Woods Hole Oceanographic Institution

Woods Hole, Massachusetts

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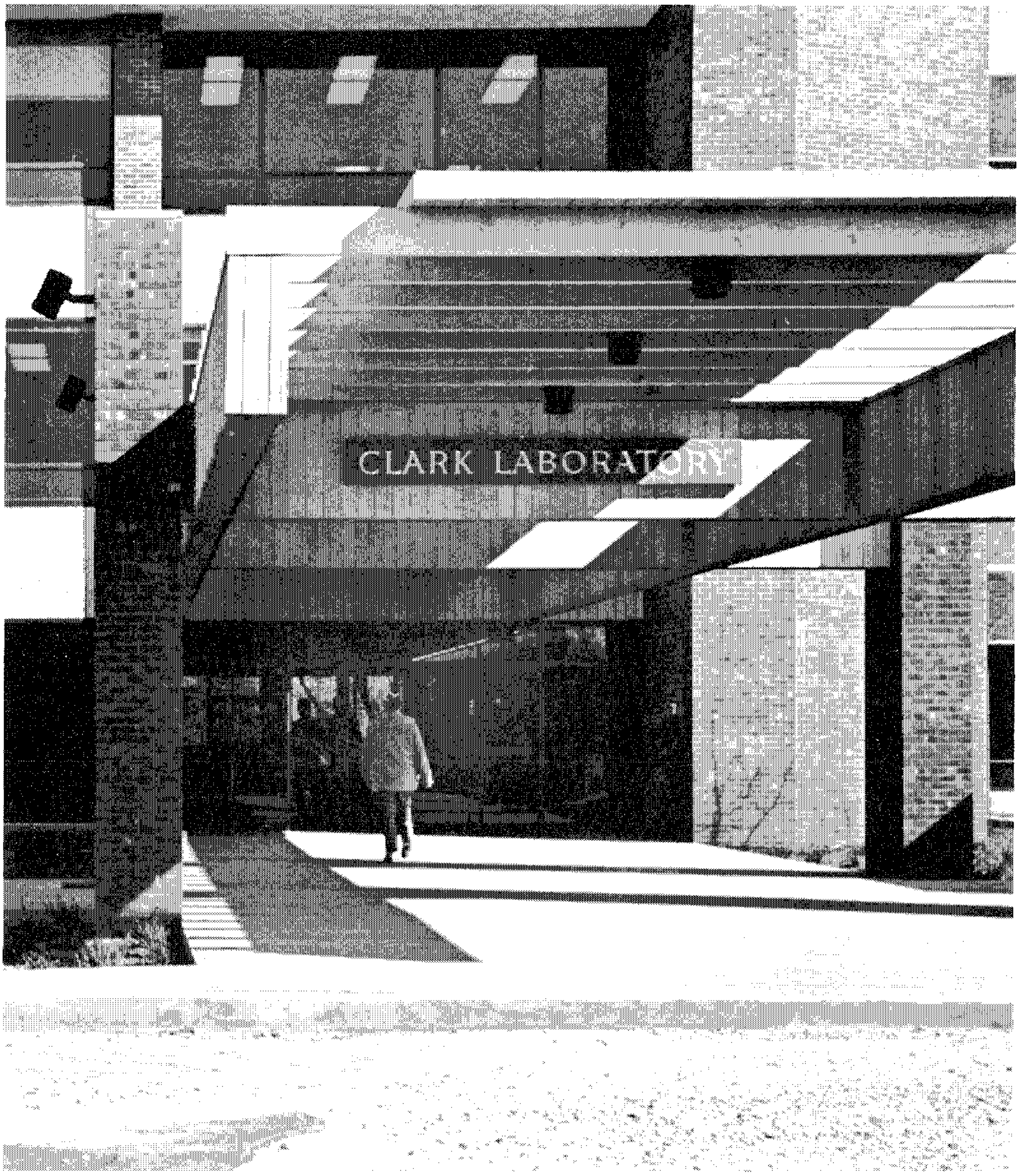


DIRECTOR'S REPORT

In last year's Annual Report, I chose to discuss three main themes which tend to co-ordinate a great variety of investigations. These were: 1) the dynamic processes of the ocean characterized by the movement of the waters, 2) the chemical and biological systems on which marine life depends including the effects of man-made pollutants, and 3) the investigations of the structure of the earth beneath the ocean bottom and the resources contained therein. A full understanding of the ocean requires an interdisciplinary approach and an ultimate consolidation of the results of the various disciplines. Nevertheless, some of our scientists work in relative independence studying particular processes, either in the laboratory or at sea, while others engage in large-scale studies involving the activities of many people. In any case, the health of the Institution is reflected by the scientific accomplishments and publications of all of our scientists and by the caliber of the students we introduce to the intricacies of oceanic processes. These are the output, the "product" of our Institution, of which we are justifiably proud.

This year, I would like to speak about the type of environment which is necessary to encourage and nourish the spirit of scientific curiosity which is the foundation of all good research. Above all, a stimulating intellectual atmosphere is essential for creative expression, and this continues to be abundantly supplied by both our Staff and our students. Also, however, appropriate facilities, outstanding personnel, both on the staff and in support positions, and adequate financial support are all essential to maintain the strength of an Institution like ours, but no one of these alone is sufficient.

The completion of the Clark Laboratory and the move of a substantial proportion of our personnel to the Quissett Campus has added significantly to our facilities and has produced a major change in the development of the Institution. The building was named in honor of Edna McConnell Clark and W. Van Alan Clark and was dedicated on October 11, 1974. It had long been apparent that the central part of the village of Woods Hole was over-crowded, especially in the summer, and that the architecture was dominated by large laboratory buildings, not only of the Institution but also of the Marine Biological Laboratories and the National Marine Fisheries Service Laboratory and Aquarium. A new major building was originally planned for the Challenger property near the center of Woods Hole but it was recognized that future building there would be seriously limited by lack of space.

The Trustees of the Institution have long been aware of the crowded conditions in Woods Hole and of the need for additional land nearby. In 1968, the Trustees acquired title to the Edward Fenno estate and shortly thereafter they added an adjacent parcel owned by the Webster family. The combined tract of 183 acres forms our new Quissett Campus. As I pointed out in my presentation at the dedication ceremonies, "It was in the winter of 1970 that we finally made the difficult decision to separate part of our activities from the village and develop these beautiful acres which our Trustees with great foresight had acquired for the Institution". This new building increases our assignable laboratory and office space in the major Institution buildings by an additional 70 percent and has done much to meet our critical needs for research and teaching facilities.

Planning and building a major facility is a long and complex process. After extensive discussions with the Trustees' Executive Committee, Quissett Campus Committee, and the Staff Council, it was decided that parts of all departments should be housed in the Clark Laboratory to avoid the isolation that might have resulted had different groups been consolidated in the center of Woods Hole or at Quissett. Since the Clark Laboratory is about a mile and a half from the laboratories in Woods Hole, some difficulties in communication have inevitably arisen. Lectures and seminars held in both locations and frequent operation of a shuttle bus during working hours have alleviated, but not solved, these problems.

The Quissett Campus itself is a beautiful area. The Clark Laboratory is surrounded by woods with the waters of Vineyard and Nantucket Sounds a short stroll away. From the Conference Center on the fifth floor, there is not only a magnificent panoramic view of the Sounds but also, looking westward, the waters of Buzzards Bay are in the near distance. The atmosphere is conducive to contemplation and, as summer returns, we expect to find our scientists holding heated discussions under the trees or walking through the woods as they wrestle with perplexing problems.

As part of the ceremonies for the dedication of the Clark Laboratory a group of distinguished scientists from Woods Hole and other laboratories discussed "The Sea Floor" and "Ocean Variability" in seminars held on the 9th and 10th of October. A seminar on the morning of October 11 discussed "Science and Its Institutions: What Does the Next Decade Hold?". These stimulating discussions formed an appropriate background not only for the dedication of a new laboratory building but also for the recognition of the accomplishments of one of our esteemed colleagues. The Sixth Bigelow Medal was awarded to Henry Stommel in recognition of his great contributions to oceanography. Although "Hank" is Professor of Oceanography at M.I.T., we are pleased that he still retains his close connection with Woods Hole and are proud to have him listed as a non-resident member of our Scientific Staff.

The size of our Scientific and Technical Staffs remained the same during 1974 at slightly over 200, equally divided between the two staffs. During 1974, we had an additional 29 individuals working in the Institution as Post-Doctoral or Visiting Investigators. During the year, 14 staff members have been promoted and 11 new appointments were made to the Scientific Staff, two of whom were previously Post-Doctoral Investigators. Three new Department Chairmen were appointed. George Grice succeeded Richard Backus as Chairman of the Department of Biology; Derek Spencer succeeded John Hunt in the Department of Chemistry and Valentine Worthington replaced Ferris Webster who had been serving both as Acting Chairman of the Department of Physical Oceanography and as Associate Director for Research.

In February of 1974, we completed an intensive study of the non-Staff employees. This group includes about 375 employees in the services, office, facilities and departmental assistant categories. The goal of this review was to make it possible to attract, retain and motivate the excellent people needed to keep the Institution functioning smoothly. The procedure involved writing a job description for every position in the Institution and assigning each job to a category or "grade". One objective of the review was to devise a system of fair and equitable salary ranges which would reflect the proficiency, education, experience and contributions of the individual Institution employees.

The financial support for our research program has continued healthy, though the rate of increase in recent years has barely kept pace with inflation. In 1974, the National Science Foundation provided 42 percent of our funding and the Office of Naval Research 33 percent. The remaining 25 percent consisted of funding by other government agencies and our private income.

In common with all other activities in the country, the fuel crisis of 1974 had an impact on our activities. Ashore, a vigorous campaign to curtail use of fuel and electricity resulted during the winter months in a saving of about 25 percent in terms of energy but, because of rising prices, no savings in terms of cost. The most serious impact was the increased fuel costs for our research vessels. Because the increased costs had not been anticipated in budgeting for the ships, it proved necessary to lay up each of our major vessels for a period of about one month toward the end of 1974. Even so, our three major ships sailed almost 100,000 miles and provided more than 800 days at sea during 1974, about 87 percent of the comparable statistics for 1973. In addition to this, the DSRV/ALVIN made 60 dives, 5 of which were for test purposes and the balance for scientific investigations.

In the fall, the continued support for ALVIN and the catamaran support vessel LULU appeared tenuous. We were fortunate in being able to obtain joint support for the next three years from the Office of Naval Research, the National Science Foundation and the National Oceanic and Atmospheric Administration. ALVIN received the new distinction of becoming a National Facility under the University-National Oceanographic Laboratory System. This will assure continued availability of this important national asset which has already proved its value in so many ways.

The negotiations for the Law of the Sea were watched with great interest. The decisions reached, particularly with regard to the width of the territorial sea and the contiguous economic zone or patrimonial sea, will surely have profound effects on the ways we conduct our research program. It seems probable that coastal states will strongly influence, if not control, activities within a zone two hundred miles wide. A review of our ship operations for a five-year period showed that about thirty-eight percent of the time spent at sea by Woods Hole vessels has been within 200 nautical miles of the coasts of other countries.

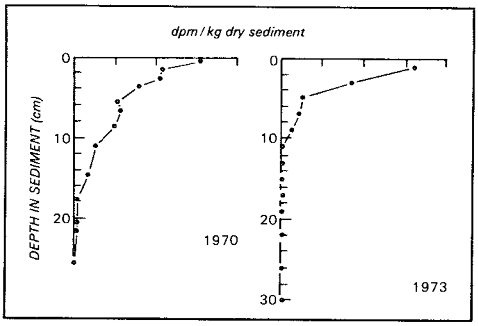
The United States position would not require consent by the coastal state, except in the territorial sea, but would recognize the legitimate concerns of coastal nations by establishing a series of obligations which would be binding on the nation conducting or sponsoring the research. These obligations would include requiring reasonable advance notice of the intent to engage in research off the shores of a coastal state and assurance that the research will be conducted by a qualified institution with a view to purely scientific investigations. Provision for participation by scientists of the coastal state would be required, all data and samples would be shared with the coastal state and significant research results would be suitably published. Furthermore, the coastal state would be assisted in assessing the data and results and the research would be conducted so that there was compliance with all international environmental standards. It is felt that this approach would achieve a better balance between the interests of coastal nations and the international scientific community than would a consent regime.

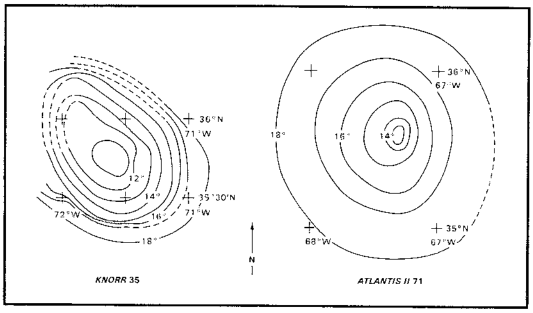
Agreement, however, has not been reached on the extent to which scientific research within the economic zone or patrimonial sea will be controlled by the coastal state. Many nations want to require prior consent for all research within waters under their jurisdiction. This provision would not be unduly burdensome if permission were customarily granted, although it would require additional advance negotiations. If, however, permission is capriciously denied, as has already happened occasionally, the cruise plans might need drastic revision. In our opinion, of course, the country denying permission would suffer the loss of the potential benefits of the research.

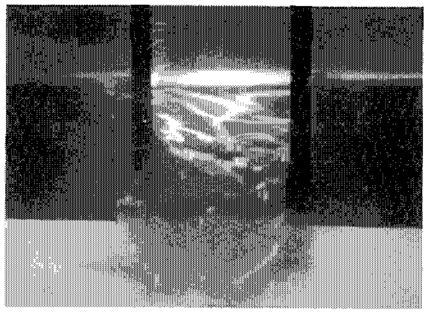
In conclusion, I am pleased to report that the Institution remains in a strong and healthy condition. The more than 200 scientific publications issued during 1974 reflect the continued contributions of our Scientific Staff to all aspects of our fundamental knowledge about the oceans (Appendix III). The strength of the Institution depends directly upon the vigor and enthusiasm of all of our personnel; qualities which we continuously strive to encourage and maintain.

As I have stated before, we must, in the future, decide to be even more responsive to the needs of society. To use the oceans wisely requires a full understanding of oceanic processes and it is encumbent upon us to interpret our scientific studies in ways which will permit wise policy decisions. Our Marine Policy Program is one approach to societal problems concerning the oceans and our increasing studies of marine pollution, its importance and what should be done about it, is another. We intend to broaden our work in applied oceanography and ocean technology and I have confidence that we will, as we have done in the past, accept these newer challenges and thus retain our position of leadership and excellence in ocean activities.

PAUL M. FYE





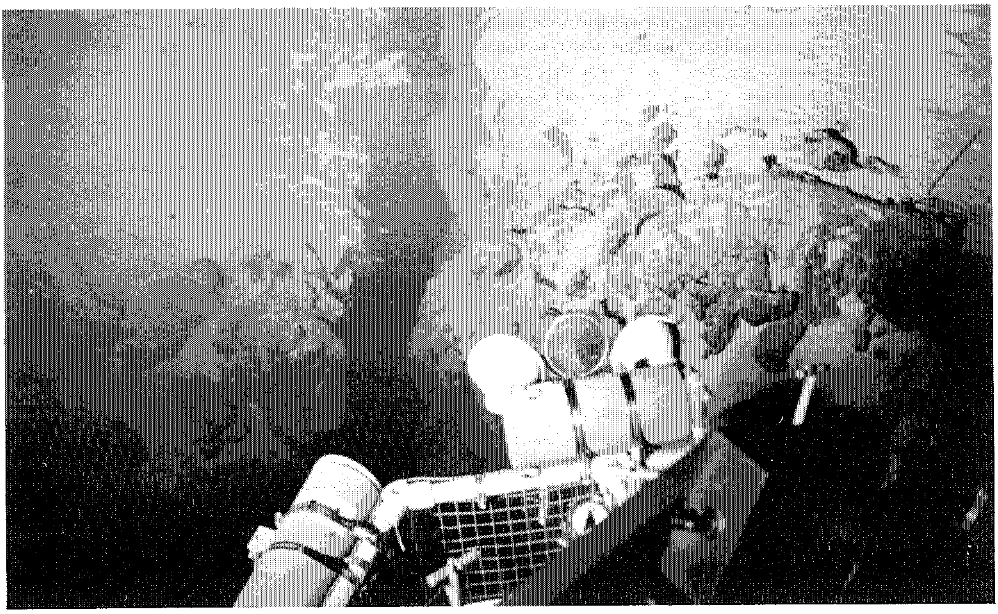


RESEARCH ACTIVITIES

During the first decade of the Institution's history, individual staff members wrote a brief statement about their work, and these were included as an appendix in the Director's Annual Report. Following the report for the year 1941, an effort has been made to present a summary of the investigations carried on at the Institution. In recent years, each of the five Department Chairmen has summarized the work in his Department for the Annual Report. With the expansion of personnel and the increase in the complexity and diversity of the investigations, this has become increasingly difficult and the tendency has been to treat a lot of disparate problems in a rather superficial way.

For the current annual report, it was decided to select a few programs for which 1974 marked a landmark in their development. This permits a more detailed description of the development of the program, of the objectives of the research and of some of the results which have been obtained. As is pointed out in the Director's Report, the two hundred or so scientific publications issued in 1974 are the best clue to the diversity and variety of our research even though publication follows completion by a year or more. If the present approach proves to be useful, it is likely that over the course of a few years, a series of annual reports will give information about all aspects of our scientific investigations.

The text of this section of the report has been prepared by Alvin Bradshaw, Harry Bryden, George Grice, James Heirtzler, Derek Spencer, John Teal, John Whitehead, Peter Wiebe and Albert Williams. In many cases, the text describes not only the investigations conducted by the author, but also results obtained by their collaborators. The drafts submitted have been compiled and edited by Bostwick Ketchum.



ALVIN looking down into narrow fissure caused by tectonic activity near center of rift valley.

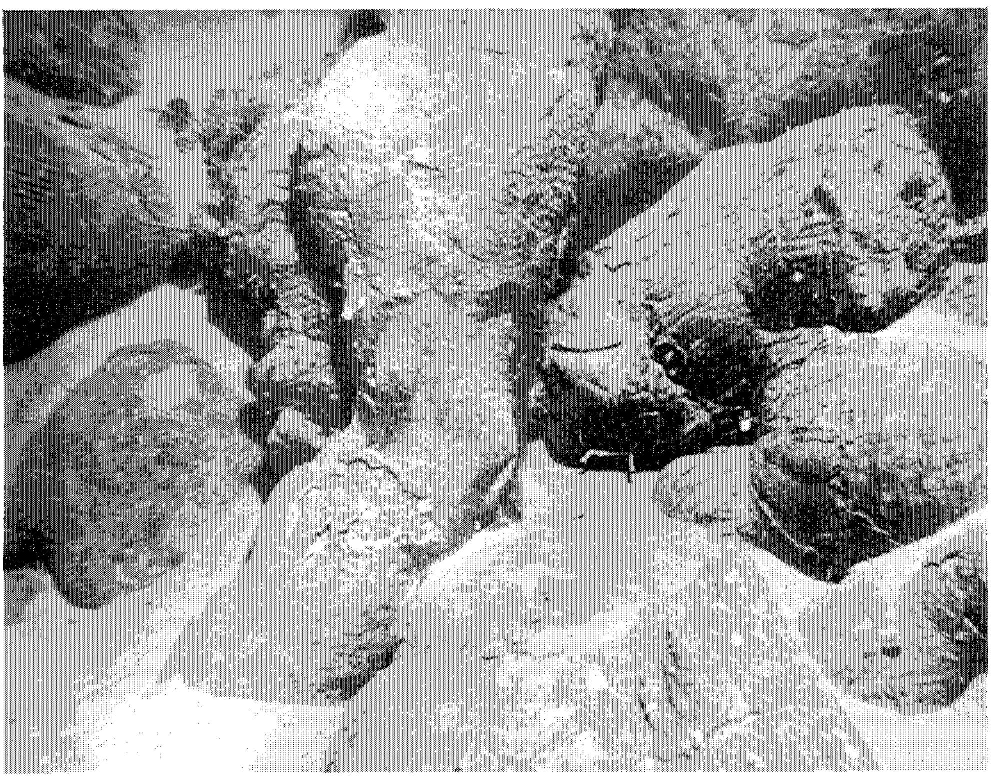
A Close Look at the Mid-Atlantic Ridge

For over ten years earth scientists have recognized that the outer part of the earth is composed of relatively few giant plates that move with respect to one another. These plates are created at the mid-ocean ridges and are consumed in the great marginal trenches. Material from deep within the earth wells up at the exact center of the mid-ocean ridges, as in the Rift Valley in the North Atlantic, affixes itself to the plates, and moves away from the center line with the two drifting plates. It is here, presumably, that minerals and ores get emplaced in the earth's crust. Whether, or how, this happens has never been clear because of the difficulty in working in the great depth of water under which the spreading center lies. The axial area of the Mid-Atlantic Ridge is, as its name implies, a vast linear mountain range. In the North Atlantic it has an axial valley about 30 miles wide. The wall of this valley drops irregularly to an inner valley floor that is 1-2 kilometers wide.

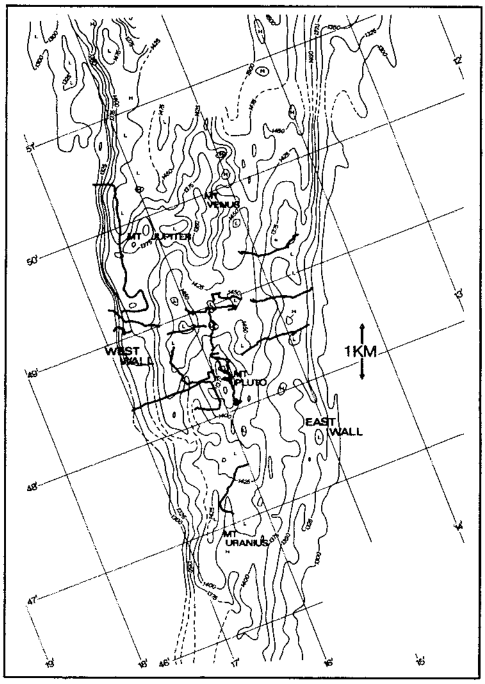
The summer of 1974 was the final and climactic year of a four-year program to study a small section of the Mid-Atlantic Rift Valley. Over 25 cruises of oceanographic vessels provided ever more detailed information of the Rift Valley floor southwest of the Azores. The French American Mid-Ocean Undersea Study (FAMOUS) was, as the name implies, an international and an inter-institutional endeavor with some 15 different ships and 40 senior scientific personnel participating. French, American, and other scientists were able to map, sample, and study features on the order of a few tens of meters in size and to lay the foundation for manned submersible dives which were carried out in a coordinated fashion by Woods Hole's ALVIN and the French ARCHIMÈDE and CYANA, from June to September 1974.

