THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

Cover,
ATLANTIS II circumnavigated the world on her second cruise to the Indian Ocean, 21 January–14 November, 1965, a distance of nearly 50,000 miles.

TABLE OF CONTENTS

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14 May 1882

27 March 1965

Dr. Alexander Forbes was one of the most versatile scientists who have ever interested themselves in the affairs of this Institution. A tremendously enthusiastic and active man, he managed to find time to know a great deal about many aspects of science and sport. Although he worked hard and effectively in his laboratory in neural physiology, weekends and holidays would find him skiing, flying or sailing. In his many hobbies he was far from being an amateur.

There is a story about him, possibly somewhat exaggerated by Dr. Bigelow, that Alex once complained to him that he had sixteen hobbies in which he was very much interested and that he was finding it difficult to so organize his life that he could fully enjoy all of them.

Having spent his summers as a boy along the shores of Vineyard Sound, it was natural for him to be a sailing enthusiast. However, before completing his career as a sailor he had covered a huge part of the ocean.

I began to know him increasingly well, beginning in 1931. He bought the original schooner ATLANTIS and thus enabled me to get married. He first took her to northern Labrador which was an additional bond in common. It was at this time that he became interested in photogrammetry which combined his love for flying and for exploration. Having supplied him with a few sketch maps of the Torngat region of Labrador, he photographed much of this interesting area from the air. His book on northern Labrador later became an important factor for the selection of air bases used during World War II.

Cruises to the Mediterranean occupied subsequent summers.

He was elected to the National Academy of Sciences in 1936 and was all his life a most active member of many other more specialized scientific organizations. He even managed to attend almost regularly meetings of the Explorers Club in Boston.

As World War II approached he was anxious to play an active part. He had an old and much salt encrusted naval uniform which soon had four stripes on its sleeves. Few people around Washington noticed that his commission was as a medical officer and he was usually able to have orders written to send him to wherever he wanted to go.

As the time for the Bikini atomic bomb tests approached it was clear that Dr. Forbes was the most knowledgeable man available to make the photographic part of the observational program a success. Still in his old medical officer's uniform he organized this to perfection.

Of recent years, as I very well know, he has been the center of the intellectual life of Milton, Massachusetts, where he had long made his home. The turnout at the memorial service held on March 31, 1965 at the First Parish Church in Milton gave ample evidence of the respect of both the medical profession and the layman for a wise and very human man.

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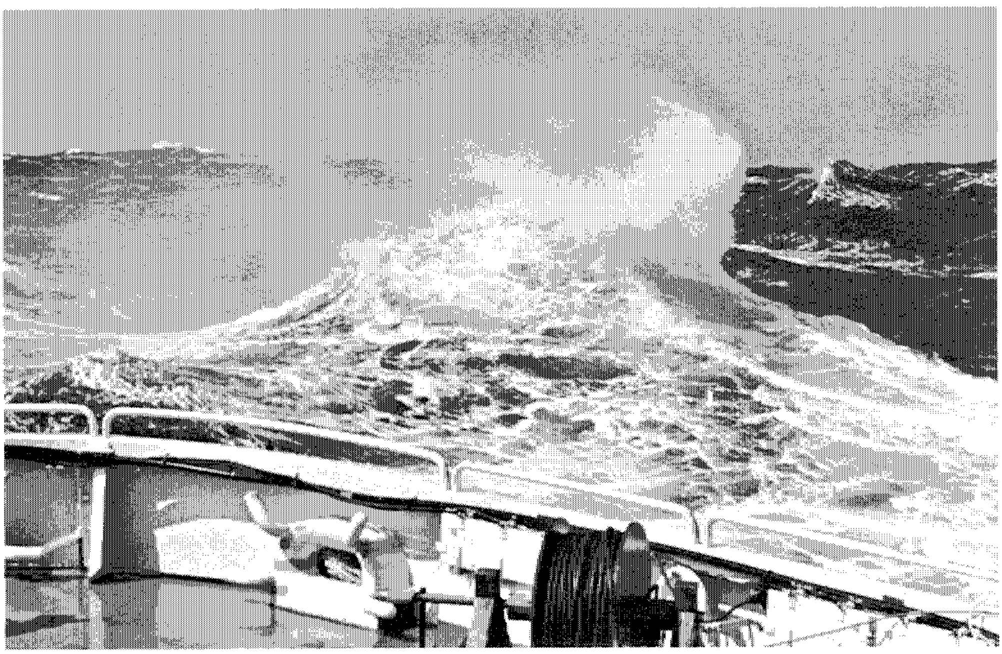

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THE DIRECTOR'S REPORT

A Decade of Progress

Oceanography has been going through an interesting and exciting stage of development during the past decade, a decade which has included the most ambitious international cooperative programs scientists have yet undertaken. Starting with the International Geophysical Year, we have participated in the International Indian Ocean Expedition, the International Cooperative Investigations of the Tropical Atlantic, and the Cooperative Study of the Kuroshio Current.

In the past decade there has also been a beginning in the engineering necessary to harvest the riches of the sea — men have descended to the deepest part of the oceans, have transversed the Arctic Ocean under the ice cap, have lived for a month within the sea, and have attempted to harvest diamonds and manganese nodules from the sea floor. This same decade has seen the greatest advances in the transition from an observational, descriptive regime, in which each scientific voyage resulted in the discovery of a new seamount, the identification of a new species of marine life or the tracking of a different ocean current, to the more precise realm of the mathematician and physicist in which theories are explored, fundamental questions about the oceans are asked and answers sought. This is the normal evolution of all science. Oceanography has arrived at this state of development later than some other branches of science because it is a derived science in which we attempt to use our capabilities as biologists, chemists, geologists, mathematicians or physicists in the study of marine phenomena. There are some among us who contend that oceanography is not a science at all but rather a state of mind — a preoccupation with nature or, indeed, an environment in which science is done. In any case, it has been the decade of greatest progress in the long history of man's desire to understand the oceans.

The most significant, and somewhat surprising, result of this transition has been a marked degree of improvement in the quality and importance of the research in oceanography as contrasted with a decade ago. This is surprising because of the rapid growth of oceanography during this period. How is it possible that the quality and sophistication of the research has improved during a period in which the numbers of people involved in these endeavors have doubled and the funds have quadrupled? Recently, the Panel on Oceanography of the President's Scientific Advisory Committee asked me to substantiate my assertion that such a development has really taken place. My answer to them was along the following lines.

I am strongly convinced that the general quality of oceanographic research being pursued in the United States has improved greatly during recent years. As I see it, there are four reasons which explain how this has come about.

First, the excitement and challenge presented by oceanography today has resulted in the attraction of a substantial number of new people into the field. These people have come into oceanography from other research areas. Twenty-one of the 35 Ph.D.'s appointed to our Resident Scientific Staff during my term as Director since 1958 are, with this appointment, starting research in oceanography for the first time. These new people have brought an infusion of new blood which has been without question of great benefit to us here in Woods Hole. The quality of people we have been able to attract into the field has been exceptionally high. Their commitment to the study of science in the oceans is strong and their impact already is substantial. A recent census of oceanographers would indicate that this is true not only within our Institution. The estimate is that 80% of today's oceanographers were trained and did their original research in one of the basic sciences rather than in marine science. The interdisciplinary nature of our work requires, for example, that a good chemical oceanographer must, first of all, be a good chemist. It also requires that the oceanographer's education include time at sea; a concept we have long endorsed, as illustrated by the granting of over 700 fellowships to young scientists interested in marine research. These are precepts we have to keep constantly in mind in our educational planning.

Second, the great advances in techniques and the development of improved understanding within the basic sciences have been of significant assistance to oceanography. In chemistry, the development of analytical techniques of very high precision permitting the analysis of elements occurring in the ocean in minute quantity has been a very recent example, as illustrated by Dr. Blumer's and Dr. Degens' work here in Woods Hole. The impact of tracer techniques, solid state electronics, computers, all are so evident in oceanography today that it is almost unnecessary to mention them. Biologists are asking more complex questions about the structure of natural communities and the environmental factors controlling the distribution of plants and animals. The introduction, about a decade ago, of the radiocarbon dating technique tremendously stimulated the study of biological productivity and has made possible better evaluation of the environmental factors controlling photosynthesis in the sea and the transfer of organic material through the food web.

Third, there has been a very distinct up-grading of facilities and instrumentation in the field. ATLANTIS II is without question a far superior vessel to the ketch ATLANTIS. Similar improvements in the fleet of research vessels can be found at all the oceanographic laboratories. The capability of attacking problems at a level of sophistication hitherto impossible is well represented by the improved quality of the work undertaken during the International Indian Ocean Expedition as compared with similar work conducted during the International Geophysical Year.

Fourth, and here I re-emphasize my earlier point, I believe a considerable reason for the improved quality of research results from the transition through which oceanography is passing. It is only within the last decade that we can see clear evidence of the transition from observational exploration to scientific investigations where there is an application of the scientific method. This evolution is by no means unique to the history of oceanography but can be traced through all branches of science.

Science progresses on two fronts simultaneously. On the one hand, new ideas and new theories must be proposed and examined; on the other, new techniques for examining nature and for processing the resultant data must be developed. As in any scientific endeavor, the more we have learned about the oceans the more unanswered questions have arisen. These unanswered questions are almost always harder to answer than the earlier questions, both in terms of satisfactorily measuring the variables involved and in terms of developing theories which will explain and predict the variations observed. Perhaps two examples will illustrate this point.

Not too many years ago oceanographers assumed that the ocean environment changed sufficiently slowly so that observations taken at one point in the ocean could be compared with similar observations at another point, even though the observations may have been taken several years apart. Average conditions in the oceans were thus established. With the advent of bigger and faster ships, improved instrumentation, and data processing techniques, a different class of questions is now being asked. We are now concerned with the dynamic fluctuations, both in distance and time, in the oceans. We do not yet have theories or ideas that will satisfactorily explain and predict all of the many fluctuations that have been observed over a wide span in time. These are problems that are now being investigated.

Similar examples could be cited for almost all aspects of oceanographic studies. In the field of chemistry, oceanographers are now relating the distribution of organic materials in the water not only to biological and geochemical processes, but also to the physical transport of the water. Our biologists are now well beyond the phase of just classifying the abundant marine life which is found in the oceans and are attempting to explain the distribution, interrelationships in communities and evolution of the many different species. These are but examples of the new questions now being asked by oceanographers.

All of this gives us high confidence in the future. There is much still to be done, but we are in a good position to do the job before us. How we have made our contribution in the past year is described in the following pages by our Department Chairmen.

PAUL M. FYE

Department of Applied Oceanography

The Department of Applied Oceanography consists of four groups and several individual investigators.

The Information Processing Center or Computer Group is primarily concerned with the operation of and programming for the GE 225 computer. In addition the Group supplied some personnel for support of the PDP-5 aboard ATLANTIS II during the world circumnavigation. The Group is working with members of every department in the Institution. A substantial library of oceanographic programs has been assembled and the Group is becoming cognizant in the problems of oceanography.

Courses in Fortran programming were again well attended; forty-six people took advantage of the opportunity.

The Electronics Group functions as a development and service organization for the Institution. The major effort in development has centered around acoustic beacons and Swallow floats or similar devices. The extension of the range of these instruments offers real improvements in efficiency in ship use in current measurements and other work. The servicing of the ships' electronics gear and the development of instruments for the scientists continues as an essential task of this group.

The Buoy Laboratory Group has continued its work in the measurements of deep ocean currents by the use of moored buoys. Concentrating on maintaining a station located at 39° 20′ N, 70° 00′ W, throughout the year, and analysis of these and previously obtained records, the Group also has participated in several other series of current measurements including those of the Sea Spider on the Blake Plateau. A number of excellent records of up to sixty days duration were obtained at all depths during the year, and their analysis is indicating the general characteristics of the spectral energy density and the periodic effects of deep ocean currents.

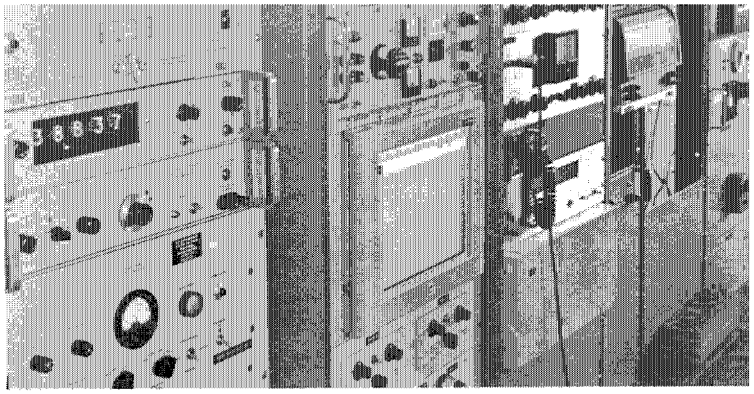
Individual investigators have been studying long range sound transmission in the Mediterranean, the prediction of sound velocity profiles and sound propagation from our hydrographic data, and underwater optics.

ALVIN Trials

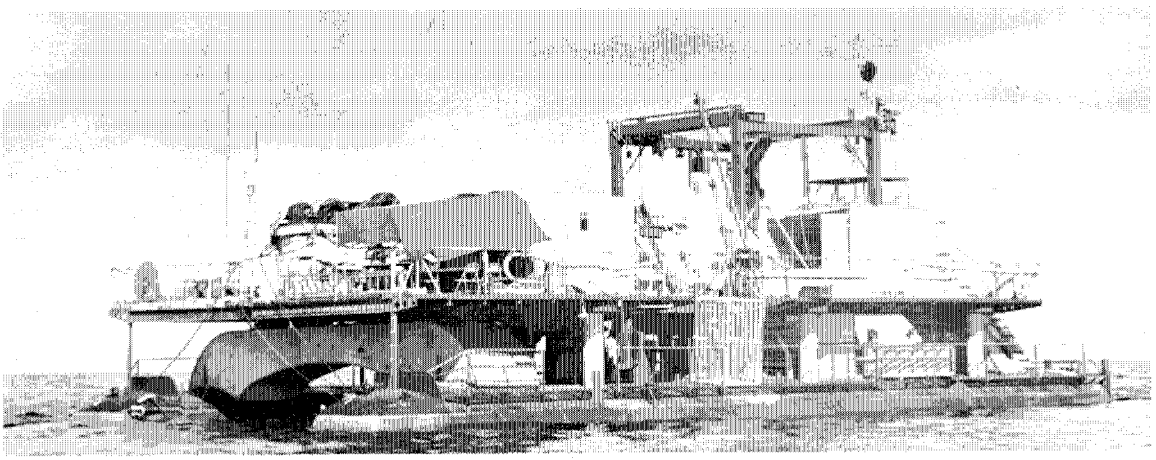
The Deep Submergence Research Vehicle Group has the responsibility of maintaining and operating the submersible ALVIN and the catamaran which acts as the mother ship. In March 1965, ALVIN and the catamaran left Woods Hole separately, one by land and one by sea, as untried vehicles (although ALVIN had made many shallow dives), but returned together in October 1965 as a tested operational team.

The Group had several problems and unknowns to resolve. One was the seakeeping ability of the catamaran. Model tests indicated that she should tow fairly well and also be stable, but did not give enough detail to predict launching and retrieving characteristics. The launching and retrieving involved the handling of thirteen tons in and out of the water at every dive, with the requirement that the structure be handled rather carefully. Another problem was the lowering of ALVIN unmanned to a depth of seventy-five hundred feet as a safety test. Finally the manned dives to six thousand feet were completely new to the operational experience.

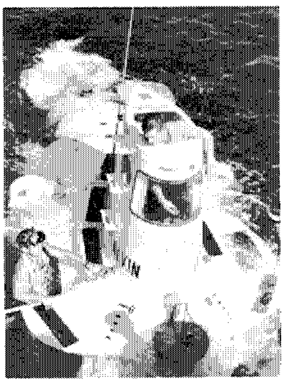
A modified Swallow float.



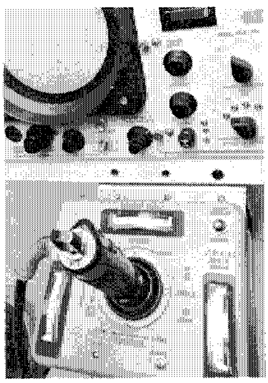
Long-range relative navigation by means of VLF transmissions, an aid in The Indian Ocean.



ALVIN cradled aboard the catamaran.

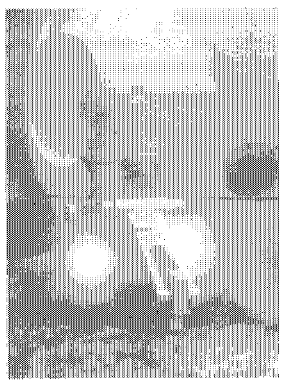


Ready for the descent.



The controls.

During the dive.



On the bottom with arm in place ready to pick up samples.

The catamaran proved to be a good towing seaworthy vehicle. Rough seas in the Bermuda area and on the tow from Bermuda to Woods Hole scarcely wetted the deck area; the tow from Woods Hole to Florida averaged 10.2 knots in seasonable spring weather.

Aboard the catamaran ALVIN is secured to a structure called the cradle. During launching ALVIN sets freely on the cradle and the assembly is lowered into the water. The cradle is negatively buoyant and is lowered away from underneath ALVIN, which is then tended aft through the catamaran by hand lines. Retrieving is just the reverse process, i.e., ALVIN on the surface is placed above the cradle by hand lines, and then the cradle is raised. Starting the launching and retrieving in calm seas, it was continued into more realistic conditions and ALVIN has been launched and retrieved in seas of four to six feet without undue strain. The relative motions of the two vehicles is small when ALVIN is above the cradle and this is an important factor in the recovery.

On 1 July 1965 ALVIN was lowered unmanned to a depth of 7,700 feet in the Tongue of the Ocean and recovered, and showed no evidence of damage in the following careful inspection. The lowering was designed to handle any single expected failure but not multiple failures. The line was strong enough (50,000 pound breaking point) to recover ALVIN in case of flooding. The line was buoyant, so in case the line parted no extra weight would be added to ALVIN. ALVIN was made positively buoyant, and a weight of approximately one ton was fastened to the underside through a pair of time release mechanisms in parallel. These releases were set to fire early the next morning after the lowering. Thus if the line parted ALVIN would continue slowly to the bottom with the buoyant line stretching upwards. When the weight struck the bottom ALVIN would remain tethered above like a balloon until one of the releases operated the next morning, and ALVIN would return to the surface. The cradle arrangement worked out nicely for this system. The weight and releases were attached to ALVIN, then the cradle was lowered below the assembly, the load was shifted to a large sheave on the aft cross bridge and the lowering proceeded. The depth of ALVIN was checked in three ways. A pinger mounted on ALVIN was used to measure height above the bottom, exactly as done in camera lowerings, an echo from ALVIN was seen on the Precision Graphic Recorder (PGR), and the length of line was measured. Little wind or current was experienced during the lowering and all three measurements agreed within fifty feet. The unwelcome presence of several sharks during the launch and retrieval when divers were used to make sure all gear was clear, did little to help a long day.

