WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

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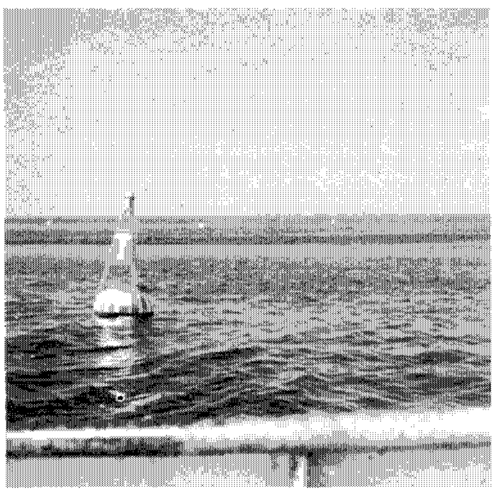

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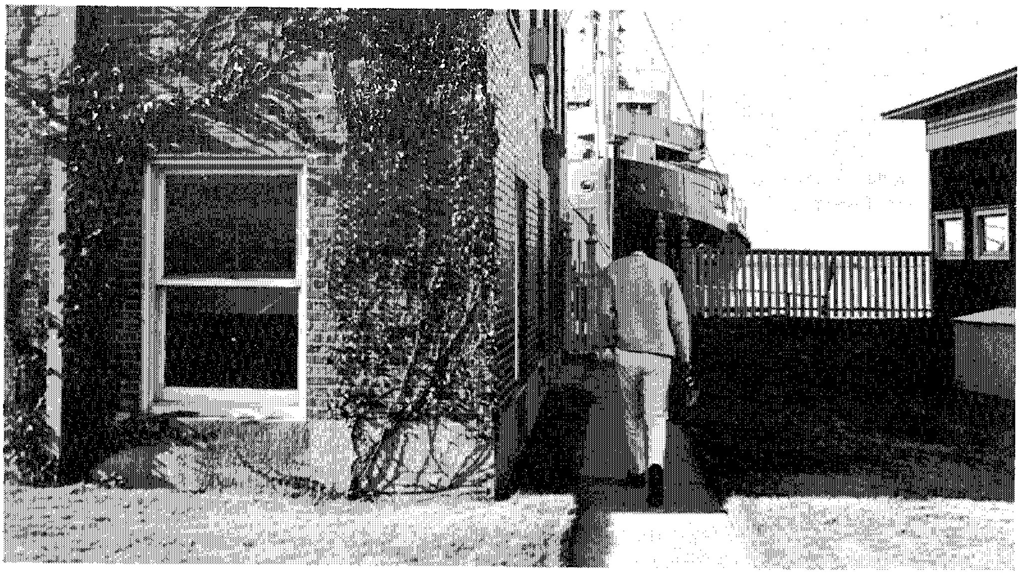

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Signing ceremony for the Joint Program in Oceanography, Woods Hole Oceanographic Institution-Massachusetts Institute of Technology, on the fantail of CHAIN, *8 May 1968. Seated: Howard W. Johnson, President (M.I.T.) (left), Paul M. Fye, President (W.H.O.I.). Standing (left to right): H. Burr Steinbach, Dean of Graduate Studies (W.H.O.I.), Jerome B. Wiesner, Provost (M.I.T.), Frank Press, Head, Department of Earth and Planetary Sciences (M.I.T.).*

THE DIRECTOR'S REPORT
Woods Hole . . . and National Goals

The temptation is always with me, when making this annual report to the various Institution constituencies, to restrict my remarks to oceanographic matters or, even more provincially, to those activities within our own Institution. But oceanography, as big and vital as it certainly is, cannot be considered a separate entity to be evaluated outside the context of national and international needs and directions.

We all recognize that extraordinary turbulence and change are reshaping our world. The purposes of our Nation in such a world are being scrutinized with great care. National priorities are being reconsidered. Major governmental and private activities, including the sciences and oceanography, are being reviewed in the light of many critical social, economic and scientific goals. In this, my eleventh Annual Report, I wish to consider the impact on the Institution and on oceanography in general as this national re-evaluation takes place.

The Report of the President's Commission on Marine Science, Engineering and Resources has assigned oceanography and ocean development a rational and meaningful place in the identification of national priorities. After two years of intensive work by a diversified and dedicated committee under the chairmanship of Dr. Julius A. Stratton, the Report was published in January, 1969, under the simple and yet prophetic title, *Our Nation and the Sea.* The achievements of this document are many. Most important, though, it has attached new national perspective to the young science of oceanography.

The Stratton Commission Report may well be the most important single document concerning the oceans in our lifetime. The New York Times calls it "A rare combination of imagination and realism." This Report has charted a course which, if followed, can insure that the oceans will benefit all mankind for generations to come through the leadership of the United States.

Our list of needs in oceanography and at the Institution is long and urgent: additional brilliant people, better facilities, more capable research ships, more money, greater freedom from restrictions and so on.

Such a catalog of needs is factual and accurate but, in my opinion, it does not include the greatest single need of oceanography. What has been needed, and what has been largely supplied in 1968 by the President's Marine Science Commission, is a thorough articulation of the logical place of oceanography in the Nation's list of priorities as it moves into the 1970's. The Commission has provided a marine sciences blueprint which is scaled to the total nation-building plans of the future.

We scientists are not unmindful of the fact that science is merely a part of an intricate mosaic of the national life, and does not comprise the entire picture. Our daily lives are immersed in the engrossing pursuit of greater understanding of the enormously complex marine environment. We often experience frustration in the conviction that our efforts and results are woefully inadequate when compared with the vast potential held by the seas.

We know full well that marine science and ocean development are vital national concerns only to the extent that a reasonable and productive proportion of national resources and energies are invested in the activity. Other national problems must be attacked, and some are more immediate than the technological ones. Many major social problems are demanding solutions which have been denied far too long. Poverty and malnutrition, unemployment, poor housing or no housing, racial strife, chaotic cities, inadequate medical care — these and other problems should and will receive an effective share of the nation's financial and human resources. Justice and common sense demand a viable national effort to solve immediate problems while maintaining long-range goals, such as developing the seas, at a reasonable and progressive rate. Responsible scientists seek no more, and the Nation deserves no less.

Those of us seeking new knowledge and understanding of the oceans so that the marine environment may be used more wisely do not hold ourselves aloof from American social and political problems. We do not expect public support merely because we are doing good science. To be aloof is to be irrelevant, and the relevance of marine sciences is self-evident. It is no understatement to suggest that greater understanding of the physical, chemical, biological and geophysical nature of the oceans will contribute to the welfare of mankind and it is on the value of this contribution that public support for oceanography must be based.

The fifteen-man Marine Science Commission has considered both science (understanding the oceans) and engineering (doing things in the oceans) in its report. The recommendations contain many details for organizing the national oceanic effort — far too many to be considered here. Many of the recommendations, if adopted, will in one way or another profoundly affect the Institution in the years ahead. Other points in the Report are aimed solely at Government reorganization for greater efficiency and productivity. I do not know how many of the recommendations will survive the territorial instincts of congressional committees and Federal agencies. I do not, myself, endorse every proposal in the Report. The subject is far too complex to receive universal commendation; but I applaud and support the purpose of the Commission's recommendations, and the general direction in which they are attempting to move the ocean sciences. I hope Congress will adopt most of the Commission's recommendations, and I believe that the Institution should prepare itself for active participation in the plans embodied by the Report.

The Commission has recommended that a new agency be set up to oversee the Federal Government's civilian activities in the oceans. The establishment of an independent agency which reports directly to the President and, most important, answers to a unified ocean activities committee in each house of Congress, is the most important recommendation in the entire Report. They have taken the position that the present confused proliferation of oceanic agencies and congressional committees, while not entirely bad, in the end is not very efficient or productive. "A new strong Federal focus for marine activity is essential . . . to meet the Nation's economic and social needs. New programs must be created. . . . Piecemeal solutions are not sufficient. It is necessary to place together the central civilian functions under single management in order to have a coherent effort."

The proposed National Oceanographic and Atmospheric Agency (NOAA) would be composed of the Bureau of Commercial Fisheries, Environmental Science Services Administration, National Oceanographic Data Center, Sea Grant College Program, U.S. Coast Guard and U.S. Lake Survey Office.

If the agency is established as recommended, NOAA would then be comprised of 55,000 employees, 320 seagoing ships and 38 laboratories. The Federal Government's ocean activities would be clearly visible to the public and the reasons for these activities would be clear and would receive a continuing place in national priorities.

Some may say this is too big an agency, but the ocean problems are gigantic. Others may quibble with the composition, and I too had proposed to the Commission over a year ago another plan for an ocean agency. But the important over-riding point now is that a new composite civilian agency is essential to the healthy growth of the Nation's ocean activities.

In my opinion the Nation's interests will be well served by the establishment of NOAA, even if modified by Congressional action.

I also support the Commission's recommendation for the establishment of a National Advisory Committee for the Oceans (NACO) composed of 15 members drawn from outside the Federal Government broadly representing the Nation's marine and atmospheric interests. NACO would report to the President and to Congress on the progress in achieving the National ocean goals and would provide two-way communication between Federal and non-Federal interests. The National Advisory Committee for the Oceans, even though of vital importance, should not be considered a substitute for the agency or other key Commission recommendations.

The Institution is likely to be affected most dramatically if the Commission's recommendation to establish three or four major University-National Laboratories is adopted.

Within the Staff Council of the Woods Hole Oceanographic Institution, we have begun a series of intensive meetings to study and analyze the entire Commission Report, and to arrive at our own policy recommendations for consideration by the Board of Trustees. We are most interested, of course, in the implications of the University-National Laboratory concept.

Here are excerpts from the Commission report which explain their reasons for proposing partial Federal support for a few larger institutions by identifying them as University-National Laboratories.

> "The Commission finds that the U.S. position of world leadership in marine science depends mainly on the work of a small number of major oceanographic institutions. These few large, well-staffed, and relatively well-financed centers of oceanographic research have had a profound influence on scientists and programs at other institutions and have established criteria of excellence for the efforts of others. Such institutions as Scripps Institution of Oceanography, Woods Hole Oceanographic Institution and Lamont Geological Observatory represent a major national investment around which the Nation's marine science program must be built.

"The need for such major centers is the result of the very nature of the seas. One of the most demanding tasks of marine science is to conduct large, multi-disciplinary efforts far from bases of logistic support and often in hostile environments. The growing sophistication of research techniques under such difficult conditions requires large complex facilities, well-equipped ships, large stable platforms, deep-drilling vessels, deep submersibles, underwater laboratories, large arrays of buoys, experimental structures of several kinds, extensive shore facilities, and open areas where experiments in environmental modification and control may be conducted.

"In brief, marine science has become big science even though its facilities' requirements still may be modest compared to those for the space, nuclear energy, and national health programs.

"Creation of big science capability in a few efficient centers is more economical than pursuing the major scientific tasks on a scattered project-by-project and facility-by-facility basis. Yet, the nature of funding by the Federal Government often has hampered the development of such centers."

In answer to a question from the Commission a year ago, I suggested that we needed a variety of types of laboratories in the United States concerned with ocean studies. Some should be matched in size and complexity with the problems to be investigated in the oceans. Many of the important problems worthy of solution are at least as large and complex as an entire ocean basin and can only be solved by teams of scientists and engineers involving many disciplines and talents using highly sophisticated (and often large and specialized) research tools such as large ships and specialized computers. Consequently, some of the oceanographic laboratories must also be large and complex enough to tackle these problems. Some of these will be involved in obtaining a better fundamental understanding of ocean phenomena and with basic problems about life in the sea. These should be funded on a continuing stable framework and given a great deal of freedom in planning programs.

If the Woods Hole Oceanographic Institution were to become one of the University-National Laboratories as outlined in the Commission Report, some of the basic operational costs of the entire Institution would be block-funded. For instance, NOAA would fund a significant portion of our salaries, ships and other facilities in order to provide the fiscal continuity so badly needed to carry on long-range research. In turn, the Institution would formalize its present informal practice of cooperating with scientists from other institutions and universities by making available to them time on our ships and in our laboratories. Perhaps 10 to 25 per cent of the Institution's facilities would be scheduled for use by non-resident scientists. Support for research projects of Institution scientists would continue to be provided by the National Science Foundation, Office of Naval Research, and other traditional supporters of basic marine studies.

Naturally, such a proposal raises many questions within the Institution. Immediately, we would seek assurance that our scientific independence would remain intact in such an arrangement. Here, it is useful to quote from the Commission's Report again, calling attention to the laudable philosophy within which it makes its recommendation:

"Scientific research and analysis must be supported to overcome inadequacies in our understanding which limit the Nation's use of the seas. The quest for basic knowledge has also for many years received Federal support, because our people share the curiosity of scientists about the nature of man, his planet, and his universe, and because they share the scientists' conviction that over the long term the quest will yield knowledge that can better man's condition.

"The Commission notes with misgiving the recent tendency to condition Federal support of science on a prospect of imminent, tangible results of economic value.

Certainly a large body of research directed to such results is necessary, but it would be contrary to the national interest to overemphasize applied research at the expense of fundamental understanding. Research motivated solely by the curiosity of scientists has produced, with compelling regularity, unanticipated applications which have improved man's lot and literally changed the face of the earth.

"There is much to be learned about the planet earth, and many keys to learning are in and under the sea. The total body of oceanic knowledge is advanced best by the pursuit of fundamental understanding of the biological, physical, geological, and chemical characteristics of the planetary oceans without regard to immediate applications. Continuing and substantial support of basic marine science is a national investment which will provide an underpinning for all future activities in the sea."

As this proposal now stands, and subject to some clarification, I believe that the marine sciences and the nation would benefit greatly if this program were to be put into effect. The Trustees of the Woods Hole Oceanographic Institution will be studying the proposal carefully in the coming months. The ultimate charter which will establish NOAA and the University-National Laboratories may well contain some modification of the Commission's recommendations. I believe that it is vital to the interests of the Nation that Woods Hole be prepared to contribute positively to the formation of that charter. It is our responsibility, as a major oceanographic institution, to contribute our best thoughts to all attempts to achieve a new and more meaningful national program for ocean science.

The Commission has provided Congress and the President with an opportunity to establish a permanent and stable place for oceanography in the list of national priorities. Much time and energy has been devoted to searching for new national perspectives, and rightly so. Dr. Stratton and his Commission have given us a national sense of direction which — if implemented by the Federal Government — now can enable us to launch a new decade of accomplishment in the oceans — a new era which will see the world begin using the oceans wisely and productively and in peace.

The opportunities for material gain are great, but the opportunities for understanding nature are even greater. Perhaps the greatest opportunity of all, as already demonstrated by many successful international expeditions, is that of cooperation among nations of the world in working together in this our common frontier. The ocean is everybody's front yard, the one physical boundary shared by 121 nations. It is today too often a confused and contested boundary, sometimes in dispute and on occasion a divisive factor rather than a uniting one. Commercial development of the world's oceans will be done in harmony, or not at all. Raw competition for the wealth of the seas is doomed to failure at best, and could lead to world disaster. The Federal Government, in cooperation with American industrial leadership, is uniquely capable of initiating peaceful, cooperative development of the oceans. This, I believe, is the moment to take the initiative. The world will not stand by while nations hold each other at bay on a sea of food and mineral resources for which there is a growing need. As the nations of the world learn to use the oceans wisely, the Woods Hole Oceanographic Institution must continue to be an important agent for positive action and scientific leadership.

PAUL M. FYE, *Director*

March 14, 1969

Report of the Dean of Graduate Studies

The past year has been marked by the moulding into a more visible form the important role the Institution has played and will develop in the training of scholars of the oceans. Since its founding in 1930, the Institution has provided scholarly guidance for the development of ocean scholars, some of whom have been awarded a doctorate by cooperating institutions, some of whom have never taken the time to invest themselves with the formal academic title, but have simply gone on to make outstanding contributions to knowledge.

Since late in 1967, the Institution has been authorized by the Commonwealth of Massachusetts to grant graduate degrees in Oceanography. In the early spring of 1968 the first formal degree program was initiated by the signing of a joint agreement with the Massachusetts Institute of Technology whereby a properly qualified student could be awarded a doctorate in oceanography by the authority of the Trustees of M.I.T. and the Trustees of the Woods Hole Oceanographic Institution upon the recommendation of joint faculty committees. Students are now registered in this joint program and several are already engaged in the final stages of their thesis work. This program was ensured of success by the wise guidance of Dr. K. O. Emery, who served as Acting Dean until September 1, 1968 when the present incumbent came on deck.

The existence of the fine and adventurous joint program with the Massachusetts Institute of Technology is not intended to limit either Institution with respect to its own programs. Especially at the Woods Hole Oceanographic Institution, it is intended to continue the fine cooperation we enjoy with a number of leading universities. In the past, this has involved primarily the pursuit of thesis research using our facilities and our staff guidance of the projects. With Yale University, the cooperative effort has been somewhat more formalized with the intention of continuing to assist Yale graduate students as we have in the past, but, in addition, providing that the Woods Hole Oceanographic Institution students will be welcome to the Yale campus for advanced course training if needed.

General Faculty Meetings have been held and advisory groups activated. The degree of interest in the educational program can give us complete confidence in the success we will enjoy in the training of young people to be the best oceanographers.

A productive and rewarding attitude adopted by the interested staff members of the Woods Hole Oceanographic Institution was that, as a community of scholars devoted to the solution of problems of the oceans, we have a special responsibility to devise a program based on fundamental objectives, unhampered by some of the academic structures deemed essential to the operation of a more diffuse type of university structure.

The following words express the general philosophy and intent of the Woods Hole Oceanographic Institution graduate degree program:

"Oceanography encompasses all of the scientific observations made on that fraction of the earth covered by sea water. The Woods Hole Oceanographic Institution offers the opportunity to a relatively small number of outstanding young men and women to prepare themselves for careers in oceanography.

"The professional oceanographer needs to possess two characteristics. First, he must be a good scientist and second, he must know his material. In the modern scientific world, the first requirement usually means special expertise so that, for example, an oceanographer interested primarily in the chemical characteristics of the oceans must be a good chemist. However, since the oceans represent a dynamic system where the interactions are of critical importance, the oceanographer must also be thoroughly grounded in a knowledge of the other interacting components. In other words, he must know his oceans. The balance between these two facets of the complete oceanographer varies widely with individual aptitudes and training. Both facets are essential for the true scientist of the seas.

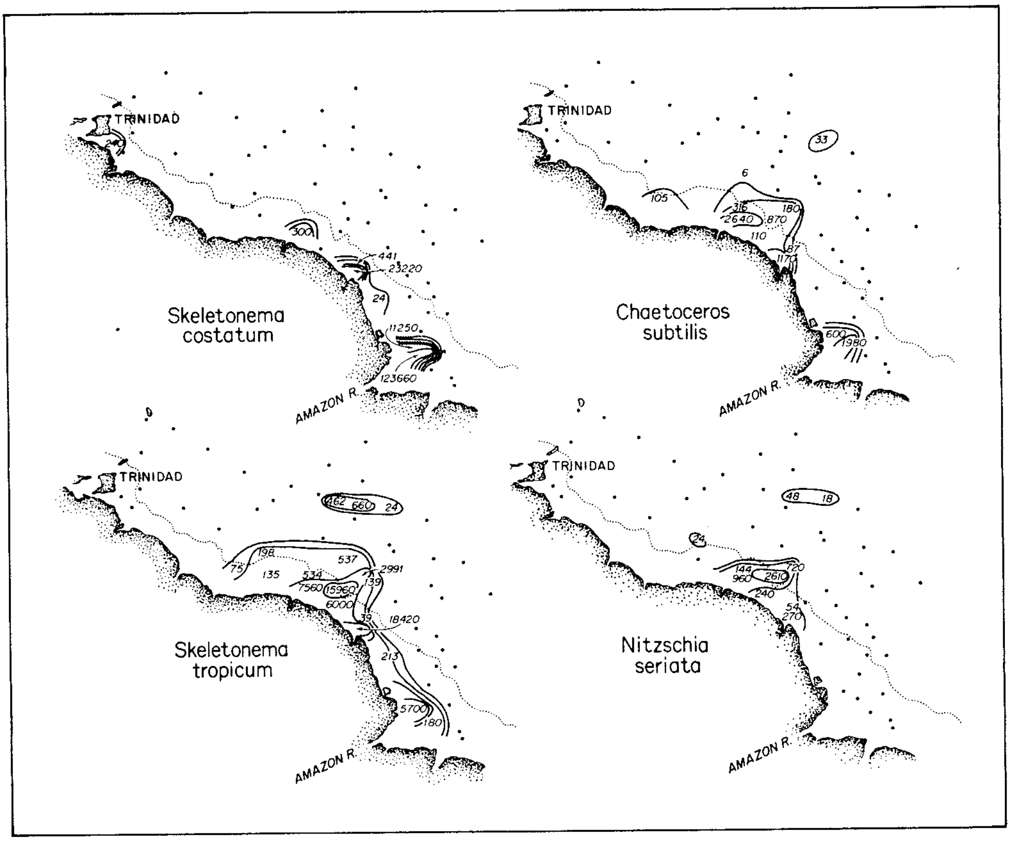
"Students working at the Institution must be capable of self-directed work. Major emphasis is placed on reading, experience in research, seminars and discussions. Relatively few courses are offered in a formal sense. Specialized and advanced basic course work may be undertaken as needed for proper intellectual development at recognized universities in the area by special arrangement.