In the initial phases of Project FAMOUS it was necessary to make some broad surveys to be sure that the area to be closely studied was, in fact, typical. In preparation for the diving season a 30-mile long section of the Rift Valley, and the north and south bounding fracture zones, were studied with all the tools that the marine geologist and geophysicist had available, including some very special ones: precision underwater benchmarks and navigation system, narrow beam bathymetry to produce five fathom (10 meter) contour charts, precisely positioned heat probes for water temperature and bottom heat flux, precision micro-earthquake epicenter location, large area bottom photography, comprehensive side scan surveys by massive surface towed transducers, and deep-towed instrument packages to provide an array of near bottom data. In addition there were the more conventional gravity, magnetic, seismic profiling, dredging and coring and current observations. The structure beneath the sea floor was also studied by explosive seismic refraction techniques using both ocean floor and floating seismic recorders. These, and other measurements, provided an intensively known area into which the research submarines could dive in 1974.

Using Ponta Delgada in the Azores as a base, ALVIN with its tender LULU, and the R/V KNORR worked in the designated FAMOUS area for more than two months on a prearranged program with the two French submersibles and their tenders. ALVIN completed 17 dives to depths of about 9,000 feet, with 15 of these being in the Rift Valley and 2 being in the southern fracture zone. She covered 29 kilometers on the seafloor, collected 867 lbs. of precisely located rocks and specimens, and took approximately 17,000 precision



Variety of pillow lavas, showing bulbous type and elongate or Cousteau pillows.



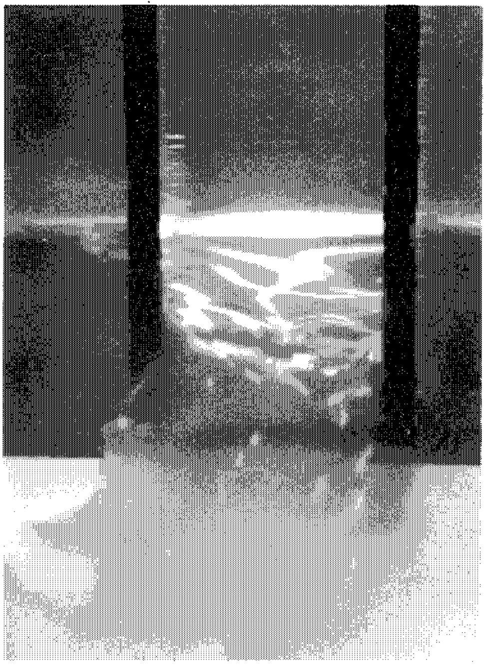
The Mid-Atlantic Rift Valley.

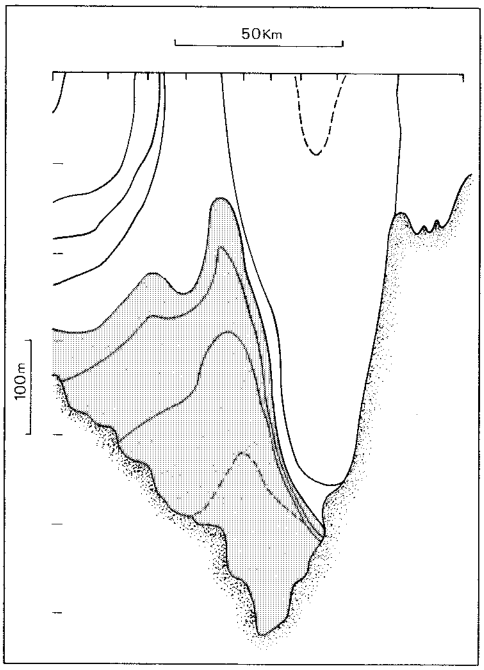
photographic shots. More important were the observations made by five trained diving scientists. The KNORR established the navigation networks, made 45 rock dredges, took about 30,000 bottom photos, and many bottom water temperature measurements while tracking the camera over about 80 kilometers. Sonobuoy and ocean bottom seismic observations were made while the submersibles were making some of their dives. The French teams completed 27 dives covering a total of 53 kilometers on the seafloor where they also obtained numerous samples. At the same time 18 miles west of the Rift Valley the GLOMAR CHALLENGER drilled deep holes into the oceanic basement.

Although more than two dozen papers have already appeared from the individual predive surveys it will take months and years before all the major results will be known. Volumes of collected works and scientific photo atlases are being undertaken.

From the submersible observations a number of facts became clear. It appears that two geologic processes are dominant in the inner Rift Valley floor. These are volcanism (although with some different aspects than land volcanism) and fissuring. The volcanism was mainly evident as pillow lavas squeezed through orifice points in the seabed, creating a feature a meter or so in size. On steeply inclined surfaces these tended to be tubular structures elongated downhill and to have hollow centers. There also appeared to be more massive lava flows but these were difficult to distinguish from constructions of a large number of pillows. Nearly all of the volcanism was confined to the central 100 meters of the Rift Valley floor, and, in particular, to a series of hills along the center line. Fissures paralleled the direction of the Rift Valley and generally became wider the further they were from the center. These fissures were quite straight, cutting individual pillows. They varied in width from a few centimeters to many meters. The underlying volcanic activity, although it only reached the seafloor along the center line, was apparently quite close to the seafloor everywhere in the Rift Valley and working in concert with the spreading plates to form a new crust of the earth.

On her way home from the Azores, ALVIN made 8 more dives with 7 of these being on seamounts along the New England Seamount chain.





(Left) Laboratory water-flow experiment resembling an actual density field of water in a section (right) stretching from Greenland to Iceland.

Fluid Motion on a Rotating Earth

Steady oceanic and atmospheric currents are significantly affected by the rotation of the earth. This effect, called the Coriolis force, acts at right angles to the direction of flow, such that fluid would tend to turn to the right in the northern hemisphere and to the left in the southern hemisphere. It is greatest at the North and South Poles, and vanishes at the equator. Surfaces of constant density generally tilt at right angles to large oceanic currents, and this cross-stream tilt is a manifestation of the Coriolis force. The cross-stream pressure gradient counteracts the Coriolis force. The magnitude and direction of such a current can be measured by determining this cross-stream pressure gradient, and a technique called the method of geostrophic sections has been extensively used for the past 60 years to estimate the mass flux of the major oceanic currents.

Analyzing a current by the method of geostrophic sections can only be done if the pressure field can be accurately determined, and if the effects of time dependence, acceleration of the fluid, and curvature of the current are understood. In meteorology the pressure field is measured directly with a barometer, but in oceanography this cannot be done. Instead it is estimated by measuring the temperature and salinity of the water, finding the resultant density field, and finally by calculating the pressure from hydrodynamic equations. We will describe here two laboratory activities now in progress at the Woods Hole Oceanographic Institution. The first involves some simplified laboratory and theoretical models of flows through constrictions, in order to clarify the hydrodynamic equations. The second involves precision experiments to determine more accurately the equation of state in support of analysis of field data.

Flows through Constrictions

Dynamical problems in oceanography such as the one described above, are similar to those in meteorology, planetary physics, and stellar dynamics. A vigorous sub-discipline of fluid dynamics has grown in the past half century called geophysical fluid dynamics, with the objective to understand such flows. The Woods Hole Oceanographic Institution has a distinguished history in this field, and many significant ideas on Gulf Stream dynamics, oceanic circulation, and mixing processes have arisen at Woods Hole.

Activity in geophysical fluid dynamics is high. We are fortunate that the Geophysical Fluid Dynamics Summer Institute, also located here, provides intensive cross-fertilization between all disciplines involved in geophysical fluid dynamics: astrophysics, planetary physics, meteorology, oceanography, and now with the general acceptance of mantle movement, solid earth geophysics. Various people from more theoretically-oriented institutions visit Woods Hole for new ideas. Woods Hole staff and students of both theoretical and laboratory persuasion are working in this area. The laboratory facilities — totaling three turn-tables, a flume, and precision temperature regulation equipment, are constantly in demand.

The year-round activity centers around dynamics of oceanic flows and comparison with data collected at sea. Oceanographers have fruitfully conducted intensive measurements in the vicinity of bathymetric constrictions such as straits at the surface, or sills in subsurface ridges, and there have been at least 20 Woods Hole ship expeditions to such places in the past two decades. Recently the fluid dynamics of flows through narrow and/or shallow constrictions has been studied theoretically and in the laboratory. The behavior of such flows has long been understood in the absence of rotation, but the earth's rotation modifies the flow through many oceanic straits and sills, and so the main thrust of such studies has been to understand the role of rotation.

The inclusion of rotation necessitated a major modification to the classical "non-rotating" theories. At the present time, a number of tractable approaches have been uncovered, and laboratory experiments confirm the theories which have been developed. A photograph of a laboratory experiment in which water flows outward, over a "weir" towards the reader is illustrated on page 19. The surface of the water tilts upwards to the left, creating a pressure gradient contrary to the Coriolis force, just as oceanic currents have long been observed to do. Sufficiently good comparison between experiment and theoretical predictions indicated that the problem was being handled correctly, and that the fluid dynamics of such flow could now be understood. In addition, even such a simple flow resembles some ocean flows as shown by the density field of water in a section stretching from Greenland to Iceland. The shaded area is water generally considered to originate in the Norwegian Sea. This section is located at the crest of a sill, and over this sill the cold dense Norwegian Sea Water spills southward over the sill into the deep North Atlantic Basin, and goes on to form North Atlantic Deep Water. The tilting of the lines of constant density in the deep part of the sill resembles the tilting of the water in the laboratory experiment. Even more interesting is the fact that the theoretical predictions of the tilt and velocity agree reasonably well with observed tilts and current.

A second "constriction-dominated" flow which has been analyzed theoretically and simulated in laboratory experiments occurs at the Strait of Gibraltar where dense salty Mediterranean Water flows outward near the bottom, and less dense, fresher Atlantic Water flows inward at the top. Again, the theory, laboratory experiment, and field observations indicate that the essential fluid dynamics is now understood.

The most recent geometry studied consists of a wide, shallow weir between two deeper basins. This is a modification of a well-known "weir" problem in hydrodynamics, first solved in 1716. This geometry is caused by ridges in the ocean, and by mountain chains in the atmosphere. The recently developed theories indicate that the principal applications for this geometry might be in the atmosphere.

The Equation of State

Oceanographers long have inferred currents from measurements of temperature and salinity as mentioned above. This calculation requires a knowledge of the relationship between density and temperature, salinity and pressure. This relationship, determined from laboratory measurements, is called the equation of state for sea water and is a fundamental part of the description of the ocean as a dynamic and thermodynamic system. Presently, oceanographic calculations use an equation of state based on measurements by Knudsen and Ekman at the turn of the century. Modern instruments allow more precise measurements to be made so a study is underway to formulate a new and more accurate equation of state.

Laboratory Evaluation

There are two parts to this study. The first is to evaluate experimental data by objective statistical tests. From such an evaluation inconsistent data can be eliminated from consideration and gaps in the experimental measurements can be defined. Recommendations then can be made as to what measurements are needed. During the last year an analysis of specific gravity measurements at atmospheric pressure was made. The second part of this study is to make the necessary laboratory measurements with sufficient precision and accuracy that the new equation of state will be a significant improvement on the old equation. As part of the program to complete the data sets, direct measurements have been made of thermal expansion and compressibility of both sea water and distilled water. These measurements are required to verify the accuracy of compressibilities derived indirectly from sound speed measurements.

Because the new equation of state is intended for international usage, the highest standards for both laboratory measurements and analytical formulation must be maintained. The final selection will require careful and critical efforts of oceanographers throughout the world.

In situ *Changes*

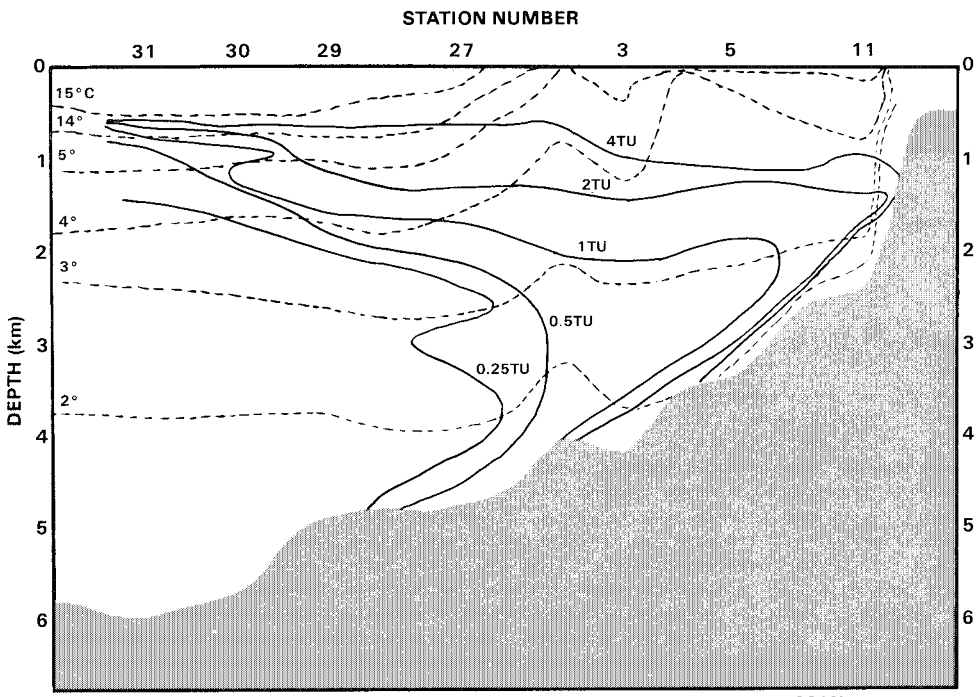
Calculation of the density field in the ocean depends upon the assumption that the relative proportion of the major constituents remains constant. While this assumption is demonstratively correct, except for calcium, some minor constituents vary greatly, particularly between surface and deep ocean water. We have used data collected in the GEOSECS (Geochemical Ocean Sections Study) to evaluate the effect of the increased alkalinity, total CO_2, silica and dissolved gases, found in deep ocean water, on the salinity/conductivity/density relationship. Through an evaluation of existing data on the partial equivalent conductances and partial molal volumes of the various components, the density anomaly of deep ocean waters is significantly affected by changes in alkalinity, in total CO_2 and in silicate, all of which vary with depth.

In the Pacific Ocean density as calculated from conductivity measurements is in error by $-0.012‰$ because of these combined changes. Salinity, derived from conductivity, is in error by $+.008‰$ when considered as a conservative tracer because silicate is not ionized and does not affect the conductivity. In the deep waters of the Pacific these combined effects lead to an adjustment of about 500 m in the depth of a surface of equal density.

As a consequence of these considerations it is necessary to reevaluate the belief that the change in alkalinity of deep ocean waters reflects simply the dissolution of calcium carbonate. Our evaluation of recent GEOSECS data suggests that this is not so. The ocean has an apparent excess of calcium; in the Pacific, this equals 20-60 micromoles Ca/kg. We suggest that this results from a flux of acid radicals which are biologically produced in photosynthesis in the surface layers and oxidative decomposition of organic material in deeper water. Free nitric and phosphoric acids are released in the decomposition process. Thus the observed change in alkalinity in the deep sea water provides an upper limit, but not a direct measure of the amount of $CaCO_3$ that has been dissolved. The corrections applied from consideration of the nitric and phosphoric acid fluxes are only a partial solution since other reactions involving sulphur and iodine will also contribute. A thorough re-evaluation of the oceanic carbon dioxide-carbonate system is required.

Geochemical Tracers of Ocean Circulation

Our present understanding of the mean circulation of waters in the deep ocean is based largely on the distributions of temperature, salinity and dissolved oxygen gas. A large number of other properties of sea-water whose distributions within the sea provide evidence regarding physical, chemical and biological processes have yet to be systematically explained. The reason is that we have not had the combination of accuracy of measurement and extent of geo-



Approximately longitudinal section of potential temperature and tritium from Denmark Strait through Sargasso Sea.

graphic coverage that has been achieved for salt, heat and dissolved oxygen. Included in the list of these properties are a number of radioisotopes whose distributions carry quantitative time imprints. The purpose of the Geochemical Ocean Section Study (GEOSECS) is to make a global survey with the highest possible precision of the distribution of all the chemical and isotopic properties of seawater which offer insight into the operation of the ocean system, and to derive from these distributions as much information as possible about physical mixing, respiration, particle formation and dissolution, and atmospheric exchange.

The first objective has been largely accomplished for the Atlantic and Pacific oceans. The shipboard programs were completed in 1974 and an atlas of sections and profiles of ten hydrographic and chemical properties is in preparation. Measurements of stable and radioactive isotopes some trace elements and particulates are continuing at various laboratories. Although many of these data are in a preliminary form we can illustrate their potential for the GEOSECS purposes. The fallout isotopes tritium, strontium-90, cesium-137 and transuranics have been introduced into the ocean largely as a result of nuclear tests carried out during the late 1950's and early 1960's. Their distribution in the ocean in 1972, when the GEOSECS sampling was started in the North Atlantic represents somewhat more than a decade of vertical and horizontal mixing, and they provide a powerful means of predicting the dispersal of other soluble and particulate pollutants added to the sea by man. The distribution of tritium in a section from 65°N to 27°N in the western North Atlantic based on data from Östlund shows the penetration of "new" tritium bearing bottom waters. Documentation now exists to show that ratios of either Sr^{90} or Cs^{137} to tritium change with latitude in the surface ocean water. This is due to differences in the delivery mechanisms of these nuclides to the ocean surface. $Strontium^{90}$ and Cs^{137} are delivered in precipitation or as "dry fallout" while tritium is delivered in formed precipitation and by molecular exchange. These mechanisms vary with latitude. In addition to its use as a tracer of the formation of deep water in the North Atlantic Ocean, the tritium distribution may be combined with measurements of the rare gas isotope helium-3 to give a unique dating tool for recent ocean water. Tritium decays to helium-3 with a half-life of 12.26 years. Measurement of the excess helium-3 attributed to *in situ* decay of tritium, combined with determination of the amount of tritium, yields an age since last in contact with the atmosphere. Preliminary measurements of this pair of isotopes indicates that recently overturned water with an age of 1-2 years exists to depths of about 1000 m at 55° to 60°N in the Labrador Sea, while 'Labrador Sea Water', at 1200-2000 meters, south of 50°N has ages of 5-15 years.

An important aspect of the non-conservative behavior of chemical species in seawater is the formation and dissolution of particulate matter. Considerable knowledge of the rates of formation, dissolution and removal of particles and of the rates of incorporation of various species into particles will be necessary before we can attain a reasonable predictive capability of the distribution of chemical elements in the ocean. Efforts toward these goals include systematic determinations of the distribution of total particulates and particulate elements and measurement of parent-daughter radioactive isotopes in both dissolved and particulate states. Of particular interest is our work on the radium-226, lead-210, polonium-210 series. The results from two profiles in the North Atlantic indicate that Pb^{210} is rapidly removed from the water column following its production by decay of dissolved Ra^{226}. Above approximately 500 meters, there is an excess of Pb^{210} supported by delivery of this nuclide from the atmosphere. Below this depth, the water column is systematically depleted in Pb^{210}, a result that probably arises in large part from the scavenging effect of sedimenting particles. Near bottom features in the profiles, however, suggest an accelerated rate of scavenging associated with the sediment-water interface. There is evidence of even more rapid turnover in the case of Po^{210} which is generally depleted relative to Pb^{210} throughout the water column. However, a profile in the western tropical Atlantic shows two maxima in the Po^{210}/Pb^{210} ratio, both maxima containing measured values greater than unity. One of these maxima is associated with the high salinity water found at a depth of about 100 m in this region and the other is found just above the core of low salinity water of Antarctic origin. These features suggest the presence of strong *in situ* sources for polonium that are yet to be identified.

Vertical Mixing in the Sea

Water characteristics vary from the oceanic scale to the millimeter scale with gradients in the horizontal being gradual and those in the vertical generally abrupt. We now understand the variability of salinity, temperature, and dissolved oxygen on the oceanic scale. But we do not yet have a good understanding of patchiness of any characteristic on the smaller scales. This will be essential to understand the mechanisms of mixing and to interpret the distribution of specific elements and radioisotopes in the ocean.

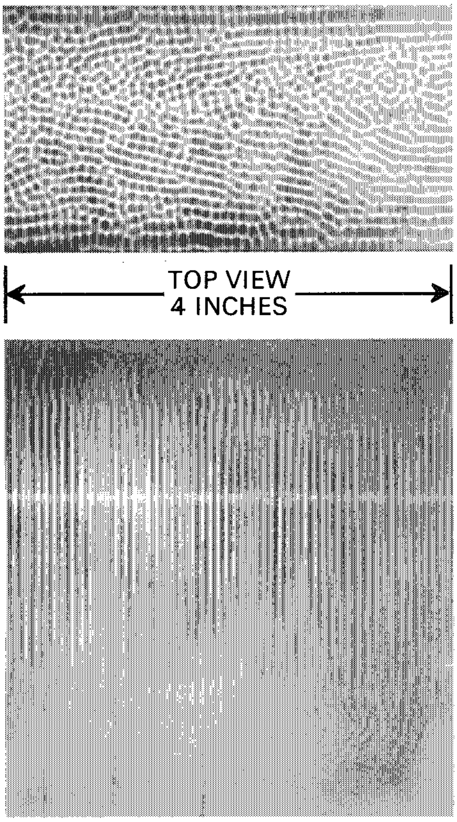
Molecular diffusion becomes important when large gradients exist at scales smaller than 10 centimeters, a scale where the term microstructure is used. The existence of such gradients implies that mixing is occuring. Mixing always passes through two stages. The first is stirring wherein material with different characteristics is brought into close proximity. The gradients become greater as the scale becomes smaller. During this stage there is little change in the distinct characteristics of the material. The second stage is diffusion. In this stage the characteristics change toward a mean value and the volume which was originally stirred tends to become homogeneous.

The physical process of mixing is rarely observed and the details are usually submerged in an eddy diffusion coefficient which relates mixing rates to changes in the mean gradients. Eddy diffusion is orders of magnitude larger than molecular diffusion and depends on the nature of the mixing process.

It is not easy to imagine how stirring occurs in the interior of the ocean. There seem to be two serious contenders, intermittent stirring which results from differences in velocity between adjacent layers and continuous stirring which results from double diffusion such as that produced by salt fingers. Both kinds of stirring are now known to occur.

Salt Fingers

Salt fingers were demonstrated to occur in our laboratory (see illustration page 25) when warm, salty water was carefully floated above cool, less salty water in a tank. A thick interface developed between the layers where warm water exchanged heat with the cool water and sank while the cool water gained heat and rose. A perturbation of the interface grew to a salt fingering region. Salt diffusion is slower than heat diffusion by a factor of 100 so the sinking water became cool and salty and thus dense while the rising water became warm and fresh and thus buoyant to continue to drive the convection. The flow occurred in vertical columns which were square packed in top view and linearly oriented in side view, with adjacent columns moving in opposite directions. This is the steady state nature of the stirring. Diffusion along the length of the inter-



Laboratory simulated salt fingers.

penetrating columns completes the mixing process in the interface.

Subsidiary stirring occurs in the layers on either side of the interface, generated by the buoyancy liberated in the salt finger interface. That is, warm, fresh water produced at the upper edge of the interface drives a large scale convection in the upper layer and cold, salty water produced at the lower edge of the interface drives a similar convection in the lower layer. This can be seen in the lower portion of the side view. The stirring is continuous because the energy which drives it is present in the initial distribution of salt in the water column.