After the deep unmanned dive and operational tests of emergency routine, i.e., dropping batteries, releasing forebody, a series of deepening manned dives was run, culminating in a six thousand foot dive on 20 July 1965. Other deep dives were also made at Bermuda later in the summer.

ALVIN behaved quite well for a prototype vehicle. Only one problem of any magnitude arose. It was of magnitude only because it was pressure sensitive, and not easily accessible for examination. Several relays in oil were used to operate solenoid valves in the propulsion system. These were inductive loads. The arc formed in breaking the current when at high pressure, would make carbon pellets that created high resistance in the circuit for the next closure. The pellets usually would wash out when the oil was drained for inspection, but careful examination did identify the problem and it was eliminated.

ALVIN is funded by the Office of Naval Research and has been certified by the Bureau of Ships as a vehicle capable of diving to six thousand feet.

For future designs the Group has worked closely with the Bureau of Ships and a continuing line of deep submergence vehicles is expected.

EARL E. HAYS, *Chairman*

Department of Biology

International Indian Oceanographic Expedition

The two-year biological survey of the western Indian Ocean, a part of the International Indian Ocean Expedition, was completed early in 1965. Although this was an international program involving over 150 scientists from the United States and abroad, it was organized and directed by members of the Biology Department of this Institution. Some fifteen scientists from Woods Hole participated in one or more of the ten cruises of the ANTON BRUUN or in related shore-based activities in the Indian Ocean region. Their work included studies of inorganic and organic chemistry, phytoplankton production, zooplankton distribution, and benthic community ecology.

In addition to the special projects carried out by the individual participating scientists, routine measurements were made of the hydrography, nutrient chemistry, primary organic production, and plankton standing crops at regularly scheduled oceanographic stations on all the ANTON BRUUN cruises. The primary productivity data have now been completed and analyzed providing what is perhaps the most comprehensive study of organic production in relation to chemistry and hydrography of a large oceanic region. On the average, the western Indian Ocean is approximately twice as productive as the open ocean in general. However, it includes some of the most impoverished waters of the world (the central basins north and south of the equator) as well as the most fertile. The productivity of the northern and western Arabian Sea is perhaps ten times the average for the open sea, due principally to the combination of a subsurface current bringing nutrient-rich water from intermediate depths northward from below the equator into the Arabian Sea, and the local upwelling of this water into the surface layers by the action of the monsoon winds and other related hydrodynamic processes.

The Amazon River Outflow

A chemical and biological survey was made of the eastern Caribbean and western Tropical Atlantic during May–June of 1965 (the South American rainy season), complementing an earlier cruise to the same region in the fall of 1964 (the dry season). The purpose of these surveys was to investigate the influence of the Amazon River discharge upon the nutrient chemistry and biological productivity of the surrounding ocean regions.

The outflow from the Amazon River becomes entrained in the northward-flowing branch of the North Equatorial Current, carrying the fresh water along the coast of South America and into the eastern Caribbean. An area of some one million square miles is appreciably influenced by the fresh water dilution, as distinguished by salinities of 36‰ in the upper 10-15 meters. The region thus influenced is rich in silicate but low in inorganic nitrogen and phosphorous compounds relative to the surrounding seawater. The low nutrient levels together with the increased stability caused by the low surface salinities, results in an over-all decrease in biological productivity. Nutrient enrichment and high biological productivity along the coasts of the Guianas is believed to result from geostrophic uptilting associated with the northerly coastal current, and is not related to land drainage.

Organic Chemistry and Microbiology

Refinement of the techniques for measuring particulate organic carbon in the ocean, including the development of an all-glass water sampler to avoid contamination, has led to the conclusion that all previous particulate carbon data for the deep sea are too high by a factor of at least five. This particulate organic carbon (i.e., detritus) appears to be remarkably constant at all depths below 200 m throughout the Atlantic and perhaps in all oceans. In the surface layers, particulate carbon consists of a combination of the resistant, residual fraction and that contained in living or recently-dead organisms. The latter fraction was shown experimentally to decompose quantitatively within 90 days (under laboratory conditions) leaving a residue equal in concentration to the particulate carbon found in the deep water. The latter did not change through decomposition in comparable experiments of the same duration. It is concluded that ocean waters from all depths contain a small but highly refractory and remarkably constant quantity of detrital carbon.

Measurements of dissolved organic carbon (DOC) indicate that this fraction also is distributed almost homogenously at all depths and all locations in the Atlantic Ocean, although this finding is in contrast to the situation in the Indian Ocean, where significant variations in DOC were observed and correlated with different water masses. This discrepancy has not been resolved, but it is hoped that by increasing the sensitivity of the method, small differences in DOC may be detectable by means of which water masses may also be distinguished and traced in the Atlantic.

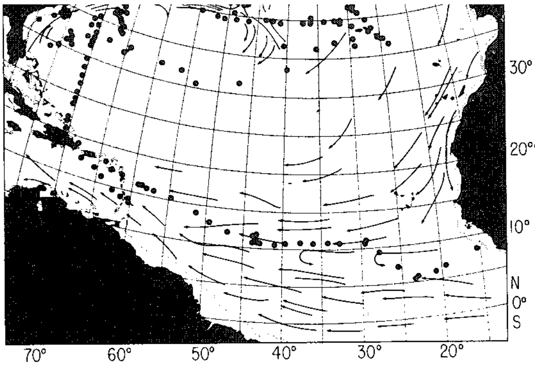
New observations in regions of high biological productivity have confirmed the hypothesis that newly-formed products of plankton excretion and decomposition are labile and quickly decomposed and do not contribute measurably to the reservoir of DOC in the ocean.

Carefully controlled bubbling experiments in the laboratory and at sea using water from several depths have failed to produce measurable organic particles from pre-filtered water or to decrease the concentration of dissolved organic carbon in the water. Previous results in which particles were produced by bubbling are believed to have been artifacts caused by contamination or inadequate experimental control.

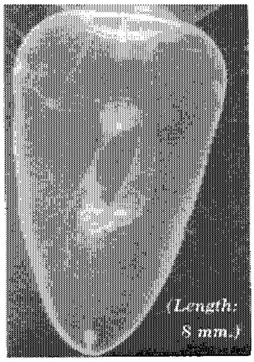
The heterotrophic activity of natural populations of microorganisms is being studied by measurement of short-term uptake rates of C^{14}-labeled glucose. Calculations based upon these observations can provide estimates of both the concentrations of glucose-like substances in the ocean and their natural rates of uptake, if it can be assumed that the uptake kinetics are in accord with those observed in pure enzyme systems. Validity of this assumption is being investigated before application of the technique is made to descriptive oceanographic studies at different depths, seasons and locations.

Also under study is an enzymatic method for water analysis which was originally developed for measuring organic substrates in portions of single cells. This technique involves a series of enzymatic reactions in which the final product measured may be as much as 10^4 times the concentration of the substrate being studied, making possible an assay for concentrations of organic compounds lower than 10^{-9} molar.

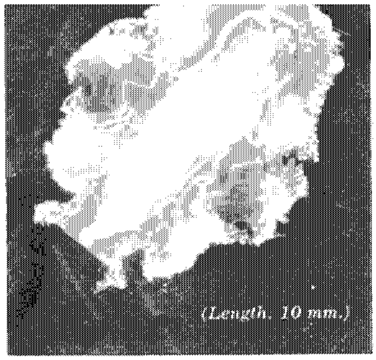
Selective competition of heterotrophic bacteria for certain organic substrates has been studied by means of a chemostat newly developed for use aboard research vessels. By adjusting for low substrate concentra-



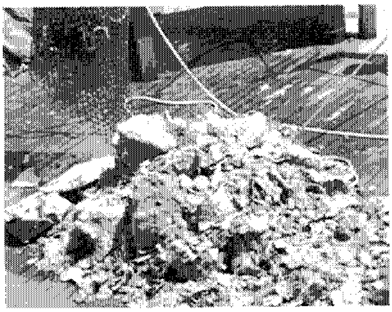
Stations in the North Atlantic where benthic invertebrate larvae have been sought. Stream lines indicate two-gyre system (Worthington, 1962).



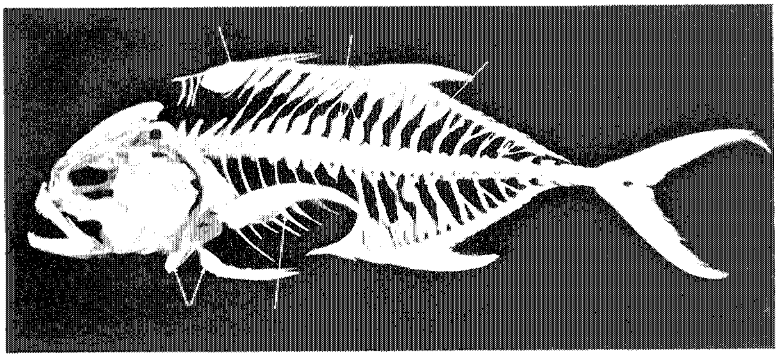
The swimming pelagosphaera larva of an unknown sipunculid worm caught in the Gulf Stream off Beaufort, North Carolina.



Auricularia nudibranchiata, *the larva of an unknown species of sea cucumber caught in the open ocean off the coast of Virginia.*

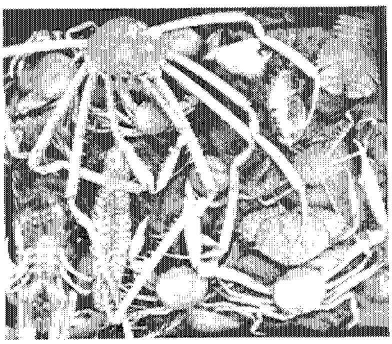


Shrimp trawl emptied aboard ANTON BRUUN in the Persian Gulf.

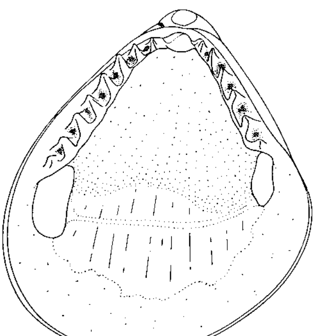


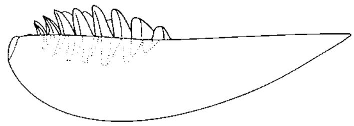
Hyperostotic bones in the skeleton of the common jack or crevalle, Caranx hippos.

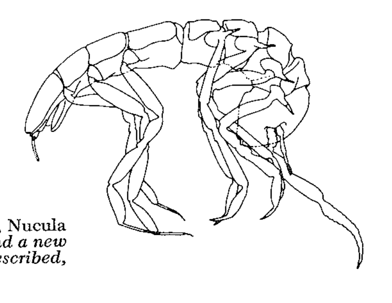
Preliminary sorting of specimens by ichthyologists and carcinologists.



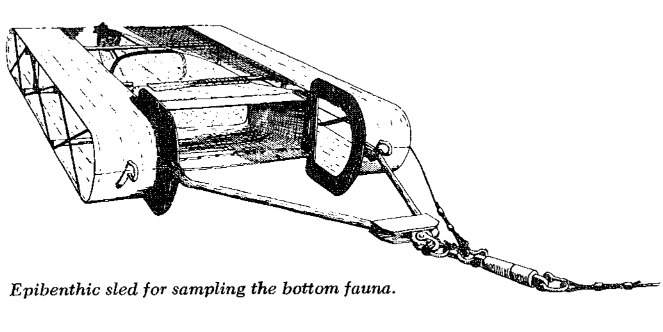
Among the crustaceans taken in the trawl.





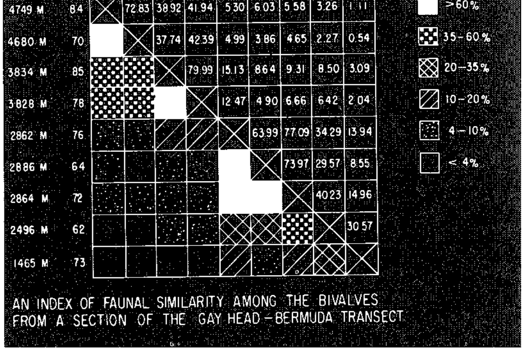


Drawings of a deep-water protobranch clam, Nucula verrilli Dall *1886 from the Bermuda slope and a new species of desmosomid isopod, as yet undescribed, from 4600 m. in the North Atlantic Basin.*



Epibenthic sled for sampling the bottom fauna.

Trellis diagram comparing faunal similarity among the bivalves from a transect, Gay Head to Bermuda.



		4749 M	4680 M	3834 M	3828 M	2862 M	2886 M	2864 M	2496 M	1465 M
		84	70	85	78	76	64	72	62	73
4749 M	84		72.83	38.92	41.94	5.30	6.03	5.58	3.26	1.11
4680 M	70			37.74	42.39	4.99	3.86	4.65	2.27	0.54
3834 M	85				79.99	15.13	8.64	9.31	8.50	3.09
3828 M	78					12.47	4.90	6.66	6.42	2.04
2862 M	76						63.99	77.09	34.29	13.94
2886 M	64							73.97	29.57	8.55
2864 M	72								40.23	14.96
2496 M	62									30.57
1465 M	73									

tions and low growth rates, new isolates have been obtained which have escaped detection by usual methods of isolation. The growth kinetics of twenty-one new isolates from offshore waters has been studied extensively revealing basic physiological differences between them.

New evidence was found for the existence of threshold concentrations of limiting nutrients as a common characteristic of open ocean water. This phenomenon appears to be population dependent in that it is associated with minimal populations of active cells which, due to their low density, are incapable of overcoming suboptimal conditions and utilizing the low substrate levels.

The work on marine nitrifying bacteria has been broadened by the isolation of two strains of *Nitrosomonas* which are physiologically comparable but morphologically distinct from the extensively-studied strain of *Nitrosocystis oceanus,* and isolation of a bacterium which oxidizes nitrite to nitrate. The comparative ultrastructure, biochemistry, and physiology of these different organisms is now being studied. A major advance in the biochemistry of *Nitrosocystis oceanus* during the past year was the demonstration of an enzyme system which oxidizes ammonia to nitrite in cell free extract. Attempts are now being made to isolate and characterize the individual enzymes concerned.

Several new and interesting strains of plankton algae have also been cultured during the tropical cruises to the Amazon region. These include clones of species which appear to be morphologically identical to temperate species already in culture. However, comparative growth studies at different temperatures reveal them to be physiologically distinct.

Nine species of dinoflagellates from local waters were found to be bioluminescent, including six not previously reported to have this property. When these organisms were kept in continuous darkness, an endogenous diurnal rhythm of bioluminescence was found to persist for at least four days with maximum luminescence near midnight and the minimum near midday. Flashing was inhibited by exposure to artificial or natural light and the sensitivity to inhibition also showed a diurnal cycle with a maximum at midday.

Invertebrate Zoology

Zooplankton samples have now been collected by the same technique from the surface to 4,000 m in the Atlantic, western Indian, and northern Pacific oceans. During the past year emphasis was given to the systematics and distributions of copepods from the epipelagic region (0-200 m) of the southwest Atlantic and the bathypelagic zone (1,000-4,000 m) of the Indian Ocean.

Small-scale distribution (i.e., patchiness) of surface zooplankton has been examined in relation to the Langmuir circulation and the latter, in turn, related to much larger-scale patterns of circulation of the atmosphere above the ocean. A model has been developed which predicts greater abundance of plankton beneath cloud lines that mark atmospheric convergence and upwelling over the sea and preliminary tests of the hypothesis have met with limited success.

The trans-oceanic dispersal of larvae from shoal-water benthic invertebrate organisms has been demonstrated from evidence pertaining to (1) the distribution of larvae in the open sea relative to the major ocean currents, (2) the rate of flow of surface currents as deduced from drift bottle observations, and (3) experiments showing that larvae can delay metamorphosis long enough to make possible their transport across the ocean. Pertinent experimental results have been obtained with the veliger larvae of molluscs, the pelagosphaera larvae of sipunculid worms, and the mesotroch larvae of an annelid worm. Many of the larvae which were found experimentally to be capable of surviving the trans-oceanic drift are known as adults from both sides of the Atlantic.

Fouling by marine invertebrates in the open sea, as studied by means of moored buoys, appears to be inconsequential in the surface layers, consisting of light attachments of goose barnacles and hydroids, and virtually non-existent at depths below 50 m. A more serious threat to moored installations are fish bites which were found at all depths, were most abundant at about 900 m, and occurred with a frequency of approximately 8 bites per day. From spacing of the marks and tooth fragments, the attacking species was identified as a Paralepid fish, probably *Sudis hyalina.*

Studies of the distribution of benthic invertebrates were continued along the transect between Woods Hole and Bermuda. Polychaetes, isopods, amphipods, and bivalve molluscs were found to constitute the major fraction of the deep-sea fauna. The community assemblages were found to change continually along a depth gradient with no pronounced faunal breaks except at the shelf-slope interface, where eurythermal shallow-water forms are almost entirely replaced by deep-water stenothermal species and higher taxa.

Use of a newly-developed deep-sea epibenthic sled gives a much more adequate representation of the total invertebrate fauna than have devices used in any previous study. The number of species thereby obtained ranges from 195 to 375 per station indicating a diversity of life far in excess of the classically-held notion of a depauperate deep-sea fauna and, indeed, comparable to that of the shallow-water tropics.

A variety of deep-sea invertebrates collected at different times of the year have been sectioned and examined to determine whether there is a seasonal or other synchronized reproductive cycle in organisms living under constant environmental conditions. In some cases no sexually mature individuals were found suggesting that the deep populations are recruited from individuals living at shallower depths. In other species, gametogenesis was always found in some individuals indicating a lack of periodicity in spawning.

Most of the polychaetes examined are believed to have larvae which are either non-pelagic or which remain planktonic for very short periods of time. The lack of synchrony in their reproduction and the absence of long-lived planktonic larvae are believed to restrict gene flow between isolated populations and thereby enhance deep-sea speciation.

Marine Physiology

Studies of respiratory and diving physiology were completed on small cetaceans ranging from a 25 kg. porpoise to a one-ton pilot whale. Identical diving bradycardia (slowing of the heart), telemetered ultrasonically, was found in both. An attempt to make similar measurements on larger whales was unsuccessful.

