# research in the sea



WOODS HOLE OCEANOGRAPHIC INSTITUTION
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Today, man must learn how to understand and use the vast resources of the oceans in all their depth and scope, through ways undreamed of by the great explorers of the past. To assist in this understanding and to explain something of the work of the Woods Hole Oceanographic Institution, we have prepared this booklet. In it, we tell a little of our history, something about our people and methods of oceanography, as well as present a brief resume of recent scientific work. Our goal over the years has been to observe, describe, measure and understand all the phenomena within the Earth's waters, as well as in the atmosphere above and the earth beneath. Herein, we record a little of the progress toward this goal.

Paul M. Fye

PAUL M. FYE
DIRECTOR

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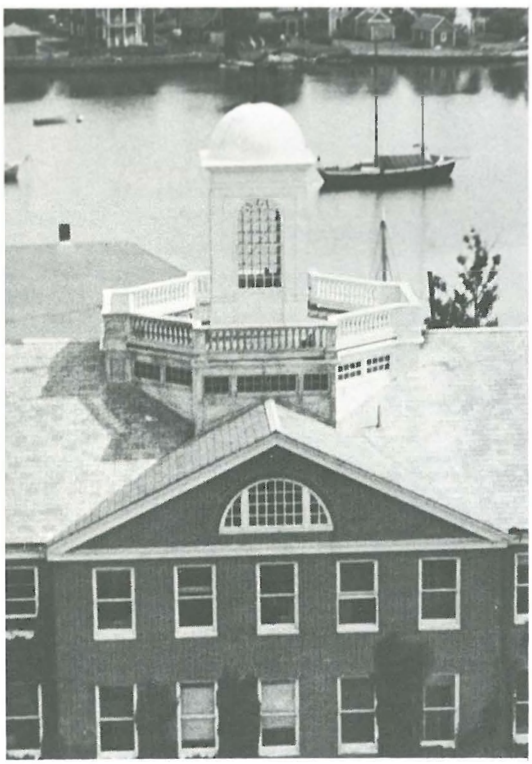
# THE INSTITUTION

Only a little more than a quarter of the surface of Earth, the Water Planet, emerges from its blanket of ocean. But while the resources of the land have been extensively utilized — and, in some cases, completely exhausted — those of the seas have barely been tapped. The oceans teem with protein-rich marine life. Bromine, magnesium, and other valuable chemicals can be extracted from sea water. Along the bottom, minerals such as cobalt and manganese are strewn in prolific deposits, and beneath the sediments bacterial decay of age-old organisms is thought to have produced huge pools of oil. Tides, rising and falling by as much as fifty feet in some locations, suggest a simple source of hydroelectric power. If man ever licks the problem of fusing atoms in the laboratory, sea water could supply his anticipated fuel requirement for millions of years.

Yet the study of the oceans has always been a neglected science. It is a well-worn cliche these days that the near face of the Moon is far better studied than our own plant's ocean bottom, and indeed it is. Nearly 60 per cent of the Moon's cratered surface has been intimately viewed, photographed and mapped under varying light conditions, while only some 2 per cent of the Earth's ocean bottoms has been charted in satisfactory detail.

***THE CORNERSTONE*** Although the curiosity of a few early scientists extended to a study of the sea (among others, Aristotle made an attempt to describe the physical forces of the ocean and Isaac Newton to explain waves and tides in mathematical terms), it was not until the 19th Century that basic research really began, and only in 1927 the National Academy of Sciences formed its first committee on oceanography.



In writing up an advisory report for the committee, Henry Bryant Bigelow, a Harvard Zoologist, made note of the work of one of his graduate students, Columbus O'Donnell Iselin, who had gone to sea on a small schooner with some of his fellow students and returned with valuable oceanographic data, and of the work of the small Norwegian research vessel ARMAUER HANSEN. The Academy committee was delighted to hear that huge ships — and huge sums of money — were not necessarily required for oceanographic research. As one of its recommendations it suggested to the Rockefeller Foundation that an independent oceanographic institution be established on the East Coast. The Foundation granted $3,000,000 to endow and outfit such an institution and provide it with a research vessel.

In 1930, the charter of the Woods Hole Oceanographic Institution was drawn up "to prosecute the study of oceanography in all its branches. . ." and Bigelow became its first Director. In the three decades since, the Institution has grown tenfold, largely due to the marriage of convenience between oceanographers and the military during World War II, when the Navy realized its dependency on oceanographers and basic oceanographic data for certain phases of its operations.

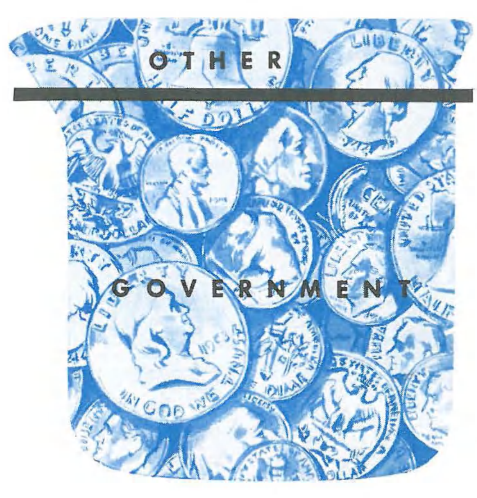
The Woods Hole Oceanographic Institution began as a summer laboratory with one ship and a handful of full-time scientific staff members. It is now a year-round laboratory of two buildings with a permanent staff of 325, five sea-going vessels, and an annual budget somewhat larger than its original endowment.

Moreover, a National Academy Committee is once again urging expansion if oceanography is to keep up with other branches of science. A program recently announced by the Academy's committee (which includes Dr. Iselin) urges a ten year expenditure of 651 million dollars to bring ships, facilities, and scientific staff up to an adequate level.

***EXPANSION INFLATION*** Expansion has brought its problems, and they are liable to intensify in the next decade. The Institution was founded on the premise that oceanography should be largely funded by private means, but there have been no substantial gifts to endowment since 1930. As a result, some 90 per cent of the annual budget is paid for by the government, most of it by the Navy. The remaining 10 per cent is income from endowment and contributions by members of the Associates. Additional memberships are available to both individuals and corporations, and this type of association has grown dramatically in recent years. However, the income from this source remains a small fraction of what is obtained from government contracts.

Inflation has made matters worse. It now may cost as much to repair ATLANTIS (launched in 1930 at a cost of $218,000) as it did to build her. Expenditures to keep her at sea for an operating year run to $250,000. Oceanographers simply could not go far out to sea without government support. The result is that much of the work done at the Institution is on a contract basis and is devoted to applied research problems. Basic research, the collection of data, and the "gambles" in all the other branches of oceanography must operate on a relatively small budget despite the considerable foresight shown by the Office of Naval Research in funding research for its own sake.

"Only a few great expeditions have been prompted by simple inquisitiveness" wrote Dr. William S. von Arx, a physical oceanographer at the Institution. "Most of our endeavors, especially for reasons of military necessity, have been approached in such a single-minded fashion that the yield beyond the questions initially asked has been small."




There is a general awareness of this problem, however, and increasing pressures are being applied from various directions to insure adequate funds to support less restricted research activity. The IGY oceanography program is one example. Although such activity at a government level will undoubtedly be beneficial to the Institution, it has become increasingly apparent that funds from outside sources are necessary to maintain the freedom of inquiry so essential to an academic institution.