Salt Finger Detector

Salt fingers in the interface refract light in a regular pattern when a collimated beam is directed horizontally along the diagonal rows of the checkerboard arrangement of the columns. Tank tests in 1970 showed that such a regular pattern of refraction only occurred when this diagonal alignment prevailed; but in a large tank, random orientations of locally square packed domains make it highly probable that such a diagonal alignment will be present at least in some region.

The pattern of refraction can be detected in several ways all of which fall under the general category of "schlieren optics". Shadowgraph is one of the simplest and is also quite effective at making the pattern visible. In shadowgraph, the collimated beam of light is refracted by the transparent object (here salt fingers) and then allowed to illuminate a screen. The nonuniformities of illumination on the screen "shadow" the index of refraction variations in the object. Diagonal rows of salt fingers produce vertical bands with regular spacing equal to the diagonal spacing of the checkerboard array of the fingers and the vertical extent of the bands is the height of the columns. This shadowgraph pattern is a signature of salt fingers.

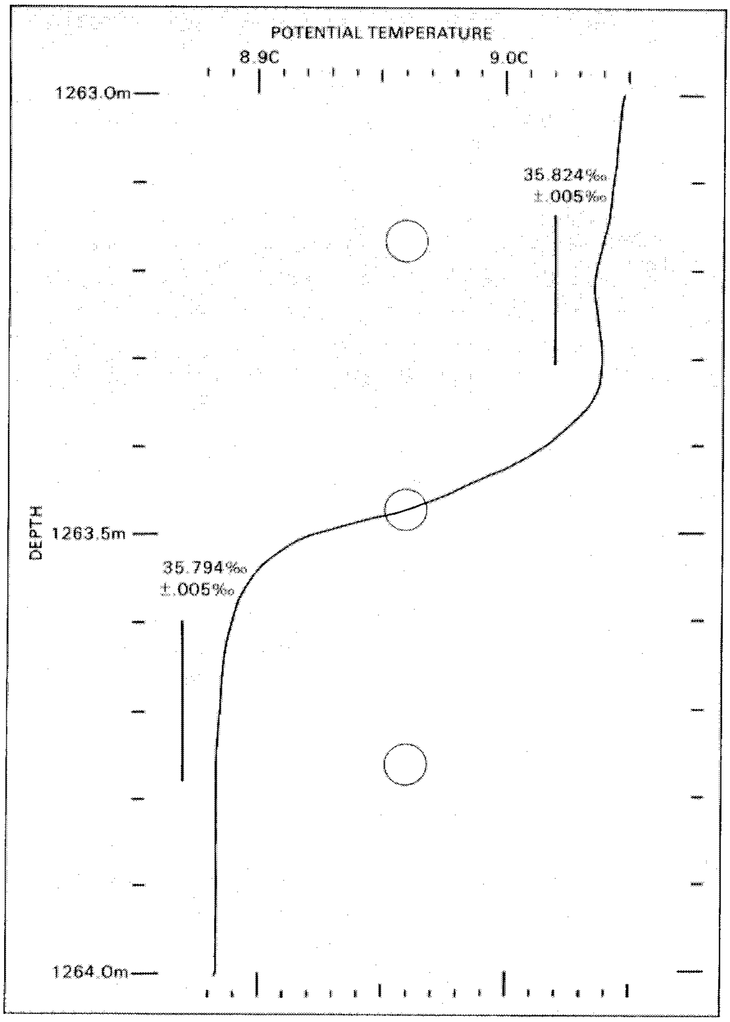
A seagoing instrument to detect salt fingers was built which photographs these patterns and also records temperature and salinity profiles. Since salt fingers are easily disrupted by a probe, the instrument was made to sink slowly, free of any connection with the surface ship, in order to minimize the disturbance. We can see salt fingers with this equipment both in our laboratory and at sea.

Mediterranean Outflow

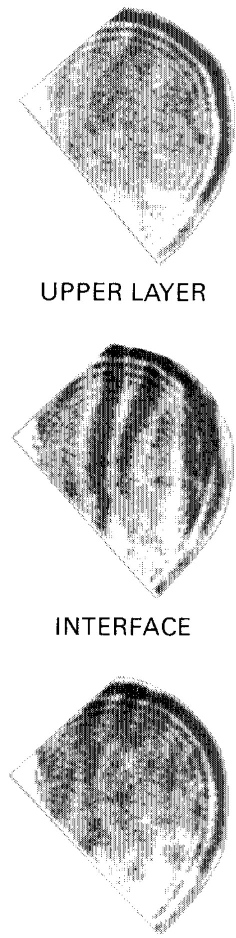
The proper place to look for salt fingers in the ocean is a region where warm, salty water overlies cool, fresh water. The Mediterranean outflow is such a region. In the Mediterranean Sea, evaporation exceeds precipitation so that Atlantic Water entering the Mediterranean becomes more saline. Eventually it leaves by spilling across the sill at Gibraltar, but because of its excess salinity, it sinks to a depth of about 1200 m and spreads west into the Atlantic as a salty layer, warmer than the water below.

This type of temperature interface was observed in the Mediterranean outflow and salt fingers were demonstrated by shadowgraphs. The sequence of images showed an abrupt transition from an amorphous pattern above, to a strongly banded pattern within, and then again to an amorphous pattern below the interface. Presumably the salt fingers and the associated buoyancy flux at the interface produced the mixed layers on either side.

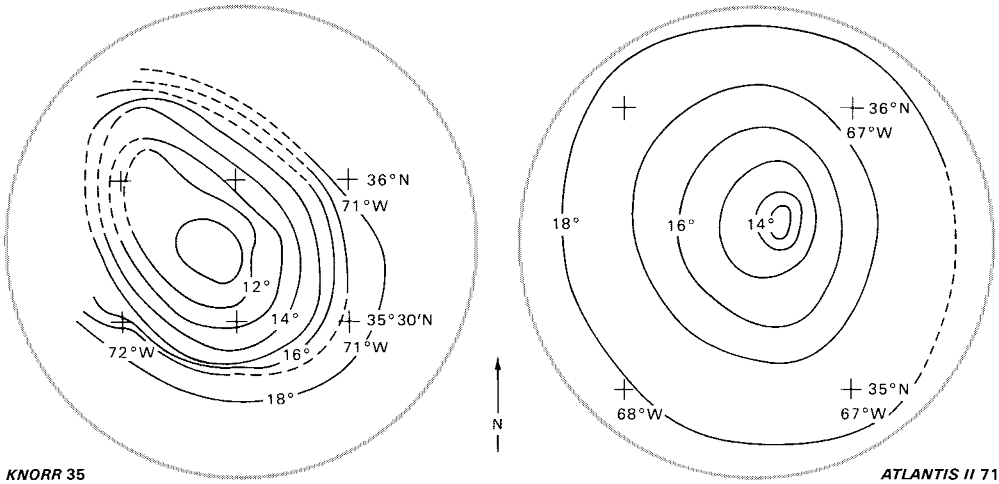
Over several days of observation, a "staircase" was observed to grow, apparently downward from the interface. This consisted of mixed layers about 12 meters thick separated by interfaces or groups of interfaces 10 to 30 centimeters thick. Within each interface, salt fingers were demonstrated as vertically banded images. At its maximum extent, the staircase occupied several hundred meters.



Temperature profile in Mediterranean outflow.



Images above, within and below the interface.



Cold core ring temperature °C at 300M.

Geographical and Seasonal Distribution of Plankton

The large-scale patterns of the distribution and abundance of many oceanic organisms are reasonably well known. The distribution patterns generally follow the patterns of water mass distribution, indicating they are determined to a considerable extent by external physical-chemical parameters. However, in spite of our extensive knowledge about the large-scale abundance patterns, we still cannot specify the factors which ultimately limit the distribution of any oceanic, planktonic organism.

Classically, two strategies have been used to study the causal factors responsible for the development and maintenance of biogeographic patterns of plankton organisms. Transect sampling of transition regions permit the investigator to observe sharp changes in the abundances of species while simultaneously monitoring the physical-chemical environment. Repetitive sampling of a species and its environment within its home range to observe seasonal or yearly change is an alternate approach.

While both approaches have yielded valuable insights into the factors which are strongly correlated with species occurrence and/or abundance, interpretation of causal mechanisms has not been possible. One problem in transition zone studies is that many variables are changing more or less simultaneously in concert with species abundance. Without ancillary field or laboratory studies to study the functional relationship between an environmental parameter and a species, significant correlations cannot be used to imply a causal relationship. In their home range, species are generally not subjected to environmental stresses beyond their tolerance limits. Thus, even if species abundances are correlated with changes in their environment, it is difficult to interpret correlated factors as those which are likely to regulate their presence or absence in other geographic areas.

The Biology of Gulf Stream Rings

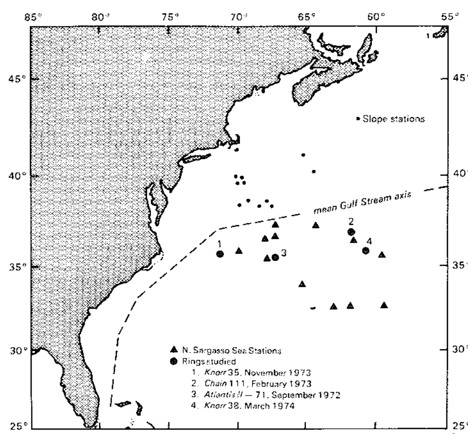
The Gulf Stream, the dominant current in the North Atlantic, has been studied for decades by physical oceanographers of the Institution. For many years it has been known that large, cyclonic eddies are frequently encountered south of the main stream, but the formation of one was first observed in 1950 during "Operation Cabot", the first multiple ship survey of the Stream. A large meander of the Stream extending southward more than 2° of latitude was observed on June 10, and nine days later the long narrow neck of this meander separated from the main body of the Gulf Stream and Edgar, as the eddy was christened, was born. These eddies south of the Stream enclose a core of sea water of slope origin, with the populations of organisms characteristic of the source sea water, which are thus isolated from their natural environment. These Gulf Stream cold core eddies or rings appear to provide a third alternative to study factors responsible for the maintenance of biogeographic boundaries.

Gulf Stream rings thus consist of swiftly moving Gulf Stream water around a core of sea water of different origin. Rings forming to the south or east of the Gulf Stream entrap cold water of slope origin. Rings forming to the north or west of the Gulf Stream contain warm core water of Sargasso Sea origin. The cyclonic or cold core rings are estimated to form about five to eight times a year. They are massive structures, ranging in size from 100-180 km in diameter when newly formed and they have been known to persist as physically identifiable structures for periods in excess of one year.

Organisms of Slope Water or Subarctic Water origin may be isolated within the cold core ring structure. Many Slope Water organisms are distinct from species living in the northern Sargasso Sea although they occupy similar ecological niches. Thus the formation of a ring could be the beginning of a large-scale invasion of one oceanic community by another with the concomitant intercommunity interaction. In essence, the time dependent events associated with the formation and decay of a cyclonic ring could constitute a large-scale natural ecological experiment which offers the possibility of being able to separate major effects of the physical-chemical environment on the structure and function of an oceanic community from biological interactions between species.

As a result of recent oceanographic cruises to two rings three months of age and two rings of 10 to 12 months of age, data on the floral and faunal uniqueness within rings of different ages and the variation in biological composition are becoming available. The first stage in the investigation of rings is necessarily descriptive. Observations of temperature, salinity, and plant nutrients have been taken to define the rings and to assist in the interpretation of the biological data. Measurements of the standing crop or biomass of the phytoplankton, zooplankton, and fish, and the turnover rate or primary productivity of the phytoplankton were made.

Cold core rings are easily detected by their temperature structure (see page 27). Although the ring surface temperatures warm to adjacent Sargasso Sea temperatures within 2 or 3 months after formation, temperatures at 200 m and deeper remain colder than surrounding waters for months or longer.

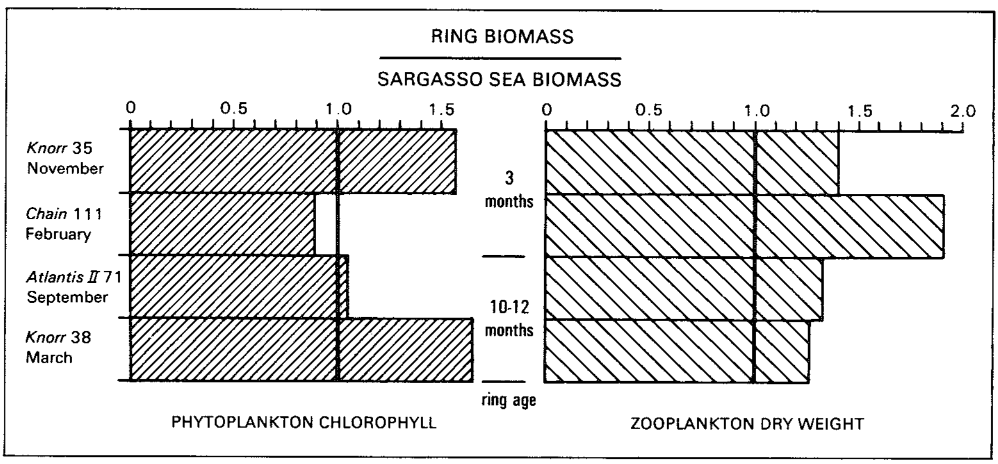


The change in the physical structure of the rings is reflected in the change in the biota. Although we have not yet sampled a ring immediately after formation, our work in a large meander and in two rings of approximately three months in age has suggested that the plant and animal biomass and species composition in newly formed rings is nearly identical to the Slope Water giving rise to the ring core. Indeed, even after three months, the amount of chlorophyll *a*, a measure of phytoplankton biomass, can still exceed the amount found in the adjacent Sargasso Sea waters by 50-60 percent (see graph below). This was the case for a ring formed in late summer and sampled in mid-November of the same year. A number of factors, however, appear to influence the degree of contrast observed and as a result rings of similar age do differ substantially in standing crop of plant material. Thus, for example on the February cruise to a 3½ month old ring, we found virtually no difference in plant biomass between the ring and surrounding area. This, we believe, was in large part a result of strong vertical mixing of the surface waters (upper 200 m) caused by winter storm activity.

In the older rings the plant chlorophyll was essentially the same as in the surrounding waters on one cruise and approximately 65% higher on the other. The differences in plant biomass in these older rings also appear to be a reflection of seasonally influenced processes. In this case, the ring with the high amount of chlorophyll was sampled in the spring at a time when the "spring bloom" was underway. At this time more nutrients were available within the ring and primary productivity was higher. The other ring was sampled in late summer, a time when phytoplankton activity and standing crops generally reach a seasonal low in most temperate areas.

Such disparate results are not evident in the zooplankton. The biomass of zooplankton in young rings was higher than in the Sargasso Sea by 40-90 percent. In the two older rings, the zooplankton biomass was lower than in the younger rings but higher than in the Sargasso Sea. The data now available on the fish biomass from the various rings are more limited, but show a similar pattern to that of the zooplankton, one of decline in biomass towards Sargasso Sea levels with increasing age of the rings.

Our knowledge about the effect of change in ring structure on species composition is less extensive. Many samples remain to be analyzed but an interesting pattern is already unfolding. Phytoplankton species counts in samples from the three-

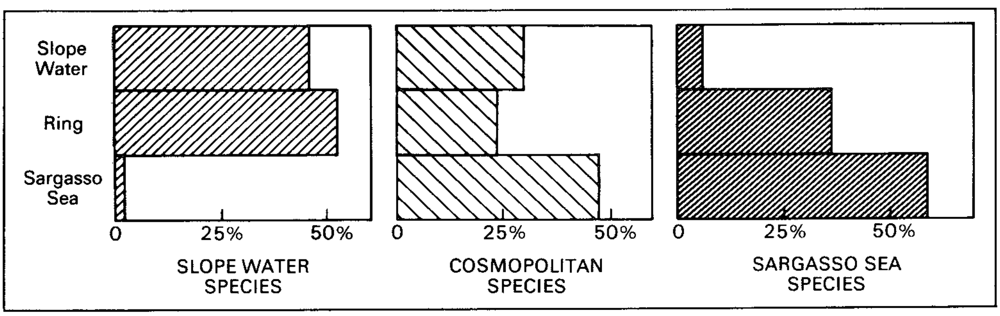


month-old November ring showed not only greater biomass, but also significant differences between the species composition within the ring and the Sargasso Sea. However, the phytoplankton species composition in the ring also differed significantly from that observed in the Slope Water. In fact, the ring species had a closer affinity with the Sargasso Sea species than with those in the Slope Water. In the ten-month-old September ring, the phytoplankton biomass differed little from that of the Sargasso Sea and there were no significant differences in the number of species, their abundance, or in species composition within and outside of this older ring.

Among the zooplankton, 32 species of euphausiids have been identified from the Slope, ring, and Sargasso Sea samples. Five species, *Euphausia krohnii, Meganyctiphanes norvegica, Nematoscelis megalops, Thysanoessa gregaria* and *T. longicaudata,* are characteristic Slope Water forms and were numerically dominant in all Slope Water samples and many ring samples thus far collected. They were almost entirely absent from the Sargasso Sea samples. The opposite pattern is seen in tropical-subtropical forms such as *Euphausia brevis, Nematoscelis microps, N. tenella, Stylocheiron affine,* and *S. suhmii* which are most abundant in the Sargasso Sea and older rings. They occur in the Slope Water only in very low numbers. In contrast, the more cosmopolitan species *Thysanoessa parva, Stylocheiron carinatum, Euphausia tenera* and *E. hemigibba* were found in considerable abundance in each type of water.

These relationships appear to change with the age of the ring. In the younger rings the euphausiids show strong affinity to those of the Slope Water, and generally weak affinity to those in the Sargasso Sea. The older rings, however, show a reverse pattern. The younger rings, with high affinity to the Slope Water contain, on the average, 3.2 times more individuals than the older rings with high affinity to the Sargasso Sea species. This may reflect the gradual change in the environmental conditions within the ring.

Superimposed on the generalizations discussed above are large variations in oceanic populations which add significantly to the complexity of marine ecosystems. A Slope Water indicator species is always found to be the most abundant at some point within the ring, but no one species appears consistently as the dominant one. The species in the Sargasso Sea and in the Slope Water exhibit a similar pattern of shifting dominance. The status of the Sargasso Sea and Slope Water populations at the time of ring formation thus appear as critical determinants of the initial biological structure of rings and their subsequent evolution. This makes it difficult to understand the general features of the decline of the Slope Water community within rings. Also some cold core rings are re-united with the Gulf



Abundance of dominant euphausiids.

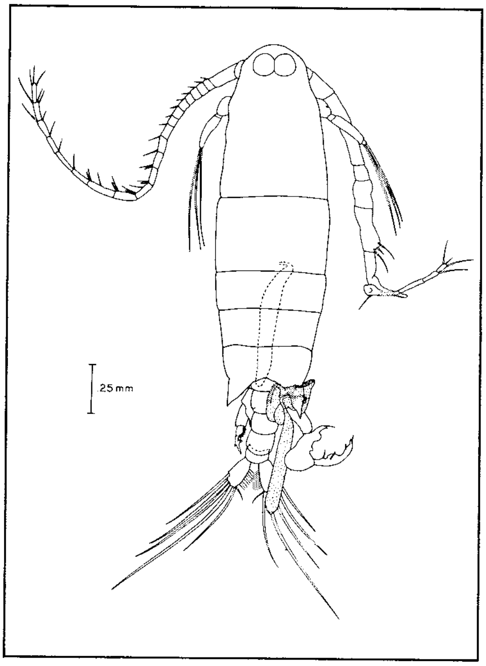
Stream after a variable period of weeks to months, which may be a mechanism by which expatriated individuals could be reunited with similar individuals in their home range. If, as appears to be the case, populations of Slope Water species living in the rings are under increasing environmental stress, this stress may provide a progressive selection of particular genotypes which can survive the rigors of this changing environment. Cold core rings may therefore be a means by which genetically altered populations are introduced into the parent population. Investigations into this part of the problem hold promise for the future.

Our present understanding of the biology of cold core rings leads us to conclude they may have a major impact on the ecology of the plankton in the Western North Atlantic. They are clearly large-scale interaction sites for planktonic communities normally separated in this part of the Atlantic by the Gulf Stream. Paleocirculation studies also suggest that the process of ring formation and decay has been of importance many thousands of years into the past.

Seasonal Occurrence of a Planktonic Copepod.

From numerous plankton investigations conducted since the early 1900's the copepod species, their abundance and period of occurrence are well known between Cape Hatteras and Cape Cod. About 50 species of planktonic copepods occur in these temperate inshore waters. Although the species that are present in winter are generally quite different from those that dominate in summer it is not known what controls their seasonal occurrence.

Four explanations have been offered to account for the seasonal appearance of a species in temperate areas after a period of prolonged absence. 1) It was brought in by currents; 2) it was present all the time but in an immature and thereby unrecognizable stage; 3) it was present but in greatly reduced numbers; and 4) it has a dormant egg stage that hatches upon return of favorable conditions. Few or no data are available to substantiate any of these explanations for marine copepods.



Male Labidocera aestiva.

One species which exhibits a marked seasonal pattern is *Labidocera aestiva,* a large and easily recognizable species. It was originally described from specimens collected near Woods Hole in 1901 and subsequently has been shown to occur as far south in inshore waters as northern Florida. However, north of Cape Hatteras it is present only from late spring to late fall; there being no records of its occurrence in winter and it has no known wintering immature stages. In the Woods Hole region it occurs during the months of June to mid-December. Through a recently concluded field and laboratory study sufficient information has now been obtained to explain the appearance and occurrence of *L. aestiva* in temperate waters.

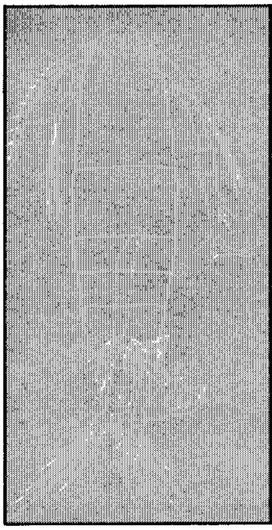
Adults of *L. aestiva* annually appear in Woods Hole plankton in June. When collected with nets and isolated from other plankton animals, females readily lay eggs in the laboratory. These eggs hatch, most of them within forty-eight hours, at culture temperatures of 18°C. The nauplii which hatch from the eggs can be reared to adults by feeding them first the dinoflagellates *Gymnodinium* and *Gonyaulax* and later the young of brine shrimp. The development time in laboratory cultures is approximately 25 days at 15°C and 18 days at 20°C. Females collected from June through August will produce eggs that readily hatch.

In mid-September eggs laid by isolated females frequently fail to hatch despite being maintained for prolonged periods at temperatures equivalent to those at which they were living when collected. The eggs laid by females obtained in October and November rarely hatch even when they are warmed to the temperatures of August (21°C). Scanning electron micrographs show that eggs are morphologically identical to those laid in summer but obviously they must be different biochemically as they do not hatch under similar conditions. They are about 100 microns in diameter and sink on being laid.