An investigation of human diving was initiated to determine those parameters of cardiovascular physiology which limit man from a better performance in the water. The metabolic cost of swimming, breathing frequency and depth, and heart rate of free-swimming divers were studied. Instrumentation of new and improved telemetering equipment for these studies has also continued.

JOHN H. RYTHER, *Chairman*
DAVID W. MENZEL, *Assistant Chairman*

Department of Chemistry and Geology

Red Sea Minerals

The finding of iron rich sediments from hot brine zones of the Red Sea was a major discovery of the past year. Previous bathymetric surveys had shown high temperature and high salinity waters in the rift trough of the Red Sea. Cruise 15 of the ATLANTIS II was the first to obtain cores of the sediments beneath these hot salty brines. The brines had a temperature of 56°C., salt content of 310 grams per liter (nearly ten times the salt content of normal sea water) and pH of 5.3. The cores beneath contained more than 50 per cent iron oxide, more than 6 per cent zinc sulfide, and smaller amounts of sulfides of other heavy metals such as copper, lead and cadmium. One core contained about 10 per cent siderite and rhodochrosite. The particular significance of this study is that it may contribute to the eventual solution of several geological problems such as the origin of heavy metal deposits, the stability relations of a number of mineral systems, and the influence of tectonism on subsurface fluid movements. During the coming year it is planned to make an intensive geophysical and geochemical survey of the entire area including the taking of piston and gravity cores from several of the hot brine deeps.

Fossil Microplankton

Another significant discovery of 1965 was the isolation of living hystrichospheres from sea water. For the first time since these microplankton were discovered as fossils in 1836, significant numbers of them have been isolated from living plankton. These include eleven species known to occur in sediments as old as the Paleocene. Following this discovery a series of single cell culture experiments were carried out with individual resting spores known to be identical with fossil hystrichospheres. These experiments proved conclusively that hystrichospheres are the resting spores of thecate dinoflagellates. Thus it was demonstrated that one member of an ancient fossil genus called *Hystrichosphaera* was in reality the resting spore stage in the life cycle of a common thecate dinoflagellate found in local waters. Over 50 new types of resting spores from local plankton were found to be homologous to ancient hystrichospheres.

Ocean Drilling

The JOIDES, or Joint Oceanographic Institutions' Deep Earth Sampling Program, is a cooperative effort of four major oceanographic laboratories, the Woods Hole Oceanographic Institution, the Lamont Geological Observatory, the Institute of Marine Science at Miami, and the Scripps Institution of Oceanography. Its purpose is to obtain sediment cores several hundred meters long from the continental margin and the deep-sea floor to determine how continents and deep ocean basins are related. What are the changes in the structure and the nature of the sediments in going from the continents to the abyssal plains?

The first project of JOIDES was on the continental margin off northern Florida. Six holes were drilled in water depths ranging from 25 to 1,032 meters with sediment penetrations ranging from 120 to 320 meters. The cores showed that geologic strata and possible economic deposits of Tertiary age known on shore extend beneath the continental shelf and beyond. More than 200 meters of sediment accumulated on the shelf and upper slope, with rates of deposition during the Upper Eocene Epoch equivalent to 1.6 cm per 1,000 years on the shelf and 0.3 cm on the Blake Plateau. The thinner cover of sediment on the Blake

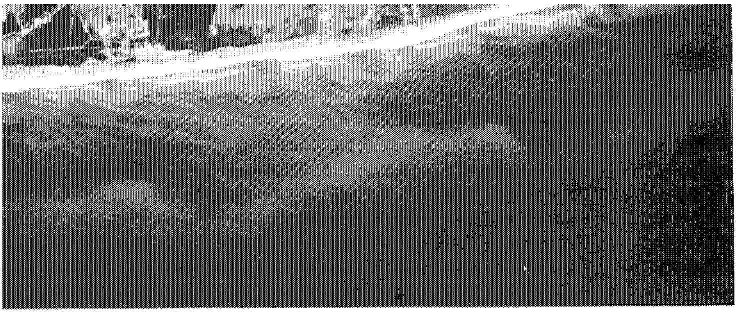
Plateau is due either to the absence of sedimentation during a long period of geologic time or to erosion of pre-existing deposits by bottom currents. Recent underwater photographs show that bottom currents are actively moving sediment on the inner part of the Blake Plateau, so the latter hypothesis is reasonable. Calcite is uniformly high (16-90 per cent) in all sediments. The continuity of seismic reflectors beneath the slope precludes major faulting or folding between the continental shelf and the Blake Plateau during the Tertiary Period. Instead, the continental margin appears to have slowly subsided.

Continental Margin

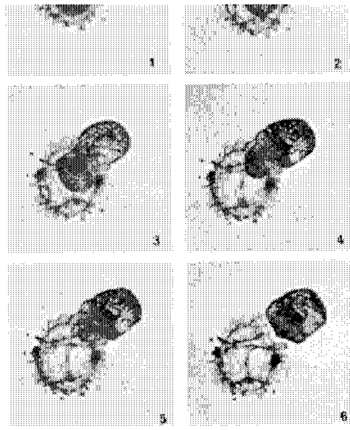
At the end of the third full year of the joint program with the U.S. Geological Survey 447 ship days had been completed with about 100 more to be made during the next two years of the five year program. The latter will involve mainly additional seismic profiling, dredging, and coring.

More detailed studies of the relict sediments reported last year show that the continental shelf off New England was a lowland probably covered with vegetation and partly marshy near the end of the last glacial advance. In addition to the shallow water oyster shells previously reported, intertidal salt marsh peats were found at 59 meters on Georges Bank. Also the tusks and molars of mammoths and mastodons have been recovered in several areas, indicating that grazing animals lived in the region that is now sea floor. Estimates of the volume of ocean water frozen in glacial ice caps suggests that former sea level was as much as 120 meters below the present one. Early man may have lived and hunted over much of the vast area now known as the continental shelf.

The topography and structure of the continental margin was further delineated by about 8,000 kilometers of continuous seismic profiles and more than 5,000 km of precision depth recording. Precision Depth Recorder (PCD) traces showed that the floor of the continental margin south of Cape Lookout can be divided into four areas: smooth; undulating, that is, with sand swells five to ten meters high; rough, with low conical hills possibly coral mounds; and blocky with areas broken by rectangular depressions. The Precision Graph Recorder (PGR) "sparker" profiles indicate that Georges Bank consists of gently-seaward-dipping Tertiary and Cretaceous strata that are truncated by the slope on the landward side of the bank and by the continental slope on the seaward side. The Acadian Basin appears to extend 120 km beyond the mouth of the Bay of Fundy into the Gulf of Maine where it becomes a thin veneer of Quaternary sediments resting on Paleozoic rocks. Both the continental slope and the Florida Hatteras Slope were formed by sediments prograding five to more than 35 km in a seaward direction. More detailed sampling of the Blake Plateau permitted delineation of an area of manganese pavement and manganese nodules at the north end of the plateau. Phosphate nodules, previously undiscovered, were dredged from several localities on the plateau, the largest concentration being adjacent to the manganese pavement. The most important environmental factor on the Blake Plateau is the Gulf Stream which flows northward across the plateau in a manner analogous to the flow of large graded rivers on land. Deeply scoured depressions and abundant coral banks beneath the axis of the Gulf Stream plus a layer of *Globigerina* sand are consequences of this environment. The relative thinness of post-Miocene strata and the absence of terrigenous sediment indicate that the Gulf Stream has maintained its flow across the Blake Plateau since before the Miocene.

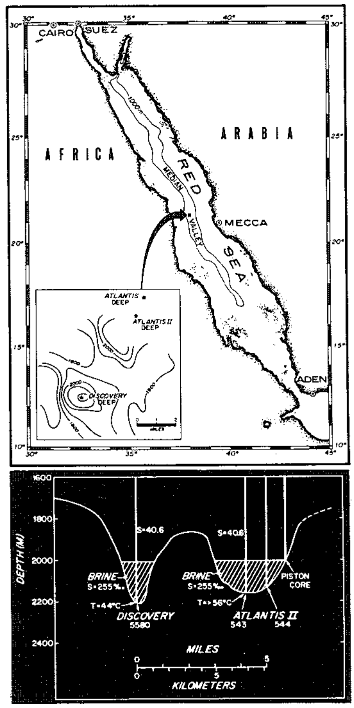


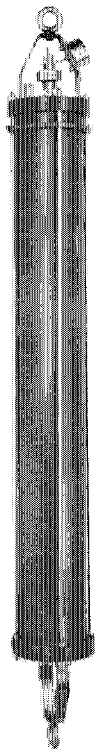
Configuration of the outer bar off Highland Light. Note its asymmetrical wave form.



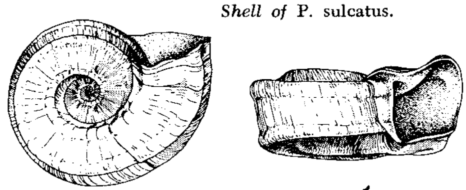
The thecate dinoflagellate, Gonyaulax digitale, *emerging from its resting spore, a living hystrichosphere (see text).*

DISCOVERY and ATLANTIS II deeps in the Red Sea. Depth contours in meters modified after Swallow and Crease (1965). The hot brine zones are shown in the schematic section.

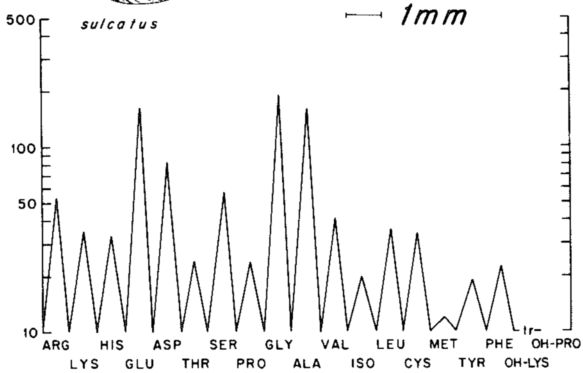




Water sampler used in studying the organic content of seawater.



Shell of P. sulcatus.



Amino acid chromatogram of the organic matter in the shell of the gastropod Planorbis sulcatus.

Studies of the mixing of fresh and salt waters along the coast are being made with the objective of eventually publishing an atlas of salinity and its variations in estuaries, coastal aquifers, and over the continental shelf. Suspended matter in surface waters of the outer shelf and slope amount to generally less than 0.125 mg/l. However, two days after Hurricane Betsy 7 mg/l was recorded within 25 km of Cape Canaveral. In estuaries along the coast the suspended matter generally varies between one and five milligrams per liter. The largest concentrations of suspended matter (up to 1 mg/l) were found 15 km offshore from the four major rivers of South Carolina and Georgia. From 30 to 80 per cent of the material is organic.

The production of calcium carbonate from the skeletons of marine animals is low along the northern continental margin due to the low average water temperature. Sediments of the shelf between Nova Scotia and Hudson Canyon contain less than five per cent calcium carbonate except in a few localities known for rapid water movement and intense mixing and where barnacles and mollusks increase the calcium carbonate content up to 50 per cent. Near the edge of the shelf in this area the carbonate increases seaward with depth until it reaches about 30 per cent in the sediments on the upper continental rise. Studies of the sand-size fraction show similar results, with the percentage of foraminiferal tests increasing 2.6 per cent with each 100-meter increase in water depth.

New instrumentation for the continental margin program includes a linear hydrophone array of five active elements dubbed the Hagfish. Basically it consists of a urethane sheath tube containing the hydrophones in short oil filled sections with the long dead sections between hydrophones containing dry nitrogen under pressure. Gas filling had the advantage of leaving the internal wiring dry and easy to get at. Also being constructed is a large piston core with a 6-inch aluminum barrel and the optional use of tenite core liners.

Geological work with the deep submergence research vehicle ALVIN was initiated in 1965. In October a dive was made on Fishing Ledge, a 6-meter protuberance at the bottom of Cape Cod Bay. Although conditions of sedimentation could be observed, no samples were taken because a surface fog required termination of the dive. Nevertheless, the dive did demonstrate that a geologist could dive on a selected spot and get a first hand view of underwater processes.

Some studies were made of offshore sediment transport as related to wind and waves during a three day low level observation flight from Miami to Nova Scotia in the Institution's C-54Q aircraft.

Coastal Hydrodynamics

Three major problems have been worked on: the internal velocity field of the breaking wave, the mechanics of sediment ripple motion, and the effect of tidal and nearshore currents on coastal orientation. The most difficult problem of studying breaking waves has been to develop a reliable current meter. Two meters are currently being tested and in one instance it was possible to determine the vertical and horizontal water velocities in breaking waves simultaneously at a location near Highland Light on outer Cape Cod. The sand ripple studies have not progressed beyond the stage of acquiring the necessary equipment. The outer coast of Cape Cod from Nauset to Race Point has been chosen for a detailed study of the effect of tidal and wave-driven nearshore currents. This coast represents a closed system in which coastal morphology is controlled by waves and associated currents acting on 100 ft. high glacial outwash cliffs as a line source of sediments. The coast exhibits continuous curvature ranging from 10° to 90° west of north. It is planned to combine current measurements with detailed aerial photographs in order to follow variations in coastal orientation with changing sea state.

Radio Isotopes

Analyses of sea water samples continue to show that the fallout of strontium-90 has been greater per unit area of ocean than of land. The ratio of sea to land delivery exceeded ten on the equator in 1961, it approached one at Lat. 35°N and at high latitudes (50° to 60°N) the ratio exceeded four. Between 1961 and 1963 the strontium-90 content of water at intermediate depths of the Atlantic Ocean between 0 and 20°N more than doubled, along with a great increase in the concentration range.

The horizontal distribution of these concentrations indicates that surface waters are picking up strontium-90 at Lat. 50° to 60°N and are sinking along isopyncnal surfaces to the more southerly areas where the concentrations are increasing. If it is assumed that the strontium-90 originated in the 1961-62 test series then water velocities appear to be about 40° of longitude per year at the axis of the North Atlantic Deep Current. Repeated sampling stations in the Sargasso Sea in 1961, 1962 and 1964 confirm the relatively rapid movement of mid-depth water through this body.

The radioactive lanthanides cerium-144 and promethium-147 behave very differently from the soluble fallout products strontium-90 and cesium-137. Cerium-144 appears to sediment more slowly than does promethium-147; some observed vertical profiles confirm its biological retention in the water column as previously postulated.

Analyses of the first ten centimeters of shallow water sediments in the area of Buzzards Bay show only about half the cerium, europium, and manganese, less than five per cent of the strontium-90 and no zinc-65 as would be expected from the mean fallout on land for this area. There appear to be two types of vertical profiles of element concentration in the sediments. One type includes cerium, europium and manganese, and the other strontium-90 and antimony-125. Deep ocean cores collected late in 1964 showed barely detectable amounts of cerium-144. Other isotope concentrations are being investigated in the sediments.

Laboratory studies were made of the interaction of yttrium-91 and lanthanum-140 with clay particles in sea water. The results indicate that these lanthanides react in sea water as ions, interacting with clays by ion exchange.

Organic Compounds

A major phase of this work continues to be the study of specific organic compounds in marine organisms whose production is determined by environmental conditions, and which are sufficiently stable to be recognized as they pass through the marine food chain into the water and associated sediments. The most detailed studies have been on the saturated and unsaturated hydrocarbons derived by marine zooplankton from the phytol in their food. The search for these compounds in sea water has required the development of increasingly sensitive analytical tools. Although it is now possible to detect some of these organic compounds at the nanogram (10^{-9} gr.) level this full sensitivity has not yet been realized due to extraneous contamination problems in the laboratory building. New methods are being sought to minimize contamination sufficiently to allow detailed analyses of both sea water and marine sediments for these biochemically derived compounds.

Shell Morphology

Further studies of the organic matter in the shells of invertebrates has shown that the most critical factor in determining shell morphological changes and evolutionary trends appears to be the content of (1) acid amino acids, particularly aspartic acid, (2) basic amino acids, particularly lysine and (3) amino sugars. Aspartic acid and lysine appear to function as an ion exchange resin, that is, the aspartic acid attracts the calcium and the lysine attracts the carbonate ion. The amino sugars appear to interfere with this nucleation process. It was also found that *Solemya* the most primitive member of a series of pelecypods contains the most organic matter (1 to 10 per cent) in its shells, whereas *Mulinia* the most advanced member of the series contains the least organic matter (0.01 to 0.2 per cent). A detailed study of the shell proteins indicates that with evolution the amino acids become enriched in aspartic acid and lysine which are primarily responsible for deposition of the calcium carbonate. Thus with evolution the invertebrates learn to eliminate the unnecessary bulk of shell proteins.

A new ion exchange technique was developed for the rapid (90 minute) separation of the purine and pyrimidine bases from protein fractions. Previously their separation required up to 3 days. Since these bases are the building blocks of RNA and DNA, this technique should have wide application in biochemistry.

Seawater Chemistry

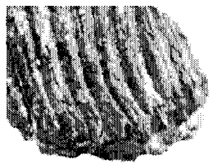
A new technique has been found for concentrating the dissolved organic matter from sea water. The technique is based on the use of ion exchange resin with a specifity for retaining transition metals. For example, copper is retained on the resin even after the passage of large volumes of sea water. Organic matter in the sea water which forms complexes or chelates with the copper is retained in the column while the salts pass through. The organic compounds can then be eluted from the column by other reagents. Initial studies with amino acid standards in artificial and natural sea water indicated that they could be recovered 100 per cent with this technique. Following this, a study was made of the concentration and state of amino acids in Buzzards Bay water. The amino acids were determined in three forms; as filterable matter, as free amino acids, and as components of proteins. About half the amino acids were found in the particulate matter and the other half divided between the soluble proteins and free amino acids. Pronounced differences were found in both the concentration and type of amino acids between these three groups.

It was also found that the resin column tended to separate the amino acids. This suggests the possible use of this technique for separating closely related organic groups such as amino acids, purines, pyrimidines, etc. Additional tests have shown that organic phosphorus compounds, humic acids, purines, pyrimidines, and algal excreted organic matter can all be extracted from sea water. The method is now being applied to large volume sampling in mid-ocean waters.

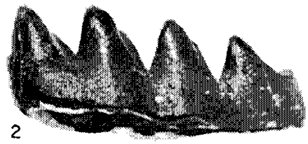
Studies have been initiated on the solubility of non-electrolytes in sea water and related synthetic electrolyte solutions. In order to properly interpret the results it is necessary to measure the effect of the sea water salts on the cohesive energy density of the water. As this effect can be measured directly only with difficulty, it may be advantageous to estimate it from more readily determinable properties of salt solutions such as the transition energy of the visible absorption bands of certain dyes added to sea water. Experiments with several dyes are in progress.

