THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

COVER

Electron photomicrograph of shell matrix protein of Mercenaria mercenaria *(enlarged 670,000 times). For the first time, the protein responsible for the deposition of calcium carbonate has been successfully crystallized.*

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the United States in a world-wide program of oceanographic research, no one could have been found so well equipped by personal experience and ability to serve as its secretary. The report he prepared for the committee led directly to the establishment of the Woods Hole Oceanographic Institution, as well as support for marine science at the Scripps Institution, the University of Washington and the Bermuda Biological Station. It was inevitable that the author of this report should have been asked to direct the newly-established institution at Woods Hole.

The years devoted to the establishment and administration of the Oceanographic Institution were but a brief interlude in a life-long career at the Museum of Comparative Zoology where he was affectionately known as Uncle Henry. There he worked for 44 years prior to his retirement and there he continued to work until his death 17 years later. His last scientific paper, written as were many others in association with William C. Schroeder, was in press at the time of his death. It was his pride that he had worked at Harvard continuously for 70 years, longer than anyone on record. Time enough to establish himself as a world-wide authority on two great groups of marine animals, the Coelenterata and the fishes, as well as to become a leader in the science of oceanography.

Although his work was in the Museum, he believed that as a member of the faculty at Harvard his first responsibility was to the undergraduates of the College. He inaugurated a course in biological oceanography in 1931 and subsequently gave the course in invertebrate zoology. Two of his students succeeded him as Director of this Institution, a third serves us as Clerk of the Corporation, while others occupy high positions in the fisheries services and elsewhere. On the occasion of the twenty-fifth anniversary of the founding of the Woods Hole Oceanographic Institution, a volume of papers by his former students and associates was dedicated to Henry Bryant Bigelow, and published as a supplement to *Deep-Sea Research.*

Henry Bigelow enjoyed warm friendships with contemporary European leaders in oceanography: Johan Hjort and Bjorn Helland-Hansen of Norway; Johannes Schmidt and Martin Knudsen of Denmark; Henry Maurice, Sir J. Stanley Gardner, Michael Graham, Sir D'Arcy Thompson and Sir Fredrick S. Russell of Great Britain; Edouard LeDanois of France, and A. G. Huntsman of Canada, to mention a few. He was honored in Europe by awards of the Johannes Schmidt Medal by the Carlsburg Foundation, Copenhagen (1947), the Monaco Medal by the Institut Océanographique, Paris (1950), an honorary degree from the University of Oslo, and by election to the Norske Videnskaps Academi, the Royal Geographical Society, the Zoological Society of London and the Marine Biological Association of the United Kingdom.

In his own country, his eminence was recognized by honorary degrees from Yale (1946), Harvard (1941) and the University of Rhode Island (1960), by election to the National Academy of Sciences, the American Philosophical Society and the American Academy of Arts and Science. He was awarded the Alexander Agassiz Medal by the National Academy of Sciences (1931), the Bowie Medal by the American Geophysical Union (1944), the Daniel Giraud Elliott Medal by the National Academy of Sciences (1948), and was the first recipient of the Henry Bryant Bigelow Medal established in his honor by the Woods Hole Oceanographic Institution.

While it is easy to recount the achievements for which Henry Bigelow is honored, it is impossible to give an adequate picture of the personality which made them possible. Professor Huntsman once said of him, "Like all of us, he has his own peculiar personality, but his is more peculiar than that of anyone else I know — a queer combination of lively humor and deadly seriousness — his way is inimitable."

He was an utter realist in his respect for the apparent facts. In considering any question he had a unique ability to strike through to the pertinent point. He appeared to be completely impersonal in his judgments and never made a foolish decision or gave unwise advice. If he were ever mistaken, it was because some needed facts were missing. Though his excitement was in the discovery of new facts, he was not one to be concerned primarily with learning more and more about less and less. He wanted to know more about more and more and to see the relations between the primary considerations. Thus, he encouraged new fields of inquiry and broadened our conception of what marine science could be.

Among the facts he recognized was the diversity and frequently the folly of his fellow men. This was the theme of the humor with which he confronted the world. "Thinking fellows" and "silly clucks" were among the categories into which he put us. His daily rounds of the laboratory at Woods Hole, in which he assessed our capabilities and kindly corrected our follies, made him a great Director. The proverbial uncle is an elder member of a family, detached from its petty turmoil, but kind and wise, to whom the youngsters turn for understanding and counsel. As such, we will remember Uncle Henry with affection and gratitude.

ALFRED C. REDFIELD

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*Deceased 15 February 1968

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KEVIN H. WHITE
Secretary of the Commonwealth
STATE HOUSE BOSTON, MASS.

ARTICLES OF AMENDMENT

For

☐ Change of Name ☒ Change of Purpose ☐ Change of Location

This certificate must be filed within thirty days of the date of the vote.

We, Paul M. Fye President Edwin D. Brooks, Treasurer, Mary Sears Clerk and Hudson Hoagland, Noel B. McLean, Harvey Brooks, Carroll L. Wilson, John P. Chase, Lawrason Riggs III, Milford R. Lawrence, Edwin A. Link, W. Van Alan Clark, Jr., James S. Coles, Charles W. Cole, J. Seward Johnson, E. Bright Wilson, Jr., Arnold Arons, Francis C. Welch, and Henry A. Morss, Jr.

being a majority of the ~~Directors~~ Trustees of Woods Hole Oceanographic Institution (Name of Corporation)

Woods Hole (City or Town)

in compliance with the provisions of Section 10, Chapter 155 and or Section 10, Chapter 180 of the General Laws as amended, do hereby certify that at a meeting of the members of said corporation, duly called for the purpose held 11 (Day) January (Month) 1967 (Year),

and by the affirmative vote of 84 Members (members) of said corporation, being at least two-thirds of the members of said corporation legally entitled to vote, it was voted to petition the State Secretary to change its Purpose (Name / Purpose / Location) to read

To prosecute the study of oceanography in all its branches, to maintain a laboratory or laboratories, together with boats and equipment and a school for instruction in oceanography and allied subjects, and in connection therewith to confer graduate degrees and such honorary degrees as are usually conferred by colleges or universities in this Commonwealth, including joint graduate degrees conferred in conjunction with any other university, college or institution having the authority to confer graduate degrees; to accept and hold money, and property of any kind whatsoever, and wherever situated, and whether received through bequest, devise, gift or otherwise; and to apply from time to time and at any time to the purposes of the corporation, or to any of them, all or any part of the income and/or principal of any funds and/or property held by the corporation.

IN WITNESS WHEREOF, we have hereunto signed our names under the penalties of perjury this 11th day of January in the year 1967.

Paul M. Fye, Pres.
Mary Sears, Clerk
Noel B. McLean
Harvey Brooks
Carroll L. Wilson
John P. Chase
Lawrason Riggs III
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Henry A. Morss, Jr.

Approved by
Board of Higher Education
11-1-67

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NOV 3 1967
CORPORATION DIVISION
SECRETARY'S OFFICE

I hereby approve the within certificate and cause the same to be recorded and filed when validated.

Kevin H. White
Secretary of the Commonwealth

THE DIRECTOR'S REPORT

The rapid transition in the nature of oceanic activities has continued during the past year. At the larger laboratories, oceanography is no longer characterized by the work of the naturalist who in exploring the oceans constantly made important discoveries. Instead, the oceanographer today is asking searching questions and developing new theories which are leading to a deeper insight and understanding of oceanic phenomena. This evolution will continue with the development of engineering techniques and the exploitation of natural resources. Evidence of the usefulness of the new engineering techniques in our research program has been most apparent this year in the use of ALVIN as a successful tool for scientific investigations.

These are years of change in oceanography, not only in its evolutionary development as a science and technology, but also in a number of other respects as well. The public has a new appreciation of the importance of the oceans. Not too many years ago, the principal public interest in the oceans arose out of a romantic attachment for the seas on the part of a relatively small number of seafaring and sealoving people. Out of their interest developed an intellectual curiosity on the part of a growing number of scientists. Moreover, today there is a pressing demand for additional knowledge on the part of many potential users of the oceans. This demand goes beyond the traditional areas of fishing, transportation, and national security. It brings to us potential users who are interested in the economic development of previously unavailable marine resources.

The increased public awareness has resulted in governmental involvement at all levels from local and state governments to national and international bodies. This has been manifest in a great quest for knowledge through the establishment of so many study groups that it would be impossible to list all of them here. An example at each governmental level illustrates their wide variety and scope.

Two years ago, the town of Falmouth with the help of the Woods Hole laboratories set up a study group to examine the appropriateness of introducing Oceanography in the curriculum in the local school system. This group soon developed a training program for interested teachers. The result has been one of the early programs using Title III funds for the development of novel educational approaches. Now there is an active teaching program in the Intermediate School, with a field station in East Falmouth.

Massachusetts, under the leadership of the Governor's Advisory Committee on Science and Technology, has undertaken an intensive six-month study of the Commonwealth's stake in the oceans. Associate Director, Arthur E. Maxwell, was chairman of the state-wide conference which initiated the study.

The early National Academy of Sciences' Committee on Oceanography studies which stressed the importance of the marine sciences to the country were truly prophetic. Last year Congress appreciated the need for a national policy for the oceans by passing the "Marine Resources and Engineering Development Act." By mid-1967, the Presidential Study Commission headed by Dr. Julius A. Stratton, and the National Council on Marine Resources and Engineering Development established by the Act, were following their respective mandates to develop a comprehensive plan for defining national objectives on marine affairs.

In characteristic fashion, Vice President Hubert H. Humphrey has been an enthusiastic and energetic chairman of the National Council, a planning body at the Cabinet level. Not content with second-hand information relating to the state of the marine sciences in the United States, the Vice President undertook to visit selected oceanographic institutions throughout the country. Woods Hole was honored with such a visit in June of this year, and we were thereby afforded the rare opportunity of explaining the nature and extent of our research program, both ashore and afloat, to the Vice President and his party. After a tour of Woods Hole scientific institutions he accompanied us on an overnight cruise on ATLANTIS II from Woods Hole to Portsmouth, New Hampshire. Preparations were demanding, but we had an excellent opportunity to demonstrate a wide range of oceanographic techniques and equipment. The entire Institution staff and ship's company felt that the Vice President's message of appreciation expressed a genuine understanding of the important scientific merit of the work at the Institution: "I have long heard of your institution's renowned work. I now have had the opportunity to see some of your activities for myself and to become better acquainted with your distinguished staff who are playing such a key role in making it possible for us to advance our understanding and use of the oceans. This was my very first trip to sea on an oceanographic research vessel, and I came home highly impressed with the complexity of instrumentation required, the difficulties of working at sea, and the smooth teamwork and competence of that ship's scientific party and crew."

Within the United Nations, the Economic and Social Council passed a resolution in 1966 asking the Secretary General to survey the marine resources of the world and the techniques for exploiting them. Later, the General Assembly of the United Nations endorsed this Council action and adopted two implementing resolutions concerning marine science and marine resources. These actions established yet another group to evaluate the importance of marine activities of member states in their relationships with each other. Thus, during this transition period the world has become aware, as never before, of the importance of the oceans.

Moreover, many other professional groups — lawyers, sociologists, economists, diplomats, politicians — have become involved in these many investigating bodies. They have quite properly turned to oceanographers for advice and information. This has resulted in an increased involvement of the Institution's staff in the national and international scene. Virtually every senior member of the staff has participated in committees and study groups outside the Institution. Many are on more than one such group. Our participation in these study groups has been rewarding in itself but, more importantly, has brought an awareness of the evolution through which oceanography is passing to staff members in an important and vital way.

The involvement of Institution personnel in external affairs has had implications far beyond the considerable amount of time involved. It has had a pronounced impact on our thinking and has provided an excellent basis for internal planning and action. Typical of this planning was a meeting, early in the year, of our Staff Council with Dr. Hudson Hoagland and Dr. Arnold B. Arons of the Executive Committee at which a new departmental structure for the Institution was designed. We believe this reorganization has enhanced our capability and efficiency in achieving our scientific goals. In addition to creating the Department of Ocean Engineering, we combined the theoretical and experimental groups in physical oceanography and amalgamated geology with the geophysics department. Each Department Chairman has undertaken a dual responsibility for the research and educational programs. This provides a sound basis for the integration for the two areas with the Institution's new responsibilities.

Dr. Nicholas P. Fofonoff's appointment as Chairman of the expanded Department of Physical Oceanography has not only promoted one of our youngest senior scientists but also has recognized his increasingly important leadership since joining the Institution's staff in 1961.

We are pleased that our extensive search for a chairman for the new Ocean Engineering Department has resulted in the appointment of Dr. Scott C. Daubin to our Scientific Staff. He comes to us with a wealth of experience, not only in science, but also in industry and in the United States Navy. His outstanding career as a physicist, submariner, marine architect and engineer will assist greatly in combining engineering with research in a fruitful way.

In the matter of appointments, I cannot resist reaching into the new year a bit. Just prior to this report going to press, Dr. H. Burr Steinbach accepted the appointment as Dean of Graduate Studies. The entire Institution — Trustees and Staff alike — are pleased by this appointment. It is a fitting culmination of the efforts of the *ad hoc* selection committee (Detlev W. Bronk, Chairman; Harvey Brooks, Paul M. Fye, Gordon J. F. MacDonald, Jerome B. Wiesner). Dr. Steinbach brings not only an enviable list of scientific, educational, and administrative accomplishments to the Institution, but he brings a great deal more. As Director of the Marine Biological Laboratory and long-time enthusiastic summer resident of Woods Hole, he has a unique awareness of Institutional and village relationships. We share fully his enthusiasm for interrelating the two neighboring institutions in new and vital ways. The excellence of our Graduate Educational Program is assured under Dr. Steinbach's leadership.

In the interim, until Dr. Steinbach's duties at the University of Chicago and his summer responsibilities at the Marine Biological Laboratory are completed, Dr. Kenneth O. Emery has agreed to serve in the capacity of Acting Dean. Dr. Emery is one of our most distinguished Senior Scientists and will provide excellent leadership during this important period.

The planning and work for our new responsibilities in education have been most extensive. Following the approval of the proposed charter modification by the Corporation in January, a comprehensive, written statement of plans was submitted to the Board of Higher Education. A committee of the Board visited Woods Hole in August as a part of a very thorough investigation. Acting on their unanimous recommendation, the Board approved the modified charter as shown on the frontispiece and it was signed by the Secretary of the Commonwealth in November. Thus, finally the Institution obtained the degree-granting authority which is essential to the educational program. Other planning went along concurrently. Courses were planned in the joint program with Massachusetts Institute of Technology. Instructors were selected, students interviewed, space was reshuffled and funds were sought. The cooperative planning with Massachusetts Institute of Technology has gone very smoothly. All of this has been most encouraging and rewarding.

During the year, two tenure appointments were made and fourteen Assistant Scientists joined the Scientific Staff while five members left the Institution. On the Technical Staff, we had eleven additions (one Research Specialist and ten Research Associates) and three terminations. Thus, the staff increased by nineteen and by the end of the year, the regular employment was 598 of which somewhat more than half (318) were in the scientific department.

Many important events have occurred in this year of continuing transition but to those of us in Woods Hole and to many throughout the world, the unhappiest indication of irrevocable change was the passing of our Founder-Director, beloved mentor and friend, Henry Bryant Bigelow. In the early days of the Institution, Dr. Bigelow personified Woods Hole to the world of oceanography, and in the days of its growth to full maturity his standards were the gauge against which we measured our achievements. I personally was not privileged to know Dr. Bigelow well until the last decade of his life. I remember my interview with him when I was trying to decide whether or not to accept the Directorship of the Institution. Without the confidence which that meeting inspired in me, I would never have had the courage to undertake this assignment. This was typical of the influence he exerted on students and of the impact his personality had on everyone who came in contact with him. The messages received from oceanographic leaders throughout the world stand as eloquent evidence of his leadership and of the affection with which he was held by everyone who knew him.

Great leaders inspire great events. The Woods Hole Oceanographic Institution owes not only its beginning but also whatever degree of success it has achieved, in large measure, to Henry Bryant Bigelow. Yes, his passing alone would make this a year of transition. In the ten years that I have been Director of the Institution, I have sought his advice on every major step that the Institution has taken. This is no longer available to us. His wisdom, advice, and charm will not be with us in the days ahead. Thus, we must all work even harder to measure up to the vision he always had for the Institution. Paraphrasing the closing remarks of Columbus Iselin in accepting the Bigelow Medal: "American Oceanography has had a fair wind ever since that day in 1901 when Henry Bigelow and Alexander Agassiz first set to sea."

Transition periods are often periods of soul searching and turbulence. Hence, these have not been relaxing and easy years within the Institution, but certainly they have been exciting and challenging ones. We continue to view the future with a great deal of confidence. The problems are many, diffuse, and difficult, but there can be little doubt that we will emerge from these years of transition with a stronger Institution, an enhanced capability in physical facilities and intellectual capacity. I am sure each member of the Institution has had a sense of participating in important and great events, and the satisfaction that comes from such participation.

PAUL M. FYE

Photograph taken from DSRV ALVIN made inside a school of Ceratoscopelus maderensis *at a depth of 600 meters near the 1000 — fathom line south of Woods Hole, 3 October 1967.*

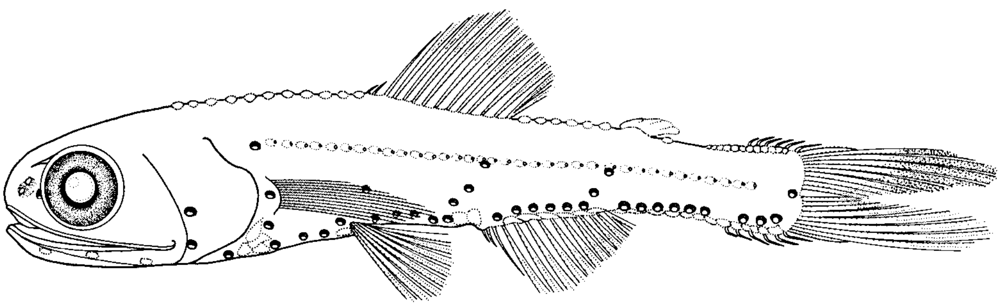
Department of Biology

Submarine Observations

In 1967, for the first time, members of the Biology Department were able to make appreciable use of ALVIN for scientific dives. For the most part, these missions were intended for orientation and reconnaissance purposes to familiarize the staff with marine life *in situ*, as a first step in the design of biological experimentation and survey work involving the use of the deep submersible. However, some immediate success was achieved by several investigators.

A new plankton fauna living just off the bottom was successfully sampled from ALVIN and is in the process of being described for publication. Macroscopic bottom fauna seldom captured by dredge or trawl because of its sparse and patchy distribution, was observed, photographed, and in some cases captured. Using techniques of aerial photogrammetry on the hundreds of Edgerton camera photographs taken on each dive, the density of these large animals living on the surface of the sediments could be plotted and quantitatively estimated for the first time.

Perhaps the most satisfying biological achievement with ALVIN was the positive identification of the peculiar sound-scattering layer commonly observed in the slope water of Eastern United States and referred to as "Alexander's Acres", the nature of which has long been a matter of speculation. Location of these sound-scattering sources by ALVIN's sonar and closing on individual targets revealed that they consist of dense and discrete schools of the lantern fish, *Ceratoscopelus maderensis*. Why the fish behaves in this peculiar way locally and why it does not school similarly in other parts of the ocean where the species is also common are questions which further submarine observation may help to explain.



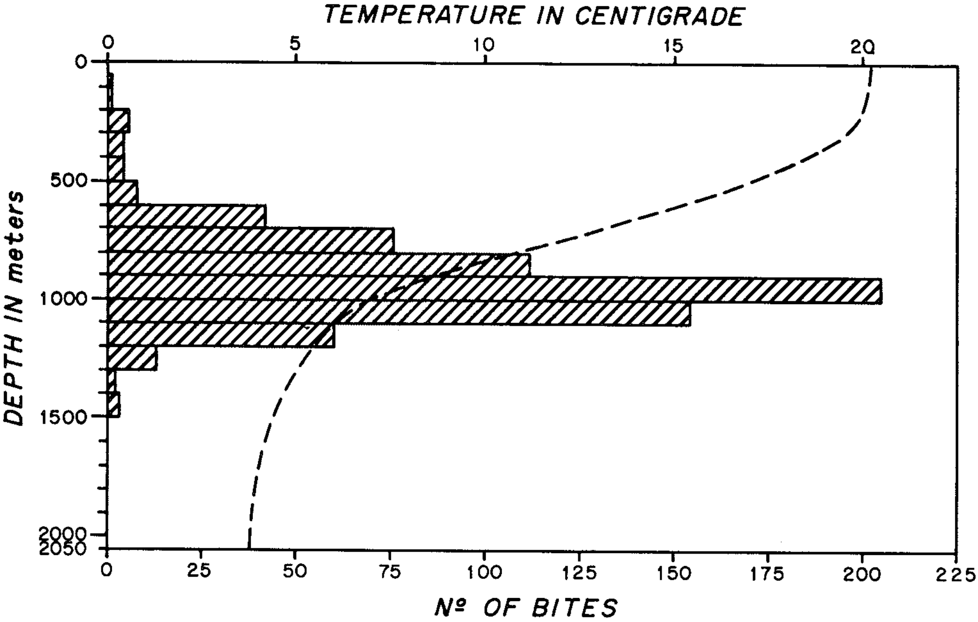
Artist's drawing of Ceratoscopelus maderensis.