In order to ascertain whether the eggs produced by fall females are viable, groups of them were placed in small jars and suspended at a depth of 15 meters from the Institution pier. Others were placed in laboratory incubators and maintained at 2° and 6°C. Egg viability was tested every 30 days for a period of 180 days by warming the eggs to 18°C and recording the number of nauplii that hatched. The high rate of hatching of those eggs suspended beneath the Institution pier (as shown in the table on page 33) clearly demonstrates that prolonged incubation at winter temperatures does not greatly reduce egg viability. Seventy percent or more of the eggs hatched in seven of the ten batches. Similar high viability was observed in those maintained in laboratory incubators. When eggs laid in summer were similarly incubated at 2° and 6°C none of them hatched. Observation of other eggs laid in the fall and suspended beneath the pier and examined frequently in April and May revealed that initial hatching of eggs occurred in May when water temperature was between 11° and 14°C. Since it has been shown by culture experiments that it requires about 25 days for nauplii to become adults at temperatures of 15°C the first appearance of adults in June plankton is thereby accounted for.

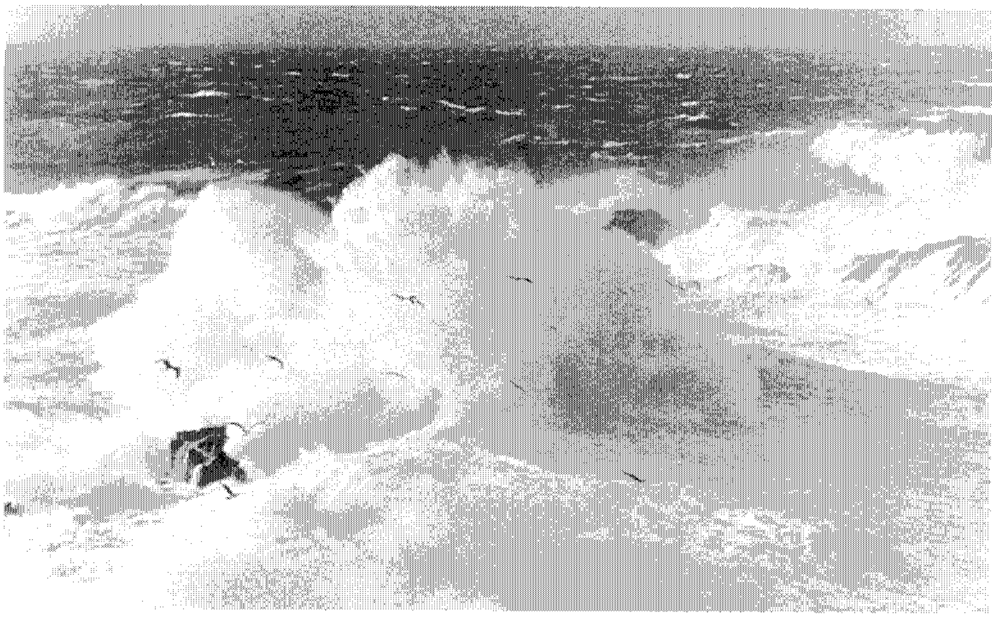
The observation that eggs laid in the fall require a prolonged period of incubation comparable to that which occurs in nature through winter suggests that temperature is involved in initiating events that lead to hatching. Additional experiments were therefore carried out to determine the influence of temperature on hatching. Eggs laid in the laboratory in November (water temperature 12°C) were divided into groups and placed at temperatures lower (2°, 6°, 9°, 11°C) and higher (20°) than that at which they were laid as well as at the laying temperature. At intervals they were warmed to 18°C. In order for hatching to occur it was found that they had to experience a period of reduced temperatures. A minimum period of 10 days at lower temperatures usually resulted in a hatch of 50% of the eggs. Incubation for longer periods, 20-30 days, improved the hatching rate. The reduced temperature could be as little as 1° or as great as 10° lower than that at which they were layed. None of the eggs maintained at or above the laying temperature hatched during these experiments. It is concluded that fall eggs can remain viable long enough to permit them to survive winter conditions but they require a period of reduced temperatures ("thermal shock") to initiate the hatching process. These laboratory observations have been corroborated by the finding of viable eggs in the sediment in March, the month of lowest water temperatures in the Woods Hole area.

Thus, the seasonal occurrence of *L. aestiva* in temperate waters depends on the presence of dormant resting eggs. The observed distribution of this species coupled with these experimental data show it to be remarkably adapted to temperate areas. The young hatch in late spring from dormant eggs that were laid the previous fall and which persisted in the bottom sediment. These eggs serve to repopulate the area after its winter disappearance from the plankton. Several generations occur through the summer as summer eggs readily hatch on being laid. In September, winter or resting eggs appear coincidentally with the onset of declining water temperatures. For these winter eggs to hatch two conditions are necessary: a minimum period of a few days at a reduced temperature followed by an increase in temperature. This combination not only permits the eggs to persist throughout winter but also protects them from premature hatching as it is unlikely that unusual temperature oscillations of this type occur in bottom waters in fall.



Incubation (Days)	Date	Water temp. °C	% Hatched After Warming
30	Dec. 19	5.6	70
60	Jan. 18	2.0	80
90	Feb. 17	2.2	70
120	Mar. 19	3.7	60
150	Apr. 18	8.0	80
165	May 3	10.0	80
170	May 8	10.2	100
175	May 13	11.0	60
180	May 18	12.6	50
185	May 23	13.8	70

Hatching of eggs of Labidocera aestiva *laid in November and incubated in Woods Hole Harbor.*



Man's Interaction with the Ocean Environment

Human activities interact with the ocean in many ways. Pollutants in sewage, industrial wastes, agriculture and other man-modified sources may reach the sea through direct discharge, via the rivers and estuaries or through atmospheric transport. Some of these pollutants have only local effects, while others are global and are detectable in all parts of the world oceans.

For several years we have been investigating the distribution of fallout radioisotopes, originating in bomb tests, in the sea. Also, natural and petroleum hydrocarbons and the chlorinated hydrocarbons distributions have been evaluated. More recently we have been considering the effectiveness of salt marshes as ultimate sinks or recycling mechanisms for the elements in domestic pollution. The present status of some of these investigations is described below.

Radiochemistry

In our continuing studies of radioactivity in the ocean considerable progress has been made in the extent of our understanding of the distribution of transuranic elements. In the past year, we have reported and submitted for publication radiochemical procedures for plutonium, americium and curium in environmental samples. In addition, we have developed a purely radiochemical method for plutonium-241 and another for americium-242m.

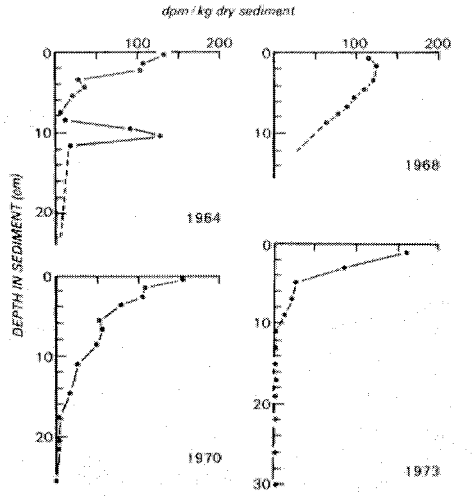
The release and dispersion of transuranic elements, particularly $Pu^{239,240}$ represents one of the greatest hazards to the environment and man. These nuclides are known to be very toxic to living things; many decay only very slowly and so require attention for tens or even hundreds of thousands of years and we have very little basis for prediction of their behavior in the environment. Our work is directed toward furthering our understanding of the behavior of the transuranic nuclides. At this time, we have a respectable body of data on $Pu^{239,240}$ in seawater, marine sediments and organisms and less information on the other nuclides.

No matter how it is introduced to seawater, plutonium appears to associate rapidly with particulate matter. The extent of the association varies depending on the chemical form of the plutonium introduced and on the chemical and physical environment with which it is interacting.

In the open Atlantic Ocean profiles of plutonium concentration versus depth tend to show one or more subsurface maxima, generally at depths quite different from those characterized by high concentrations of such soluble tracers as tritium, strontium-90 or cesium-137. Further, as with other fallout nuclides, the concentrations of plutonium in the North Atlantic Ocean are higher than in the South Atlantic with a maximum occurring in the 40°-50°N latitude band. In two experiments, so far, we have found about 70% of the plutonium in open ocean water samples removable by filtration through 0.45 micron filters.

In both open ocean and shallow water sediment cores, we have found plutonium penetration to surprising depths. Measureable plutonium at a depth of 8 to 14 cm is not unusual. Earlier data on plutonium in sediments seemed to indicate a rather simple relationship, between the depth of the overlying water column and the fraction of the predicted plutonium fallout that had reached the sediment, that could be explained by postulating three or four populations of particles settling at different rates. However, more recent data indicate that surface productivity and the redistribution of bottom sediments are at least two factors that disturb the simple relationship.

In shallow water marine sediments, there appears to have been a progressive redistribution of plutonium, presumably to the overlying water. Cores collected in 1964 showed one or more major buried peaks of Pu concentration, and very jagged profiles, with the details of vertical distribution differing strongly from core to core. However, the total integrated Pu was about equal to the estimated delivery. Since 1964, there appears to have been a steady smoothing of the curves of Pu concentration versus depth, a reduction of maximum penetration and by 1973 a definite loss of Pu from the sediment. We believe that the process responsible must be migration upward, in the interstitial solution, of Pu in a reduced form. In the years of high rates of fallout delivery, this was overbalanced by bioturbation processes achieving a rapid downward translocation of freshly delivered plutonium attached to sediment particles. These data clearly suggest that plutonium continues to be available to benthic biota for considerable periods of time even after it has reached the sediments and been buried to some depths.



Plutonium in near-shore sediment.

Studies of plutonium concentrations in marine organisms do not support the conclusions of earlier laboratory experiments that indicated the ability of both plants and animals to discriminate against plutonium. In *Sargassum,* the mean concentration relative to seawater is about 20,000; in attached marine plants concentration factors of 100 to 1000 are common; both plankton and benthic animals have concentration factors of about 1000; filter feeding animals show concentration factors of about 300 to 400 and predators on them about 1000 to 1500. Concentration factors in fish are lower, averaging about 5 for muscle tissue and about 50-75 for bone, liver and intestine.

Although direct releases of americium-241 to the environment have been recorded, its principal source is from the beta decay of Pu^{241} which is a significant constituent of weapons grade plutonium and a major constituent of the plutonium from nuclear power generation.

At the present time, we have little data on Am^{241} but what is available indicates a strong tendency for Am^{241} and $Pu^{239,240}$ to covary both in seawater and sediments. However, their ratio proves by no means constant and it is clear that some separation of plutonium and americium is taking place in the marine environment but by processes that we do not yet understand. It is important that this problem be investigated because Am^{241} promises to be a major part of the radiobiological hazard of the wastes from such "advanced" nuclear power technologies as the liquid metal-fueled breeder reactors.

Hydrocarbons

Various organic chemicals have been widely distributed by man's activities. In the broad field of marine organic geochemistry, work has continued in several areas—the origin and fate of hydrocarbons, the recognition of petroleum contamination, the dispersal of petroleum products in the marine environment and the distribution and factors controlling polychlorinated biphenyls (PCB's) in the ocean.

Work on the origin and fate of hydrocarbons has recently concentrated on the occurrence and nature of polycyclic aromatic hydrocarbons (PAH) in soils and recent marine sediments.

The analyses of these samples demonstrate an unanticipated complexity of the PAH fraction. The principal series, from which only unsubstituted hydrocarbons and some alkyl derivations have been known to occur in environmental samples, stretch over a wide molecular weight range. The minor series, previously unknown from recent sediments, cover an equally wide carbon number range. They are interpreted as napthenologs and thienologs of the basic PAH series.

The striking complexity of the PAH fractions resembles in some respects that of fossil fuels, however, marked differences from crude oil and ancient-sediments occur. The fact that similar series of alkyl homologs having similar molecular weight ranges occur in a wide variety of samples from distinct depositional environments suggests a more uniform source. The composition of the PAH fraction and its distribution is not incompatible with the hypothesis of formation in natural fires, dispersal by atmospheric transport and delivery to the soils and sediments.

We have completed analyses of sediment samples taken in the western North Atlantic in the area around Bermuda and approaching the continental shelf of the United States. In this study, we have concentrated on the types of biogenic hydrocarbons present and have attempted to trace their origins by comparing their composition to the known composition of hydrocarbons in organisms. Abyssal plain sediments have a n-alkane distribution similar to that reported for land plants and animals. This is true even for sediments 400 to 600 miles southeast of Bermuda. There is no clear predominance of hydrocarbons from marine phytoplankton, zooplankton or fish found in the abyssal plain sediments. If it is assumed that the traces of specific hydrocarbons in the sediments, such as n-hexadecane, originate solely with marine organisms in the overlying water column, then only 0.5 to 3% of the organic matter produced in the euphotic zone ever reaches the abyssal sediments. Detectable petroleum contaminants in abyssal sediments are not present. However, both PCB and DDT have been found in most North Atlantic sediments including those of the abyssal plains. Preliminary data would suggest a flux of about 2 x $10^{-6}g/m^2/yr$ of PCB's to the sediment surface.

Research has continued into methods of identification of low level petroleum contamination in marine organisms and sediments. A comparison of extraction methods, specifically, soxhlet extraction, homogenization and alkaline digestion in methanol, indicates that the soxhlet extraction technique is significantly more efficient for hydrocarbons but only slightly so.

Samples of clam homogenate *(Mercenaria mercenaria)* spiked with 10ppm AP1 No. 2 fuel oil have been analyzed. Gas chromatographic analysis indicated that the lower molecular weight hydrocarbons of the spike were lost during the analysis. Further, the passive tagging parameters of the No. 2 fuel oil were altered by interference from hydrocarbons already present in the clams prior to spiking.

A program of hydrocarbon analysis of sediment cores from the continental margin and estuarine areas of the northeastern U. S. indicates that there is a record of increasing petroleum contamination in the marine environment preserved in these cores. These data, together with Pb^{210} dating will be useful for quantifying the extent of petroleum contamination.

Salt Marshes and Pollution

Salt marshes lend themselves ideally to environmental research for a number of reasons, the most basic of which is their simplicity. This simplicity results from the effects of tidally caused alternation of land and sea environments. As examples, extremes of temperature and salinity occur irregularly; in winter ice damages plant parts above ground; marsh plants with land ancestry have to grow watered by sea water. It is these extremes which reduce the salt marsh ecosystem to the relative simplicity of few dominant species of plants

Great Sippewissett Marsh — taller grasses show fertilized area.

and animals. It is possible to concentrate on fewer species when manipulating the marsh experimentally and a better understanding of the interactions between the total salt marsh ecosystem and the individual species of which it is comprised can be achieved.

It has been postulated that salt marshes contribute large amounts of organic matter in the form of dead and partially decayed plant material (detritus) to the surrounding waters. This organic matter serves as a source of food for estuarine animals and contributes to the high productivity of waters surrounding the marshes. Also, the marshes remove elements from the water and can serve as a purifying mechanism for sewage wastes. We are studying the removal of nutrients, heavy metals and other pollutants by salt marshes, but we are not yet ready to recommend that they be used for tertiary or even secondary sewage treatment, due largely to the possible spread of pathogenic bacteria and viruses that might result.

We began experiments on Great Sippewissett Salt Marsh in 1970 in cooperation with the Boston University Marine Program at the Marine Biological Laboratory. The goals of the research are to understand the function of the marsh and to predict how disturbances of the environment can affect both the marsh and surrounding waters. For example, what limits plant growth on the marsh and marsh productivity; what are the effects of sewage pollution on salt marshes; and what are the mechanisms for the export of organic material from marshes to the surrounding water?

Our basic experimental manipulation consisted of fertilizing marsh plots with a commercial fertilizer made from sewage sludge. Supplemental plots were fertilized with urea and phosphate to isolate the effects of these major nutrients and to serve as controls for the potentially injurious materials, such as heavy metals, pesticides, and hydrocarbons contained in the sewage sludge.

Fertilization with mixtures containing bound nitrogen increased the growth of marsh grass about twofold over the controls, but other elements in the fertilizers had no measurable effect. At a low level of fertilization several years were needed for the grass to reach its maximum growth but at the higher levels the increase occurred within one year. No differences in production appeared between plots fertilized with sewage sludge fertilizer and those to which urea had been added.

The nitrogen budget of salt marshes helps to evaluate the impact of pollution and the upper limits of tolerance. The high levels of fertilization have produced no visible harmful effects on the grass or algae which support the salt marsh food web. The salt marsh is able to retain most of the added nitrogen and other elements in the fertilizers whether or not they are potentially harmful. In a practical sense this means that marshes are useful in removing pollutants from coastal waters and in limiting the extent to which human activities cause eutrophication at the edge of the sea.

In a pristine salt marsh, nitrogen is supplied to the marsh plants principally by nitrogen fixation by blue-green algae living on the marsh surface from the abundant supply of free nitrogen in the air. The algae fix nitrogen only in light, but bacteria associated with the roots and rhizomes of the marsh grasses fix nitrogen throughout the day and night. Fixation is highest in the summer when marsh soils are warm. The fixed nitrogen supports the growth of grasses at a level below their maximum potential growth over most of the marsh. Nitrate and other forms of combined nitrogen are also added to the marsh in rain and in ground water, including that leaching

Tall Spartina alterniflora *by tidal creek.*

from nearby cesspools. However, these additions amount to less than one percent of the added nitrogen that marshes can retain. The extra nitrogen stops nitrogen fixation by algae and bacteria and supports increased plant production, containing more protein. These processes increase the ability of the marshes to absorb nitrogen. The increase in production and the increased protein content of that production and the detritus which results from it are the most important consequences of fertilization of the salt marsh.

Some of the bound nitrogen is lost from the marsh by export to the estuaries either in soluble form or in particles. Some fixed nitrogen dissolves in the water as it leaks from the fixing organisms or is released when they decay or are eaten. This extra, tidally transported nitrogen becomes available twice a day to the grasses growing along the creeks and provides them with enough fertilization so that they are able to attain maximum growth. This tidal supply of nitrogen is the principal pathway by which the tides subsidize salt marsh production. A larger loss occurs through denitrification, a process by which denitrifying bacteria in anoxic mud convert nitrate to nitrogen gas which then escapes to the atmosphere. Fertilization increases denitrification. This return of nitrogen to the air is probably the most important process by which the salt marshes contribute to the global nitrogen balance.

The distribution of plants on the marsh is to a large extent controlled by the nitrogen supply. *Salicornia* and *Distichlis* are opportunists and respond quickly to changing conditions. *Spartina alterniflora* and *S. patens* are slower to respond but under good conditions out produce and crowd out the former species.

We have also changed the growth form of *Spartina alterniflora* by our experiments. A dwarf form, about 10 cm tall, grows on parts of the marsh with poor drainage back from the creeks. A tall form with larger stems and leaves held more vertically than that of the dwarf form, grows along the tidal creeks where marsh production is greatest. The two were thought to be different varieties of grass, so dissimilar were they. During the four years of the experiments the dwarf form in the highly fertilized plots has gradually changed into the tall form. The process is not yet fully complete, however. This aspect of the distribution of plants upon the salt marsh is also a function of the nitrogen cycle on the marsh.

The increased marsh production supports increased production of marsh animals. Herbivorous insects, which are not normally a very conspicuous or important part of the marsh ecosystem, are increased sevenfold by the enrichment experiments. The amphipods and mussels on the surface of the marsh, the small arthropods of many sorts that live within the upper layers of marsh surface, and the animals that live within the creeks associated with the experimental marsh plots also increased. The oxygen uptake of the organisms living in a creek draining a fertilized marsh plot increased because of the increased productivity of the experimental marsh, and the increase in production of estuarine animals.

Another experiment modified predation by excluding the marsh minnow, *Fundulus,* from the experimental plots. This minnow lives in the tidal creeks at low tide but moves up with the flood and swims into the marsh at high tide to feed. It is excluded by putting a simple fence across the creek. Trapping behind the fence at low tide enables us to remove the few minnows which do get around the fence. As a result of reduced predation, the amphipods and snails both increased in numbers beyond the increase previously seen as a result of the changes in productivity. Their distribution on the marsh also changed, showing that their relative abundance from place to place on the surface was a result of predation rather than some other sort of zonation. For example, snails are readily eaten by *Fundulus* until they reach a length of 1 cm. But the minnows feed most in the low marsh where the spaces between *S. alterniflora* plants are larger and can be foraged through more easily. In marshes with minnows, only large snails are found in the low marsh. All the younger stages are confined to the high marsh where the closely spaced *S. patens* stems restrict fish movements. In the marshes where fish are excluded, all sizes of snails occur throughout the marsh area.

Pollution of marshes also adds heavy metals in the sludge-based fertilizer. Some metals such as lead are retained almost fully while cadmium is lost in appreciable quantities. The differences are largely due to chemical properties of the metals in the various compounds they form in the marsh. Lead is mostly bound in the sediments as the very insoluble sulfide. Cadmium forms soluble complexes with chlorides in sea water and so is lost. The latter then shows up in shellfish associated with the fertilized plots, although in amounts too small to be hazardous to themselves or to other animals feeding on them. Lead is also lost from the marsh in the grass. Apparently the oxygen which supplies the *Spartina* roots also oxidizes the lead sulfide to soluble lead sulfate which is absorbed by the plants in small amounts. A part of the lead, contained in the plant tissues, is exported from the marsh when the plants die and wash out. This amounts to only a few percent of the added lead but is a significant process in the redistribution of heavy metals that find their way into salt marshes.

Hydrocarbons and pesticides are also contained in the sludge-based fertilizer and we hope to work out the mechanisms by which these contaminants are handled by the marshes. Such studies should have special significance for areas such as the Hackensack Meadows which are highly polluted with industrial wastes but whose conservation and protection is of great concern.

At this time the only damage to the marsh ecosystem which we have discovered from the fertilizer additions involves the death of fiddler crabs, larval tabanids and other biting flies. The cause seems to be traceable to pesticides contained in the sludge. Aldrin and Dieldrin were responsible for the original results obtained but these have since declined in the fertilizer after their use became restricted. However, there are other pesticides as yet unidenti,-fied which continue to keep these animals at low population levels. This result provides us with another experiment in predator reduction since the larval flies are voracious feeders on other mud dwelling insects. We also have plans for using the change in numbers of fiddler crabs to measure their effect on the distribution of substances in the marsh as a result of their feeding and burrowing activities.

After five years of our marsh experiments we have learned a great deal about the limits of production on the marsh, about the factors that determine the distribution of marsh animals and plants, and about the responses of salt marshes to pollutants. We have only begun to exploit the possibilities of these experiments, however. Feeding by birds, eels and bluecrabs on both marsh animals and minnows that feed on the marsh have yet to be worked out so that we can better understand the role of predation in marsh functioning. We hope to look into further details of the carbon budget of the marsh, especially with regard to the gas exchanges between air and water. The sulfur budget of fertilized and control plots should be compared. As with all good research we have, in the process of providing answers to our original questions, found many more questions yet to answer. We have also established a series of marsh areas where there are different productivities and different animal populations with which to answer these provocative questions.

Student in short **Spartina alterniflora.*****(Inset) dwarf; fertilized (formerly dwarf) and tall*** **S. alterniflora.**

Students maneuver CTD with rosette sampler on R/V KNORR cruise to Mediterranean in early 1975.