"All students are encouraged to develop broad competence in the several fields of science related to oceanography, as well as exhibiting special skills and knowledge necessary to offer a thesis representing an independent contribution to knowledge in depth. Students wishing to undertake graduate work in oceanography should develop competence in general science including mathematics, physics, biology and chemistry. A first class science major is desirable, preferably with the breadth indicated above.

"Consistent with the very scope of the oceans themselves, the Institution recognizes that students may enter their training from a wide variety of intellectual backgrounds. With a relatively small student body and large staff, programs may be formulated and progress gauged with proper attention to individual needs.

"Students in residence on the Woods Hole campus have an unparalleled opportunity to work as junior scientists in a major world center for Marine Sciences. Lectures, courses and seminars are available at the Marine Biological Laboratory, as well as at the Oceanographic Institution. In addition, the special skills of the staff members of the Bureau of Commercial Fisheries constitute a major asset to the total intellectual atmosphere of Woods Hole. Especially during the summer months, visitors from all parts of the world give the Institution the benefit of their knowledge."

H. BURR STEINBACH,
Dean of Graduate Studies



Phytoplankton and outflow from the Amazon River. Certain diatoms were abundant out to the 100-fm contour off the mouth of the Amazon and even farther off French and Dutch Guiana.

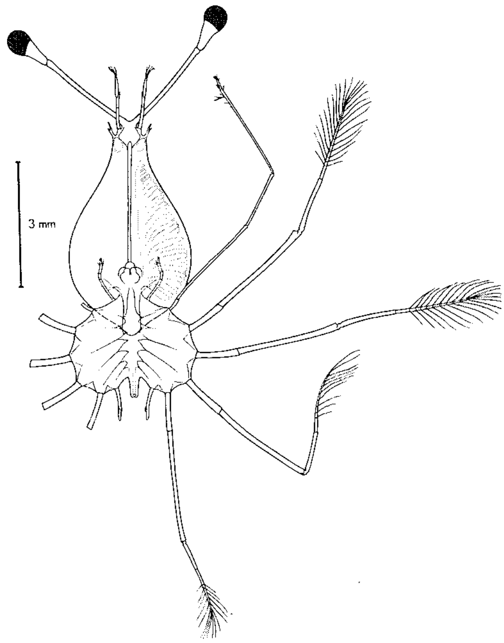
Department of Biology

Carbon Budget and Food Chains

During the past several years our observations have shown that the concentration of both dissolved and particulate organic matter is essentially constant, both vertically and spatially, throughout the Atlantic Ocean below depths in excess of a few hundred meters. This being the case it is not clear how populations of deep-living planktonic and benthic animals are related to varying levels of organic production at the surface of the ocean. During 1968 two major cooperative cruises were made to gain some insight into these problems; the first to the rich coastal area of Southwest Africa and the second to the impoverished Campeche Bank in the Gulf of Mexico. Attempts were made to study the effect of bottom depth on the carbon budget of the overlaying water column including the major faunal groups within it and associated with the sediment below it. Preliminary results from these two cruises indicate that the particulate carbon in deep water (i.e., the food available to deep-dwelling organisms) is not influenced by the rate of organic production at the surface. The biomass of zooplankton and benthos decreased exponentially with increasing depth of the water and large population differences in plankton were noted only in the upper few hundred meters.

These observations strongly suggest that the quantity of organisms occurring in the deep-sea is not controlled by particles "raining" down from the surface as has commonly been presumed (and in fact that no such "rain" exists). The process of elimination dictates that the primary mechanism by which energy is transferred vertically through the water column must be by the organisms themselves by means of overlapping migratory excursions reaching eventually to the bottom.

Implicit in the above argument is that the recycling of surface-produced organic matter must occur rapidly near the surface, and that little or no decomposable material enters the deep-sea either in particulate or dissolved form. The correctness of this statement may be argued from several directions. Our studies of the distribution patterns of biological tracers have shown that changes in the concentration of oxygen, phosphate and nitrate cannot be correlated with *in situ* alteration in organic matter, but that their concentrations are dependent upon the physical mixing of water masses. It is now felt that this situation exists at depths in excess of 200-300 meters and therefore that all regeneration of organic matter must occur above this depth. The oxygen minimum zone, long presumed to be either the layer of maximum biological and chemical activity or the layer of least motion, is probably produced in very local areas of the coastal Canaries' Current in the North and the Benguela Current in the South Atlantic. Significant quantities of nitrifying bacteria have been found only in the upper ten meters of the water column and no detectable uptake of glucose or acetate by bacteria have been measured in deep waters of the open ocean. These facts together lead us to consider the ocean as a two-layered system in which over 95% of the biological cycling and regeneration occurs in the upper five percent of the ocean depths.



Phyllosoma larva of ? Arctides quinensis *(6.6 mm).*

Primary Production and Phytoplankton Physiology

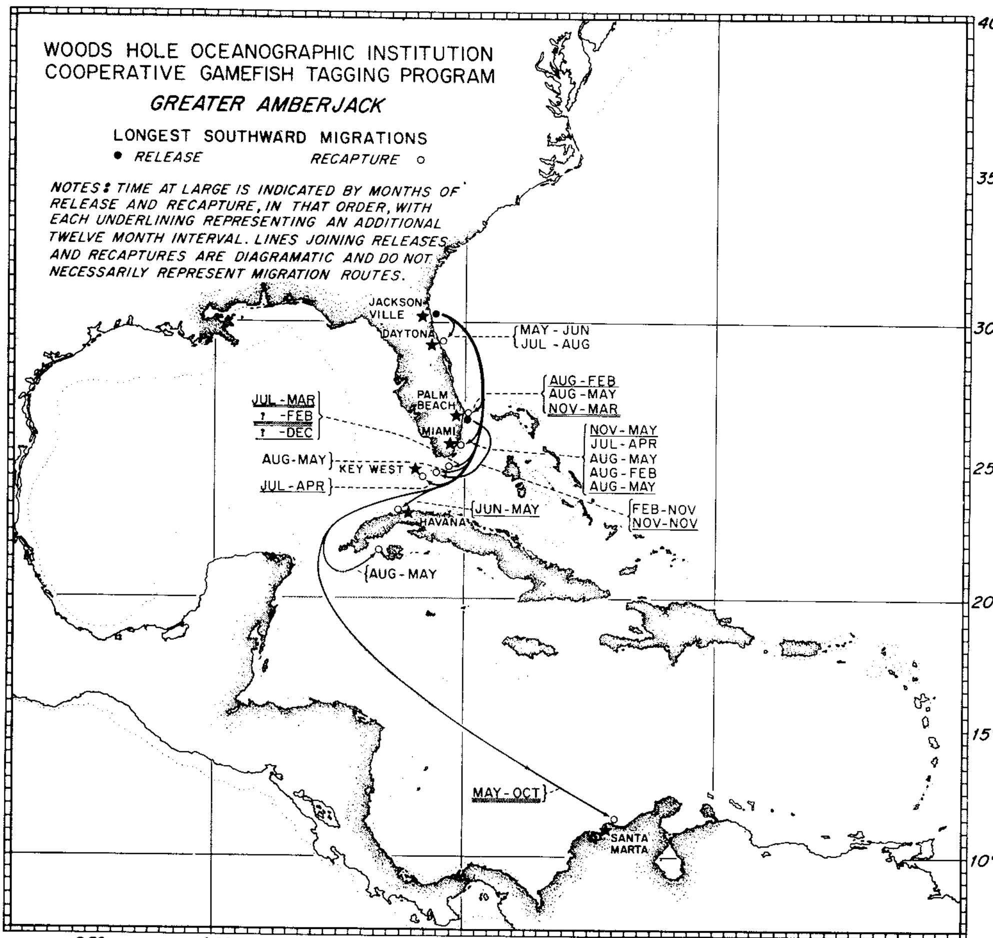
When visible radiation from the sun and sky passes into the sea, differences in the rates of adsorption and scattering result in changes in the spectral composition of the light beneath the surface, due in part to the water itself, and in part to the particles suspended within it. During 1968 a spectrophotometer has been used which can measure these changes from aircraft flying rapidly over the sea surface, primarily with the intent of mapping the areal distribution of plant pigments. When perfected, this technique will constitute a valuable new tool for rapid oceanographic survey in relation to the productivity of the sea.

Statistical treatment of a large volume of available productivity data has shown that significant correlations between surface chlorophyll and both productivity of the entire water column and the depths of the euphotic zone may be obtained.

Physiological studies in the laboratory are being continued to determine the mutualistic interactions between marine bacteria that produce vitamin B_{12} and algae which require the vitamin and in turn produce the organic matter upon which the bacteria metabolize.

Bacteriology

A new method has been devised for measuring rates of bacterial growth and biochemical transformation in seawater. The principle of this technique is based on the calculation of the actual growth rate, from the dilution rate of a chemostat system run with natural seawater, and the washout rate of the particular bacterial isolate tested. Doubling times ranged from six hours in estuaries to more than 300 hours in offshore tropical waters. Studies have also continued on another group of



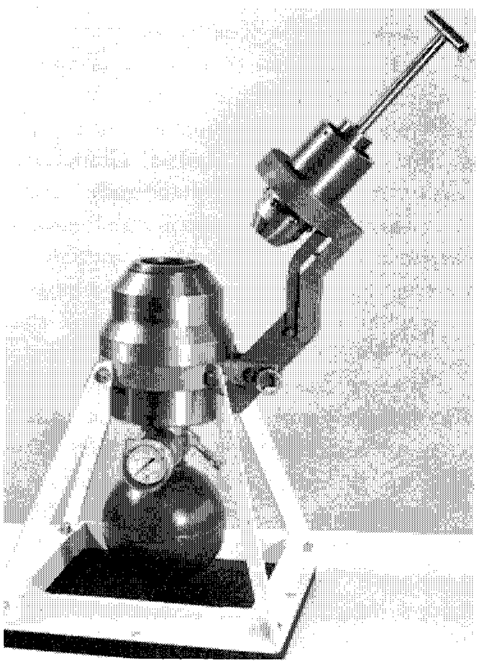
Migrations of the greater amberjack.

bacteria, those that oxidize ammonia to nitrite and nitrite to nitrate. Particular attention has been paid to enzyme systems, their relation to plasma membranes, and the modes by which these oxidative reactions are accomplished.

Vertebrate Physiology

Studies are being continued on the capacity of and the mechanisms by which, large oceanic fishes are able to achieve thermal regulation. Several species of shark and tuna have now been shown to have this capacity and may have body temperatures as much as 10°C higher than the surrounding water. The blood of these warm bodied fishes has been shown to be clearly different from other fish in that its affinity for oxygen shows little sensitivity to temperature change.

In the area of diving physiology, a technique has been developed to obtain oxygen exchange measurements on a free diving porpoise. On command the animal dives to 500 feet, turns off a buzzer, returns to the surface, and breathes into a funnel. Results show that a continued but diminished rate of oxygen absorption occurs while the animal is at depth, and that part of the breath is still in the lungs and is available for diffusion to the pulmonary blood flow at the conclusion of the dive. Man, on the other hand, does not have a comparable functionally-useful diving reflex and is therefore a poor diver.



A pressure transfer capsule for the retrieval of living benthic animals from the deep sea.

An investigation of physiological parameters of sustained flight in sea gulls was initiated during the past year. Their heart beat, breathing, wing beat, and body temperature has been monitored by telemetry during relatively long sustained flights.

Distributional Studies

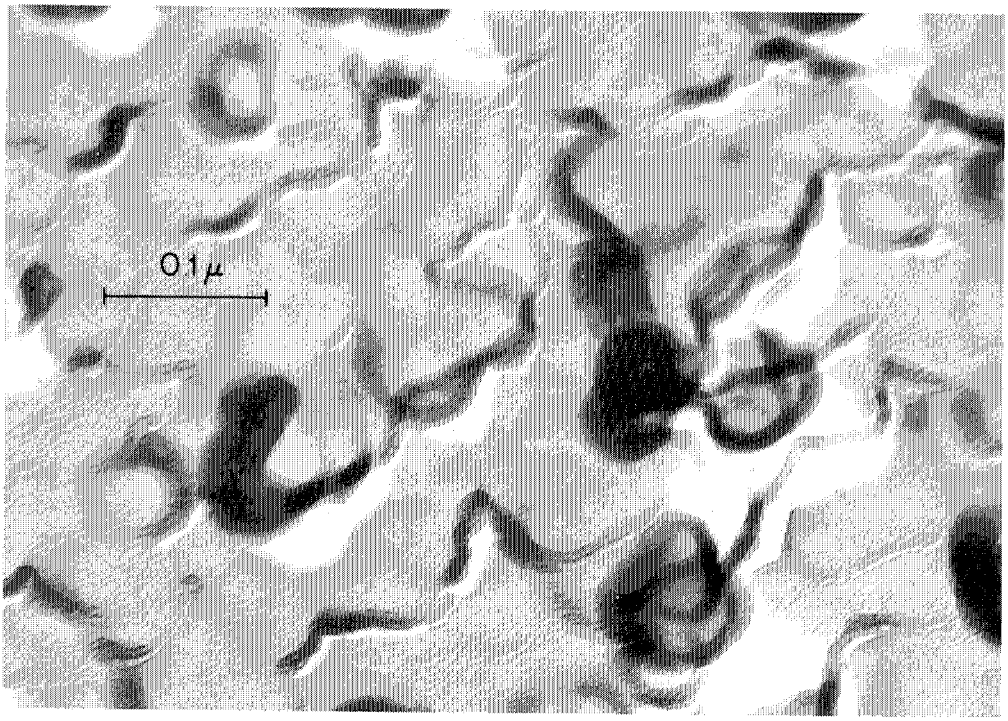
Other studies during the past year in the Department of Biology have furthered our knowledge of the systematics, distribution, migration, means of dispersal and general ecology of marine organisms. Specific groups which have been studied in this context include the phytoplankton, copepods, benthic invertebrates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

Particularly noteworthy was the discovery of several species of calanoid copepods which live only in close proximity to the bottom. These results were obtained by towing closing plankton nets from the DSRV ALVIN a few meters above the bottom.

Studies of mesopelagic fishes have now progressed to the extent that distinct faunal boundaries and the distribution of particular species in the Atlantic Ocean may be associated with recognized though sometimes subtle physical characteristics of water mass boundaries.

JOHN H. RYTHER, *Chairman*

DAVID W. MENZEL, *Assistant Chairman*



Electromicrograph of otilith of Aplodinotus grunniens. *The protein chains are coiled in a systematic pattern (plantinum-carbon replica).*

Department of Chemistry

This Department, which was formed in the re-organization of departments in May 1967, reached its peak size of 47 total personnel early in 1968. The staff had been increasing at the rate of about 30% a year since 1964, with several new areas of chemical research being initiated. Space for the expanding Department was provided on the third floor of the Laboratory of Marine Science, the biggest increase occurring when the computer group moved out in the spring of 1968. During 1968 the unanticipated severe budget cuts caused a reduction in staff. Total staff by mid-1969 will be about 35, representing a 25% decrease from our peak. This reduction was accomplished largely through normal attrition and some transfers, plus the closing down of the radiochemical work at Clark University. Although none of the major areas of research have been eliminated, several projects are working with essentially a skeleton staff.

Red Sea—Black Sea

The Red Sea project, which has been discussed in detail in previous Annual Reports, was completed early in 1968. This work will be published as a symposium volume by Springer-Verlag Inc. in the spring of 1969. Over 70 scientists contributed 50 papers on various aspects of the Red Sea study using samples and data obtained during our cruise in the fall of 1966. Our work in the Red Sea has encouraged several companies to consider this area for its economic potential. Current estimates are that the top 10 meters of sediment in the Atlantis II Deep are worth about 2.3 billion dollars counting only the elements copper, zinc, silver, and gold.

As part of our general program to make a study of inland seas and their relation to the oceans, we have made elaborate plans for a cruise to the Black Sea in the spring of 1969. This cruise will involve personnel from all five of the departments of the Institution as well as scientists from Sweden, Germany, Turkey, Romania, and possibly Russia.

Sea Water Chemistry

The stochastic modeling of trace element distributions in the ocean has been attempted using a first order Markov chain to describe and predict the distribution of such elements as nickel in the Atlantic Ocean. The Atlantic Ocean was divided into seven blocks, each having a surface and deep layer. Within each block and layer, nickel was considered to be in a dissolved and particulate state, and each of these states was considered as transient states for the absorbing Markov chain. The bottom of each block of the ocean and the Antarctic Ocean were established as absorbing states. Using literature data a matrix of transition probabilities between transient states and between transient and absorbing states was constructed, and from this a matrix of mean residence times for nickel in each of the transient states was calculated. The equilibrium concentration of dissolved nickel in each block and layer of the ocean was calculated from the matrix of mean residence times and the literature data on the annual input of nickel from rivers and from the Antarctic Ocean. The preliminary model gave the following conclusions: (1) The uptake of trace metals by organisms at a rate so low that it is not detected as seasonal variations (less than 5% per year) can be effective in causing differences in the mean concentrations of dissolved metals in different parts of the ocean. These differences may be as much as a factor of 3 or 4 in the Atlantic Ocean; (2) The concentration of trace metals such as nickel in the Atlantic Ocean may be dominantly controlled by an input from the Antarctic Ocean.

Sea water samples from the northeast Atlantic were analyzed for zinc, copper, nickel, iron and cobalt using a technique of solvent extraction coupled with atomic absorption spectrometry. The results confirmed previous work on trace metal distribution in the northeast Atlantic, in particular, showing a significant increase in the concentrations of nickel with depth from about 1.5 micrograms per kilogram at the surface to about 2.4 in the deep water. Samples from 7,000 meters in the Puerto Rico Trench did not have anomalously high trace metal concentrations.

A new method for trace metal analysis involving the formation of volatile metal chelates and their analysis by gas chromatography and mass spectrometry is being investigated.

In studies on the determination of fluoride in sea water using a fluoride specific ion electrode, it was established that about 50% of the fluoride is combined as the ion pair, MgF^+. The degree of pairing is temperature dependent with less fluoride being complexed at lower temperatures. The existence of this ion pair probably has an important bearing on the formation of fluoride minerals in the ocean. It also may aid marine animals in tolerating a relatively high fluoride environment.

Additional refinements were made in the technique of difference chromatography used to examine small variations in the major ions in sea water. The threshold sensitivity of the analysis being used is about 5 ppm for Na^+, 0.6 ppm for Mg^{++}, 0.1 ppm for Ca^{++}, and 0.1 ppm for K^+. To yield these sensitivities a membrane salinometer has to detect changes as small as 0.00005 parts per thousand. The technique was used to examine entire water columns from the Puerto Rico Trench, the Sargasso Sea, and the Gulf of Mexico. Large enrichments of Ca^{++} (2.0%) were found in the deep waters of the Gulf of Mexico, minor depletions of Ca^{++} were found in surface water near Bermuda, and a slight enrichment of K^+ was in surface water off Puerto Rico. In general, however, the North Atlantic is too well mixed to show differences in major ions. The largest differences appear to show up in isolated or nearshore water masses. The membrane salinometer also was used to analyze squeeze waters from shallow underwater muds around Cape Cod. Very substantial potassium enrichments, typically about 30%, were found in the first 30 centimeters below the sea floor bottom. The cause of the increase is not yet known. During this study it was found that the potassium content of the water phase in clay-water mixtures is substantially increased if the clay is warmed up before the water is removed. Consequently, samples should be kept near their natural temperatures prior to squeezing.