Oxygen Minimum Layer

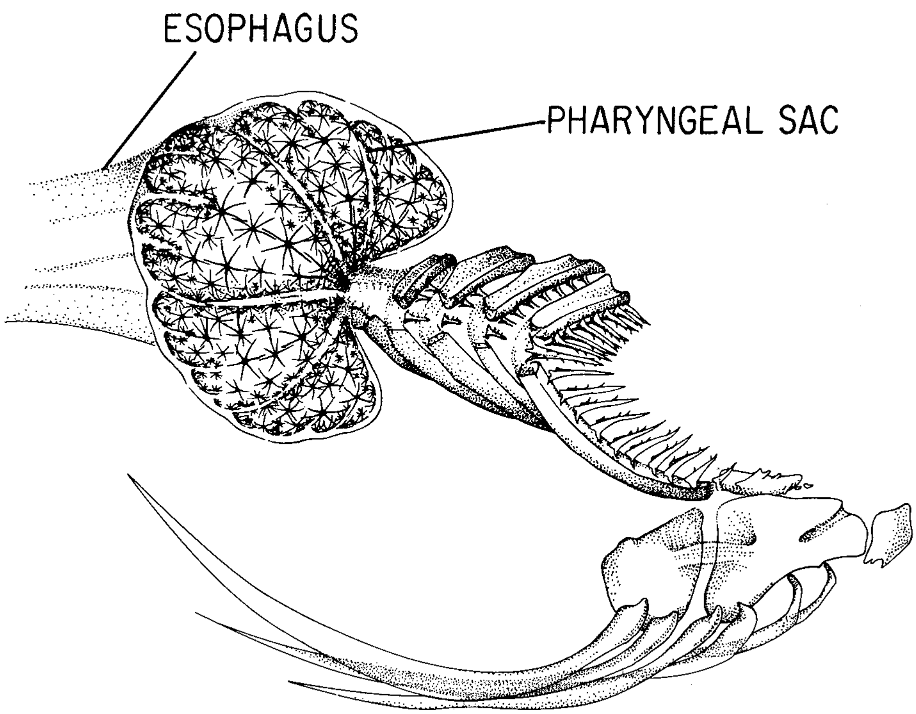
Our studies of the distribution of dissolved and non-living particulate organic matter in the deep sea have shed light on another long-standing oceanographic problem — the origin of the oxygen minimum layer. While the subject has been a matter of some controversy over the years, the prevailing view is that oxygen is slowly depleted from subsurface water masses through the decomposition of organic matter initially entrained in the water when it sinks from the surface as well as from particulate organic matter raining into the layer from the overlying surface. According to this concept, the oxygen is continually depleted and the oxygen minimum intensified with age and latudinal displacement of the water mass from its source of origin, the rate of depletion being most rapid in regions of high surface productivity where more organic matter rains into the subsurface layer. This theory appeared to be inconsistent with our observations that both dissolved and particulate organic matter are almost constant geographically and at all depths and are independent of both the oxygen concentration at depth and rate of organic production at the surface. This inconsistency was studied specifically on a north-south section in the South Atlantic during ATLANTIS II Cruise 31 from Recife to Buenos Aires. There it was found that the decrease in the oxygen content of the Antarctic Intermediate Water as it flows northward is caused by mixing with oxygen-poor water which presumably originates off the West African coast, in the highly-productive upwelling region, and moves across the Equatorial Atlantic and thence southward, overriding the Antarctic Intermediate Water. It is thus our tentative conclusion that formation of the oxygen-minimum layer of the sea is geographically restricted to a few areas of coastal upwelling and that the oxygen depletion takes place immediately after the heavy load of organic matter produced in these areas sinks or is carried below the euphotic layer. The subsequent distribution and attenuation of this oxygen-poor water is then accomplished by physical processes of circulation and mixing.

Pigment Studies

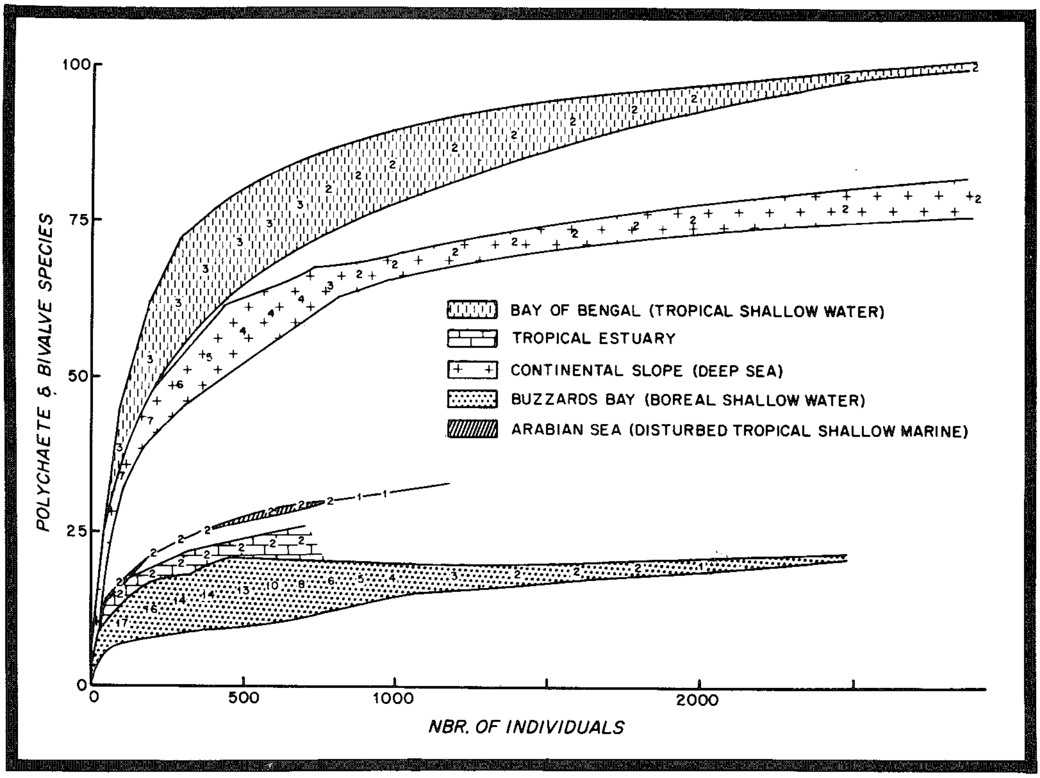
Other studies of the cycle of organic matter in the sea suggest that the decomposition products of phytoplankton pigments may provide a clue to the pathways of utilization of the primary organic production. Laboratory studies have shown that the magnesium-free chlorophyll derivatives, such as phaeophorbide, are not produced by natural death and/or bacterial decomposition of the phytoplankton, but are the



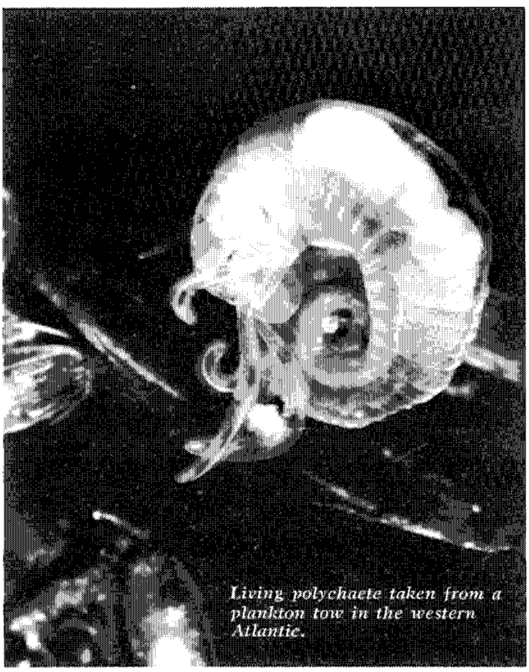
Frequency of bites of Sudis hyalina, *a fish, on polyethelene mooring lines at various depths near Bermuda from 10 June to 1 September 1965.*



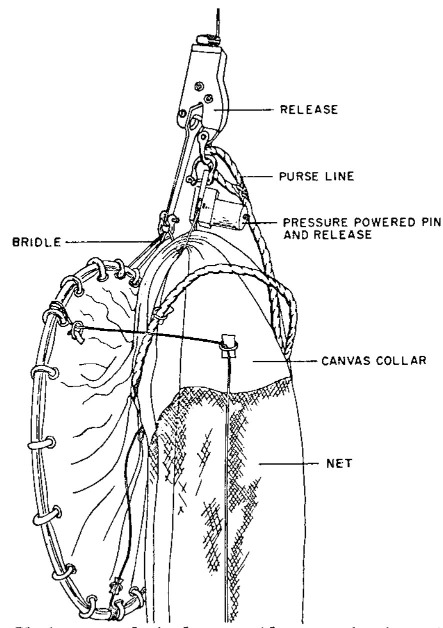
Branchial region of Nomeus gronovii *("Portuguese man-of-war fish").*



The diversity of polychaete and bivalve species in various habitats. The small numerals on the graph indicate the number of samples examined.



Living polychaete taken from a plankton tow in the western Atlantic.



Closing net devised to avoid contamination of deep plankton tows by organisms living in the shallower layers. It descends and ascends with the mouth closed.

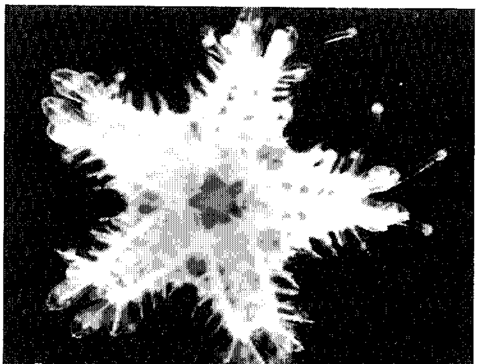
major pigment constituent of algal remains which have passed through the intestinal tracts of zooplankton. The relative proportion of chlorophyll and phaeo-pigments may therefore be used as an index of that fraction of primary production which is consumed by the grazing action of the herbivorous population.

Carbon Isotope Fractionation

For some time it has been known that plankton living in cold oceanic water have a lower ratio of the stable carbon isotopes $C^{13}:C^{12}$ than do those from warm water. This was initially thought to result from a temperature-dependent biochemical fractionation by the plants, but experiments have now shown that the fractionation is physical, temperature affecting the isotope ratios of the various components of the carbonate equilibrium system. Biologically, these experiments are significant in demonstrating that the carbon source of phytoplankton is predominantly dissolved CO_2 rather than bicarbonate, the isotope ratio in the algae reflecting that of the CO_2-fraction of the carbonate system.

Bacteriology

The heterotrophic behavior of marine microorganisms continues to be studied both in the field and in the laboratory, leading to an improved understanding of such important processes as rates of assimilation, efficiencies, and turnover times of representative organic compounds. Kinetic growth characteristics of marine bacteria under natural substrate concentrations have been measured by means of chemostat culture systems, making possible the quantitative estimation of natural rates of microbial transformations and interactions. For example, survival rates of terrestrial and polluting microorganisms in the sea have been shown to be influenced by competition for limiting nutrients as well as by direct bactericidal action by the indigenous microflora.


Recently metamorphosed sea star belonging to the genus Luidia.

Diving Physiology

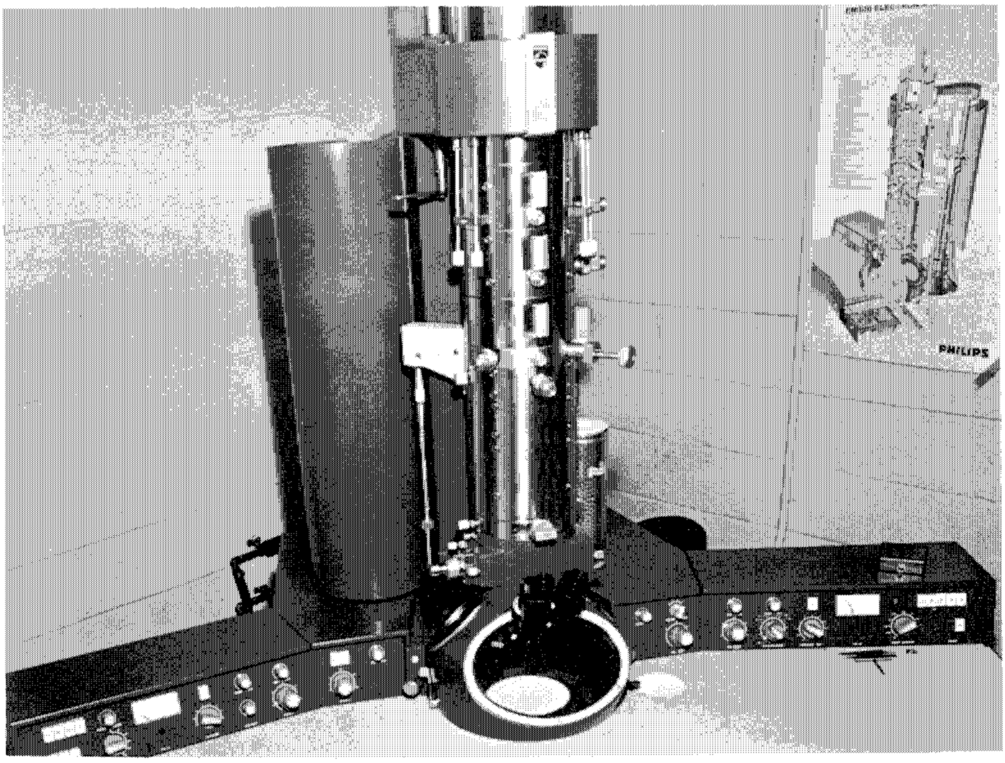
In the continuing study of animal and human diving physiology, it is now becoming possible to see why the true marine mammals such as porpoises and seals can do so much better in this respect than can man. Since both are air breathers, how long they can dive depends on how well they can stretch out the limited oxygen supply in their lungs and blood. An essential part of this oxygen saving in a porpoise consists of starving most of the body by cutting off its circulation. Only the heart and brain appear to get the same amount of oxygen as at the surface, the heart slowing down in the process by a factor of three- to fourfold.

In man, the heart also slows when diving but to a much less degree. It now appears that he does not have any significant ability to orient his circulation in the manner of marine mammals and thus increase the length of time he can dive.

Distributional Studies

Other studies during the past year in the Department of Biology have furthered our knowledge of the systematics, distribution, migration, means of dispersal, and general ecology of marine organisms. Specific groups which have been studied in this respect include the phytoplankton, copepods, benthic invertebrates and their larvae, mesopelagic fishes, and large pelagic game and food fishes.

JOHN H. RYTHER, *Chairman*



New electron microscope

Micrograph of a frozen-etched replica of Nitrosocystis oceanus.

Department of Chemistry

Radioelement Studies in the Oceans

This program, which is supported by the Atomic Energy Commission, has as its objective the use of the changing distributions of fallout radionuclides in order to understand the processes and rates of the transport of elements through the hydrosphere. Distributions of the stable elements and of some naturally produced radionuclides are also studied as needed to clarify the questions raised by movement of fallout nuclides through marine organisms, sea water and bottom sediments.

Radionuclides have also been examined in over-ocean aerosols collected intermittently from the Atlantic Ocean from 1964 to 1966. Although the mean over-ocean concentration between 40°N and 0° did not differ significantly from that over land, month to month comparisons within 10° latitude bands have shown significant differences. Over-ocean aerosols from 20° to 30°N have been lower, but those from 0° to 10°N higher in fallout radionuclides than corresponding over-land collections. Fresh debris from the May 1965 Chinese test was collected over the ocean above the equator at the same time that it appeared over England, although it was never seen over equatorial land stations, and not even over the northern Caribbean islands till much later. Differences in the beryllium-7 to cesium-137 ratio over the ocean also seem to confirm a special fallout delivery mechanism over the tropical Atlantic, not seen over land. Ratios of fallout radionuclides do not indicate any discrimination among the various elements represented in marine aerosols.

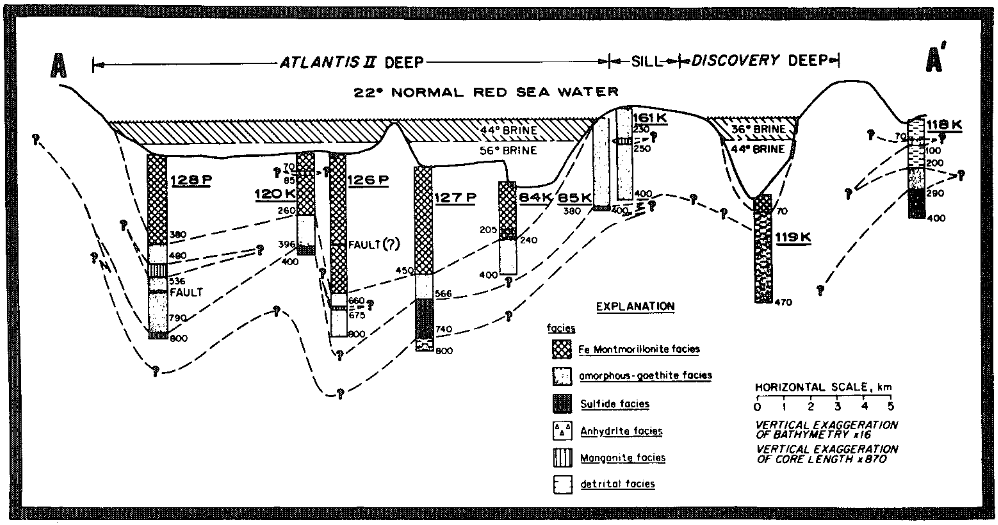
In sea water strontium-90, cerium-144 and promethium-147 have been analyzed routinely and cesium-137 occasionally; in addition to samples collected on our own cruises both at the surface and at depth, samples have been collected on regular schedule from the North Atlantic weather ships, those operated both by the United States and by various European countries, and from various merchant ships and local fishing boats. When this body of surface-water data was averaged by 10° latitude bands and by year, it showed the degree to which strontium-90 concentrations must be controlled by downward mixing and by convection. Between 1961, the last year of the bomb-test moratorium, and 1964, the peak of over-ocean fallout from the 1961-1962 atmospheric tests, surface-water concentrations increased threefold or more in the bands between 30°N and 70°N, and about twofold between 30°N and 10°S, the southern limit of adequate sampling. The rate of fallout decreased after 1964; by 1967 concentrations in the bands from 70° N to 40°N and from 30°N to 10°N had fallen to less than the 1962 values; only in the band 40°N to 30°N was the 1967 concentration still well above that recorded in 1962. During this period when all surface concentrations north of 10°N showed large decreases, areas south of 10°N showed no corresponding increases; this indicates that the Sr-90 lost from the surface must have disappeared to deeper in the water column. Although a dispute persists over the significance of the very difficult analysis of Sr-90 in deep water, below 1000 m, the concentrations found between the surface and 700 m are readily measurable. Since these do not show a systematic increase to balance the decrease seen in the surface concentrations, we take this to confirm that the small concentrations of Sr-90 often found in the Atlantic at depths from 1000 m to 5000 m are real.

The thirteen stable lanthanide elements and yttrium have been measured in a considerable number of Atlantic samples. The concentration ratios among the lanthanides are characteristic of the various water masses: North Atlantic Deep Water samples exhibit a uniform lanthanide pattern in samples from 16°N to the equator and this same pattern occurs in bottom water from the eastern basin; Antarctic Intermediate Water and Antarctic Bottom Water exhibit statistically different patterns, which also differ from each other. Except in the very shallow Barents Sea, all the water patterns are unlike those which characterize both modern and ancient marine sediments. The uniformity of lanthanide patterns over such wide areas in individual water masses indicates longer lanthanide residence times than have been estimated indirectly. We believe the lanthanide concentration patterns are controlled by complexing of exometabolites of the plankton populations which characterize the source regions for various deep water masses.