Report of the Dean of Graduate Studies

The educational programs at the Institution derive their strength by being integrated with our research life. Not only do our programs draw their substance from oceanographic research, but the research programs themselves are invigorated by the questions raised by talented people who wish to learn. The Institution's educational programs range from those aimed at inspiring oceanographic interests in high school students to those providing advanced training opportunities for postdoctoral students with our principal program being the Joint Graduate Program with the Massachusetts Institute of Technology.

In 1974 all of our programs flourished with record-high levels of participation:

— Total graduate programs enrollment increased to seventy-five, after adding fifteen new students and graduating three doctorates during 1974. Although the program attracted about ten percent fewer applicants in 1974 than in the previous year (a national trend), the quality level of the applicants remained very high. The Joint Graduate Program with M.I.T. has benefited from a reorganization of the academic-administrative leadership of the program, with the restructuring of the M.I.T./W.H.O.I. Education Committee, under the co-chairmanship of Dr. Frank Press, Director of the Joint Program at M.I.T. and myself, to include all department chairmen at both M.I.T. and Woods Hole whose departments are actively involved in the program. This change has provided an opportunity to involve formally departments at M.I.T. that previously have not been active participants, such as the Departments of Nutrition and Food Science, Civil Engineering, and Electrical Engineering. We anticipate that as interest in the program broadens other departments will become more actively involved.

— The Postdoctoral Scholars program continued to draw a large number of applications from new science Ph.D.'s who wish to explore a possible career in oceanographic research. Eight fellowship awards were made in 1974. We believe this program to be an essential one for the Institution at a time when the number of young and talented scientists is high and the number of openings for scientists in teaching institutions is limited.

— Seventeen summer student fellowships were awarded in 1974. These awards, made competitively from some two hundred applications, allow promising undergraduates to work with our staff on research projects proposed by the students. The final research reports delivered by these students, as in the past, demonstrated remarkably high levels of both talent and effort.

— The successful sixteenth summer session of the Geophysical Fluid Dynamics Seminar had as its central topic "General Circulation of the Oceans". Ten advanced graduate students and postdoctoral fellows participated by attending lectures, presenting seminars and working closely on selected research topics with the eighteen faculty and staff participants.

— The summer Visiting Scholars program was particularly successful in 1974. For each of nine weeks during the summer a visiting scientist was invited by the graduate students to come for a week and give one or two seminars and meet with students informally and at social affairs arranged by students. Such scientists, often with their families, live in an apartment in the Student Center where they can easily share in the activities of the Institution. Crowded evening discussions with beer and blackboards were a regular feature of the Student Center's lounge during the summer.

— The Secondary School program was more active in 1974 than it had been in recent years. A series of lectures presented by members of the Woods Hole staff attracted audiences up to one hundred students and teachers from secondary schools both on and off Cape Cod.

— The Marine Policy and Ocean Management program, which provides opportunities for social scientists to work on marine problems, had nine postdoctoral participants in the fall of 1974. An innovation for the program was the initiation of a multidisciplinary study of the impact of possible offshore oil drilling on the fishing industry of the northeast coast. The study, involving several policy fellows and members of the scientific staff, should be completed in the summer of 1975.

It is not common today in the midst of an educational recession for a graduate Dean's report to be anything but pessimistic about the immediate future, and so one might question the general optimism of the above remarks. The sharply diminished requirement for new faculty in universities coming at a time when Ph.D. output was at an all-time high has created a severe "over-production" of the Ph.D.'s in many fields. Because of the high cost of graduate study and the severe financial pressure on universities today, most universities are cutting back rather stringently on Ph.D. enrollment. What seems to be the situation in oceanography?

In general it is not easy to make reliable forecasts about professional man-power. (Indeed the collection of individual decisions made by students in their own career choices generally contains more wisdom in guessing the future than most forecasts.) However, there is little doubt that in many fields, such as physics, there is an "oversupply" of Ph.D.'s which may persist for some time when measured against the job markets which traditionally employ Ph.D.'s. The situation with oceanography, however, is not so clear. In the first place, it is not obvious how to make estimates of the supply functions for professional manpower in oceanography. The "supply" cannot be measured by the number of Ph.D.'s awarded in oceanography since these represent only a fraction of those who eventually become oceanographers — many others, of course, coming from such fields as biology, chemistry and geology. The "demand" for oceanographers depends upon industrial and governmental activities, as well as universities. Past evidence suggests that the most important single factor in determining the future demand for oceanographers is governmental expenditures on ocean-related research (which secondarily involves both academic and industrial employers). With increasing national interests in resources, pollution, waste disposal and energy, all of which have large oceanic components, there has been a steady increase in such expenditures over the past decade. Forecasts indicate future growth in these expenditures, both by government and by industry.

Thus there does not seem to be cause for immediate concern that our investments in graduate education may not be well utilized in the future. The principal worry perhaps should be about the types of specializations which will be most needed in the future. At the present time, for example, the demand would appear to be greatest (or the supply is shortest) for oceanographers with specialties in geology and geophysics.

The record of placement of our recent Ph.D. graduates seems to bear out these observations. A total of thirty-three degrees have been awarded in the Joint Program through 1974, twenty-six doctorates and seven Ocean Engineer degrees. With the exception of two graduates who chose to leave the field entirely, three who returned to Navy duty, and one who returned to graduate school, the remaining twenty-seven have been successful in finding employment in their chosen field. In summary, nine hold faculty appointments, twelve have research positions with either oceanographic institutes or government research laboratories, and six are working for industry in research capacities.

Of the twelve that have graduated in the last two years, six specialized in marine geology or marine geophysics; five hold research appointments, two at Lamont-Doherty Geological Observatory, two with geological survey groups, and one with an oceanographic research center in Israel. These are all staff appointments, in two cases following a postdoctoral year. Two physical oceanographers graduated, and one has a staff appointment as a research scientist at Bedford Institute of Oceanography and the other is a Physical Oceanographer for an environmental firm. The sole chemical oceanographer who graduated in this period spent a postdoctoral year at the Chalmers Tekniska Hogskola Institutionen for Teknisk in Sweden and is now at the Geologisch-Paläontologisches Institut, University of Hamburg, West Germany. The two Ocean Engineer degree recipients accepted research positions in industry, one with Sanders Associates and one with Exxon Production Research.

It is too early to pass judgment on the professional success of our graduates, but we certainly can say that they have taken the first step to a successful career.

ROBERT W. MORSE
Dean of Graduate Studies

Joint Woods Hole Oceanographic Institution/
Massachusetts Institute of Technology
DEGREE RECIPIENTS — 1974

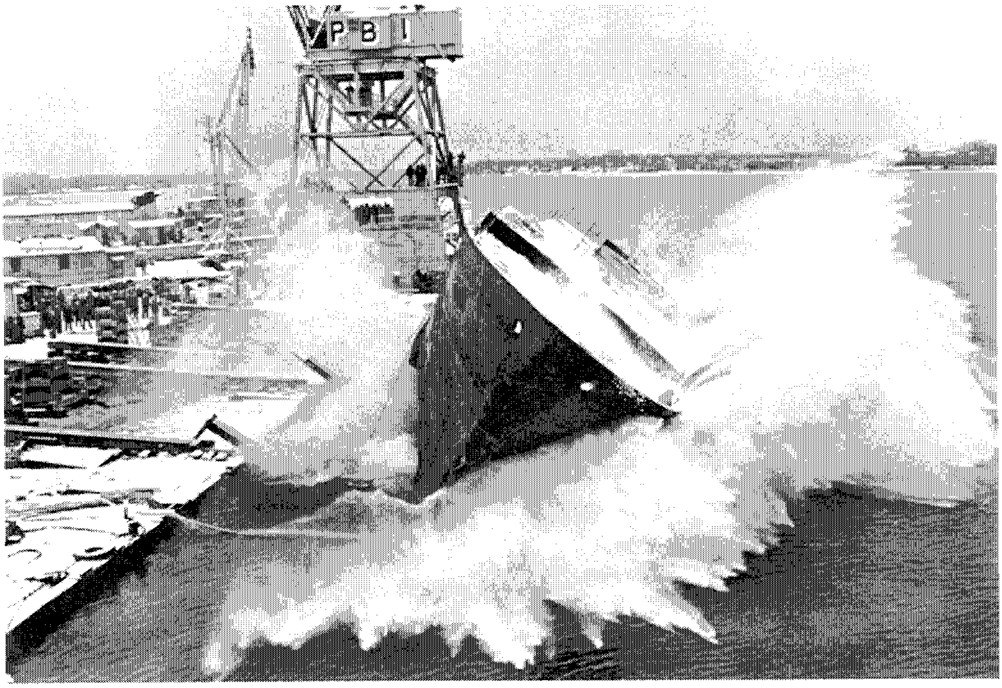
Doctor of Science

PETER C. SMITH
Sc.B., Brown University
M.S., Brown University
Special Field: Physical Oceanography
Dissertation: *The Dynamics of Bottom Boundary Currents in the Ocean*

Doctor of Philosophy

DONALD W. FORSYTH
B.A., Grinnell College
Special Field: Marine Geophysics
Dissertation: *Anistrophy and the Structural Evolution of the Oceanic Upper Mantle*

DAVID L. WILLIAMS
B.A., University of Texas
Special Field: Marine Geophysics
Dissertation: *Heat Loss and Hydrothermal Circulation Due to Sea-Floor Spreading*



OCEANUS launching, December 1974.

Ashore and Afloat

The Environmental Systems Laboratory was dedicated on June 20 at the time of the Annual Meeting of the Trustees and Members of the Corporation in Woods Hole. Dr. Paul Fye introduced the program which included brief remarks by Dr. John Ryther, head of the Laboratory, and an address by Dr. Athelstan Spilhaus, a former Institution staff member and currently a consultant to the National Oceanic and Atmospheric Administration. The 4,800 square foot building houses laboratories, office space and facilities to pump, heat and cool the sea water used in aquaculture studies. The primary characteristics of the facility are the outdoor ponds for the growth of algae and raceways in which various marine animals which feed upon the algae can be maintained.

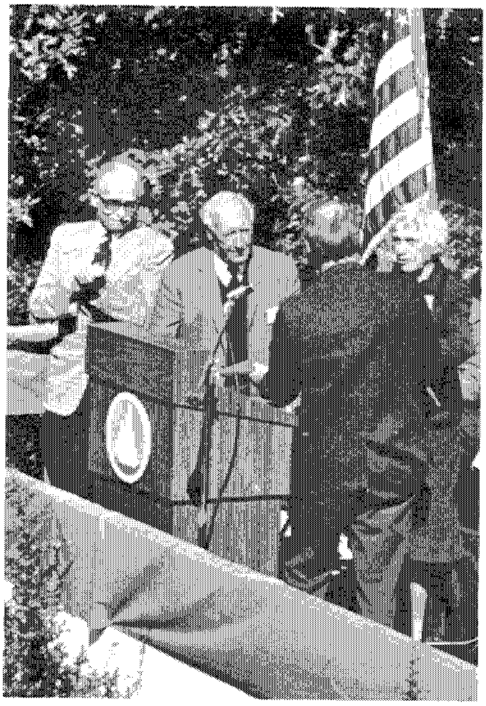
A building was also constructed to provide permanent quarters for the United States Geological Survey for their marine investigations on the Atlantic and Gulf Coasts of the United States. Site clearing began on January 11th and construction started in mid-February. The building was partially occupied in October before it was completed. It will provide space for about 50 investigators with the U.S.G.S.

In addition to the Clark Laboratory, which was dedicated on October 11th (Pages 11 to 12), there are now four newly constructed smaller buildings on the Quissett Campus. Plans have been started for an additional building to serve as a warehouse.

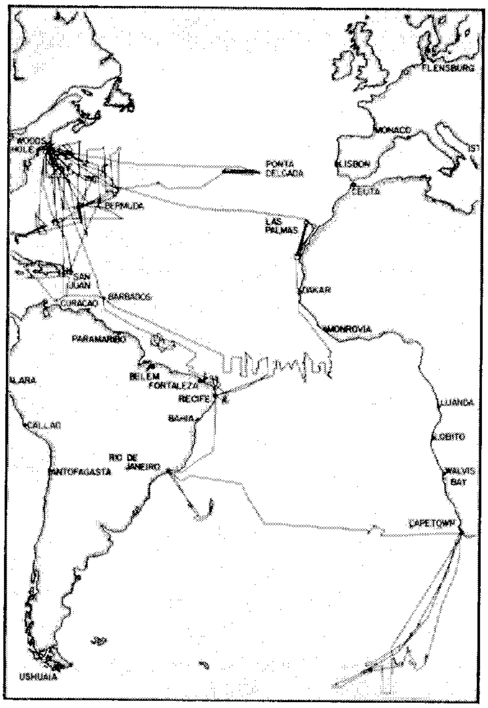
The Institution has continued the operation of the University-National Oceanographic Laboratory System (UNOLS) on behalf of the 16 member oceanographic laboratories. UNOLS has been operating since 1971 as a planning and coordinating mechanism for oceanographic facilities, primarily the 30 research ships operated by the members. It also provides a forum for meetings and workshops on common problems and interests of the university laboratories.

Our new research vessel, OCEANUS, was launched at Peterson Builders Inc., Sturgeon Bay, Wisconsin, on December 19th. The christening of OCEANUS and the launching of her sister ship WECOMA, which will be operated by Oregon State University, is scheduled for May 31, 1975. At the time of launching, OCEANUS was 45 percent completed. Interior finishing is underway now and delivery to the Institution is scheduled for late fall, 1975. After reaching our own dock in Woods Hole, it is anticipated that the installation of the necessary scientific equipment will require about three months before the ship can be actively used in oceanographic research. OCEANUS is 177 feet in length with a beam of 33 feet and displacement of 960 tons, and will be capable of operating worldwide except for regions of ice. Cruising speed is expected to exceed 14 knots, and the variable pitch propeller and bow thruster will provide slow speed maneuverability essential for operations at oceanographic stations. She will carry a crew of 13 and a scientific party of 12 with operating costs about half those of our larger ships.

The ATLANTIS II, CHAIN and KNORR provided about 800 days at sea during 1974 (Appendix IV) and 741 scientists, technicians and students participated in the research investigations. Of these participants, 42 percent were from other United States and foreign laboratories, somewhat more than usual, demonstrating the value of institution vessels as national and international facilities. These cruises provided a total of over 14,000 man-days of scientific effort at sea. Of the research projects sponsored, 56 percent were supported by NSF, 24 percent by ONR and the remaining 20 percent by other Federal, or non-Federal, activities.



The Clarks, Dr. Fye and Selectman Payne at dedication.



Research Cruises–1974.

The
Henry Bryant Bigelow Medal
awarded to
Henry Melson Stommel

In recognition of his contributions to our understanding of ocean circulation and dynamics
For his continuing intellectual leadership in theoretical and experimental marine science and
For his profound influence on the advance of oceanography throughout the world

by the
Board of Trustees of the Woods Hole Oceanographic Institution

October 10, 1974

We have the privilege today to honor Henry Melson Stommel, one of the world's most distinguished physical oceanographers, with the award of the HENRY BRYANT BIGELOW MEDAL.

Thirty years ago, Dr. Stommel started his career here at the Woods Hole Oceanographic Institution and we have had to struggle to keep up with him ever since. Lively and spirited with a marvelous sense of humor, he very soon influenced every aspect of life in Woods Hole. Whether it was in a small group meeting in his office, traveling together to a meeting at Brown University or Harvard or M.I.T., or with a larger group in a class or at the "Journal Club", there was always a sense of excitement, originality, and good fellowship.

Early in his career, Henry Stommel developed a remarkably clear and perceptive view of physical oceanography. Developments in this field over the last two decades seem almost blueprinted in his formal and informal writings of the early 1950's. He was most influential in attracting the very best scientists to Woods Hole and to the field of physical oceanography. It would be impossible to list here the names of all those that came to attend the seminars to prepare for teaching in the field, to do research on particular problems, and in some cases to become members of the staff of the Institution. One of the eventual results of this inspired leadership was the starting of the Geophysical Fluid Dynamics Seminars that are held bi-weekly at Harvard, M.I.T., and Woods Hole alternately.

Although many of his papers have dealt with the Gulf Stream and in 1958 he published the textbook on the subject, Professor Stommel's work and interests were never confined to one subject or one portion of the world ocean.

Top ranking scientists from many countries are numbered among his collaborators and the international body of oceanographers owes much to his success in cross fertilizing the entire field. An example of this is his editorship, together with Kozo Yoshida, of the large comprehensive treatise on the physical aspects of the Kuroshio. And when Stommel perceived that some of the most important and fundamental problems of oceanography were beyond the grasp of any single laboratory or research group, he set about to generate concentrated multi-institutional attacks on them. With his tact, enthusiasm, and intellectual stimulation, he has recently been able to engage the participation of many oceanographers in several large international projects and much of the contribution which these projects have made to oceanography must be credited to his initial leadership.

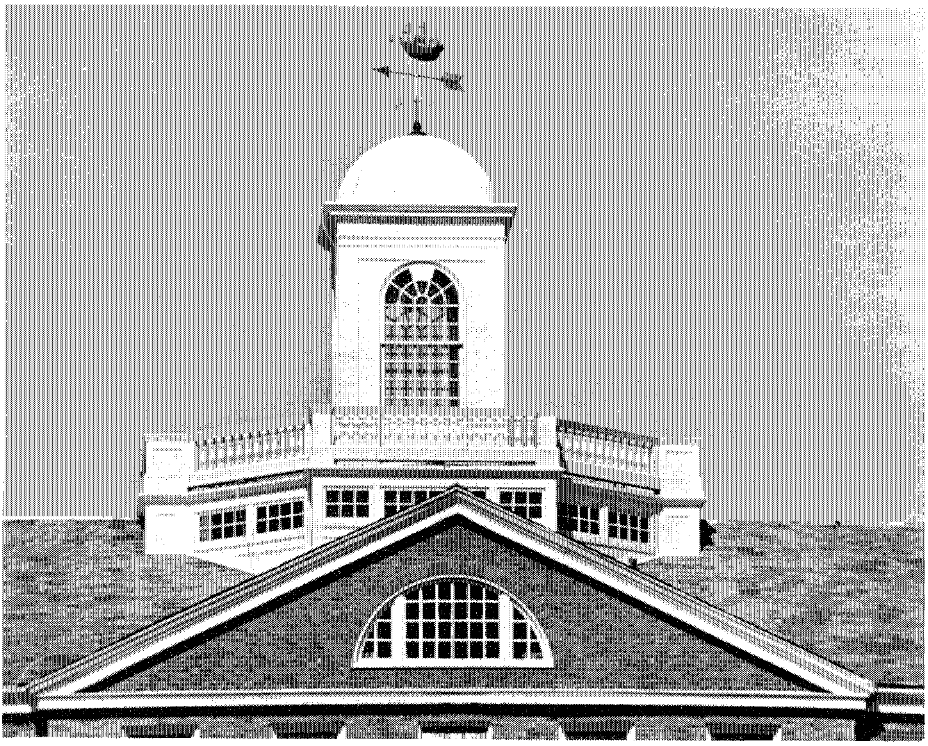
In writing about Peter Martyr and his early Gulf Stream descriptions, Henry Stommel perhaps characterized himself — "he has a very blessed gift: skepticism about his own ideas". [The Gulf Stream, *The Scientific Monthly,* Vol. LXX, No. 4 p. 242].

Stommel has always valued simple rational arguments to develop his and our concepts of how the ocean behaves. He always chose against sophistication and pretentiousness in his writing. Yet his grasp of the world ocean is complex and multi-dimensional and he has contributed original ideas in nearly every aspect of physical oceanography.

Although Henry accepted a professorship at Harvard and then at M.I.T., we have continued to consider him as being at the hub of the Physical Oceanography Department here at the Woods Hole Oceanographic Institution.

— Frederick C. Fuglister

HENRY MELSON STOMMEL
Professor of Oceanography
Massachusetts Institute of Technology
Physical Oceanographer
(non-resident)
Woods Hole Oceanographic Institution



William W. Rubey

19 December 1898–12 April 1974

William Rubey became a Member of the Woods Hole Oceanographic Institution in 1959. He was elected a Trustee in 1966 and an Honorary Trustee in 1970. He was well known to the scientists of the Institution as a member of the Visiting Committee for the Departments of Chemistry and Geology and Geophysics in 1962, 1963, 1964, and 1972.

Rubey received his A.B. and Ph.D. at the University of Missouri and soon afterward joined the U.S. Geological Survey where he remained until retirement as Research Geologist in 1960. He taught geology courses at Yale University, California Institute of Technology, and Johns Hopkins University, and following retirement from the Survey, he became professor of geology at the University of California at Los Angeles. His active role in national and professional affairs included, at one time or another, chairman of several committees of the National Research Council, member and councilor of the National Academy of Sciences, president of the Geological Society of America, a director of the Lunar Science Institute, and a trustee of the Science Service Corporation and Carnegie Institution. In these positions and in his service on innumerable government and university committees, Rubey was well known for his ability to absorb the pertinent information and to make a calm reasoned appraisal of the solution to the problem at hand. The judgment was so graciously given that it generally was accepted by all.

He published a score of very well respected articles — nearly all during his years with the U.S. Geological Survey. Probably best known of these to oceanographers is his Geological Society of America presidential address in 1951, "Geologic History of Sea Water". This broad-ranging speech and publication drew upon information from astronomy, geophysics, geochemistry, paleontology, and biochemistry to show that the oceans were born and are being slowly and continuously augmented by juvenile waters carrying salts and volatiles in solution from solidifying rocks of the earth's interior. Maintenance of a roughly uniform water line on the continents is due to a coupling of the increasing volume of ocean water with the rising of continents as new crust is added to their bottoms and their surfaces are removed by erosion.

Service to geology and to science in general was recognized in many other ways. He received three honorary degrees, the gold Penrose Medal of the Geological Society of America, and the National Medal of Science that is the highest government recognition available to a scientist.

Rubey's good advice and other contributions to the Woods Hole Oceanographic Institution will be sorely missed.

William S. Richardson

10 October 1923 –

William S. Richardson was presumed lost at sea with four other colleagues on board R/V GULF STREAM during a research cruise in the Gulf of Maine on or about January 7, 1975. He was Director of the Nova University Laboratory of Physical Oceanography and formerly a scientist at the Institution from 1952-1963.

Dr. Richardson was a highly respected scientist and while at Woods Hole developed pioneering and innovative programs in current measurements, buoy technology and airborne instrumentation. The cause of the loss of the R/V GULF STREAM with all hands remains unknown.

C. Lloyd Claff

15 October 1895 – 28 March 1974

Lloyd Claff was elected a Member of the Corporation in 1955. He contributed also as a member of a Biology Department visiting committee in 1968 and was an occasional sea-goer on Institution vessels. His great mechanical ability served him well in two worlds — as president of the family business, M. B. Claff and Sons, manufacturers of shoe boxes in Brockton and as an amateur bio-medical researcher, largely at the Marine Biological Laboratory, where he was Trustee and Clerk of the Corporation. He held patents for machinery used in box-making and developed a number of devices useful in medicine, foremost of which was one for preventing irregular beating of the heart. Dr. Claff was a graduate of Bowdoin College (1918) and was given an honorary degree (Sc. D.) by his alma mater in 1958.