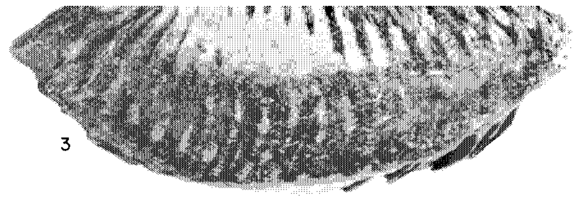
A new method of ion exchange analysis of sea water known as "difference chromatography" is being investigated. Basically it is a null method which consists of calibrating an ion exchange column with standard sea water, and then passing through an unknown sea water previously adjusted to the same nominal salinity as the standard. Variations are detected with a membrane salinometer. The present system has a sensitivity, when everything is working, of $\pm.00001$ in the K^+/N^+ ratio. Further development of this system may enable us to study variations in the proportions of several major ionic components.

An *in situ* study of salinity in the inter-

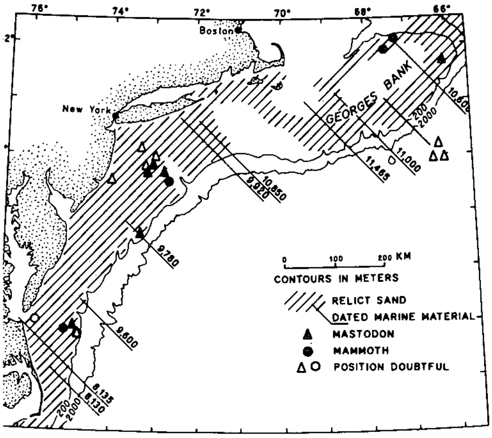


Fossil teeth of mammoth (1, 3) and mastodon (2).

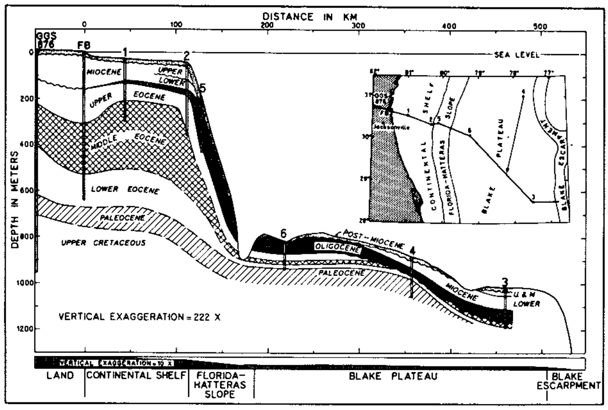




Localities where fishermen have recovered fossil teeth.



Geological section showing the location and depth of cores drilled on the first JOIDES project.



stitial waters of bottom muds of the Pocasset estuary was made with the salt bridge salinometer in cooperation with the Biology Department. Detailed salinity profiles were obtained in the mud showing the depth of penetration of cyclic variations produced by tidal alterations between salt intrusion and fresh water run off.

Indian Ocean

During February and March about 40 piston, free fall, and gravity cores were taken in the western Indian Ocean for geological and geochemical studies. Most of the cores were olive gray lutites with occasional silty laminae and a few layers of coarser material possibly turbidity sediments from abyssal regions. It is planned to study these cores for mineral content, organic material and fossil microplankton with the objective of understanding more about the origin and nature of the sediments

Analytical Equipment

The chemists have been fortunate in acquiring three new major analytical instruments during the year. A direct reading emission spectrometer was acquired under an Atomic Energy Commission contract and has been calibrated for the determination of 34 elements with another four to be added shortly. Analyses are currently being made in sea water, marine sediments, basalts and organic substances such as plankton.

A carbon isotope ratio mass spectrometer was acquired under a National Science Foundation contract and put into operation during the summer. It is being used for a study of isotope variations in the organic matter of Atlantic coast sediments. Studies also have been initiated on plankton from various marine environments.

A nuclear magnetic resonance spectrometer also acquired under a National Science Foundation contract, will be installed early in 1966 for the study of non-electrolytes in sea water. Future plans will involve its use in the identification of high molecular weight organic compounds.

JOHN M. HUNT, *Chairman*

Department of Geophysics

Compared with similar periods in the past 1965 was a vacation period for the members of the Geophysics Department from sea-going work. CHAIN was used for five cruises totaling about eight months and GOSNOLD on several short cruises occupying only slightly more than a month. The nature and scope of the Department's program continues, as in previous years, to lie in submarine geophysics and geology and in those aspects of physical oceanography and marine biology that relate to underwater acoustics. This program has led various members of the Department to concerns with special techniques at sea such as underwater photography, thermometry, and the digital computer technology of simultaneous data-taking and reduction, record-keeping, and process control that may seem remote from a Department of Geophysics.

Individual published papers of the Department, a major preoccupation during a year of minimal sea-going, will be found among the list of publications on pages 49 to 56. A book entitled *Deep-Sea Photography* has been edited in the Department. It is introduced by a comprehensive review of the technology of deep-sea photography and consists of twenty-five chapters based on the use of deep-sea cameras in physical oceanography, geology, and marine biology. These were written by members of four departments of the Institution and by several authors from other institutions.

In addition to publications, journals of four major cruises, and six volumes of data summaries, one per cruise have been issued for limited distribution. The latter include track charts, the general nature and location of observations taken, and echo soundings plotted for the entire cruise at intervals of five or ten minutes or more often, depending on the complexity of the bottom profile.

Submarine Geophysics and Geology

The structures characteristic of enclosed basins, of the deep basins of the Atlantic, and of bordering seas have been shown to be alternating horizontal layers of sand and clay (Hersey 1965; Ryan *et al.*, 1965). It is supposed that the coarse beds and some of the fine materials are deposited by turbidity currents originating either on slopes of continents, oceanic islands or submarine relief and flowing down submarine canyons to be dammed and contained by the basin. The remainder of the fine materials of the clay layers are probably transported in suspension in slower, more persistent currents. Seismic reflections show that in some basins, even in so active a region as the Mediterranean, sediment has accumulated undisturbed in such basins to thicknesses of somewhat more than one kilometer. Making use of the layers of ash found in cores and resulting from historic volcanic eruptions the period of this accumulation is estimated as somewhat greater than a million years (Ryan *et al.*, 1965). By inspecting several sedimentary basins and related structures the evolution of such basins is suggested to develop through stages of compaction of the sediment, folding, faulting, and considerable uplift, even to mountain building. All of the deep basins including those of the Mediterranean Sea, thus far measured have also been found to be underlain by a thin crust more like that under the ocean basins than under the continents. It has been suggested (Hersey, 1965a) that the action of the earth's mantle on the crust in the Alpine-Himalayan mountain belt has been to force aside or assimilate a local portion of the crust say, 100-300 miles across, to create the depression forming the basin. The basin then fills with sediment which compacts until subsequent shearing and compressional forces distort and possibly lift the resulting sedimentary rock to form mountains.

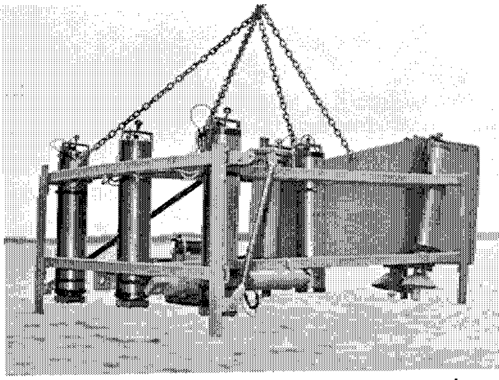
The topmost layer revealed by reflection seismic profiling on the Outer Ridge just north of the Puerto Rico Trench varies in thickness from a few meters to over half a kilometer, has a top surface of gentle rolling relief which slopes gradually both northward toward the Nares Basin and southward toward the Puerto Rico Trench. Several authors have called it the transparent layer because it is so uniform as to contain few and generally weak reflecting layers. Dredge samples suggest that the age of this layer dates from the Eocene to the Oligocene. It has been traced continuously from the Outer Ridge down the North Wall of the Trench beneath the thick deposit of ponded sediments there, thus demonstrating that it is older than at least the most recent development of the Trench. The form and known sediments of the transparent layer suggest that its source may have been from the south. Specifically, the suggestion has been made, in a paper now in press, that this layer is the remnant of a continental rise which sloped away from a land area where Puerto Rico now is before the formation of the modern Puerto Rico Trench.

In an attempt to find evidence for the mode of origin of the topography of the North Slope of the Puerto Rico Trench, an analysis was made of sparker and boomer profiles recorded there in 1962 and 1964 aboard CHAIN and ATLANTIS II. Unexaggerated geologic cross-sections were constructed from echo-sounding profiles to which velocity and slope corrections had been applied, and from the sparker and boomer profiles. Velocities assumed for sub-bottom layering were based on evidence from the refraction analysis of Bunce and Fahlquist (1962). The cross-sections show that the declivity of the North Slope, where uninterrupted, is as low as 3°. In most places, however, the slope is broken by steep scarps, flat-floored valleys, or both. On the basis of the cross-sections it is postulated that one or more of several mechanisms could be responsible for the topography of the North Slope. The mechanisms include normal and trans-current faulting, and gravity sliding. The latter has been invoked by other investigators to explain chaotic structure and topography in Timor, the Apennines, islands of the Greater Antilles, and on the slopes of the Hawaiian Rise.

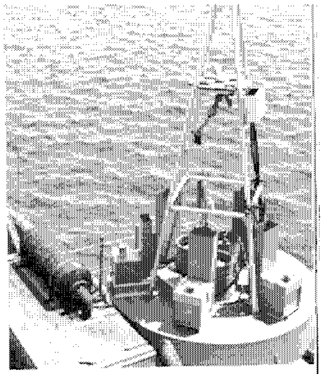
A comparison of the gravity characteristics of the major rifts of the world show that all have negative free-air gravity anomalies over the center of the rift. The Bouguer gravity anomaly (equal to the free-air value plus a mass correction for density variations above or below sea level) becomes increasingly positive as the width of the rift increases. Thus, narrow rifts such as the Gulf of Aqaba and the East African rifts have negative Bouguer anomaly values which suggest a mass deficiency beneath those rifts, whereas positive Bouguer anomalies and seismic refraction investigations show that there is dense material beneath the Red Sea, Gulf of California, and Cayman Trough. This analysis suggests that about 40 to 100 km of extension of the earth's continental crust appear to be necessary before dense substratum begins to rise upward beneath the rift, and thereby changes the gravity characteristics of the central trough.

A considerable body of geological, topographical, and geophysical data exist for the Caribbean region, but these studies leave in doubt the continuity and direction

Photo-montage of the sea floor on the ridge between Saya de Malha Bank and Mauritius, Indian Ocean. Outcrops of probable reefal limestone in 770 fms. of water, partially covered by rippled calcareous sand.



Edgerton stereo camera for making photo-montages of the sea floor. The center camera at the front has a shorter focal length than the two stereo cameras and is used for close-up photography.



The Sea Spider goes to sea.

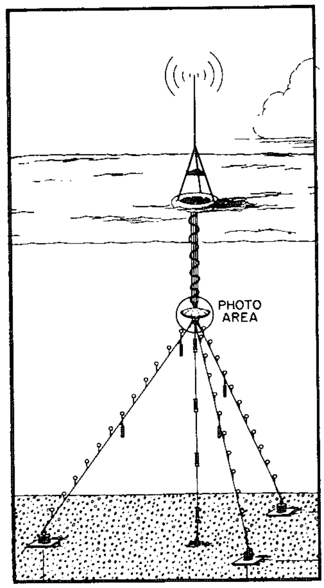
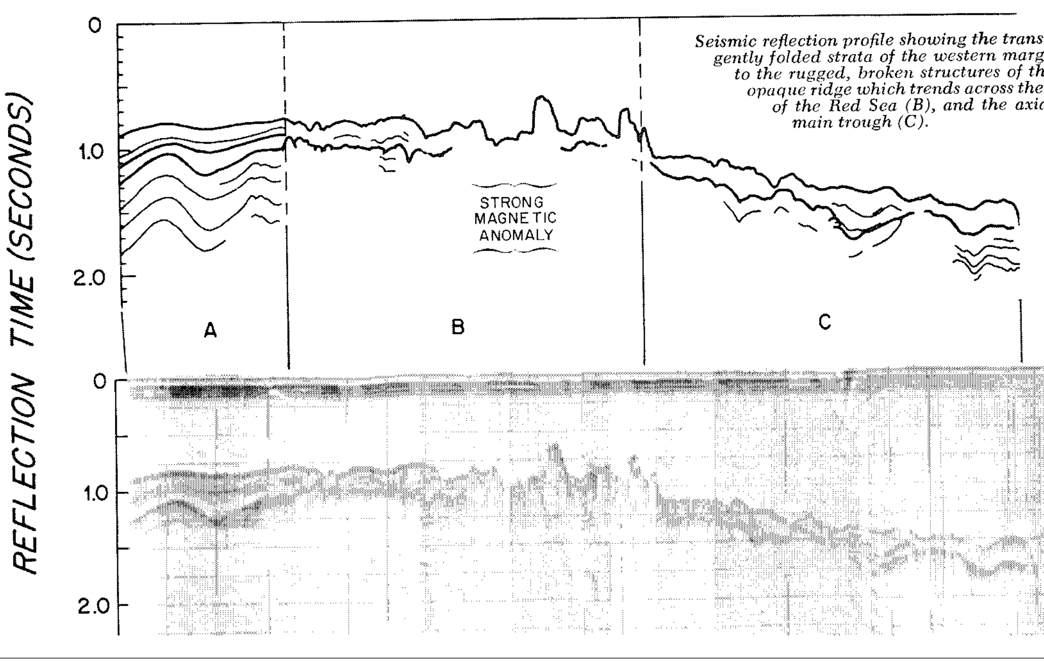


Diagram of the Sea Spider assembly.

Subsurface float of the Sea Spider.



Seismic reflection profile showing the transition from the gently folded strata of the western marginal zone (A), to the rugged, broken structures of the acoustically opaque ridge which trends across the mid-latitudes of the Red Sea (B), and the axial zone of the main trough (C).

of large-scale structural trends. Gravity information averages the mass contribution over a considerable areal extent, thereby allowing deep major structural patterns to be more readily recognized than from surface geologic studies alone. To assist in the delineation of such structures, gravity measurements were conducted in the Caribbean Sea during four months of 1965. The magnitude of the magnetic field, the depth of water, and the surface temperature were also determined. This study supplements a previously established gravity net on the island of Hispaniola. Detailed measurements were made around this island as well as over much of the western Caribbean. These data combined with geological information on the Caribbean islands, northern South America and Central America and the earlier results of geophysical investigations both on land and at sea are being used to determine the structure of the crust and the upper mantle in order to decipher the geologic history.

Photographs of the ocean floor combined with dredge sampling in Mona Canyon revealed that layered rocks, probably sedimentary, extend at least to depths of 3,700 meters in the canyon. Age determination of the dredged rock samples indicates that the sedimentary rock is at least as old as the Miocene.

Some new seismic reflection observations were made on and near the Blake Plateau. One pair of continuous profiles was made east of Jacksonville, Florida, to coincide as nearly as possible with a line of holes later drilled as the first project of the Joint Oceanographic Institutions' Deep Earth Sampling Program (JOIDES). Prominent reflectors revealed in these profiles have been identified tentatively with the top of the Upper Eocene, the top of the Middle Eocene, and the top of the Paleocene (see also page 32). Other work on the Blake Plateau showed that the modern continental shelf is transgressing over an eroded surface at least locally, and that between the Blake Escarpment and the outer ridge there are at least two generations of very large wave-like formations in the unconsolidated sediment. Presumably these waves are caused by local current action, possibly tidal.

Internal Waves

Temporal changes in water structure in the Bermuda-Bahamas-Puerto Rico area were examined by means of precise measurements of the velocity of sound, in an attempt to interpret the wave-like patterns of long wave length (several hundred miles) observed in the shape of the main thermocline. These patterns were first observed in 1962. Analysis of presently available data suggests that they are long Rossby waves possibly forming standing waves reflected from the Bahamas. In addition, experiments intended to generate internal waves have been successfully carried out, and the thermal front described a few years ago has been shown to be a source of internal waves.

Fixed Instrument Platform (Sea Spider)

For a number of years the need for spatially fixed oceanographic or acoustical sensors anywhere in the ocean has been apparent. For instance, it would now, for the first time, be possible to make acoustical measurements of the temporal changes in the water structure in the open ocean well away from continents or islands with hydrophones that were not subject to considerable motion. Furthermore, these measurements could be designed to provide nearly synoptic information in thousands of square miles of ocean. Many other observations of temporal changes in the ocean would be greatly improved if they could be made by means of fixed sensors.

The first step toward providing a fixed mounting was achieved by completing the design and first feasibility test of such a structure in 3,000 feet of water on the Blake Plateau. The structure, called "Sea Spider", consisting of a float 115 feet below the surface with 9,000 pound buoyancy, had three anchors, each weighing 8,500 pounds, and three weightless mooring cables (see figure). The latter were partly special torque-compensated steel and partly steel-clad electrical cables for telemetering data from instruments mounted 800 feet below the surface on the mooring lines to the main float. These were made weightless by attaching glass fishing floats at appropriate intervals along their length, a device already used with success by scientists of U.S. Coast and Geodetic Survey and others. The structure was designed to move as little as possible even in strong currents. Maximum total motion was forecast for between 5 and 10 feet in a 5-knot current near the surface and 0.5 knot between a surface layer and the bottom based on design and model studies conducted in cooperation with the Department of Naval Architecture at the Massachusetts Institute of Technology.

The "Sea Spider" was installed successfully in July. During ten of the twenty-seven days in position, currents were measured using three Richardson current meters on a fourth cable held tautly between a fourth anchor on bottom and the main float. In addition oblique seismic reflection profiles were recorded through hydrophones mounted on the structure, the sound source being a sparker towed by CHAIN on planned courses in an area ten miles square centered about the Sea Spider. Acoustical navigation tests were made between CHAIN and a fixed, three-dimensional array of four hydrophones mounted on the anchor cables and float of the Sea Spider.

Motion of the Sea Spider was observed by measurements of the travel time of a sound pulse from a pinger fixed to the bottom 0.6 miles north of Sea Spider to a hydrophone on the main float. These measurements, recorded once a second for about thirty hours, showed a maximum variation in travel time of 4×10^{-3} seconds over periods of the order of fourteen to twenty hours. Variation over periods of less than an hour was less than the resolution of the recording (about 0.5×10^{-3} seconds). The observed variation can be explained either by supposing ten feet of displacement either side of a mean position, a change in the harmonic mean sound velocity of the local water, or, as is suspected, by an artifact of the measurement. However, any displacement larger than ten feet about a mean position or displacement larger than two or three feet over periods less than a few hours is most unlikely. Failure of some components of the apparatus prevented the measurement of the full motion of the structure, and the high acoustic ambient noise caused by curious fishes made it necessary to utilize all recorders aboard ship while this measurement was in progress. Records of the motion of Sea Spider over many days had been planned while simultaneously conducting other experiments. In order to conduct motion studies in this way the signal-to-noise ratio must be much greater than was achieved in this first test.