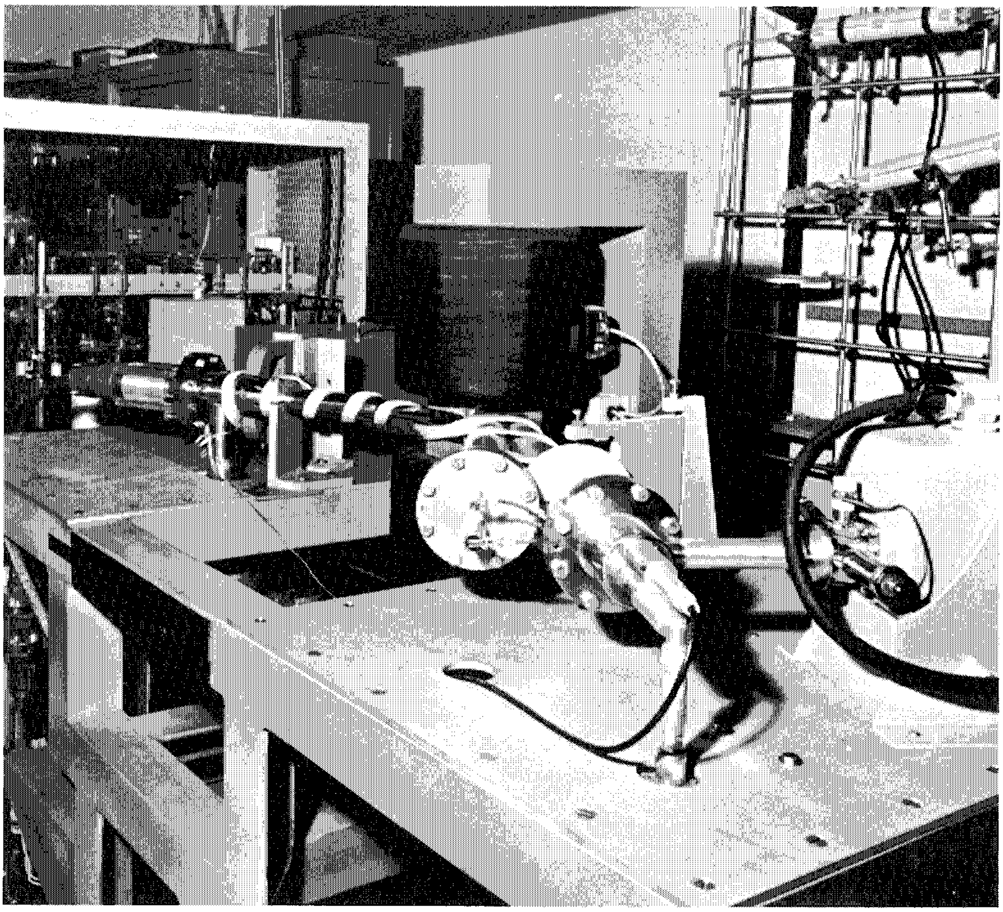
Using lithium-drifted germanium detectors to minimize chemical processing after neutron activation, the stable lanthanide patterns of marine corals are being determined. Comparison of modern coral patterns with those determined for the water masses they inhabit will confirm whether corals may be used as paleontological indicators of water lanthanide patterns, or whether uptake by corals may be significant in determining these lanthanide patterns. Preliminary data for La, Ce, Sm, Eu, Tb, Yb and Lu among the lanthanides, and for Sc, Fe, Co, Zn, Cr and Ce have shown large differences in trace element content between shallow water corals from the open ocean and a typical near-shore species. Analyses of the residue after dissolution of the carbonate matrix indicate much of this difference is produced by incorporation of suspended matter from the corals' environment.

Studies of the elemental composition of marine plankton species are continuing. Twenty-six elements were analyzed on mixed collections of phytoplankton and on single species representing the Phaeophyceae (*Sargassum*), the coelenterates, ctenophores, molluscs, Crustacea, tunicates and chaetognaths. These are the first data available for many species over a wide spectrum of elements. The results indicate a wide and varied range of concentrations between phyla and between classes within the same phylum. The original prediction that for any given chemical element there will eventually be found at least one planktonic species capable of spectacularly concentrating it is not invalidated.

Detailed surveys have continued of the Mid-Atlantic Ridge. In the vicinity of 43°N a segment of "normal ridge" was found with the heat-flow in the central valley little higher than in valleys east or west of the Ridge axis. Fresh basalt was recovered from the slopes, and magnetic linearity was well developed. An adjacent section of "disturbed ridge" was also surveyed where the whole plane of the ridge (over three degrees of longitude or more) had been tilted. It did not show the marked lateral displacement of the Ridge axis characteristic of fracture zones. Heat flow was unusually high in the central valley, magnetic linearity was not apparent and only serpentinized peridotite was recovered from the slopes. Surveys of the Vema Fracture Zone (near 11°N) have shown that the sediment fill of the Fracture Zone valley must have accumulated over a long period of seismic inactivity, indicating an interruption of some millions of years in sea-floor spreading at this point on the Ridge. The southern wall of the Fracture Zone was found to be a high, steep, narrow wall of rock, extending more than four degrees of longitude from east to west and containing both serpentinized peridotite and basalt,



Geologic cross-section through Red Sea hot deeps showing mineral facies.



Mass spectrometer for determination of stable isotopes of carbon and oxygen.

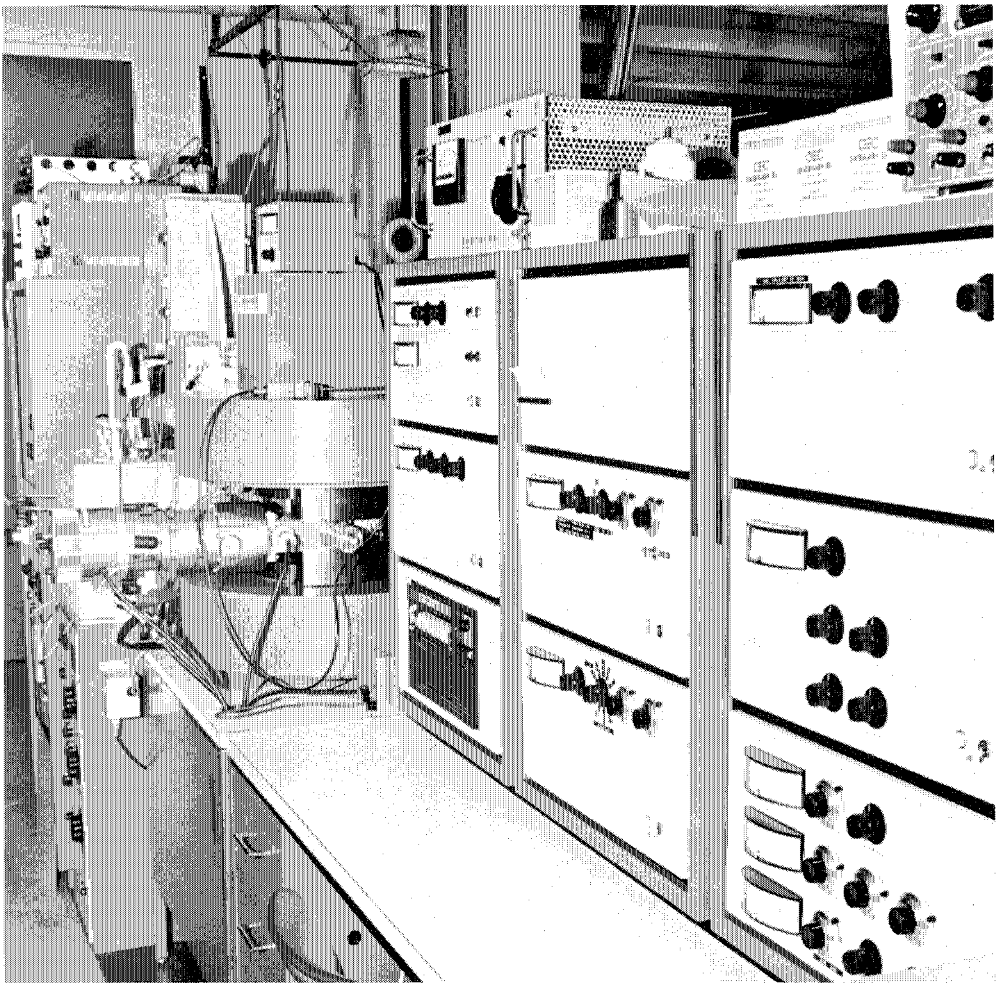
the basalt being from the uppermost slopes. A high nepheline-normative basalt was dredged from the flanks of the St. Paul's massif, possibly the first ever found that is not associated with a large tholeiitic volcanic pile. Dredging along the Ridge in general has recovered large amounts of carbonate sediments ranging from loosely consolidated foraminiferal or coccolithoophorid oozes, to well-lithified oozes, tuffaceous limestones, recrystallized calcite, and massive dolomite. The frequent close association of carbonate rocks of obviously very different histories of sedimentation suggests that carbonate lithification on the sea floor depends on very local variations in the chemical and physical environment.

Red Sea

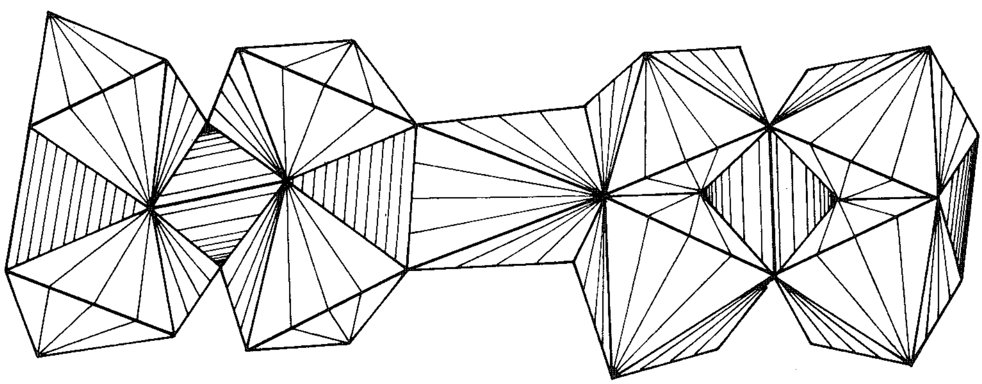
The major part of the geochemical program was concerned with the analysis of samples obtained on the Red Sea cruise of CHAIN in the fall of 1966. A bathymetric chart of the area was prepared from over sixty traverses of the deeps and used to guide the research program. Determinations of the true salinity of the brine samples were made gravimetrically and, in addition, some ions were analyzed individually. These results combined with the temperature data indicate that the DISCOVERY pool has been gradually cooling and losing its brine over the period from 1944 to 1966. This strengthens the concept that the source of hot brines and heavy metals is the ATLANTIS II Deep and the DISCOVERY hole is a spill-over area. This is further verified by the higher concentration of brine deposits and unusual minerals in the ATLANTIS II hole as compared with the DISCOVERY Deep. Cores from the former contained 95% brine deposits and 5% detrital-pelagic debris compared with about 50/50 in the DISCOVERY Deep. The brine precipitate, which ranges in particle size from 2 to 62 microns, is largely amorphous iron hydroxide with goethite, lepidocrocite, and limonite. The uppermost deposits in the ATLANTIS II hole contain a previously undescribed iron montmorillonite, while the lower sections contain sulphides (sphalerite, pyrite, chalcopyrite). The carbonates rhodocrosite and siderite are also present as well as the oxides manganite, todorokite, and hematite. Hematite, which is believed to form under more elevated temperature conditions than goethite, was found in one core only. Its presence suggests a possible close proximity to the source of the hot brines. The mineral precipitation is believed to occur through (1) cooling of the subterranean brine as it comes up through the ATLANTIS II Deep to yield sulphides and silicates and (2) mixing of the brine and overlying sea water with the resultant oxidation of iron and manganese and their precipitation as oxides and hydroxides.

Analyses of the heavy metals in the sediments showed wide variation with many of the deeper sulphide samples containing 3% of copper and zinc on a dry weight basis. A preliminary estimate of the value of the copper, zinc, silver, and gold in the first ten meters of the ATLANTIS II deposits indicated that 130 million tons of the dry salt-free ore has a value of 1.5 billion dollars. The economics of recovering such ores is unknown, however, because there are no mining procedures for handling such watery sediments at great depth. Each cubic meter of bulk mud in the first ten meters contains only 250 kg of salt-free dry solids.

Oxygen and carbon isotope analyses of fossil Foraminifera and pteropods from the hot-brine deeps and surrounding sea floor of the Red Sea show considerable fluctuations in both O^{18}/O^{16} and C^{13}/C^{12} ratios with depth in all cores. Comparison of foraminiferal tests from inside and outside the deep showed that isotopic exchange between the tests and the hot brines is taking place and that the hot brine has been



High mass spectrometer for organic chemistry.



Hydrated triphosphate, illustrating the formation of metal ion polyhedra.

present, at least intermittently, for the last 10,000 years. Pronounced changes in the O^{18}/O^{16} ratios show at least three cycles of slowly increasing and then rather abruptly decreasing values. These cycles have been tentatively related to the glacial periods through C^{14} dating.

It appears that the periodic drop in sea level resulted in periods of evaporation and increase in salinity of the Red Sea with corresponding changes in the fossils now found in the sediments.

Geochronology

An alpha-counting laboratory has been set up for the study of the longer-lived nuclides in the naturally occurring radioactive decay series. The laboratory has a 512-channel analyzer with readout and spectrum stripping modules for measuring U^{238}, U^{234}, Th^{232}, Th^{230}, Th^{228} and Po^{210}, and a low alpha background flow-type proportional counter for measuring Pa^{231}.

Th^{230} and Pa^{231} are rapidly removed from the solution and are found greatly concentrated relative to the parent uranium in deep-sea sediments. The evidence for varying ocean climates recorded in the sediments can thus be dated by the amount of unsupported Th^{230} and Pa^{231} remaining in various layers of sediment. On the other hand, the uranium, found in sea water practically free of its daughter products, is commonly incorporated in carbonate secreting organisms and in inorganically precipitated carbonates. These fossil carbonates are then dated by the extent to which Th^{230} and Pa^{231} have returned to equilibrium.

A tentative time scale for sea-level fluctuation and climatic variation on the earth in the last 200,000 years has been obtained from Th^{230}/U^{234} and Pa^{231}/U^{235} dates on fossil corals from the elevated reef terraces of the Barbados Island, West Indies. Current geochronological investigations on sediment cores taken from the Red Sea are expected to yield valuable information regarding the Quaternary history of the area. In view of the importance of the two radium isotopes, Ra^{226} and Ra^{228}, as oceanographic tracers, development of techniques for solid source radium spectrometry will be sought.

Interstitial Water Studies

Water squeezed from cores taken through 1000 feet of sediments in the Gulf of Mexico were analyzed for Cl^-, pH, buffer capacity, and major ions (Na, K, Mg, Ca, So_4, and Sr). Data show that for the two holes drilled above inferred salt diapirs, Cl^- increased continuously with depth. Projection of Cl^- to estimated depth of cap rock shows a close approach to NaCl saturation. The remaining three holes showed no such increase. Thus, dissolved salts seem to be streaming off the dome and diffusing through clayey sediments with a facility not previously appreciated. Increase of K/Cl ratio on one of the salt diapir holes suggests the presence of sylvite (KCl) in the cap rock, an occurrence not reported for the onshore cap rocks in the area. For all the holes a general inverse relation was noted between SO_4 concentration and buffer capacity, indicating the activity of sulfate-reducing bacteria.

Carbon Isotopes

The equilibrium distribution of the stable isotopes of carbon, C^{12} and C^{13}, in the marine environment is being studied as part of our effort to interpret C^{13}/C^{12} relationships between plankton and sea water. It was found that dissolved CO_2 is isotopically identical to atmospheric CO_2 and that the hydration of CO_2 to form bicarbonate results in an enrichment in C^{13} of 9 to 7 parts per thousand over the temperature range 0 to 30°C. Marine plankton becomes depleted of C^{13} relative to sea water by 1 to 3% due to the photosynthetic process in the plankton. Factors such as pH, temperature, and the carbon dioxide available in the sea water affect this depletion: In general, plankton living in warm waters with a high pH show the smallest C^{13} depletion, while plankton in cold waters with a low pH show the most.

An investigation of the C^{13}/C^{12} ratios of dissolved inorganic and organic carbon in sea water has been initiated. The purpose is to detect changes with depth and to look for differences between water masses. A good correlation has been found between the C^{13}/C^{12} ratio and the dissolved oxygen concentration, especially in the region of the oxygen minimum layer. The results to date indicate that a few per cent of the carbon in the bicarbonate at the depth of the oxygen minimum are of organic origin, derived from the decomposition of biological detritus.

Organic Compounds

Studies are continuing on the dispersal of organic compounds through the marine food chain, the sea, and the sediments underneath. A simple and rapid survey technique has been developed for the analysis of the hydrocarbons of marine plankton and fishes. This has been applied to a preliminary survey of the hydrocarbons in mixed zooplankton samples collected from Cape Cod to about 45°W. Samples taken nearshore show the typical hydrocarbon distribution found in *Calanus*. The transition to other faunas, however, results in a marked decrease in pristane and a corresponding increase of olefinic hydrocarbons.

The lipids of copepods, cod, basking sharks, and tuna have been examined for fatty acids. Several new homologous series of saturated and olefinic branched fatty acids have been discovered and their structures are currently being investigated.

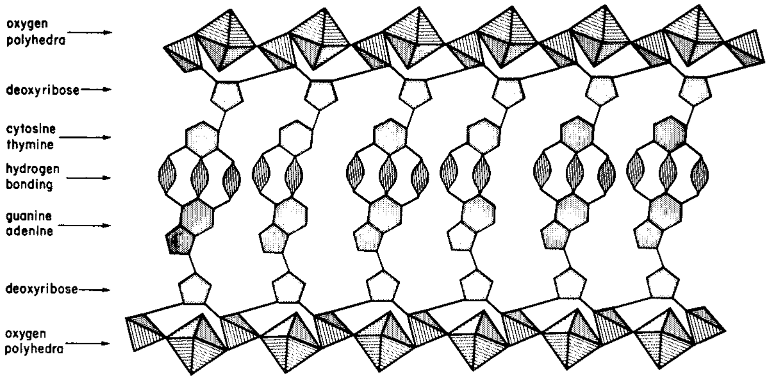
The metabolism of phytol in *Calanus* has been examined in co-operation with investigators from the National Institutes of Health. A terpenoid alcohol is converted either by the crustacean or by its intestinal bacteria to phytanic acid. Subsequently, pristane is formed by decarboxylation of the acid.

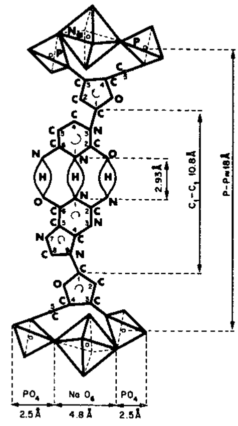
Phytanic acid, pristanic acid, and 4, 8, 12-trimethyltridecanoic acid have been isolated from three recent marine sediments. The ratio of palmitic to pristanic acid is similar to that encountered in typical marine lipids. This suggests a biochemical origin of these sedimentary acids; phytol is their presumed biochemical precursor. Other isoprenoid acids between C_{11} and C_{22} which are common in ancient sediments have not been found. They are probably geochemical products formed slowly and at a greater depth.

The presence in recent sediments of singly branched (iso- and anteiso-) fatty acids is of considerable interest because of their possible role as precursors of the branched paraffins in ancient sediments and crude petroleum. Also, these acids are commonly formed by bacteria and may well provide a marker for the bacterial contribution to the sedimentary lipids.

Earlier investigators had isolated but only partly resolved C_{12}–C_{18} iso- and anteiso-acids. With improved gas chromatographic substrates we now have resolved the iso- and anteiso-acids from C_9 to C_{21} in three not previously studied recent environments.

We have installed a high mass spectrometer through support of the Office of Naval Research. The combination of this instrument with a gas chromatograph enables very complex samples to be separated into their components. The data obtained are often sufficient for complete structural identification without further processing. We anticipate that this will save many man-hours of time in the identification of organic compounds isolated from organisms, sediments, and sea water.





Schematic model of DNA showing metal coordinated phosphate groups.

Organic Structures

An attempt was made to determine if mineral matrices participate in the synthesis of organic compounds under natural life conditions. About sixty different minerals comprising representative members of silicates, oxides, phosphates, carbonates, and sulphates were treated with amino acids. It was found that during reorganization of the mineral phase (e.g. dehydration, recrystallization, and mechanical abrasion) the coupling of amino acids occurred to yield polypeptides with molecular weights ranging up to 10,000. Hydrolysis of these polymers resulted in the total recovery of the original amino acids.

From these and related investigations, the hypothesis has been developed that biochemical compounds tend to build up in a biocrystallographical order due to the close association of oxygen co-ordinated metals in the systems. For example, the oxygen in PO_4 tends to associate itself with metal ions and to fabricate an oxygen polyhedron introducing a crystallographical order to the DNA molecule. This may explain why a single-stranded DNA can associate with another single-stranded DNA resulting in a double helix, but it cannot couple with itself by looping. Current work is aimed at forming additional well-ordered organic structures on mineral templates by gel filtration and electrophoretic techniques. The products will be analyzed by high resolution mass spectrometry and electron microscopy. The objective is to determine how metal ions become co-ordinated with the various organic molecules.