William Maurice Ewing
12 May 1906 – 4 May 1974

The death of William Maurice Ewing on May 4, 1974 at Galveston, Texas following a severe stroke was a great loss to his family, to his many friends around the world and to the field of earth sciences. Born in 1901 at Lockney in the Texas Panhandle he studied physics at Rice Institute while doing part-time work in commercial geophysics. Throughout his four decades of leadership he retained his Texan mannerisms and unique sense of humor.

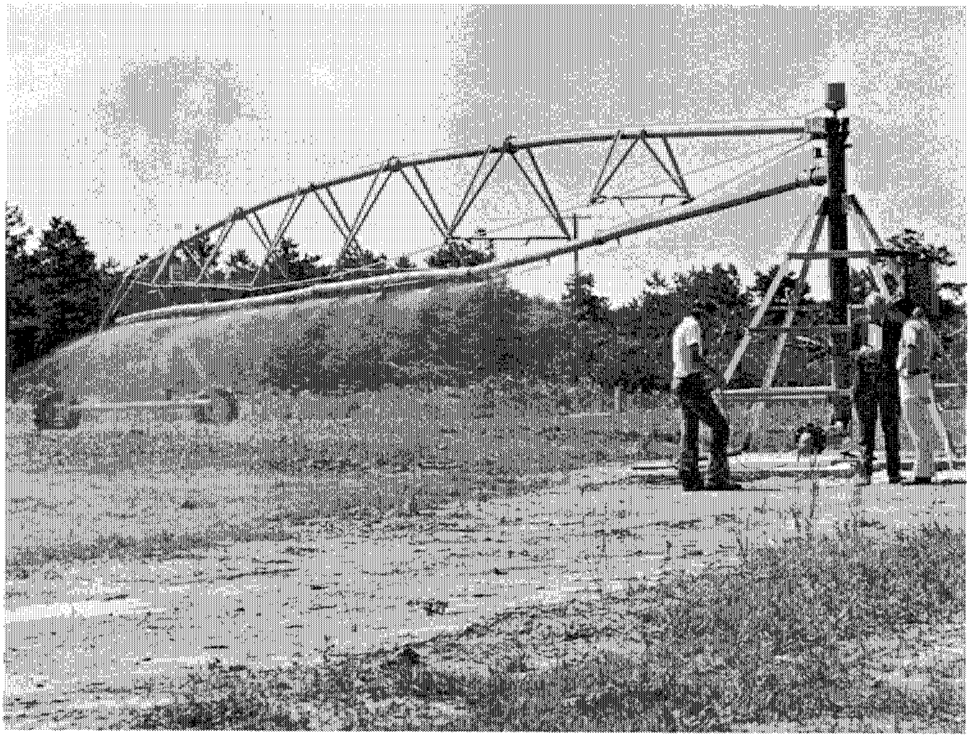
While an instructor at Lehigh University in the early 30's his aggressive geophysical research caught the attention of Richard Field and William Bowie of the American Geophysical Union who helped persuade Ewing to apply new geophysical techniques to the study of the ocean and convinced the Woods Hole Oceanographic Institution to furnish time on ATLANTIS. Thus starting in 1935, Ewing with the first of his many graduate students and co-workers began their long association with the young oceanographic institution. Ewing's first and major interest in ocean research was advancing knowledge about fundamental geologic differences between oceans and continents. To better achieve that understanding he successfully intrigued and led a large number of students and co-workers. Many of the not so obvious co-workers involved were sailors, administrators, naval officers and politicians who sensed and caught the excitement and the importance that things should be done: and be done now!

Ewing supplemented his early seismic work on the continental shelf with complementary observations on land. This was followed by trips on ATLANTIS developing techniques for making seismic observations and bottom photographs in the deep sea. He also made expeditions on submarines measuring gravity to better understand how the sea and the land met.

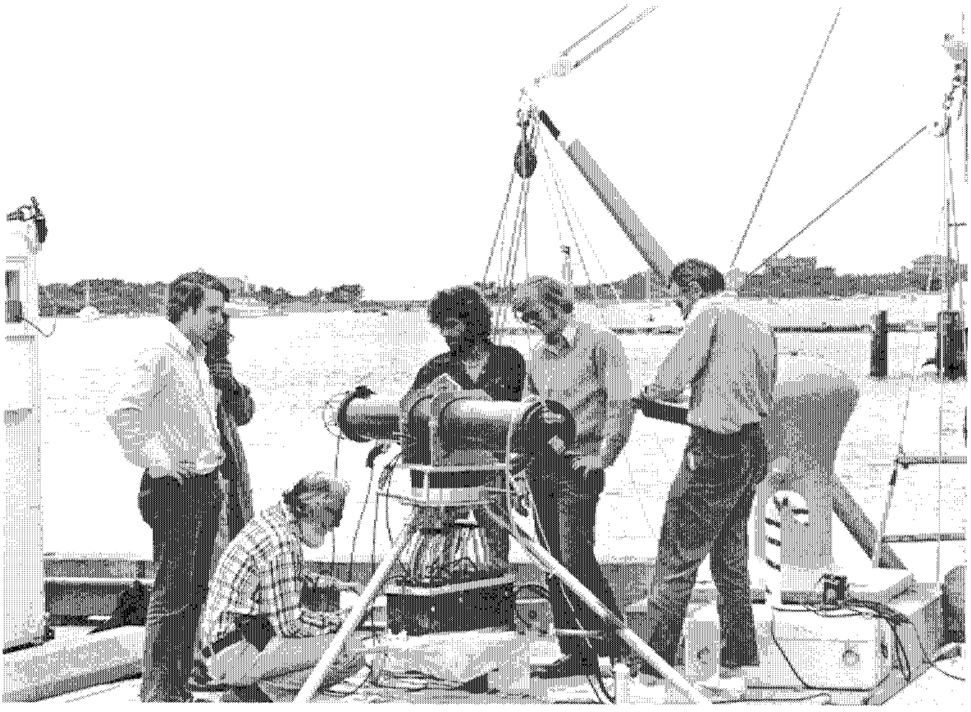
With the outbreak of World War II the Institution's new director, Columbus Iselin, in cooperation with Ewing, obtained government help permitting year round operations at Woods Hole and for Ewing's small group at Lehigh to come to Woods Hole to work on submarine warfare problems. During those war years Ewing developed or contributed to many aspects of civilian and military oceanographic theory and techniques. These included bathythermograph usage, sonar prediction, submarine diving, countermining and particularly the existence of the acoustic SOFAR sound channel in the deep ocean.

In 1946 Ewing moved to Columbia University where he started the Lamont Geological Observatory, and later acquired the VEMA and R/V CONRAD. Ewing and an increased number of students and co-workers were then able to expand the global aspect of geophysics that became a hallmark of his philosophy. Thus, the new laboratory became one of the world's great oceanographic institutions, with interests ranging from the ocean to the moon, from ice ages to submarine landslides and ocean ridges to plate tectonics.

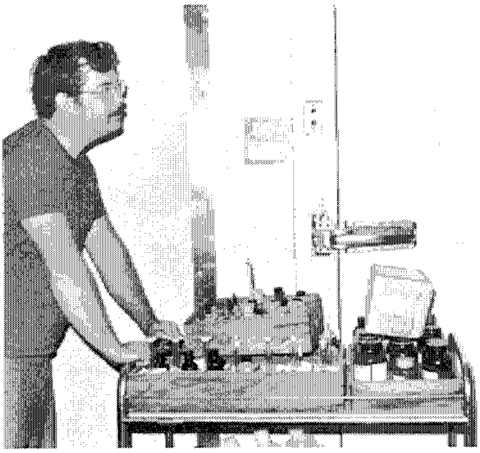
In 1972 Ewing retired from Columbia and moved to the University of Texas. Death caught him in typical full stride, building up the laboratory both afloat and ashore. Along with many national and international honors Ewing left a legacy of students, ideas, friendships and oceanographic traditions.

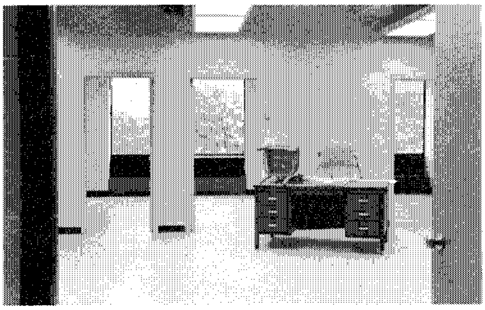


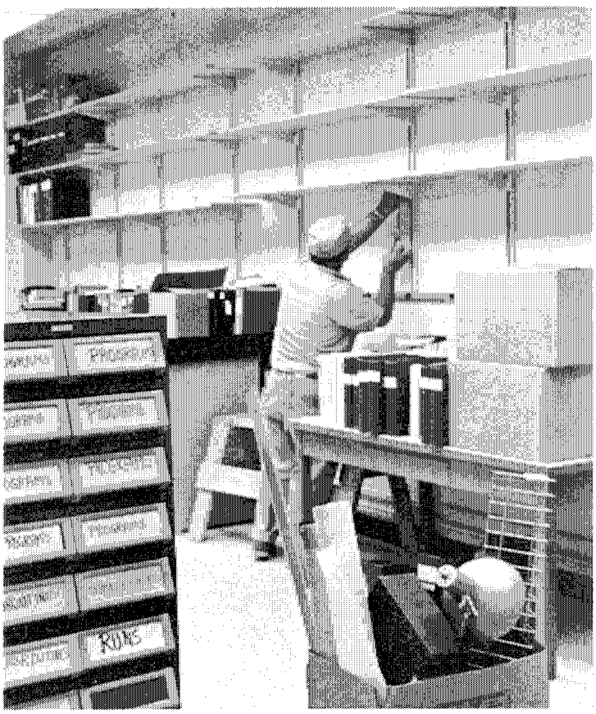
Living filter sewage treatment — spray irrigation for hay.



Vector Magnetometer.







On the move . . .

Personnel*

Appendix I

Paul M. Fye	*Director*
Arthur E. Maxwell	*Provost*
Robert W. Morse	*Dean of Graduate Studies and Associate Director*
Ferris Webster	*Associate Director for Research*
Bostwick H. Ketchum	*Associate Director*
David D. Scott	*Assistant Director for Administration*
Frederick E. Mangelsdorf	*Assistant Director*

Alfred C. Redfield, *Senior Oceanographer (Emeritus)*
Professor of Physiology (Emeritus), Harvard University

William C. Schroeder, *Emeritus Scientist*
H. Burr Steinbach, *Dean Emeritus*

Resident Scientific and Technical Staff

Department of Biology

Richard H. Backus, *Senior Scientist*
Associate in Ichthyology, Harvard University
Francis G. Carey, *Associate Scientist*
Edward J. Carpenter, *Associate Scientist*
George L. Clarke, *Marine Biologist, non-resident*
Professor of Biology, Emeritus, Harvard University
Charles H. Clifford, *Research Associate*
Nathaniel Corwin, *Analytical Chemist*
James E. Craddock, *Marine Biologist*
R. John Gibson, *Assistant Scientist*
Cameron E. Gifford, *Aquaculturist*
Joel C. Goldman, *Assistant Scientist*
J. Frederick Grassle, *Associate Scientist*
George D. Grice, Jr., Department Chairman *Senior Scientist*
Robert R. L. Guillard, *Senior Scientist*
Richard L. Haedrich, *Associate Scientist*
Associate in Ichthyology, Harvard University
George R. Hampson, *Research Associate*
G. Richard Harbison, *Assistant Scientist*
John E. Huguenin, *Research Associate*
Edward M. Hulburt, *Associate Scientist*
Holger W. Jannasch, *Senior Scientist*
Privat Docent in Microbiology, University of Göttingen
Adrianus J. Kalmijn, *Associate Scientist*
John W. Kanwisher, *Senior Scientist*
William B. Kerfoot, *Assistant Scientist*
Andrew Konnerth, Jr., *Research Associate*
Kenneth D. Lawson, Jr., *Research Associate*
Thomas J. Lawson, Jr., *Research Associate*
John M. Mason, Jr., *Research Associate*
Frank J. Mather III, *Associate Scientist*
B. Joan R. Mitchell, *Research Associate*
Pamela T. Polloni, *Research Associate*
Charles C. Remsen III, *Associate Scientist*
Gilbert T. Rowe, *Assistant Scientist*
John H. Ryther, *Senior Scientist*
Dennis J. Sabo, *Assistant Scientist*
Howard L. Sanders, *Senior Scientist*
Consultant in Marine Ecology, Marine Biological Laboratory, Woods Hole; Research Affiliate of the Marine Sciences Research Center, State University of New York, Stony Brook; Associate in Zoology, Harvard University
Rudolf S. Scheltema, *Associate Scientist*
William E. Schevill, *Biological Oceanographer, non-resident*
Associate in Mammalogy, Museum of Comparative Zoology, Harvard University
Brian W. Schroeder, *Research Associate*
Mary Sears, *Senior Scientist*
Kenneth L. Smith, Jr., *Assistant Scientist*
John J. Stegeman, *Assistant Scientist*
Craig D. Taylor, *Assistant Scientist*
John M. Teal, *Senior Scientist*
Kenneth R. Tenore, *Assistant Scientist*
Jon H. Tuttle, *Assistant Scientist*
Ralph F. Vaccaro, *Associate Scientist*
Frederica W. Valois, *Microbial Chemist*
William A. Watkins, *Bioacoustic Engineer*
Stanley W. Watson, *Senior Scientist*
Peter H. Wiebe, *Assistant Scientist*
Asa S. Wing, *Research Associate*
Carl O. Wirsen, Jr., *Research Associate*

Department of Chemistry

Donald C. Bankston, *Research Associate*
Max Blumer, *Senior Scientist*
Vaughan T. Bowen, *Senior Scientist*
Peter G. Brewer, *Associate Scientist*
John C. Burke, *Research Associate*
Wen Man Chang, *Research Associate*
Werner G. Deuser, *Associate Scientist*
John W. Farrington, *Assistant Scientist*
Nelson M. Frew, *Assistant Scientist*
Robert B. Gagosian, *Assistant Scientist*
George R. Harvey, *Associate Scientist*
John M. Hunt, *Senior Scientist*

*As of 31 December 1974.

William J. Jenkins, *Assistant Scientist*
Hugh D. Livingston, *Analytical Radiochemist*
Donald R. Mann, *Research Associate*
Peter L. Sachs, *Research Associate*
Jeremy Sass, *Research Associate*
Richard M. Sawdo, *Research Associate*
Frederick L. Sayles, *Associate Scientist*
Derek W. Spencer, Department Chairman, *Senior Scientist*
William G. Steinhauer, *Research Associate*
Geoffrey Thompson, *Associate Scientist*
Research Associate, Smithsonian Institution
Lee S. Waterman, *Research Associate*
Oliver C. Zafiriou, *Associate Scientist*

Department of Geology and Geophysics

Thomas C. Aldrich, *Research Associate*
Robert D. Ballard, *Assistant Scientist*
John C. Beckerle, *Associate Scientist*
William A. Berggren, *Senior Scientist*
Visiting Professor, Brown University; Research Associate, Department of Micropaleontology, American Museum of Natural History
Carl O. Bowin, *Associate Scientist*
Wilfred B. Bryan, *Associate Scientist*
Elizabeth T. Bunce, *Associate Scientist*
‡Barrie Dale, *Research Associate*
Raymond E. Davis, *Research Associate*
Charles R. Denham, *Assistant Scientist*
Alan H. Driscoll, *Research Associate*
William M. Dunkle, Jr., *Research Associate*
Kenneth O. Emery, *Senior Scientist*
Robert G. Goldsborough, *Research Associate*
U. Z. Bilal ul Haq, *Assistant Scientist*
James R. Heirtzler, Department Chairman, *Senior Scientist*
Charles D. Hollister, *Associate Scientist*
Susumu Honjo, *Associate Scientist*
Hartley Hoskins, *Research Associate*
David A. Johnson, *Assistant Scientist*
Sydney T. Knott, *Hydroacoustics Engineer*
Donald E. Koelsch, *Electronics Engineer*
George P. Lohmann, *Assistant Scientist*
‡Bruce P. Luyendyk, *Assistant Scientist*
John D. Milliman, *Associate Scientist*
‡Walter D. Nichols, *Research Associate*
David M. Owen, *Research Associate*
Joseph D. Phillips, *Associate Scientist*
Kenneth E. Prada, *Research Associate*
David A. Ross, *Associate Scientist*
Visiting Instructor, Fletcher School of Law and Diplomacy; Visiting Instructor, Massachusetts Institute of Technology
Colin P. Summerhayes, *Assistant Scientist*
Elazar Uchupi, *Associate Scientist*
Allyn C. Vine, *Senior Scientist*
‡Richard P. Von Herzen, *Senior Scientist*
David Wall, *Associate Scientist*
Warren E. Witzell, *Hydrocoustics Engineer*
Earl M. Young, *Research Associate*

Department of Ocean Engineering

Lincoln Baxter II, *Applied Physicist*
Stanley W. Bergstrom, *Research Associate*
David S. Bitterman, Jr., *Research Associate*
Edward L. Bland, Jr., *Research Associate*
Paul R. Boutin, *Research Associate*
Albert M. Bradley, *Research Associate*
Clayton W. Collins, Jr., *Research Associate*
C. Dana Densmore, *Research Associate*
Stephen C. Dexter, *Assistant Scientist*
John D. Donnelly, *D.S.R.V. Pilot*
Donald L. Dorson, *Research Associate*
‡James A. Doutt, *Research Associate*
Willard Dow, *Electronics Engineer*
Robert G. Drever, *Electronics Engineer*
Eric H. Frank, Jr., *Research Associate*
Roger A. Goldsmith, *Research Associate*
Earl E. Hays, Department Chairman, *Senior Scientist*
Frederick R. Hess, *Research Associate*
David S. Hosom, *Research Associate*
Mary Hunt, *Research Associate*
Maxine Jones, *Research Associate*
Peter E. Kallio, *Research Associate*
Richard L. Koehler, *Research Associate*
William S. Little, Jr., *Research Associate*
William M. Marquet, *Instrumentation Engineer*
James W. Mavor, Jr., *Mechanical Engineer*
Marvin J. McCamis, *Research Associate*
Paul T. McElroy, *Assistant Scientist*
Paul C. Murray, *Research Associate*
Richard T. Nowak, *Acoustics Engineer*
Marshall H. Orr, *Assistant Scientist*
N. N. Panicker, *Assistant Scientist*
Kenneth R. Peal, *Research Associate*
Robert P. Porter, *Assistant Scientist*
George H. Power, *Computer Analyst*
Melvin A. Rosenfeld, Manager, Information Processing Center, *Senior Scientist*
Arnold G. Sharp, *Research Associate*
Lawrence A. Shumaker, Manager, Deep Submergence Engineering & Operations Section, *Oceanographic Engineer*
Woollcott K. Smith, *Research Associate*
Robert C. Spindel, *Assistant Scientist*
Jess H. Stanbrough, Jr., *Research Physicist*
Foster Striffler, *Research Associate*
Constantine D. Tollios, *Computer Engineer*
Barrie B. Walden, *Research Associate*
Robert G. Walden, Manager, Ocean Structures Moorings & Materials Section, *Electronics Engineer*
Roger S. Walen, *Research Associate*
Douglas C. Webb, Manager, Instrument Section, *Electrical Engineer, Senior Research Specialist*
Jacqueline Webster, *Computer Analyst*
Albert J. Williams III, *Assistant Scientist*
Valentine P. Wilson, *D.S.R.V. Pilot*
‡Clifford L. Winget, *Electromechanical Engineer*

‡On Leave of Absence

Department of Physical Oceanography

KEITH F. BRADLEY, *Research Associate*
ALVIN L. BRADSHAW, *Applied Physicist*
MELBOURNE G. BRISCOE, *Assistant Scientist*
JOHN G. BRUCE, JR., *Research Associate*
DEAN F. BUMPUS, *Senior Scientist*
ANDREW F. BUNKER, *Associate Scientist*
JOSEPH CHASE, *Associate Scientist*
Visiting Lecturer, State College at Bridgewater
GABRIEL T. CSANADY, *Senior Scientist*
C. GODFREY DAY, *Research Associate*
JEROME P. DEAN, *Research Associate*
GIFFORD C. EWING, *Senior Scientist*
NICHOLAS P. FOFONOFF, *Senior Scientist*
Gordon McKay Professor of the Practice of Physical Oceanography, Harvard University
FREDERICK C. FUGLISTER, *Senior Scientist*
JAMES E. GIFFORD, *Research Associate*
ROBERT H. HEINMILLER, *Buoy Engineer*
NELSON G. HOGG, *Assistant Scientist*
TERENCE M. JOYCE, *Assistant Scientist*
ELI J. KATZ, *Associate Scientist*
JAMES R. LUYTEN, *Assistant Scientist*
JOHN A. MALTAIS, *Research Associate*
GERARD H. MARTINEAU, *Research Associate*
JAMES R. MCCULLOUGH, *Instrument Engineer*
WILLIAM G. METCALF, *Associate Scientist*
ROBERT C. MILLARD, JR., *Research Associate*
ARTHUR R. MILLER, *Associate Scientist*
DONALD A. MOLLER, *Research Associate*
BERTHOLD H. G. PADE, *Research Associate*
CHARLES E. PARKER, *Research Associate*
RICHARD E. PAYNE, *Research Associate*
PETER B. RHINES, *Senior Scientist*
PHILIP L. RICHARDSON, *Assistant Scientist*
THOMAS B. SANFORD, *Associate Scientist*
PETER M. SAUNDERS, *Associate Scientist*
KARL E. SCHLEICHER, *Oceanographic Engineer*
WILLIAM J. SCHMITZ, JR., *Associate Scientist*
ELIZABETH H. SCHROEDER, *Research Associate*
ALLARD T. SPENCER, *Design Engineer*
MARVEL C. STALCUP, *Physical Oceanographer*
ROBERT J. STANLEY, *Research Associate*
HENRY M. STOMMEL, *Physical Oceanographer, non-resident*
Professor of Oceanography, Department of Meteorology, Massachusetts Institute of Technology
RORY THOMPSON, *Associate Scientist*
GORDON H. VOLKMANN, *Research Associate*
WILLIAM S. VON ARX, *Senior Scientist*
ARTHUR D. VOORHIS, *Associate Scientist*
BRUCE A. WARREN, *Associate Scientist*
JOHN A. WHITEHEAD, JR., *Associate Scientist*
GEOFFREY G. WHITNEY, JR., *Research Associate*
ALFRED H. WOODCOCK, *Oceanographer, non-resident*
L. VALENTINE WORTHINGTON, *Department Chairman*
W. REDWOOD WRIGHT, *Assistant Scientist*

Postdoctoral Investigators in 1974

RICHARD P. BLAKEMORE (Chemistry)
YVES J. F. DESAUBIES (Physical Oceanography)
JOHN G. FARMER (Chemistry)
NICHOLAS S. FISHER (Chemistry)
EDWIN F. FORD (Physical Oceanography)
HOWARD J. FREELAND (Physical Oceanography)
EDWARD R. GONYE, JR. (Biology)
LOREN R. HAURY (Biology)
STANLEY P. HAYES (Physical Oceanography)
DAVID C. JUDKINS (Biology)
MICHAEL S. MCCARTNEY (Physical Oceanography)
LYNDA S. MURPHY (Biology)
CHRISTOPHER P. ONUF (Biology)
BRUCE M. ROBISON (Biology)
RICHARD S. SCOTTI (Physical Oceanography)
JAMES D. SULLIVAN, JR. (Biology)
CRAIG D. TAYLOR (Biology)
RUDOLF C. TJALSMA (Geology and Geophysics)
JAMES M. VAUGHN (Biology)
DAVID L. WILLIAMS (Geology and Geophysics)

Departmental Assistants**

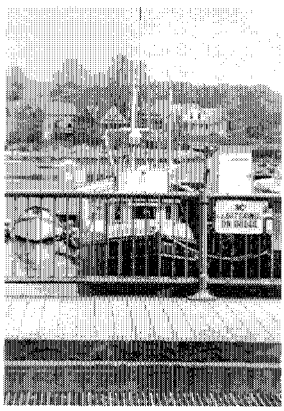
Department of Biology

Anderson, Susan J.
Azarian, Debra M.
Banashak, Duane D.
Bireley, Linda E.
Bowker, Paul C.
Bowman, Pamela E.
Boyd, Steven H.
Bray, Teresa A.
Breeding, Robert E.
Chesney, Edward J., Jr.
Clarner, John P.
Cole, Linda M.
Collins, Anne C.
Davidson, John A.
Dennett, Mark R.
Ellis, Elaine M.
Garner, Susan P.
Gibson, Victoria R.
Gilmer, Ronald W.
Griffith, Robert W.
Gunning, Anita H.