More detailed studies on the distribution, mineralogy and chemistry of the suspended particulate matter in the Gulf of Maine have resulted in the following conclusions: (1) The distribution of suspended particles is characterized by an exponential increase as the bottom is approached. Seasonal variations exist only in the surface layer (approximately 50 meters) where concentrations range from 0.1 mgm/1. in winter to 0.5 mgm/1. in summer. Deep suspended matter concentrations are about 0.1 mgm/1. for intermediate waters and range up to 1.5 mgm/1. close to the bottom; (2) The intermediate and deep suspended matter are principally silicate particles. Organic particles dominate only in the surface layer during the summer; (3) The total amount of inorganic suspended matter in the Gulf is approximately 3.7 x 10^{10} kg which is several orders of magnitude higher than the annual contribution of the stream load entering the Gulf; (4) A close linear relationship between Fe, Al, and total suspended matter suggests that the occurrence of particulate Fe and Al is controlled by the occurrence of silicate particles and that neither element occurs abundantly as a separate hydroxide phase or in organic particulates. The lack of a Mn-Al relationship indicates that at least one phase other than silicates is an important control for Mn in both the surface and deep waters. Zn, Cu, and P are clearly concentrated in organic particles at the surface, but there is no evidence that a significant quantity of these elements reaches the bottom in an organic particulate form; (5) The data indicate that the reworking and resuspension of bottom sediments is the dominant source for the suspended matter. During the winter months, when the stable thermocline at 25-50 meters is absent, the resuspended particles may reach the surface layers, some 200-300 meters above the bottom.

Studies of suspended particulate matter were also made in other deep open ocean waters. Near bottom waters in the Puerto Rico Trench, northward on to the Nares Abyssal Plain, and on the continental slope of the United States near Hudson Canyon were found to be relatively clear. Substantial concentrations of particulate matter were found at stations made on the continental rise, the Sohm Abyssal Plain, and on the continental slope some 300 kilometers east of the Hudson Canyon. It is not yet known whether these differences are due to variations in reworking of bottom sediment or the lack of very fine-grained particles in some areas. At some stations there are significant differences between the mineralogy of suspended matter and that of bottom sediments. For example, in bottom samples from halfway down the slope, at the foot of the slope, and on the abyssal plain off Hudson Canyon, there are small amounts of calcite present in the less than 2 micron fraction, whereas no carbonate is evident in the suspended matter in the overlying water. A telemetering laser nephelometer is being constructed to make light scattering measurements in sea water. It is planned to use this instrument to follow continuously small variations in suspended matter concentration.

Carbon Isotopes

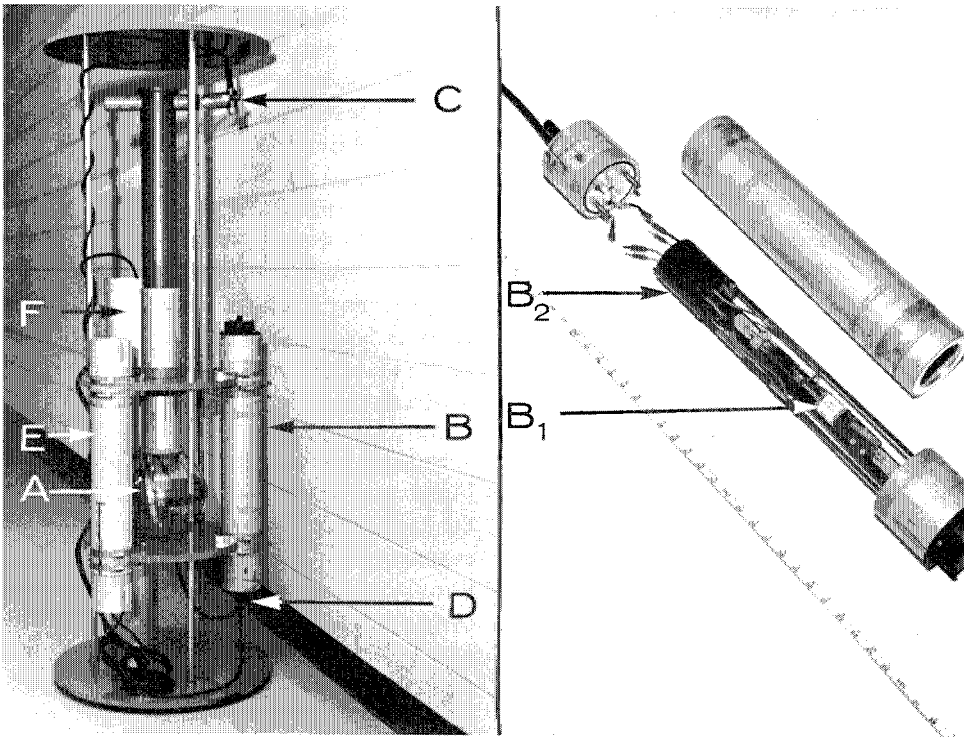
The previously reported correlation between the C^{13}/C^{12} ratios of dissolved inorganic carbon and dissolved oxygen in sea water appears to be consistent in both the North and South Atlantic. Exceptions to the correlation are found only in coastal areas where there is a strong freshwater influence in the upper layers, as for example off the Congo River mouth, and where there is strong photosynthetic activity in the near-surface waters. The correlation below the surface waters is due to the oxidation of organic matter which typically is depleted in C^{13} by 15 to 20 per mil relative to oceanic bicarbonate. Below the depth where both oxygen and δC^{13} reach minima all δC^{13} values tend to lie near +0.5 per mil. This appears to be the characteristic value of the deep sea. The enrichment in C^{13} of the near-surface waters, due to photosynthetic removal of C^{12}, is more than balanced by the C^{13} depletion of the deeper waters due to oxidation of organic matter. It thus appears that a significant portion of the isotopically light carbon at the oxygen minimum depth did not originate in the directly overlying waters but has been brought in by horizontal transport.

A program for measuring the C^{13}/C^{12} ratio in dissolved organic matter in sea water has been initiated. First results show δC^{13} in the range of –25 to –30 per mil. Thus it is isotopically lighter than the bulk carbon of marine plankton and the organic matter reaching the sediment. This indicates that the dissolved organic matter in sea water is derived from the most stable organic constituents of marine organisms which are isotopically the lightest. It also suggests that the organic matter in sediments is largely derived from the particulate rather than the dissolved organic matter.

Studies of inorganic carbonates from Pleistocene evaporation periods in the Red Sea as well as from other highly saline environments showed that such carbonates form close to isotopic equilibrium with the carbon remaining in solution, i.e., they are enriched in C^{13} by about 4 per mil relative to the dissolved carbon. This stands in contrast to most organic carbonates which show no enrichment but rather closely resemble the dissolved carbon in their isotopic content. By comparing the inorganic precipitates of the Red Sea with Foraminifera tests from the upper, less saline waters, it could also be shown that the dissolved carbon pool is significantly depleted in C^{13} during periods of massive carbonate precipitation.

Organic Compounds

Our continued research program is directed at the following questions: What are the sources of organic compounds in the sea and what are their concentrations? How great is the variability of the organic compounds in the sea and what are the reasons for this variability? How do organic compounds interact with other components of the sea? What is the long-term fate of organic compounds in the sea, in marine organisms and in sediments? How can this knowledge be applied to the study of oceanic processes?



The laser nephelometer measures light scattering in sea water and thus determines variations in the concentration of suspended matter.

Work on the nature of the dissolved organic compounds in the sea has been concerned initially with the analysis of the pentane soluble fraction of local, nearshore surface waters. Later, this will be expanded to other waters and to different fractions of the dissolved organic matter. Each of the structural types of organic compounds isolated so far provides strong clues to their origin from a particular type of organism or environment. Thus, the straight chain hydrocarbons from C_{14} to C_{33} resemble the hydrocarbons of marine algae in their molecular weight distribution pattern. They are dissimilar from the hydrocarbons in recent marine sediments or in petroleum (pollution). Relative to the straight chain hydrocarbons, the branched paraffins are much less abundant in sea water — and in marine organisms — than in crude oil. Consequently, the branched to straight chain ratio should provide a sensitive marker for oil pollution of the sea water. The isoprenoid hydrocarbons in sea water are represented by pristane and phytane. In contrast, their lower and higher homologues are abundant in ancient sediments and petroleum but not in sea water. This suggests derivation of pristane and phytane from marine organisms rather than from pollution. The two principal olefinic hydrocarbons of sea water are squalene and a C_{21} hexaolefin, both derived from organisms. Other constituents include saturated and unsaturated fatty acids. The branched iso- and anteisoacids are particularly interesting, their molecular weight distribution resembles that of many classes of bacteria and suggests bacterial derivation of these acids.

Calanus, the principal zooplankton copepod of the boreal North Atlantic, contains numerous olefinic hydrocarbons. Their structural elucidation has now been completed by a combination of ozonolysis, gas chromatography, mass spectrometry and time averaged proton magnetic resonance spectrometry. This detailed investigation puts us in an excellent position to study and understand the fate of these compounds both in sea water and in marine organisms, and to obtain insight into the dynamics of the marine food chain.

An exploratory study suggests that hydrocarbon analysis of fish livers may be a valuable tool for the study of the feeding and migration patterns of fishes. Herring taken inshore in the Gulf of Maine have the typical hydrocarbon complement of *Calanus* and are readily distinguished from herring obtained off Cape May, New Jersey. The latter fall into four sharply divided categories which may reflect either different feeding or migration histories. We consider further work in this promising area as urgently needed.

We have initiated work in the area of marine chemotaxis. This field includes the study of the interaction of dissolved organic compounds with marine organisms, and of the stimulation and modification of behavior patterns through chemical clues. Chemotaxis plays an important role in marine ecology; thus, we found that the starfish *Asterias vulgaris* can chemically sense intact oysters at considerable distances. The starfish respond positively to aqueous extracts of oyster tissue at concentrations in the parts per billion range. Isolation and characterization of the stimulant by extraction, molecular weight separation and ion exchange is in progress and has already produced an active concentrate which is resistant to boiling and prolonged hydrolysis.

Our mass spectrometer for organic analysis is being applied to an increasing scope of problems related to the chemistry of sea water, of marine organisms and of sediments. Sweep stability and reproducibility has been improved and a split screen storage oscilloscope has been added to permit immediate comparison of unknown spectra with reference spectra stored on the screen. This has greatly simplified selection of best operating conditions as well as identification and mass assignment of compounds.

The use of the mass spectrometer for the identification of trace elements in sea water is being explored through the analysis of organic metal complexes. Spectra of volatile complexes of chromium, iron, cobalt, nickel and copper are readily measured in amounts below the microgram range.

The proton magnetic resonance spectra of submilligram amounts of organic compounds from gas chromatographic effluents are now being measured with the aid of a time averaging computer. The signal to noise ratio of the spectra is enhanced proportional to the square root of the number of successive scans which are stored in the computer memory. This has enabled us to obtain pmr spectra and structural data on marine samples which were too small for direct analysis.

Naturally occurring surfactants have a solubilizing effect on marine lipids. Proton magnetic resonance spectra have been particularly useful for the understanding of the molecular environment of a lipid molecule contained in a soap micelle. Our measurements on benzene in water indicate that anionic surfactants create micelles with a hydrocarbon-like interior, while neutral surfactants have an essentially aqueous interior. The addition of sodium chloride increases the micelle size and reduces the critical micelle concentration.

Organic-Inorganic Interactions

Both the soluble and particulate organic matter in sea water appear to have a high content of nitrogenous compounds. This is not surprising since they are the dominant metabolic waste materials. However, it is not yet known how these excretionary products are stabilized in the marine environment. A high percentage of the dissolved organic matter has a molecular weight greater than 400, generally in the 3,000 to 5,000 range as determined by molecular sieve techniques. Hydrolyzation decomposes part but not all of this material, releasing substantial amounts of amino acids and aromatic compounds along with urea. The presence of oxygen in the products suggests that oxygen and nitrogen are used in the structural stabilization of the high molecular weight fraction.

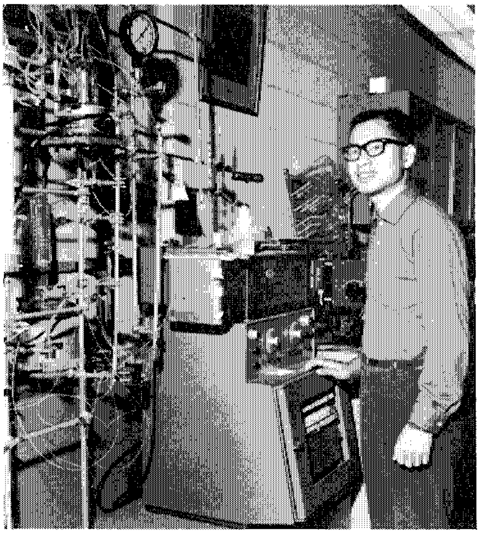
Continuing studies of the polymerization of amino acids on inorganic surfaces have shown that both montmorillonite and kaolinite cause polymerization of amino acids under wet and dry conditions. Peptides and polyphenolic compounds are the principle condensation products. The chief amino acids incorporated in the synthesized peptides are aspartic and glutamic acids. A variety of other molecules including fatty acids, hydrocarbons, and phenols can be formed in a clay-amino acid system.

Amino acid polymers can also be produced using urea, carboxylic acids, alcohols, and sugars. Clay minerals promote catalysis and polymerization with the organic additives determining the nature of the amino acid constituents of the polymers. There also appears to be some polymerization of the bases of the purines and pyrimidines on clay minerals with the formation of polynucleotides.

The interrelationship between the organic and inorganic matter of fish otoliths is being studied. The mineral matter of otoliths is aragonite which appears to form by epitaxial growth on a protein matrix. The aragonite fibrils are arranged with their long axis about perpendicular to the outer margin of the otoliths. Bands of organic matter intersect the aragonite fibrils transverse to the axis, and the spacing of the bands narrows toward the center of the otoliths. It is probable that the calcium becomes coordinated to the oxygen atoms displayed on the outer organic tissue resulting in the formation of calcium ion coordination polyhedra and the bicarbonate becomes linked via hydrogen bridges to amino acids. Subsequent exchange of bicarbonate oxygen for calcium ion polyhedra oxygen will stabilize the structure and introduce the nucleation of mineral seeds. The mineralized tissue is a fibrous protein with a molecular weight exceeding 150,000. The amino acid composition appears to be biochemically unique and the term otolin is proposed for this new kind of protein. Preliminary studies indicate that the variation in the quantity and type of organic structures in otoliths and the stable isotope distribution of its aragonite can be used to distinguish environmental criteria such as the salinity of the water and the mean temperature at which the fish lived.

Geochronology

Sediment cores taken from the central part of the Red Sea near the hot brine area have been dated by radiocarbon and uranium series isotopes. Sedimentation rates for the calcareous lutite are of the order of 10 cm/10^3 yr, whereas those for the brine-derived materials are more than 40 cm/10^3 yr. The intrusions of hot brine into the Atlantis II Deep may have occurred over the last 10,000 years. The 11,000 years age datum found in the cores, together with the lithological, oxygen isotopic and paleontological data, have established that during the last glaciation period the Red Sea environmental condition must have been one of high salinity and regression of the sea. The sill located near the Strait of Bab



Automatic analyzer for major chemicals in sea water. Kwan M. Chan to the right.

el Mandeb must have been effective in limiting the water exchange between the Red Sea and the Indian Ocean during the low sea stand of the Wisconsin. Such a condition has prevailed with short term exceptions back to about 70,000 years ago.

Measurements of uranium, thorium, protactinium and radium isotopes on 23 manganese nodules from the world oceans give nodule growth rates of 1 to 6 mm/10^6 yr. The $Th^{230}:Pa^{231}$ ratios at nodule surfaces are considerably smaller than that predicted from the production of these two nuclides by the uranium dissolved in the ocean. This offers concrete evidence as to the separation of the two species during sedimentary processes. The explanation of this phenomenon is being sought, as it is fundamental to the use of the ratio $Th^{230}:Pa^{231}$ as an age-index for deep-sea sediment dating. A similarity between manganese accumulation rates of nodules and the adjacent sediments is noted, implying that manganese may be transported to nodules by the same mechanism by which it is transported to sediments.

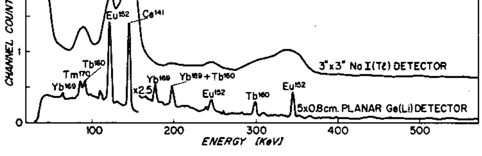
Current investigations are being made on the geochronology of Mid-Atlantic Ridge sediments. Preliminary results indicate a sedimentation rate of 1 to 3 cm/10^3 yr prevailing at the crest and flanks of the Ridge in an area north of the Azores (40° to 43°N). Combined with mineralogical and interstitial water chemistry studies, the program is expected to contribute to the understanding of the geological processes in the Mid-Atlantic Ridge sedimentary regime.

Radioelement Studies in the Oceans

Studies are continuing on the distribution of fallout radionuclides, some naturally produced radionuclides, and stable elements in order to understand processes and rates of transport of elements through the hydrosphere, biosphere, and lithosphere. This work, which is supported by the Atomic Energy Commission, is primarily carried out in the Department of Chemistry with cooperative programs in progress at the Smithsonian Institution, Oregon State University, Scripps Institution of Oceanography, Massachusetts Institute of Technology, and several European laboratories.

Our study of fission products in over-ocean aerosols has been considerably improved by the use of a large (about 25 cc) lithium-drifted germanium detector for high resolution gamma spectrometry. Patterns of fallout circulation over the oceans

A typical curve obtained with a germanium detector (bottom) showing high resolution in contrast to a curve from a sodium iodide detector (top).



continue to differ from those over the land, indicating that there may be some over-ocean "leaks" through the tropopause that do not operate over land. The data continue to confirm no over-ocean fractionation of fallout nuclides. Using Zr 95: Nb 95 ratios, it was possible to trace the December 1967 Chinese test debris through at least six complete circuits of the northern hemisphere. This appears to confirm that there is no great discrepancy in rate of "washout" of fallout from troposphere air over-ocean versus over-land.

Study has begun of the content of a variety of stable elements, by neutron activation, in fractions of our over-ocean aerosol collections. Concentrations of such elements as cadmium reach, even over the open tropical Atlantic, levels as much as 30% of those reported over highly industrial cities — a quite surprising finding and one requiring careful confirmation in view of the present interest in the public health aspects of cadmium ingestion. The lanthanide ratios in over-ocean samples show no systematic deviation from those described for soils, confirming that the meteoritic contribution of these elements cannot be a large fraction of the total circulating in the atmosphere.

Much effort has gone into collection and analysis of all the surface and subsurface strontium-90 data in the Atlantic Ocean. This was prompted by the request of a summary of all oceanic fallout data for the NAS-NRC publication "Radioactivity in the Marine Environment" now in preparation. Gratifyingly both surface and subsurface data collected by many different laboratories are very concordant and agree in supporting our findings that strontium-90 has penetrated to depth in the Atlantic at rates much faster than would have been expected, and that the ocean has received an amount of fallout per unit area several times that delivered to the land.

Cooperative work between our group and those under Münnich and Roether at Heidelberg and under Fairhall at the University of Washington has resulted in our having now several vertical stations on which strontium-90, tritium, and carbon-14 have been measured in parallel on the same samples. The strontium-90 and tritium profiles of concentration versus depth are quite similar, while that of carbon-14 is distinctly different. Additional comparisons are being made, but it now appears that strontium-90 and tritium are better tracers of water movement than is carbon-14. Studies on recently collected samples from the central equatorial and South Atlantic will better clarify this problem.

During 1968 we considerably improved our separation procedures for fallout nuclides in sea water and sediments to provide higher chemical yield, lower reagent blanks and to include routine separations of fractions containing antimony 125 and plutonium 239. No detectable amounts of these latter two elements have yet been found in our open-ocean samples, although they are present in shallow water sediments.

In cooperation with the USAEC Health and Safety Laboratory, we have devoted considerable effort to interlaboratory quality-control sample preparation, distribution and analysis. We have successfully used and distributed diluted oil-well brine as a zero-activity simulated-sea water blank, and are planning the exchange of reference samples containing several nuclides such as Sb 125, Ru 106, Ce 144, and so on.

