriptions of the characteristics, distribution, and relationships of water masses. Field work has continued, of course, but at a relatively modest pace.

Variability

Time-series analysis of horizontal velocities as measured by current meters at our permanent moorings in the slope water (39° 20′N, 70° 00′W), and Sargasso Sea (36° 00′N, 70° 00′W) has progressed without requiring major changes in our previously developed ideas about the local current fluctuations. Energy is concentrated at the inertial and semi-diurnal tidal frequencies, and at higher frequencies the power spectra appear consistent with the theory of homogeneous, isotropic turbulence. At lower frequencies, however, there seems now to be considerably more intermittence than anticipated: both the mean current speeds and the amplitudes of the inertial and tidal motions may vary by an order of magnitude within a few days. New statistical techniques will have to be introduced for a proper understanding of these non-stationary processes.

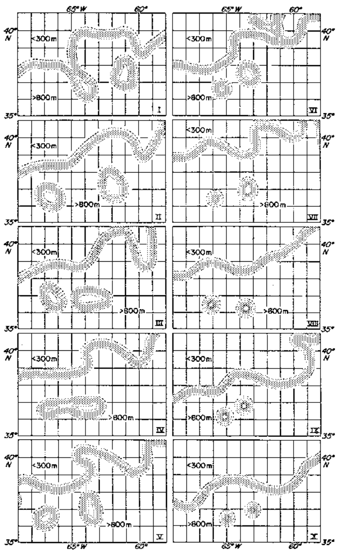
These moorings are equipped with wind recorders to investigate relations between the shallow motions and changing weather patterns. As a preliminary step in this investigation the wind recorder results have been evaluated by comparison with wind vectors derived from daily weather maps; this comparison shows reliable performance by the recorders, and indicates that during periods of directional persistence, gaps in the recorder data can be filled in from the weather maps.

Large-scale motions with a seasonal period are known to occur at the sea surface in the North Indian Ocean, and it seems likely that similar variations might be observed at mid-depths in the saline water emanating from the Red Sea. Data collected during the southwest and northeast monsoons by the ATLANTIS II, ARGO, and DISCOVERY have been examined from this viewpoint, but did not, however, indicate any very significant, broad-scale differences.

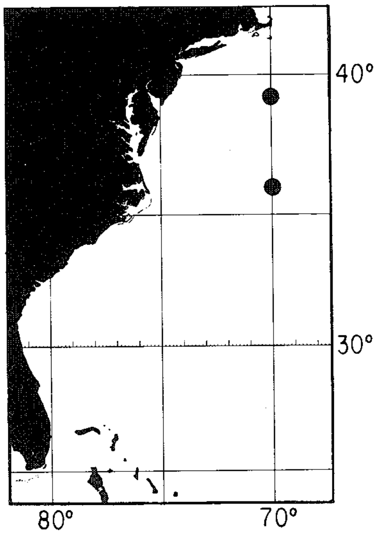
Changes of still longer period have been anticipated in the flow on the continental shelf off the Middle Atlantic States in connection with the continuing drought in this area. Usually the low-density river effluent forces a southwestward flow along the shelf, but it appears from salinity observations made from lightships over the last ten years that the river discharge has been so much reduced during the drought years that the prevailing southwesterly winds have stopped and even occasionally reversed this "normal" drift. The coastal water has thus tended to stagnate, and exchange less water with that offshore.

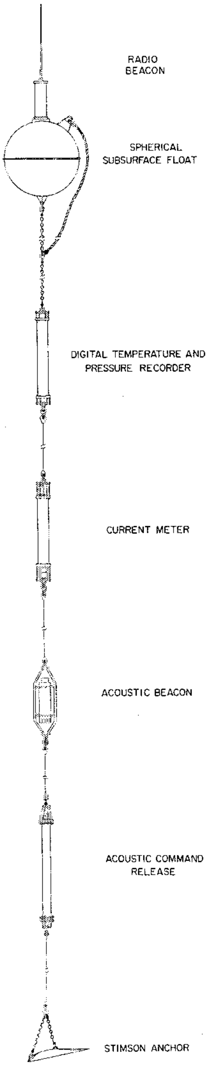
Water Masses

For several years an atlas of horizontal charts based substantially on data collected during the International Geophysical Year has been in preparation as a description of the relations between potential temperature and salinity in the deep North Atlantic. This material has now been completed, and shows with clarity and detail the distributions of the five types of deep and bottom water in the North Atlantic: the two differ-

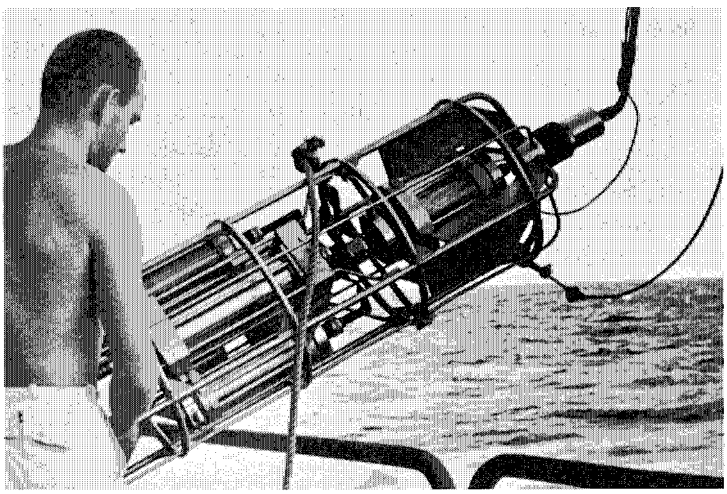


Depth of the 10° isotherm for ten periods from September 1965 through February 1966.





Localities for complete buoy stations (chart) and diagram of buoy array.



In situ *salinometer.*

ent overflows from the Norwegian Sea (one through the Denmark Strait, the other past the Faroe Islands), the outflow from the Mediterranean Sea, water sinking from the surface of the Labrador Sea, and Antarctic Bottom Water. Despite the obvious value of such an atlas to Atlantic oceanographers, its publication has been delayed by a perplexing lack of financial support.

Some publication funds have, however, been obtained for an atlas of profiles pertaining to the Mediterranean Sea. To supplement these profiles, calculations have been made of the volumetric distribution of Mediterranean water in terms of temperature-oxygen characteristics, matching earlier calculations made in terms of temperature-salinity characteristics.

Water-mass analysis is often not suitable for tracing flow in near-surface water because of air-sea interaction processes, and for this reason attempts to identify the "source" region of the Equatorial Undercurrent by its temperature-salinity characteristics have been ambiguous. Examination of temperature-oxygen characteristics, however, has proved most productive. In the temperature range 13-24°C Equatorial Undercurrent water is higher in dissolved-oxygen concentration by about 1 ml/l. than the water on its flanks. Although similar water exists in abundance well to the north of the Undercurrent, a belt of low-oxygen water between precludes any direct connection. On the other hand, the oxygen maximum of the Undercurrent can be traced directly to the North Brazilian Coastal Current; therefore the Undercurrent itself must be primarily a continuation of the latter current.

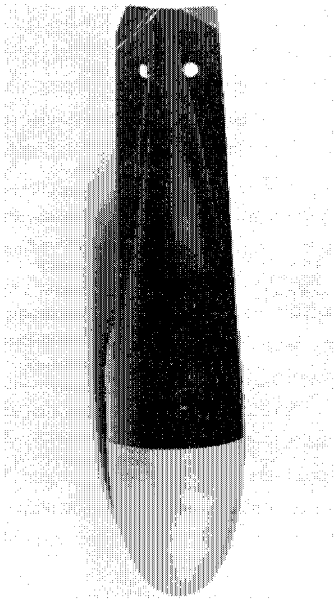
Field Investigations

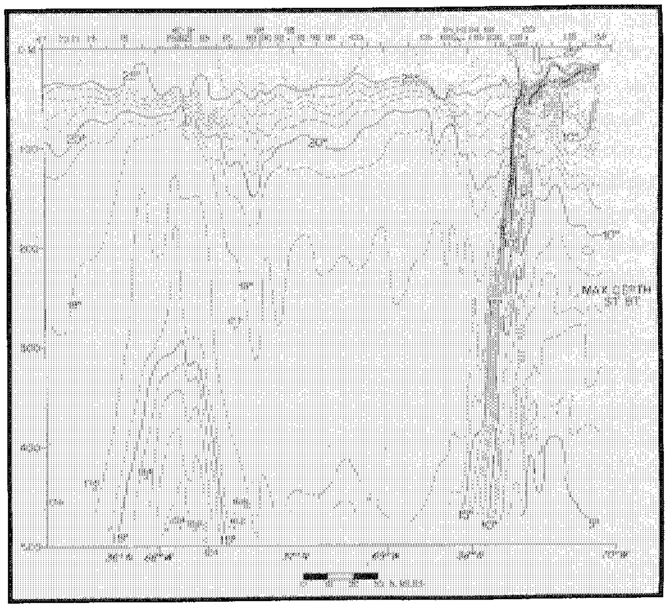
The series of monthly cruises begun in September 1965 to monitor the behavior and structural changes in two cyclonic (cold core) eddies detached from the Gulf Stream was terminated at the end of February 1966. During this six-month period the eddies contracted slowly in the horizontal, but were still easily detectible by temperature measurements at the end of the survey. Extrapolation of their rates of decay suggests life times of the order of one year for such eddies. Shortly after detaching from the Stream, both eddies moved rapidly westward (speeds around 13 cm/sec), but later on when they were smaller, they moved about much more erratically, and showed little additional net displacement. Such behavior is vaguely suggestive of Rossby-wave dynamics, but no definite conclusions can be drawn.