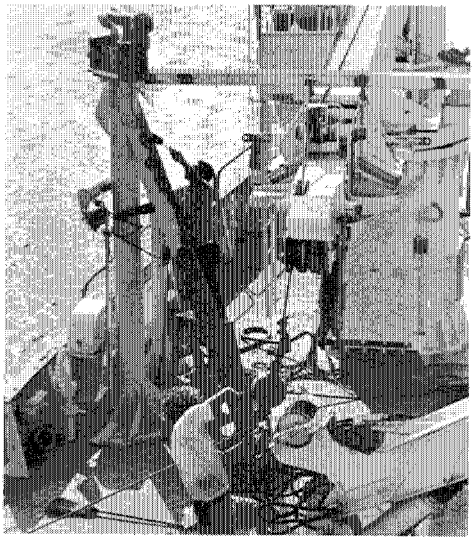
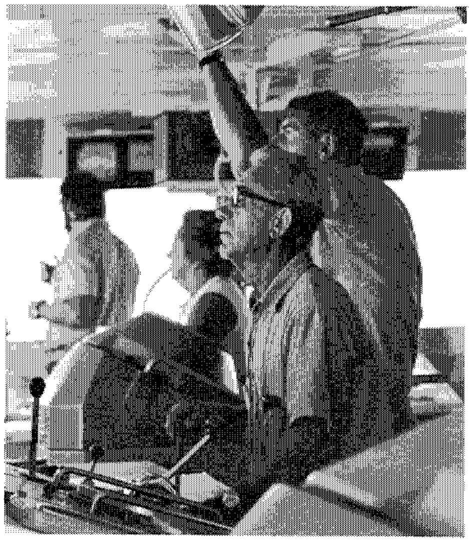
**Full Time Employees

*Administrative and Service Personnel***

Aiguier, Edgar L.
Anders, Wilbur J.
Anderson, Joseph
Augusta, Susan E.
Babitsky, Ellen J.
Backus, Denise
Barnes, Lynda R.
Barnes, Susan M.
Battee, Howard
Battee, Janice R.
Becktol, George
Berthel, Dorothy J.
Billings, John A.
Botelho, Eleanor M.
Botelho, Linda J.
Bourne, Wallace T.
Bowman, Richard W.
Brauneis, Frederick A.
Breivogel, Richard J.
Brown, Norma H.
Burt, Sandra J.
Campbell, Eleanor N.
Carlson, Gustaf A.
Carver, Kenneth W.
Cassidy, Bernard J.
Chalmers, Agnes C.
Charette, Ernest G.
Christian, John A.
Clemishaw, Charles W.
Clough, Auguste K.
Coneybear, Edna W.
Corr, James P.
Costa, Arthur
Craft, Ronald C.
Creighton, James E.
Crinkley, Kathryn L.
Crobar, John A.
Croft, Donald A.
Croft, Harold E.
Crouse, Porter A.
Dastous, Roland L.
Davis, Francis L.
Davis, Robert C.
Dean, Mildred W.
DeLisle, Homer R.
DeSanti, Judith C.
Dinsmore, Robertson P.
Dodge, William B.
Drew, Roberta E.
Eastman, Arthur C.
Eggleston, Fred S., Jr.
Fennelly, Cyril L.
Fernandes, Alice P.
Ferreira, Anthony
Ferreira, Steven R.
Field, Michael J.
Fleming, Ruthanne
Fontana, Victor F.
Fredriksen, Mauritz C.
Fuglister, Cecelia B.
Gallagher, William F.
Galvin, Yvonne S.
Gandy, Curtis, III
Gervais, Linda A.
Gibson, Laurence E.
Graham, Russell G.
Green, Nancy H.
Greenawalt, Charles A.
Greenawalt, Maureen A.
Grosvenor, Richard C.
Gunter, Carol A.
Halbert, John R., Jr.
Hatzikon, Kaleroy L.
Henry, Ann E.
Hindley, Robert J.
Holland, Howard A.
Ingram, Ruth C.
Jenkins, Delmar R.
Jenney, Philomena S.
Johnson, Harold W.
Joseph, Charles R.
Kelley, Robert F.
Kennedy, Percy L., Sr.
Korgen, Judith K.
Lajoie, Therese S.
LeBlanc, Donald F.
Lewis, Daniel M.
Livingston, Stella J.
Lobo, Wayne F.
Long, Shirley-Anne
Lowe, Robert G.
Lumsden, George W.
Magowan, Joan K.
Martin, Donald J.
Martin, Loretta M.
Martin, Olive
Masse, Roland G.
Matthews, Francis S.
Mayberry, Ernest H.
McClung, Philip E.
Medeiros, Frank
Meinert, Dorothy
Mendousa, Anthony G.
Mendousa, Tina C.
Merson, Carole R.
Mikolajczyk, Walter C.
Moniz, Mozart P.
Moore, Karen E.
Motta, Joseph F.
Muller, John T.
Murphy, Cheryl C.
Murphy, William E.
Oakes, Harry E.
Page, Stephen G.
Peters, Charles J., Jr.
Phares, Edward J.
Picard, Eleanor P.
Pocknett, Marie D.
Price, Nancy G.
Pucci, Joseph F.
Pykosz, Patricia A.
Quigley, Alexsandra
Ramsey, William S., Jr.
Reeves, Jeannette W.
Reeves, A. Stanley
Rennie, Thomas D.
Rice, John E.
Rioux, Robert R.
Ross, David F.
Rubino, Barbara J.
Rudden, R. David, Jr.
Ruffen, Kenneth T.
Sage, Eben A.
Schneider, Gloria F.
Sharpe, Michael S.
Simmons, Roland R.
Singer, Joseph M.
Smart, Charlotte M.
Smart, Thomas H.
Souza, Carol J.
Souza, Donald P.
Sprague, Evelyn M.
Staltare, Michelle E.
Stimpson, John W.
Stone, Louise D.
Swan, James A.
Tavares, Maurice J.
Thayer, Mary C.
Vallesio, Barbara M.
Walker, Jean D.
Weeks, Robert G.
White, Haskel E.
Whitmore, Wendy
Wildes, Nancy K.
Woodward, Fred C., Jr.
Woodward, Martin C.
Woodward, Ruth F.
Young, Carleton F.
Zmuda, Laura A.
Zwinakis, Jeffrey A.



**Full Time Employees

Afterdeck and bridge of R/V KNORR.

Marine Staff

Herbert L. Babbitt	Master, R/V ATLANTIS II
Richard H. Dimmock	Port Engineer
Richard S. Edwards	Marine Superintendent
Emerson H. Hiller	Master, R/V KNORR
Jonathan Leiby	Naval Architect
Stanley O. McDaniel	Chief Engineer, R/V CHAIN
Barrett H. McLaughlin	Chief Engineer, R/V KNORR
Michael Palmieri, Jr.	Master, R/V CHAIN
John F. Pike	Port Captain
Raymond H. Rioux	Chief Engineer, R/V ATLANTIS II

The following were in the employ of the Institution on December 31, 1974.

Marine Personnel

Allison, John W.
Bailey, James A.
Baker, William R.
Bauerlein, Gunter
Bazner, Kenneth E.
Bizzozero, John P.
Brennan, Edward J.
Brodrick, Edward R.
Bumer, John Q.
Butler, Dale T., Sr.
Casiles, David F.
Casiles, Phyllis B.
Clarkin, William H.
Clinton, Harry F.
Colburn, Arthur D., Jr.
Cotter, Jerome M.
D'Anjou, Peter J.
Devine, Kevin M.
Dunn, Arthur J.
Ellis, Floyd J.
Farnsworth, Donald C.
Flaherty, Peter M.
Flegenheimer, Richard C.
Flynn, Dana M.
Folsom, Kenneth R.
Fortes, Eugene B.
Frawley, J. Michael
Gassert, John M.
Gifford, C. Gregory
Gordon, Robert L.
Hartke, David L.
Howland, Paul C.
Jefferson, Albert C.
Johnston, Alexander T.
Kilbreth, Bernard E.
Leahy, James E.
Lineaweaver, Toby T.
Linehan, John F., Jr.
Lobo, John T.
Madison, William J., Jr.
Manley, Thomas F.
Martin, John W.
McAuliffe, J. Brian
Metzger, Donald J., Jr.
Moye, William E.
Munns, Robert G.
Murphy, George E.
Mysona, Eugene J.
Ocampo, Conrad H.
O'Neil, Thomas F.
O'Reilly, Peter P.
O'Toole, John E.
Pierce, George E.
Pierce, Samuel F.
Pope, Christopher M.
Ribeiro, Joseph
Rogers, Richard D.
Rougas, Harry
Sainz, Alfonso B.
Sepanara, James M.
Sequeira, Jorge A.
Small, Charles E.
Smith, Martin G.
Smith, Robert E.
Soucy, Trefton A.
Stack, William M.
Sture, Armas V.
Sweet, John K., Jr.
Sylvia, William L., Jr.
Vogel, Carl E.
Volovski, Donald S.
Warecki, Joseph

Fellows, Students and Visitors

Appendix II

Rossby Fellows

John C. Swallow (1973-74)
Institute of Oceanographic Sciences, England

Angus D. McEwan (1974-75)
Commonwealth Scientific and Industrial Research Organization, Victoria, Australia

Senior Fellows

Richard B. Bilder
Law School, University of Wisconsin-Madison

Edward L. Miles
Warburg Fellow
Center for International Affairs
Harvard University

Gunnar Randers
Former Assistant Secretary General for NATO

Postdoctoral Scholars

Awardees 1974-75

Syed A. Ali
Rensselaer Polytechnic Institute

Robert W. Griffith
Brooklyn College

Richard J. Hoffman
Stanford University

Laurence P. Madin
University of California at Davis

James R. Payne
University of Wisconsin

Brian D. Petrie
Dalhousie University, Canada

Graham M. Purdy
Cambridge University, England

Hsueh-Wen Yel
Case Western Reserve University

Marine Policy and Ocean Management

Scholars and Fellows 1974-75

David W. Allen
Oregon State University

Robert E. Black
Clark University

Dan Ciobanu
Harvard Law School
Fletcher School of Law and Diplomacy

James M. Friedman
University of Chicago Law School

Victor A. Gallardo
University of Southern California, Los Angeles
University of Rhode Island

Sayed Mohamed Hosni
Legal Petroleum Consultant, Kartoum, Sudan
New York University Law School

Lawrence G. Mallon
University of Miami Law School

Hugon Waldemar Niemotko
Columbia University School of Law
University of Poznan School of Law, Poland

Susan B. Peterson
University of Hawaii

Leah J. Smith
Johns Hopkins University

Jan-Olaf Willums
Massachusetts Institute of Technology

Woods Hole Doctoral Program

Thomas J. Goreau
California Institute of Technology

Philip M. Gschwend
California Institute of Technology

Andrew E. Jahn
University of California, Davis

Peter B. Ortner
Yale University

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

1974-75 Academic Year

James A. Austin, Jr.
Amherst College

Michael P. Bacon
Michigan State University

Marianne Betz-Wiser
University of Liege, Belgium

Douglas C. Biggs
Franklin & Marshall College

James K. B. Bishop
University of British Columbia, Canada

Edward A. Boyle
University of California, San Diego

Larry E. Brand
University of Texas

Scott R. Briggs
Brown University

Harry L. Bryden, Jr.
Dartmouth College

Kathryn A. Burns
Michigan State University

Richard H. Burroughs
Princeton University

Bradford Butman
Cornell University

Robert B. Campenot
University of California, Los Angeles

Alain Colin de Verdiere
Ecole de Physique Chimie de Paris, France

Jean Nichols Driscoll
Pomona College

James L. Durham
United States Naval Academy

Jonathan Erez
Hebrew University

Charles Eriksen
Harvard University

Eric Firing
Massachusetts Institute of Technology

Charles N. Flagg
Massachusetts Institute of Technology

Roger D. Flood
Massachusetts Institute of Technology

Wilford D. Gardner
Massachusetts Institute of Technology

M.I.T.-W.H.O.I. Joint Graduate Program (Continued)

JOY A. GEISELMAN
Carleton College
KENNETH E. GREEN
Massachusetts Institute of Technology
DALE B. HAIDVOGEL
Massachusetts Institute of Technology
PETER J. HENDRICKS
University of California, San Diego
ROSS M. HENDRY
University of Waterloo, Canada
ROBERT L. HOUGHTON
Hope College
ROBERT W. HOWARTH
Amherst College
SUSAN E. HUMPHRIS
University of Lancaster, England
RICHARD J. JAFFEE
Brown University
KUH KIM
Seoul National University, Korea
JOHN R. KREIDER
Lehigh University
GWEN GRABOWSKI KRIVI
Bucknell University
EDWARD P. LAINE
Wesleyan University
BRUCE W. LARSON
Southeastern Massachusetts University
KEVIN D. LEAMAN
University of Michigan
H. DAVID LESLIE
University of Wisconsin
STEVEN J. LEVERETTE
Gettysburg College
KEITH E. LOUDEN
Massachusetts Institute of Technology
DOUGLAS S. LUTHER
Massachusetts Institute of Technology
KENNETH C. MACDONALD
University of California, Berkeley
PAUL W. MAY
Southern Missionary College
TRACY K. MCLELLAN
Massachusetts Institute of Technology
AURELIO MERCADO, JR.
University of Puerto Rico
MARLENE A. NOBLE
Princeton University
C. GREGORY PARIS
Rensselaer Polytechnic Institute
JAN A. PECHENIK
Duke University
JOHN W. PEIRCE
Dartmouth College
KENNETH A. POEHLS
University of California, Los Angeles
DAVID L. PORTER
University of Maryland
JAMES G. RICHMAN
Harvey Mudd College
GEORGE RODENBUSCH
Rice University
BARRY R. RUDDICK
University of Victoria, Canada
EDMUND SAMBUCO
Johns Hopkins University
RICHARD S. SCHABOWSKY
University of Rhode Island
SUSAN SCHULTZ TAPSCOTT
Swarthmore College
MARY I. SCRANTON
Mount Holyoke College
JOHN S. SHIH
Stanford University
ALEXANDER N. SHOR
Harvard University
ROBERT F. STALLARD
Massachusetts Institute of Technology
NICHOLAS S. STARESINIC
University of Pittsburgh
DANIEL H. STUERMER
University of California, Santa Barbara
PAUL F. SULLIVAN
United States Naval Academy
WILLIAM G. SUNDA
Lehigh University
NEIL R. SWANBERG
University of California, Davis
CHRISTOPHER R. TAPSCOTT
Princeton University
JOHN S. TOCHKO
The Cooper Union
KEVIN M. ULMER
Williams College
JOHN KIM VANDIVER
Massachusetts Institute of Technology
GEORGE T. F. WONG
California State College
ROBERT A. YOUNG
Brooklyn College

Summer Student Fellows, 1974

BRADFORD C. BERK
Amherst College
ADAM B. BORISON
Yale University
CAROL ANN BROWN
Baylor University
LAWRENCE P. BURKHARD
Pennsylvania State University
PETER G. DOYLE
Harvard University
DOREEN L. FUNDILLER
State University of New York, Stony Brook
DENISE C. GAUDREAU
Brown University
COLLEEN A. HOGAN
Mount Holyoke College
SARAH G. HORRIGAN
Carleton College
LISA A.LEVIN
Harvard University
JULIE ANN MILLIGAN
Colgate University
DAVID M. RIPER
Pennsylvania State University
KARINE K. ROMINE
University of Georgia
AILEEN M. SCHUMACHER
New Mexico State University
WINDSOR SUNG
Massachusetts Institute of Technology
JOHN M. TOOLE
University of Maine
ELIZABETH C. WALKER
Hampshire College

Geophysical Fluid Dynamics Summer Seminar

Staff Members and Lecturers:

JAMES ANDERSON
Stevens Institute of Technology

JOHN BENNETT
NOAA, Rockville
Maryland

KIRK BRYAN
Princeton University

FRIEDRICH H. BUSSE
University of California, at Los Angeles

LOUIS N. HOWARD
Massachusetts Institute of Technology

VLADMIR M. KAMENKOVITCH
Institute of Oceanology, Moscow, USSR

JOSEPH B. KELLER
Courant Institute of Mathematical
Sciences, N.Y.U.

WILLEM V. R. MALKUS
Massachusetts Institute of Technology

CHRISTOPHER N. K. MOOERS
University of Miami

DENNIS W. MOORE
Nova University

GEORGE NEEDLER
Bedford Institute, Dartmouth, Nova Scotia

PEARN P. NIILER
Nova University

PETER B. RHINES
Woods Hole Oceanographic Institution

EDWARD A. SPIEGEL
Columbia University

MELVIN E. STERN
University of Rhode Island

J. STEWART TURNER
University of Cambridge, England

GEORGE VERONIS
Yale University

PIERRE WELANDER
University of Washington

JOHN A. WHITEHEAD
Woods Hole Oceanographic Institution

Fellows:

LAURENCE D. ARMI
University of California at Berkeley

KENNETH H. BRINK
Yale University

JOSEPH R. BUCKLEY
University of British Columbia, Canada

MARK A. CANE
Massachusetts Institute of Technology

ALLAN J. CLARKE
Cambridge University, England

ROBERT E. HALL
University of California at San Diego

ROSEMARY G. KENNETT
California Institute of Technology

MARK KOENIGSBERG
Massachusetts Institute of Technology

KARL E. TAYLOR
Yale University

JÜRGEN WILLEBRAND
University of Kiel, Germany

Visiting Scholars

DR. ROBERT A. BERNER
Yale University

DR. STANLEY CORRSIN
Johns Hopkins University

DR. SYLVIA EARLE
Los Angeles County Museum of Natural History

DR. WILLIAM C. HERONEMUS
University of Massachusetts

DR. JOHN ISAACS
Scripps Institution of Oceanography

DR. JAMES J. MORGAN
California Institute of Technology

DR. KENNETH S. NORRIS
University of California, Santa Cruz

DR. E. R. OXBURGH
Oxford University, England

DR. SEIYA UYEDA
Earthquake Research Institute
University of Tokyo

Visiting Investigators

HERMAN FRANSSEN
Fletcher School of Law and Diplomacy
Tufts University

ANDREW A. FEJER
Illinois Institute of Technology

CLAUDE FRANKINGNOUL
University of Liege, Belgium

HERBERT E. HUPPERT
Cambridge University, England

LAURENT O. LABEYRIE
University of Paris, France

PAUL C. MANGELSDORF
Swarthmore College

JOHN D. MOODY
Falmouth High School

JAMES F. O'SULLIVAN, JR.
Massachusetts Institute of Technology/
Woods Hole Oceanographic Institution

ISABELLA PREMOLI-SILVA
Institute of Paleontology, State University, Italy

BRYCE PRINDLE
Babson Institute

FRIEDRICH A. SCHOTT
Institut für Meereskunde, Kiel, Germany

HERBERT H. UHLIG
Massachusetts Institute of Technology

CHENG YI YANG
University of Delaware

WILLIAM W. YOUNGBLOOD
Florida Technological University

WALTER ZENK
Institut für Meereskunde
Kiel, Germany

Guest Investigators

JELLE ATEMA
Boston University
HENYO T. BARRETTO
Petroleo Brasileiro S. A. Petrobrás, Brasil
HAROLD L. BURSTYN
William Paterson College
RONALD COMEAU
University of New Hampshire
JAIRO M. DA ROCHA
Compañhía de Pesquisa de Recursos Minerais
Brasil
VASILE DIACONU
Romanian Institute for Marine Research
Constantza, Romania
KONSTATIN N. FEDEROV
Institute of Oceanology, Moscow, USSR
MICHELE FIEUX
Museum of Natural History
Laboratory of Physical Oceanography, Paris
Massachusetts Institute of Technology
RICHARD A. FRALICK
University of New Hampshire
A. JANE GIBSON
Cornell University
WALTER GIGER
Swiss Federal Institute for Water Resources and Water Pollution Control, Switzerland
JOHN J. GOERING
University of Alaska
WILLIAM J. GOULD
Institute of Oceanographic Sciences, England
GORDON L. HENDLER
University of Connecticut
DAVID C. JUDKINS
Scripps Institution of Oceanography
VLADIMIR M. KAMENKOVITCH
Institute of Oceanology, Moscow, USSR
PETER KILHAM
University of Michigan
BARBARA JEAN KING
Fairleigh Dickinson University
MIKHAIL KOSHLYAKOV
Institute of Oceanology, Moscow, USSR
STUART L. KUPFERMAN
University of Delaware
THEODORE G. METCALF
University of New Hampshire
ROBERT E. MOONEY
University of New Hampshire
GEOFFREY K. MORRISON
Institute of Oceanographic Sciences, England
W.R.A. MUNTZ
University of Sussex, England
JOSEPH PEDLOSKY
University of Chicago
OMAR ROCHA DO PRADO
Universidade de São Paulo, Brasil
MICHELE REGNAULT
Museum d'Histoire Naturelle, Paris, France
GEORGE V. SALOMIE
Romanian Institute for Marine Research
CARLOS I. SANTANA
Compañhía de Pesquisa de Recursos Minerais
Brasil
LUCILLE SHAPIRO
Albert Einstein College of Medicine
MARY SWALLOW
Institute of Oceanographic Sciences, England
MARCO A. VICALVI
Departmento Nacional da Produção Mineralis
Brasil
LUIZ O. VIEIRA
Petroleo Brasileiro S. A. Petrobrás, Brasil
TIMOTHY C. WILLIAMS
State University of New York, Buffalo
EDWARD ZYZNAR
University of Montreal, Canada

Guest Students

ALISON S. AMENT
University of Pennsylvania
SUSAN L. ANDREW
Middlebury College
RICHARD D. BRODEUR
University of Massachusetts
CHARLES F. BRUSH
Norwich Senior High School, New York
RICHARD E. CHAISSON
University of Massachusetts
MEREDITH COMMONS
University of Massachusetts
MARGARET L. DARCY
University of Massachusetts
PAUL G. DAVIS
University of Massachusetts
CLAIRE L. DONAHUE
University of Massachusetts
THOMAS FAHEY
Lawrence Academy
PAMELA GORDON
Colby College
R. TABER HAND
Pomona College
BRUCE F. HARTLEY
University of Massachusetts
PATRICIA S. HIBBERT
University of Massachusetts
JODIE L. HURWITZ
Mount Holyoke College
SUSAN G. INGALLS
University of Massachusetts
RUSSELL V. IULIANO
Browne and Nichols High School, Cambridge
KATHRYN E. KING
University of Massachusetts
CHARLES A. LAWS
Harvard University
LAWRENCE A. LAWVER
Scripps Institution of Oceanography
VALERY E. LEE
Massachusetts Institute of Technology
DAVID LEIBOWITZ
University of North Carolina
JOSEPH S. LEVINE
Boston University Marine Program
JEFFREY LEWIS
George School, Newtown, Pennsylvania
SHERRY W. MACLAY
Pomona College
SHIRLEY MATHIS
Operation Mainstream Volunteer
Chatham, Massachusetts
R. SCOTT MCKENZIE
Massachusetts Institute of Technology
PETER M. MCSHERRY
Governor Dummer Academy
FREDERICK M. MENCHER
Harvard University
PAUL NEWMAN
Roslyn High School, New York
DOMINICK V. NINIVAGGI, II
Southampton College of Long Island University
ARLEEN O'DONNELL
University of Massachusetts
DAVID J. O'NEILL
University of Rhode Island
BARBARA PLASMAN
Wells College
L. KENNETH ROSENTHAL
Massachusetts Institute of Technology
BRUCE T. RANKIN
Hawken School, Gates Mills, Ohio

Guest Students (continued)

TERESA RAUTIO
Ithaca College

GREG A. REDMANN
Harvard University

KENNETH R. SIMMONS
University of Massachusetts

DAVID H. SIMSER
University of Massachusetts

KAIGHN SMITH, JR.
St. Paul's School, New Hampshire

PATTI K. SMITH
Hampshire College

ALLISON SNOW
University of Massachusetts

JEFFREY STAR
Massachusetts Institute of Technology

DENISE R. STOLL
Boston University Marine Program

JEFFREY L. THIELKER
University of Delaware

EDWARD J. TIERNEY
University of Massachusetts

PETER A. UNDERHILL
California State University, Humboldt

ELIZABETH C. WALKER
Hampshire College

LINDA M. WITT
University of Massachusetts

Jake Hornor Traineeship

LAURA A. NIELSEN
Mt. Abraham Union High School

Lawrence High School Scholarship

JOHN J. FARRELL, JR.
University of Notre Dame

Publications 1974* *Appendix III*

No. 2474. RON W. GIRDLER, AL J. ERICKSON and RICHARD VON HERZEN. Downhole Temperature and Shipboard Thermal Conductivity Measurements Aboard D/V *Glomar Challenger* in the Red Sea. *Initial Repts, Deep-Sea Drilling Proj.* 23:879-886. 1974.