The analysis of corals for lanthanides and other trace elements first reported last year has shown interesting differences that may enable us to tell whether a fossil coral grew in an open-ocean or a nearshore environment and in some cases even how rapidly it was buried after death. The trace elements found in the dead corals were consistently in higher concentrations than those in live or fresher specimens from the same species and environment. The highest concentrations were in the older, deep ocean specimens on which ferromanganese coatings were deposited. The ratios of scandium and zirconium to calcium in the corals were particularly high compared to sea water. Open-ocean corals including one live specimen consistently showed enrichment of the low atomic weight lanthanides when compared to either sea water or marine sediments. The nearshore live reef corals contained lower lanthanide concentrations than the open-ocean specimens and their lanthanide patterns were more comparable to nearshore sediments.

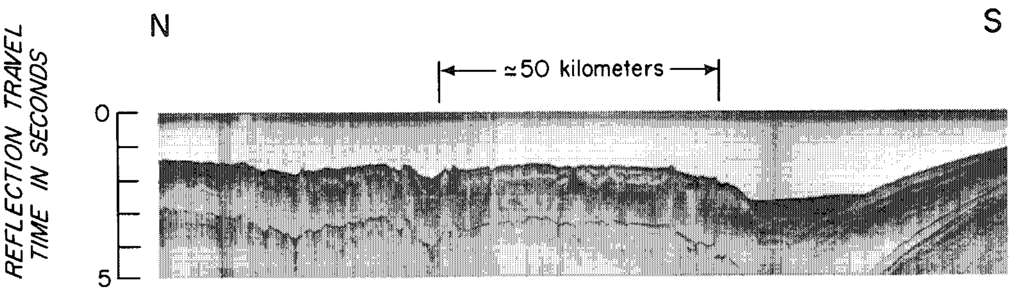
Surveys are continuing on the sedimentary and igneous rocks in the vicinity of the Mid-Atlantic Ridge. Trace elements in carbonate sediments from ponds on the flanks of the Ridge show little variation in cores from the same pond but some variations between ponds. Such variation is probably related to input differences from locally outcropping rocks.

Our studies of igneous rocks on the Mid-Atlantic Ridge have been concerned primarily with possible element redistribution and loss related to changes in rocks exposed at the sea floor. We are presently studying metamorphosed basalts from the Ridge in conjunction with some continental basalts metamorphosed under similar pressure-temperature conditions and with similar resulting mineral assemblages. We are also studying the effects of submarine weathering on ultrabasic rocks, particularly serpentinised periodotite. Our results to date indicate some redistribution and mobility of elements but perhaps less change in bulk chemical composition than we had expected.

During the summer of 1968 we participated in the ATLANTIS II Equatorial Atlantic cruise and extended our studies of sections of the Mid-Atlantic Ridge to an area at 4°S. Preliminary evaluation of our data indicates that we surveyed the southern edge of a fracture zone. Dredging in the area recovered ultrabasic rocks from deep in the fracture and metabasalts from the axial portion of the Ridge.

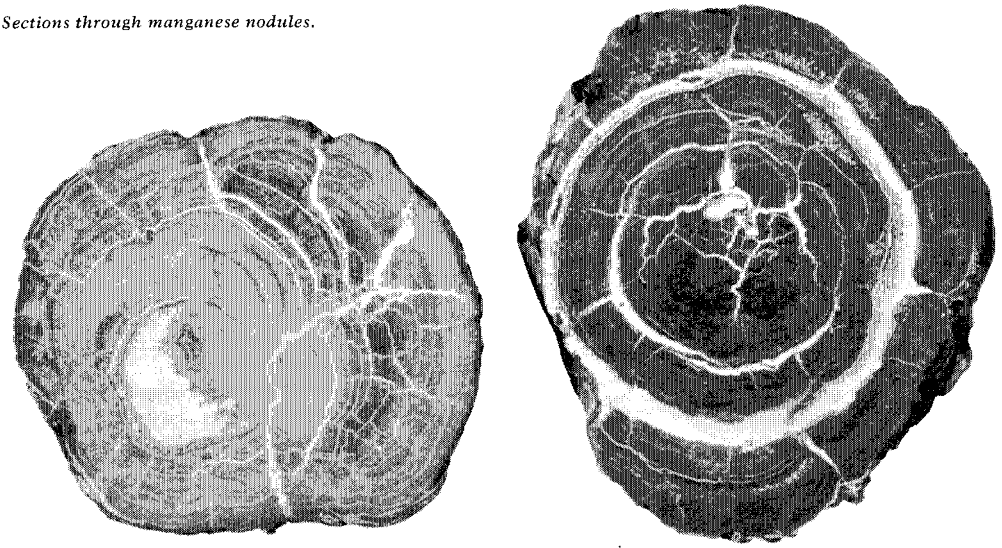
Several improvements have been made in the design of the 8-inch diameter gravity corer, which was used with considerable success to collect highly organic muds on the shelf off Walvis Bay. The cross-section area of the nose-cone and the wall friction both have been reduced so that a very small amount of weight will bury the corer in soft material. The conventional 4-foot unit has been extended to 10 and 20-foot models which will be tested in the Black Sea. A "sphincter" core catcher was designed for this unit to allow recovery of many very soft cores that are now lost. Also the free-piston system has been redesigned to reduce the frequency of distortion of cores, especially at the very top or bottom.

JOHN M. HUNT, *Chairman*



Folded, faulted and intruded sedimentary structures of the continental shelf off southern Spain (left) and the more uniformly bedded structures of northern Africa (right).

Sections through manganese nodules.



Department of Geology and Geophysics

The year 1968 was a special one for marine geology and geophysics. For the first time since the preliminary MOHO program, samples were obtained from hundreds of feet beneath the ocean bottom beyond the continental slope. The Joint Oceanographic Institutions Deep Earth Sampling (JOIDES II) program came to fruition in the fall of 1968 and will continue at least until 1970. Although the maximum depth of the drilling is the available drill string length, the practical limit is the life of the single bit that can be used, as no capability for hole reentry exists at present. When basalt or other hard rock is reached the drilling usually continues only a few more feet. But in most places much geologic history lies above the first hard rock contact. Here is a chance actually to sample the material that is the cause of the reflecting layers that have been traced for miles using continuous seismic profilers, to date the sediment down to basement, and to correlate this with the position *vis-à-vis* the seafloor spreading hypothesis. Many other interesting studies will be made of the collected samples. We have had participants in the planning programs and on several of the JOIDES cruises.

Members of the department have chiefly worked from Institution ships along the east coast, across the South Atlantic, in the North Atlantic and in the Mediterranean, and have participated on cruises in the Pacific and Yellow seas aboard ships of other Institutions.

Paleontology

Only preliminary results are available from the first leg of the JOIDES program. Among the outstanding biostratigraphic results are the following. A significant unconformity was demonstrated atop the Challenger Knoll in the Gulf of Mexico, which involves a sequence between mid-Pliocene (ca. 35 million years ago) and early late Miocene (ca. 11 million years ago). Oil was discovered in the cap-rock of this dome. Nannofossils and Radiolaria were recovered as common constituents in deep-sea cores in the early Cretaceous at the Bahama Islands site (near San Pedro Island). These serve to identify the late Jurassic age of the sediments at the bottom of Site 5, the oldest recovered to date from the ocean floor. Radiolarian-diatom oozes which became progressively more indurated with depth were recovered on the Bermuda Rise, indicating that this area has been at its present depth (over 17,000 feet) since the Tertiary.

Late Pleistocene and Holocene climatic fluctuations in the Red Sea are reflected in the distributional patterns of planktonic Foraminifera in twenty deep-sea cores. Fluctuations in the percentages of various species are related to salinity and temperature variations during this interval which, in turn, are related to glacio-eustatic movements of sea level and late Pleistocene glaciation in northern latitudes. In two species, *Globigerinoides rubra* and *G. sacculifera,* these have allowed the recognition of four biostratigraphic assemblage zones spanning the last 80,000 years.

An extensive program for the collection of samples of the resting spore phase of thecate marine and freshwater dinoflagellates was carried out, near Bermuda, Puerto Rico, Isla de Vieques, and on a transect from Woods Hole to Lanier Island, Georgia. Studies are being carried out on the life cycles of some members of this group. For example, *Pyrodinium bahamense,* which is one of the most prominent bioluminescent species was shown to be a living representative of the fossil hystrichosphere *Hemicystodinium,* and to produce resting spores. It was thus possible to demonstrate from fossilized resting spores that the geological history of *P. bahamense* extends back to the Eocene.

Marine Acoustics and Environment

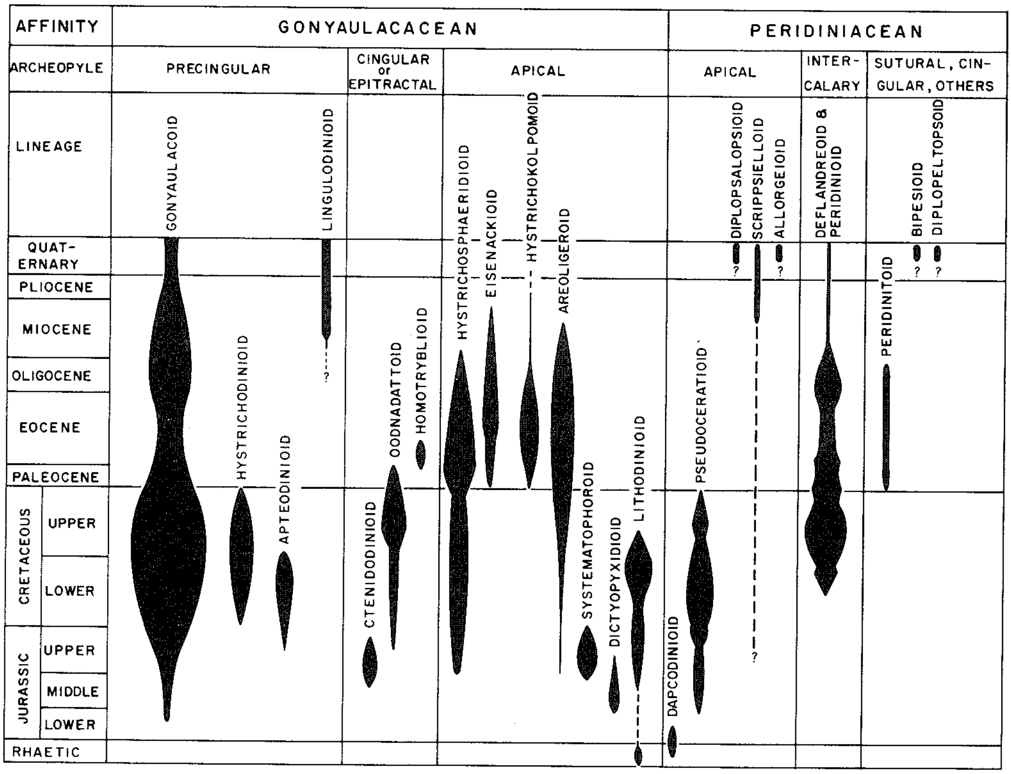
A major acoustics cruise was undertaken during the summer as a joint operation with the Admiralty Underwater Weapons Establishment of Great Britain. The phenomena of major concern were bottom and surface reflectivity and long range sound transmission. Several long runs were made to observe the effectiveness of bottom scattering from slopes into the sound channel. The bottom-surface reflectivity experiments used explosives and continuous-wave sources with a variety of receiving systems. The analyses of the data are proceeding independently at the two laboratories with hopes that our conclusions will be in essential agreement about the bottoms studied.

It is well known that Mediterranean Water flows out into the Atlantic, creating a double sound channel over a large region of the northeast Atlantic Ocean. This gave us an opportunity to make some measurements to confirm the theoretical work we have been doing on sound propagation at turning points. This is one of the regions where the ray theory is not applicable, and the appropriate theoretical analysis is fairly complex.

Of interest in our collection of environmental data in the northeast Atlantic was the distribution of the Mediterranean Water over the Mid-Atlantic Ridge. The secondary sound channel it produces was frequently found over the median valley, but it was not continuous, as if the topography somehow induced a complex mixing process.

A large acoustic propagation experiment (PARKA) took place in the Pacific north of Hawaii, and we participated in the environmental measurements using our newly developed sound-velocity profiler. This was the first field test of this instrument and it performed well.

The study of the voices and sounds of cetaceans and pinnipeds continued with an expedition to the southern Chilean islands. Analysis of the echo-location signals of *Phocoena phocoena* show it to have signals



Stratigraphic distribution and pattern of evolution of two dinoflagellate lineages. The width of the columns represent relative diversity of morphology, not *numerical abundance.*

somewhat different from other echo-locating animals which use wide-band short-duration clicks. *Phocoena* uses a short pulse composed of up to ten cycles of sound near 2000 Hz.

Geology and Geophysics

Analyses of the sediment and rock samples collected as part of the joint United States Geological Survey - Woods Hole Oceanographic Institution continental shelf study continued. Several thousand sediment samples from the eastern continental margin were examined during the year. Most shelf sediments are composed of sand with minor amounts of gravel. Only those adjacent to major rivers or depressions contain appreciable amounts of a finer material. The Chesapeake Bay-Cape Hatteras area seems to be one of change in sediment type from north to south, particularly as to the type of clay minerals. This probably is related to glaciation and the subsequent drainage. Studies of grain size lends support to the idea that sand, gravel and clay are the "basic" populations of sediments, while silt and granules are transitory types.

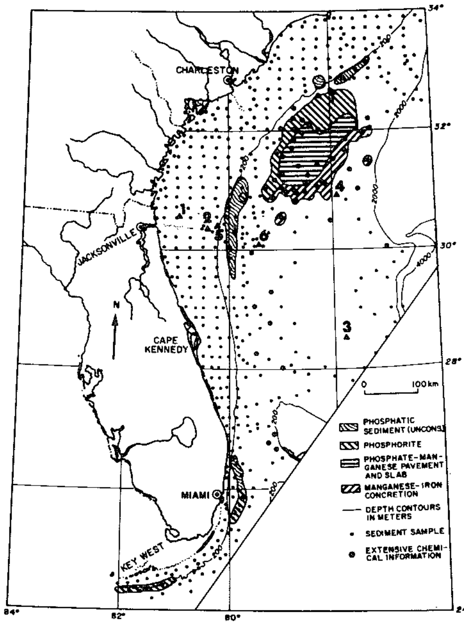
Shelf sands north of Cape Hatteras are relatively rich in feldspar, generally contain less than 3% carbonate, and are mostly iron stained. South of Cape Hatteras the coastal water temperature environments are semi-tropical to tropical. As a result carbonate content increases markedly. Most shelf sediments contain more than 15% carbonate and those areas not directly influenced by Piedmont rivers, such as

Onslow Bay and the Florida shelf contain more than 50% carbonate. Many carbonate deposits, notably oolite, coralline algae and beachrock were deposited during previously low stands of sea level. Carbon[14] dates from these and other shallow water constituents have allowed the construction of a curve for the last regression and transgression of sea level.

The clay fractions of samples from the Florida-Hatteras slope and the Blake Plateau are characterized by kaolinite, montmorillonite and clay-size aragonite and magnesium calcite. Clay-size calcite also occurs in these areas, but it is more prominent in the slope and rise sediments north of Cape Hatteras owing to contributions of material from planktonic Foraminifera. Most of the clay near the sediment surface along the slope and rise must have been deposited during the Pleistocene when the East Coast rivers flowed across the shelf and debouched directly onto the continental slope. Southerly currents distributed these river sediments along the slope and rise. Slumping, reworking by bottom dwelling organisms, and redistribution by bottom currents of these Pleistocene material obscures the relatively minor contribution of river borne Holocene sediments.

On the seaward edge of the continental shelf off New England and New Jersey large pieces of carbonate rich sandstones were dredged. X-ray data reveal aragonite in three of the deposits and calcite in one (George's Bank). The carbonates occur in the form of distinct layers, as spherulites or as matrix, and account for up to fifty per cent of the total rock. Feldspar and quartz grains are frequently replaced by carbonates, and relict outlines of the original grain boundaries can be observed.

The stable-carbon-isotope distribution of these carbonates is rather unusual (δC^{13} –45), and the δO^{18} values suggest the carbonate phases in these sandstones have been deposited in isotopic equilibrium with the sea at a temperature of 0°C. With the extreme depletion of C^{13} in the secondary carbonates, methane, which has been oxidized either chemically or microbiologically to CO_2, appears to be a reasonable carbon source for the carbonates. A C^{14} age of 20,000 years for the carbonate suggests that Holocene marsh gases are likely precursor materials for the generation of such light CO_2 or bicarbonates.



Manganese and phosphorus deposits on the Blake Plateau. Dots indicate bottom sampling stations and triangles the JOIDES drill holes. (Phosphorite deposits on the continental shelf are omitted.)

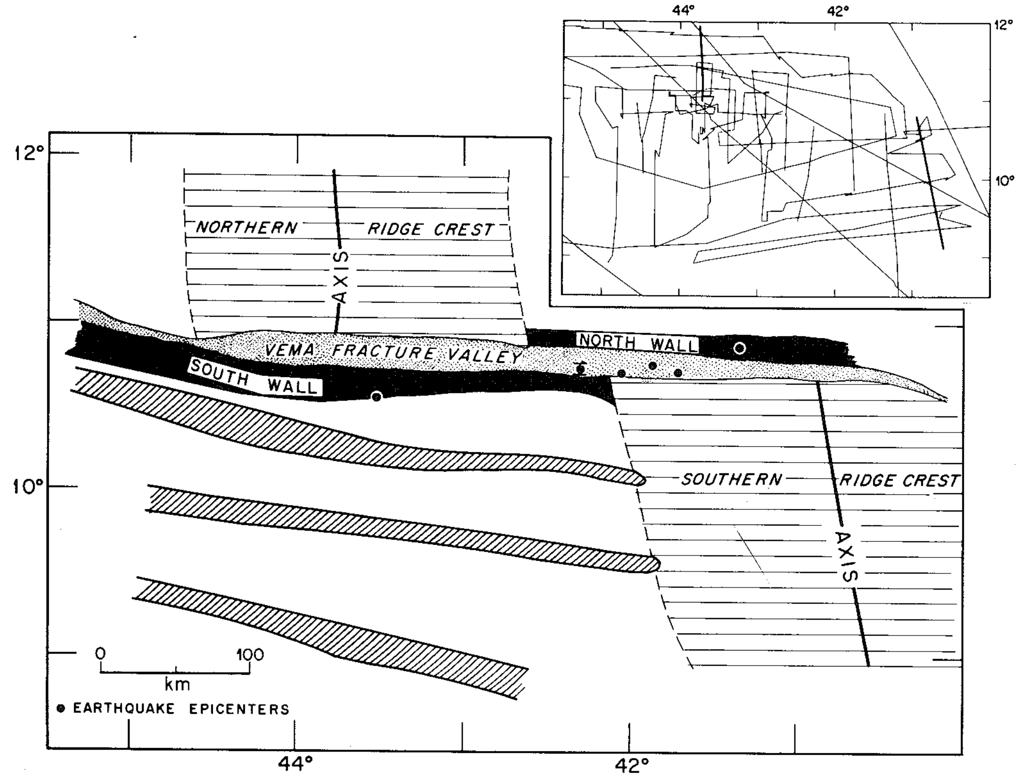
Analyses of deep-sea carbonates from the Red Sea indicate that over half have been inorganically precipitated. During glacially lowered sea levels, the Red Sea was isolated and the salinity was about twice the normal values. Lithified layers of aragonite were found under these conditions.

Analyses of pore water from sediments collected along the east coast and the Gulf of Mexico are leading to a better understanding of the processes involved in its formation and the distribution of subsurface water along the coasts and under the sea. Holes near diapiric structures in the Gulf show systematic increases in pore-water salinity with depth. Samples from holes away from the diapiric structures showed little change in pore water chemistry with depth, aside from loss of sulfate and other variations due to early diagenesis. It is expected that the existence of shallow salt plugs may be detected by pore-water measurements in sediments only a few tens of feet deep.

Seismic profiling in the Yellow Sea and the East China Sea has indicated that these could have a great potential as oil and gas reservoirs. The high organic productivity of the rivers leading into the area and the presence of several seaward ridges which have trapped the sediments coming down the rivers are the basis for this judgment, in addition to the structures observed in the profiling records.

The gravity field of the Caribbean Island Arc has been studied in some detail, using our own data and that obtainable from all other sources. It indicates a rather complicated structure that is consistent with the underthrusting of Atlantic Ocean sediments and basement beneath the sedimentary material of the Lesser Antillean Arc margin, thus agreeing with the concept of seafloor spreading.