On the basis of a few deep current measurements it has become apparent that the volume transport of the Gulf Stream downstream from Cape Hatteras cannot be reliably estimated by the conventional method of dynamic computations based on assumptions of level isobaric surfaces somewhere in the Stream. Detailed velocity measurements are mandatory. Ideally, one would like to see a series of current-meter strings moored across the stream, but moorings of this sort are not yet feasible. One seems required therefore to fall back on dynamic computations, but computations tied to closely-spaced velocity measurements across the Stream. A moderately successful attempt to make a single measurement of volume transport in this way was carried out in June on a section across the Stream south of New England, based on neutrally buoyant floats for the velocity measurements. Over a time of two weeks, nine floats, spaced at ten to twelve mile intervals across the Stream, were followed for periods of two to three days each, their tracks being bracketed with concurrently occupied hydrographic stations. The derived volume transport was 101 x $10^6 m^3/sec$, but with an uncertainty of 20-30%, arising primarily from the mixture of time scales involved in the measurements and vagueness in the boundaries of the "Stream". (The latter difficulty must always be present because of inherent imprecision in the meaning of "Gulf Stream" away from continental boundaries, and will probably require an uncertainty of at least twenty per cent in measurement by any method.)

The deep velocities observed directly in the Stream on this cruise were notably smaller than the few earlier measurements made elsewhere. Whether this difference is one of variation primarily in time or in space cannot be determined at the present time.

Investigation of thermal fronts occurring in the general region of the North Atlantic Subtropical Convergence continued on a





Expendable bathythermograph (left). Vertical cross section of Gulf Stream (right) using this instrument. Note greater depth and closer spacing of observations than is possible with ordinary BT.

cruise during March. A network of fourteen hydrographic stations across the frontal region, made for computation of the field of geostrophic shear, showed penetration of the fronts from the surface to depths of 100-200 m. In addition, parachute drogues launched both north and south of the surface frontal edge moved toward the edge, demonstrating clearly that the front was associated with horizontal convergence.

During the International Indian Ocean Expedition two patches of very hot brine were discovered at the bottom of the Red Sea. More detailed measurements of temperature and salinity this year revealed layering in the brine patches, with estimated salinities reaching 320°/₀₀, and maximum temperatures of 56°C in one patch, 45°C in the other.

Physical Properties of Sea Water

Since electrical conductivity has now become the measure of salinity in the ocean, it is important to measure the various factors which determine it. The effect of nitrate and phosphate utilization during photosynthesis has therefore been assessed experimentally for the case of sea lettuce. The exchange processes are evidently complex, but the actual effect for typical oceanic concentrations of nutrients is very small, only about 0.001°/₀₀ salinity units, which is insignificant for routine salinity measurements.

Existing values of the thermal-expansion coefficient for sea water are derived from compressibility or sound-velocity measurements, and are not up to the accuracy of modern oceanic temperature observations. Improvements in thermometry have thus been of little help in making more detailed investigations of adiabatic effects in the ocean. To remedy this deficiency, apparatus has been constructed and tested for making careful direct measurements of changes in volume of sea water as a function of changes in temperature. The measurements soon to be undertaken are expected to give more accurate and hence considerably more useful values of the thermal-expansion coefficient.

FREDERICK C. FUGLISTER, *Chairman*

Department of Theoretical Oceanography and Meteorology

A central theme for the year's activities is that of interface phenomena and, in a wider sense, also thermocline processes. Greater competence in these problems is one of the main goals of current personnel recruitment efforts.

The meterological work on the Indian Ocean data has continued to demand the most attention. Next year we should see its completion with the preparation of a monograph on the climatic aspects of the work, as well as a group of special papers related to cloud structures, air mass formation, etc. Preparations are underway for further studies of air-ocean exchange processes with our research aircraft carrying improved instrumentation. In addition, a strong effort is being made to develop new ways of measuring oceanic parameters of various kinds through retrievable instruments or expendable telemetering equipment based on the aircraft.

Last, but not least, in new techniques, efforts are being made to utilize the ALVIN for studies of vertical transfer processes in the thermocline regions and on continental slopes, where a wide spectrum of processes in benthic boundary layer flows await study.

Atmospheric Physics

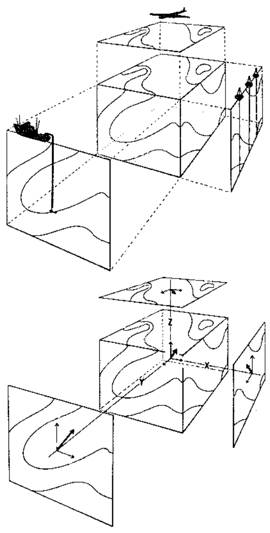
A new research program, started in May, has been an experimental study of the generation of exponential-type raindrop size distributions. Such a study is of importance, for raindrop size distributions have been extensively used as aids in understanding the mechanisms that initiate rain in both continental and marine clouds. There is a possibility that in heavy rains extensive coalescence and breakup amongst the drops will cause their distribution to approach a certain form, dependent only on rain intensity. If this be so, the drop distribution should be independent of the mechanism that initiates it. It follows that attempts to understand the generation of heavy rain by studying drop distributions measured at ground or sea level are doomed to failure.

Initial efforts to verify this hypothesis consisted in pouring water under zero pressure from a fire hose mounted about 60 meters above the floor of the large U.S. Navy blimp hangar in South Weymouth, Massachusetts. If drop interaction and breakup is the prime factor in determining the drop distribution then we should find evidence of it in measurements of the drop sizes in the "rain column" at the hangar floor. In short, in only 60 meters of fall, a solid stream of water should be partially transformed into an artificial rain whose drop size distribution has some resemblance to that found in natural rain.

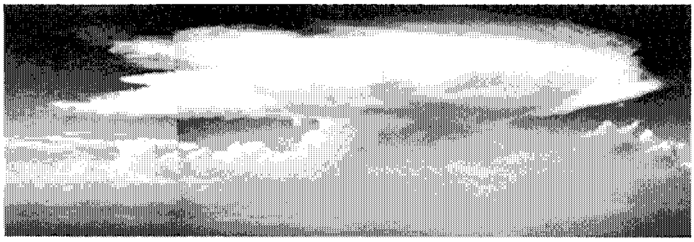
The results to date are encouraging. In the high intensity "rain" the distribution of drops at the small end of the spectrum ($<$ 3 mm diameter) is that of natural rain; at the large end the drops are more numerous. It is felt that many of these large drops would break up if the fall distance exceeded 60 m, and that with increasing distance a natural rain distribution would be approached. This work is being continued.

Studies of Infrared Transmission and Reflection at the Air-Sea Boundary

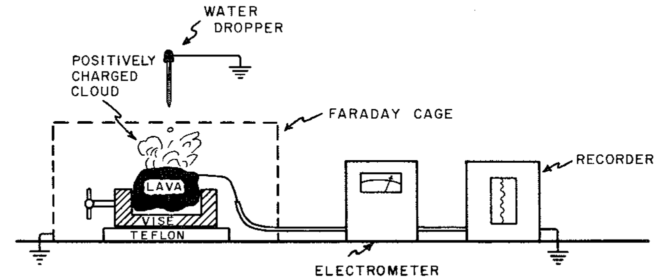
Attempts to extend an earlier study of the conditions of the formation of marine fogs led to an effort to utilize airborne infrared radiometry (IRR). It was quickly found that for the purpose of determining the boundary conditions for the process of heat



A gradient field in the ocean as seen by a ship, by a string of buoys and by an airplane.



Cumulonimbus cloud (approximately 35 miles long) over Puerto Rico taken from 20 miles to the south.



The apparatus used to determine the magnitude and sign of the charge carried by the cloud that was generated when a drop of sea water fell on molten lava.