## THE SHIPS

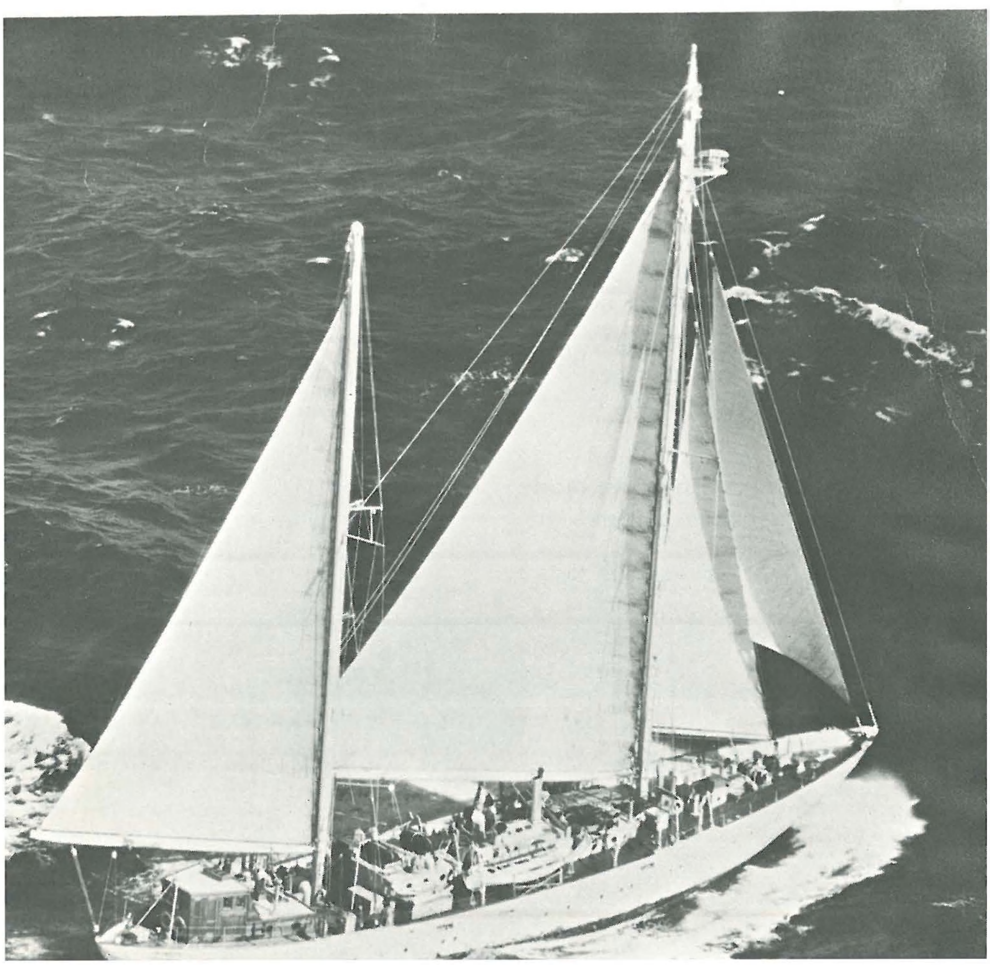
Drawing from his experiences on several oceanographic cruises, Dr. Iselin helped Dr. Bigelow plan the ATLANTIS, a 142-foot steel hulled ketch, then skippered her back from Copenhagen where she was built. For thirty years ATLANTIS was one of the very few ships designed and built from the keel up for oceanographic research.

Since 1930, ATLANTIS has cruised some 1,200,000 miles over the Earth's oceans, nearly four times the distance to the Moon. During the average year she is at sea for some 250 days, and often covers more than 20,000 miles in a single cruise.

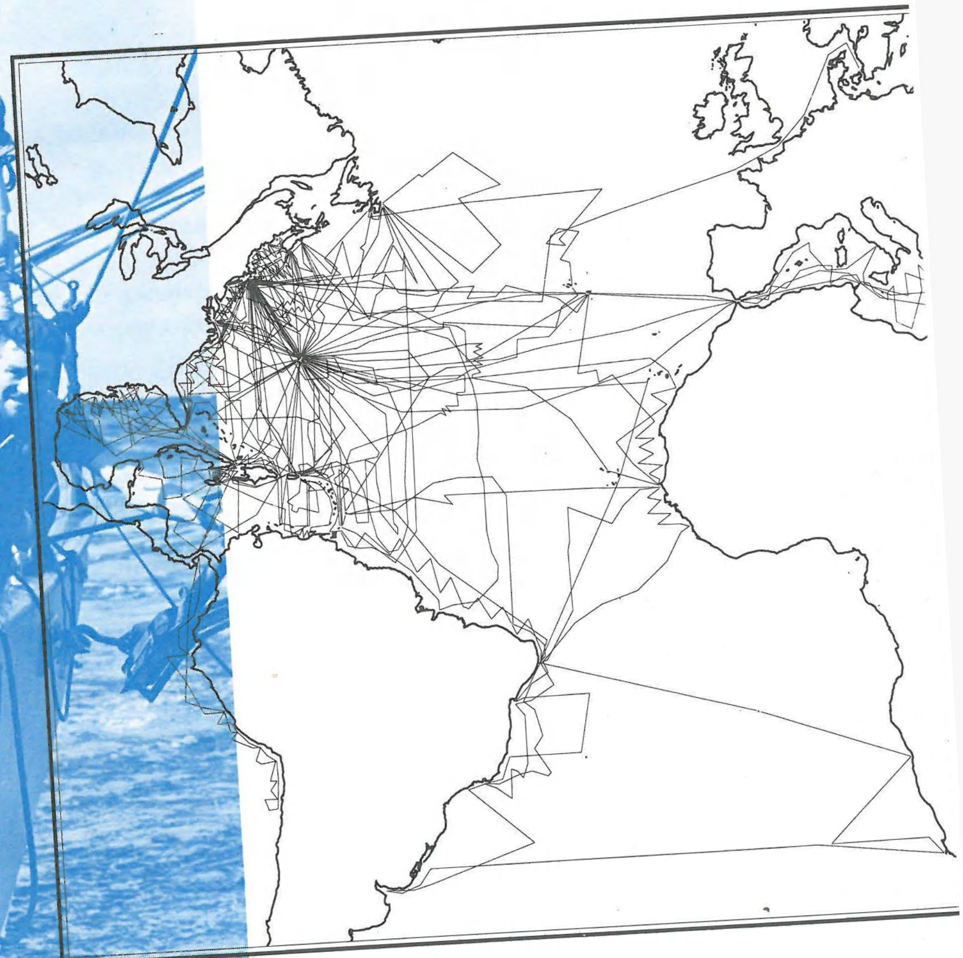
The rest of the Institution's fleet has been recruited over the years from converted yachts and military vessels. They are no substitute for ships especially tailored to the exacting demands of oceanography, though the work they are capable of performing is essential. Currently, the fleet totals four additional deep sea vessels: BEAR is a 110-ton converted Army transport. The tiny ship recently made an important contribution to the search for a likely Mohole site near the deep trench off Puerto Rico; CRAWFORD, a converted C.G. cutter, completed seven transverse sections of the North and South Atlantic Oceans during the International Geophysical Year; ARIES, a 93-ton ketch, recently acquired by the Institition through the generosity of Associate R. J. Reynolds, is now stationed at Bermuda where she is charting deep circulation patterns.

The largest of the Institution vessels is the 213-foot CHAIN, a 1,800-ton rescue and salvage ship taken out of mothballs by the Navy and converted for oceanographic research under the direction of the Institution's staff at a cost of $700,000.

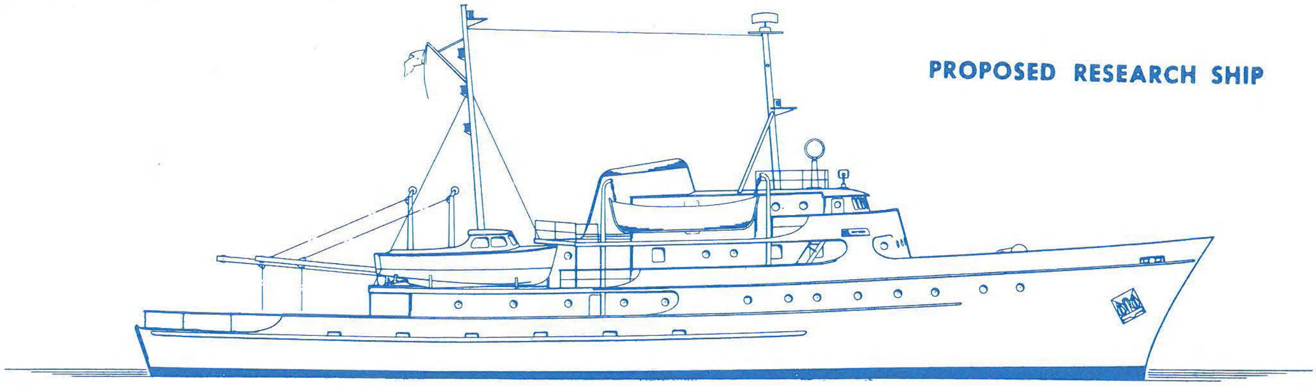
CHAIN carries a complement of 27 scientists, compared to 9 on ATLANTIS, and her laboratory space is a vast improvement on the



R V ATLANTIS



ATLANTIS' 1,200,000 MILES



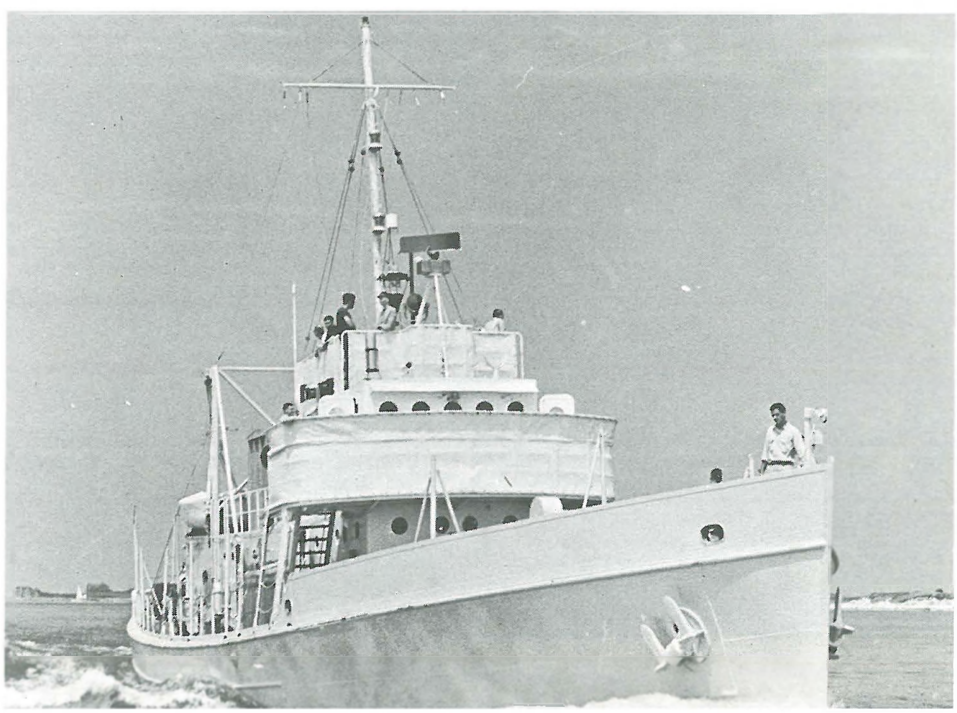
PROPOSED RESEARCH SHIP

cramped scientific quarters of the other ships. She has proved extremely useful, not only in acoustics and geophysical work, but in physical ocean-orgraphy as well.