Measurement of gravity in the eastern Mediterranean leads to the conclusion that their is a thicker crust and/or that there



Tectonic sketch map of the intersection between the Vema Fracture Zone and the Mid-Atlantic Ridge. Diagonally cross-hatched areas represent old fracture valleys.

are lower crustal and mantle densities there than in the western basin.

Gravity measurements off the east coast coupled with model studies suggest that there is a basement ridge beneath the continental shelf, that the continental shelf and rise are largely in isostatic equilibrium, and that only crustal segments near the continental slope with widths of 40-50 kms are not in equilibrium.

A major development in the seagoing gravimeter system was underway in 1968. A new type of meter (vibrating string accelerometer), a stable table for its foundation, and a new computer were assembled. Tests of these new instruments at sea showed that they would function in higher sea states than other types and also that they are more accurate. This development is going well and we anticipate making routine measurements at sea again shortly.

Measurements of the magnetic field along the eastern continental slope and rise of North America show the anomaly field to be rather smooth out to a distance of 400 km from the shelf's edge. West of this region there is a belt of strong positive anomalies trending along the slope. East of the smooth region there is an abrupt transition to a disturbed region of high amplitude short wavelength anomalies, commonly greater than 500 gammas. Based on model studies and seafloor spreading data the smooth region is inferred to have been formed during the Kiaman Magnetic Interval, a period of 50 million years during late Paleozoic when the geomagnetic field was uniformly reversed. The magnetic materials to the west of the continental slope that cause the anomalies there have been assumed to have been formed during the Lower Permian.

Other measurements were also made of the magnetism over the Mid-Atlantic Ridge and the Azores-Gibraltar Ridge during the year from an aircraft and from ships. Interpretation of these data and that from the Mid-Atlantic Ridge east of the Lesser Antilles Arc are in progress.

Geothermal studies of the seafloor were primarily associated with the Mid-Atlantic Ridge near 19°N and 43°N. The characteristic zone of low heat flow on the western flank of the ridge is a phenomenon not yet understood. The heat flow pattern near the ridge crest is variable but appears to indicate some systematic correlation with different ridge topographic provinces. Two instrument development programs concerning heat flow were undertaken, one of which was completed. The latter is concerned with the continuous acoustic telemetry of the thermal data from the ocean floor for a real time display during the measurement, and a high resolution method for obtaining vertical profiles of the bottom water temperature. The other is an instrument for use in the JOIDES program in making heat flow measurements in the hole periodically during the drilling, and it will thus obtain a vertical profile of the heat flow, rather than a single surface observation.

Continuous seismic profiling played an important part in the delineation of the ocean bottom structure during the year. With multi-element arrays, the simultaneous use of sparker and air-gun sources has allowed us to increase the towing speeds, thus giving greater coverage per day. Interestingly enough with the present configuration the signal-to-noise ratio improves with higher speeds from about four to eight knots.

Profiles near the southeastern end of the Puerto Rico Trench and the northern end of the Barbados Ridge show that the strata of the ocean floor including the basement, dip westward beneath the eastern flank of the Antilles Arc. These can be interpreted as evidence that the seafloor has been pushed beneath the Antilles.

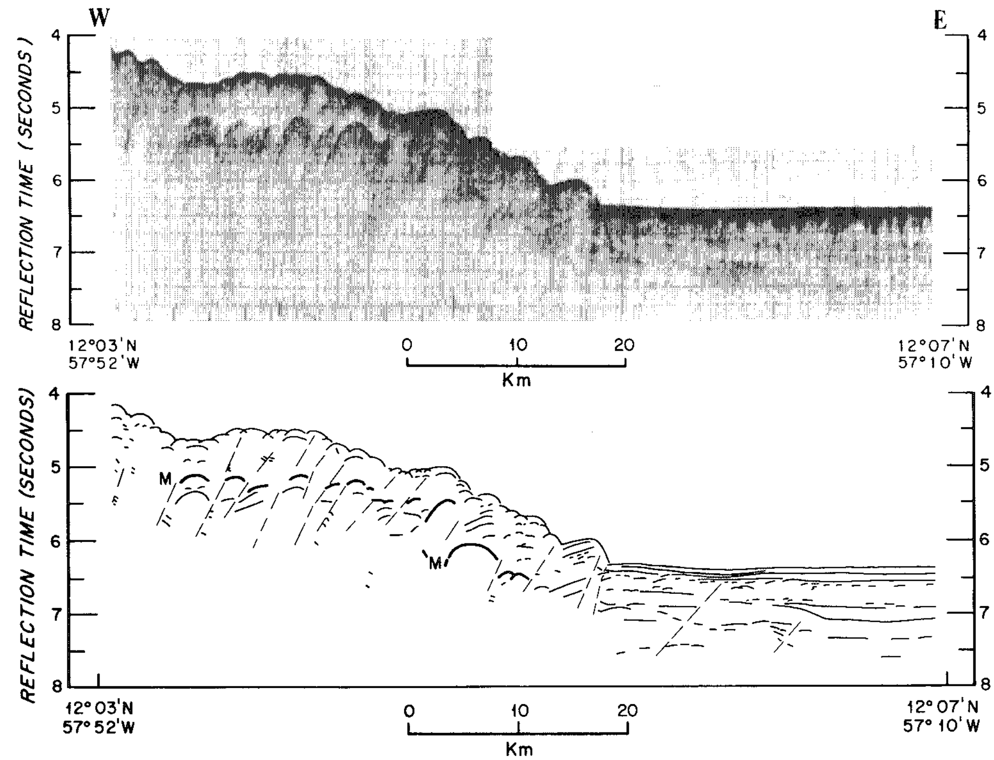
One might suspect that the shelf structures off southern Spain would be similar to those off northern Africa (Gibraltar region). To the contrary, seismic profiling has revealed that the Spanish shelf is characterized by strongly disturbed sediment layers but that the African shelf lies over gently dipping strata.

The Mid-Atlantic Ridge crest is offset more than 300 km along the east-west trending Vema Fracture Valley (ca. 11°N). The trend of the extremities of this valley outside of the region of recent earthquakes, as well as that of apparently inactive transverse valleys to the south, is somewhat south of east. These observations, and the fact that the valleys to the south do not extend across the ridge crest, strongly imply that a new pattern of ridge growth and seafloor spreading represented by the Vema Fracture Valley, has been superimposed on an older one.

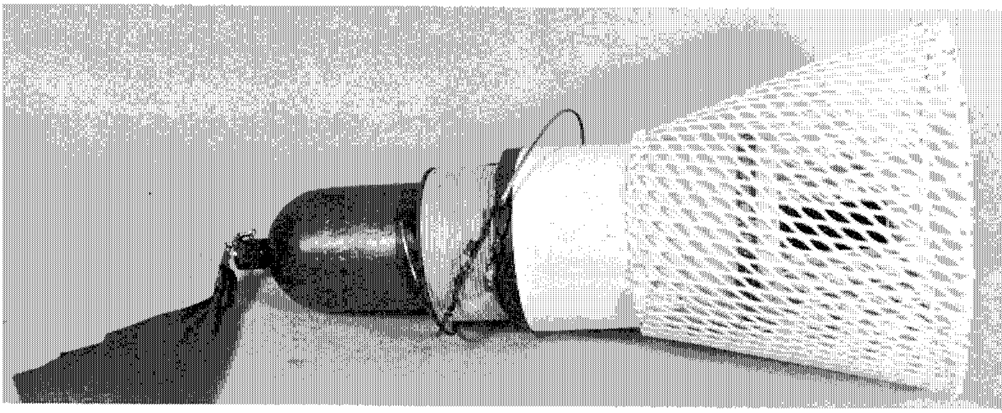
A seismic and magnetic survey of the New England seamounts suggest that they are pre-Cretaceous in age. Mytilus Seamount appears to have had a flat top in the past, possibly an erosional surface. Eocene calcareous algae recovered from the overlying cap would indicate that an organic reef had formed on the flat top of the seamount.

We have not made an attempt to discuss all phases of our work; to a large extent we have not included many of the technical aspects. Much of our success, however, rests clearly upon such efforts by members of the department, and on the excellent cooperation of the ships and their crews.

EARL E. HAYS, *Chairman*



Continuous seismic reflection profile (top) across the eastern margin of the Barbados Ridge. Dashed lines (bottom) are inferred thrust faults. Reflector M may possibly be correlated with M'.



The expendable free fall bottom marker beacon is a compact navigational aid for deep diving submersibles. It may be quickly released from a surface vessel to mark a predetermined position on the ocean floor.

Department of Ocean Engineering

Ocean engineering at the Institution concentrates on the observational aspects of oceanography. Thus the department's major field of concern encompasses oceanographic data systems considered in their most general sense, ranging from the development of instruments and instrument systems to the transmission, and processing of data. A study of the following list of activities and projects will show the breadth of the department's technical commitments:

a. deep submergence engineering and operation
   1. vehicles
   2. tools
   3. underwater navigation systems
   4. automatic data logging systems

b. instrument engineering
   1. autonomous probes (SOFAR Probe, AUTO Probe)
   2. synchronous beacons
   3. transponders

c. buoy systems engineering
   1. instrumented test moorings
   2. component test and development
   3. telemetry development

d. sediment sampler and instrument engineering
   1. penetrometers
   2. corers

e. information processing and analysis
   1. digital computer applications to oceanography
   2. computers at sea and satellite navigation
   3. A/D conversion

The major single event during the year 1968 was the unfortunate accident which resulted in the sinking of ALVIN in 5000 feet of water. This shattering event has not been without its constructive side. The department and the whole Institution have been challenged in two particulars. The first challenge is to learn well some dearly bought lessons in the handling of heavy weights at sea. Because the first 307 operations are successful does not necessarily guarantee the 308th. The second challenge reflects the new age at sea where man's capability to see and do no longer stops at the surface, but extends to the bottom. It is the challenge to get ALVIN back. The Institution has accepted both challenges. ALVIN is down, but not out.

Deep-Submergence Engineering and Operation

The operation of DSRV ALVIN and the development of instruments and tools as part of the submersible system occupied the principal departmental efforts in deep submergence during the year. At the beginning of 1968 ALVIN and LULU were in annual winter refit at Woods Hole. Submersible operations commenced in April and extended into October. Budgetary limitations dictated that scientific operations be limited to the New England area. The first cruise was to Provincetown for training and engineering purposes, followed by a scientific cruise to investigate the annual migration of right whales in that vicinity in May. Unfortunately the whales did not appear as usual and that goal was not achieved. Nevertheless, in the process, the navigation precision-timed pinger system was tested satisfactorily in shallow water and the ALVIN was certified to 600 feet following the winter refit. A second cruise was conducted in the Gulf of Maine for geological investigations. Commencing in June after Navy deep-water certification, dives were made out to a maximum of 6000 feet on the continental slope. In July a high prioirty project of the U. S. Navy Underwater Sound Laboratory interrupted the summer's scientific program and sent ALVIN and LULU to the Azores to conduct an underwater survey of a potential instrumented range site. ALVIN's observations of the seafloor resulted in some fundamental changes in the planned locations of elements of the range and at the same time permitted some science to be accomplished by Institution observers. ALVIN once again proved her value as an engineering and research tool. Scientific operations recommenced locally in about mid-September and continued to mid-October.

On the 16th of October a very serious accident occurred which was most disrupting to the deep submersible program at the Institution. The two forward cables on the launching cradle broke unexpectedly during a routine launch of the ALVIN for Dive No. 308 and the submarine sank to the bottom in 1520 meters near Hydrographer Canyon. Most fortunately, the three occupants of the submarine escaped with very minor bruises. A bathymetric survey was immediately conducted by LULU and GOSNOLD relative to a buoy that was being inspected by ALVIN when the accident occurred. In addition CHAIN obtained a satellite navigation fix at the scene. It is therefore known where ALVIN rests within a very small area so that when the opportunity presents itself to return for the recovery next summer, using SEA CLIFF, no difficulty in locating the ALVIN is anticipated.

An attempt to locate ALVIN and recover it was made in November without success. The Deep Ocean Work Boat (DOWB), owned and operated by General Motors Corporation, was flown to Otis Air Force Base from California almost immediately. The LULU was quickly modified to launch and recover the DOWB and the CHAIN was outfitted with special gear to affect the recovery when found. However, the weather was unduly severe and the search and recovery attempt did not succeed for this reason primarily. The expedition departed Woods Hole on November first, only two weeks after the accident and DOWB made one dive, but mechanical difficulties on the submarine required a return to port. The next attempt had barely started when a violent storm (100 knot winds) forced another return to port. A final effort was made, but again was thwarted by the deteriorating weather off New England at this time of year. Thus, operations were reluctantly suspended until next summer.

On December 11th, a new submarine was commissioned at Electric Boat Division of General Dynamics Corporation in Groton, Connecticut and named the SEA CLIFF. This submarine, similar to ALVIN, was christened by Mrs. Thomas B. Owen, wife of the Chief of Naval Research and is to be operated by the Woods Hole Oceanographic Institution. Expected delivery of this new craft is next spring. It is hoped to return to the ALVIN loss site with SEA CLIFF and effect a recovery. However, much remains to be done to acquire a support capability for the new submarine. It weighs 45,000 lbs. vs 32,000 lbs. for ALVIN.

In summary, a total of 67 dives were conducted prior to 16 October divided into general categories as follows:

Biology	15	Ocean Engineering	6
Geology	19	Testing, Training and Certification	27

A major lesson of deep-submersible operations to date relates to the constraints imposed by the surface support system. In 1968 dives were not conducted because of weather on approximately 40% of the days on station when the submarine was in all other respects ready to dive. This weather sensitivity represents a costly limitation and it is one which modern engineering can solve.

The Naval Oceanographic Office has sponsored a program for the development of DRV-related instruments and tools at the Institution. During the year three projects within this program progressed to the stage of field testing of prototypes. First a hard rock coring device provides the scientist with the capability of selectively retrieving a hard rock core, ¾ inches in diameter by 3 inches long. The drill is guided by the mechanical manipulator and can be used at any depth down to 6000 feet. The device is capable of recovering multiple cores through a reversible water jet which holds the sample in the core barrel and at the proper time expels it into a sample quiver. Both the data logging system, which automatically measures and records on digital magnetic tape such environmental variables as temperature, salinity, pressure and time, and the underwater acoustical navigation system, whose heart is the precision synchronous acoustical beacon, were successfully field tested in ALVIN during the year.

Instrument Engineering

The development of advanced instrumentation continued to the field test stage during the year. The SOFAR Probe was tested at sea on two different occasions with less than complete success. This oceanic version of an instrumented space satellite drifts at a pre-determined stable depth in the ocean, measures and reports an environmental variable acoustically over extremely long ranges using the deep sound channel propagation path. The AUTO Probe, a similar device, but one which actively controls its depth and is of shorter duration and range, was also field tested and unfortunately lost after a successful series of dives.

Buoy Systems Engineering

The buoy engineering development, test and evaluation program was intensified this year to determine the causes and factors contributing to low reliability of moored buoy stations and to recommend solutions to their long-term deployment. Laboratory testing of materials including wire rope, nylon line and hardware provided quality assurance and indicated those materials and constructions most suitable for further testing in the ocean. Several types of wire ropes are being evaluated on actual moorings south of Cuttyhunk Island to provide comparative data on their effectiveness. Ten engineering evaluation moorings were set near site D (70°W, 39°N) this year to test various techniques, materials, and constructions. The moorings were instrumented to obtain tension data at several depths. An additional mooring was set to be inspected by DSRV ALVIN. All moorings were maintained on station and were retrieved with the exception of one (later recovered) which was apparently run down by a passing vessel.

Analysis techniques including a computer program were developed for single point moorings.

A telemetry system has been developed and installed in the 12-foot discus buoy to monitor surface and near-surface events from the laboratory. A deep-sea buoyancy module has been designed and a prototype constructed to support near bottom mounted instruments.

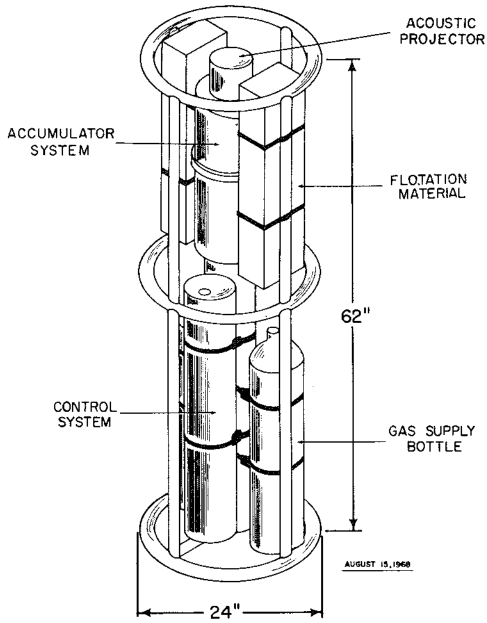
Information Processing and Analysis

Many changes have taken place during 1968 in physical location, equipment, applications and areas of responsibility for the Information Processing Center. Most of the changes were attributable to the new Scientific Data Systems Sigma 7 computer system, which replaced the GE-225. In addition to this new system the Information Processing Center also acquired responsibility for a Digital Equipment Corporation PDP-5 computer, a model 663 Calcomp 30″ plotter, and for a Hewlett Packard 2116A computer and a Magnavox 702-CA Satellite Navigation Shipboard Receiver system. The initial work of developing and building an analog to digital converter to operate in association with the Sigma 7 computer system was started in mid-year and is scheduled for completion during the first quarter of 1969. In addition all keypunching equipment has been changed over to the new 029 models to accommodate the EBCDIC code needed for the new computer system.

General Engineering — Coring Technology

The problem of obtaining long core samples of the ocean floor has plagued marine geologists for years. With the objective of developing the technology required for long coring (in excess of 200 feet) a program has been initiated to study the penetration mechanics of an object which interacts dynamically with sediment and to obtain some insight into structural problems associated with very long corers.

The structural stability of a long slender column protruding from a sediment surface has been examined. It is found that such structures are inherently unstable when sufficiently perturbed and must be held up at



Autoprobe III.

the top to prevent failure. The general problem of determining the penetration depth and loads acting on an object which is dynamically interacting with a sediment has been treated. It is found, as might be expected, that when an object strikes a sediment which exhibits rate dependent terms in its constitutive relation, with high kinetic energy, this energy is quickly dissipated and the ultimate penetration depth is not greatly affected. However, the loads acting on the projectile may be very high and may lead to structural failure.

A computer routine has been developed which may be used to determine the velocity and acceleration trajectories of such an object when the general nature of the surface forces acting on the object are known. This information may also be used to attain some insight into the basic mechanical properties of a sediment when the velocity or acceleration trajectories of an interacting projectile are known.

One conclusion that seems evident from this work, and from experience in the field, is that further extension of the old concept of pushing a core tube into the ocean floor with large weights is not practical from an engineering and economic viewpoint.

VLF/Omega/Satellite Navigation

Prior to 1968 effort has been directed to (1) assessing the long-range capabilities of very low frequency (VLF) transmission for relative navigation (circular grid) and (2) the determinations of ship velocities using VLF. Two systems were completed. X-Y plots of station versus station were commenced on a small scale. The work in 1968 was expanded to include Omega navigation and to make greater use of the direct plots with the X-Y recorder. The objectives were to improve the use of VLF/Omega systems on aircraft and ships and to integrate Omega with satellite navigation.

If plots are made of one VLF station versus another by connecting the two signals to an X-Y recorder, then the real time ship track can be drawn. During the Oporto-Lisbon-Gibraltar transects aboard CHAIN in June many such plots were made, sometimes to the scale of one inch per nautical mile. Such amplification permitted discrimination of movements to one ship's length. Ship speed and course *made* were readily determined from the microsecond per unit time readings of the two VLF receivers.

An Omega navigational set was also employed on CHAIN in June. Understanding came with use, and it became vital to the scientific programs en route to Woods Hole from the Mediterranean, especially in the Azores region. Two lanes of Omega were combined with one lane of Loran C for the flights aboard the C54-Q airplane out of Malta between 15 May and 6 June (MED MILOC 68). The sea surface temperature plots would have been less meaningful without the Omega. On several occasions the aircraft provided navigational checks to participating surface ships. Nominal results were to within one nautical mile. In October a program was commenced to achieve the integration of Omega with an airborne navigation system. Two airborne sets with computer have been constructed, the first will be placed on the C54-Q for the Peru program, April-May 1969. Omega will provide the updating and continuity of navigation. Latitude and longitude will be computed and then read out visually by NIXIE tubes. The Woods Hole contribution to the endeavor will be the aircraft, the Omega equipment, and technical assistance on VLF/Omega techniques. This program should prove beneficial to the eventual integration of the satellite navigation sets on our ships to Omega.