Sea Water Chemistry

The distribution of Fe, Cu, Zn, Co, Ni and Pb has been determined in waters from the Gulf of Maine and in sections across the Gulf Stream. All the measurements have been made with filtered water (0.45μ) using a solvent extraction procedure followed by atomic absorption spectrophotometry. It has been found that trace metal contents show little direct relationship, either on a diurnal or on an annual basis, to the level of plant nutrients. Deep water in the Gulf of Maine appears to have relatively constant amounts of elements throughout the year. Surface waters close to shore have significantly higher concentrations of trace metals during the summer. Atlantic Slope Water has higher levels of Cu, Zn and Ni than both the Gulf Stream and Sargasso Sea Water. These differences appear to be maintained throughout the year. Slope Water trapped in the center of an isolated Gulf Stream eddy maintained its higher contents of Zn and Cu over a period of 7 months.

A submersible pump capable of filtering 100 liters per hour of sea water *in situ* at any depth was constructed. The pump forces a split sample of the total particulate matter suspended in the water. Examination of the suspended matter in the Gulf of Maine showed that there is a zone of high concentration from 50 to 10 meters above the bottom where the particulate matter is five times that found in near-surface water. Elaborate precautions were taken so as not to stir up bottom sediments with the sampling gear. Near-surface concentrations of particulate matter were found to be relatively uniform, whereas near-bottom concentrations varied with topography and location. Ashing of the product at 500°C showed that 90% of the near-bottom material is refractory compared to only 15% of the near-surface material. Mineralogy of the particulate matter appeared to be related to that of bottom-sediment samples obtained nearby.

An improved method for detecting small differences in the relative proportions of major ions of sea salt has been developed. The technique known as "difference chromatography" involves passing the sample through a thermostatic ion exchange column preceded and followed by a standard known sea water of closely similar salinity. The differences between the sample and the standard emerge as a series of fronts or waves which are detected by a highly sensitive membrane salinometer. For example, the method is capable of detecting an addition of 5×10^{-8} equivalents of K^+ to a 2 ml sample of sea water. The method will be applied to further our understanding of the processes which determine the chemical composition of sea water.

Nuclear magnetic resonance studies of water-electrolyte and water-nonelectrolyte interactions in solutions are continuing. PMR (Proton magnetic resonance) chemical shifts of the water protons have been measured as a function of salt concentration for eleven pure salt systems. Measurements were made relative to four internal, and an external standard. The non-linear dependence of chemical shift on salt concentration has been accounted for on the basis of an overlap of the polarizing influences of neighbor ions in solution. These measurements also provided some information on non-electrolyte–salt interactions. In the absence of salt effects on the chemical shifts of the non-electrolytes (CH_3CN, CH_3SOCH_3, $t\text{-}C_4H_9OH$) used as internal references, identical water shifts should be observed against each of the references. In fact, the observed water shifts are always different for the three, but the three sets of data form a relatively constant pattern independent of salt identity. This is the result of salt-induced shifts of the references. A published explanation of the discrepancy between internally and externally referenced shifts in salt solutions was tested using these data and others involving a variety of reference structure variations. Neither that model nor any we have devised account for all of the observations, though many of them can be rationalized as proceeding from specific chemical interactions.

Measurements are being made on systems in which the solubility of an organic non-electrolyte has been enhanced by the presence of an organic salt. Such solutions are of two kinds. In those containing long-chain organic salts there is good evidence that the non-electrolyte is solubilized in the interior of micelles whose structure is fairly well known. In solutions of short-chain salts, the salting-in mechanism is poorly understood. Our work of last year indicated the importance of specific, short-range organic ion–nonelectrolyte interactions. PMR spectra of such solutions will be made to yield structural information to complement our thermodynamic results.

JOHN M. HUNT, *Chairman*

Department of Geology and Geophysics

The Department of Geology and Geophysics carries out investigations concerning the past, present and future structures of the ocean floor using many oceanographic techniques. Direct sampling, thermal acoustic, magnetic and gravimetric methods provide most of our field measurements. The correlation of the laboratory analysis of bottom samples with interpretation of the field studies result in our description of the present ocean floor. Extrapolation of this description to the past and future is based on the laws of physics and chemistry. The record of the past is often reasonably defined by paleo-biological and physical structure which allow the dating of the sea floor sediment and rocks. Despite these powerful techniques which can be used to study the ocean basins our detailed knowledge of the sea floor is so small that rather broad assumptions must be made in describing various sea-floor provinces and their relations with each other. Fortunately, recent studies are clearly indicating that the morphology and structure of these provinces are not independent of each other. We are presently carrying out investigations on an ocean-wide basis in an effort to relate these various provinces by a unified model of ocean basin structure and history.

Continental Rise and Shelf

During the year a synoptic geophysical investigation of the continental rise from the Grand Banks of Newfoundland to Cape Hatteras was accomplished. About 8000 kilometers of continuous profiles of bathymetric, seismic reflection, gravity and magnetic measurements were obtained aboard CHAIN. These data combined with similar previous data and with stratigraphic information from dredging, piston cores, JOIDES holes off Florida, oil wells ashore and seismic refraction velocities will be used in determining the structure and possible formation processes for the rise.

Continental rises are the largest sedimentary feature of any depositional units of the world. They are related in some presently unknown manner to the growth of continents. Most marine geologists have believed the continental rise to be a depositional feature akin to coalesced alluvial fans ashore, but deposited largely by turbidity currents. The hypothesis has recently been presented that the rise may owe its shape to the redistribution of sediments by currents that flow parallel to the bottom contours. Information about the source, direction of movement and places of deposition of the coarse grained components may be obtainable from interpretations of continuous seismic profiles made over large regions.

Seismic refraction data provide good information about the regional variation in the thickness of the Tertiary strata inshore of the continental rise. Since the sediments of the continental rise lap onto Upper Cretaceous strata of the continental slope and lie above the Upper Cretaceous strata referred to as Horizon 'A' in the deep ocean, the major part of the continental rise off eastern North America appears to be post-Cretaceous in age.

In the preliminary analysis of the data the basement structure and the family of reflections related to Horizon 'A' have been traced under the rise and slope with tentative ties to onshore well data and to previous refraction data. Generally the composite of reflectors making up Horizon 'A' and the sediments above and below are flat, suggesting that the rise from Nova Scotia to Cape Hatteras has been stable since pre-Cretaceous time.

Abyssal hills on the Hudson Fan appear to result from down slope slipping of material, possibly of Pleistocene and later age.

Correlations of the seismic profiles with gravity and magnetic observations indicate that some of the unusual internal relief observed in the structure of the rise off Nova Scotia may be due to sediment slumping rather than to intrusion. A detailed survey of the lower continental slope and upper rise off Block Island and Rhode Island suggests that slumping and gravitational sliding have also played a significant role in molding the present surface morphology of that area.

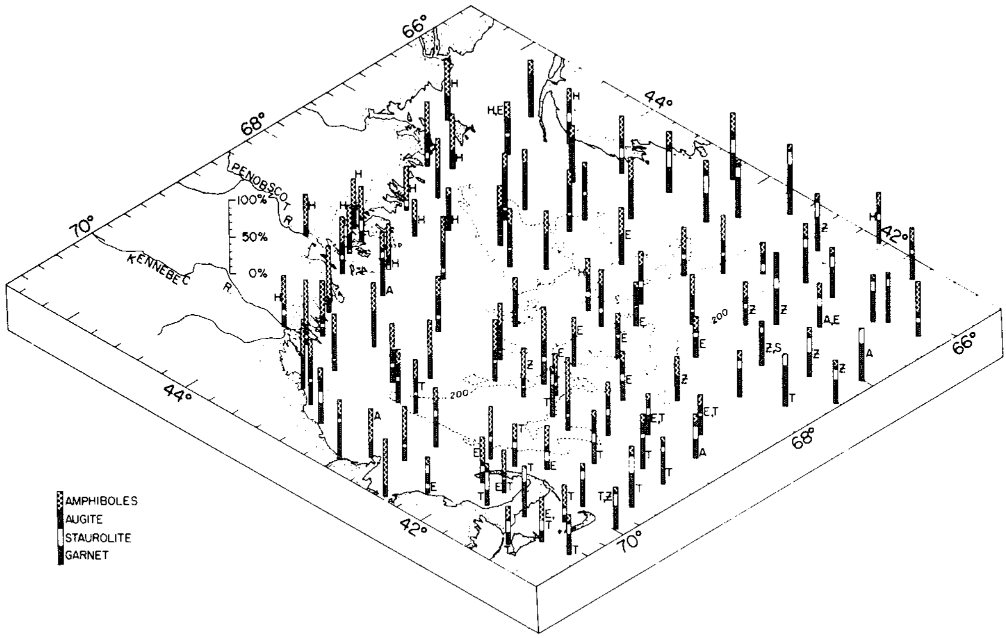
The geological literature contains speculation about the rates of erosion of the continents, based chiefly upon the annual load of suspended sediments discharged by streams and rivers. Attempts have been made to verify the estimates by using the volume of sediment deposited on the sea floor during a given time. This has been done for areas where sufficient seismic profiles have been made. However, the lack of information on the relative amount of detrital sediment as compared to the biogenic sediment coupled with the somewhat limited measurements of sediment thicknesses on the continental rise cause rather large uncertainties in the estimated erosional rates.

Sediments along the eastern coast of the United States are derived from a variety of sources and are subjected to reworking by currents and biological activity. The shelf sediments along the southeastern United States have been reworked by ocean bottom circulation to a nearly uniform grain size (medium to coarse sand). Beyond the continental shelf near the western edge of the Blake Plateau a narrow belt of comparatively fine (silt size) biogenous sediment at least 200 miles long occurs. This accumulation lies along the seaward margin of the Gulf Stream axis where the westerly flowing Antilles Current meets the northerly flowing Gulf Stream.

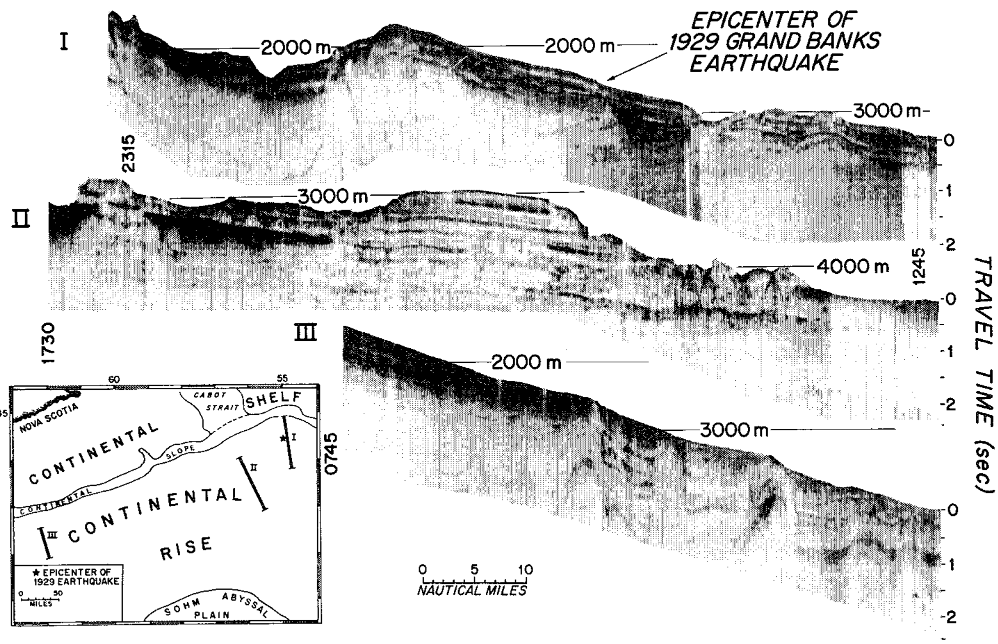
The sediments of the shelf from Nova Scotia to Cape Hatteras contain less than 5% calcium carbonate by dry weight. However, south of Cape Hatteras the concentration generally exceeds twenty percent. The concentration increases near the shelf edge and increases to more than thirty percent on the rise and the Florida-Hatteras slope.

The clay minerals carried by rivers of the east coast show a systematic variation with location. Kaolinite decreases with increasing latitude and chlorite is important only north of 40°N. Mica tends to vary inversely with kaolinite. Montmorillonite occurs in rivers originating within the coastal plains. Samples dredged from the canyons along the northeastern shelf show a correlation with stratigraphy. Samples of Cretaceous and Tertiary age tend to contain either montmorillonite or kaolinite with calcite, clinoptilolite or opal; whereas, samples of Late Tertiary-Quaternary age tend to contain chlorite and mica with various amounts of feldspar.

The continental shelf sediments are composed mainly of quartz, with supporting amounts of feldspar and rock fragments and lesser percentages of heavy minerals. Gravel is found along the eastern continental margin but most of it is in the Gulf of Maine, Scotian Shelf and the northern part of Georges Bank. Its areas of abundance are related to Pleistocene glaciation, which has shaped the topography and dispersed much of the gravel. The sorting of the gravel is related to the tidal currents to which it has been exposed, varying considerably from area to area. Interpretation of the gravel distribution allows us to fix approximate limits of glaciation on the continental shelf, interpret the bedrock geology of the Gulf of Maine and the Scotian Shelf and determine the agents that dispersed the gravel.



Mineral composition of the sand fraction of the sediments in the Gulf of Maine and Georges Bank.



Continuous seismic profiles of the continental rise off the Grand Banks and the Scotian Shelf.

Marine Geophysics

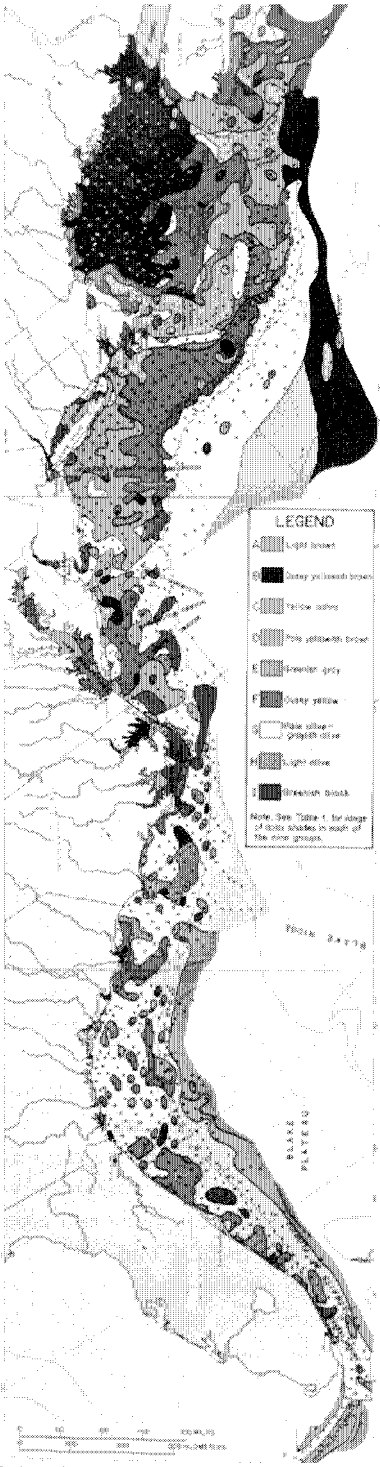
A two-month geophysical cruise aboard CHAIN to the Caribbean Sea area provided new information about the sea floor structure adjacent to the Puerto Rico Trench. Five geophysical sections were made across the Lesser Antillean Arc including profiles of continuous seismic reflection, magnetics and gravity. These sections extended from west of the Aves Ridge to east of the Puerto Rico Trench and Barbados Ridge. This cruise also included two profiles out to the Mid-Atlantic Ridge and a detailed study of the ridge crest.

The Aves Swell is a feature composed of both a broad swell and buried ridges of acoustically opaque material covered by layered sedimentary material. The latter generally occur on the western flank, but in the south where the swell is wider they occur on both the east and west flank. Weathered volcanic rock was dredged from a rugged ridge on the west flank at the northern end of Aves Swell. The Grenada Basin lies between the southern part of the Aves Swell and the Lesser Antilles. This basin contains a thick sequence of flat lying sedimentary material which laps up over sedimentary material on the east flank of the Aves Swell and possibly on the west flank of the Lesser Antilles Bank. A topographically low area lying between the northern part of the Aves Swell and the Lesser Antilles Bank is underlain by a disturbed sedimentary sequence continuous with that on the Aves Swell.

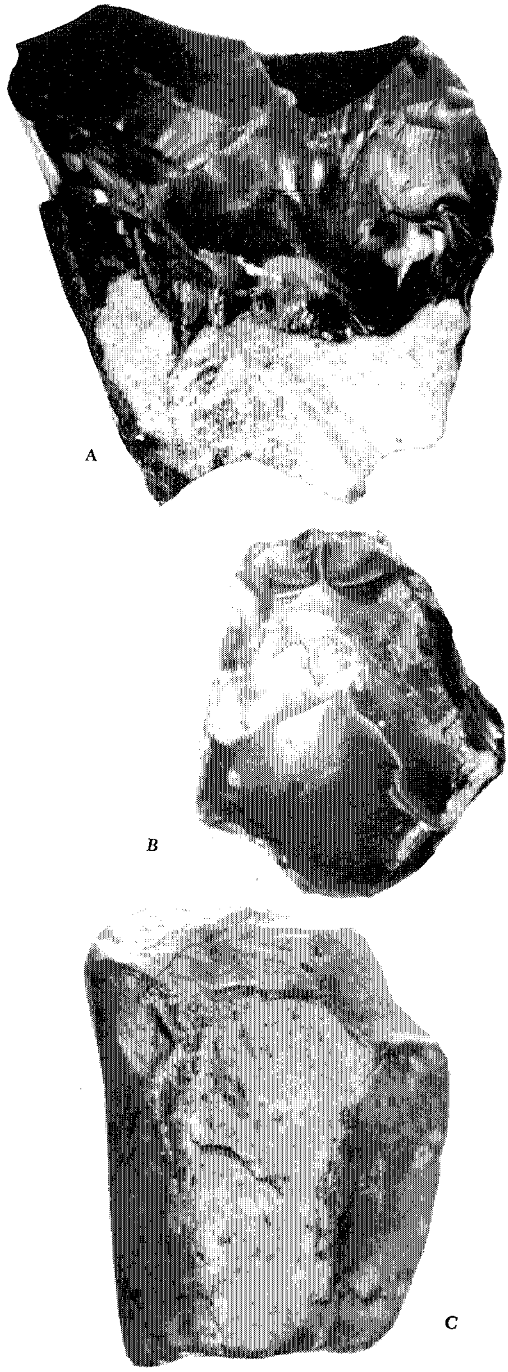
Heat flow measurements this year have centered for the most part over the Mid-Atlantic Ridge in an area near the ridge crest at 11°N which includes a major transverse displacement of the crest by the Vema Fracture Zone. Two profiles from the Lesser Antilles to the ridge were made north of the Vema Fracture Zone, and a long profile from England to Canada crossed the ridge at 43°N. Large variations in the heat-flow values were observed near the ridge crest on all cruises. It is probable that the lowest values represent a non-equilibrium condition rather than a source distribution effect.

Magnetic field studies near the ocean ridges strongly support the concept of sea floor spreading. Our work near 22°N, 27°N and 44°N indicates that the spreading near 22° and 27°N has been rather similar, showing some differences in rate with time. Near 44°N the symmetrical north-south magnetic trends characteristic of sea-floor spreading regions disappear, being observed in only the two southernmost of the five transverse profiles between 43° and 45°N. The southernmost profiles contain a well defined central rift valley while the northern ones have only rugged topography without an obvious rift valley. Dredged rocks and heat flow measurements were quite different for the two areas also. This region then must be considered atypical.

Acoustic work in the Baltic gave us the opportunity to make three end-to-end seismic refraction profiles: two were south of Oland Island, Sweden and one north of the Peninsula of Hel, Poland. The receiving positions of the profiles south of Oland Island are only forty-six kilometers apart in a north-south line but the structures are quite different. The northern section only 500 meters thick shows a rather thin sedimentary cover above 350 meters of 3.7 km/sec material that in turn overlies a 5.6-5.9 km/sec velocity material. The southern section, almost two kilometers thick has an equivalent amount of low velocity material and a layer about one kilometer thick having a velocity of 4.8 km/sec that overlies a 6.0 km/sec velocity material. The eastern profile shows high velocity material (5.6 km/sec) at a depth of two and one-half



Color of surface sediments from the continental shelf, slope and upper continental rise.



Typical pieces of Upper Cretaceous flint from England found along the Atlantic coast of the United States: (a) joint fragment brought to Boston in 1918 as part of ballast of munitions ships, (b) gunflint of Dutch style made about 1675 found on Marthas Vineyard, (c) irregular fragment found off New Jersey with a mastodon tooth; probably part of ballast of a wooden-doweled ship whose remains were found nearby.

kilometers. Correlation of the layers determined by seismic refraction suggests that the structural change south of Oland Island may represent the boundary of the Sarmatian Shield.