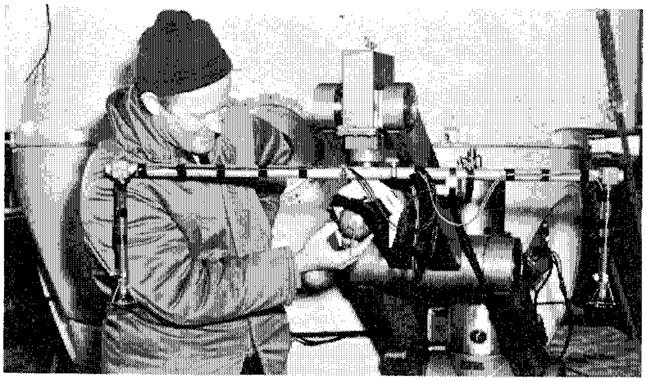
and vapor exchange the main limitation of IRR did not depend on lack of instrumental sophistication, but that the techniques of measuring radiation *per se* had in fact advanced far beyond our detailed knowledge of expected radiation intensities under different natural conditions.

The task of providing an improved physical background for the interpretation of IRR measurement has reached a point where some definite results are available, and a procedure was developed for minimizing the effect of sea surface reflectivity, as well as for the absorption and emission effects in the air column. A series of laboratory experiments related to the question of the dependence of the temperature difference between the air-sea interface and the bulk water below it, on the exchange process has been completed. The important result to date is the substantiation of the value of a multiple interrogation technique. This technique allows for a simultaneous compensation for reflectivity errors and for air column interference by combining the results of vertical and oblique (60° zenith angle) IRR measurements.

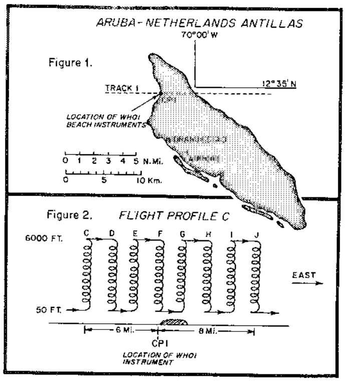
Studies of Convective Motion and of Turbulent Mixing Processes in a Stratified Environment

A study of the relation between heat flux, stirring intensity and stratification in the system, has almost been completed. It has been established that the dynamic interaction between a stirred (turbulent) mixed fluid layer can be resolved into two kinds of effects. One is an entrainment effect, i.e., a tendency to sharpen up the pycnocline edge by mixing fluid into the stirred layer. This effect is essentially independent of the intensity of the stratification, being controlled by a balance between available turbulent energy and the energy requirements of the induced changes in vertical density distribution. The other major effect is an induced irregular motion in the stratified layer below, which allows the establishment of turbulent density flow in the stable layer even without local mean shear flow. The latter effect is strongly dependent upon the stability in the thermocline.

In an effort to prepare for future observational work in the ocean along these lines, a trial dive with ALVIN was made off Chat-



Checking installation of thermisters and dye "squirter" on the ALVIN.



Aruba, Netherlands Antilles and flight profile used in studying the Trade Wind inversion over a small island.

ham. The equipment carried consisted of a temperature gradient measuring device and dye trace release arrangements. Several regions of sequential temperature discontinuities were observed. Efforts to study the possible occurrence of turbulence in such a layer were thwarted by biological activity—a tuna swimming through the dye trace.

The marked correlation observed between minute temperature transitions and the biological activity indicates a promising future avenue for cooperation between biologists and fluid dynamicists in this type of study.

Large-Scale Air-Sea Interaction

Based on data gathered during the 1963 International Indian Ocean Expedition, a study has been made of the cloud formations, winds, air masses, and modification of the air by interactions with the land and sea. The history of the air is traced as the air flows from the source region east of India, over the mountains of India and descends to the west coast. Over the Arabian Sea other air penetrates the air mass flowing from the northwest causing convergence and lines of cumulus clouds. Aircraft winds, temperatures, humidities, and turbulence are used to give detailed descriptions of the mixing process and the merging of the two air masses.

During the Indian Ocean flights, many reels of time-lapse motion pictures of clouds were obtained by aircraft of the Woods Hole Oceanographic Institution, the Research Flight Facility of the U.S. Weather Bureau, and the Royal Air Force. The photographs covered nearly all parts of the northern Indian Ocean from altitudes ranging from 100 feet to 30,000 feet. These films were brought to Woods Hole for study and measurement. The work will be published as one in the series of meteorological monographs of the Indian Ocean.

Boundary Layer Effects Near an Island

The analysis of data from the second Aruba expedition to the Netherlands Antilles in 1965 has been completed. The results show that the stress decreases approximately by a factor of 10 as air moves out from the island over the sea. It increases again, but not to the same extent, as the fetch over water increases and a wave field develops. From balloon observations we have also found, in the lee of the island, vertical motions of large amplitude in the lowest 400 meters. These were probably associated with inertial waves.

Although the island is quite flat, it also exerts a strong influence on the humidity structure at the level of the trade wind inversion which usually is well above 1000 meters elevation.

Claës G. H. Rooth, *Acting Chairman*

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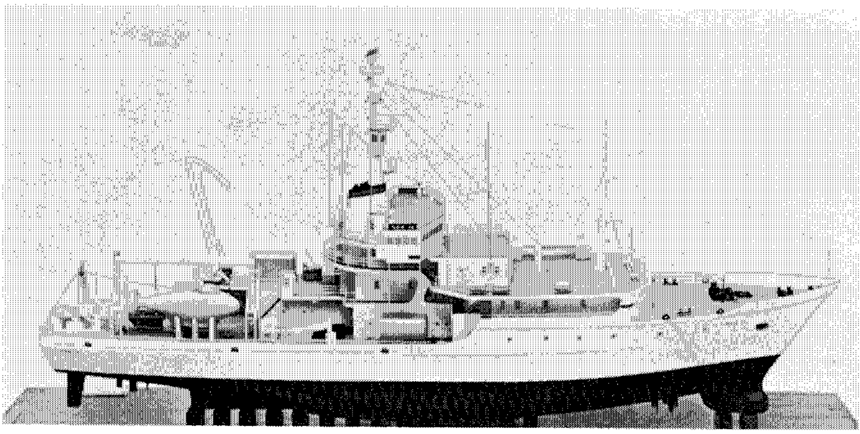
Ashore and Afloat

Godspeed and farewell were bid to ATLANTIS on November 9, 1966 as she sailed from Woods Hole wearing the ensign of the Argentine Republic. Rechristened EL AUSTRAL to commemorate an earlier vessel, but still the sentimental flagship of the Woods Hole fleet, she has been sold to the Argentine Council of Scientific and Technical Investigations. The terms of the sale provide that the Institution shall have the opportunity to repurchase her if she is no longer required for Argentina's oceanographic research program.

The transfer ceremony was attended by many who had been associated closely with ATLANTIS during her thirty-six years of service to the Institution, and by representatives from the Argentine Embassy in Washington.

On September 30, 1966, the Naval Ship Systems Command entered into a contract with the Defoe Shipbuilding Company of Bay City, Michigan, for the construction of two new oceanographic research vessels. One of these, to be named OCEANUS, will be assigned to Woods Hole for operation after delivery in 1968. These vessels, of new design, are somewhat larger than ATLANTIS II and CHAIN, 245 feet long compared with about 210 feet. They will be diesel-driven through two cycloidal propellers, one forward and one aft. The Naval



Model of OCEANUS to be delivered in 1968.

Ship Systems Command and the Office of Naval Research afforded both this Institution and the Scripps Institution of Oceanography the opportunity to participate extensively in the design of these vessels, and we expect them to be excellent research vessels.

A contract was made on November 16, 1966, with the Westcott Construction Company of North Attleboro, Massachusetts, for the construction of a new pier. This new facility, when completed in the late fall of 1967, will provide 740 linear feet of dock face for berthing our vessels. It will extend out from the existing dock about 220 feet, and will be a truncated triangle with an outer face of 80 feet. The pier will have an area of some 40,000 square feet.