SCOTT C. DAUBIN, *Chairman*

Robert M. Alexander at the scientists' control panel (left) and Harold G. Merry at the navigational control panel (right) aboard the C54-Q aircraft.

Department of Physical Oceanography

Research within the Department of Physical Oceanography is directed toward measuring and understanding the behavior of the ocean over the broad spectrum of phenomena that occur naturally within its boundaries. As a continuing effort in exploring the ocean environment, field studies were carried out during 1968 in several regions of the Atlantic and adjacent seas. Cruises to the Gulf Stream and Bermuda areas were undertaken to measure transport and current trajectories, and to study internal waves and microstructure. Members of the Department participated in an oceanographic survey conducted in the Mediterranean. As part of the program, the Institution aircraft flew repeated surveys of surface temperature using an infrared radiometer. A cruise to the western tropical Atlantic was carried out in early 1968 to continue studies of the complex current system in the approaches to the Caribbean.

Water Masses and General Circulation

Outflow of cold deep water from the Norwegian Sea over the Greenland-Scotland ridge has been estimated from measurements off Cape Farewell, Greenland to be about 10 million cubic meters per second. Such a flow must be compensated by an inflow of at least 8 million cubic meters per second between Iceland and Scotland. The heat carried by the inflow and given up to the atmosphere in the Norwegian Sea is about 60 x 10^{12} cal/sec, comparable to rates estimated from meteorological data.

Five sections of hydrographic stations taken off the Brazilian and Guiana coasts support the hypothesis that the South Atlantic surface water does not flow continuously towards the Caribbean but turns eastward before reaching 50°W. The deeper Subantarctic Intermediate Water does not appear to be interrupted in the same manner and flows continuously toward the Caribbean. As the Caribbean Sea is a source of water for the Gulf Stream, the tropical circulation and inflow into the Caribbean must be examined to describe the source waters for the formation of the Gulf Stream.

Analysis is continuing of two zonal hydrographic sections taken across the South Pacific in 1967. The deep western boundary current, expected on theoretical grounds, was detected in both sections and estimated to have a northward transport of 13-17 million cubic meters per second. The current flows east of New Zealand and the Tonga-Kermadec Ridge at depths below 2500 meters.

The Gulf Stream

Studies of the Gulf Stream continue as a major activity of the Department. Observations made in previous years were analyzed to examine the relationships between the Gulf Stream and the cyclonic rings of current formed from the Stream at irregular intervals. Seasonal shifts of the Stream may be dependent on the number of current rings detached into the Sargasso Sea. The formation and subsequent behavior of the rings has been studied intensively during the past few years. Their persistence over many months has led to an examination of the historical hydrographic station and bathythermograph data collected over the past three decades to estimate the number and distribution of the current rings. In addition to forming an important dissipative process for the Gulf Stream, the rings constitute a mechanism for transferring large quantities of slope water into the Sargasso.

Three sections were completed across the Gulf Stream between Cape Cod and Bermuda to estimate the transport by direct measurement with free-fall instruments. These measurements, complemented by hydrographic stations and salt-bridge GEK measurements, can be used to compare transport estimates from the direct and indirect (geostrophic) methods.

Drogued floats were set out in the core of maximum current in the Gulf Stream and followed for a distance of 800 miles downstream. These unique current trajectories showed sustained speeds of 4.0 to 4.5 knots over 400 miles. With only minor deviations, the floats maintained their original relationship to the temperature structure of the upper 200 m layer though the path of the Stream varied between cyclonic and anticyclonic curvatures.

Neutrally buoyant floats equipped with vanes were used to measure vertical motion within the Gulf Stream for comparison with the internal wave activity external to the Stream. Preliminary examination of the data revealed no characteristic differences in the wave statistics.

A theoretical study has been carried out to examine conditions of bottom topography that may cause the Stream to separate into two distinct branches. The study is an extension of the theory developed to relate Gulf Stream meanders to the bottom configuration.

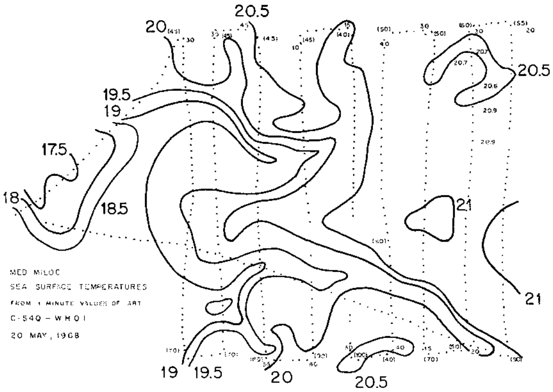
Ocean Variability

Although the major emphasis in operations with moored buoys was to improve survival and reliability of the moorings and instrumentation, measurements of currents and temperature continued to be made in the slope water south of Cape Cod. Several short-term experiments were set with vertical arrays of current and temperature sensors to examine vertical coherence of the fluctuations as a function of separation. These experiments are part of a series to examine the spatial structure of the internal wave field in the ocean.

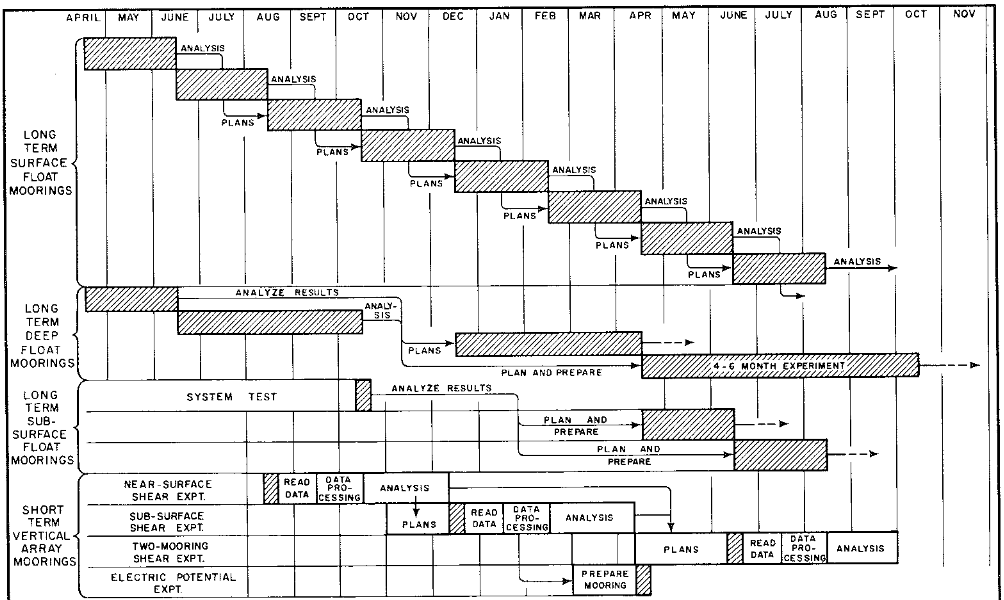
Further evidence of the internal wave character of fluctuations at frequencies between 0.1 and 1.0 cycle per hour was obtained by comparing spectra of temperature and velocity fluctuation. The mean amplitude of the observed temperature fluctuation agreed with estimates from the velocity spectra based on linear internal wave theory.

Current records from Site "D" (39°20′N, 70°W) in the slope water have been col-

Roberto Frassetto (left) and Peter M. Saunders (right) with the airborne radiation thermometer aboard C54-Q aircraft.



Sea surface temperatures in the Ionian Sea as recorded aboard the C54-Q aircraft.



Deep-sea mooring program, April 1968—August 1969.

FIGURE 1
PROPOSED SCIENTIFIC PROGRAM
FOR APRIL '68-AUGUST '69

C54-Q aircraft chiefly used by the meteorologists.

lected since 1965. These records show a persistent westward drift at all depths with speeds ranging from nearly 1 mile per day near bottom to 6 miles per day near the surface. Large deviations (30-40 miles per day) from the mean westward drift are common.

The medium and small-scale temperature structure in the surface layers of the ocean is determined by the exchange of momentum and energy between the ocean and atmosphere and the incoming solar radiation. Repeated measurements of surface temperature in the Mediterranean with an infra-red radiometer aboard the Institution C-54 aircraft showed remarkable persistence of the spatial pattern during fair weather and rapid change in stormy weather especially where the surface layer was shallow. Computer methods for objective contouring of surface temperature are being developed to extend the analysis of these measurements.

Microstructure

The complex small-scale structure associated with turbulent and convective transfer of heat, salt and momentum may hold the key to understanding the mechanism of diffusion of properties within the ocean interior. Studies in the laboratory have revealed mechanisms that yield either layers or "salt fingers" as part of the transfer process of heat and salt. Measurements at sea, while hindered by inadequate sensors, have revealed that the small-scale layered structure is a common feature of ocean gradients.

Numerous profiles of temperature and salinity have been made during the past year in the Sargasso and Mediterranean to examine the small-scale features. Efforts are being made to increase the resolution of the sensing and recording equipment used for these studies.

Nonlinear wave-wave interactions of internal waves are probably a source of energy for some of the micro-scale processes. These interactions have been studied in a wave tank using waves generated in a stratified salt-water layer.

Atmospheric Processes

Studies of turbulence and turbulent fluxes in the lowest 3 kilometers of the tropical marine atmosphere are continuing using data collected over the Indian Ocean and the Line Island region of the Pacific. The measurements show clearly the interdependence of turbulent transports and the large-scale atmospheric structures. In the tropical zone, turbulent flux of water vapor is increased by large-scale subsidence of dry air and decreased in the convergence zone because of diminished water vapor gradients.

Marine Geodesy

The program in marine geodesy has been prompted by a need to establish an equipotential datum as reference for the gravity potential of the sea surface and to study the topography and variation of the surface. The figure of the geoid is calculated from measurements of the magnitude and direction of gravity over the surface of the ocean. If sufficiently precise instruments are developed, the slope of the sea surface relative to the geoid can be measured directly by sensing the visible horizon.

An attempt to measure undulations of the geoid was made along a meridional traverse from Nantucket Island to Hispaniola in October. The results were not entirely satisfactory because of instrumental problems and failures. During the same cruise a gravity survey was made in the Florida Straits to determine level surface topography between tide gauges at Miami and Bimini.

NICHOLAS P. FOFONOFF, *Chairman*

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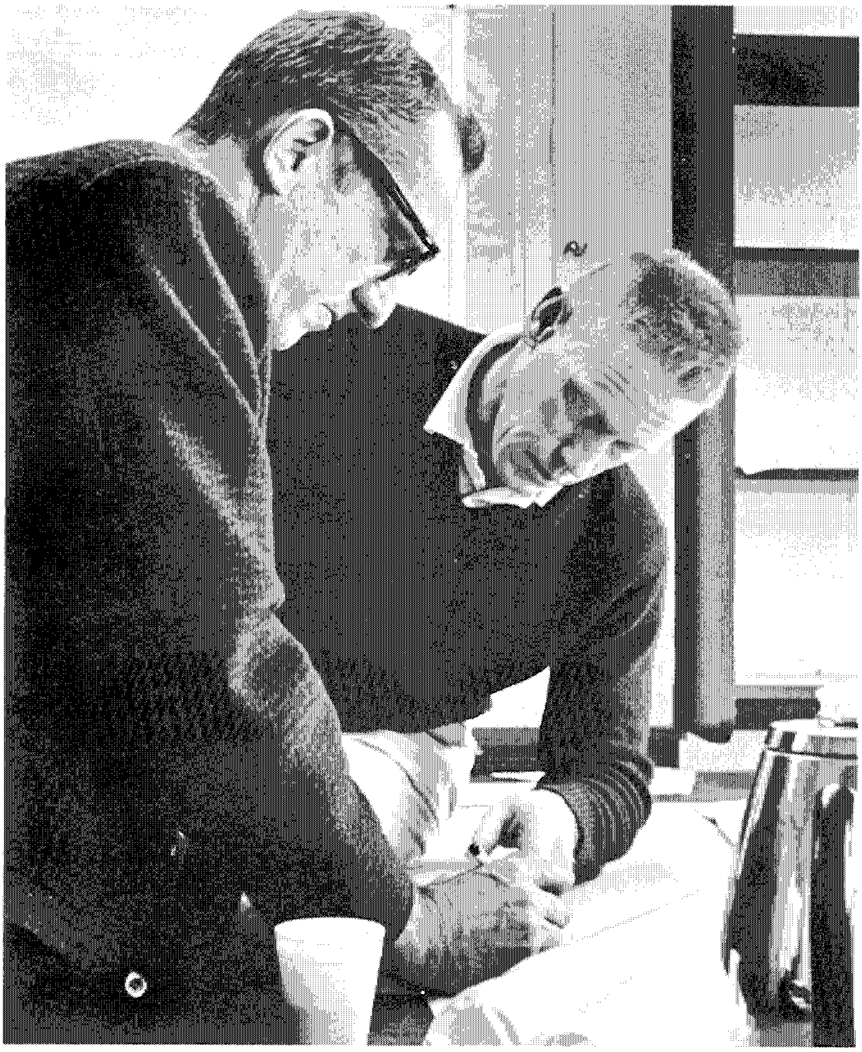


Conference between the Ocean Engineering and Marine departments: William O. Rainnie (left) and Richard S. Edwards (right).

Ashore and Afloat

A marked increase in our waterfront facilities occurred during the year with the completion of the new pier. The cornerstone was laid on June 20th by the Chairman of the Board of Trustees, Mr. McLean, and work was commenced by the C. & B. Building Company of Newport, R. I., on the new Marine Services Building. This building will house laboratories, mechanical and electrical shops, a transit area for loading and unloading research vessels, and a high bay with traveling crane for the accomplishment of large engineering projects. Some difficulty was encountered in placing the pilings for the building and completion is now scheduled for mid-summer 1969.

In October the Institution took title to the one-hundred-thirty-nine-acre Fenno estate, now designated as the Quissett Campus. In advance of the purchase, the property was leased for the summer and the house was made available to the National Academy of Sciences for its Summer Study Center Activities.

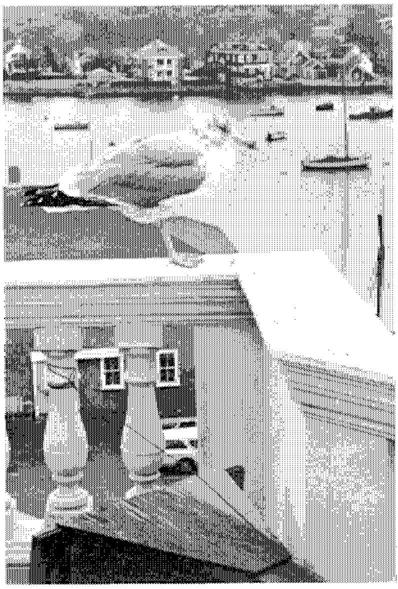
The studies in the life cycle of the Atlantic salmon were continued at the Institution's Matamek Research Station in Quebec, again, in cooperation with the University of Waterloo, Ontario. The Helio Courier seaplane was used to transport the scientists from lake to lake.

The Research Vessel KNORR (AGOR-15) was launched at Defoe Shipbuilding Co., Bay City, Michigan, on August 21 — this vessel is being constructed by the U.S. Naval Ship Systems Command and upon completion will be chartered to the Institution for use. Delivery is scheduled for October 27, 1969. She is to be 245 feet in length with a beam of 44 feet. Her propulsion will be by means of two cycloidal propellers, one forward and one aft. This will provide a high degree of maneuverability when making stations.

With considerable reluctance, the venerable R/V CRAWFORD was placed in an inactive status in October, a victim of diminished financial support. She now lies at the Institution pier awaiting disposal.

The hangar on Dyer's Dock was used during the summer months for exhibits to illustrate the work of the Institution for the thousands of visitors passing through Woods Hole who want to learn about oceanographic studies at first hand.

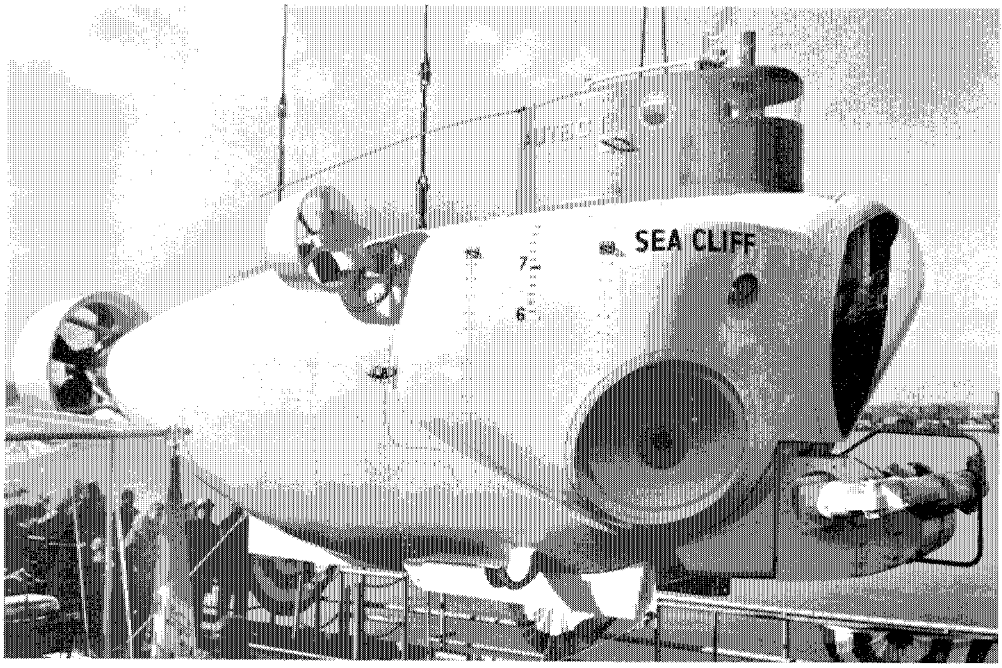
Summer visitors at the oceanographic exhibits in the hangar on Dyer's Dock.



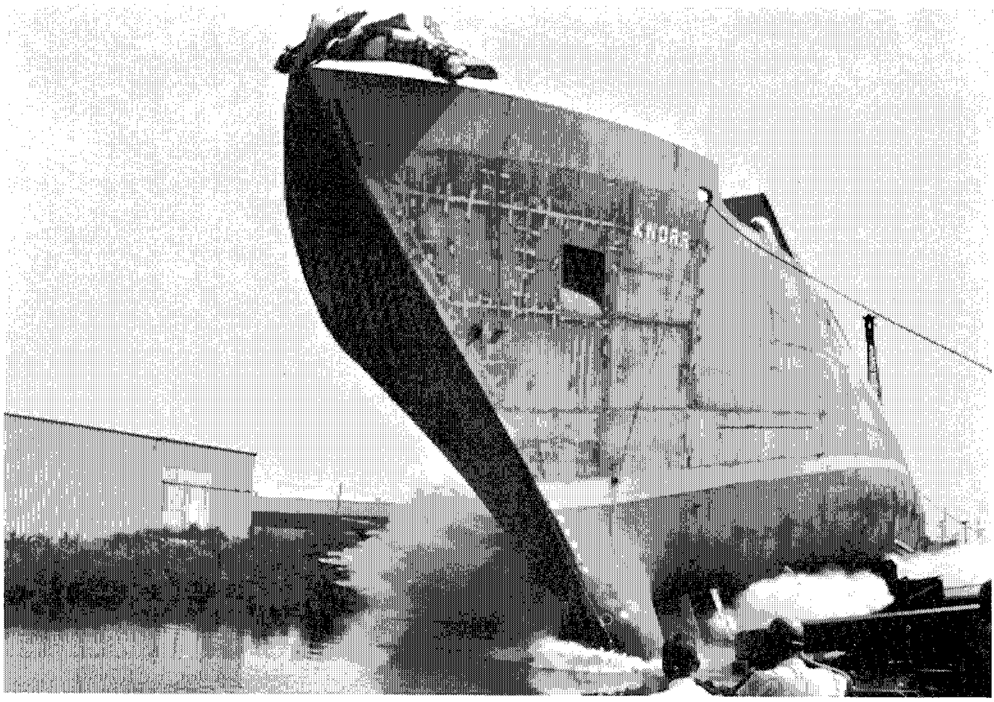
Watch over the Eel Pond.