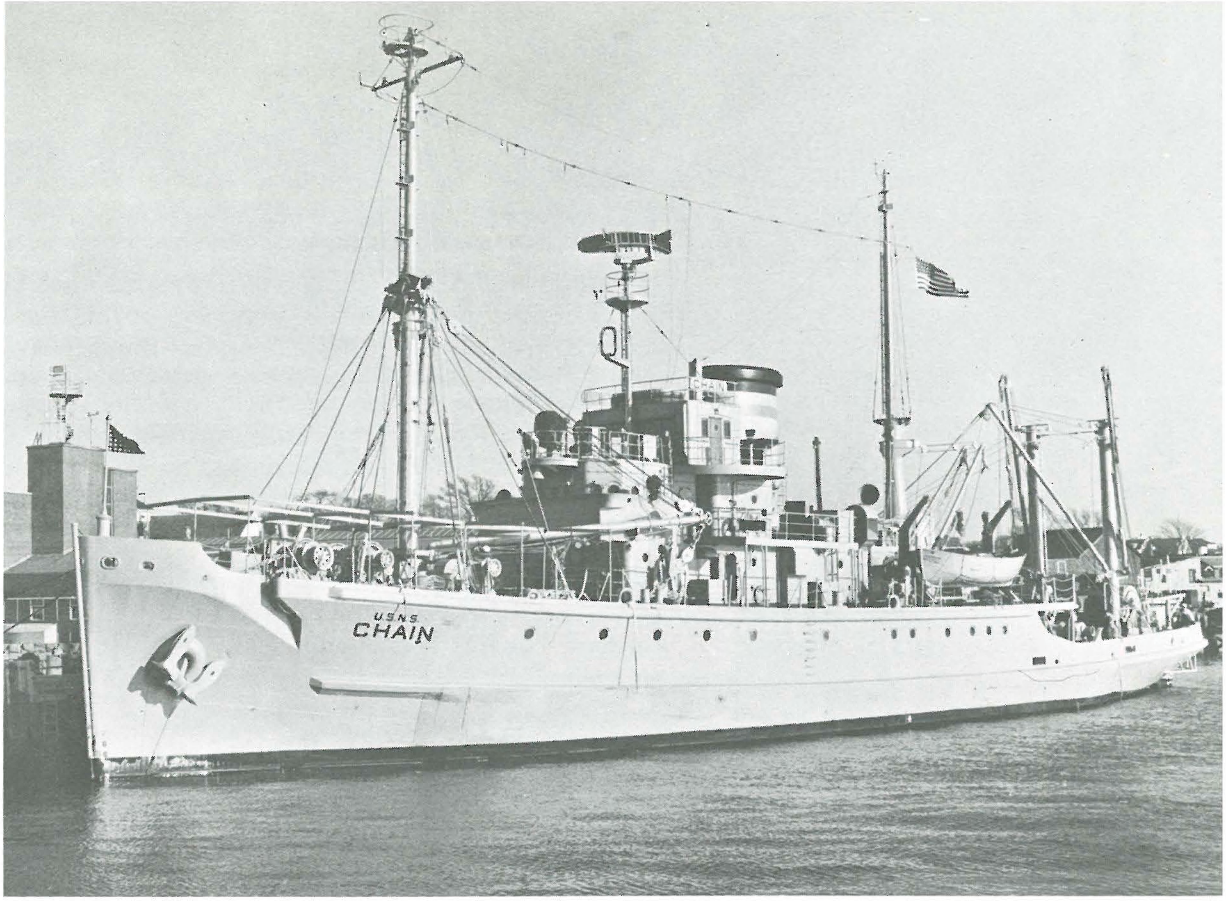
The Navy also has plans for a series of vessels designed from scratch for oceanographic duties. In 1961 the first of these 1,100-ton SCB-185s may be ready. If the recommendations of the National Academy of Scientists are carried out, the future looks even brighter. The Academy has recommended that no less than 70 additional oceanographic vessels be built in the period of 1960-1970 at a cost of $213,000,000, and that funds be provided to keep them at sea.

***ATLANTIS RETIREMENT*** While these ships look good on paper, they have a way of not materializing, and the Institution will soon be losing ATLANTIS (engineers feel that her useful life is almost at an end). "She must be replaced," in Dr. Fye's words, "by a vessel whose excellence will be recognized the world over." The Director feels that the new vessel should be privately financed, "so that in the future our fleet will not be wholly owned or controlled by the government." Design work has now begun on a replacement under the direction of Mr. Francis Minot, who also worked on the design of the ATLANTIS.

As presently conceived, the new vessel will be 195 feet long and equipped with comforts and devices that have been the dream of oceanographers for years: stabilization to keep the ship on an even keel while on station; an observation chamber for sub-surface sea gazing; a center well to lower instruments from the inside of the ship; bow propulsion units to keep the ship steady while hove to; newly designed hoisting equipment to handle the deck gear. Her cost is estimated at $3,750,000, and it is hoped that these funds can be raised before the ATLANTIS is decommissioned.



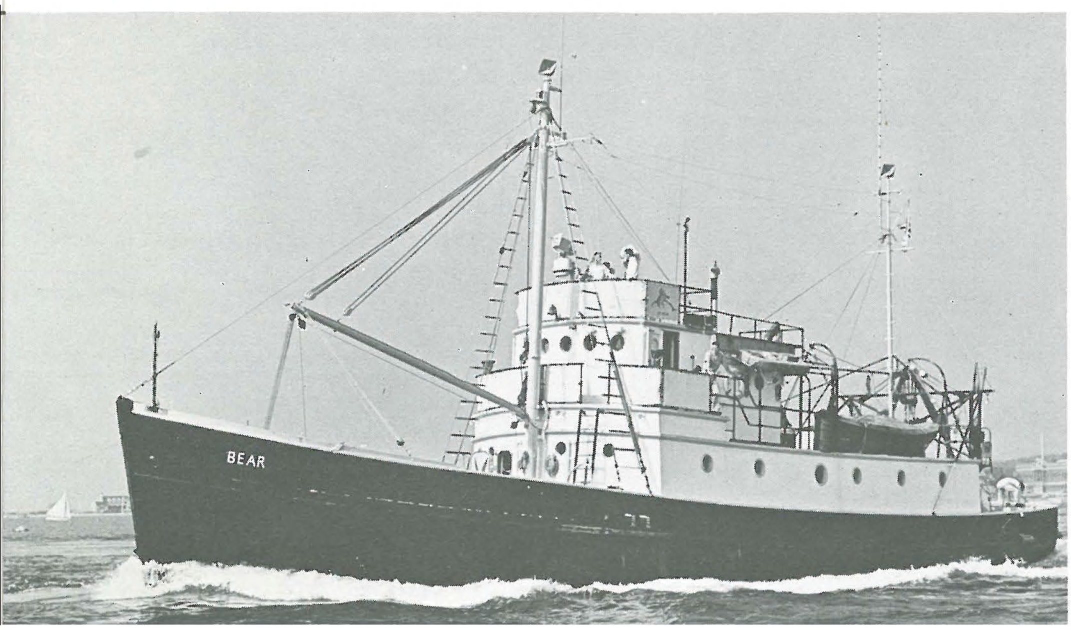
R V CRAWFORD




R V CHAIN

R V ARIES

R V BEAR



## THE MEN

Before World War II, it was estimated that there were fewer than 50 oceanographers in the U. S., and during the war this number increased to about 100. Today there are roughly 500.