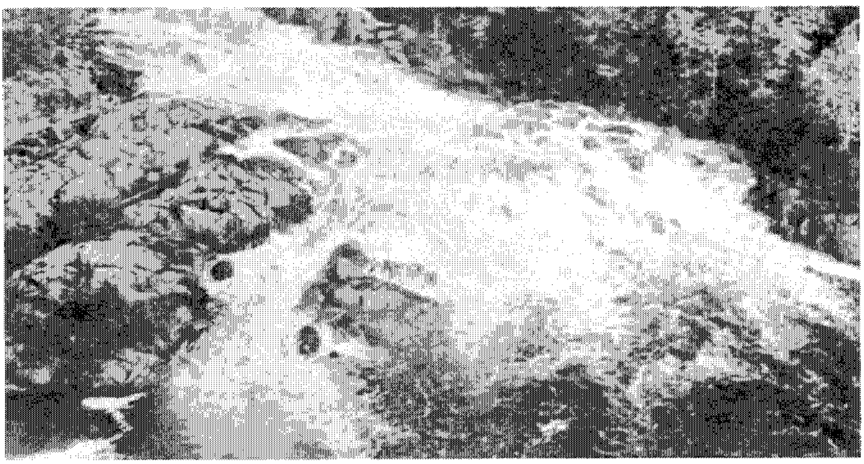
A new boat-basin for our small craft will be constructed off the Eel Pond channel on the eastern side of the Laboratory of Oceanography.

Upon completion of the pier, work will begin on a new waterfront facilities building to house the groups supporting the operation of the ships and the mechanical shops.

The modernization of our vessel support capabilities is being undertaken with the support of the National Science Foundation.

A ten-year lease was taken on an industrial-type warehouse in Falmouth Center in September. The building contains some sixteen thousand square feet of covered and heated storage area as well as considerable outside area. All of the equipment and materials stored in the Blake Building, as well as the great quantity of miscellaneous gear that had accumulated in the School Street swamp area were moved into the new area. An irritating eyesore was removed from the village and the space released in the Blake Building can be available to satisfy some of the demand for more laboratories.

To alleviate to some degree the housing problems of our staff, and particularly to have accommodations for our students and fellows, a complex of houses and apartments on the main road in Woods Hole was purchased on May 28, 1966. The property is known familiarly as the Winding Lane, and was for many years owned by Mr. Sidney W. Lawrence, a life-long resident of Woods Hole. There are four single-family houses, two duplex-houses, and three dormitory rooms on the property.



Falls on the Matamek River.

In November, the Institution acquired by purchase, Matamek Camp, located near Sept-Iles in the Province of Quebec where the Matamek River flows into the St. Lawrence. The camp consists of some fifty acres of land and several cabins. In the 1920's, it was the site of a conference on cyclic phenomena in nature.

The Matamek River has been almost untouched by man and the area affords an excellent opportunity for basic ecological studies of an unpolluted estuary.

The purchase, which had the approval of the Government of Quebec, was made possible by the Atlantic Foundation and Mr. J. Seward Johnson.

Cruises - 1966

ATLANTIS II

Days at Sea – 258 Total Miles Sailed – 36,676

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
18	4–24 January	Gulf Stream	21	F. Fuglister
19	26–29 January	Continental Shelf	4	N. Fofonoff
20	2 Feb–9 May	Equalant, Romanche Trench	97	V. Bowen
21	24–27 May	Off Nantucket	4	J. Beckerle
22	10 June–4 August	Bermuda – San Juan	56	Beckerle-Payne
23	5–10 August	Bermuda	6	R. Scheltema
24	15–25 August	Continental Shelf	11	H. Sanders
25	29 August–1 September	Montauk-Bermuda Line	4	R. Heinmiller
26	14–28 September	Gulf of Maine	15	B. Ketchum
27	3–9 October	Montauk-Bermuda Line	7	J. Gifford
28	1–19 November	Gulf Stream	19	L. Worthington
29	1–9 December	Montauk-Bermuda Line	9	R. Heinmiller
30	15–19 December	North of Gulf Stream	5	R. Scheltema
			258	

CRAWFORD

Days at Sea – 178 Total Miles Sailed – 20,444

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
135	25–29 January	Veatch Canyon	5	R. Conover
136	2–25 February	Gulf Stream	23	F. Fuglister
137	1–4 March	Veatch Canyon	4	R. Conover
138	10–30 March	Bermuda	21	A. Voorhis
139	1–9 April	Bromfield Shipyard	- -	- - - - -
140	12–27 April	Local Trips	16	R. Heinmiller
141	17–21 May	Montauk-Bermuda Line	5	N. Fofonoff
142	1–21 June	Gulf Stream	21	B. Warren
143	23–29 June	Montauk-Bermuda Line	7	R. Heinmiller
144	11–15 July	Gulf Stream	5	D. Menzel
145	22 July–5 August	Montauk-Bermuda Line	15	P. Foxton
146	8–13 August	Montauk-Bermuda Line	6	R. Heinmiller
147	17–18 August	Continental Slope	2	H. Jannasch
148	22–27 August	Gulf of Maine	6	G. Clarke
149	14–21 September	Montauk-Bermuda Line	8	D. Menzel
150	11–24 October	Gulf Stream	14	G. Volkmann
151	9–26 November	Gulf Stream	20	A. Voorhis
			178	

GOSNOLD

Days at Sea – 162 Total Miles Sailed – 14,711.5

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
81-A	4 January	Vineyard Sound	1	S. Knott
81-B	5 January	Vineyard Sound	1	S. Knott
81-C	7 January	Vineyard Sound	1	S. Knott
81-D	12 January	Vineyard Sound	1	S. Knott
81-E	19 January	Vineyard Sound	1	S. Knott
82	10–14 February	Continental Shelf	5	P. Stimson
83	11–14 April	Gulf of Maine	4	R. Conover
84	18–22 April	Bromfield Shipyard	- -	- - - - -
85	25 April–3 May	4 Sub. Canyons	9	R. Pratt
86	6–10 May	Gulf of Maine	5	R. Conover
87 Leg I	21 May–5 June	Woods Hole to New York	16	E. Uchupi
87 Leg II	8–11 June	Local	4	E. Uchupi
88	18 June–1 July	Off Cape Cod	14	R. Pratt
89	29 July	Vineyard Sound	1	D. Bumpus
90	1–25 August	Continental Slope	25	J. Schlee
91	8–23 September	Georges Bank–Gulf of Maine	16	E. Uchupi
92	1–5 October	Continental Shelf–Hudson Canyon	5	E. Uchupi
93	12 October	Vineyard Sound	1	G. Clarke
94	13–17 October	Off New York	5	S. Knott
94-A	27 October	Local	1	K. Emery
95	1 November–16 December	Gulf of Mexico	46	E. Uchupi
			162	

CHAIN Days at Sea – 285 Total Miles Sailed – 37,690

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
56	1 January–4 February	General Ship and Engine	- -	- - - - -
56-A	5–8 February	Off Cape Cod	4	P. Stimson
57	16 February–21 April	San Juan Area	65	E. Bunce
58	27 April–5 May	Montauk-Bermuda Line	9	H. Sanders
59	6–15 May	Munro's Shipyard	- -	- - - - -
59-A	15–17 May	Off Cape Cod	3	C. Bowin
60	18 May–30 June	Colombia, Mexico	44	R. Backus
61	11 July–17 December	Mediterranean–Red Sea	160	Hays-Zarudzki
			285	

C 54 Q Aircraft Flights – 1966

FLIGHT NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
1	21 February	Local Test Flight	1	- - - - -
2	27 February	Otis to Miami–400 hr.	1	- - - - -
3	29 March	Test Flight Miami	1	Plane damaged
4	13 May	Test Flight Miami	1	- - - - -
5	14 May	Test Flight Miami	1	- - - - -
6	18 May	Miami to Otis	1	- - - - -
7	23 May	Local Test Flight	1	- - - - -
8	25 May	Local Flight	1	P. Saunders
9	26 May	Local Flight	1	P. Saunders
10	27 May	Local Test Flight	1	- - - - -
11	1 June	Local Flight	1	P. Saunders
12	9 June	Local Flight	1	P. Saunders
13	15 June	Local Flight	1	P. Saunders
14	16 June	Local Flight	1	P. Saunders
15	21 June	Local Flight	1	P. Saunders
16	23 June	Local Flight	1	P. Saunders
17	24 June	Local Flight	1	P. Saunders
18	14 July	Local Flight	1	P. Saunders
19	17 August	Local Test Flight	1	- - - - -
20	18 August	Instrument Check Flight	1	- - - - -
21	24 August	Local Flight	1	P. Saunders
22	25 August	Local Flight	1	P. Saunders
23	26 August	Local Flight	1	P. Saunders
24	2 September	Local Test Flight	1	- - - - -
25	8 September	Local Test Flight	1	- - - - -
26	9 September	Local Flight	1	C. Parker
27	16 September	Local Flight	1	C. Parker
28	19 September	Otis to Bradley–Maitn.	1	- - - - -
29	20 September	Local Flight	1	G. Ewing
30	23 September	Night Proficiency Test	1	- - - - -
31	26 September	Local Flight	1	G. Ewing
32	27 September	Otis to Brunswick NAS	1	Dr. Fye & party
33	28 September	Brunswick to Otis	1	- - - - -
34	8 November	Test Flight new No. 3 Engine	1	- - - - -
35	10 November	Local Flight	1	C. Parker
36	15 November	Otis to Bermuda and return	1	C. Parker
37	17 November	Otis to Bermuda and return	1	C. Parker
38	21 November	Otis to Bermuda and return	1	C. Parker
39	1 December	Otis to Bermuda and return	1	C. Parker
40	15 December	Otis to Wilmington, Delaware	1	- - - - -
41	30 December	Local Test Flight	1	- - - - -

HELIO FLIGHTS 1966

March, April and May spent with Dr. Schevill hunting whales.