David F. Casiles on the bridge.

A clean desk and ready for sea.



DRV SEA CLIFF *christened and launched at Electric Boat Division of General Dynamics Corporation on 11 December 1968. (Courtesy of General Dynamics Corporation.)*



Launching of R.V. KNORR *(AGOR-15) at Bay City, Michigan.*

Cruises - 1968

ATLANTIS II Days at Sea – 222 Total Miles Sailed – 31,427

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
42	15 March–28 July	West Coast of Africa	135	Menzel, Ryther, Sanders, Scheltema and Von Herzen
43	30 July–8 August	Munro's Shipyard – upkeep	- -	- - - - -
44	13–24 August	Station "D"	12	R. Heinmiller
45	29 August–19 September	Argus Island	21	H. Stommel
46	24 September–3 October	Buoy Line	9	J. Gifford
47	15–29 October	Bermuda Area	17	C. Wunsch
48	2–29 November	Gulf of Mexico	28	D. Menzel
		Total	222 days	

CHAIN Days at Sea – 268 Total Miles Sailed – 34,631

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
76	9–23 February	70th Meridian Buoy Line	15	N. Fofonoff
77	1–5 March	South of Nantucket	5	W. Dow
78	8–23 March	Sargasso Sea	16	H. Stommel
79	26–31 March	South of Nantucket	6	W. Dow
80	3–16 April	Gulf of Maine	14	B. Ketchum
81	20 April–2 May	Continental Shelf	13	E. Uchupi
82	10 May–15 September	England, Med. & Azores	129	E. Hays, Chase
83	30 Sept.–19 October	Florida Straits	20	W. Von Arx
84 Leg I	22–25 October	Alvin Salvops	4	J. Gifford
84 Leg II	1–8 November	Alvin Salvops	8	R. Edwards
84 Leg III	9–12 November	Alvin Salvops	4	R. Edwards
84 Leg IV	15–22 November	Alvin Salvops	8	R. Edwards
85	24 November–14 December	Sargasso Sea	21	R. Backus
86	16–20 December	Buoy Line	5	R. Heinmiller
		Total	268 days	

CRAWFORD Days at Sea – 202 Total Miles Sailed – 24,616

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
165	15 January–17 April	Equatorial Atlantic Ocean	94	W. Metcalf
166	25 April–27 May	South of Bermuda	33	A. Voorhis
167	7–16 June	Buoy Line	10	J. Gifford
168	24 June–22 July	Gulf Stream	29	J. Barrett
169	23 July–2 August	Newport Shipyard	- -	- - - - -
170	7 August	Block Island Sound – students	1	G. Clarke
171	8 August	Block Island Sound – students	1	G. Clarke
172	9–15 August	Edge of Continental Shelf	7	J. Craddock
173	19–29 August	Cape Cod Bay	11	C. Lorenzen
174	24 September–9 October	Gulf Stream	16	F. Fuglister
		Total	202 days	

GOSNOLD Days at Sea – 211 Total Miles Sailed – 14,693

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
110	3–11 January	Off Provincetown	9	D. Halpern
111	16 January–9 February	Caribbean Area	25	E. Hulburt
112	10 February–27 February	Caribbean Area	18	H. Goodbody
113	28 February–25 March	Caribbean Area (9 days shipyard)	18	P. Sachs
114	28 March–5 April	Caribbean Area	8	B. Dale
115	6–25 April	Charleston, S.C.	20	J. Teal
116	1 May	Vineyard Sound	1	R. Von Herzen
117	3 May	Vineyard Sound	1	Tabor Students
118	20–28 May	Gulf of Maine	9	J. Schlee
119	3–7 June	Cape Cod Bay	5	S. Daubin
120	10–18 June	Corsair, Lydonia & Gilbert Canyons	9	D. Ross
121	24 June–3 July	Continental Slope	10	R. Hessler
122	8–14 July	Off Continental Shelf	7	G. Grice
123	20–26 July	Bear Seamount	7	K. O. Emery
124	31 July–1 August	So. of Nomans in Slope Water	2	L. Hobson
125	2 August	Vineyard Sound Whistle Buoy	1	G. Siedler
126	3 August	Vineyard Sound Whistle Buoy	1	G. Siedler
127	5–8 August	Gulf Stream Axis	4	C. Nyblade
128	9 August	Buzzards Bay	1	P. Rhines
129	10 August	Cuttyhunk Harbor	1	P. Rhines
130	12–14 August	Race Point	3	C. Remsen
131	16 August	Vineyard Sound	1	J. Kanwisher
132	19–29 August	Continental Slope Water	11	P, Sachs
133	3–7 September	Shelf Waters south of M.V.	5	J. Teal
134	21–26 September	Oceanographer's Canyon	6	W. Marquet
135	1–8 October	Alexander's Acres	8	R. Backus
136	12 October	Vineyard Sound	1	G. Clarke
137	15–20 October	Continental Shelf	6	H. Hoskins
138	22–28 October	Alvin Site	7	S. Knott
139	7–12 December	Buoy Station "D"	6	R. Heinmiller
		Total	211 days	

C 54 Q Aircraft Flights – 1968

FLIGHT NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
1	16 January	Gulf Stream	1	C. Parker
2	20 January	Local test flight	1	- - - - -
3	23 January	Gulf Stream	1	C. Parker
4	5 February	Gulf Stream	1	C. Parker
5	14 February	FAA instrument check	1	W. Ketchen
6	16 February	Gulf Stream	1	C. Parker
7	22 February	Otis to Miami (400 hr. check)	1	- - - - -
8	30 March	Test flight out of Miami	1	- - - - -
9	1 April	Test flight out of Miami	1	- - - - -
10	2 April	Miami to Otis AF Base	1	- - - - -
11	25 April	Local flight	1	J. Phillips
12	6 May	Local flight	1	P. Saunders
13	7 May	Otis to Argentia NAS, Nfld.	1	P. Saunders
14	8 May	Argentia to Lajes, Teceira	1	P. Saunders
15	9 May	Lajes to Rota NAS, Spain	1	P. Saunders
16	10 May	Rota to Moron, Spain	1	P. Saunders
17	11 May	Moron, Spain to Luqua, Malta	1	P. Saunders
18	15 May	Local Luqua flight	1	G. Ewing
19	20 May	Local Luqua flight	1	G. Ewing
20	28 May	Local Luqua flight	1	G. Ewing

FLIGHT NO.	DATES	AREA OF OPERATION	DAYS	SCIENTIST
21	31 May	Local Luqua flight	1	G. Ewing
22	4 June	Local Luqua flight	1	G. Ewing
23	6 June	Local Luqua flight	1	G. Ewing
24	9 June	Luqua to Madrid, Spain	1	G. Ewing
25	9 June	Madrid to Oporto, Portugal	1	G. Ewing
26	10 June	Oporto to Lajes, Azores	1	G. Ewing
27	11 June	Lajes to Argentia NAS, Nfld.	1	G. Ewing
28	12 June	Argentia to Otis AF Base (Underwent 100 hr. check Otis 14–22 June)	1	G. Ewing
29	23 June	Local test flight	1	- - - - -
30	24 June	Otis to Azores	1	J. Phillips
31	27 June	Local Azores	1	J. Phillips
32	29 June	Local Azores	1	J. Phillips
33	2 July	Local Azores	1	J. Phillips
34	4 July	Local Azores	1	J. Phillips
35	8 July	Local Azores	1	H. K. Wong
36	9 July	Local Azores	1	H. K. Wong
37	10 July	Local Azores	1	H. K. Wong
38	12 July	Local Azores	1	H. K. Wong
39	17 July	Local Azores	1	H. K. Wong
40	20 July	Local Azores	1	H. K. Wong
41	21 July	Local Azores	1	H. K. Wong
42	22 July	Azores to Argentia, Nfld.	1	H. K. Wong
43	22 July	Argentia NAS to Otis AF Base	1	H. K. Wong
44	18 August	Local test flight	½	- - - - -
45	18 August	Local test flight	½	- - - - -
46	19 August	Local flight	1	P. Saunders
47	22 August	Local flight	1	G. Clarke
48	26 August	Local flight	1	G. Clarke
49	27 August	Local flight	1	G. Clarke
50	1 September	Plane flown to Barnstable airport due to Otis closing its runways from 9/3 to 9/6		
51	5 September	Local flight	1	P. Saunders
52	10 September	FAA flight check	1	W. Ketchen
53	16 September	Local flight – Gulf Stream		C. Parker
54	18 September	Local flight – Gulf Stream		C. Parker
55	24 September	Local test flight	1	- - - - -
56	30 September	Local test flight	1	- - - - -
57	2 October	Local test flight	1	- - - - -
58	18 October	Photo flight to Alvin site	1	- - - - -
59	31 October	Ferry A-II personnel to Bda.	1	- - - - -
60	1 November	Exchange personnel from A-II – Bda.	1	- - - - -
61	5 November	Local to Cuttyhunk	1	J. Gifford
62	15 November	To Alvin site & Station "D"	1	S. Daubin
63	20 November	Calibration of scientific equipment	1	- - - - -
64	21 November	Return from Johnsville, Pa.	1	- - - - -
65	26 November	To All American Eng. Co., Wilmington, Del.		- - - - -
66	26 November	Return from Wilmington, Del.	1	- - - - -
67	13 December	Local test flight	1	- - - - -

TOTAL HOURS 1968: 331.8 hrs.

The Helio Courier made several local photo flights but worked mainly with the Buoy Project (Fofonoff) necessitating many trips to Gay Head and Cuttyhunk. The plane also made a trip to Canada to service the pond project (Sept. Isles) in Matamek Lake. There was also a line towing project (G. Ewing) and Charles Flagg made numerous flights over Buzzards Bay.

Satellite navigation gear aboard ATLANTIS II *with Donald E. Woods, the navigator.*

The completely remodeled Shiverick House at 11 School Street which houses the new Sigma 7 computer (p.46)

Scientific Departments and Supporting Services Personnel

Paul M. Fye	Director
H. Burr Steinbach	Dean of Graduate Studies
‡Bostwick H. Ketchum	Associate Director
Arthur E. Maxwell	Associate Director
Frederick E. Mangelsdorf	Assistant Director for Development and Information
David D. Scott	Assistant Director for Administration

The following were in the employ of the Institution for the twelve month period ending December 31, 1968:

Department of Biology

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

Department of Chemistry

Bankston, Donald C.
Blumer, Max
Bowen, Vaughan T.
Brewer, Peter G.
Burke, John C.
Degens, Egon T.
Deuser, Werner G.
‡Fitzgerald, William F.
Hess, Marilyn R.
*Hummon, Margaret R.
Hunt, John M.
Ku, Teh-Lung
Langley, Louise R.
Lawson, Charlotte M.
Livingston, Hugh D.
McAuliffe, Julianne
McNulty, Patrick S.
Noshkin, Victor E., Jr.
Pasley, Susan
*Richards, Heidi
Robertson, J. Colin
Ross, Edith
Sachs, Peter L.
Sass, Jeremy
Schroeder, Brian W.
Smith, C. LeRoy
Spencer, Derek W.
Surprenant, Lolita D.
Thompson, Geoffrey
Whittle, Kevin J.
Wilson, T. R. S.

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.
*Brown, June A.
Bunce, Elizabeth T.
Church, William J.
*Coppenrath, Agnes I.
Dale, Barrie
Davis, James A.
Doutt, James A.
Dow, Willard
Dunkle, William M., Jr.
Emery, Kenneth O.
*Gallagher, Gloria S.
Gaudette, Louis F.
Grant, Carlton W., Jr.
Guild, Ritchey L.
Gurney, Elaine B.
†Hathaway, John C.
Hayes, Carlyle R.
Hays, Earl E.
Hays, Helen C.
‡Hess, Frederick R.
Hilliard, Channing N., Jr.
Hollister, Charles D.
Jones, J. Fred
*Jones, Maxine M.
Kadar, Susan
Katz, Eli J.
Knott, Sydney T., Jr.
Maifeld, Judy
†Manheim, Frank T.
†Meade, Robert H.
Mellor, Florence K.
Milliman, John D.
Miner, Arnold W.
Morehouse, Clayton W.

‡On Leave of Absence

*Part Time Employment

Department of Geology and Geophysics (continued)

Murphy, Edward L.
Nichols, Walter D.
Nowak, Richard T.
Owen, David M.
†Oldale, Robert N.
‡Peterson, Jane M.
Phillips, Joseph D.
Poole, Stanley E.
Prada, Kenneth E.
Ross, David A.
Ruiter, Robert G.
†Schlee, John
Scott, Carl W., Jr.
Stetson, Thomas R.
Stone, Louise D.
Sutcliffe, Thomas O.L.
Toner, Lois G.
Uchupi, Elazar
Vine, Allyn C.
Von Herzen, Richard P.
Wall, David
Watkins, William A.
Wertheimer, Alice M.
Weston, Edith A.
Whalen, Thomas L.
Witzell, Grace M.
Witzell, Warren E.
Wong, How-Kin
Wooding, Frank B.
Young, Earl M., Jr.
Zarudski, 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.
Brown, Charles
Burt, Kenneth H.
Chute, Edward H.
Collins, Clayton W., Jr.
Daubin, Scott C.
Dorson, Donald L.
Drever, Robert G.
Eliason, Andrew H.
Evans, Emily
Fairhurst, Kenneth D.
Frank, Eric H., Jr.
Freund, William F., Jr.
Gibson, George W.
Graham, Russell G.
Hamill, Clifford J.
Hunt, Mary M.
Kallio, Peter G.
Lenart, Alice
Lyon, Thomas P.
Marquet, William M.
*Mavor, James W., Jr.
McCamis, Marvin J.
Muzzey, Charlotte A.
Olmstead, Ellen K.
O'Malley, Patrick
Omohundro, Frank P.
Page, William F.
*Paine, Kathryn
*Paxon, Louis J.
Porembski, Chester R.
Power, George H.
Rainnie, William O., Jr.
*Reese, Margaret L.
Rosenfeld, Melvin A.
Roy, Pamela A.
Sharp, Arnold G.
Shultz, William S.
Stern, Margaret P.
Stimson, Paul B.
*Sullivan, James R.
Tollios, Constantine D.
Walden, Robert G.
Weaver, Roger D.
Webb, Douglas C.
Webert, Warren F.
Webster, Jacqueline
Wilson, Valentine P.
Winget, Clifford L.
Woods, Donald E.

Department of Physical Oceanography

Alexander, Robert M.
Allen, Ethel B.
Andersen, Nellie 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.
Cornell, Sidney
Daniels, Dolores H.
Day, C. Godfrey
*Dennis, Joan B.
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.
Hays, Betty C.
Heinmiller, Robert H.
Houston, Leo C.
Iselin, Columbus O'D.
Johnson, Carl A.
*Kahler, Yolande A.
Knapp, George P. III
Machado, Richard A.
Maltais, John A.
Mason, David H.
McCullough, James R.
Metcalf, William G.
Millard, Robert C., Jr.
Miller, Arthur R.
Munns, Robert G.
Parker, Charles E.
Payne, Richard E.
Phillips, Helen F.
Reese, Mabel M.
Reynolds, Carol J.
Ronne, F. Claude
Sanford, Thomas B.
Saunders, Peter M.
Schleicher, Karl E.
Schmitz, William J., Jr.
Schroeder, Elizabeth H.
Shodin, Leonard P.
Simmons, Charles F.
Simoneau, R. David
Soderland, Eloise M.
Spencer, Allard T.
Stalcup, Marvel C.
Stanley, Robert J.
Striffler, Foster L.
Tarbell, Susan A.
Thayer, Mary C.
Tupper, George H.
Vastano, Andrew 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.
Ziegler, Evelyn L.
‡Zwilling, Avron M.

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

Department of Administrative and Service Personnel

Aiguier, Edward L.
*Allen, Norman T.
Anders, Wilbur J.
Andrews, Josephine A.
Anthony, Jane Ann
Backus, Jeanne M.
*Banay, Barbara B.
Bard, Wallace R.
Battee, Janice A.
Behrens, Henry G.
Benttinen, Dave D.
Bowman, Richard W.
Branham, Roy L.
Brown, Joseph C.
Callahan, Sharon L.
Campbell, Eleanor N.
Carlson, Alfred G.
Carlson, Eric B.
Carlson, Gustav A.
Carlson, Ruth H. E.
Carver, Kenneth W.
Chalmers, Agnes C.
*Chase, Elizabeth L.
Christian, John A.
Clough, Auguste K.
Condon, John W.
Conway, George E.
Copestick, Louis B.
Corr, James P.
Crawford, Bruce
Crocker, Marion W.
Croft, Donald A.
Crouse, Porter A.
*Dalton, George A.
Davis, Ruth H.
Day, Joseph V.
Dean, Mildred J.
Dimmock, Richard H.
Eastman, Arthur C.
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
Gibson, Laurence E.
*Gioiosa, Albert A.
Grant, Carlton W., Sr.
*Hahn, Jan
‡Hall, Arthur B.
Hampton, Carolyn S.
Hanley, Marie J.
Hatzikon, Kaleroy L.
Henderson, Arthur T.
Hodgson, Sloat F.
Ingram, Ruth C.
Innis, Charles S., Jr.
Jenkins, Delmar R.
Johnson, Harold W.
Kostrzewa, John A.
LeBlanc, Donald F.
Leonard, Susan
Lizotte, Richard
MacKillop, Harvey
Martin, Olive
Mayberry, Ernest
McGilvray, Mary K.
Medeiros, Frank
Mitchell, James R.
Morrison, Kenneth
Motta, Joseph C.
Motta, Joseph F.
Muller, John T.
Ortolani, Mary
Peirson, A. Lawrence III
Pereira, Janice A.
Phares, Edward
Picard, Eleanor P.
Queenan, Martha L.
Quigley, Ralph W.
Ramsey, William S., Jr.
Reeves, Stanley A.
Rennie, Thomas D.
Roberts, Harry A.
Ross, David F.
Rudden, Robert D., Jr.
Schilling, John L.
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.
Sullivan, Gerard E.
Tometich, Louis J.
Vallesio, Barbara M.
von Dannenberg, Carl A.
Walker, Jean D.
Watson, L. Hoyt
Weeks, Robert G.
Wessling, Andrew L., Jr.
White, Haskel E.
Williams, Sally A.
Wing, Carleton R.
Woodward, Fred C., Jr.
Woodward, Martin C.
Woodward, Ruth F.
Wright, Hollis F.
Ziegler, William N. D.

Marine Personnel

Babbitt, Herbert L.
Baugh, Jess D.
Bazner, Kenneth E.
Bizzozero, John P.
Brereton, Richard S.
Brown, John W.
Bumer, John Q.
Butler, Dale T.
Cabral, John V.
Cahoon, Geraldine B.
Caranci, Donald H.
Casiles, David F.
Cavanaugh, James J.
Clarkin, William H.
Colburn, Arthur D., Jr.
Cornell, Jack W.
Cotter, Jerome M.
‡Coughlin, Brooks W.
Crocker, John D.
Davis, Charles A.
Devlin, Gerald X.
Edwards, Richard S.
Erwin, Clarence E.
Farnsworth, Donald C.
Field, Michael J.
Gordon, Robert L.
Halverson, Leonard C.
Hamblet, Dwight F.
Hartke, David L.
Henton, H. Dean
Hiller, Emerson H.
Howe, Paul M.
Howland, Paul C.
‡Jackson, Edward B.
Jefferson, Albert C.
Johnston, Alexander T.
Jorgensen, Peter A.
‡Knight, Olin T.
La Porte, Leonide
Leiby, Jonathan
Lobo, Wayne F., Jr.
Lowney, Edwin A.
Martin, John W., Jr.
Martin, Ralph S.
Matthews, Francis S.
McLaughlin, Barrett J.
Merry, Harold G.
Moller, Donald A.
Morse, Joseph C.
Moye, William E.
Mysona, Eugene J.
Ocampo, Conrad H.
Palmieri, Michael, Jr.
Pennypacker, Thomas R.
Pierce, George E.
Pierce, Samuel F.
Pike, John F.
Ribeiro, Joseph
Rioux, Raymond H.
Roy, Alfred J.
Russell, Lee T.
Seibert, Harry H.
Seifert, Charles T.
Stires, Ronald K.
Szymanski, Theodore J.
Tully, Edward J.
Walden, Henry A.
Weber, Eric F.
‡Westberg, Donald R.
White, William A.
Wolcott, William R.