With another period of rapid — if not explosive — expansion ahead, one critical question still remains: Where will more oceanographers be found? The question has no easy answer. For one thing, it is still being argued whether the greatest hope lies with men trained in "Oceanography" as such, or with those who bring a thorough knowledge of a single discipline such as physics, chemistry, geology or biology to bear upon the problems of the sea. Skirting this, the Academy committee recommends expanding existing university facilities, providing more fellowships, and actively recruiting scientists to the oceanographic cause.

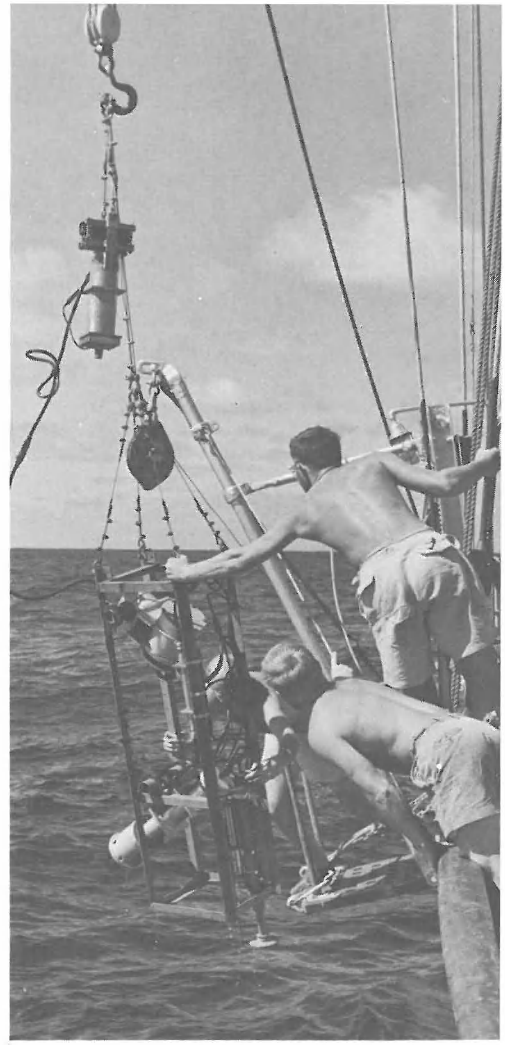
**FELLOWSHIPS** At the Institution, an expansion of the already vigorous fellowship program (under the direction of a newly formed Educational Policy Committee) is thought to be the best way to attract new talent to the oceanographic field. Each summer since the Institution's founding, 5 to 10 fellowships with a small stipend attached have been awarded from endowment. Recently, three year-round predoctoral fellowships (supported by the Associates) were added. They are designed to support the entire graduate training of promising students. These fellowships are in turn supplemented by grants which enable staff members to return periodically to academic life, grants which enable oceanographers from abroad to visit Woods Hole, and by the Rossby Memorial Fellowship, which finances a year of postdoctoral research and study by a meteorologist or oceanographer. The first Rossby Fellow, Dr. P. M. Saunders of the Imperial College of Science and Technology, was recently appointed. He will spend a year in Woods Hole working with Dr. Joanne S. Malkus.

In 1959, the stipends for summer fellowships were substantially increased, and the availability of the positions widely publicized. The response was enthusiastic — more than 100 students for ten available positions. Summer jobs were found for fifteen more applicants. With funds now in hand, fifteen such fellowships are planned for 1960.

But this is not enough, and additional graduate and post-doctoral fellowships are urgently needed. The cost of expanding the program to fill all the needs and capacity of the present staff requires annually $100,000 from outside sources, $35,000 from the Institution's own funds.

In many other ways, the Institution assists in disseminating information about our environment. Seminars are held, both winter and summer, on the problems of oceanography. A tutorial program for the benefit of summer students is being installed. Staff members hold positions and teach at half-a-dozen colleges and universities. At MIT alone, 5 now have professorships; also in association with that University, the Institution publishes a scientific journal called "Papers in Physical Oceanography and Meteorology." In addition, more than 1,000 scientific contributions from Institution staff members have been published in various other scientific journals.

Time, money, and facilities are granted to visiting colleagues from abroad, and wherever the Institution's fleet travels an attempt is made to establish contact with foreign laboratories, with a resulting benefit to all concerned.



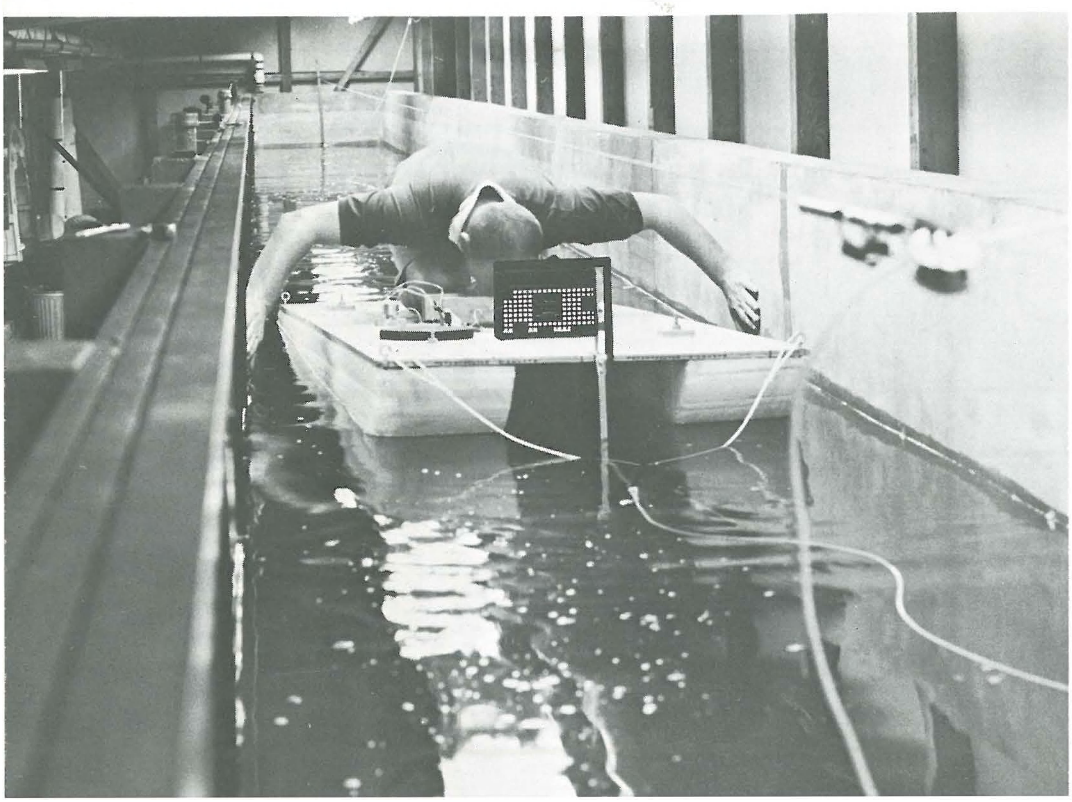
# THE TOOLS AND TECHNIQUES

The oceanographer is faced with many unique and difficult problems when he goes to sea to make his observations. The vastness of the sea in itself makes it costly and time consuming to obtain adequate coverage in any observational program. Sea water has been called "the most corrosive liquid known to man" and this annoying property causes a continuous series of headaches in the maintenance of scientific instruments. For work in the ocean depths instruments must be designed for very high hydrostatic pressures and low temperatures. Water attenuates light rapidly and experiments in mapping, which on land can be done quite simply with photography and optical triangulation, must be done in the ocean with acoustic echo sounding.

Because of the high cost of ship time and the difficulty of working at sea, the oceanographer put a very high premium on simplicity, ruggedness and reliability in his instruments. For this reason many of the standard tools of his trade date back many years and have undergone only a very gradual and methodical metamorphosis. For instance the drift bottle, despite the limited information it provides, has its place in the measurement of ocean currents, and the standard method for measurement of deep ocean temperatures and the collection of deep water samples, the Nansen bottle, dates back to the early 1900's.

The supplement observations made by these older, accepted techniques, the Institution supports a large program in instrumentation in an effort to improve the measurements currently being made and to develop methods for making observations which have not before been possible. Two instruments, designed at the Institution, which have gained general acceptance during the last few years, are the precision echo sounder developed by Dr. J. B. Hersey and his associates and the electrical conductivity salinometer due to Mr. K. Schleicher. Of course, the use of the best available navigational methods is an integral part of any observational program.

***DATA CONTINUITY*** With the exception of the echo depth sounder, observations and collections at sea are made primarily on a spot basis. Many problems with which oceanographers are now concerned require continuous data either in the vertical or in the horizontal (or both). Institution scientists have helped to design and are now using a system



*100-foot Flume with a current meter test in progress* of towed instrumentation for continuous temperature measurements to depths of about 500 feet. This consists of a streamlined chain on which many temperature sensors can be placed and which contains a channel for the many electrical leads required. Continuous temperature data are then obtained from each sensor and a computing machine in the ship's laboratory converts this data to a plot of depth vs distance traveled on which the lines of constant temperature are contoured. It should be possible to measure other variables of interest in a similar way in the near future.