Paleomagnetic Stratigraphy

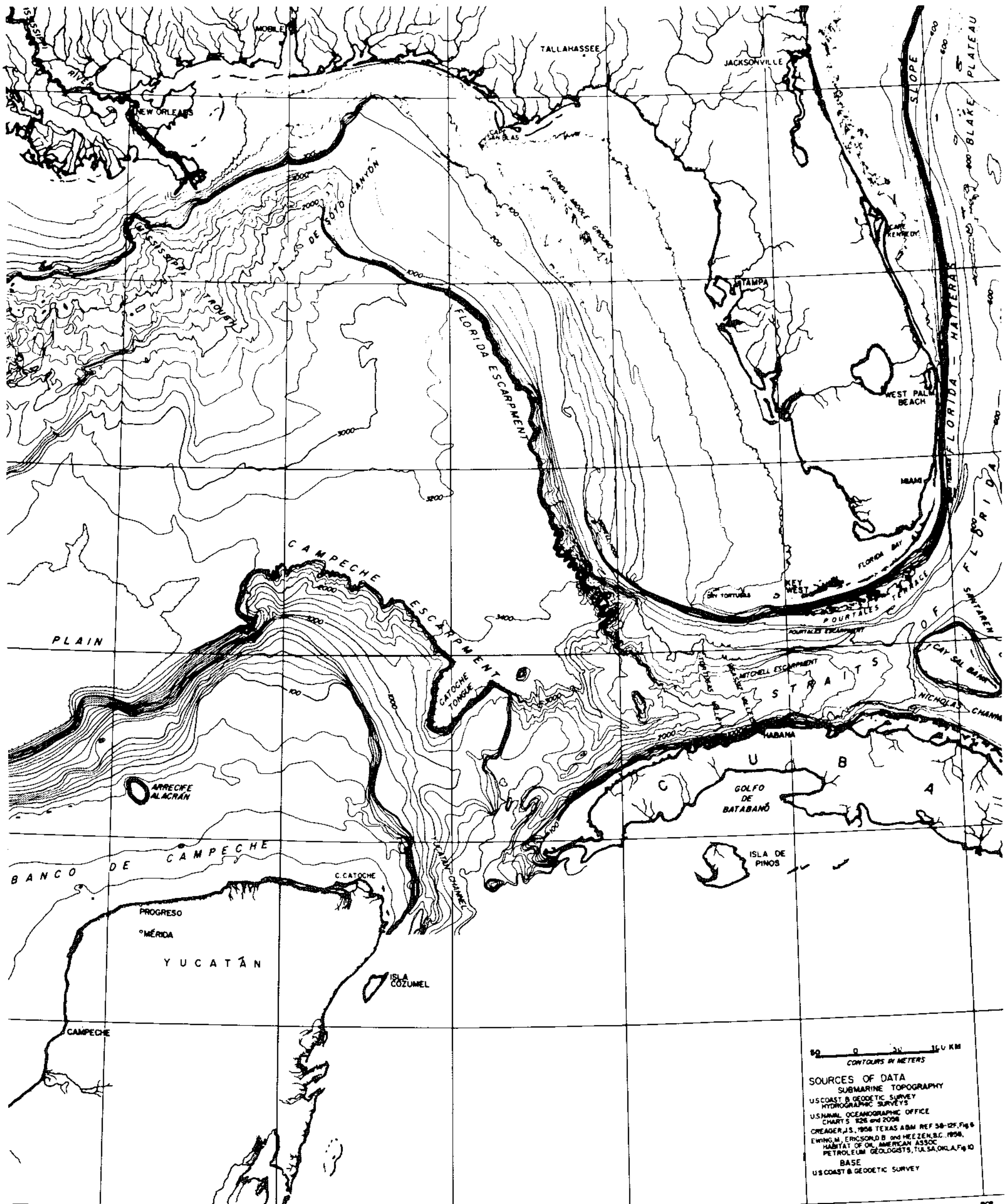
Recent studies of deep-sea cores have shown that a continuous record of the geomagnetic polarity-reversal history may be preserved in deep-sea sediments. Consolidating sediments retain evidence of the direction of the magnetic field during periods of consolidation. Radioactive dating in appropriate materials gives the absolute time sequence. Much of our knowledge of the geologic ages has been based on micropaleontological evidence — the evolution and/or disappearance of certain microfossils being used to define epoch boundaries. It is now possible to correlate this paleontologic evidence from deep-sea cores with the remanent magnetism of the sediments. In this way a better estimate of absolute time for the geologic epoch can be made. For example, our paleomagnetic-paleontological studies have provided an age of 1.85 million years for the Plio-Pleistocene boundary.

Oceanic Acoustics

The Baltic Sea in June is one of the more pleasant places to make acoustical measurements. The sea is generally quiet, the air is light and cool and daylight never really departs. Members of the Department of Geology and Geophysics and the Department of Physical Oceanography participated in a cruise of ATLANTIS II under these ideal conditions. Ships from five NATO nations made a concentrated environmental study of three areas in the Baltic in June of 1967. With ten ships collecting oceanographic and meteorological data within a 30 by 30 mile square it is hoped that an understanding and energy budget for the upper layer mixing processes can be evolved. With this density of oceanographic data it seemed also to be an ideal time to make some acoustic measurements. The Baltic in June is not typical of what is normally called shallow-water transmission. The surface water is runoff from the land bordering the Baltic and is fresh enough to be potable. The deeper water is an influx from the North Sea with a salinity of thirteen parts per thousand. The result is a rather well-defined sound channel that at first sight might serve as a model for the deep oceans. The relative water depth variations observed in the working areas are similar to those in the ocean.

Six sound transmission runs were completed in three different areas and are being analyzed. Along with the interpretation of these data, analysis has continued on diffraction phenomena associated with turning point regions, the variability of the bottom return in continuous seismic profiling, and the relation of long-range sound transmission to internal waves.

Acoustic studies in the ocean require knowledge of the environment in sufficient detail to predict effectively the transmission of the signals. The thermal front region near 30°N between Bermuda and the Antilles presents a large scale phenomenon of interest to oceanographers and acousticians. We have continued experimental measurements in the area and the analysis of related data to it. T-S diagrams from lowerings of a salinity-temperature-depth meter this spring clearly show two types of water near the surface and indicate the shape of the boundary in depth. Currents can be inferred from these boundary conditions and related to the large scale shape of the front we have observed. Sound velocity observations south of the front have indicated disturbances on the same scale as the variations in the front and we are investigating the possible relationships.



Bathymetry of the eastern Gulf of Mexico. Chart is based on soundings from U. S. Coast and Geodetic Survey hydrographic surveys.

Animal Sounds

The sounds of three seals have been studied and correlated with their behavior where possible. The Weddell seal (*Leptonychotes weddelli*), the Arctic bearded seal (*Erignathus barbatus*) and the harp seal (*Phoca groenlandica*) each have their own characteristic sounds. We observed the Weddell seals in greatest detail. Trills seem to be related to dominance, low pulses to threats and chirps to inquiry and navigation.

Micropaleontology

Studies in micropaleontology in 1967 have been carried on with two major points of emphasis: 1) comparative biostratigraphic investigations of selected Tertiary marine sections on land and in deep-sea cores with a view toward delineating criteria useful in the recognition and determination of major geologic time boundaries of the Tertiary and 2) electron scanning microscopy of surficial morphology of planktonic Foraminifera.

Among the interesting results which were achieved this year was the recognition for the first time of the Pliocene/Pleistocene boundary in deep-sea sediments based on paleontologic criteria directly referable to the holostratotype locality in Calabria, Italy, and the determination of an "absolute" age for this boundary of about 1.85 million years. It was found to occur within the Olduvai Normal Paleomagnetic Event. The date for this was determined by radiometric dating of oriented lava flows in Olduvai Gorge, Tanzania, with which some of the earliest proto-hominids are associated. Thus it is possible to trace evolutionary trends in certain groups of marine microplankton and hominids within an absolute time-framework for the past two million years.

In cooperation with Japanese scientists we have been examining the surficial morphology of planktonic Foraminifera using an electron microscope. A maximum resolution of 150-250 A combined with an extremely high depth of focus has made it possible to examine details of morphology heretofore unavailable by means of conventional light microscopy.

Dinoflagellate Studies

Our investigation of the life histories of resting spore-producing dinoflagellates are being carried out from both biological and paleontological viewpoints. Approximately four years ago it became apparent that certain small microfossils called hystrichospheres and fossil dinoflagellates by paleontologists were homologous with the resting spores of modern dinoflagellates. These investigations instigated by geologists, revealed a need for information concerning the life histories of modern dinoflagellates and the nature of fossil dinoflagellates which might be found in marine Quaternary sediments. Very little information was available on either subject.

Our biological investigations have led to the compilation of a monograph devoted to description of modern dinoflagellate resting spores belonging to over thirty species from seven genera. The cyst-cycle in the life histories of these species was determined in a series of over 700 incubation experiments during which the resting spores were isolated and individually germinated in the laboratory under directly observable conditions. The interspecific and intergeneric fluctuation in morphology shown by these spores parallels the systematic pattern observed by biologists who studied the motile phase in the life cycle on which the classification of dinoflagellates is at present based. However, studies have revealed certain relationships which were not apparent from study of the marine planktonic organisms alone.

In the paleontological field, early and late Pleistocene fossil dinoflagellate species associations have been determined from a borehole through a local type succession in Ludham (East Anglia, Britain) and in piston-cores taken in the Caribbean and Red Sea areas. The vertical distribution of dinoflagellates in these sequences appears to be controlled by paleoclimatic variations and this raises the possibility that dinoflagellates can be used in Quaternary marine stratigraphy in a manner analogous to the application of pollen and spores in Pleistocene-Holocene limnic and peat deposits.

EARL E. HAYS, *Chairman*

Department of Ocean Engineering

In 1967, the Department of Ocean Engineering was organized to centralize the engineering efforts of the Institution. The Department of Applied Oceanography was discontinued, but most of its sections or projects were transferred to the new organization. The members of this department will anticipate the needs of oceanographers and also give engineering support for various projects undertaken by the Institution staff. The group will provide the competence and facilities necessary for the conduct of engineering research projects. The ultimate objective is to contribute to the conduct of better oceanography.

Deep Submergence

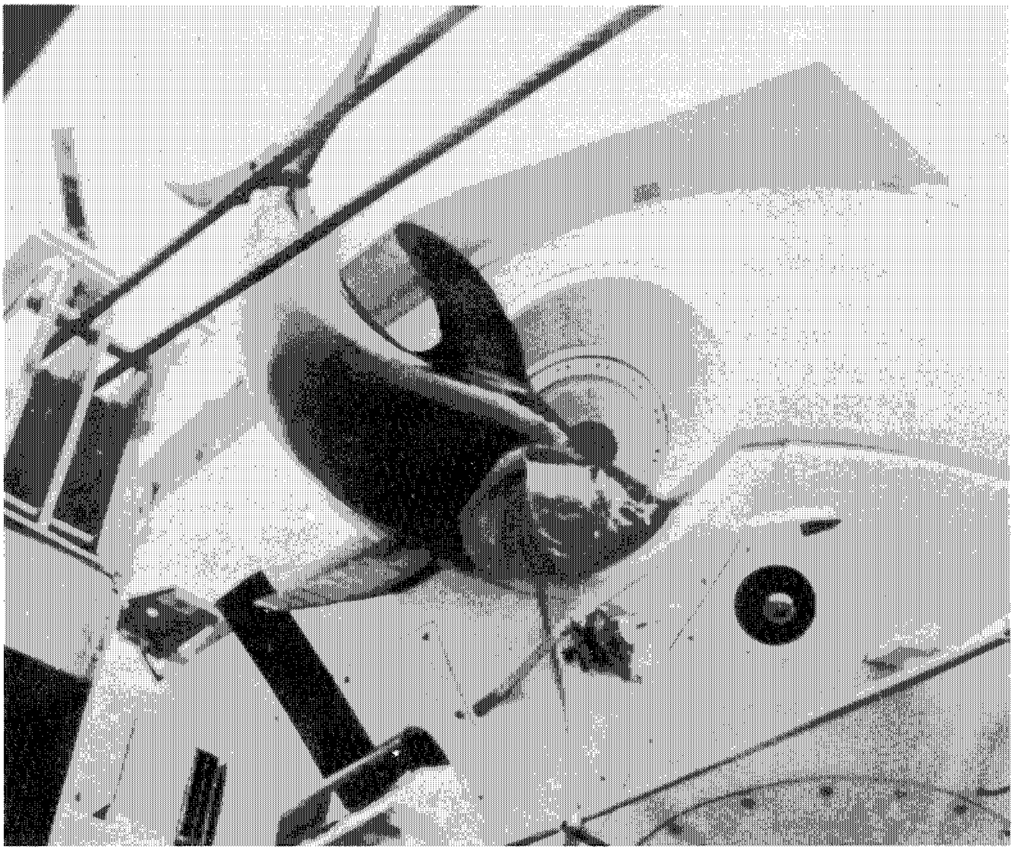
ALVIN again had a busy year. While there were some frustrations and delays, still there was a marked increase in her scientific accomplishments. The spectacular achievements of the previous year which started with the successful location and recovery of the lost bomb off Spain were exceeded in 1967 in scientific interest and even in excitement. The photographic potential has been greatly improved. There is no better testimony to this than the beautiful films of the scattering layers made by Dr. R. H. Backus. Sonar located the "targets" to be identified, which were then approached to range zero before the area was illuminated by the high-powered lights. In this way animals were identified which otherwise would have remained out of sight (see page 22).

An extensive refit and modification was carried out on both ALVIN and the catamaran support ship during the winter and spring of 1966-67 in order to improve significantly the operating capabilities of both. Commencing on May 2 the USS ACCOKEEK (ATA) towed the catamaran with ALVIN aboard to the Tongue of the Ocean in the Bahamas. The launch and recovery system on the catamaran failed on the first launch of the submarine and delayed the scientific work for about one month while repairs were made in Miami.

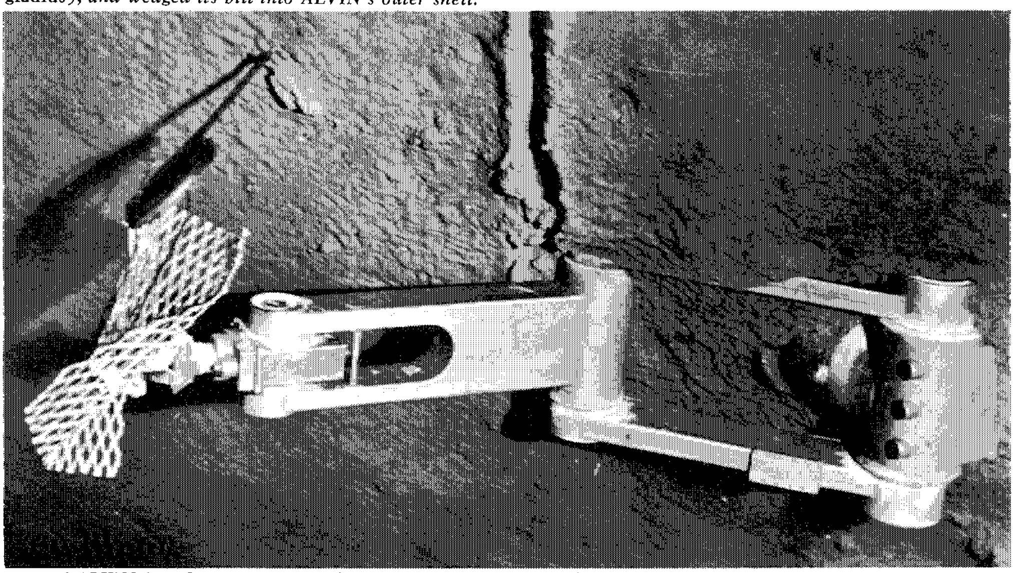
The schedule was shortened to account for the time lost and the catamaran worked slowly up the coast on a program planned to insure arrival in Woods Hole in July. Geological studies were made on the Blake Plateau, off Cape Hatteras and off the Virginia Capes. One of the dives on the Blake Plateau was unusual in that a 200 pound swordfish unexpectedly made an unprovoked attack on the submarine on the bottom at a depth of 1,900 feet. The fish became impaled by his sword and was brought back to the surface. No serious damage was sustained by the submarine; the swordfish was served for dinner.

Upon return to Woods Hole, local trips were made to various parts of the continental shelf and slope south and east of Woods Hole. Several canyons were visited for geological observation. A number of dives were made to observe the fish populations and to correlate direct observation of the bottom with side-scanning sonar records. These were conducted at various depths to the operating limit of 6,000 feet. Studies were made of the micro-thermal structure of the water above the slope and the deep scattering layer known as "Alexander Acres". Acoustic measurements were made at the surface of the output from the Sparker by ALVIN while on the bottom and during the return to the surface. Of the fifty-five dives made in 1967, the geological and biological observations accounted for 60 percent of the total.

While ALVIN was being recovered south of Martha's Vineyard in rough weather, a handling line became fouled on the catamaran. The resulting collision dislodged the mechanical arm which plunged to the bot-



During a dive on the Blake Plateau, the submersible ALVIN was attacked by a 200 pound swordfish (Xiphias gladius), *and wedged its bill into ALVIN's outer shell.*



Arm of ALVIN found at 1300 meters depth on continental slope about 180 km south of Marthas Vineyard. Note that stiffness of bottom permitted the arm to sink only about 20 cm into the bottom after its free fall through the water and presence on the bottom about three weeks prior to recovery.

tom in 4,400 feet of water. Three weeks later, ALVIN returned to the same spot and was successful in locating and recovering the lost device. Fortunately, the arm sustained little damage and will be restored to normal operation for 1968.

Information Processing and Analysis

As in the previous year, the information processing center continues to expand its influence at the Institution, particularly in analysis for sea-going computations. The buoy-acquired data still require the largest amount of time at the processing center, followed by physical, chemical, and biological applications. A large number of investigators have been turning to the computer to eliminate long hours, if not months, of hand computations. Several courses in FORTRAN were given in 1967. Courses in general statistics and multivariate statistical analysis were offered. The latter were a cooperative effort offered by a member in the Department of Chemistry.

Business applications were expanded and they now include payroll allocation, personnel data, property inventory, stockroom material, telephone listings, and other day-to-day requirements.

It has been apparent for some time that the small capacity of the GE225 computer restricted the scope of many investigators and was uneconomically slow. After a considerable amount of study, a Scientific Data Systems Sigma-7 computer was selected as a replacement and an order was placed for its delivery during the first quarter of 1968. The installation will have a 32,000-word storage, four magnetic tapes units, two memory discs, paper-tape reader, punch-card reader, punch and line printer. The Sigma-7 is a third generation computer which will increase capabilities ten to twenty times in speed and six-fold in storage. There will be some conversions to be made but they are not considered major or beyond present capabilities.

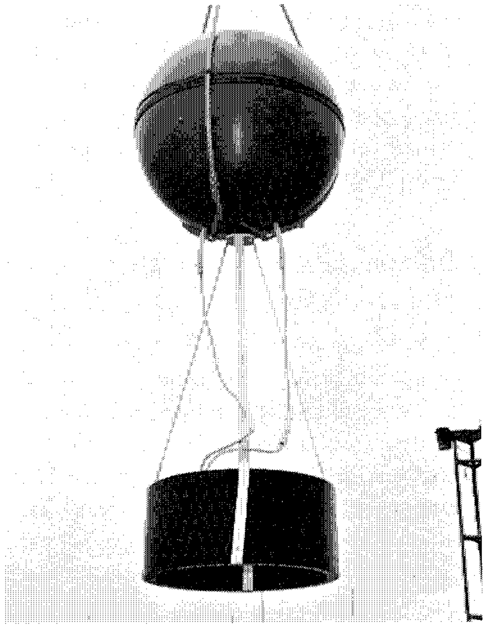
The Institution now uses a Hewlett-Packard 2116A computer on CHAIN as part of a configuration for the acquisition of gravity, magnetic, bathymetric, and navigational data. This will be expanded to 16,000-word storage and will have two plotters. Similar units have been ordered for ATLANTIS II and will be used first with satellite navigation and for general purpose scientific programs. It is planned that the shipboard systems will be more or less alike in capability in order to ease the computing problems at sea and to become a more useful tool to a larger group of sea-going scientists.