July, August and September local flights with Kuenzler, Halpern and Sherman. Also a few miscellaneous flights.

Plane taken to Chatham Airport in October for the rest of the year.

Scientific Departments and Supporting Services Personnel

PAUL M. FYE	Director
BOSTWICK H. KETCHUM	Associate Director
ARTHUR E. MAXWELL	Associate Director
DAVID D. SCOTT	Assistant Director for Administration
FREDERICK E. MANGELSDORF	Assistant Director for Development and Information

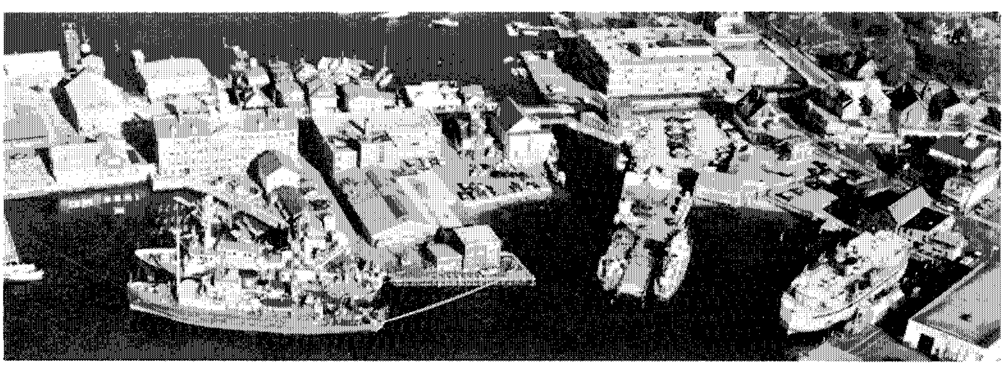
The following were in the employ of the Institution for the twelve-month period ending December 31, 1966:

Department of Applied Oceanography

Andersen, Nellie T.
Andrade, Marie
Armstrong, Harold
Barstow, Elmer M.
Bartlett, Arthur C.
Baxter, Lincoln II
Brockhurst, Robert R.
Broderson, George de P.
Chute, Edward H.
Collins, Clayton W., Jr.
Davison, Allan R.
English, Jean J.
Fairhurst, Kenneth D.
Fofonoff, Nicholas P.
Freund, William F., Jr.
Gifford, James E.
Graham, Russell G.
Hartke, Richard A.
Hays, Earl E.
Heinmiller, Robert H.
Hinton, Clifford H., Jr.
Howland, Myron P., Jr.
*Jones, Maxine M.
Kelly, Alfreida W.
Lyon, Thomas P.
Maltais, John A.
Marquet, William M.
Mason, David H.
Mavor, James W., Jr.
McCamis, Marvin J.
Muzzey, Charlotte A.
Omohundro, Frank P.
Porembski, Chester R.
Rainnie, William O., Jr.
*Reese, Margaret L.
Rosenfeld, Melvin A.
Sharp, Arnold G.
Shodin, Leonard F.
Shultz, William S.
Stimson, Paul B.
*Sullivan, James A.
Webb, Douglas C.
*Webster, Jacqueline
Wilson, Valentine P.
Woods, Donald E.
Zwilling, Avron M.

Department of Biology

*Ashmore, Judith A.
Bartlett, Martin R.
Baylor, Edward R.
Breivogel, Barbara B.
Carey, Francis G.
*Casiles, Phyllis M.
*Clarke, George L.
Clarner, John P.
Corwin, Nathaniel
Craddock, James E.
Denton, Edward A.
*Fraser, Grace C.
Freund, Jean D.
Graham, Linda B.
Grice, George D., Jr.
Guillard, Elizabeth D.
Guillard, Robert R. L.
Gunning, Anita H.
Hampson, George R.
Hessler, Robert R.
Hulburt, Edward M.
Hülsemann, Kunigunde
Jannasch, Holger W.
Kanwisher, John W.
Konnerth, Andrew, Jr.
Laird, John C.
Lawson, Thomas J., Jr.
Maddux, William S.
Masch, David W.
Mather, Frank J. III
Menzel, David W.
Mogardo, Juanita A.
Rodman, Janet H.
Rogers, M. Dorothy
Ryther, John H.
Sanders, Howard L.
Scheltema, Rudolf S.
*Schroeder, William C.
Sears, Mary
Stanley, Helen I.
Teal, John M.
Turner, Harry J.
Vaccaro, Ralph F.
Valois, Frederica W.
Waterbury, John B.
Watson, Stanley W.
*Wilson, Esther N.
Yentsch, Charles S.
Zullo, Janet



Department of Chemistry and Geology

*Athearn, Nadine N.
Athearn, William D.
Behrendt, Monika
Blumer, Max
Bowen, Vaughan T.
Burke, Barbara A.
Burke, John C.
Byrne, Robert J.
Coppenrath, Agnes I.
Cormack, Douglas
Dale, Barry
Degens, Egon T.
Emery, Kenneth O.
Fitzgerald, William F.
Gordon, Allan G.
Gordon, John E.
†Hathaway, John C.
Hayes, Carlyle R.
Hülsemann, Jobst B.
Hunt, Jeannette E.
Hunt, John M.
†Manheim, Frank T.
McAuliffe, Julianne G.
†Meade, Robert H.
Mott, Norman S.
Noshkin, Victor E., Jr.
Paul, Russell K.
Pratt, Richard M.
*Richards, Heidi
Ross, David A.
Rudrum, Michael
Sass, Jeremy
†Schlee, John S.
Schroeder, Brian W.
Siegel, Alvin
Simmons, Charles F.
Spencer, Derek
Strickland, Charlotte M.
Surprenant, Lolita D.
†Tagg, A. Richard
Tasha, Herman J.
Thompson, Geoffrey
Thorne, Robert L.
†Trumbull, James V. A.
Uchupi, Elazar
Wall, David
Zeigler, John M.

†*Member of U.S. Geological Survey assigned for work at the Woods Hole Oceanographic Institution*

Department of Geophysics

Allstrom, Frank C.
Backus, Richard H.
Beckerle, John C.
Berggren, William A.
Bergstrom, Stanley W.
Boutin, Paul R.
Bowin, Carl O.
Broadbent, Alice G.
Bunce, Elizabeth T.
Cain, Henry A.
Carter, Jane C.
Chase, Richard L.
Church, William
Doutt, James A.
Dow, Willard
Dunkle, William M., Jr.
Fuglister, C. Kurt
*Gallagher, Gloria S.
Grant, Carlton W., Jr.
Hays, Helen C.
‡Hersey, J. Brackett
‡Hess, Frederick R.
Howbert, Martha M.
Knott, Sydney T., Jr.
Mellor, Florence K.
Mizula, Joseph W.
Morehouse, Clayton B.
Nichols, Walter D.
Nowak, Richard T.
Payne, Richard E.
Peterman, Carol I.
Peterson, Jane M.
Phillips, Joseph
Poole, Stanley E.
Ruppert, Gregory N.
*Schevill, William E.
Scott, Carl W., Jr.
Shores, David L.
Stetson, Thomas R.
Stone, Louise D.
Sutcliffe, Thomas O. L.
Vine, Allyn C.
Watkins, William A.
Wing, Asa S.
Witzell, Grace K.
Witzell, Warren E.
Wooding, Frank B.
Young, Earl M., Jr.
Zarudzki, Edward F. K.
Zwilling, Judith B.

Department of Physical Oceanography

Allen, Ethel B.
Bailey, Phyllis T.
Barbour, Rose L.
Barrett, Joseph R., Jr.
Bradshaw, Alvin L.
Bruce, John G., Jr.
Bumpus, Dean F.
Chase, Joseph
Day, C. Godfrey
Densmore, C. Dana
Frank, Winifred H.
Fuglister, Frederick C.
Hammond, Paul D.
Hays, Betty C.
Houston, Leo C.
*Kahler, Yolande A.
Metcalf, William G.
Miller, Arthur R.
Munns, Robert G.
Parker, Charles E.
Phillips, Helen F.
Reynolds, Carol J.
Schleicher, Karl E.
Schroeder, Elizabeth H.
Soderland, Eloise M.
Stalcup, Marvel C.
Stanley, Robert J.
Volkmann, Gordon H.
Voorhis, Arthur D.
Warren, Bruce A.
Webster, T. Ferris
Whitney, Geoffrey G., Jr.
Worthington, L. Valentine
Zemanovic, Marguerite P.