Recent advances in the construction of strong electrical cables have been exploited to provide equipment which generates a continuous trace of temperature vs depth, and Institution scientists are now working on electrode systems to be used in a similar way for plotting salinity and oxygen vs depth. In addition to the cable measurements, preliminary testing is underway on free instrument vehicles which offer the possibility of even faster sampling in the vertical. These are streamlined torpedo-like bodies which are sunk to the bottom of the ocean by heavy ballast. At the bottom, the ballast is released and they return to the surface by their own buoyancy. Continuous records of temperature (and other variables) can be obtained by instruments contained in the vehicle. Such systems promise to be as much as five times as fast as cable lowerings but, of course, require the ship to recover the buoy when it returns to the surface.

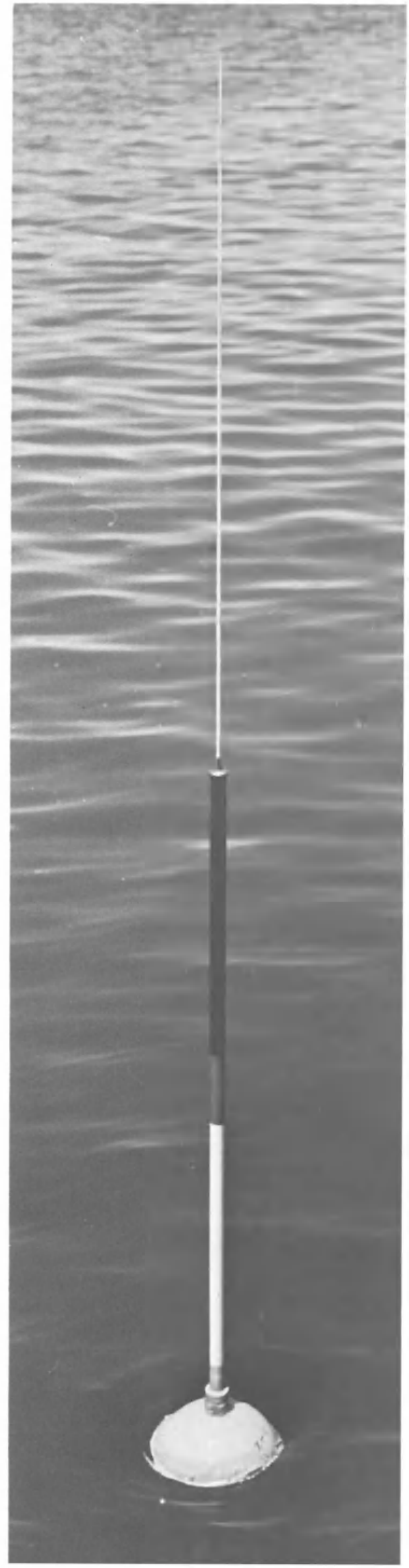
***NEW MEASUREMENTS*** Mr. J. S. Reitzel is active in developing techniques for the measurement of the flow of heat through the ocean floor. A thin probe is dropped into the bottom and a recorder attached to it records the temperature at several points along the probe. Alternatively, the probe may be connected to the ship by conducting cables of the type mentioned above and the records read on deck. Such measurements are giving us new insight into the structure of the ocean floor and the heat balance near the bottom.

A new instrument for measurement of the velocity of sound in water has been developed by scientists at the National Bureau of Standards and is now being used extensively by the underwater acoustics group at the Institution. This instrument has proved very reliable and for the first time accurate measurements of this important quantity as a function of depth are possible.

New, high intensity sound sources, derived from underwater sparks, are now being used to obtain echos from geological structures beneath the ocean floor and a mechanical sound source developed by Mr. H. E. Sawyer promises even deeper penetration of the bottom.

The ability of an airplane to traverse large areas of the ocean rapidly has been exploited in the airborne radiation thermometer. This instrument can measure the surface temperature of the sea over which it is flown and has been used for tracking the boundaries of various currents, particularly the Gulf Stream, on a more synoptic basis than is possible with ships.

Techniques of underwater photography have been improved so that photographs of selected subjects can be obtained by triggered camera by



*"Pop up" buoy after return from the ocean bottom with the radio-homing antenna extending above the sea surface*

sound, bioluminescence and proximity. The wide angle lens, time lapse systems, developed by Dr. W. S. von Arx, are used as basic recording systems for meteorological and oceanographic observations at sea and in the air.

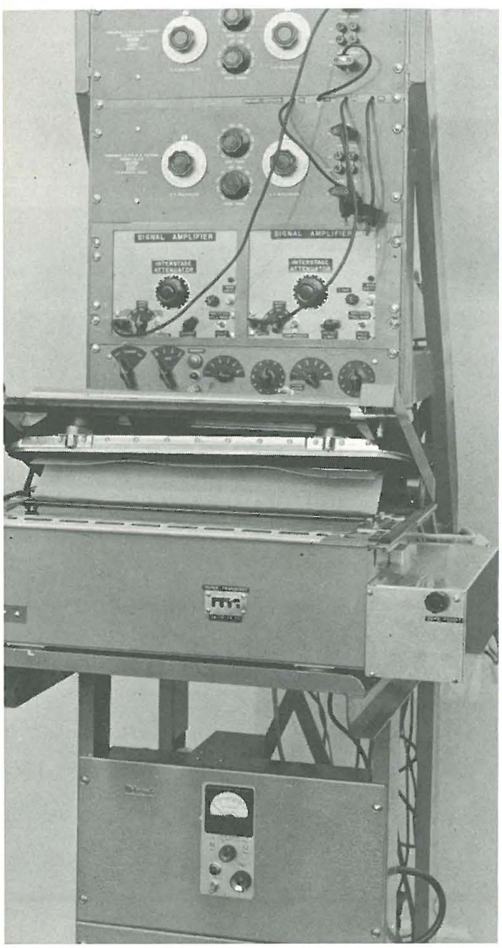
***BUOYS*** Shipborne equipment is seldom used for extended periods of observation at a fixed point in the ocean. To provide for such measurements a variety of buoys have been developed by Institution scientists. A radio telemetering buoy with a range of about 100 miles has been constructed by Messrs. D. D. Ketchum, R. G. Walden and D. H. Frantz, Jr. Provision is made within the buoy for storage of a series of temperature (or other variable) measurements which can then be transmitted at periodic intervals as the buoy may be interrogated by radio to obtain the information on demand. This buoy has also been used as a sophisticated drift bottle for the measurement of ocean currents. In this case, the buoy is interrogated from an airplane and the answering signal is used to locate the buoy so its position can be plotted on a day-to-day basis.

For longer time sequences, Mr. Frantz has developed a "pop-up" buoy. This may be anchored in very deep water without a surface float and carries temperature or current measuring equipment. After a period of up to 400 days, the buoy and its attached instruments may be recovered by exploding a small charge in its vicinity. When listening equipment in the buoy hears the explosion it releases from its anchor and floats to the surface where a self-contained radio transmitter aids in its location.

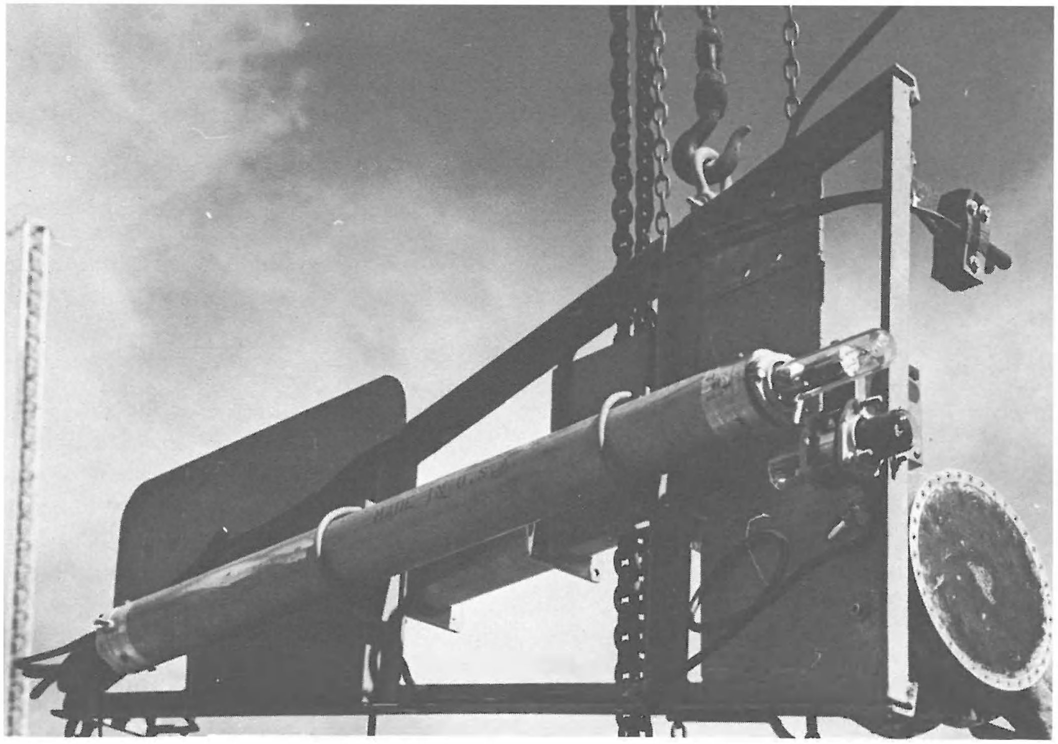
Mr. G. H. Volkmann has been utilizing the technique developed by Dr. J. C. Swallow in the measurement of deep ocean currents. This consists of a drifting buoy which floats at a preselected mid depth and emits pulses of sound by which means it may be tracked by a surface vessel. Mr. A. C. Vine has been involved in similar measurements using a surface float connected by piano wire to a deep parachute drogue.