Buoy Engineering

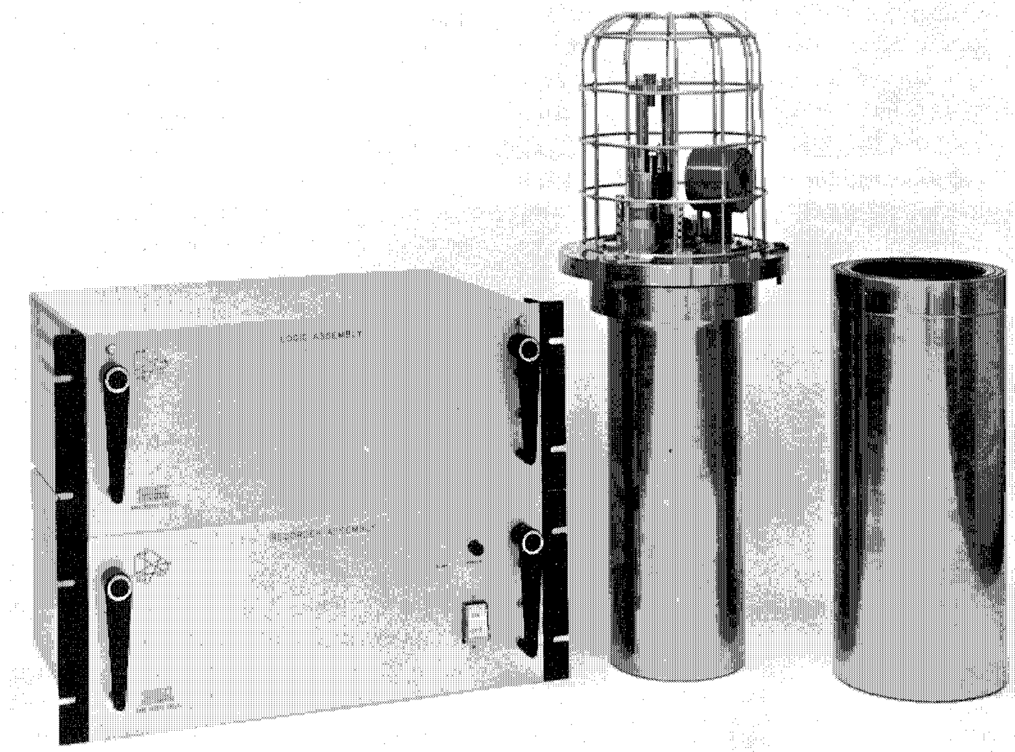
Present considerations for the buoy group fall into two classes: (1) continuing programs and (2) the design of mooring systems, including both new applications and improvements to existing equipment. Cable terminations, corrosion, and cable failure continue to be the primary sources of trouble. To solve these problems, a tensile-strength machine is to be acquired during the first quarter of 1968. The *in situ* behavior of compound-mooring lines of wire and rope have been analyzed by incorporating telemetering tension instruments into the moorings and these data are transmitted to Woods Hole. Fluctuations have been correlated with passing storms and some changes in the current regime; a gross reduction in tension indicates a break.

Two large buoys, ten and twelve feet in diameter, discus- and conical-shaped, have been designed and constructed for supporting telemetry and sensor systems. A high-density foam buoy was developed to provide flotation for bottom-mounted instruments; it has a buoyancy of 400 pounds and operates to a depth of 5,000 meters.

Deep submersible navigational beacon



Sofar probe



ALVIN data acquisition and data system

Omega navigator on bridge of R. V. CRAWFORD.

Navigation

VLF/Omega Navigation was employed on cruises of ATLANTIS II from Buenos Aires, Argentina, to Recife, Brazil, in March and April and to the Baltic in May and June, and of CRAWFORD in August by Dr. Paul Mangelsdorf in the Gulf Stream. These measurements were for relative positioning either for ship speed and course made good or for current studies over short periods. Differential Omega Navigation was used by the C54Q aircraft during November and December in the area 61°W to 55° to 14°N for ten flights totalling 16,000 nautical miles. Magnetic anomalies were mapped on a ten-mile spacing to within one mile.

Electronics and Instrumentation

The responsibilities for electronics and instrumentation fall primarily into two areas: (1) the design and development of new instrumentation, and (2) the maintenance of instruments in the laboratories and on the ships, including the ship and shore radio operation. New measuring and recording techniques, and prototype systems have kept the group working diligently.

All ships and shore stations now have one kilowatt single-side band equipment which permits direct communication over most of the North Atlantic. The shore station is modern and compact with amplitude modulation (AM), single side band (SSB), and multi-channel very high frequency (VHF) modes of operation. Radars, fathometers, and direction finders are examples of maintenance required by the Marine Department.

Development of navigational equipment and a data-logging system for Deep Submergence Research Vehicles was initiated with the support of the Naval Oceanographic Office. The goal is a compact data-acquisition system for use aboard ALVIN which will include salinity, temperature, depth, sound velocity and several spare channels for other purposes, for digital recording of the data on magnetic tape. This is being completed under a subcontract with the Bissett-Berman Corporation for use in the 1968 series of dives. A navigational range-range system is in progress and has been tested during the year. It operates on the principle of a one-way acoustic path relying on precision clocks in the beacon, on ALVIN, and on the catamaran.

Two other ingenious devices are the long-range, long-life SOFAR floats operating at 500-600 Hz, which signal both navigational and environmental data. Three are under construction and one will be launched in January 1968. The Autoprobe, a general purpose autonomous instrument with a variable displacement system, can adjust its depth without connections extending to the surface. It can be operated in isobaric or isothermal mode or make programmed excursions at any depth, carrying recording and sonic-telemetering equipment. Observations of internal waves, tides, and oceanic microstructure can be carried out which would be difficult or impossible by other means.

It is with some satisfaction that we can report that all these instruments have had sea trials and have progressed well beyond the conceptual stages.

SCOTT C. DAUBIN, *Chairman*

Department of Physical Oceanography

The Department of Physical Oceanography has been reorganized and now includes in addition to its earlier membership the former Department of Theoretical Oceanography and Meteorology and personnel from the Buoy Project. The reorganization is accompanied by a centralization of activities within the Department in the Laboratory of Oceanography building. The reorganization reflects the necessity for simplifying the administrative structure within the Institution and for accommodating the rapid growth of oceanographic activities in the past few years.

Research efforts in 1967 were devoted both to continuing and new activities. Earlier programs included the study of observations from the International Indian Ocean Expedition, the International Geophysical Year and Equalant Cruises. New field programs ranged from measurements of overflow in the Denmark Straits to participation in ELTANIN cruises in the South Pacific; from meteorological sections in the Pacific Line Island experiment to observation in the Baltic. Intensive series of observations were carried out on current rings or eddies shed from the Gulf Stream and of higher frequency current fluctuations from moored buoys.

The increasing body of observations of variability in the ocean has stimulated interest in the design of instruments and experiments to examine more selectively specific portions of the spectrum of variation in both time and space.

Water Masses and General Circulation

The Denmark Strait between Greenland and Iceland is one of the major sources of deep water for the world oceans. A joint cruise with the Bedford Institute of Oceanography was carried out in the period January to April 1967 to examine the overflow through the Strait and to estimate its transport. Direct measurements were attempted with moored current meters but were unsuccessful because currents were apparently too strong for the moorings. Speeds at the periphery of the overflow approached 3 knots.

The discovery of the Equatorial Undercurrent in the Atlantic has required a reexamination of the circulation at its western source. Recent hydrographic stations along the South American coast reveal discontinuities in the temperature, salinity and oxygen that are consistent with a discontinuity in the current structure. It appears that the North Brazilian Coastal Current may be the major source of water for the Undercurrent, and the North Equatorial Current for the Guiana Current. The conventional picture of a strong surface current carrying South Atlantic Central Water across the equator into the Caribbean Sea may be in error and a cruise is planned in 1968 to investigate the source region in more detail.

A cooperative program to run two hydrographic sections across the South Pacific at 43°S and 28°S was carried out during the period March to August 1967 with participating scientists from the Scripps Institution of Oceanography, University of Hawaii, Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution. Of particular interest are indications of northward abyssal flows in the western Pacific as required by simple circulation models.

Seasonal and Climatological Changes

In an effort to describe the present state of the North Atlantic for future climatological studies, a compilation has been made of the volumes of abyssal water classified according to its potential temperature-salinity values. This volumetric table indicates that the Denmark Strait overflow was probably the most active contributor to the deep water volume of the North Atlantic during the eight-year period from which observations were used. Other clearly identified sources were the Antarctic Bottom Water and the Iceland-Faroe overflow.

Numerous hydrographic stations occupied in the slope water north of the Gulf Stream have indicated a decrease since 1960 in the deep water of the salinity on potential temperature surfaces. The decrease is slight ($<0.01°/_{oo}$) but significant in terms of the precision attainable in conductivity measurements. The decrease may be an indication of intensification of the northern deep water sources. Salinities near Bermuda have increased during the same period, possibly as a result of a northward shift of the core of high salinity water originating from the Mediterranean. The joint effect of these long term trends is to reduce the net transport north of Bermuda by 10%, an indication possibly of a climatic variation in the large-scale Atlantic circulation pattern.

Coastal observations at lighthouse stations during 1967 indicated a well developed southerly drift that occasionally extended beyond Cape Hatteras. The increased drift compared with 1966 is believed to be associated with increased river runoff marking the end of the recent drought period.

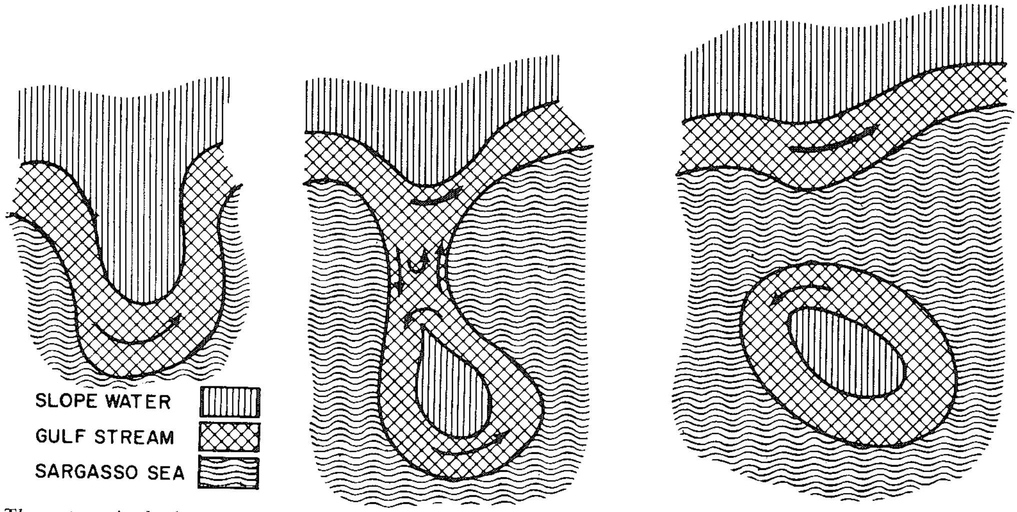
Ocean Variability

In addition to the regular variations that are imposed on the ocean by tidal forces, daily and seasonal cycles of energy input from the sun, the ocean is subjected to a wide spectrum of excitation through interaction with the atmosphere. These inputs, together with internal mechanisms of momentum transfer serve to produce variations in the velocity and density field throughout the spectrum in both space and time.

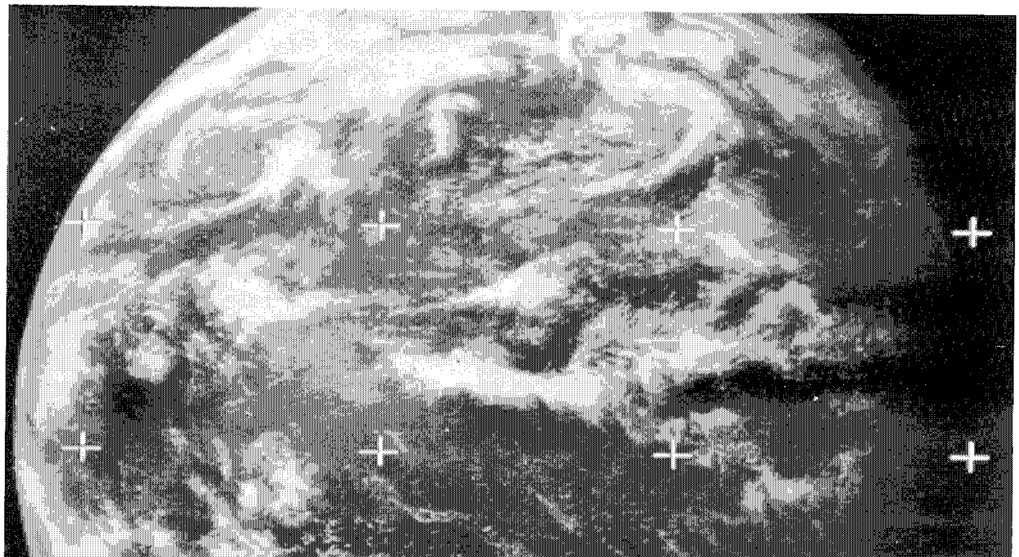
One of the more vigorous features that has been studied during 1967 is the formation and subsequent history of cyclonic rings of current formed by the Gulf Stream. At irregular intervals, Gulf Stream meanders grow and deform until the Stream rejoins along the northern edge to leave a segment in the form of a counterclockwise ring of current south of the Stream. The current ring slowly weakens but is estimated to persist for a year or more after formation. Such a ring was tracked from its formation in March to its apparent reabsorption into the Gulf Stream in November in a series of nine cruises on CRAWFORD and ATLANTIS II.

Because formation of the current rings constitute an important dissipative mechanism for the Gulf Stream, their rate of formation and subsequent fate in the Sargasso Sea must be known to understand the dynamics of the Gulf Stream itself.

Measurements of the current field from moored buoys show that fluctuations occur throughout the observable spectrum. Although energy density is high at low frequencies and at the inertial and tidal peaks, considerable energy is found throughout the entire internal wave frequency band. In this portion of the spectrum (0.1 to 1.0 cycles/hours), the energy density decreased with frequency much like the spectrum of turbulent motion. However, because of the vertical stratification of density, the fluctuations must exhibit some characteristics of internal waves. Measurements of vertical motion using neutrally buoyant floats fitted with vanes show that the magnitude of the vertical currents are consistent with internal wave theory. The potential energy of the vertical displacement of density sur-



Three stages in the formation of a Gulf Stream cyclonic ring.



Photograph of clouds over the Pacific Ocean taken from the synchronous satellite stationed over the equator at 150°W. California is at the upper right of the picture; Australia is on the lower right.

faces is comparable to the kinetic energy of the horizontal motion as expected from theory.

Microstructure

The flow of heat, salt and momentum through a layer of water in the ocean cannot be characterized by simple molecular transfer. The rates of transfer are much larger than would be expected from the mean vertical gradients. These higher rates are achieved by a complex small scale structure in which regions of turbulent or convective transfer are separated by sharp gradients. Although the structure is complicated, laboratory measurements indicate that the transfers are governed by simpler basic mechanisms. These laboratory studies can be applied to interpreting microstructure observed in the ocean. Some measurements have been made by lowering continuously recording instruments from shipboard. An interesting development is the use of the deep submersible ALVIN to investigate the microstructure at depth. In a series of dives in the slope water off Oceanographer Canyon, the ALVIN was used to examine shear with vertical dye traces. These traces, photographed with stereo cameras, reveal small scale shear throughout the depth examined (900 meters).

Air-Sea Interface

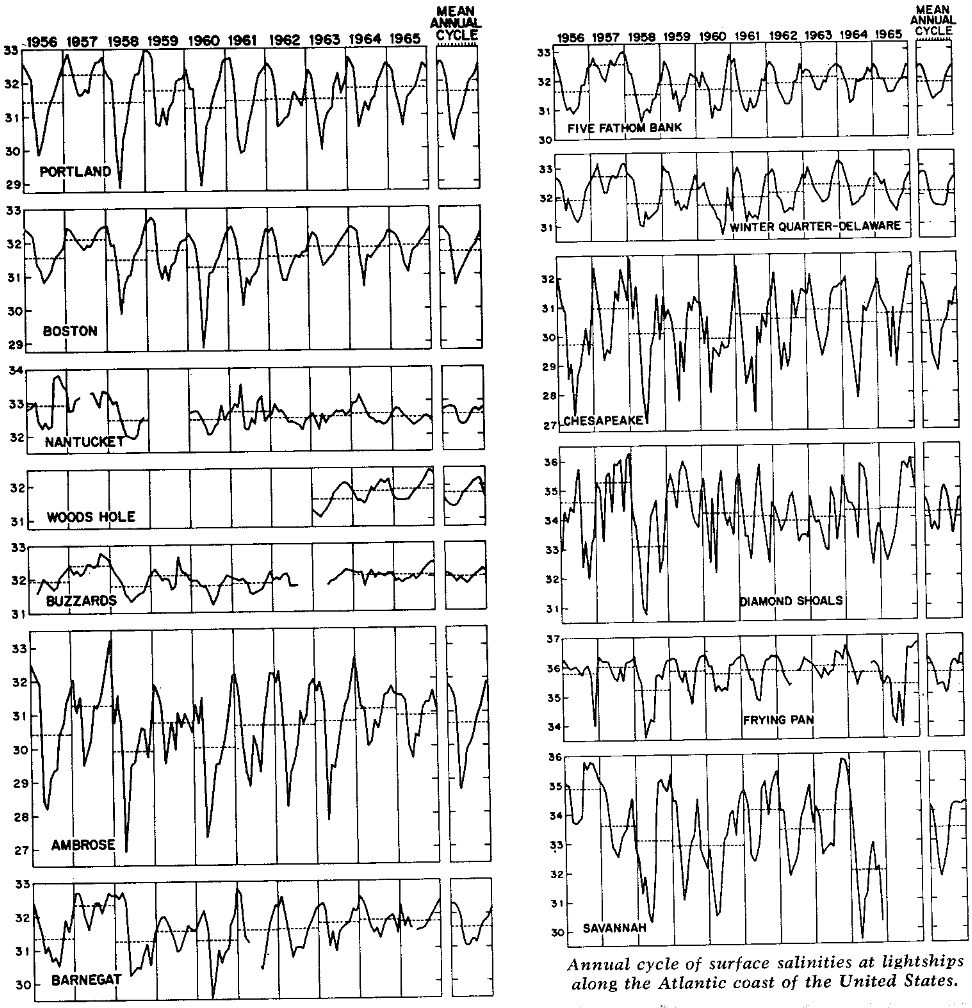
Most of the energy that is present in the ocean is accumulated as a result of fluxes of heat, momentum and mass across the ocean surface. The study of interfacial processes is central to understanding the ocean mechanism as a whole. A considerable portion of the exchange across the surface is in the form of radiant energy entering and being emitted from the ocean. Radiation from the ocean is measured to estimate surface temperatures. Because it can be sensed remotely from an airplane or satellite, the factors affecting the radiation must be known with precision. Studies are continuing to improve the accuracy of instrumentation for surface temperature measurements. The possibility of worldwide coverage using remote sensors lends emphasis to these studies.

The momentum imparted to the ocean by winds over the surface is a major factor in determining ocean circulation and in sustaining motion over the entire spectrum. There are few observation points for continuous monitoring of surface winds. Measurements from moored buoys can fill this gap but evaluation of the data is necessary. The motion of the buoy in a sea degrades the observations to an unknown extent. Comparisons with standard weather charts and ship reports show that data from buoys is of comparable quality. However, spectral estimates cannot be accepted with confidence without further verification.

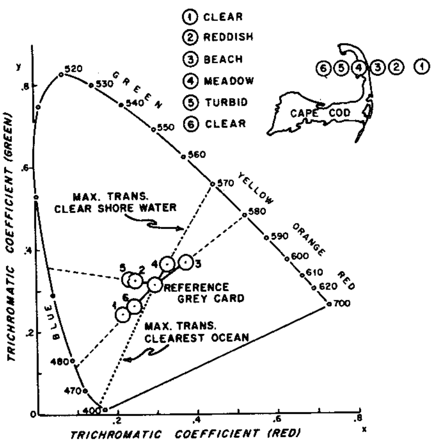
Atmospheric Processes

Meteorologists from the Woods Hole Oceanographic Institution participated in a study of the intertropical convergence zone of the Pacific Ocean in the region of the Line Islands. Measurements included observations of clouds, rain areas, temperature, humidity, winds, turbulence fluxes and solar radiation. These measurements are part of a larger experiment to determine the structure of the convergence zone and its relation to the clear equatorial zone to the south.

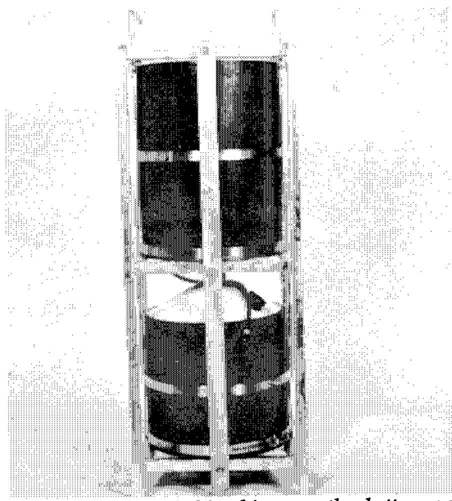
An experiment to determine raindrop size distribution was carried out by examining the breakdown of a solid stream of water into droplets over a 70-meter fall. The statistics of drop-size distribution indicate that the drop size does not reach the distribution found in heavy rain except for the smaller drops. The experiments suggest that 200-300 meters of fall are required to reach the drop size distribution achieved in rainfall.