The installation of the structure took two days despite the interference for several hours of a 60-knot gale. The submerged portion operated without failures for twenty-seven days. The moorings were then cut by cable cutters and all apparatus except the anchors were recovered. The least successful part of this test was a surface buoy containing radio transmitters for telemetering data from the Sea Spider to the ship. This float and the radios require more development before they can be expected to function without frequent attention. Louder pingers are needed for future positioning experiments because of the unexpectedly high noise levels caused by visiting fish. Nevertheless, all of the critical experiments planned for this first test indicate that similar structures can be installed in the deep ocean, and can be expected to operate there continuously for many months.

Twenty-eight vertical profiles of sound velocity were made within five miles of Sea Spider while it was in place. Between early morning on July 27 and midday on July 31 the shape of the main thermocline changed from a three-layered structure, typical of the upper 800 m. of Sargasso Sea water, to a structure with a constant sound velocity (or temperature) gradient from surface to bottom. This second structure is typical of Gulf Stream water. Between evening on July 31 and midday on August 2 the structure reverted to its original three layers. The harmonic mean sound velocity from surface to bottom was changed at most by about 2 m/sec. even though changes as large as 6 m/sec. were measured. The average position of the Gulf Stream at this time of year is about 30 miles to the west of where Sea Spider was and it is quite likely that the change in the sound velocity structure was caused by a shift in position of the edge of the Gulf Stream water. During the motion study of Sea Spider the maximum change in harmonic mean velocity was 0.3 m/sec. This change of velocity could account for a very small fraction of the ten feet of displacement already mentioned.

Scattering Layers and Thermal Fronts

The thermal fronts south of Bermuda are major boundaries in the ocean, not as marked as the Gulf Stream, but, nevertheless, regions of significant geographic change, which might well influence the distribution of animals. On a transect made between the Bahamas and Woods Hole, systematic mesopelagic fish samples were taken with an Isaccs-Kidd midwater trawl and continuous recordings of the deep scattering layers were made to test this point. A sudden, marked increase in the intensity of sound scattering from the scattering layers occurred at the thermal front. The displacement volumes of fish catches averaged four times as large north of the front as those taken to the south. The identification of the fishes captured is incomplete, but preliminary indications are that the change in abundance was accompanied by a change in species composition.

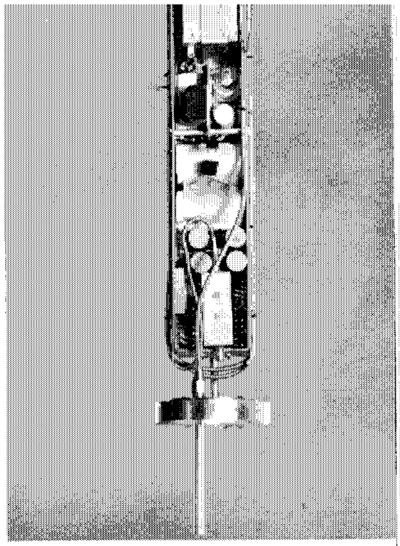
Natural Sounds of the Sea

This year observations of polar ambient noise have been continued and extended. The moving ice fills the sea with a high and variable background noise, making the polar regions distinctively different from the open seas. The departmental library of magnetic tapes has been enlarged in this direction.

A report of the analysis of killer whale recordings has been completed. Marked directional features are apparent in the orienting and navigational signals of this animal; structure of the screams shows pulse trains of changing rate, a study which has led to a critical evaluation of our analytical instruments. This in turn has led to another paper on these and related characteristics of spectral analyzers.

A report has been completed on the little known underwater sounds of walrus, based chiefly on recordings of a captive in the New York Aquarium. These consist of not especially unusual clicks, and also of an occasional bell-like sound which is well-known to the Eskimo but not to scientists.

Sound velocimeter and inverted echosounder being lowered from side of CHAIN.



Quartz thermometer installed on ATLANTIS II and CHAIN (see text).

The work was done in collaboration with Dr. Carleton Ray of the New York Zoological Society.

In the spring another attack upon the migration mystery of the white whale led to a small success. From the air it was possible at last to track the whales a few miles out on the beginning of their travels, and so to gain a hint as to their course, and a likely offshore area for the next season's investigation.

Measurements of Temperature

The temperature of the water near the surface is well-known as a useful indicator of water structure that affects sound transmission. Bathythermographs and thermistor chains have been used for years to record this structure. Neither instrument is a truly satisfactory means of measuring temperature a few inches to a few feet below the surface. For this reason temperature has been recorded at the bow using thermistors for several years during cruises on the CHAIN. The vertical motion of the bow reduces the quality of these data in a heavy sea or when the ship pitches strongly. Furthermore, the thermistor is not sufficiently stable for prolonged, accurate operation. This year on the ATLANTIS II and the CHAIN tests were completed using quartz thermometers installed in a sword below the keel. This mounting has proved to be very satisfactory with prolonged testing. It holds the sensor much more nearly at constant depth and in water not seriously affected by the ship, and the quartz sensor is basically more accurate and stable than thermistors. The output of the quartz sensor can be stored digitally for later analysis, or, on the CHAIN, it can be fed directly into the ship's computer.

Computers

Nearly all the analyses of the data depend to some extent on computer programs, and at sea full use has been made of the IBM 1710 on the CHAIN in data-taking as well as analysis. Its efficiency has been increased by installing a greatly improved automatic depth reading system, by adding surface temperature recordings to the basic data-recording program, and by minor changes that have improved reliability and efficiency of the existing system. The need for increased control, storage, and analysis capacity in the sea-going computer is apparent, and technical plans have been made for these changes.

J. B. Hersey, *Chairman*

Department of Physical Oceanography

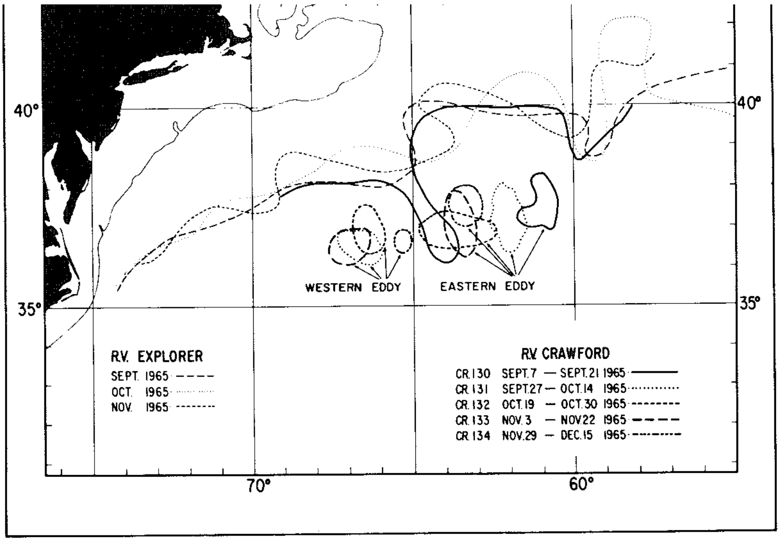
Physical-oceanographic research during the past year represented both a continuation of long-range programs in the Atlantic Ocean and an extension of activities into the Indian and Pacific oceans. Development of new techniques for following ocean currents, for example, permitted us to make frequent, rapid surveys of the path of the Gulf Stream and to observe the movement of eddies detached from the Stream, thus providing a much sounder picture than ever before available of time-changes in the Stream. On the other hand, as part of our contribution to the International Indian Ocean Expedition, the ATLANTIS II made a ten-month cruise to the Indian Ocean, returning home by way of the Pacific in order to participate in the Cooperative Kuroshio Investigations. She traveled nearly 50,000 miles, and became the first Institution vessel to circumnavigate the world.

Atlantic Ocean

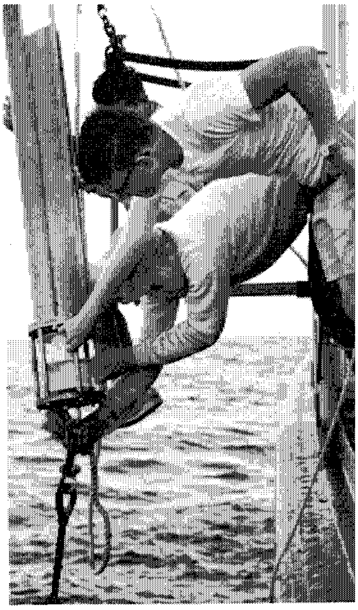
In collaboration with the U.S. Coast Guard and Geodetic Survey and the University of Rhode Island we carried out a four-month program (which is to continue indefinitely into 1966) of synoptic surveys of the flow pattern in the Gulf Stream and adjacent waters. Using a V-fin towed at a depth of 200 m to track the 15°C isotherm, the U.S. C. & G. S. vessel EXPLORER made monthly observations of the path of the Gulf Stream between Cape Hatteras and the Grand Banks. At the beginning of this period the CRAWFORD discovered two eddies which had broken away from meanders in the Gulf Stream, and, with similar equipment, made subsequent monthly observations of their movement and changes in shape. The results of this program (see figure) are analogous to a series of local weather maps, and provide a detailed basis for quantitative discussions of time and space variation in the Gulf Stream System flow pattern.

The water budget for the Gulf Stream remains a vexatious question, since to date, efforts to account geostrophically for its enormous downstream increase in volume transport have failed. In an attempt to locate the "sources" and "sinks" of Gulf Stream water, transports for layers defined by isothermal surfaces are being calculated for a number of sections across the Stream and in its vicinity. We have made attempts with consolan radio drogues to measure directly portions of the inflow to the Stream from the Sargasso Sea, but direct measurements are difficult on account of the low velocities and large horizontal scale involved. A few radio drogues set this year in the western Sargasso Sea, for example, indicated average speeds in the upper kilometer of the ocean of 2-7 cm/sec toward the Stream. Unfortunately, with the closing of the Miami consolan station, this rather promising technique for monitoring broad, slow movements has had to be abandoned. It was found on a cruise in August, however, that the bottom water is of the same type on both sides of the Stream and under it, despite a depth variation of 1,000-1,500 m; there may therefore be some relation between the increase in volume transport and the deep counterflow inshore of the Stream.

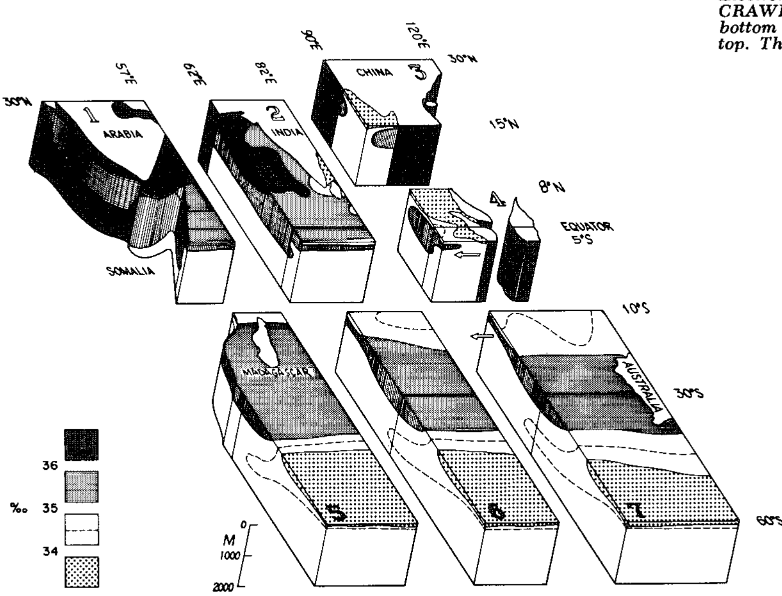
Our survey of the Atlantic Equatorial Undercurrent was continued with four hydrographic sections across the equator, lying between 37.5°W and 47.5°W, and designed to fill a gap between sites of previous observations and the Brazilian coast.



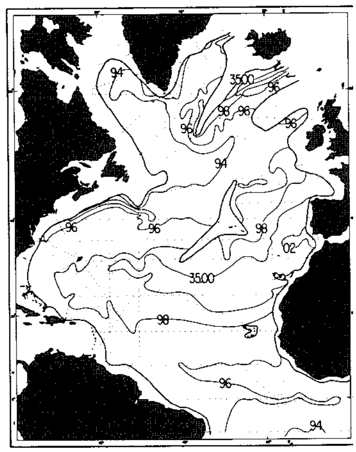
Eddies detached from the Gulf Stream as detected by V-fin towed at 200 m. (see text).



Electronic current meter about to be lowered from CRAWFORD. Current velocity is recorded with the bottom sensor, direction with the sensor at the top. The data is recorded on a photographic film.



Three-dimensional diagram of the salinity distribution in the Indian Ocean.



Salinity at the 3.2°C potential temperature surface in the Atlantic Ocean.

High salinities, above 36.5‰, were again observed in the core of the Undercurrent, at a depth of about 70 m. Similar high salinity water is observed both north and south of the equator, and a controversy exists concerning the relative importance of these two possible sources in the formation of the Undercurrent. To estimate the northward transport of saline water from the south, parachute drogues were placed in the Brazilian coastal current, and followed northward and then northwestward for over 600 miles. Measured speeds varied from 70-140 cm/sec.

It is usually assumed that deep water in enclosed oceanic basins is renewed continuously and rapidly by inflow over their sills. A thorough examination of two sections of closely-spaced hydographic stations, made by the CRAWFORD in 1963, across the sills of the Cayman and Venezuelan Basins of the Caribbean Sea has conclusively disproved this assumption in the case of the Caribbean. Not only is there no discernible continuity in these sections between water on the sills and water at great depth in the basins, but there is a distinct difference in silicate concentration between the deep basin water and the Atlantic water outside the basins at sill depth. The general problem of circulation at depth in oceanic basins may therefore require reappraisal.

A program of measurement of the residual bottom drift along the continental shelf (i.e., exclusive of the periodic tidal currents) has been undertaken with sea-bed drifters, to complement our long-term measurements of surface drift with drift bottles. The recoveries of sea-bed drifters have far exceeded expectations, amounting to 25% of releases between Cape Cod and Delaware Bay, in contrast to 11% for drift bottles. The bottom drift is of the order of 1 cm/sec, and appears to tend toward the coast inshore of the 30-35 fathom line, whereas in deeper water the drifters tend to move offshore. There is also a definite residual drift towards the mouths of estuaries.

In July 1963, Kane Basin, located north of Baffin Bay, was free of ice for the first time in history. Therefore a general oceanographic survey of the region was quickly organized by representatives of the International Ice Patrol and the Woods Hole Oceanographic Institution. Three current-meter stations were set, the records from which were just analyzed this year. In agreement with the distribution of nutrients measured during the same program, they show a circulation dominated by semi-diurnal tides, with a net transport out of the Basin into Baffin Bay.

Work has continued on a series of 22 charts showing the distribution of salinity and depth on selected surfaces of constant potential temperature in the North Atlantic. These are based on observations made during the International Geophysical Year and on subsequent cruises in the northern North Atlantic. They show in a particularly vivid way the horizontal patterns of deep-water circulation, and they complement Fuglister's atlas of vertical profiles, which was derived in part from some of the same data. Strangely, however, it has proved difficult to obtain the modest funds necessary for final publication of this useful reduction of an otherwise indigestible body of observations (modest compared with the cost of collecting the data).

The great and continuing increase in surface observations has made new calculations of average distributions pertinent, and a new sequence of charts showing monthly-average fields of surface temperature in the North Atlantic has accordingly been prepared.

In the surface water of the central North Atlantic one often observes small thermal fronts (temperature contrast up to 2°C), oriented zonally with considerable lateral extent (of order 1,000 km). These have been an object of continuing study, and were tracked once a month by aircraft from January through June. They showed considerable meandering during this time and exhibited features which seemed to persist for more than a month. They appear to be another instance of the streakiness common to geophysical fluid motion.

Indian Ocean

During the late-winter and spring months the ATLANTIS II returned to the Indian Ocean to follow up its observations of 1963, made under the southwest (northern summer) monsoon. On this second cruise, during the northeast phase of the monsoon, a broad hydrographic survey of the western

Indian Ocean was again carried out, with particular attention to the northern Arabian Sea. It is hoped that careful comparison of the distributions of properties as observed during these two cruises will bring out the general changes in circulation of the western Indian Ocean caused by the seasonal reversal of the monsoon.

The ATLANTIS II also performed a hydrographic traverse of the Indian Ocean at Latitude 32°S, to match one made in 1936 by the DISCOVERY II. No appreciable changes seem to have occurred in the temperature and salinity structure of the deep water during this 29-year period.

Analysis has been completed of a detailed survey of the Somali Current made jointly by the ARGO (Scripps Institution of Oceanography) and DISCOVERY (National Institute of Oceanography, Great Britain) in late summer, 1964, with members of this department participating. Direct current measurements combined with hydrographic observations show that near the equator the current was narrow (50-100 km wide), close to shore, with a volume transport less than $15 \times 10^6 m^3/sec$ in the upper 200 m. It flowed northeast, widening and increasing in transport, and turned eastward away from the coast at 8°N, with a transport in the upper 200 m of more than $50 \times 10^6 m^3/sec$. In the deep water small differences in temperature-salinity characteristics revealed a narrow northward flow adjacent to the continental slope, which roughly parallels the Somali Current. It is not known, however, whether this deep current changes seasonally, like the surface current.

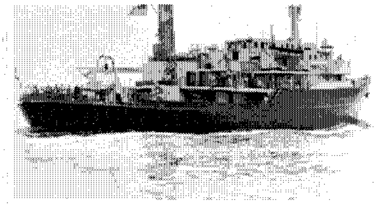
During its winter-monsoon cruise this year the ATLANTIS II made a section of hydrographic stations and current measurements along Latitude 9°N, corresponding to one of those made by the ARGO during the previous summer monsoon. The Somali Current had completely disappeared: measured currents were less than 50 cm/sec (often less than 25 cm/sec) and highly variable in direction, quite in contrast to the steady, swift current (speeds up to 350 cm/sec) observed the previous summer.