Measurements at a fixed point are also being made by Mr. H. G. Farmer, Jr., in connection with his wave research program. In this case, a tower rigidly mounted on the bottom is used and installed on it is instrumentation for the continuous measurement of wave height and slope. Information from the tower is transmitted to the laboratory by means of a VHF radio link and in the laboratory it is automatically digitized and recorded on punched tape for machine computer analysis.

***TRENDS IN INSTRUMENTATION*** As oceanographers ask more and more detailed questions about the distribution of variables in the ocean and about the water movements, more extensive observations utilizing new and sophisticated instrumentation will be required to provide the answers. Because very small changes in the distribution of temperature and salinity (and the density field which they determine) have far ranging effects on the circulation, very high accuracy is required in their measurement. Still higher precision is required to elucidate the slow secular variations of these quantities. The problem of establishing a frame of reference within which the slow movements of the deep water can be easily measured is a very challenging one. Much time and money and the efforts of many people will be required to reduce such observational requirements to a routine basis.

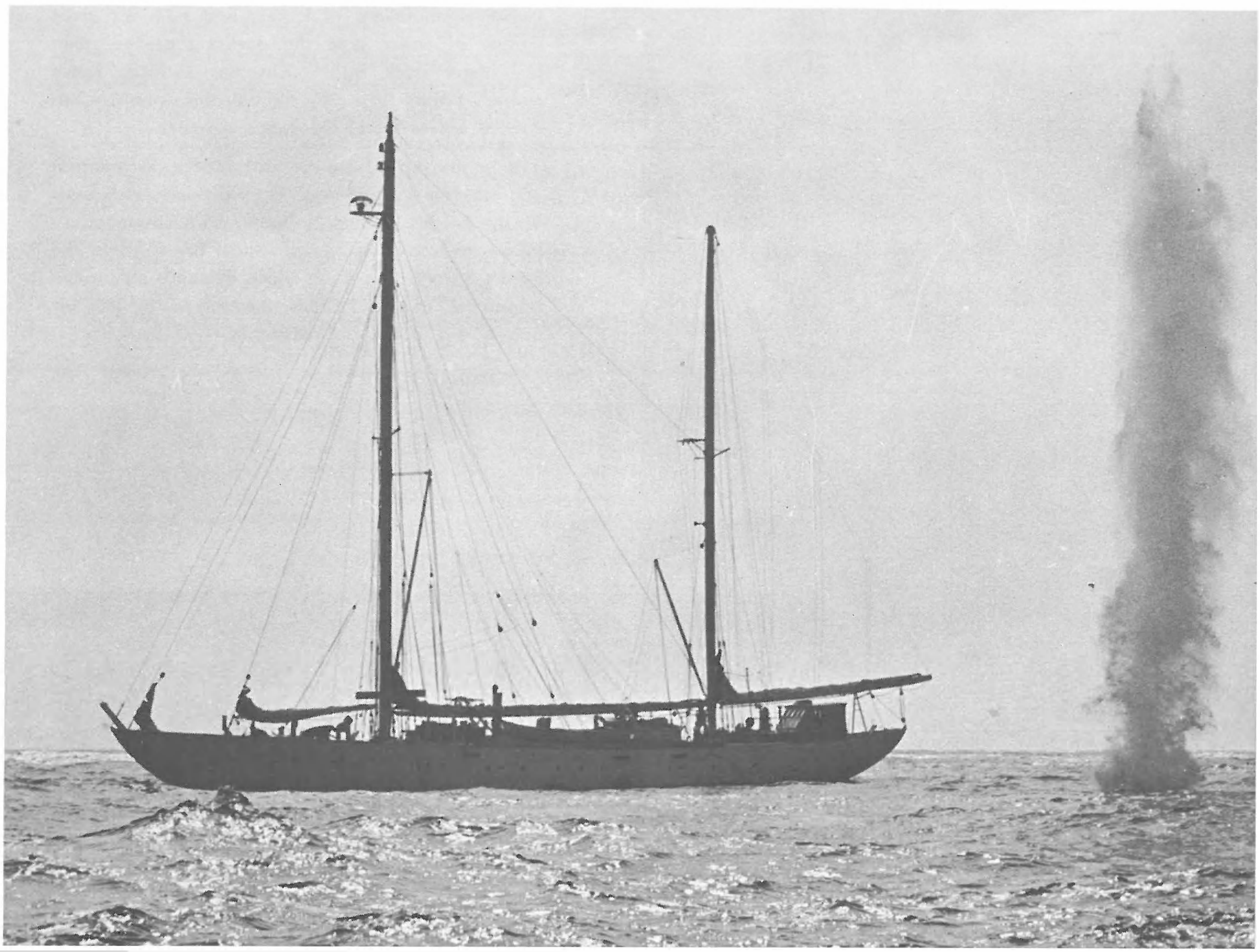


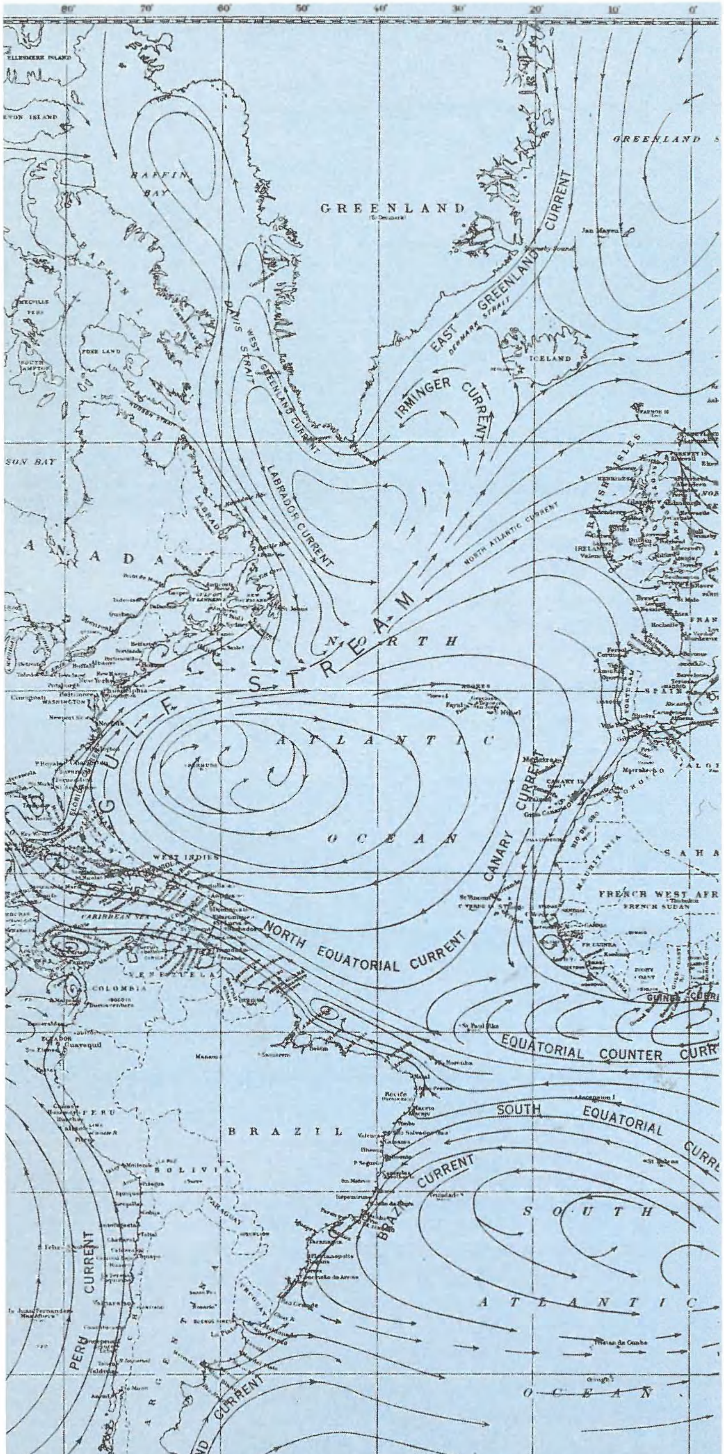
*Console for the "Precision Graphic Recorder" used for the detailed survey of bottom topography*