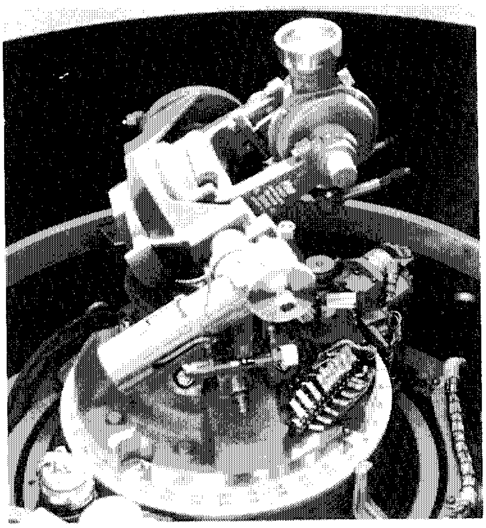
Annual cycle of surface salinities at lightships along the Atlantic coast of the United States.



Chromaticity diagram of sea color observed from an aircraft at stations shown in the chartlet.



An acoustic beacon. This chirps on the bottom permitting a precise spot to be located over a period of time.



Two-inch equatorial theodolite mounted on the phantom of a Mark-19 gyrocompass. This instrument makes possible geodetic measurements at sea.

Measurements of sea-salt particles for salt and surface active organic material were carried out on a field trip to Hawaii. The organic material may be the source of high iodine content found in sea-salt particles. The production of salt particles by the sea is important as a source of condensation nuclei in the atmosphere and experiments to measure production have been carried out.

New Techniques

In connection with the scientific work in physical oceanography, new techniques are constantly being developed for measurement and old ones improved. Oceanographers are involved in a wide variety of measurements, the more obvious of which are temperature, salinity and current. Other quantities are measured as well and often involve the use of special and new techniques.

For example, a method has been developed for determining the deflection of the vertical using the GEON system. This system can be used to find astronomical ship's position, and with refinement the difference between astronomical and geographic position can be observed at sea. From these differences, it is possible to define the departures of a level surface from the geographic spheroid and thus to establish a reference surface against which to study ocean tides and so forth. In preparation for measurements of tilt of the horizon studies, low altitude star images have been observed. Based on these observations it seems possible that real time image processing on long persistence cathode ray tube (CRT) screens may permit the horizon image to be examined, not only with atmospheric disturbances largely eliminated, but also corrected for ship heave and wave motion to a point where meaningful measurements of sea surface tilt may be made at sea.

In order to recover one millegal in gravity measurement at sea, ship's speed must be known within 0.1 knot. Navigation techniques are being studied combining Mark 19 heading data, Very Low Frequency (VLF) range rate and satellite fixes in the hope of obtaining ship's speed to the required accuracy.

A technique for studying sea surface color has been developed using a pair of spectrophotometers each equipped with 28 narrow band interference filters. One of these was flown at an altitude of 1,000 feet and the other used simultaneously underwater from shipboard. Comparison of the spectra obtained suggests the possibility of airborne discrimination between water masses and the location of areas of high sediment load or biological activity.

Equipment is being developed for possible satellite over-flight of the ocean to obtain oceanographic data. The technique now being developed will depend on the use of instrumented free floating buoys which will on interrogation transmit to the satellite temperature and other oceanographic data. The position of the buoy at the time of interrogation can also be inferred from time delay of the response and satellite position.

NICHOLAS P. FOFONOFF, *Chairman*

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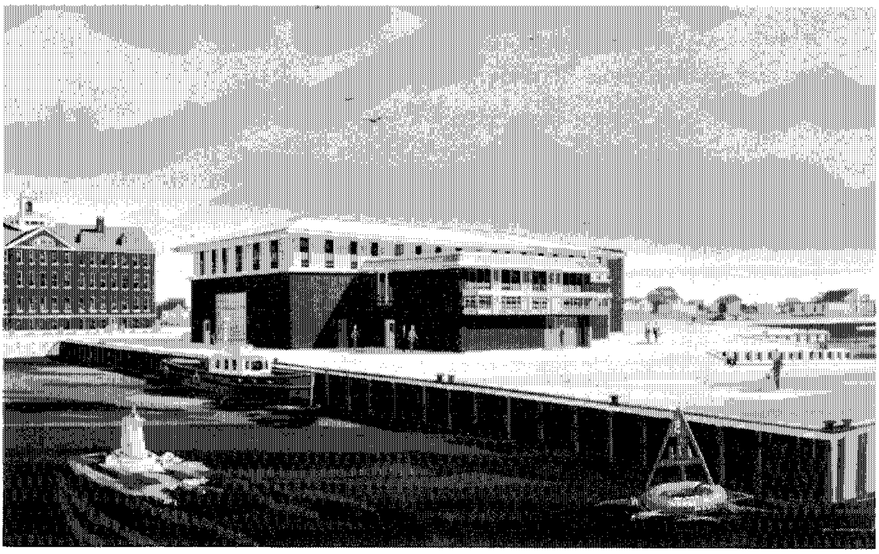
Ashore and Afloat

The spring and the summer were endured as the pile drivers on the waterfront put down two hundred fifty-four piles measuring a total of thirty-eight thousand feet for the foundations of the new pier. Forty-four hundred cubic yards of concrete were poured over the four hundred fifteen tons of reinforcing steel to make a surface of almost an acre. At year-end the construction was nearing completion, and we shall soon have a most satisfying capability for the servicing of our research fleet. Seven hundred sixty linear feet of pier space will allow the outfitting of the vessels in an efficient fashion.

The design and the specifications for the marine services building were finished and bids will be solicited early in 1968 for its construction. The architect is Mr. Ray C. Bump, Jr. of Jackson & Moreland International, Inc. of Boston with Mr. Walker Cain of Walker Cain Associates of New York assisting as the consulting architect. The building will provide twenty-five thousand square feet in two stories plus a mezzanine for waterfront shops, laboratories, transit area for the scientific gear going aboard the ships, and a high crane bay for working on the larger heavy equipment. Completion of the building is scheduled for February, 1969. The funds for both construction projects were provided by grants from the National Science Foundation.



Model of marine services building.

Several parcels of real estate were acquired in Woods Hole which will provide room for growth and some student housing facilities for the educational program. A lot of nine thousand square feet and the building known familiarly for many years as the Shiverick house at 11 School Street is being extensively altered to provide space for a new computer for the Information Processing Center. Care is being taken to maintain the external character of the building, yet extensive internal changes will provide an excellent lay-out for the equipment. The house on the property at one time was on the site now occupied by the Laboratory for Marine Sciences, having been moved across the street in 1949.

The former Senate property at 573 Woods Hole Road, next to the Challenger House was acquired for housing purposes and a possible later use for the controller and accounting offices. The lot consists of some sixteen thousand square feet, and the house contains four apartments. A small garden at the front of the property is dedicated to the memory of Michael Walsh, long-time gardener for the Fay Estate and developer of the Rambler Rose.

When Dr. John Zeigler resigned from our Resident Scientific Staff to accept an appointment at the University of Puerto Rico, he sold his residence at 9 Maury Lane to the Institution. This property of seventeen thousand five hundred square feet adjourns the Shiverick lot. It is planned to use this parcel for the educational program.

In November the Institution entered into an agreement to purchase the estate in Quisset of the late Edward N. Fenno. This is a tract of one hundred thirty-nine acres with frontage on Vineyard Sound and on Woods Hole Road. Execution of the sale is in suspense pending the outcome of litigation between the trustees of the estate and a third party.

The Institution's facilities on the Matamek River in Quebec were used during the summer months for a research program in the life cycle of the Atlantic salmon. The project was carried out in concert with the University of Waterloo, of Waterloo, Ontario.

Not before the action was quite overdue, some of the outbuildings at the rear of the Co-op property across the street from the Institution were razed and the ground leveled. This property housed in the earlier days, among other things, a grocery store. The store itself is also marked for early dismantling and the Eel Pond shoreline will be bulkheaded in agreement with that of the abutters.

ATLANTIS II undertook early in the year a long cruise into the South Atlantic. During a port call in Buenos Aires, those fortunate enough to be aboard had an opportunity to see once again the earlier ATLANTIS, now EL AUSTRAL of the Argentine Hydrographic Office.

ATLANTIS II was also engaged during the summer months in a multi-national investigation in the Baltic Sea. Their research was of such high quality as to merit close and continual scrutiny by vessels and aircraft of some of the neighboring countries. En route to the Baltic via the Kiel Canal, ATLANTIS II was able to pay a visit to the Institut für Meereskunde in Kiel.

GOSNOLD made her longest voyage yet from Woods Hole, going deep into Lake Maracaibo for geological studies, and affording some ship time to scientists of the University of the West Indies in Jamaica on her return.

The C-54Q aircraft flew fourteen thousand miles while taking part in a major study program of weather phenomena in the Line Islands of the Central Pacific.

Cruises - 1967

ATLANTIS II — Days at Sea – 287 — Total Miles Sailed – 43,679

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
31	10 January–3 May	Equatorial Atlantic	114	Scheltema, Sanders, Ryther, Von Herzen, Bowen
32	14 May–25 July	Baltic Sea	73	J. Phillips, E. Hays, V. Bowen
33	27–29 July	Vice Pres. trip to New Hamp.	3	P. Fye
34	1 August–17 August	Shipyard, Boston	- -	- - - - -
35	17 August–10 September	Gulf Stream	25	M. Stalcup
36	12 September	International Cup Races	1	Associates
37	19 September–6 October	Gulf Stream	18	C. Parker
38	11 October–31 October	Gulf Stream	21	M. Stalcup
39	3–21 November	Gulf Stream	19	C. Parker
40	27 November–2 December	Woods Hole to Bermuda	6	R. Hessler
41	6–12 December	Woods Hole to Bermuda	7	R. Heinmiller
			287	

CHAIN — Days at Sea – 231 — Total Miles Sailed – 27,008

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
62	1 January–10 February	Shipyard, Boston	- -	- - - - -
63	14–27 February	70th Meridian Buoy Line	14	R. Heinmiller
64	19–23 March	Gulf Stream	5	T. Stetson
65	27 March–9 April	Gulf of Maine	14	B. Ketchum
66	17–29 April	70th Meridian Buoy Line	13	R. Heinmiller
67	10 May–9 June	Woods Hole to Bermuda	31	J. Beckerle
68	16–27 June	70th Meridian Buoy Line	12	R. Heinmiller
69	28 June–9 July	Shipyard, Boston	- -	- - - - -
70	12 July–2 August	Brown's Bank	22	S. Knott
71	7–18 August	70th Meridian Buoy Line	12	R. Heinmiller
72	22 August–1 September	Georges Bank to Sargasso Sea	11	D. Menzel
73	6–26 September	Continental Rise	21	S. Knott
74	2–11 October	70th Meridian Buoy Line	11	R. Heinmiller
75	16 October–19 December	Barbados	65	C. Bowin
			231	

CRAWFORD — Days at Sea – 176 — Total Miles Sailed – 21,659

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
152	2–24 March	Gulf Stream	23	C. Parker
153	27 March–1 April	Shipyard	- -	- - - - -
154	5–25 April	Gulf Stream	21	A. Voorhis
155	1–23 May	Gulf Stream	23	C. Parker
156	26 May–16 June	Gulf Stream	22	M. Stalcup
157	21 June–10 July	Gulf Stream	10	C. Parker
158	14 July–3 August	Gulf Stream	21	C. Parker
159	9–12 August	Gulf of Maine	4	T. Lawson
160	15 August–4 September	Gulf Stream–Cont. Shelf	21	P. Mangelsdorf
161	12–29 September	North edge Gulf Stream (70° West Long.)	18	R. Knox
162	12–16 October	Atlantis Canyon	5	D. Ross
163	20–23 October	Narragansett Bay	4	K. Emery
164	6–9 November	Gulf of Maine	4	T. Lawson
			176	

GOSNOLD — Days at Sea – 222 — Total Miles Sailed – 13,070

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
96	15 January–15 February	Maracaibo, Gulf of Paria	32	J. Hunt
97	9 March–12 April	Jamaica	35	B. Dale, J. Sanders
98	13 April–5 July	Bahamas	84	ALVIN
99	13–25 July	Continental Shelf	13	N. Fofonoff
100	2–8 August	Oceanographer's Canyon	7	J. Trumbull
101	11–17 August	Oceanographer's Canyon	7	C. Rooth
102	20–25 August	South of Nantucket	6	E. Hays
103	29 August–3 September	Georges Bank	6	J. Trumbull
104	8–11 September	South of Martha's Vineyard	4	C. Rooth
105	18–27 September	Hydrographer's Canyon	10	R. Hessler
106	2–7 October	Hydrographer's Canyon	6	R. Haedrich
107	13–18 October	Gulf of Maine	6	D. Spencer
108	19–21 October	Off Nantucket	3	G. Simmons (MIT)
109	16–18 November	600 Fathom Curve	3	B. Magnell
			222	

C 54 Q — Aircraft Flights – 1967

FLIGHT NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
1	6 January	Local test flight	1	- - - - -
2	30 January	Local test flight	1	- - - - -
3	31 January	Local test flight	1	- - - - -
4	2 February	Otis to Miami – 100 hr. check	1	- - - - -
5	11 March	Test flight out of Miami	1	- - - - -
6	12 March	Test flight out of Miami	1	- - - - -
7	15 March	Test flight out of Miami	1	- - - - -
8	17 March	Miami to Otis	1	- - - - -
9	24 March	Local test flight	1	- - - - -
10	30 March	Local test flight	1	- - - - -
11	2 April	Local test flight	1	- - - - -
12	3 April	1st leg Line Island flight (Otis to Denver)	1	A. Bunker
13	4 April	Denver to Travis	1	A. Bunker
14	6 April	Travis to Honolulu	1	A. Bunker
15	11 April	Honolulu to Xmas Island	1	A. Bunker
16	13 April	Local flight Xmas Island	1	A. Bunker
17	15 April	Local Xmas and back to Honolulu	1	A. Bunker
18	17 April	Honolulu to Canton Island	1	A. Bunker
19	19 April	Local flight Canton Island	1	A. Bunker
20	21 April	Canton to Honolulu for 100 hr.	1	A. Bunker
21	28 April	Local test flight–Honolulu	1	A. Bunker
22	1 May	Honolulu to Canton Island	1	A. Bunker
23	3 May	Local Canton Island	1	A. Bunker
24	5 May	Local Canton Island	1	A. Bunker
25	7 May	Local Canton Island	1	A. Bunker
26	9 May	Local Canton Island	1	A. Bunker
27	10 May	Canton to Honolulu	1	A. Bunker
28	13–14 May	Honolulu to Travis	1	A. Bunker
29–30	14 May	Travis to Cedar Rapids, Iowa	1	A. Bunker
31	16 May	Iowa to Otis	1	A. Bunker

FLIGHT NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
32	31 May	Training flight–local	1	R. Weeks
33	1 June	Training flight–local	1	R. Weeks
34	2 June	Training flight–local	1	R. Weeks
35	5 June	Training flight–local	1	R. Weeks
36	7 June	Local test flight	1	- - - - -
37	9 June	Otis to Miami–400 hr. check	1	- - - - -
38	23 June	Test flight, Miami	1	- - - - -
39	24 June	Miami to Otis	1	- - - - -
40	6 July	Flight off Cape	1	M. Stalcup
41	7 July	Flight off Cape	1	M. Stalcup
42	12 July	Otis to Bermuda	1	M. Stalcup
43	12 July	Local off Bermuda	1	M. Stalcup
44	13 July	Bermuda to Otis	1	M. Stalcup
45	21 July	Local test flight	1	- - - - -
46	26 July	Otis to New Bedford (FAA check)	1	- - - - -
47	1 August	Otis to Bermuda	1	M. Stalcup
48	2 August	Bermuda to Otis	1	M. Stalcup
49	4 August	Otis to Nantucket	1	M. Stalcup
50	7 August	Flight off Cape	1	M. Stalcup
51	10 August	Gulf Stream Survey (to Bermuda)	1	C. Parker
52	11 August	Bermuda to Otis	1	C. Parker
53	15 August	Gulf Stream Survey	1	C. Parker
54–55	16 August	Flight off Cape	1	J. Phillips
56	22 August	Transponder test	1	- - - - -
57	23 August	Transponder test	1	- - - - -
58	24 August	Transponder test	1	- - - - -
59	8 September	Flight off Cape	1	G. Ewing
60	13 September	Flight off Cape	1	C. Parker
61	14 September	Flight off Cape	1	G. Ewing
62	18 September	Flight off Cape	1	M. Stalcup
63	26 September	Transponder test	1	- - - - -
64	27 September	Otis to Bermuda	1	J. Gifford
65	28 September	Bermuda to Otis	1	J. Gifford
66	3 October	Gulf Stream Survey	1	M. Stalcup
67	11 October	Otis to Miami–200 hr. check	1	- - - - -
68–69	21 October	Local test flight, Miami	1	- - - - -
70	22 October	Miami to Austin, Texas (Omega)	1	- - - - -
71–72	24 October	Local test flight, Austin	1	- - - - -
73	25 October	Austin to Washington, D.C.	1	- - - - -
74	26 October	Washington to Otis	1	- - - - -
75	3 November	Otis to Miami (Barbados trip)	1	J. Phillips
76	4 November	Miami to Barbados	1	J. Phillips
77	6 November	Local flight, Barbados	1	J. Phillips
78	9 November	Local flight, Barbados	1	J. Phillips
79	11 November	Barb. to Miami (repair nose wheel)	1	- - - - -
80	14 November	Test flight, Miami	1	- - - - -
81	15 November	Miami to Antigua	1	J. Phillips
82	17 November	Local flight, Antigua	1	J. Phillips
83	19 November	Local flight, Antigua	1	J. Phillips
84	21 November	Local flight, Antigua	1	J. Phillips
85	22 November	Antigua to Trinidad (200 hr. insp.)	1	- - - - -
86	27 November	Trinidad to Antigua	1	- - - - -
87	30 November	Local flight, Antigua	1	J. Phillips
88	2 December	Local flight, Antigua	1	P. Saunders
89	5 December	Local flight, Antigua	1	P. Saunders
90	8 December	Local flight, Antigua	1	P. Saunders
91	10 December	Local flight, Antigua	1	P. Saunders
92	11 December	Antigua to Miami	1	- - - - -
93	13 December	Miami to Otis	1	- - - - -
94	21 December	Gulf Stream Survey	1	C. Parker

HELIO FLIGHTS — 1967

During January and February, four flights for Schevill hunting for whales.
Then during the summer, a few more whale flights and also a few for Halpern, an MIT student.

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, 1967:

Department of Biology

*Ashmore, Judith A.
Backus, Richard H.
*Brown, Anna
Carey, Francis G.
*Casiles, Phyllis M.
*Clarke, George L.
Clarner, John P.
Collins, Barbara Ann
Corwin, Nathaniel
Craddock, James E.
*Erwin, Susan K.
*Fraser, Grace C.
Freund, Jean D.
Graham, Linda B.
Grice, George D., Jr.
Guillard, Robert R. L.
Gunning, Anita H.
Haedrich, Richard L.
Hampson, George R.
Hessler, Robert R.
Howbert, Martha M.
Hulburt, Edward M.
Hülsemann, Kunigunde
Jannasch, Holger W.
Kanwisher, John W.
Konnerth, Andrew, Jr.
Lawson, Thomas J., Jr.
Lorenzen, Carl J.
Masch, David W.
Mather, Frank J. III
Menzel, David W.
Mogardo, Juanita A.
Moller, Janet H.
Park, Tai Soo
Rogers, M. Dorothy
Ryther, John H.
Sanders, Howard L.
Scheltema, Rudolf S.
*Schroeder, William C.
Sears, Mary
Shores, David L.
Stanley, Helen I.
Teal, John M.
Trüper, Hans G.
Turner, Harry J.
Vaccaro, Ralph F.
Valois, Frederica W.
Waterbury, John B.
Watson, Stanley W.
*Wilson, Esther N.
Wing, Asa S.

Department of Chemistry

Bankston, Donald C.
Blumer, Max
Bowen, Vaughan T.
Burke, John C.
Degens, Egon T.
Deuser, Werner G.
‡Fitzgerald, William F.
Gordon, John E.
Hess, Marilyn R.
Hunt, John M.
Kimata, Robert N.
Livingston, Hugh D.
Matheja, Johann H.
McAuliffe, Julianne
McNulty, Patrick S.
Noshkin, Victor E., Jr.
‡Reppmann, Edith
*Sachs, Peter L.
Sass, Jeremy
Schroeder, Brian W.
Soderberg, Jon R.
Spencer, Derek W.
Strickland, Charlotte M.
Surprenant, Lolita D.
Thompson, Geoffrey
*Thomson, Gerald B.
Thorne, Robert L.