Pacific Ocean

En route home from the Indian Ocean, the ATLANTIS II spent two months investigating the strong currents along the western boundary of the North Pacific. As the North Equatorial Current approaches the Philippines, it branches, most turning northward to form the Kuroshio, and some turning southward into the Mindanao Current, which eventually enters the Equatorial Countercurrent. Since deep, detailed observations were lacking in this area, two closely-spaced hydrographic sections were run across the Mindanao Current, and one across the Southern Kuroshio in the vicinity of the Ryukyu Islands. (These three sections were collaborative work with the Massachusetts Institute of Technology and Johns Hopkins University.)

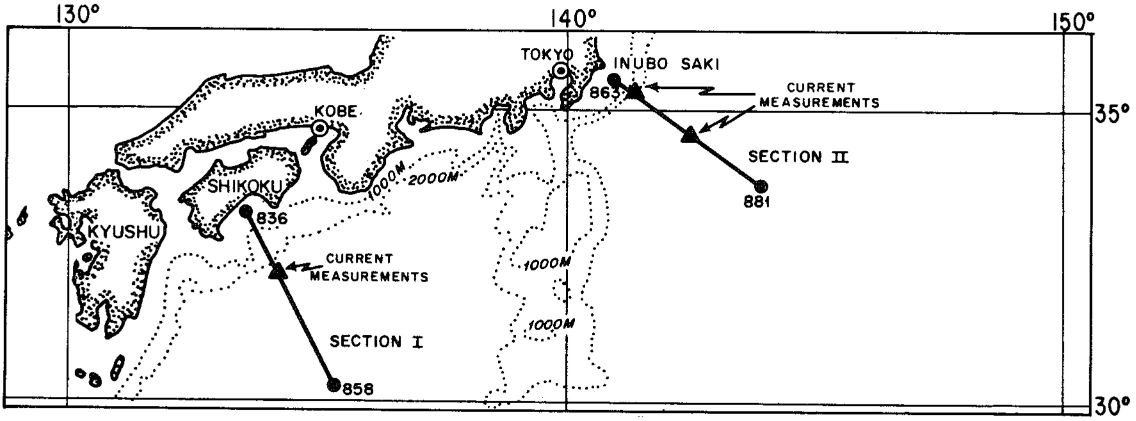
Downstream in the Kuroshio, near Japan, two additional deep sections were made, one south of Shikoku, the other running southeast from Tokyo. These show a striking contrast to comparable Gulf Stream sections: the sharp cross-stream density gradient characteristic of the Kuroshio vanishes below 2,500 m, whereas that of the Gulf Stream persists to the ocean bottom. Deep, neutrally buoyant floats were also followed on these two sections, and their behavior was consistent with the absence of density gradients in that they moved only very slowly or not at all. Inshore of the Kuroshio on the Tokyo section, however, a counter-current was found having speeds up to 16 cm/sec, comparable to that off the Carolina coast of the United States.

East of Japan, the path of a portion of the Kuroshio extension was tracked in



Departure of ATLANTIS II for the Indian Ocean.

PDP-5 computer aboard ATLANTIS II.



ATLANTIS II Kuroshio investigations September, 1965.

detail using towed-thermistor equipment similar to that currently being employed in our Gulf Stream investigations.

High-Frequency Motions

Apart from long-period motions of a specific geographic character, we are also investigating the high-frequency motions which are presumed to occur rather generally throughout the ocean. The technique employed is spectral analysis of records from moored current meters, with immediate attention now being given to the kinetic energy spectrum, particularly to energy concentrations in the range of inertial frequencies. Unfortunately, most current meter measurements have been of too short duration to be suited for such analysis, but two records from depths of 50 m and 100 m at 28°N, 65°W had a duration of 3½ months and have been successfully analyzed. Strong concentrations were indeed found near the inertial period, but the peaks occurred at slightly different periods at the two depths. This difference is not yet understood.

At higher frequencies, current meter records appear to have an energy density which is inversely proportional to the five-thirds power of the frequency, and thus consistent with the Kolomogoroff theory of homogeneous isotropic turbulence.

Physical Properties of Sea Water

Measurements of the effects of dissolved oxygen and nitrogen concentrations on the electrical conductance of de-alkalinized sea water and sodium chloride solutions have been completed, with the happy result that such concentrations do not impair the conductometric measurement of salinity.

In recent years the accuracy of temperature measurements has exceeded that of present formulas for the adiabatic temperature gradient, as based on old measurements of the thermal expansion coefficient for sea water. Therefore, to improve determinations of stability, preparations have been made for new, more accurate laboratory measurements of this coefficient.

FREDERIC C. FUGLISTER, *Chairman*

Department of Theoretical Oceanography and Meteorology

The bottom of the atmosphere and the surface of the oceans form a transition region within which strongly dissipative processes couple the essentially non-dissipative large-scale flows inside the two media. But even away from this interface there is a tendency, discernible in atmosphere and ocean alike, for sharp transition regions, fronts, inversions, or thermoclines, to appear between regions of greater homogeneity. What is the nature of the transfer processes in such transition regions? What aspect of their character serves to maintain their narrowness? These, and similar questions, provide the common broad aims for attacks on a multitude of detailed problems in convection, turbulent mixing, generation of wind waves, etc.

The study of transfer processes will probably remain a central theme in our activities for several years to come, but we may also expect a rapid regrowth in the attention given to large-scale dynamics. The possibilities for critical testing of theories in the latter area have so far been limited essentially to experiments in rotating laboratory tanks. Now, rapidly expanding capabilities for intensive deep-sea data acquisition raise the hope that a period of intensified interaction between theory and ocean observations is about to begin.

We are probably just now in the first phase of the stormy adolescence of oceanography, when in a turmoil of new ideas and techniques, our science will strive to establish its rightful place in the family of interdisciplinary endeavors.

Indian Ocean

During 1963 and 1964, members of the meteorology group, with the Institution's C54Q research aircraft, participated in the meteorological phase of the International Indian Ocean Expedition. The task of analyzing and interpreting the extensive body of data on wind and temperature structure, vapor flux, etc., continues. Tie-ins are being made with observations from surface ships and with Tiros satellite pictures of cloud cover structure.

Cumulus clouds over the Indian Ocean and the Arabian Sea during the monsoon season were frequently found to be immersed in a dense haze. It is known that a deep haze layer prevails over Middle and Far East Asia during the pre-monsoon season, as a result of dust raised from the deserts in that area. But the present observation was surprising since during the monsoon season the air flow is not from the deserts. A study of the cloud and haze data, together with the relative humidity measurements from our aircraft work has shown that condensation on sea-salt particles can account for this maritime-haze layer.

Continued analysis of vertical wind profiles indicates that a low level (ca. 1 km) wind maximum is a persistent feature of the wind structure during the southwest monsoon. The dynamic implications of this, and the vertical momentum flux measurements are subject to further study.

Cloud Dynamics and Composition

A theoretical dynamic model was used to study the effect of suspended liquid water on the updraft structure in convective clouds. The results of numerical integrations indicate the formation of downdrafts in the lower parts of the cloud as a consequence of the growing load of suspended raindrops.

Instruments for determining liquid water content in clouds, which were developed here over the past few years were made available to the ESSA Research Flight Facility for use in their hurricane cloud studies.

Aruba Expedition

A second expedition for study of air-sea interaction processes was staged to Aruba in the Dutch Antilles. The project aroused interest in participation from several groups outside the Institution. Two results stand out as particularly interesting at the present stage of data reduction and processing. One is the occurrence of a pronounced system of internal waves in the low level air in the lee of the island. The other is the finding of systematic differences in wind profiles between the Aruba data, and measurements made locally in Buzzards Bay. These differences are tentatively being interpreted as an effect of the shoreline position, with obvious consequences for the problem of extrapolating coastal observations to open sea conditions.

Infrared Thermometry

The usefulness of airborne infrared thermometry for oceanographic purposes has been limited by an incomplete understanding of the sources of systematic observational errors. An observational procedure has been worked out, which should allow essential elimination of the atmospheric transmission and re-emission effects in low altitude work. Glitter, i.e., reflections of solar radiation, has been found to be a relatively unimportant error source in the 8-13μ window region presently used in our work.

We are now beginning to approach the absolute accuracy level of one or two tenths of a degree C, where infrared sea surface temperature observations can form an important part in studies of air-sea energy exchange.

Wind Waves

Analyses of wave spectra collected during several years of observational efforts are leading to the conclusion that contrary to the commonly used notion of a continuous wave spectrum, short period samples show a marked line structure region imposed on a background continuum. This suggests that in terms of spatial structure, groups of waves within a narrow wavelength band might be a fairly common feature of a seemingly disorganized sea state.

If further substantiated, this observation will lead to interesting theoretical questions regarding the generation of and interactions between wind waves.

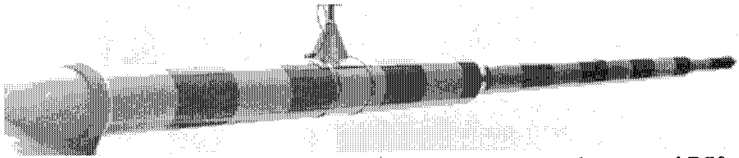
Electrical Phenomena in Marine Aerosol Formation

In a field work effort extending in time over the past several years, and in space from the coral beaches of Hawaii to emerging volcanic islands off the Icelandic coast, a variety of conditions under which charge-carrying marine aerosols are produced have been investigated. The most recent findings include the establishment of a satisfactory agreement between electric field observations in the vicinity of a steam plume produced as lava flows into the sea, and earlier laboratory observations of charge separation caused by splashing of sea water onto hot surfaces.

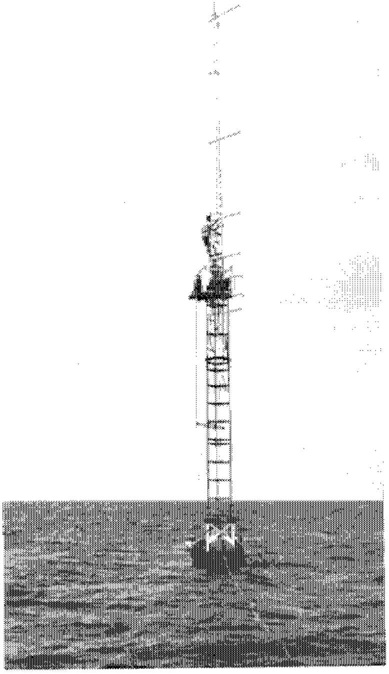
The outstanding question, which has yet to be answered, in this context, is the physical-chemical nature of the charge separation mechanism.

Experiments on Mixing Processes

A wide range of laboratory experiments have been carried out with an aim to develop our understanding of the energy transport processes in the thermocline, and the interactions between neutrally and stably stratified regions. A promising avenue for further investigation has been opened by the work on breakdown of internal waves. An example of this breakdown is shown as the formation of bead-like exten-

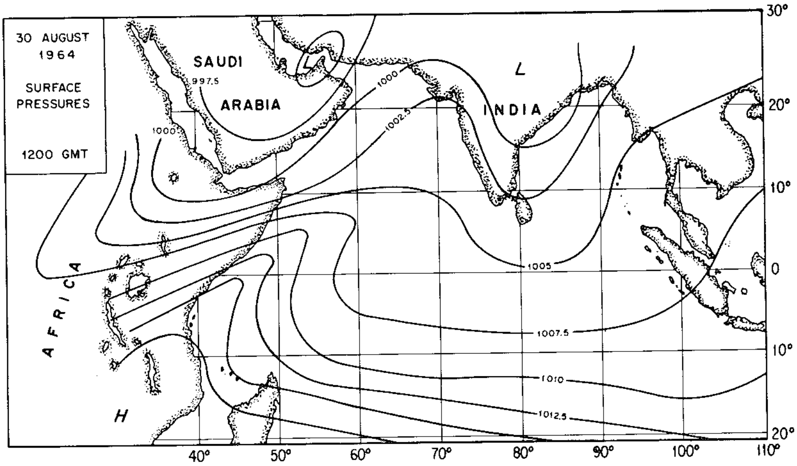


Photograph of cloud instrument system installed on boom projecting from nose of DC6. The rain instrument is mounted on the tip and the cloud instrument on the side.

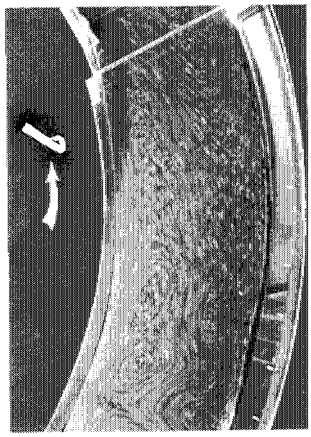


Stable meteorological instrument buoy being readied for recording of wind and temperature in the Caribbean.

Aircraft cloud photograph taken in August during a field trip to Barbadoes aboard the Institution's C-54 aircraft.

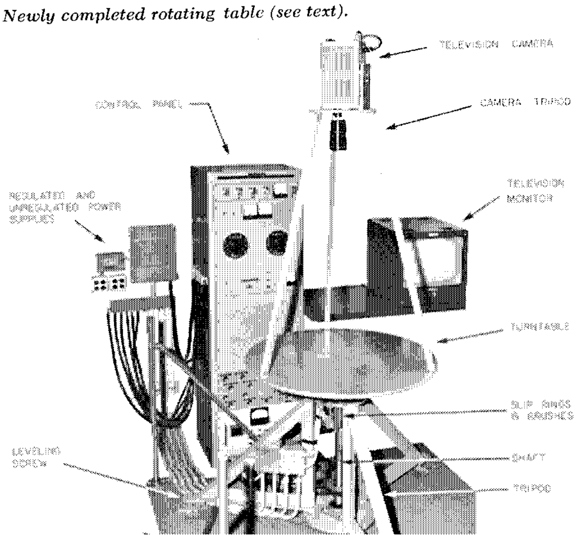


Surface pressure chart of the Indian Ocean during the southwest monsoon showing a ridge of high pressure off the coast of Somalia.

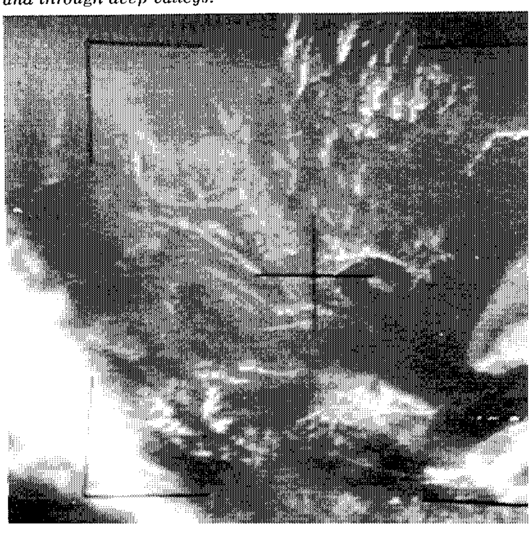


Currents obtained with a somewhat different rotating system.

Newly completed rotating table (see text).



TIROS VII photograph of southern India and cumulus cloud formations produced by air flow around the Ghat Mountains and through deep valleys.



sion on a dyed layer of density transition between two uniform fluid layers.

Thermocline Studies

Partly based on the above-mentioned laboratory studies of mixing due to stirring at the surface of a stably stratified fluid body, a theoretical study of seasonal thermocline formation has been made. The important result of this investigation is that some essential features of the annual development of thermal structure in oceanic regions not influenced by strong currents can be reproduced by considering a variable heat source at the surface, in conjunction with a constant source of stirring energy.

Further development of this type of theoretical model is in part dependent on improvement of our understanding of the dynamics of stirring processes in stable surroundings. We hope in the future to be able to pursue these questions not only in the laboratory, but also with *in situ* observations using submersible research craft.

Convection Experiments

Fluid mixtures with non-linear dependence of density on composition were used for modeling some thermodynamic properties of atmospheric convection. It was found that the oscillatory development of cloud top height, which is a common characteristic of deep cloud development, could be realistically reproduced in a situation where the input of buoyant fluid was steady.

Quantitative studies of tornado-like convective model circulations have shown important effects of the conditions at the lower, frictional, boundary layer on the structure of the whole motion field. This property of the boundary layers of being not just layers of adjustment, but in fact at times the controlling agents for the internal flow structure, is an important general property of flows in rotating fluids. It is brought about by the fact that the constraints on the motion imposed by the rotation is overpowered by viscous effects in the boundary layers. In this way a link exists between the studies of such disparate phenomena as tornadoes and oceanic eddies.

Convection Theories

Classes of so-called self-similar or self-preserving flows play an important role in the rationalization of laboratory experiments with isolated convective systems. A theoretical survey of the energetics of such flows leads to the somewhat surprising conclusion that the level of internal or small-scale turbulence in such a system is inversely related to its gross instability. In other words, the more unstable the system is, the better organized is the motion in the convective cells.

A deepened understanding of the internal dissipation by small-scale turbulence in convective elements is of prime importance for applications such as the thermocline theory mentioned above.

Planetary Wave Studies

The current emphasis on studies of eddies and meanders in the Gulf Stream system within the Department of Physical Oceanography lends actuality to our laboratory investigations of "planetary waves," i.e., waves in the geostrophic flow regime. An extensive series of measurements on the propagation of such waves in an annulus, showing excellent agreement with theory, have been completed. Work is progressing to elucidate the effect of isolated topographic features on geostrophic flow — Taylor columns effects. A newly-completed rotating table (illustrated) featuring a closed circuit television monitor for observation of experimental details, allows this work to be carried out under a wide range of rotation conditions.

CLÄES G. H. ROOTH, *Assistant Chairman*

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Ashore and Afloat

In September the Institution took title, through purchase, to the former Edward Swift residence. This property consists of a frame dwelling and several outbuildings on some 19,000 square feet adjacent to the Laboratory of Marine Sciences on the north. The town zoning authorities have granted a temporary permit for its use as laboratory and office space for the Computer Group.

The ASTERIAS, our 40-foot dragger, in her thirty-fifth year at the Institution, set a record of some sort for small research craft by making a scientific cruise along the Atlantic seaboard to Miami and return. The 21-day expedition was concerned with the Woods Hole-U.S. Geological Survey investigations of the Continental Shelf.

An unscheduled and unintended Man-*on*-the-Sea experiment was conducted near Aruba in the Caribbean during the spring. While the R. V. CRAWFORD was in the port of Paarden Bai her radio operator, Phillip Clegg, borrowed the rubber Zodiac boat for a fishing trip just off the harbor entrance. When the motor failed the boat was carried off to the northwest by wind and current. An air and sea search conducted by the Dutch authorities was unsuccessful. During the evening of the fifth day Mr. Clegg and the boat were sighted by a tanker, the U.S.N.S. LAURENTIA. Mr. Clegg was in good physical condition as a result of his resourcefulness in catching fish for food and fluids. The drift of the raft was found to have been much slower than expected and its set had a component across the wind and seas.