*Acoustically-triggered deep-sea camera; the flash and shutter are operated by the echo from a passing sea animal*

*ATLANTIS dropping explosive charge for seismic refraction studies of sub-bottom structures*

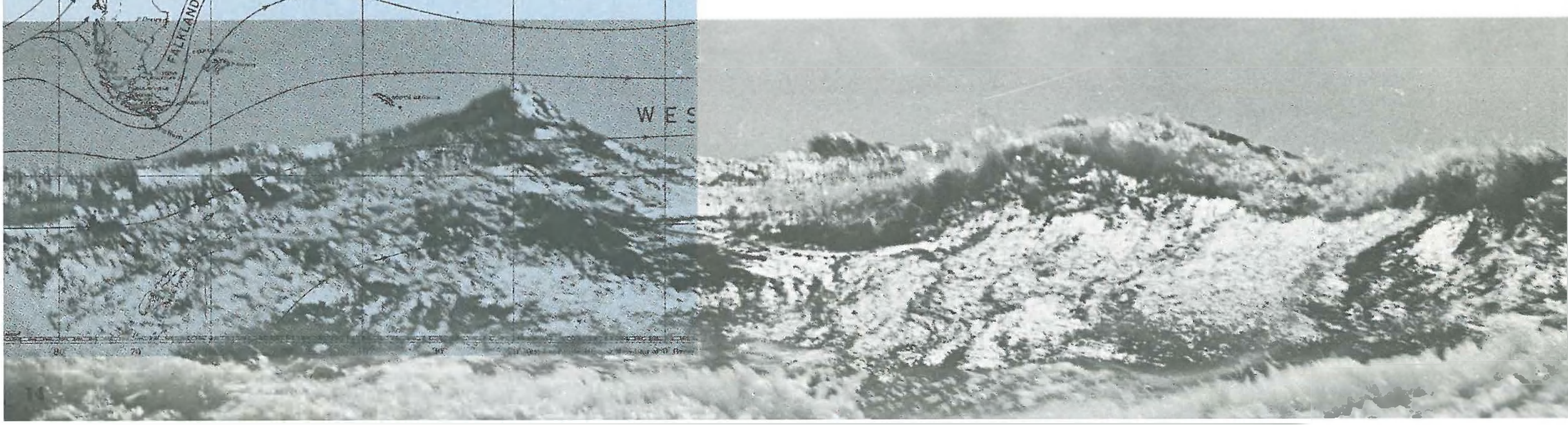





## THE **PROBLEM**

The ocean is not a homogeneous, uniform mass. Oceanographers know it to be a highly stratified body, layered like a deck of playing cards with waters of differing temperature and salinity. Near the Poles, cold water sinks and moves sluggishly towards the Equator. Above this slow deep circulation currents wind through the sea, pulsed by unknown combinations of forces, and tides lift great masses of water onto the earth's shoreline, then pull them back again. On the surface, faster currents thread their way through the oceans, wind-flecked waves travel thousands of miles.

It is the job of the oceanographer to measure and estimate the effect of these oceanic movements on the Earth's weather, climate, and marine population, and to look beneath them for clues to the Earth's history. It is a job which demands exhaustive researches in the oceans themselves, in the air above, and in the earth beneath.



# water

With the great age of exploration during the 16th Century, many of the principal features of oceanic circulation were first discovered. Not until the 19th Century, however, were detailed observations made of the oceans subsurface physical characteristics — its density, salinity, and temperature — and even in the first part of the 20th Century data collection proceeded slowly.

With the advent of modern instrumentation, however, it became possible to make oceanographic measurements on a large scale. To the layman such measurements may result in a mystifying mass of data whose eventual purpose may be only vaguely understood. To the physical oceanographer, however, the datum points plotted on a chart may provide the answers to the questions he asks: how fast is the ocean turning over — and bringing bottom nutrients to the surface; what drives the great current systems of the world's oceans; how fast does cooling surface water sink to the bottom; where and how fast do submarine currents flow?

During the eighteen months of the International Geophysical Year, data piled up faster than ever before. In the Atlantic, more than 1,000 stations were taken by Woods Hole Oceanographers under the leadership of Mr. Frederick C. Fuglister. In addition to a survey of the North Atlantic, a resurvey of the south Atlantic — the first since the classic METEOR expedition of the nineteen twenties — was made by the ATLANTIS, the CRAWFORD, and the British vessel DISCOVERY II from the National Institute of Oceanography.

The resurvey of the South Atlantic has already provided considerable reassurance to oceanographers regarding the persistence of patterns of salinity, temperature and other properties of the water masses. It gives research workers much greater confidence in charts and atlases which have been prepared from data accumulated over longer, irregular intervals of time. The IGY data for both the North and South Atlantic basins will provide an oceanic atlas of unparalleled completeness and detail, standing as an invitation to other research workers to explain the patterns and deepen our understanding of the migration of ocean waters.

***THE GULF STREAM*** The study of the meandering Gulf Stream has long intrigued many scientists at the Institution, perhaps because new information about it is constantly changing or modifying pet theories. In the early days of oceanography the stream was thought to be the backwash of the Equatorial current which flows West across the Atlantic, a huge river of hot water flowing through the oceans and warming the shores it touched.

These simple statements and assertions, however, give no insight into the mechanisms which drive the stream or into the forces which control its width and intensity. Since 1948, under the leadership of Mr. Henry M. Stommel, substantial progress has been made in developing an understanding of the way in which wind, heating, frictional forces, inertia and the deflecting effects of the earth's rotation combine to produce intense streams on the western sides of oceans. The Gulf Stream is now better understood as a kind of "boundary layer", a very general phenomenon arising in many different kinds of fluid flow and not restricted to the ocean alone.

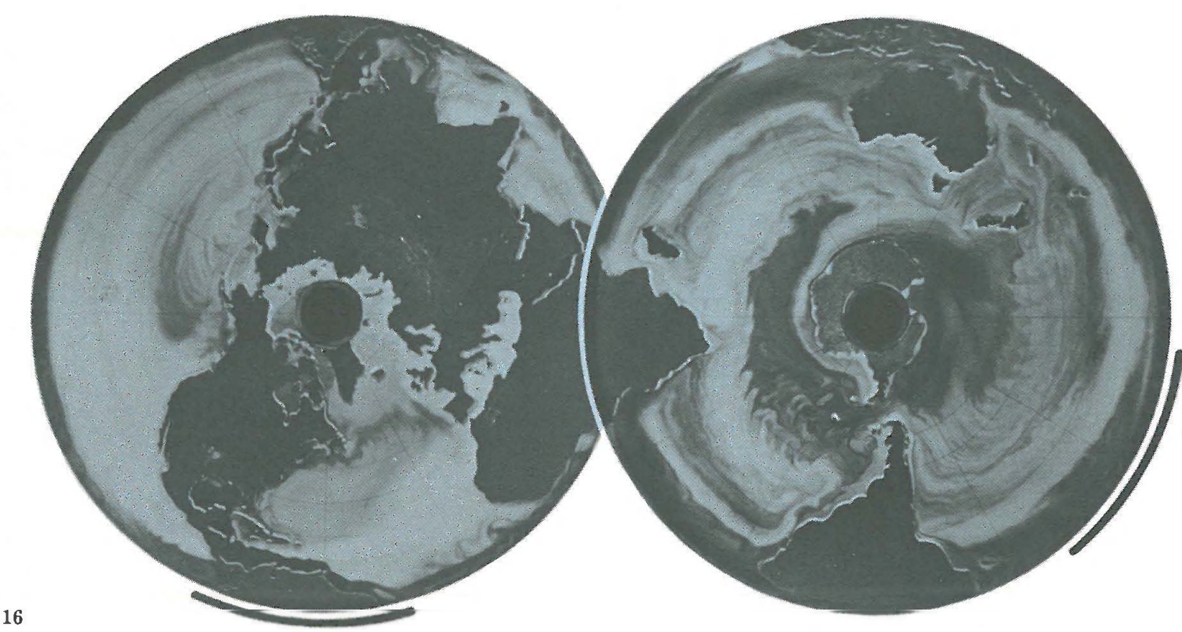
When examined in still finer detail, the Gulf Stream turns out to be a multiple series of meandering eddies and filaments. Much still remains to be learned about the nature, origin and significance of these details.

The Gulf Stream separates the warm waters of the Sargasso Sea from the cooler, denser waters to the north. It is conceivable that Northern Europe might actually be warmer without the presence of the Gulf Stream. A decrease in the intensity of the Stream might allow warm waters of the Sargasso to spread out over the colder, denser northern waters in a shallower layer, bringing more warm water into high latitudes around Europe than is transported by the Gulf Stream itself. While this theory is highly speculative, there are a few bits of evidence to provide support. Over the last thirty years, the surface temperatures of the Norwegian Sea have risen by about two degrees Centigrade, the depth of warm water in the Sargasso Sea has decreased somewhat and the average transport of water by the Gulf Stream seems to be diminishing.