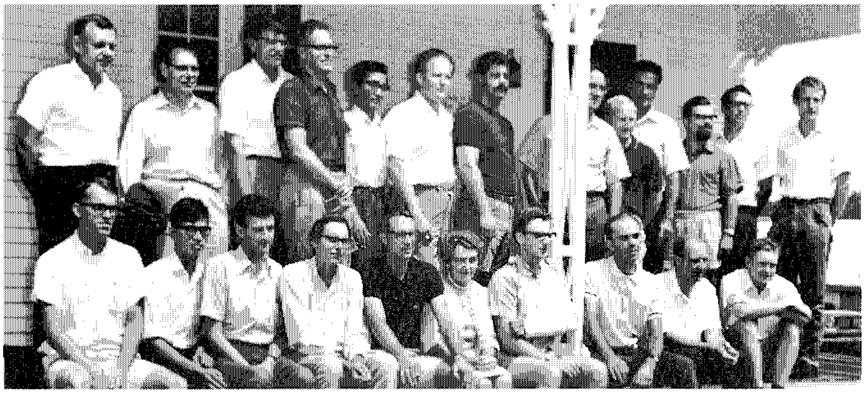
‡On Leave of Absence
*Part Time Employment

1968 Summer Course Program

During the summer, a special program of courses in oceanography was given in Woods Hole in conjunction with the Massachusetts Institute of Technology as part of the Joint Program. Thirty-two students were enrolled. The program was designed so students could take various combinations of two or three of the seven courses offered for a full credit summer program. The subjects covered included Physical Oceanography, Experimental Fluid Mechanics, Marine Geology, Marine Geodesy, Biological Oceanography, and Ocean Engineering. Admission to this special summer program was open to all students enrolled in the Joint Program, as well as to qualified students from other universities. Of particular interest was the resultant mixture of the student body. Students from the Joint Program were joined by a group of graduate students from the Department of Naval Architecture at M.I.T., and a selected group of young scholars from colleges and universities across the country. A total of 24 of these students received partial or full fellowship support for the summer.

K. O. EMERY, *Acting Dean,*
Summer of 1968

Air view of the recently-purchased Fenno estate, now designated as the Quissett Campus, looking toward Vineyard Sound.



Members of the 1968 Geophysical Fluid Dynamics Program. Back row: Henry Stommel, Henry Charnock (England), Charles S. Cox, J. Stewart Turner (England), Kozo Yoshida (Japan), Claes Rooth, Anthony Rosati, Melvin E. Stern, Gunnar E. B. Kullenberg (Sweden), George Veronis, Douglas O. Gough (England), Willem V. R. Malkus, Philip Hazel (England). Front row: Michael R. Foster, Han-hsuing Kuo, Bruce R. Morton (Australia), James R. Luyten, John S. Allen, Jr., Mary C. Thayer, Christopher N. K. Mooers, Michael C. Gregg, Michael S. Longuet-Higgins (England), Louis N. Howard

Grants and Fellowships

Year-Round Postdoctoral Fellowships

Awarded 1968:

MICHAEL HORN
Harvard University

TOGWELL A. JACKSON
University of Missouri

PHILIP B. ROBERTSON
University of Miami

GILBERT T. ROWE
Duke University

FREDERICK SAYLES
University of Manchester, England

TIMOTHY WILLIAMS
Rockefeller University

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

Academic Year Fellowships / Graduate Research Assistantships

WILLIAM F. FITZGERALD
JANICE L. GLENDE
BRUCE M. GORDON
BRYAN L. KOLITZ
JAMES W. MURRAY
HENRY T. PERKINS
WILLIAM G. SUNDA
LAWRENCE A. WOOD

Summer Fellowships only:

DAVID ANATI
PAUL A. HEINEKEN
TERRENCE M. JOYCE
JAMES M. KINGSLEY
CHI-YUAN LEE

Predoctoral Fellowship

LION F. GARDINER
University of Rhode Island

Summer Student Fellowships

WILLIAM C. BOICOURT
Johns Hopkins University

DAVID M. CHECKLEY, JR.
University of Washington

BARBARA R. FINK
City College of New York

CLAUDE FRANKIGNOUL
University of Liège

RUTH GRANT
Douglass College

KATHERINE KEENAN
University of Illinois

KENT C. NIELSEN
University of North Carolina

CARL F. NYBLADE
Oberlin College

BLAKEMAN S. SMITH
Juanita College

Summer Course Fellowships

CHUNG SUNG AHN
Massachusetts Institute of Technology

HARRY L. BRYDEN
Dartmouth College

RICHARD H. BURROUGHS
Princeton University

MEADE H. CADOT
University of Kansas

ROBERT F. CORWIN
University of California, Berkeley

R. P. DICKENSON
Massachusetts Institute of Technology

CHARLES EDWIN DOWNS
Stanford University

WILLIAM E. HERONEMUS
University of Massachusetts

MARK L. HUBERMAN
Cornell University

CHUL MIN KIM
Korea, Seoul National University

WAYNE R. MARTIN
Massachusetts Institute of Technology

JOHN A. MOODY
State University of New York

JAMES H. NATLAND
Massachusetts Institute of Technology

WILLIAM R. PATTERSON
Massachusetts Institute of Technology

GEORGE L. RANDALL
Massachusetts Institute of Technology

ROBERT J. STEWART
Massachusetts Institute of Technology

MORRIS L. THATCHER
Massachusetts Institute of Technology

JOHN KIM VANDIVER
Massachusetts Institute of Technology

RONALD WALROD
Massachusetts Institute of Technology

CHARLES L. WOOD
Pomona College

Geophysical Fluid Dynamics Seminar

Staff Members and Lecturers

AKIO ARAKAWA
University of California, Los Angeles

WALLACE S. BROECKER
Lamont Geological Observatory

KIRK BRYAN
Geophysical Fluid Dynamics Laboratory, ESSA, Princeton

HENRY CHARNOCK
Southampton University, England

CHARLES S. COX
Scripps Institution of Oceanography

HARMON CRAIG
Scripps Institution of Oceanography

DONALD V. HANSEN
Atlantic Oceanographic Laboratories, ESSA, Miami

MYRL C. HENDERSHOTT
Scripps Institution of Oceanography

WILLIAM C. HOLLAND
Geophysical Fluid Dynamics Laboratory, ESSA, Washington

LOUIS N. HOWARD
Massachusetts Institute of Technology

KENNETH HUNKINS
Lamont Geological Observatory

ROBERT H. KRAICHNAN
Peterborough, New Hampshire

JOHN KROLL
Yale University

ANTS LEETMA
Massachusetts Institute of Technology

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

ROBERT L. MILLER
University of Chicago

BRUCE R. MORTON
Monash University, Australia

H. GÖTE OSTLUND
University of Miami

KILHO PARK
Oregon State University

ALLAN R. ROBINSON
Harvard University

CLAËS G. H. ROOTH
University of Miami

EDWARD A. SPIEGEL
New York University

MELVIN E. STERN
University of Rhode Island

HENRY STOMMEL
Massachusetts Institute of Technology

KARL K. TUREKIAN
Yale University

J. STEWART TURNER
Cambridge University, England

GEORGE VERONIS
Yale University

PIERRE WELANDER
University of Göteborg, Sweden

CARL I. WUNSCH
Massachusetts Institute of Technology

KOZO YOSHIDA
University of Tokyo, Japan

Summer Fellowships:

JOHN S. ALLEN
Princeton University

MICHAEL R. FOSTER
Case Institute of Technology

MICHAEL C. GREGG
University of California, San Diego

PHILIP HAZEL
University of Cambridge, England

GUNNAR ERIK S. KULLENBERG
University of Göteborg, Sweden

HAN-HSIUNG KUO
Yale University

JAMES R. LUYTEN
Harvard University

CHRISTOPHER N. K. MOOERS
Oregon State University

Guest Investigators
1968

D. James Baker, Jr.
Harvard University

Gregory K. Bergey
Princeton University

Francis S. Birch
Princeton University

Richard L. Chase
University of British Columbia

Sneed B. Collard
Harvard University

Ralph Mitchell
Harvard University

Samuel Raymond
University of Pennsylvania

Robert Robertson
Academy of Natural Sciences of Philadelphia

William F. Simmons
Massachusetts Institute of Technology

Guest Student Investigators

Frank W. Barvenik
University of New Hampshire

Arthur G. Gaines, Jr.
University of Rhode Island

Kenneth C. Haines
University of Rhode Island

John Hall
University of North Carolina

Mrs. Dorothy G. Swift
Johns Hopkins University

Visiting Investigators

Harold L. Burstyn
Carnegie-Mellon University

Michael S. Longuet-Higgins
Oregon State University

Andrew J. Nalwalk
University of Connecticut

Gerold Siedler
Institut für Meereskunde, Kiel, Germany

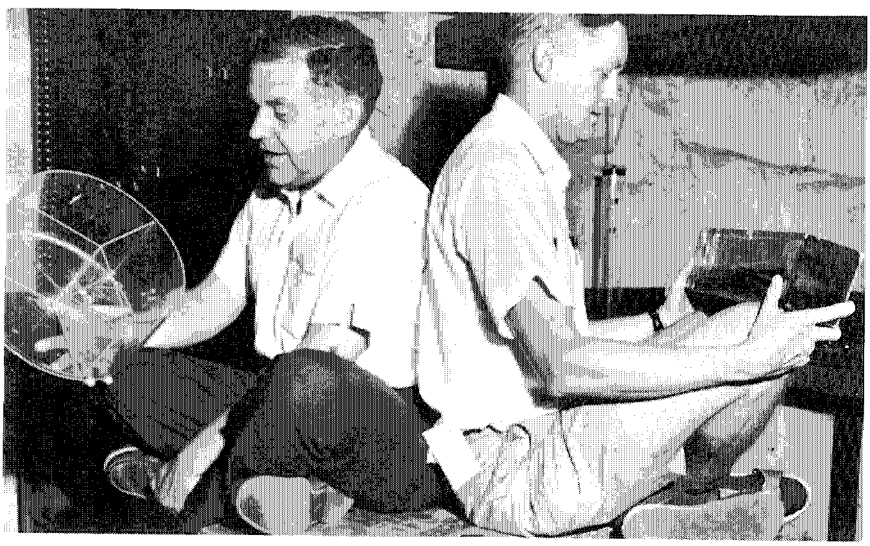
Alden L. Winn
University of New Hampshire

Lawrence High School Scholarships

Thomas Chase
Oberlin College

Richard Panton
Worcester Polytechnic Institute

Leon Turner
Lowell Technological Institute



Principal instructors in the 1968 Geophysical Fluid Dynamics Program — Henry Stommel (left) and Louis N. Howard (right).

Treasurer's Report

The accounts for the year 1968 have been audited by Lybrand, Ross Bros. & Montgomery.

The book value of endowment funds at December 31, 1968 was $5,772,428, of which $2,391,095 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 $8,954 in cash was $8,528,716. Endowment fund investments and income received therefrom are summarized on page 79

Income received on endowment assets was $277,179 for the year ended December 31, 1968 compared with $255,743 the previous year.

During 1968, a total of $1,244,519 was received from generous individuals, foundations, and corporations to support research and education at the Institution. Of particular significance is a major grant from the Henry L. and Grace Doherty Charitable Foundation for the establishment of the Doherty Chair in Oceanography.

Endowment income represented a return on endowment fund investments of 3.3 per cent at year-end market quotation, 4.8 per cent on book amount and 8.2 per cent on the contributed amount of the endowment fund.

Endowment income was allocated for 1968 operating expenses at the rate of 6 per cent of the contributed amount of endowment funds, or $179,816. The remaining balance amounting to $97,363 was transferred to the income and salary stabilization reserve.

The Institution's 1968 contribution to the Woods Hole Oceanographic Institution Employees' Retirement Trust amounted to $367,557.

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, 1968 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 practical to confirm receivables from United States Government departments, but we have satisfied ourselves as to such accounts by means of other auditing procedures.

In our opinion, the accompanying statements (with investments stated at cost) (pages 76 to 77, inclusive) present fairly the financial position of Woods Hole Oceanographic Institution at December 31, 1968 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

The supplemental schedules included in this report (pages 78 to 79, inclusive) although not considered necessary for a fair presentation of the financial position and results of operations, are presented primarily for supplemental analysis purposes. This additional information has been subjected to the audit procedures applied in the examination of the basic financial statements, and in our opinion, is fairly stated in all material respects in relation to the basic financial statements taken as a whole.

Boston, Massachusetts

March 20, 1969

Lybrand, Ross Bros. & Montgomery

BALANCE SHEET

December 31, 1968

ASSETS

Current Fund Assets:	
Cash	$ 1,114,400
Marketable securities, at cost	690,172
Reimbursable research costs:	
Billed	928,979
Unbilled, including December costs of $334,064 and $118,058 awaiting contract amendments	542,182
Supplies, prepaid expenses and deferred charges	122,237
Plant funds advanced to current	(1,304,770)
	2,093,200
Endowment Fund Assets:	
Investments:	
Marketable securities, market value $8,465,250	5,708,962
Real estate	54,512
	5,763,474
Cash	8,954
	5,772,428
Plant Fund Assets:	
Laboratory plant and equipment	3,923,619
Atlantis II, contingent title	4,831,130
Other vessels, equipment and property	3,824,157
Dock facility under construction	201,758
	12,780,664
Less accumulated depreciation	2,713,507
	10,067,157
Plant funds advanced to current	1,304,770
	11,371,927
	$19,237,555

LIABILITIES

Current Liabilities and Reserves:	
Accounts payable and accrued expenses	$ 403,569
Contribution payable to employees' retirement plan and trust	367,557
Unexpended balances of restricted gifts and grants	310,103
Reserves	1,011,971
	2,093,200
Endowment Funds:	
Unrestricted as to income	2,521,420
Unrestricted as to principal and income	109,913
Restricted as to income	750,000
Accumulated net gain on sales of investments	2,391,095
	5,772,428
Plant Funds:	
Expended for plant, less retirements	12,780,664
Less accumulated depreciation	2,713,507
	10,067,157
Unexpended	1,304,770
	11,371,927
	$19,237,555

Statement of Operating Expenses and Income

Year Ended December 31, 1968

Operating Costs and Provisions		
Direct costs of research activity:		
Salaries and wages		$3,279,363
Vessel and aircraft operations		2,130,709
Materials, equipment and services		2,110,245
Laboratory costs		418,650
Travel		213,038
Service departments		283,663
Computer center		320,157
		8,755,825
Educational operations		145,420
Indirect costs:		
General and administration		1,143,186
Total depreciation	$428,770	
Less amount funded in direct and indirect costs above	183,477	245,293
Miscellaneous		77,498
Other charges:		
Provision for working capital and contingencies		123,468
		$10,490,690
Income:		
Income for sponsored research (including $3,033,583 gifts and grants expended):		
For direct costs		8,653,672
For indirect costs		1,106,065
Fees for use of facilities		385,349
		10,145,086
Endowment income availed of:		
For institution research		85,055
For education		35,141
For institution indirect costs		37,120
Development program contributions		126,732
Revenue from educational operations		41,298
Miscellaneous		20,258
		$10,490,690

Statement of Changes in Funds

Year Ended December 31, 1968

		Plant Funds				Reserves	
			Unexpended				
	Endowment Funds	Invested in Plant	Acquisition of Capital Assets	General Plant and Equipment Reserve	Unexpended Balances of Restricted Gifts and Grants	Income and Salary Stabilization	Working Capital and Contingency
Balance beginning of year	**$4,890,523**	**$9,294,512**	**$1,010,533**	**$376,409**	**$36,767**	**$795,823**	**$142,539**
Restricted gifts and grants received	763,015		531,380	5,000	3,274,483		
Endowment income					15,015	262,164	
Net gain on sales of investments	118,890						
Provision for working capital and contingencies							123,468
Provision for depreciation:							
Funded		(183,477)		183,477			
Unfunded		(245,293)					245,293
Availed of for education, and research costs					(3,033,583)	(157,316)	
Transferred to acquisition of capital assets fund from working capital and contingency reserve			400,000				(400,000)
Invested in plant		1,202,029	(1,064,869)	(137,160)			
Miscellaneous		(614)			17,421		
	$5,772,428	**$10,067,157**	**$877,044**	**$427,726**	**$310,103**	**$900,671**	**$111,300**

Direct Costs of Research Activity

Year Ended December 31, 1968

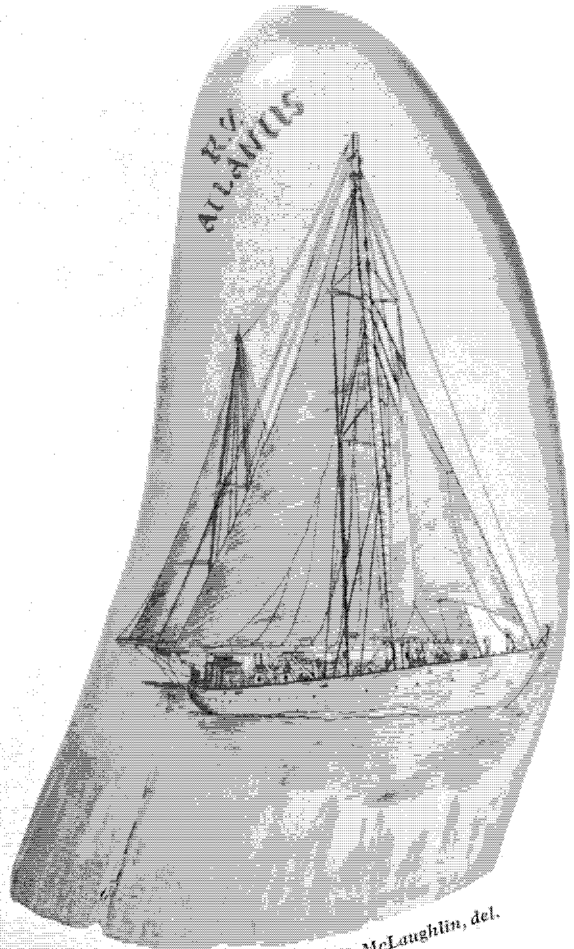
	Salaries and Wages	Vessel and Aircraft Operations	Materials, Equipment and Services	Laboratory Costs	Travel	Service Departments	Computer Center	Total
U.S. Government:								
Contracts	$2,313,964	$1,199,753	$1,527,307	$294,613	$137,295	$210,835	$279,361	$5,963,128
Grants	877,362	929,488	443,221	112,616	68,713	51,895	35,871	2,519,166
Other sponsored research	19,145	1,468	136,884	2,526	4,942	19,071	4,440	188,476
Total direct costs of sponsored research	3,210,471	2,130,709	2,107,412	409,755	210,950	281,801	319,672	8,670,770
Institution research	68,892		2,833	8,895	2,088	1,862	485	85,055
Total direct costs of research	$3,279,363	$2,130,709	$2,110,245	$418,650	$213,038	$283,663	$320,157	$8,755,825

Summary of Investments

As at December 31, 1968

	Book Amount	% of Total	Market Quotation	% of Total	Endowment Income
BONDS:					
Government and government agencies	$1,663,931	28.9	$1,607,888	18.8	$ 66,797
Railroad	288,213	5.0	235,106	2.8	13,371
Public utility	484,958	8.4	397,654	4.7	21,477
Industrial	612,321	10.6	555,756	6.5	17,669
Financial and investments	395,768	6.9	366,201	4.3	15,771
Total bonds	3,445,191	59.8	3,162,605	37.1	135,085
STOCKS:					
Preferred	212,448	3.7	234,026	2.8	3,760
Common:					
Public utility	482,921	8.4	1,118,011	13.1	39,612
Industrial	1,409,826	24.5	3,721,445	43.7	85,593
Miscellaneous	158,576	2.7	229,163	2.7	10,134
Total common stocks	2,051,323	35.6	5,068,619	59.5	135,339
Total stocks	2,263,771	39.3	5,302,645	62.3	139,099
Total marketable securities	5,708,962	99.1	8,465,250	99.4	274,184
REAL ESTATE	54,512	.9	54,512*	.6	2,995
Total investments	$5,763,474	100.0	$8,519,762	100.0	$277,179

*At book amount.



Barrett H. McLaughlin, del.