In January R. V. CHAIN underwent extensive alterations and modernization of the scientific and living spaces. Particularly noteworthy are the addition of a scientific plotting room and a library. The shelves of the library are being filled with books as rapidly as the resources allow.

The Institution is especially proud that of the eighty-five men who man our ships, twenty-nine have been with us for more than five years.

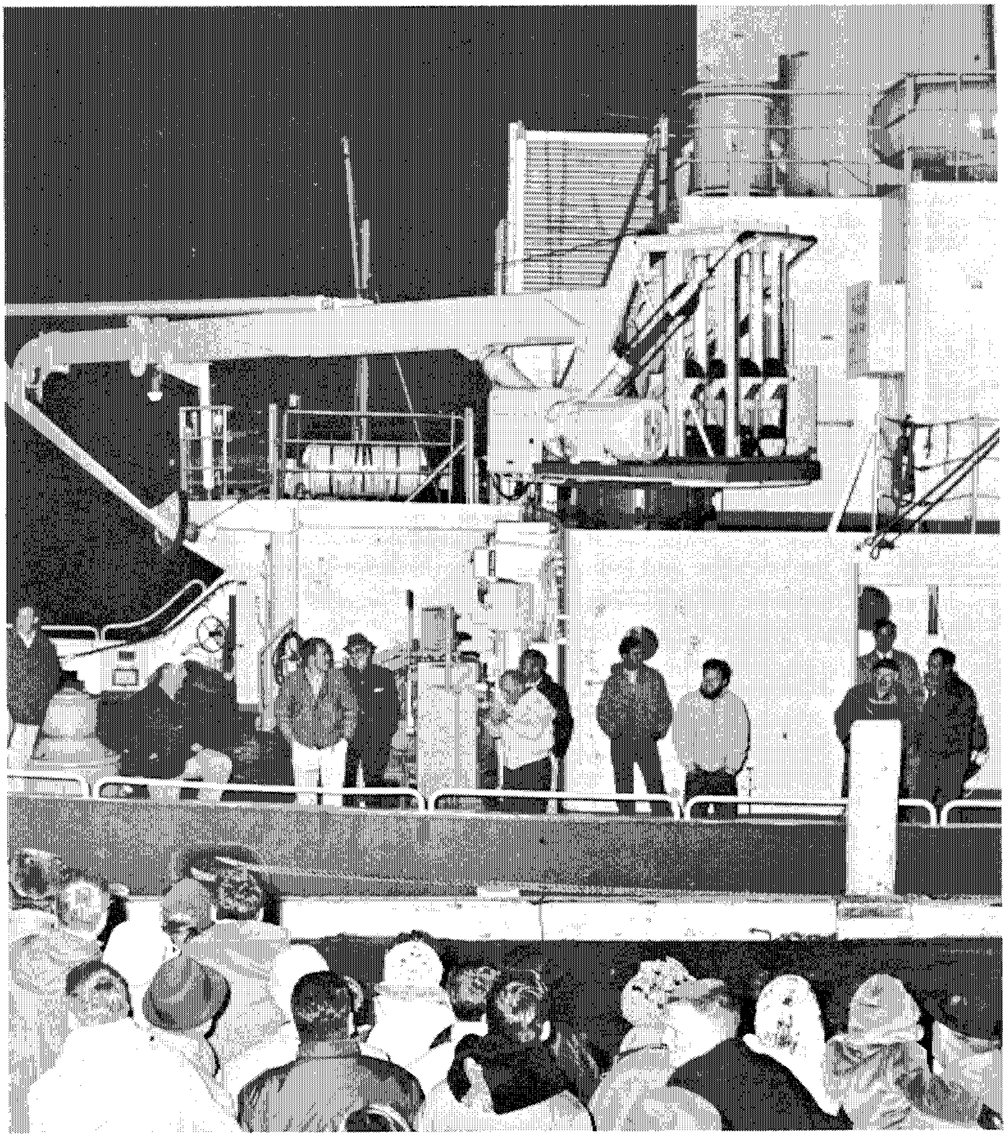
In the late fall a contractor began replacing the wooden sea-wall along the Eel Pond side of the Laboratory of Marine Sciences site. The new wall, some 150 feet in length and of driven steel sheet-piling, is scheduled for completion in the early spring. The primary purpose of the project is to preserve the shore, but a very useful berthing space for the Institution's smaller craft will also result.

The National Science Foundation made a grant to the Institution in June to conduct engineering and design studies of possible waterfront improvements. To obtain data upon which to specify the piling requirements, the engineers conducted test borings in the harbor immediately off the shore line. Bedrock was found at 281 feet below low mean water and the bearing characteristics of the soil appear favorable.

Cruises - 1965

ATLANTIS II Days at Sea – 307 Total Miles Sailed – 50,041

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
15	21 January–14 November	Around the World	298	A. Miller
16	17 November–10 December	Munro's Shipyard	- -	- - - - -
17	10 December–18 December	Toward Bermuda	9	J. Ryther
			307	



On a cold wintry night, friends and relatives greet ATLANTIS II and her crew on her return to Woods Hole after circumnavigating the world.

CHAIN Days at Sea – 249 Total Miles Sailed – 40,021

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
46	10 February–10 April	Caribbean Area	60	C. Bowin
47	20 April–11 May	South of Bermuda	22	J. Beckerle
48	17 May–11 June	South America	26	J. Ryther
49	12 June–25 June	South America	14	R. Backus
50	28 June–7 July	Bermuda	10	R. Hessler
51	22 July–31 August	"Spider", Blake Plateau	41	G. Savage
52	20 September–8 October	Between Woods Hole and Bermuda	19	E. Zarudzki
53	14 October–27 October	Blake Plateau	14	S. Knott
54	2–4 November	South of Nantucket	3	J. B. Hersey
55	10 November–19 December	Caribbean Area	40	C. Bowin
56	27 December–31 December	General Shipyard	- -	- - - - -
			249	

CRAWFORD Days at Sea – 277 Total Miles Sailed – 41,678

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
122	28 January–16 February	Caribbean Area	20	V. Worthington
123	17 February–26 March	Caribbean Area	38	E. Kraus
124	27 March–3 April	Munro's Shipyard	- -	- - - - -
125	6 April–1 July	South American Waters	87	G. Metcalf
126	19 July–2 August	Bermuda	15	C. Parker
127	4–5 August	Continental Slope	2	H. Jannasch
128	7–26 August	Gulf Stream	20	J. Barrett
129	3 September	Local	1	C. Parker
130	7–21 September	Gulf Stream	15	A. Voorhis
131	28 September–18 October	Bermuda	21	F. Fuglister
132	19 October–2 November	Bermuda	15	F. Fuglister
133	3–25 November	Bermuda	23	A. Voorhis
134	26 November–15 December	Bermuda	20	C. Parker
			277	

GOSNOLD Days at Sea – 216 Total Miles Sailed – 18,231

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
60	19–21 January	Wilkinson Basin	4	R. Conover
61	27–30 January	South of Nantucket	4	N. Fofonoff
62	5 February	Local	1	N. Fofonoff
63-A	23–25 February	South of Nantucket	3	N. Fofonoff
63-B	27–1 March	1,000 Fathom Shoal	3	N. Fofonoff
64	2–9 March	Norlantic Shipyard	- -	- - - - -
65	10–13 March	Wilkinson Basin	4	R. Conover
66	22–25 March	South of Nantucket	4	N. Fofonoff
67-A	30 March–2 April	100 Miles South of Gay Head	4	E. Tasko
67-B	7–8 April	South of Nantucket	2	E. Tasko
68	12–15 April	1,000 Fathom Curve	4	R. Conover
69-A	20–22 April	South of Nomansland	3	N. Fofonoff
69-B	26–29 April	South of Nomansland	4	N. Fofonoff
70	3–7 May	South of the Cape	5	R. Walden
71	9–13 May	Gulf of Maine	5	R. Conover
72	15 May–30 June	Coast of Florida	47	E. Uchupi
73	9 July 5 August	Off South Carolina	33	A. Erickson
74	17 August–23 September	Blake Plateau	38	R. Pratt
75	28 September–1 October	Gulf of Maine	4	R. Conover
76	4–8 October	South of Nantucket	4	P. Stimson
77	13 October–9 November	South Carolina	30	E. Uchupi
78	16–17 November	Wilkinson Basin	3	R. Conover
79	29 November–2 December	Nantucket	4	N. Fofonoff
80	8–10 December	South of Martha's Vineyard	3	C. Yentsch
			216	

Changes in the Resident Research Staff

Our Staff is strengthened as new members are added; and we console ourselves that those who leave will contribute to oceanographic research at other places. During 1965 these changes took place in the Resident Staff:

Joining

March 1, 1965

JOHN E. GORDON, *Assistant Scientist*
From the Mellon Institute (Fundamental Group in Organic Chemistry)
B.S. 1953 Ohio State
Ph.D. 1956 University of California

March 3, 1965

GEOFFREY THOMPSON, *Assistant Scientist*
From the Geology Department of Manchester University, U.K.
B.S. 1961 Manchester University
Ph.D. 1965 Manchester University

April 5, 1965

EDWARD F. K. ZARUDZKI, *Research Specialist*
From the Pan American Petroleum Corp., Alberta, Canada
M.S. 1939 Technical College of Lwow (Poland), Mech. Engr.

June 22, 1965

MELVIN A. ROSENFELD, *Manager, Information Processing Center*
From the Pure Oil Research Center, Crystal Lake, Illinois
B.S. 1942 University of Chicago
M.S. 1950 Pennsylvania State College
Ph.D. 1953 Pennsylvania State College

November 4, 1965

DEREK W. SPENCER, *Associate Scientist*
From Imperial Oil Co. (Exploration Research Group), Alberta, Canada
B.S. 1954 Manchester University
Ph.D. 1957 Manchester University

November 27, 1965

ARTHUR E. MAXWELL, *Associate Director*
From Head, Geophysics Branch, Office of Naval Research, Navy Dept.
B.S. 1949 New Mexico A&M
M.S. 1952 University of California, Scripps Institution of Oceanography
Ph.D. 1959 University of California, Scripps Institution of Oceanography

December 7, 1965

WILLIAM A. BERGGREN, *Assistant Scientist*
From Oasis Oil Co., Tripoli, Libya
B.A. 1952 Dickinson College
M.S. 1957 University of Houston
Ph.D. 1960 University of Stockholm
D.Sc. 1962 University of Stockholm

Resignations and Retirements

February 26, 1965

FLOYD M. SOULE, *Associate in Physical Oceanography*
Retired

April 30, 1965

DUNCAN E. MORRILL, *Manager, Computer Facility*
To Lockheed Electronics Co., Plainfield, N.J.

August 31, 1965

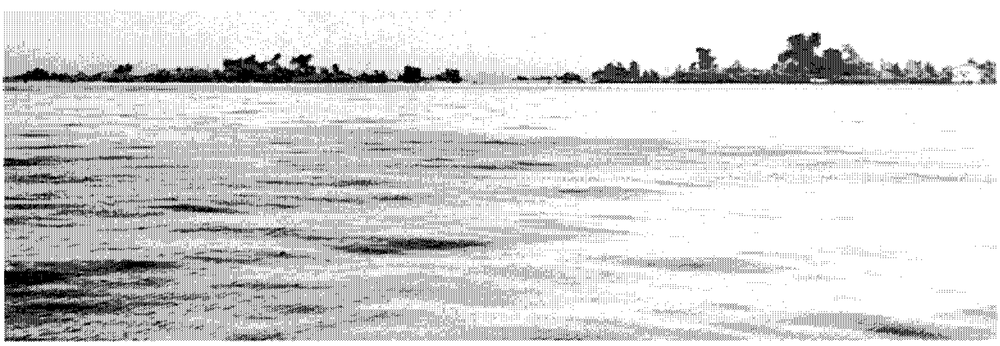
MARGARET WATSON, *Assistant Scientist*
To Institute for Muscle Research, Marine Biological Laboratory

September 3, 1965

EDWARD KUENZLER, *Associate Scientist*
To the Department of Environmental Sciences & Engineering, University of North Carolina, Chapel Hill, N.C.

October 28, 1965

ROBERT WALDEN, *Electronics Engineer*
To Alpine Geophysical Associates, Inc., Norwood, N.J.



Scientific Departments and Supporting Services Personnel

PAUL M. FYE	Director
BOSTWICK H. KETCHUM	Associate Director
ARTHUR E. MAXWELL	Associate Director
DAVID D. SCOTT	Assistant Director for Administration

The following were in the employ of the Institution for the twelve-month period ending December 31, 1965:

Department of Applied Oceanography

Andersen, Nellie T.
Andrade, Marie
Barstow, Elmer M.
Baxter, Lincoln II
Brockhurst, Robert R.
Broderson, George de P.
Chute, Edward H.
Davison, Allan R.
English, Jean J.
Fairhurst, Kenneth D.
Fofonoff, Nicholas P.
Fox, Mark P.
Freund, William F., Jr.
Gifford, James E.
Graham, Russell G.
Hays, Earl E.
Heinmiller, Robert H.
Howland, Myron P., Jr.
*Jones, Maxine M.
Lyon, Thomas P.
Marquet, William M.
Mason, David H.
Mavor, James W., Jr.
McCamis, Marvin J.
Michael, Joseph C.
Muzzey, Charlotte A.
Norton, Elizabeth
Omohundro, Frank P.
Porembski, Chester R.
Rainnie, William O., Jr.
Scully, William C.
Sharp, Arnold G.
Shodin, Leonard F.
Shultz, William S.
Simmons, Charles F.
Stimson, Paul B.
*Walsh, Joseph B., Jr.
Webb, Douglas C.
*Webster, Jacqueline H.
Wilkins, Charles H.
Wilson, Valentine P.
Woods, Donald E.

Department of Biology

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

Department of Chemistry and Geology

Athearn, William D.
Bentley, Harold W.
Blumer, Max
Bowen, Vaughan T.
Burke, Barbara A.
Burke, John C.
Coppenrath, Agnes I.
Cormack, Douglas
Dale, Barry
Degens, Egon T.
Emery, Kenneth O.
Fitzgerald, William F.
Foley, Robert
Frothingham, Joseph R., Jr.
Gatrousis, Christopher
†Hathaway, John C.
Hayes, Carlyle R.
Hülsemann, Jobst B.
Hunt, John M.
Jakubec, Fides
Keleman, Steve P.
Kite, Sherril A.
†Manheim, Frank T.
McAuliffe, Julianne G.
McFarlin, Peter F.
†Meade, Robert H.
Mott, Norman S.
Noshkin, Victor E., Jr.
Paul, Russell K.
Pratt, Richard M.
Sass, Jeremy
†Schlee, John S.
Schmidt, Heidemarie
Schroeder, Brian W.
Siegel, Alvin
Strickland, Charlotte M.
†Tagg, A. Richard
Tasha, Herman J.
†Trumbull, James V. A.
Uchupi, Elazar
Wall, David
Zeigler, John M.

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

Department of Geophysics

Aldrich, Thomas C.
Allstrom, Frank C.
Backus, Richard H.
Beckerle, John C.
Bennett, Lee C., Jr.
Bergstrom, Stanley W.
Boutin, Paul R.
Bowin, Carl O.
Broadbent, Alice G.
Bunce, Elizabeth T.
Cain, Henry A.
Chase, Richard L.
Dakin, Frances M.
Dow, Willard
Dunkle, William M., Jr.
*Gallagher, Gloria S.
Grant, Carlton W., Jr.
Hays, Helen C.
Hersey, J. Brackett
Hess, Frederick R.
Johnston, Alexander T.
*Jones, Barbara A.
Knott, Sydney T., Jr.
Laura, Arthur C.
Lynch, Frank L., Jr.
Mellor, Florence K.
Mizula, Joseph W.
Morehouse, Clayton B.
Nichols, Walter D.
Nowak, Richard T.
Olmsted, Coert D.
Payne, Richard E.
Peterson, Jane M.
Poole, Stanley E.
Rhoads, Sandra S.
Ruppert, Gregory N.
*Savage, Godfrey H.
*Schevill, William E.
Stetson, Thomas R.
Stillman, Stephen L.
Stone, Louise D.
Sutcliffe, Thomas O. L.
Tasko, Edward R.
Vine, Allyn C.
Watkins, William A.
Welby, Kevin M.
Wing, Asa S.
Witzell, Grace K.
Witzell, Warren E.

Department of Physical Oceanography

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

Department of Theoretical Oceanography and Meteorology

Alexander, Robert M.
Armstrong, Harold C.
Blanchard, Duncan C.
Bunker, Andrew F.
Ching, Jason K. S.
Collins, Clayton W.
Frazel, Robert E.
Ibbetson, Alan
Iselin, Columbus O'D.
Kraus, Eric B.
Levine, Joseph
Ridolfi, Mary
Ronne, F. Claude
Rooth, Claës G. H.
Saunders, Peter M.
Spencer, Allard T.
Srivastava, Ramesh C.
Stevens, Raymond G.
Thayer, Mary C.
Turner, J. Stewart

*Part Time Employment

Department of Administrative and Service Personnel

*Allen, Norman T.
Anders, Wilbur J.
Ayres, Elaine O.
Backus, Jeanne M.
Bard, Wallace R.
Behrens, Henry G.
Bjorkmann, William P.
Branham, Roy L.
Bowman, Richard W.
Burke, John E.
Cabral, John P.
Campbell, Eleanor N.
Carlson, Alfred G.
Carlson, Eric B.
Carlson, Ruth H. E.
Carver, Kenneth W.
Chalmers, Agnes C.
Christian, John A.
Clough, Auguste K.
Condon, John W.
Conway, George E.
Cook, Harold R.
Corr, James P.
Couto, Patricia A.
Crocker, Marion W.
Croft, Donald A.
Cummings, Priscilla J.
Day, Joseph V.
Dean, Mildred
Dimmock, Richard H.
Doty, Jeanne C.
Eastman, Arthur C.
Eldridge, Stanley N.
Ferguson, Sandra K.
Fernandes, Alice P.
Ferris, George A.
Fielden, Frederick E.
Fisher, Stanley O.
Fleet, Kenneth F.
*Fuglister, Cecelia B.
Gallagher, William F.
Gaskell, Fred
Geggatt, Edward E.
Gioiosa, Albert A.
Grace, Cynthia C.
Grant, Carlton W., Sr.
*Hahn, Jan
Hampton, Carolyn S.
Hatzikon, Kaleroy L.
Henderson, Arthur T.
Hewins, William H.
Hinton, Clifford H., Jr.
Hodgson, Sloat F.
Hunt, Otis E.
Ingram, Ruth C.
Innis, Charles S., Jr.
Jenkins, Delmar R.
Johnson, Harold W.
Kania, Martha L.
King, Una T.
Kostrzewa, John A.
Lane, Egbert B.
Leach, David G.
LeBlanc, Donald F.
MacKillop, Harvey
Mangelsdorf, Frederick E.
Martin, Olive
McGilvray, Mary K.
McHardie, James
Medeiros, Frank
Mitchell, James R.
Morrison, Kenneth
Motta, Joseph C.
Motta, Joseph F.
Orr, Elizabeth D.
Ortolani, Mary
Palmer, Howard V. R., Jr.
Pasley, Gale G., Jr.
Patterson, John E.
Pimental, John M.
Quigley, Ralph W.
Reis, Janice A.
Roberts, Harry A.
Rudden, Robert D., Jr.
Simons, Cecelia M.
Slabaugh, Luther V.
Smith, Donald C.
*Solberg, Otto
Souza, Donald P.
Souza, Thomas A.
Stanbrough, Jess H.
Stansfield, Richard
Stimpson, John W.
*Sullivan, James R.
†Veeder, Ronald A.
von Dannenberg, Carl A.
Walker, Jean D.
Watson, L. Hoyt
Weeks, Robert G.
Wessling, Andrew L., Jr.
Williams, Sally A.
Williamson, David A.
Wing, Carleton R.
Woodward, Fred C., Jr.
Woodward, Ruth F.
Wright, Hollis F.
Yoches, Jean L.
Zwilling, Avron M.