Department of Theoretical Oceanography and Meteorology

Alexander, Robert M.
Blanchard, Duncan C.
Bunker, Andrew F.
Chaffee, Margaret A.
*Ewing, Gifford C.
Frazel, Robert E.
Iselin, Columbus O'D.
‡Kraus, Eric B.
Ridolfi, Mary
Ronne, F. Claude
Rooth, Claës G. H.
‡Saunders, Peter M.
Spencer, Allard T.
Thayer, Mary C.
*von Arx, William S.

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

Department of Administrative and Service Personnel

Allen, Eugene H.
*Allen, Norman T.
Anders, Wilbur J.
Backus, Jeanne M.
Bard, Wallace R.
Behrens, Henry G.
Benttinen, Dave D.
Branham, Roy L.
Bowman, Richard W.
Burke, John E.
Campbell, Eleanor N.
Carlson, Alfred G.
Carlson, Eric B.
Carlson, Ruth H. E.
Carver, Kenneth W.
Chalmers, Agnes C.
*Chase, Elizabeth L.
Christian, John A.
Clough, Auguste K.
Condon, John W.
Conway, George E.
Cook, Harold R.
Corr, James P.
Crocker, Marion W.
Croft, Donald A.
Cummings, Priscilla J.
Day, Joseph V.
Dean, Mildred
Dimmock, Richard H.
Doty, Jeanne C.
Eastman, Arthur C.
Edmed, Sharon L.
Eldridge, Stanley N.
Fernandes, Alice P.
Fielden, Frederick E.
Fisher, Stanley O.
Fleet, Kenneth F.
Fredericksen, Mauritz C.
*Fuglister, Cecelia B.
Gallagher, William F.
Gaskell, Fred
Gioiosa, Albert A.
Grace, Cynthia C.
Grant, Carlton W., Sr.
*Hahn, Jan
Hall, Arthur B.
Hampton, Carolyn S.
Hatzikon, Kaleroy L.
Henderson, Arthur T.
Hodgson, Sloat F.
§Hunt, Otis E.
Ingram, Ruth C.
Innis, Charles S., Jr.
Jenkins, Delmar R.
Johnson, Harold W.
Kostrzewa, John A.
Lane, Egbert B.
LeBlanc, Donald F.
LeBlanc, William A.
MacKillop, Harvey
Mangelsdorf, Frederick E.
Martin, Olive
McGilvray, Mary K.
McHardie, James
Medeiros, Frank
Mitchell, James R.

§Deceased 24 November 1966

Morrison, Kenneth
Motta, Joseph C.
Motta, Joseph F.
Muller, John T.
Orr, Elizabeth D.
Ortolani, Mary
Patterson, John E.
Picard, Eleanor P.
Pimental, John M.
Queenan, Martha L.
Quigley, Ralph W.
Reeves, Stanley A.
Reis, Janice A.
Rennie, Thomas D.
Roberts, Harry A.
Rudden, Robert D., Jr.
Schilling, John L.
Simons, Cecelia M.
Slabaugh, Luther V.
*Solberg, Otto
Souza, Donald P.
Souza, Thomas A.
Stanbrough, Jess H.
Stansfield, Richard
Stimpson, John W.
von Dannenberg, Carl A.
Walker, Jean D.
Watson, L. Hoyt
Weeks, Robert G.
Wessling, Andrew L., Jr.
Williams, Sally A.
Wing, Carleton R.
Woodward, Fred C., Jr.
Woodward, Ruth F.
Wright, Hollis F.

Marine Personnel

Babbitt, Herbert L.
Backus, Cyril
Bailey, Peter H.
Baker, William R.
Bazner, Kenneth E.
Brereton, Richard S.
Brown, Joseph C.
Buckley, Francis E.
Bumer, John Q.
Cabral, John V.
Cahoon, Geraldine B.
Caranci, Donald H.
Carter, Richard J.
Carver, Ralph C.
Casiles, David F.
Cavanaugh, James J.
Clarkin, William H.
Colburn, Arthur D., Jr.
Copestick, Louis B.
Cornell, Jack W.
Cotter, Jerome M.
Coughlin, Brooks W.
Crocker, John D.
Crouse, Porter A.
Davis, Charles A.
Devlin, Gerald X.
Edwards, Richard S.
Halpin, William T.
Hamblet, Dwight F.
Hiller, Emerson H.
Holmes, Edwin M.
Holmes, Roy
Howe, Paul M.
Howland, Paul C.
Jefferson, Albert C.
Janes, George
Jorgensen, Peter A.
Karram, Calvin D.
La Porte, Leonide
Leiby, Jonathan
Lowney, Edwin A.
Martin, John W., Jr.
Matthews, Francis S.
McLaughlin, Barrett J.
McMahon, James H.
Miner, Arnold W.
Moller, Donald A.
Morse, Joseph C.
Mysona, Eugene J.
Ocampo, Conrad H.
Palmieri, Michael, Jr.
Penman, Norman A.
Pennypacker, Thomas R.
Pierce, George E.
Pierce, Samuel F.
Pike, John F.
Porrata, Carlos F.
Ribeiro, Joseph
Rioux, Raymond H.
Roy, Alfred J.
Seibert, Harry H.
Seifert, Charles T.
Smalley, Walter S.
Sointu, Sulo
Stires, Ronald K.
Tully, Edward J.
Westberg, Donald R.
Woodward, Jan A.

Retirement

As of the 31st of December, 1966, there were two retirements, George A. Ferris, *Property Custodian,* and Alfred John, *Seaman.*

Seminars and Fellowships

Fellows

An integral part of the program since 1932 have been the fellows who are in residence for the three summer months. In 1966, there were one pre-doctoral and fifteen post-doctoral fellows working under the guidance of staff members in all departments.

On a year-round basis, there were six pre-doctoral and five post-doctoral fellows. In addition, the staff has had the advantage of many fruitful discussions with Professor Maurice Rattray, Jr., of the University of Washington, Seattle, who was awarded the Rossby Memorial Fellowship for the Academic Year 1966-1967. He has been in residence since late August.

A fourth student on graduation from Lawrence (Falmouth) High School was awarded a scholarship to enable him to continue studies toward a degree in one of the sciences or in engineering at the college or university of his choice. Thus far, recipients have elected to attend McGill, Tufts and Oberlin universities.

Lectures

The Monday evening lectures, established when the Institution first opened, have continued to provide a forum for the staff and guests from other laboratories to present recent work for discussion. Similar opportunities are afforded at weekly departmental "lunches" of the biologists, geologists and geophysicists.

Seminars

As in previous years, a biweekly interinstitutional seminar series during the academic semesters has made it possible for the New England geophysicists interested in fluid dynamics to keep abreast of the work in this area.

The eighth seminar on Geophysical Fluid Dynamics with the support of the National Science Foundation and under the leadership of Professor Willem V. R. Malkus of the University of California at Los Angeles occupied the thirty-one participants for ten weeks during the summer. The three lecturers, Dr. Louis N. Howard and Dr. George Veronis, both of the Massachusetts Institute of Technology, and Dr. Melvin E. Stern of the University of Rhode Island, introduced the participants to some of the more recent research. The choice of topics not only had a pedagogic function but also indicated a variety of unsolved problems. In this way the nine fellows were guided to questions which might be solved in a preliminary way in a two-month period, but which might also prove challenging for future work on return to their universities. The lectures centered on such topics as "The effects of rotation on wave motions", "Analogy between rotating and stratified fluids", "Problems in galaxy formation", and "Dynamics of disc galaxies".