No. 2504. J. G. NIKELLY and MAX BLUMER. Laboratory-made Porous Layer Open Tubular Gas Chromatography Columns. *Amer. Lab.* 6:12-15. 1974.

No. 2624. R. R. L. GUILLARD, EDWARD J. CARPENTER and BERNHARD E. F. REIMANN. *Skeletonema menzelii,* sp. nov., a New Diatom from the Western Atlantic. *Phycologia* 13(2):131-138. 1974.

No. 2653. JOHN M. HUNT. Hydrocarbon and Kerogen Studies. *Initial Repts, Deep-Sea Drilling Proj.* 22:673-675. 1974.

No. 2679. P. G. BREWER, R. A. HORNE and T. R. S. WILSON. Water Constituent Sensors. In: *Geoscience Instrumentation,* Wolf and Mercandi, editors, Wiley 530-544. 1974.

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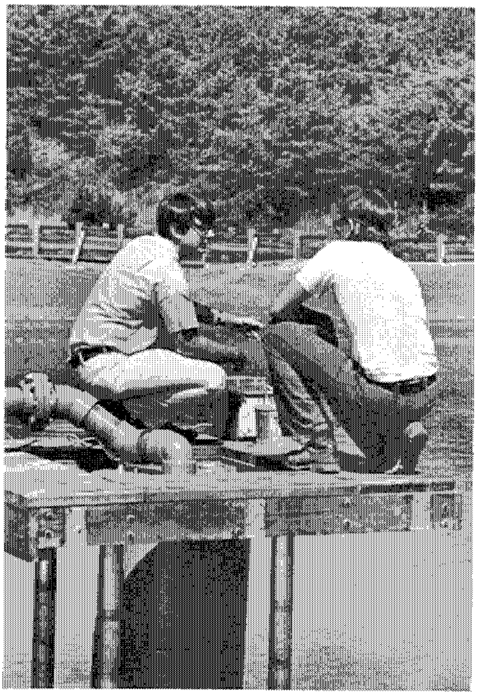
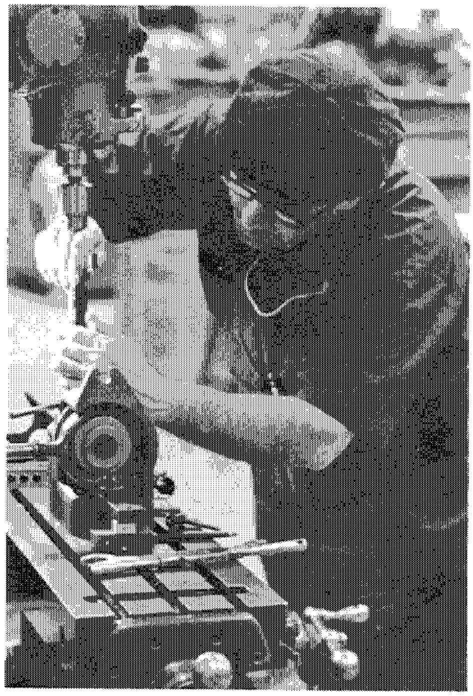


Lagoon of treated sewage for spray irrigation.



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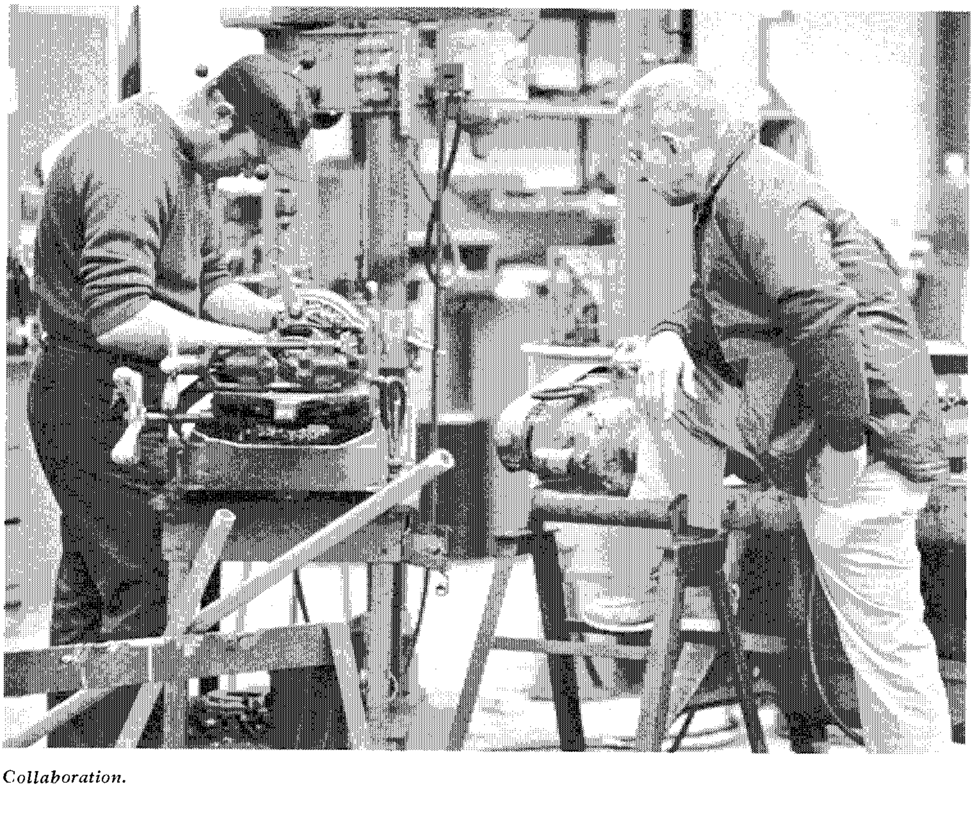
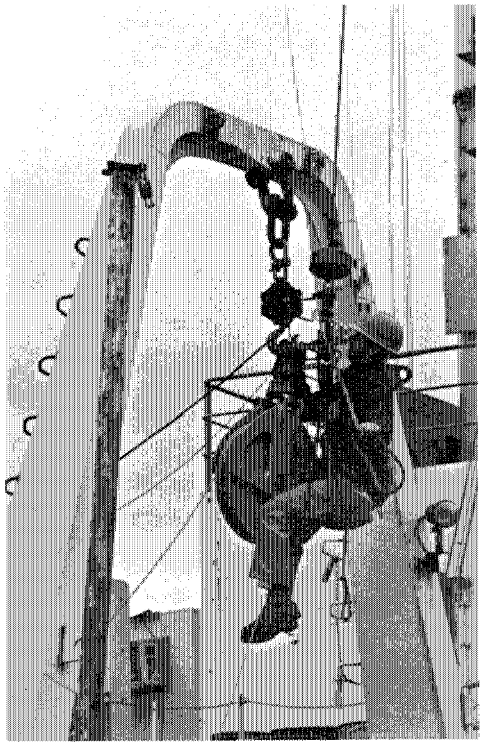
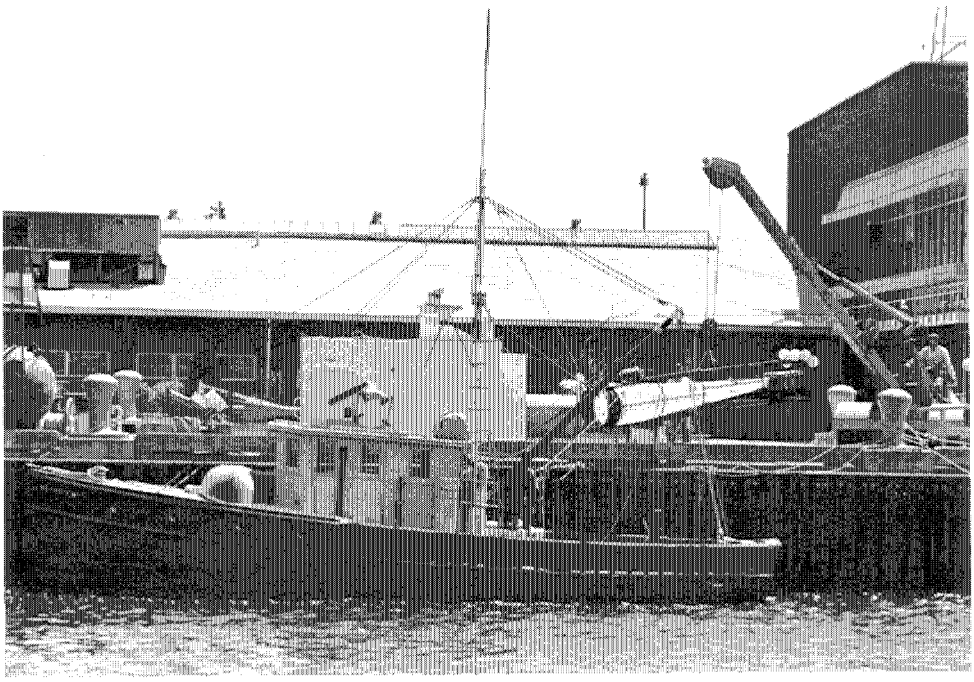


Collaboration.

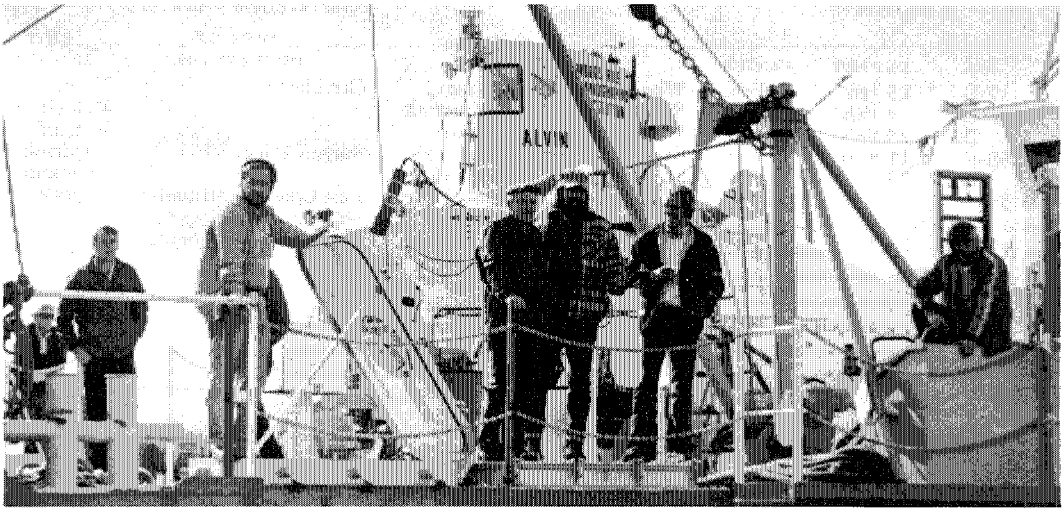
Air compressor for sound production in seismic work.



Mounting sheave on A-frame.



ASTERIAS — our senior research vessel.



Voyage Statistics for 1974

Appendix IV

R/V ATLANTIS II

Total Nautical Miles for 1974 — 31,418

VOYAGE NO.	DEPART	ARRIVE	PORTS		AREA OF OPERATIONS	CHIEF SCIENTIST
80	13 Jan	14 Jan	Staten Island	Woods Hole	Return from shipyard	
81	1 Feb	8 Feb	Woods Hole	Woods Hole	Continental Shelf	Harvey
82-0	19 Feb	3 Mar	Woods Hole	Las Palmas	Northwest Coast of	Kelley
I	6 Mar	25 Mar	Las Palmas	Las Palmas	Africa Shelf Waters	Dugdale
II	29 Mar	10 Apr	Las Palmas	Nouadhibou		Kelley
	11 Apr	16 Apr	Nouadhibou	Las Palmas		Kelley
III	20 Apr	12 May	Las Palmas	Las Palmas		Barber
IV	15 May	29 May	Las Palmas	Las Palmas		Haedrich
V	1 Jun	4 Jun	Las Palmas	Dakar	Transit to Dakar	Piety
83-I	8 Jun	3 Jul	Dakar	Recife	S. Equatorial Waters	Katz
II	6 Jul	30 Jul	Recife	Bridgetown	Brazilian Waters	Katz
84	7 Aug	22 Aug	Bridgetown	Woods Hole	Sargasso Sea	Carpenter
85-I	26 Aug	12 Sep	Woods Hole	St. George's	New England Seamounts	Thompson
II	14 Sep	16 Sep	St. George's	St. George's	and Bermuda Waters	Farrington
	16 Sep	24 Sep	St. George's	St. George's		Farrington
III	26 Sep	8 Oct	St. George's	St. George's	Sargasso Sea	Teal
IV	12 Oct	23 Oct	St. George's	Woods Hole	Continental Shelf	Wiebe

R/V CHAIN

Total Nautical Miles for 1974 — 38,316

VOYAGE NO.	DEPART	ARRIVE	PORTS		AREA OF OPERATIONS	CHIEF SCIENTIST
115-II		10 Jan	Dakar	Cape Town	Antarctic South of Cape	Summerhayes
III	14 Jan	11 Feb	Cape Town	Cape Town	of Good Hope	Bowin
IV	15 Feb	15 Mar	Cape Town	Cape Town		Hoskins
V	23 Mar	18 Apr	Cape Town	Rio de Janeiro	South Atlantic Crossing	Sayles
VI	22 Apr	14 May	Rio de Janeiro	Rio de Janeiro	Brazilian Coast	Johnson
	14 May	18 May	Rio de Janeiro	Recife		Johnson
VII	22 May	29 May	Recife	Fortaleza		Milliman
	1 Jun	22 Jun	Fortaleza	Bridgetown		Milliman
IX	24 Jun	1 Jul	Bridgetown	Woods Hole	Sargasso Sea	McDowell
116	22 Jul	10 Aug	Woods Hole	Woods Hole	Buoy Line	Heinmiller
117-I	15 Aug	29 Aug	Woods Hole	Miami	East of Bahamian Shelf	Spindel
II	2 Sep	20 Sep	Miami	Miami		Porter
III	26 Sep	27 Sep	Miami	Key West		Nowak
	27 Sep	15 Oct	Key West	St. George's		Nowak
IV	20 Oct	12 Nov	St. George's	St. George's	Bermuda Waters	Stanbrough
V	14 Nov	17 Nov	St. George's	Woods Hole		Stanbrough

COOPERS & LYBRAND

CERTIFIED PUBLIC ACCOUNTANTS

To the Board of Trustees of

Woods Hole Oceanographic Institution:

We have examined the balance sheet of Woods Hole Oceanographic Institution as of December 31, 1974, and the related statements of current fund revenues, operating expenses and transfers, and changes in fund balances 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. We previously examined and reported upon the financial statements for the year ended December 31, 1973.

In our opinion, the aforementioned financial statements (with investments stated at market) (pages 85 to 87 inclusive) present fairly the financial position of Woods Hole Oceanographic Institution at December 31, 1974 and 1973, its current fund revenues, operating expenses and transfers for the years then ended, and the changes in its fund balances for the year ended December 31, 1974, in conformity with generally accepted accounting principles applied on a consistent basis after restatement for the change, with which we concur, in the method of accounting for investments as described in Note C to the financial statements.

The supplemental schedule included in this report (page 88), although not considered necessary for a fair presentation of the financial position and current fund revenues, operating expenses and transfers, is presented primarily for supplemental analysis purposes. This additional information has been subjected to the audit procedures applied in the examination of the basic financial statements and, in our opinion, is fairly stated in all material respects in relation to the basic financial statements taken as a whole.

Boston, Massachusetts
March 28, 1975

Coopers & Lybrand

BALANCE SHEETS

December 31, 1974 and 1973

ASSETS

	1974	1973
Current Fund Assets:		
Cash	$ 61,603	$ 108,232
Short-term investments, at market which approximates cost	400,000	3,100,000
Reimbursable contract and grant costs:		
Billed	1,687,213	401,358
Unbilled	1,464,678	1,584,474
Supplies, prepaid expenses and deferred charges	529,045	486,256
Due from (to) plant funds	214,586	(1,236,175)
Due from endowment funds	87,022	163,835
	4,444,147	**4,607,980**
Endowment Fund Assets (Notes A and C):		
Investments:		
Securities, at market (cost $31,196,321 in 1974 and $32,441,017 in 1973)	25,329,483	35,448,593
Real estate	49,234	51,023
	25,378,717	35,499,616
Cash (including certificate of deposit of $100,000 in 1973)	53,473	329,116
Other assets	11,037	14,227
Due to current fund	(87,022)	(163,835)
Due from plant funds	1,250,000	—
	26,606,205	**35,679,124**
Annuity Fund Assets (Note B):		
Investments, at market (cost $94,453)	63,440	—
Cash	1,125	—
	64,565	—
Plant Fund Assets (Notes A and F):		
Laboratory, plant and equipment	15,436,409	7,051,048
Atlantis II (Note A)	4,831,130	4,831,130
Other vessels, equipment and property	3,530,450	3,575,404
Construction in progress	314,485	4,883,789
	24,112,474	20,341,371
Less accumulated depreciation	5,488,780	4,994,952
	18,623,694	15,346,419
Due (to) from current fund	(214,586)	1,236,175
Due to endowment funds	(1,250,000)	—
	17,159,108	**16,582,594**
	$48,274,025	**$56,869,698**

LIABILITIES AND FUND BALANCES

	1974	1973
Current Fund Liabilities and Balances:		
Accounts payable and other accrued expenses	$ 864,407	$ 894,516
Accrued vacation	569,146	561,806
Contribution payable to employees' retirement plan and trust (Note E)	204,000	175,000
Unexpended balances of restricted gifts and grants	1,235,560	1,565,664
Current fund balance designated for:		
Income and salary stabilization	1,445,895	1,354,509
Working capital and contingency	125,139	56,485
	4,444,147	**4,607,980**
Endowment Funds (Notes A and C):		
Restricted as to principal and income	16,553,846	21,751,006
Restricted as to principal	4,873,241	6,729,452
Unrestricted as to principal; restricted as to income	4,991,861	6,961,638
Unrestricted as to principal and income	187,257	237,028
	26,606,205	**35,679,124**
Annuity Fund Liabilities and Balance (Note B):		
Annuities payable	36,660	—
Fund balance	27,905	—
	64,565	—
Plant Funds (Note F):		
Invested in plant, less retirements	24,112,474	20,341,371
Less accumulated depreciation	5,488,780	4,994,952
	18,623,694	15,346,419
Unexpended (overexpended) (Note F)	(1,464,586)	1,236,175
	17,159,108	**16,582,594**
	$48,274,025	**$56,869,698**

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

Supplemental Schedule

Summary of Endowment and Annuity Assets

as at December 31, 1974

	Book Amount	% of Total	Market Quotation	% of Total
ENDOWMENT FUND ASSETS**				
SEPARATELY INVESTED (FUNDS RESTRICTED AS TO PRINCIPAL AND INCOME):				
BONDS	$ 5,798,067	29.4	$ 5,412,010	32.7
COMMON STOCKS	12,684,259	64.2	9,888,461	59.7
CASH	3,375	.1	3,375*	.1
DUE FROM PLANT FUNDS	1,250,000	6.3	1,250,000*	7.5
TOTAL	**19,735,701**	**100.0**	**16,553,846**	**100.0**
POOLED INVESTMENTS:				
BONDS	6,078,072	47.4	5,424,409	53.5
COMMON AND PREFERRED STOCKS	6,635,923	51.7	4,604,603	45.4
REAL ESTATE	49,234	.4	49,234*	.5
CASH	50,098	.4	50,098*	.5
OTHER ASSETS	11,037	.1	11,037*	.1
TOTAL	**12,824,364**	**100.0**	**10,139,381**	**100.0**
DUE TO CURRENT FUND	(87,022)		(87,022)*	
TOTAL ENDOWMENT FUND ASSETS	**$32,473,043**		**$26,606,205**	
ANNUITY FUND ASSETS**				
BONDS	20,322	21.3	20,800	32.2
COMMON STOCKS	74,131	77.6	42,640	66.1
CASH	1,125	1.1	1,125*	1.7
TOTAL ANNUITY FUND ASSETS	**$ 95,578**	**100.0**	**$ 64,565**	**100.0**

Note: Investments in securities traded on a national securities exchange are valued at the last reported sales price on December 31, 1974; securities traded in the over-the-counter market and listed securities for which no sales prices were reported on December 31, 1974 are valued at closing bid prices. Prices are then rounded to the nearest whole point.

*At book amount.

**See Note A to the financial statements.