Marine Personnel

Babbitt, Herbert L.
Backus, Cyril
Bailey, Peter H.
Baker, William R.
Bazner, Kenneth E.
Bizzozero, John P.
Bowen, Harold E.
Brereton, Richard S.
Brown, Joseph C.
Buckley, Francis E.
Bumer, John Q.
Byron, Paul C.
Cabral, John V.
Cahoon, Geraldine B.
Carter, Richard J.
Carver, Ralph C.
Casiles, David F.
Cavanaugh, James J.
Clarkin, William H.
Clegg, Philip R.
Cochran, Patrick F.
Colburn, Arthur D., Jr.
Cook, Alden H.
Cook, Hans
Copestick, Louis B.
Cornell, Jack W.
Cotter, Jerome M.
Coughlin, Brooks W.
Crouse, Porter A.
Davis, Charles A.
Devlin, Gerald X.
Edwards, Richard S.
Ewing, William R., Jr.
Grisham, Andrew C.
Halpin, William T.
Hamblet, Dwight F.
Hiller, Emerson H.
Howe, Paul M.
Howland, Paul C.
Jefferson, Albert C.
John, Alfred C.
Jorgensen, Peter A.
Karram, Calvin D.
La Porte, Leonide
Leiby, Jonathan
Lorraine, Frederick G.
Martin, John W., Jr.
Matthews, Francis S.
McKenna, Michael J.
McLaughlin, Barrett J.
McMahon, James H.
Miner, Arnold W.
Moller, Donald A.
Morse, Joseph C.
Mosier, Craig R.
Mysona, Eugene J.
Palmieri, Michael, Jr.
Parent, John P.
Pennypacker, Thomas R.
Pierce, George E.
Pierce, Samuel F.
Pike, John F.
Ribeiro, Joseph
Rioux, Raymond H.
Rose, Lawrence
Roy, Alfred J.
Seibert, Harry H.
Seifert, Charles T.
Snure, James J.
Sointu, Sulo
Stires, Ronald K.
Thurston, Theodore G.
Tully, Edward J.
White, William A.
Woodward, Jan A.

†Deceased 2 March 1966

Seminars and Fellowships

Fellows

During the summer, there were fourteen predoctoral and two postdoctoral fellows working under the general supervision of various staff members in all departments of the Institution. This program, which has been in operation since the Institution first opened its doors in 1932, has been important in recruiting and training oceanographers for the past three decades. It has given students an opportunity to continue and to develop research programs, often resulting in a doctoral thesis. In many instances, it has for the first time introduced an individual to the study of the oceans.

There have also been six postdoctoral fellows working at the Institution throughout the year. Twelve students registered at nearby universities spent the year in Woods Hole, where they found more suitable facilities to pursue their particular studies toward a doctorate. The Institution has awarded eight fellowships for work away from Woods Hole at one or another university. Three students upon graduation from Lawrence (Falmouth) High School have now been awarded scholarships for undergraduate scientific and engineering studies.

Lectures

The Monday evening lectures, initiated in 1932, have continued to afford the staff and visitors to the laboratories the opportunity to present their most recent work for discussion. Similar chances have also been afforded at weekly departmental "lunches".

Seminars

Throughout the academic year, a biweekly interinstitutional seminar series has served to maintain close ties between the members of the New England community in geophysical fluid dynamics. Regular participants come primarily from the Massachusetts Institute of Technology, Harvard University, the University of Rhode Island, Brown University and the Woods Hole Oceanographic Institution. Then, during the summer, a formal seminar course, with the support of the National Science Foundation, has brought in a group from a wider range of geographic and scientific environments.

An interdisciplinary subject can thrive for a time by borrowing techniques and transplanting ideas, but it is only by actively engaging those at the forefront of the developments in the related fields in an intellectual dialogue that continuous vitality can be assured. Through the seven years of its existence, under the principal leadership of Professor Willem V. R. Malkus of the University of California, Los Angeles, the summer seminar in Geophysical Fluid Dynamics has established itself as a very effective forum for such an interaction. Each summer, it has brought together specialists with a wide variety of backgrounds and research interests, but with a common language and frame of reference in the mathematical analysis of processes in fluids. For a period of ten weeks they have engaged in an intensive exchange of ideas, viewpoints and techniques.

Turbulent flow in rotating systems has through the years provided an underlying central theme for the seminar activities. In 1965, Dr. Francis P. Bretherton of the University of Cambridge, England, as the principal invited lecturer, gave a series of fourteen lectures on "Rotating and stratified fluids". There followed two symposia, one on turbulence and one on current theoretical problems in oceanography. Each symposium occupied two weeks.

Eight staff members and eight selected visitors took part in the discussions and gave some sixty formal lectures. These covered topics ranging from waves and general circulation in the oceans and in laboratory models to solar convection and galactic spiral arms. Eight participants were predoctoral students who came from as many different universities. They were assigned research problems to be pursued with the advice and support of one of the staff. It was hoped that the topic selected might open up bigger problems, possibly providing the inspiration for a doctoral thesis.

Grants and Fellowships

The following persons were awarded grants, fellowships or honoraria during 1965:

JOHN ALLEN
University of Newcastle-upon-Tyne, Northumberland, England

NEIL R. ANDERSEN
Massachusetts Institute of Technology

JAMES A. ANDERSON
Massachusetts Institute of Technology

TANYA ATWATER
University of California, Berkeley

DAVID BENNY
Massachusetts Institute of Technology

GERALD C. BOND
University of Alaska

JOHN R. BOOKER
Institute of Geophysics and Planetary Physics, University of California, San Diego

WILLIAM A. BOWMAN
Florida State University

FRANCIS P. BRETHERTON
University of Cambridge, England

ROBERT J. BYRNE
University of Chicago

PETER CAMPBELL
Carleton College

LO-CHAI CHEN
University of Alaska

REV. DAVID CLARK
Weston Observatory, Boston College

DONALD P. COX
University of California, San Diego

JAMES E. CRADDOCK
University of Louisville

STEVEN CROW
California Institute of Technology

RUSS E. DAVIS
Stanford University

JOHN DAY
Marine Laboratory, Duke University

IAN DONALDSON
Johns Hopkins University

ROBERT DUCE
Massachusetts Institute of Technology

JOSEPH M. EGAR
University of Akron

JOHN D. GAGE
The University, Southampton, England

JORIS GIESKES
University of Manitoba, Canada

BARBARA GOSS
Carleton College

DOUGLAS O. GOUGH
St. John's College, Cambridge, England

CYNTHIA GRANT
Yale University

RICHARD L. HAEDRICH
Harvard University

LOUIS N. HOWARD
Massachusetts Institute of Technology

STANLEY JACOBS
University of Michigan

R. B. JOHNS
University of California, Berkeley

FRANZ KAHN
Columbia University

JOSEPH B. KELLER
Courant Institute, New York University

JOHN KENNEDY
Massachusetts Institute of Technology

JUSTIN KERWIN
Massachusetts Institute of Technology

ROBERT H. KRAICHNAN
Peterborough, New Hampshire

BÖRJE KULLENBERG
U.S. Coast & Geodetic Survey and Oceanografiska Institutet, Göteborg, Sweden

Sidney Kurn
University of California, Berkeley

Martin Landahl
Massachusetts Institute of Technology

John Latham
University of Manchester, England

Ching Clifton Ling
University of Washington, Seattle

Robert R. Long
Johns Hopkins University

R. A. MacLeod
McGill University

Willem V. R. Malkus
University of California, Los Angeles

Benoit Mandelbrot
International Business Machines (Research)

D. H. Mathews
University of Cambridge, England

Erik L. Mollo-Christensen
Massachusetts Institute of Technology

Derek Moore
Goddard Institute for Space Studies

Karlis Muehlenbachs
University of Washington, Seattle

Gerhard Neumann
New York University

Hiroshi Niino
Tokyo University of Fisheries

Richard T. Nowak
Massachusetts Institute of Technology

Richard Payne
University of Rhode Island

Joseph Pedlosky
Massachusetts Institute of Technology

Henry Perkins
Massachusetts Institute of Technology

James Perras
University of Georgia

S. George Philander
Harvard University

Owen M. Phillips
Johns Hopkins University

Donald C. Rhoads
University of Chicago

Gordon A. Riley
Yale University

Allan R. Robinson
Harvard University

John L. Robinson
Massachusetts Institute of Technology

Hans U. Roll
Seewetteramt, Hamburg, Germany

Peter L. Sachs
University of Reading, England

Douglas D. Sameoto
Queens University,
Kingston, Ontario, Canada

Elliott Schulman
Harvard University

Judith E. Selwyn
Brooklyn College

Raymond Siever
Harvard University

Edward A. Spiegel
New York University

Stanley Spiegel
Harvard University

Melvin E. Stern
University of Rhode Island

Wesley E. Stimpson
Tufts University

Mattias Tomczak
Universität Kiel, Germany

Hans True
University of Copenhagen, Denmark

George Trustrum
University of Sussex, England

Kathleen Trustrum
University of Sussex, England

Leon Turner
Clarkson College of Technology

George Veronis
Massachusetts Institute of Technology

Peter Weganer
Yale University

Marjorie A. Wexler
William Smith College

Wolfgang Wieser
University of Vienna, Austria

Peter J. Williams
National Research Council, Ottawa, Canada

John Woodcock
McGill University, Montreal, Quebec, Canada

W. Redwood Wright
University of Rhode Island

Treasurer's Report

The accounts for the year 1965 have been audited by Lybrand, Ross Bros. & Montgomery.

The book value of endowment funds at December 31, 1965, was $4,330,673, of which $1,756,581 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 $171,945 in cash was $6,942,746. Endowment fund investments and income received therefrom are summarized on page 72.

Income received on endowment assets was $233,492 for the year ended December 31, 1965, compared with $221,990 the previous year.

Endowment income represented a return on endowment fund investments of 3.4 per cent at year-end market quotation, 5.6 per cent on book amount and 9.1 per cent on the contributed amount of the endowment fund.

Endowment income was allocated for 1965 operating expenses at the rate of 6 per cent of the contributed amount of endowment funds, or $152,525. Of the remaining balance amounting to $80,967 there was transferred to the income and salary stabilization reserve, $79,182 and to Oceanographic Associates as income from investment of life memberships, $1,785.

During 1965 $275,000 was transferred from the working capital and contingency reserve and $150,000 from the Development account to fund for acquisition of capital assets.

The Institution's 1965 contribution to the Woods Hole Oceanographic Institution Employees' Retirement Trust amounted to $204,982.

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, 1965 and the related statements of changes in funds and of operating expenses and income for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances. It was not practicable to confirm receivables from United States Government departments, but we have satisfied ourselves as to such accounts by means of other auditing procedures.

In our opinion, the accompanying statements (pages 69 to 70, inclusive) present fairly the financial position of Woods Hole Oceanographic Institution at December 31, 1965 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

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

Boston, Massachusetts

March 11, 1966

Lybrand, Ross Bros. & Montgomery

BALANCE SHEET

ASSETS

Endowment Fund Assets:	
Investments:	
Marketable securities, market value $6,711,228	$ 4,099,155
Real estate	59,573
	4,158,728
Cash	171,945
	4,330,673
Plant Fund Assets (note):	
Laboratory plant and equipment	3,453,412
Atlantis II, contingent title	4,831,130
Other vessels, equipment and property	1,223,433
	9,507,975
Plant funds advanced to current	1,185,808
	10,693,783
Current Fund Assets:	
Cash	743,213
Reimbursable research contract costs:	
Billed	360,332
Unbilled, including December costs of $444,264	457,396
Costs incurred in anticipation of contract amendments subsequently received	746,054
Supplies, prepaid expenses and deferred charges	143,013
Plant funds advanced to current	(1,185,808)
	1,264,200
	$16,288,656

LIABILITIES

Endowment Funds:	
Unrestricted as to income	$ 2,519,420
Unrestricted as to principal and income	54,672
Accumulated net gain on sales of investments	1,756,581
	4,330,673
Plant Funds:	
Invested in plant	9,507,975
Unexpended	1,185,808
	10,693,783
Current Liabilities and Reserves:	
Accounts payable and accrued expenses	266,727
Contribution payable to employees' retirement plan and trust	204,982
Unexpended balances of gifts and grants for research	117,053
Reserves	675,438
	1,264,200
	$16,288,656

NOTE — Depreciation is provided on plant assets, other than vessels ($5,098,000) and the Laboratory of Marine Science ($2,082,000), at annual rates of 2% on buildings and 5% to 33⅓% on equipment. The amount provided is credited to general plant and equipment reserve.

Statement of Operating Expenses and Income

Year Ended December 31, 1965

	1965
Operating Costs and Provisions:	
Direct costs of research activity:	
Salaries and wages	$2,305,387
Vessel operations	1,864,012
Materials, equipment and services	2,514,962
Laboratory costs	316,914
Travel	262,139
Service departments	271,571
Computer center	190,773
Aircraft operations	62,965
	7,788,723
Indirect costs:	
General and administration	813,670
Miscellaneous	86,115
Other charges:	
Provision for working capital and contingencies	243,961
	$8,932,469
Income:	
Income for sponsored research (including $2,740,201 gifts and grants expended):	
For direct costs	7,703,247
For indirect costs	792,837
Fees for use of facilities	280,370
	8,776,454
Endowment income availed of:	
For institution research	85,476
For institution indirect costs	67,049
Miscellaneous	3,490
	$8,932,469

Statement of Changes in Funds

Year Ended December 31, 1965

		Plant Funds				Reserves	
			Unexpended				
	Endowment Funds	Invested in Plant	Acquisition of Capital Assets	General Plant and Equipment Reserve	Unexpended Balances of Gifts and Grants for Research	Income and Salary Stabilization	Working Capital and Contingency
Balance beginning of year	**$4,155,304**	**$9,287,081**	**$547,101**	**$161,628**	**$ 269,878**	**$527,381**	**$ 99,914**
Gifts and grants received	1,000		92,587		2,790,482		
Endowment income						233,492	
Net gain on sales of investments	174,369						
Additions from current year operations:							
Provision for depreciation				168,806			
Provision for working capital and contingencies							243,961
Availed of for direct and indirect research costs					(2,740,201)	(152,525)	
Transferred to plant funds from:							
Unexpended balance of gifts from Oceanographic Associates			150,000		(150,000)		
Working capital and contingency reserve			275,000				(275,000)
Transferred to unexpended balance of gifts from Oceanographic Associates					1,785	(1,785)	
Invested in plant		219,711	(138,013)	(81,698)			
Other additions (reductions)		1,183		10,397	(54,891)		
	$4,330,673	**$9,507,975**	**$926,675**	**$259,133**	**$ 117,053**	**$606,563**	**$ 68,875**

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

Direct Costs of Research Activity

Year Ended December 31, 1965

	Salaries and Wages	Vessel Operations	Materials, Equipment and Services	Laboratory Costs	Travel	Service Depart-ments	Computer Center	Aircraft Operations	Total
U.S. Government:									
Contracts	$1,583,982	$1,083,562	$1,751,594	$217,573	$146,653	$211,677	$139,793	$62,965	$5,197,799
Grants	693,166	767,665	681,951	95,414	107,075	55,874	48,041		2,449,186
Other sponsored research	5,186	3,593	35,896	424	4,852	3,372	2,939		56,262
Total direct costs of sponsored research	2,282,334	1,854,820	2,469,441	313,411	258,580	270,923	190,773	62,965	7,703,247
Institution research	25,053	7,192	45,521	3,503	3,559	648			85,476
Total direct costs of research	**$2,307,387**	**$1,862,012**	**$2,514,962***	**$316,914**	**$262,139**	**$271,571**	**$190,773**	**$62,965**	**$7,788,723**

*Includes grants and fellowships

U.S. Government grants	$29,215
Other sponsored research	34,671
Institution research	34,905
	$98,791

General and Administration Expenses

Year Ended December 31, 1965

General Expenses:		
Staff benefits:		
Contribution to retirement plan		$ 27,782
Social security taxes		10,201
Employee health benefits		33,465
		71,448
Provision for depreciation (credited to general plant and equipment reserve)		16,166
Service departments		26,601
Administration Expenses:		
Salaries and wages	$404,216	
Insurance, travel, supplies and other	295,239	699,455
		$813,670

Summary of Investments

As at December 31, 1965

	Book Amount	% of Total	Market Quotation	% of Total	Endowment Income
Bonds:					
Government	$1,048,412	25.2	$1,035,819	15.3	$ 45,141
Railroad	403,676	9.7	384,468	5.7	17,799
Public utility	337,401	8.1	316,179	4.7	14,403
Industrial	314,585	7.6	298,045	4.4	13,783
Financial and investment	277,940	6.7	275,219	4.0	9,440
Total bonds	2,382,014	57.3	2,309,730	34.1	100,566
Stocks:					
Preferred	52,270	1.3	56,300	0.8	2,680
Common:					
Public utility	420,507	10.1	1,128,172	16.7	33,788
Industrial	820,375	19.7	2,538,189	37.5	71,081
Miscellaneous	423,989	10.2	678,837	10.0	23,373
Total common stocks	1,664,871	40.0	4,345,198	64.2	128,242
Total stocks	1,717,141	41.3	4,401,498	65.0	130,922
Total marketable securities	4,099,155	98.6	6,711,228	99.1	231,488
Real Estate	59,573	1.4	59,573*	0.9	2,004
Total investments	$4,158,728	100.0	$6,770,801	100.0	$233,492

*At book amount.