Grants and Fellowships

The following persons were awarded grants, fellowships or honoraria during 1966:

JOHN A. ALLEN
University of Newcastle-on-Tyne, Northumberland, England

JAMES L. ANDERSON
Stevens Institute of Technology

NANCY BALDWIN
University of Oregon

ROBERT BEARDSLEY
Massachusetts Institute of Technology

PAUL BERDAHL
Rice University

JAMES L. BISCHOFF
University of California, Berkeley

THOMAS CHASE
Oberlin College

STEPHEN CHILDRESS
Courant Institute, New York University

GEORGE M. CRESSWELL
Tiburon Oceanographic Institute

JOHN M. EDMOND
Scripps Institute of Oceanography

RUSSELL L. ELSBERRY
Colorado State University

GEORGE FIELD
University of California, Berkeley

DAVID FINKELSTEIN
Yeshiva University

WILLIAM FITZGERALD
Massachusetts Institute of Technology

LION GARDINER
University of Rhode Island

ANN E. GARGETT
University of Manitoba, Canada

CHRISTOPHER J. R. GARRETT
Trinity College, Cambridge, England

RONALD GIRDLER
University of Newcastle-on-Tyne, Northumberland, England

PETER GOLDREICH
University of California, Los Angeles

ROBERT GOLL
Ohio State University

KLAUS GRASSHOFF
Kiel University, Germany

RAZIEL HAKIM
Queens College, New York

FREDERICK R. HESS
University of New Hampshire

SONJA E. HICKS
Indiana University

LOUIS HOBSON
University of Washington

SUSUMU HONJO
University of Hokkaido, Japan

LOUIS N. HOWARD
Massachusetts Institute of Technology

JAMES H. JUSTICE
University of Maryland

JOSEPH B. KELLER
Courant Institute, New York University

ROBERT KRAICHNAN
Peterborough, New Hampshire

WILLEM V. R. MALKUS
University of California, Los Angeles

RICHARD W. MICHIE
Kitt Peak National Observatory, Tucson, Arizona

BRUCE MORTON
Manchester University, England

ROBIN D. MUENCH
Dartmouth College

RICHARD T. NOWAK
Massachusetts Institute of Technology

STEVEN A. ORSZAG
Institute for Advanced Study, Princeton

JOHN M. PARSON
Harvard University

RICHARD E. PAYNE
University of Rhode Island

JOSEPH PEDLOSKY
Massachusetts Institute of Technology

HENRY T. PERKINS
Massachusetts Institute of Technology

OWEN M. PHILLIPS
Johns Hopkins University

MOIZ RASIWALA
Institut d'Astrophysique, Paris

MAURICE RATTRAY, JR.
University of Washington

ALLAN R. ROBINSON
Harvard University

JONATHAN D. ROUGHGARDEN
University of Rochester

PETER E. SACHS
University of Reading, England

WILLIAM C. SASLOW
Cambridge University, England

JAMES E. SCHINDLER
North Dakota State University

JOHANNES SCHMID-BURGK
Heidelberg University, Germany

JOSEPH SILK
Harvard University

SISTER BONAVENTURE
New Rochelle College, New York

J. Dungan Smith
University of Chicago

Edward A. Spiegel
New York University

Melvin E. Stern
University of Rhode Island

Wesley Stimpson
Tufts University

Sandra L. Stone
Cornell University

Stephen A. Thorpe
National Institute of Oceanography, Surrey, England

Alar Toomre
Massachusetts Institute of Technology

Dudley H. Towne
Amherst College

Martin S. Tracton
University of Massachusetts

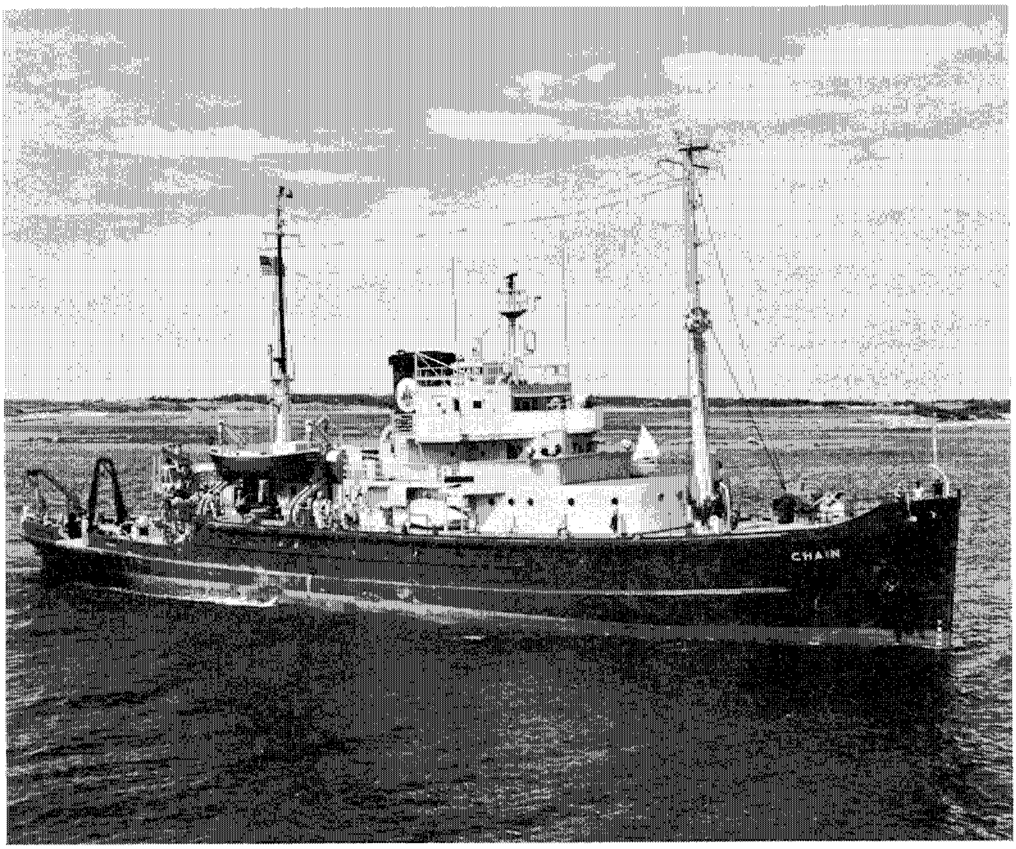
George Veronis
Yale University

Lorraine Whitman
New York University

Peter J. Williams
The University, Southampton, England

R. Keith Wilson
North Texas State College

John Woodcock
McGill University



CHAIN — The chief scientist's and captain's quarters have been moved forward to permit construction of a library and a science office with facilities for drafting and assembling scientific data.

Treasurer's Report

The accounts for the year 1966 have been audited by Lybrand, Ross Bros. & Montgomery.

The book value of endowment funds at December 31, 1966, was $4,483,594, of which $1,872,277 represented accumulated net gain from sales of investments. The market value of endowment assets on the same date, including real estate at book amount, and $15,349 in cash was $6,698,169. Endowment fund investments and income received therefrom are summarized on page 72.

Income received on endowment assets was $245,914 for the year ended December 31, 1966, compared with $233,492 the previous year.

Endowment income represented a return on endowment fund investments of 3.7 per cent at year-end market quotation, 5.5 per cent on book amount and 9.4 per cent on the contributed amount of the endowment fund.

Endowment income was allocated for 1966 operating expenses at the rate of 6 per cent of the contributed amount of endowment funds, or $155,663. The remaining balance amounting to $90,251 was transferred to the income and salary stabilization reserve.

The Institution's 1966 contribution to the Woods Hole Oceanographic Institution Employees' Retirement Trust amounted to $297,043.

LYBRAND, ROSS BROS. & MONTGOMERY

CERTIFIED PUBLIC ACCOUNTANTS

COOPERS & LYBRAND
IN AREAS OF THE WORLD
OUTSIDE THE UNITED STATES

Woods Hole Oceanographic Institution

Woods Hole, Massachusetts

We have examined the balance sheet of Woods Hole Oceanographic Institution as at December 31, 1966 and the related statements of changes in funds and of operating expenses and income for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances. It was not practicable to confirm receivables from United States Government departments, but we have satisfied ourselves as to such accounts by means of other auditing procedures.

In our opinion, the accompanying statements (pages 69 and 70, inclusive) present fairly the financial position of Woods Hole Oceanographic Institution at December 31, 1966 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

The supplemental schedules included in this report (pages 71 and 72, inclusive) although not considered necessary for a fair presentation of the financial position and results of operations, are presented primarily for supplemental analysis purposes. This additional information has been subjected to the audit procedures applied in the examination of the basic financial statements and, in our opinion, is fairly stated in all material respects in relation to the basic financial statements taken as a whole.