Department of Geology and Geophysics

Aldrich, Thomas C.
Baxter, Lincoln II
Beckerle, John C.
Berggren, William A.
Bergstrom, Stanley W.
Boutin, Paul R.
Bowin, Carl O.
Brockhurst, Robert R.
Bunce, Elizabeth T.
Cain, Henry A.
Carter, Jane C.
Chase, Richard L.
Church, William J.
Coppenrath, Agnes I.
Dale, Barrie
Doutt, James A.
Dow, Willard
Dunkle, William M., Jr.
Emery, Kenneth O.
*Gallagher, Gloria S.
Grant, Carlton W., Jr.
Guild, Ritchey L.
†Hathaway, John C.
Hayes, Carlyle R.
Hays, Earl E.
Hays, Helen C.
‡Hersey, J. Brackett
‡Hess, Frederick R.
Hilliard, Channing N., Jr.
Hülsemann, Jobst B.
Jones, J. Fred
*Jones, Maxine M.
Kadar, Susan
Katz, Eli J.
Knott, Sydney T., Jr.
†Manheim, Frank T.
†Meade, Robert H.
Mellor, Florence K.
Milliman, John D.

*Part Time Employment
‡ On Leave of Absence

Department of Geology and Geophysics (continued)

Morehouse, Clayton B.
Murphy, Edward L.
Nichols, Walter D.
Nowak, Richard T.
Owen, David M.
†Oldale, Robert N.
Paul, Russell K.
Peterson, Jane M.
Phillips, Joseph D.
Poole, Stanley E.
Prada, Kenneth E.
Ross, David A.
Ruppert, Gregory N.
*Schevill, William E.
†Schlee, John
Scott, Carl W., Jr.
Stetson, Thomas R.
Stone, Louise D.
Sutcliffe, Thomas O. L.
Toner, Lois G.
†Trumbull, James V. A.
Uchupi, Elazar
Vine, Allyn C.
Von Herzen, Richard P.
Wall, David
Watkins, William A.
Witzell, Grace M.
Witzell, Warren E.
*Witzell, Wayne
Wooding, Frank B.
Young, Earl M., Jr.
Zarudzki, Edward F. K.

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

Department of Ocean Engineering

Aldrich, Thomas B.
Barstow, Elmer M.
Bartlett, Arthur C.
Berteaux, Henri O.
Bland, Edward L., Jr.
Broderson, George DeP.
Chute, Edward H.
Collins, Clayton W., Jr.
Dorson, Donald L.
Drever, Robert G.
Fairhurst, Kenneth D.
Frank, Eric H., Jr.
Freund, William F., Jr.
Graham, Russell G.
Hartke, Richard A.
Hinton, Clifford H., Jr.
Horton, Susanne M.
Lyon, Thomas P.
Marquet, William M.
Mason, David H.
‡Mavor, James W., Jr.
McCamis, Marvin J.
Muzzey, Charlotte A.
O'Malley, Patrick
Omohundro, Frank P.
*Paine, Kathryn
Porembski, Chester R.
Power, George H.
Rainnie, William O., Jr.
Ralya, Jerry A.
Reese, Margaret L.
*Rooth, Ingrid
Rosenfeld, Melvin A.
Sharp, Arnold G.
Shultz, William S.
Stern, Margaret P.
Stimson, Paul B.
*Sullivan, James R.
Webster, Jacqueline
Williams, Rees C.
Wilson, Valentine P.
Woods, Donald E.

Department of Physical Oceanography

Alexander, Robert M.
Allen, Ethel B.
Andersen, Nellie E.
Andrade, Marie E.
Armstrong, Harold C.
Bailey, Phyllis T.
Barbour, Rose L.
Barrett, Joseph R., Jr.
Blanchard, Duncan C.
Bradshaw, Alvin L.
Breivogel, Barbara B.
Bruce, John G., Jr.
Bumpus, Dean F.
Bunker, Andrew F.
Chaffee, Margaret A.
Chase, Joseph
Cooper, John W.
Day, C. Godfrey
Densmore, C. Dana
Denton, Edward A.
Ewing, Gifford C.
Fofonoff, Nicholas P.
Frank, Winifred H.
Frazel, Robert E.
Fuglister, Frederick C.
Gifford, James E.
Guillard, Elizabeth D.
*Hammond, Paul D.
Hays, Betty C.
Heinmiller, Robert H.
Houston, Leo C.
Iselin, Columbus O'D.
*Kahler, Yolande A.
Maltais, John A.
Metcalf, William G.
Millard, Robert C., Jr.
Miller, Arthur R.
Munns, Robert G.
Parker, Charles E.
*Payne, Richard E.
Phillips, Helen F.
Reynolds, Carol J.
Ronne, F. Claude
Saunders, Peter M.
*Scaglione, Ferdinand C., Jr.
Schleicher, Karl E.
Schroeder, Elizabeth H.
Shodin, Leonard P.
Simmons, Charles F.
Simoneau, R. David
Soderland, Eloise M.
Spencer, Allard T.
Stalcup, Marvel C.
Stanley, Robert J.
Tarbell, Susan A.
Thayer, Mary C.
Volkmann, Gordon H.
von Arx, William S.
Voorhis, Arthur D.
Warren, Bruce A.
Webster, T. Ferris
Whitney, Geoffrey G., Jr.
Williams, Audrey L.
Worthington, L. Valentine
Wright, W. Redwood
Zemanovic, Marguerite P.
‡Zwilling, Avron M.

* Part Time Employment

‡ On Leave of Absence

Department of Administrative and Service Personnel

Aiguier, Edgar L.
*Allen, Norman T.
Anders, Wilbur J.
Anthony, Jane Ann
Backus, Jeanne M.
Bard, Wallace R.
Behrens, Henry G.
Benttinen, Dave D.
Branham, Roy L.
Bowman, Richard W.
Broadbent, Alice G.
Campbell, Eleanor N.
Carlson, Alfred G.
Carlson, Eric B.
Carlson, Gustav A.
Carlson, Ruth H. E.
Carreiro, Edward J.
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.
Crawford, Bruce
Crocker, Marion W.
Croft, Donald A.
*Dalton, George A.
Davis, Ruth H.
Day, Joseph V.
Dean, Mildred J.
Dimmock, Richard H.
Eastman, Arthur C.
Edmed, Sharon L.
Elder, C. Jean
Eldridge, Stanley N.
Endy, Judith E.
Fernandes, Alice P.
Fielden, Frederick E.
Fisher, Stanley O.
Fleet, Kenneth F.
Fredriksen, Mauritz C.
*Fuglister, Cecelia B.
Gallagher, William F.
Gaskell, Fred
Gioiosa, Albert A.
Grant, Carlton W., Sr.
Hafner, Richard D.
*Hahn, Jan
Hall, Arthur B.
Hampton, Carolyn S.
Hatzikon, Kaleroy L.
Henderson, Arthur T.
Hodgson, Sloat F.
Holmes, Linda A.
Ingram, Ruth C.
Innis, Charles S., Jr.
Jenkins, Delmar R.
Johnson, Harold W.
Kostrzewa, John A.
LeBlanc, Donald F.
LeBlanc, William A.
MacKillop, Harvey
Martin, Olive
McGilvray, Mary K.
§McHardie, James
Medeiros, Frank
Mitchell, James R.
Moniz, Priscilla J.
Morrison, Kenneth
Motta, Joseph C.
Motta, Joseph F.
Muller, John T.
Ortolani, Mary
Patterson, John E.
Phares, Edward
Picard, Eleanor P.
Pimental, John M.
Queenan, Martha L.
Quigley, Ralph W.
Ramsey, William S., Jr.
Reeves, Stanley A.
Reis, Janice A.
Rennie, Thomas D.
Roberts, Harry A.
Ross, David F.
Rudden, Robert D., Jr.
Schilling, John L.
Shave, Charlet A.
Simons, Cecelia M.
Smart, Thomas H.
*Solberg, Otto
Souza, Donald P.
Souza, James H.
Souza, Thomas A.
Stanbrough, Jess H.
Stansfield, Richard
Stimpson, John W.
Tometich, Louis J.
Vallesio, Barbara M.
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.
Ziegler, Evelyn L.
Ziegler, William N. D.

§ Deceased 3 January 1968

Marine Personnel

Allen, Thomas J.
Babbitt, Herbert L.
Backus, Cyril
Bailey, Peter H.
Barber, Courtenay III
Bazner, Kenneth E.
Brereton, Richard S.
Brown, John W.
Brown, Joseph C.
Bumer, John Q.
Cabral, John V.
Cahoon, Geraldine B.
Caranci, Donald H.
Casiles, David F.
Cavanaugh, James J.
Clarkin, William H.
Colburn, Arthur D., Jr.
Copestick, Louis B.
Cornell, Jack W.
Costa, Kenneth E.
Cotter, Jerome M.
‡Coughlin, Brooks W.
Crocker, John D.
Crouse, Porter A.
Curtis, Theodore J.
Davis, Charles A.
De Costa, Eugene P.
De Terra, George
Devlin, Gerald X.
Edwards, Richard S.
Erwin, Clarence E.
Halpin, William T.
Halverson, Leonard C.
Hamblet, Dwight F.
Hayden, Richard C.
Hiller, Emerson H.
Hiller, Hilliard
Holmes, Edwin M.
Howe, Paul M.
Howland, Paul C.
Janes, George R.
Jefferson, Albert C.
Johnston, Alexander T.
Jorgensen, Peter A.
Knight, Olin T.
La Porte, Leonide
Leiby, Jonathan
Lowney, Edwin A.
Martin, John W., Jr.
Martin, Ralph S.
Matthews, Francis S.
McLaughlin, Barrett J.
Miner, Arnold W.
Moller, Donald A.
Morse, Joseph C.
Mysona, Eugene J.
Ocampo, Conrad H.
‡Palmieri, Michael, Jr.
Pennypacker, Thomas R.
Pierce, George E.
Pierce, Samuel F.
Pike, John F.
Porrata, Carlos F.
Ribeiro, Joseph
Rioux, Raymond H.
Roy, Alfred J.
Santos, James E.
Seibert, Harry H.
Seifert, Charles T.
Smalley, Walter S.
Stires, Ronald K.
Sutcliffe, Leonard C.
Tully, Edward J.
Westberg, Donald R.
Wolcott, William R.

* Part Time Employment

‡ On Leave of Absence

Grants and Fellowships

The following persons were awarded grants, fellowships or honoraria during 1967:

RICHARD T. BARBER
Stanford University

VICTOR BARCILON
Massachusetts Institute of Technology

THEODORE BENTTINEN
Massachusetts Institute of Technology

STEVEN L. BLUMSACK
Massachusetts Institute of Technology

JAMES L. BISCHOFF
University of California, Berkeley

ANNE BOERSMA
Smith College

W. FRANK BOHLEN
Massachusetts Institute of Technology

FREDERICH BUSSE
University of California, Los Angeles

GEORGE BUZYNA
Yale University

THOMAS CHASE
Oberlin College

STEPHEN CHILDRESS
New York University

ALEXANDRE J. CHORIN
New York University

SYDNEY P. CLARK
Yale University

GEORGE M. CRESSWELL
Tiburon Oceanographic Institute

C. DAVID DECKER
Wabash College

CHARLES L. DENIS
University of Liège, Belgium

HOWARD J. EDENBERL
Queens College, New York

ARTHUR FINK
Swarthmore College

SULOCHANA GADGIL
Harvard University

LION GARDINER
University of Rhode Island

ROBERT M. GOLL
Ohio State University

BRUCE GORDON
Massachusetts Institute of Technology

HARVEY GREENSPAN
Massachusetts Institute of Technology

FREDERICK HESS
University of New Hampshire

SONJA E. HICKS
Indiana University

GREGORY K. HINCKLEY
Claremont Men's College

LOUIS HOBSON
University of Washington

RICHARD G. INGRAM
McGill University

LEONARD E. JOHNSON
University of California

JAMES J. KELLEHER, JR.
Rutgers University

BYRON KOLITZ
Massachusetts Institute of Technology

JOHN W. LADD
Williams College

M. JAMES LIGHTHILL
Imperial College, London

MICHAEL E. MCINTYRE
University of Cambridge, England

CHRISTOPHER NEVISON
Dartmouth College

STEVEN ORSZAG
Institute for Advanced Study, Princeton

THEODORA C. PAULSON
Queens College, New York

HENRY PERKINS
Massachusetts Institute of Technology

ROBERT PINKEL
University of Michigan

MAURICE RATTRAY, JR.
University of Washington

HANS T. ROSSBY
Massachusetts Institute of Technology

PETER E. SACHS
University of Reading, England

RICHARD I. SCARLETT
Cornell University

RACHELLE SENDER
Pembroke College

ANNE SPACIE
Mount Holyoke College

WESLEY STIMPSON
Tufts University

ALFREDO SUAREZ
University of Illinois

SUSAN TAFLER
Cornell University

WAYNE R. THATCHER
California Institute of Technology

RORY THOMPSON
Massachusetts Institute of Technology

NAFI TOKSOZ
Massachusetts Institute of Technology

HARRY TYLER
University of New Hampshire

PIERRE WELANDER
University of Stockholm

CARL WUNSCH
Massachusetts Institute of Technology

Treasurer's Report

The accounts for the year 1967 have been audited by Lybrand, Ross Bros. & Montgomery.

The book value of endowment funds at December 31, 1967 was $4,890,523, of which $2,272,205 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 $11,703 in cash was $7,174,280. Endowment fund investments and income received therefrom are summarized on page 79.

Income received on endowment assets was $255,743 for the year ended December 31, 1967, compared with $245,914 the previous year.

Endowment income represented a return on endowment fund investments of 3.6 per cent at year-end market quotation, 5.2 per cent on book amount and 9.8 per cent on the contributed amount of the endowment fund.

Endowment income was allocated for 1967 operating expenses at the rate of 6 per cent of the contributed amount of endowment funds, or $156,734. The remaining balance amounting to $99,009 was transferred to the income and salary stabilization reserve.

The Institution's 1967 contribution to the Woods Hole Oceanographic Institution Employees' Retirement Trust amounted to $331,923.

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, 1967 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 76 to 77, inclusive) present fairly the financial position of Woods Hole Oceanographic Institution at December 31, 1967 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, except for the changes, in which we concur, as explained in the note to the balance sheet.

The supplemental schedules included in this report (pages 78 to 79, inclusive) although not considered necessary for a fair presentation of the financial position and the 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 12, 1968

Lybrand, Ross Bros. & Montgomery

BALANCE SHEET

December 31, 1967

ASSETS

Endowment Fund Assets:	
Investments:	
Marketable securities, market value $7,103,962	$ 4,820,205
Real estate	58,615
	4,878,820
Cash	11,703
	4,890,523
Plant Fund Assets (note):	
Laboratory plant and equipment	3,566,915
Atlantis II, contingent title	4,831,130
Other vessels, equipment and property	1,492,928
Dock facility under construction	1,772,441
	11,663,414
Less accumulated depreciation (note)	2,368,902
	9,294,512
Plant funds advanced to current	1,386,942
	10,681,454
Current Fund Assets:	
Cash	1,208,189
Marketable securities, at cost	200,187
Reimbursable research contract costs:	
Billed	528,324
Unbilled, including $400,722 of December costs and $355,657 awaiting contract amendments	836,369
Supplies, prepaid expenses and deferred charges	180,156
Plant funds advanced to current	(1,386,942)
	1,566,283
	$17,138,260

LIABILITIES

Endowment Funds:	
Unrestricted as to income	$ 2,519,420
Unrestricted as to principal and income	98,898
Accumulated net gain on sales of investments	2,272,205
	4,890,523
Plant Funds:	
Expended for plant, less retirements	11,663,414
Less accumulated depreciation (note)	2,368,902
	9,294,512
Unexpended	1,386,942
	10,681,454
Current Liabilities and Reserves:	
Accounts payable and accrued expenses	259,231
Contribution payable to employees' retirement plan and trust	331,923
Unexpended balances of gifts and grants for research	36,767
Reserves	938,362
	1,566,283
	$17,138,260

NOTE — Prior to 1967 no depreciation was provided on Atlantis II and Laboratory of Marine Science and depreciation accumulated on other plant fund assets was not reflected in the valuation of such assets. Commencing in 1967, the Institution adopted the policies of reflecting accumulated depreciation in the valuation of plant fund assets and providing depreciation on Atlantis II and Laboratory of Marine Science. Accordingly, the beginning balance of funds invested in plant has been reduced by $2,046,992, representing accumulated depreciation on all plant funds assets as at December 31, 1966. Operating costs for 1967 include $203,252 of depreciation on Atlantis II and Laboratory of Marine Science. Depreciation is provided at annual rates of 2% on buildings, 3⅓% on Atlantis II and5% to 33⅓% on equipment. The amount provided is credited to accumulated depreciation.

Statement of Operating Expenses and Income

Year Ended December 31, 1967

Operating Costs and Provisions		
Direct costs of research activity:		
Salaries and wages		$2,848,248
Vessel operations		1,879,402
Materials, equipment and services		2,434,435
Laboratory costs		372,591
Travel		181,388
Service departments		290,061
Computer center		194,425
Aircraft operations		115,227
		8,315,777
Indirect costs:		
General and administration		1,136,501
Total depreciation	$389,180	
Less amount funded in direct and indirect costs above	185,928	203,252
Miscellaneous		115,329
Other charges:		
Provision for working capital and contingencies		22,083
		$9,792,942
Income:		
Income for sponsored research (including $3,080,412 gifts and grants expended):		
For direct costs		8,217,090
For indirect costs		1,078,454
Fees for use of facilities		199,488
		9,495,032
Endowment income availed of:		
For institution research		98,687
For Institution indirect costs		58,047
Development program contributions		79,589
Miscellaneous		61,587
		$9,792,942

Statement of Changes in Funds

Year Ended December 31, 1967

		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	**$4,483,594**	(Note) **$7,739,328**	**$789,439**	**$282,888**	**$161,446**	**$696,814**	**$217,204**
Gifts and grants received	7,000		1,643,601		3,064,171		
Endowment income						255,743	
Net gain on sales of investments	399,929						
Provision for working capital and contingencies							22,083
Provision for depreciation:							
Funded		(185,928)		185,928			
Unfunded		(203,252)					203,252
Availed of for direct and indirect research costs					(3,080,412)	(156,734)	
Transferred to acquisition of capital assets fund from:							
Working capital and contingency reserve			300,000				(300,000)
Unexpended balance of gifts from Oceanographic Associates			113,691		(113,691)		
Book value of asset removals		(1,182)					
Invested in plant		1,945,546	(1,836,198)	(92,407)	(16,941)		
Miscellaneous additions					22,194		
	$4,890,523	**$9,294,512**	**$1,010,533**	**$376,409**	**$36,767**	**$795,823**	**$142,539**

Note — The beginning balance has been reduced by $2,046,992 as explained in the note to the balance sheet.

Direct Costs of Research Activity

Year Ended December 31, 1967

	Salaries and Wages	Vessel Operations	Materials, Equipment and Services	Laboratory Costs	Travel	Service Departments	Computer Center	Aircraft Operations	Total
U.S. Government:									
Contracts	$1,971,029	$ 887,769	$1,809,975	$257,687	$116,315	$220,768	$152,669	$ 47,100	$5,463,312
Grants	818,194	991,360	510,934	107,527	57,346	48,170	38,361	66,762	2,638,654
Other sponsored research	14,613	273	69,851	1,973	5,463	18,806	2,780	1,365	115,124
Total direct costs of sponsored research	2,803,836	1,879,402	2,390,760	367,187	179,124	287,744	193,810	115,227	8,217,090
Institution research	44,412		43,675	5,404	2,264	2,317	615		98,687
Total direct costs of research	**$2,848,248**	**$1,879,402**	**$2,434,435***	**$372,591**	**$181,388**	**$290,061**	**$194,425**	**$115,227**	**$8,315,777**

*Includes grants and fellowships:	
U.S. Government grants	$ 44,504
Other sponsored research	22,102
Institution research	40,664
	$107,270

Summary of Investments

As at December 31, 1967

	Book Amount	% of Total	Market Quotation	% of Total	Endowment Income
BONDS:					
Government and government agencies	$1,132,525	23.3	$1,086,853	15.3	$ 53,421
Railroad	288,243	5.9	231,880	3.2	16,575
Public utility	485,262	9.9	409,106	5.7	21,477
Industrial	404,127	8.3	343,453	4.8	15,245
Financial and investment	337,047	6.9	310,504	4.3	15,839
Total bonds	2,647,204	54.3	2,381,796	33.3	122,557
STOCKS:					
Preferred	52,270	1.0	41,250	.5	2,680
Common:					
Public utility	409,673	8.4	1,031,176	14.4	35,473
Industrial	1,434,279	29.4	3,353,840	46.8	76,527
Miscellaneous	276,779	5.7	295,900	4.2	15,512
Total common stocks	2,120,731	43.5	4,680,916	65.4	127,512
Total stocks	2,173,001	44.5	4,722,166	65.9	130,192
Total marketable securities	4,820,205	98.8	7,103,962	99.2	252,749
REAL ESTATE	58,615	1.2	58,615*	.8	2,994
Total investments	$4,878,820	100.0	$7,162,577	100.0	$255,743

*At book amount.