Boston, Massachusetts
March 15, 1967

Lybrand, Ross Bros. & Montgomery

BALANCE SHEET

December 31, 1966

ASSETS

Endowment Fund Assets:		
Investments:		
Marketable securities, market value $6,623,583	$ 4,409,008	
Real estate	59,237	
	4,468,245	
Cash	15,349	
		4,483,594
Plant Fund Assets (note):		
Laboratory plant and equipment	3,609,587	
Atlantis II, contingent title	4,831,130	
Other vessels, equipment and property	1,345,603	
	9,786,320	
Plant funds advanced to current	1,072,327	
		10,858,647
Current Fund Assets:		
Cash	776,657	
Marketable securities, at cost	494,004	
Reimbursable research contract costs:		
Billed	798,274	
Unbilled, including December costs of $679,560	725,343	
Supplies, prepaid expenses and deferred charges	110,792	
Plant funds advanced to current	(1,072,327)	
		1,832,743
		$17,174,984

LIABILITIES

Endowment Funds:		
Unrestricted as to income	$2,519,420	
Unrestricted as to principal and income	91,897	
Accumulated net gain on sales of investments	1,872,277	
		4,483,594
Plant Funds:		
Invested in plant	9,786,320	
Unexpended	1,072,327	
		10,858,647
Current Liabilities and Reserves:		
Accounts payable and accrued expenses	460,236	
Contribution payable to employees' retirement plan and trust	297,043	
Unexpended balances of gifts and grants for research	161,446	
Reserves	914,018	
		1,832,743
		$17,174,984

Note — Depreciation is provided on plant assets, other than vessels ($4,831,000) and the Laboratory of Marine Science ($2,111,000), at annual rates of 2% on buildings and 5% to 33⅓% on equipment. The amount provided is credited to general plant and equipment reserve.

Statement of Operating Expenses and Income

Year Ended December 31, 1966

Operating Costs and Provisions	
Direct costs of research activity:	
Salaries and wages	$2,484,420
Vessel operations	1,738,872
Materials, equipment and services	2,262,016
Laboratory costs	351,504
Travel	175,602
Service departments	278,398
Computer center	190,561
Aircraft operations	50,192
	7,531,565
Indirect costs:	
General and administration	945,212
Miscellaneous	137,940
Other charges:	
Provision for working capital and contingencies	148,329
	$8,763,046
Income:	
Income for sponsored research (including $2,688,155 gifts and grants expended):	
For direct costs	7,472,093
For indirect costs	922,969
Fees for use of facilities	196,400
	8,591,462
Endowment income availed of:	
For institution research	59,472
For institution indirect costs	96,191
Miscellaneous	15,921
	$8,763,046

Statement of Changes in Funds

Year Ended December 31, 1966

		Plant Funds				Reserves	
			Unexpended				
	Endowment Funds	Invested in Plant	Acquisition of Capital Assets	General Plant and Equipment Reserve	Unexpended Balances of Gifts and Grants for Research	Income and Salary Stabilization	Working Capital and Contingency
Balance beginning of year	**$4,330,673**	**$9,507,975**	**$926,675**	**$259,133**	**$ 117,053**	**$606,563**	**$ 68,875**
Gifts and grants received	7,225	173,070	82,140		2,827,701		
Endowment income						245,914	
Net gain on sales of investments	115,696						
Additions from current year's operations:							
Provision for depreciation				173,455			
Provision for working capital and contingencies							148,329
Availed of for direct and indirect research costs					(2,688,155)	(155,663)	
Transferred to endowment funds from:							
Unexpended balance of gifts from Oceanographic Associates	30,000				(30,000)		
Removals from plant		(266,801)					
Invested in plant		372,076	(219,376)	(152,700)			
Other additions (reductions)				3,000	(65,153)		
	$4,483,594	**$9,786,320**	**$789,439**	**$282,888**	**$ 161,446**	**$696,814**	**$217,204**

Note — Unexpended balances consist of amounts received in advance of expenditure, and do not include receipts or expenditures under reimbursement type contracts.

Direct Costs of Research Activity

Year Ended December 31, 1966

	Salaries and Wages	Vessel Operations	Materials, Equipment and Services	Laboratory Costs	Travel	Service Depart-ments	Computer Center	Aircraft Operations	Total
U.S. Government:									
Contracts	$1,705,381	$ 928,580	$1,668,689	$241,249	$109,297	$222,928	$141,884	$49,822	$5,067,830
Grants	753,384	809,114	513,301	106,442	51,719	49,654	40,387		2,324,001
Other sponsored research	14,028	1,178	37,752	2,001	11,944	4,772	8,290	297	80,262
Total direct costs of sponsored research	2,472,793	1,738,872	2,219,742	349,692	172,960	277,354	190,561	50,119	7,472,093
Institution research	11,627		42,274	1,812	2,642	1,044		73	59,472
Total direct costs of research	**$2,484,420**	**$1,738,872**	**$2,262,016***	**$351,504**	**$175,602**	**$278,398**	**$190,561**	**$50,192**	**$7,531,565**

*Includes grants and fellowships:

U.S. Government grants	$31,297
Other sponsored research	9,020
Institution research	36,276
	$76,593

General and Administration Expenses

Year Ended December 31, 1966

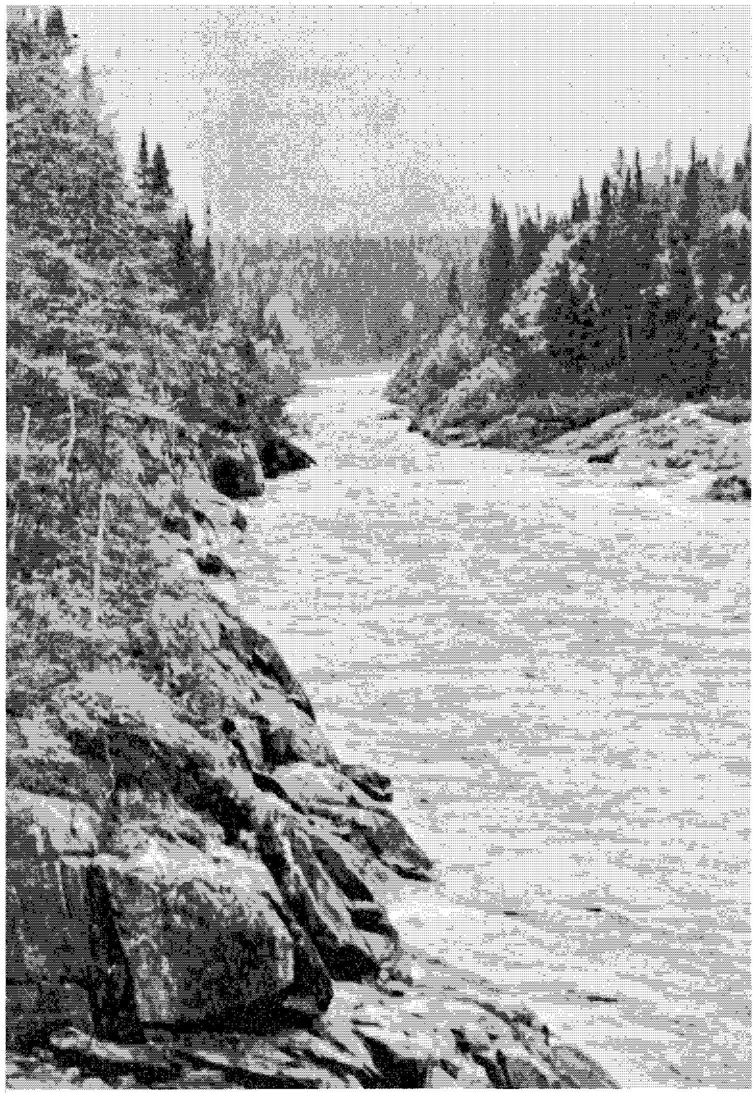
General Expenses:		
Staff benefits:		
Contribution to retirement plan		$ 39,737
Social security taxes		15,074
Employee health benefits		39,024
		93,835
Provision for depreciation (credited to general plant and equipment reserve)		14,122
Service departments		35,827
Administration Expenses:		
Salaries and wages	$482,881	
Insurance, travel, supplies and other	318,547	801,428
		$945,212

Summary of Investments

As at December 31, 1966

	Book Amount	% of Total	Market Quotation	% of Total	Endowment Income
BONDS:					
Government and government agencies	$1,129,574	25.3	$1,127,011	16.9	$ 51,851
Railroad	403,539	9.0	362,176	5.4	17,793
Public utility	485,565	10.8	433,230	6.5	16,457
Industrial	344,519	7.8	307,573	4.6	13,781
Financial and investment	339,173	7.6	320,034	4.8	13,294
Total bonds	2,702,370	60.5	2,550,024	38.2	113,176
STOCKS:					
Preferred	52,270	1.2	47,525	.7	2,680
Common:					
Public utility	361,399	8.1	980,713	14.6	33,688
Industrial	895,093	20.0	2,478,521	37.1	72,294
Miscellaneous	397,876	8.9	566,800	8.5	21,082
Total common stocks	1,654,368	37.0	4,026,034	60.2	127,064
Total stocks	1,706,638	38.2	4,073,559	60.9	129,744
Total marketable securities	4,409,008	98.7	6,623,583	99.1	242,920
REAL ESTATE	59,237	1.3	59,237*	.9	2,994
Total investments	$4,468,245	100.0	$6,682,820	100.0	$245,914

*At book amount.



Matamek River.