In the last few years improved understanding of motions in the upper layers of the ocean, together with greatly advanced observational techniques, have made it possible to begin to ask meaningful questions about the character of currents and transports in the ocean depths. Bringing to bear his accumulated experience and understanding of the physics of ocean currents, Stommel, in 1956, predicted that in the deep waters underneath the Gulf Stream there should be flowing another boundary current in the completely opposite direction.

In the spring of 1957, ATLANTIS (with the Institution's L. Valentine Worthington aboard) and DISCOVERY II met in the Gulf Stream to search for the countercurrent. The whole effort was made possible by the Swallow float (designed by Dr. John Swallow of the National Institute of Oceanography), which contains a sonic tracking source and can be set to reach depth equilibrium at any chosen level. Nine thousand feet down, the Swallow "Pinger" drifted to the southwest some eight miles per day, clearly confirming Stommel's prediction.

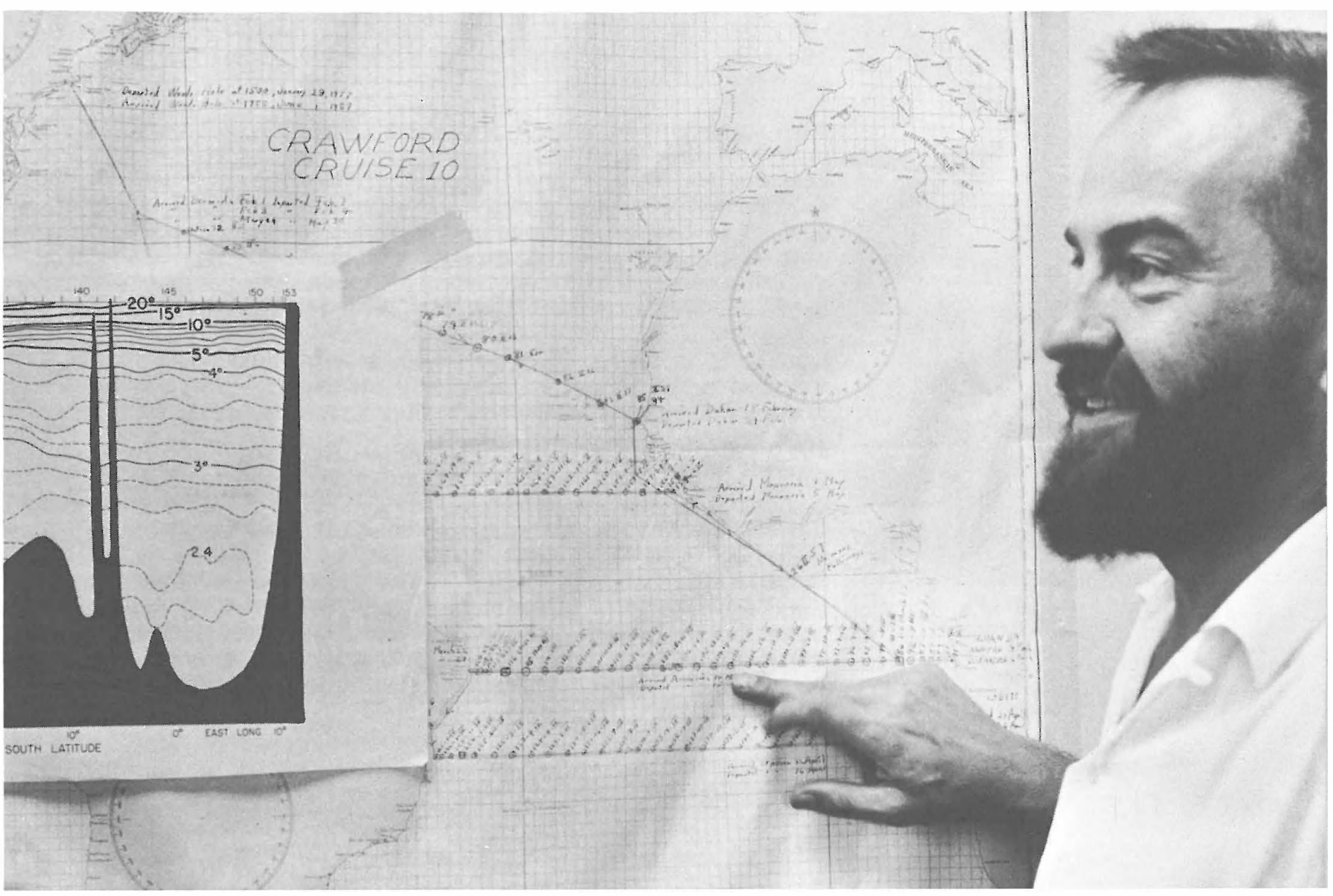
Encouraged by this successful test of their basic concepts, Stommel and his co-workers have constructed a more extensive theoretical model of circulation in the depths of the world ocean. This model has yielded several new, still untested, predictions. Among these are the prediction of an intense northward current deep in the Tonga-Kermadec trench off New Zealand and two oppositely directed currents beneath the great Kuroshio Current off Japan.



*North and South Pole models of the ocean circulation as developed in a rotating tank*

One of the most complex physical processes playing an important role in the motions of both the ocean and the atmosphere is that of turbulence. The disorderly, swirling motion of a turbulent fluid intimately controls the diffusion of heat, the transport and distribution of salt and oxygen, the internal forces which we ultimately describe under the general heading of "friction". Until recent years the onset, growth and influence of turbulence have been studied more or less empirically and have been incorporated into theoretical analyses in arbitrary and rather unsatisfactory ways. A more sophisticated attack on the study of turbulence is now occupying physicists, applied mathematicians, oceanographers and meteorologists the world over. At the Institution, Dr. Willem Malkus and his colleagues are attacking the question in a very fundamental way. Trying first to refine our understanding of the development and influence of turbulent flow in the simplest laboratory situations, in terms of the most fundamental physical laws and mathematical analysis, they hope eventually to learn how to ask more penetrating and meaningful questions about its effect and role in oceanography and meteorology.

***USEFUL ISOTOPES*** If there are beneficial aspects to the radioactive fall-out which sifts down after atomic bomb tests, the chief is certainly its usefulness as tracers. Deposited on the ocean surface, the hot isotopes begin a gradual descent towards the ocean bottom. By correlating the date of the A-blasts with the age and depth of the radio isotopes, Dr. Vaughan T. Bowen, with Professor T. T. Sugihara of Clark University, is calculating the rate at which surface ocean water filters to the bottom. The Atomic Energy Commission has a more pragmatic interest in where and when these isotopes fall, and the program is supported by AEC funds.

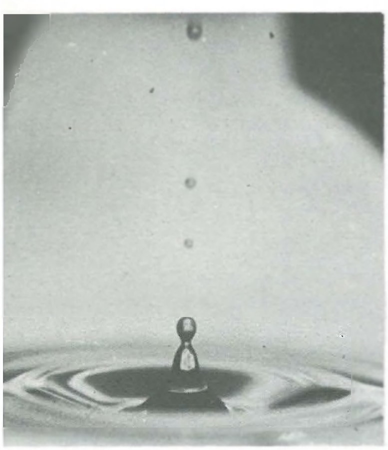


# atmosphere

Man can exist as a continental animal only because vast quantities of water are siphoned from the oceans and poured over the land. Of such importance to humans, rain is merely an "exhuast" product of the huge atmospheric heat engine whose moving parts are the global winds and jet streams, and in which $H^2O$ is a primary working substance. At every stage, the ocean plays a crucial role in this engine's operation, from fuel input to final dissipation of the winds in driving waves and currents. The ultimate power supply of the entire air-sea circulation is the unequal heating of the earth by the sun, so that equatorial regions receive more radiation energy than the poles. In the tropics, the excess heat is first absorbed by the oceans; most is used there in evaporating vast quantities of sea water into the overlying air, the first step in the complex energy cycle that later builds the "pressure heads" to drive the winds. These winds finally carry heat back to the poles to balance their radiation losses, and in so doing condense the water vapor to rain or snow many thousands of miles from its tropical birthplace.

Marine meteorology attempts to understand these energy exchange and conversion processes between air and sea; it is thus concerned with how the very heart of this engine works — how in nature is heat energy converted into air and ocean motions? A clue to how the atmospheric engine converts and utilizes its vapor fuel can be gained from the irregularity of its output; the most obvious feature of rainfall is its unequal distribution in space and time. Some areas are parched deserts, others steaming disease-ridden jungle, while much of the earth's cultivated surface rides a precarious see-saw between extremes. Since the ocean is a vast inert heat and water reservoir, this implies that those parts of the atmospheric machine which pick up and combust the fuel must be small-sized (compared, say, to continents) short-lived and probably limited but variable in number. The pursuit of this deduction lies at the heart of the Institution's work in marine meteorology.

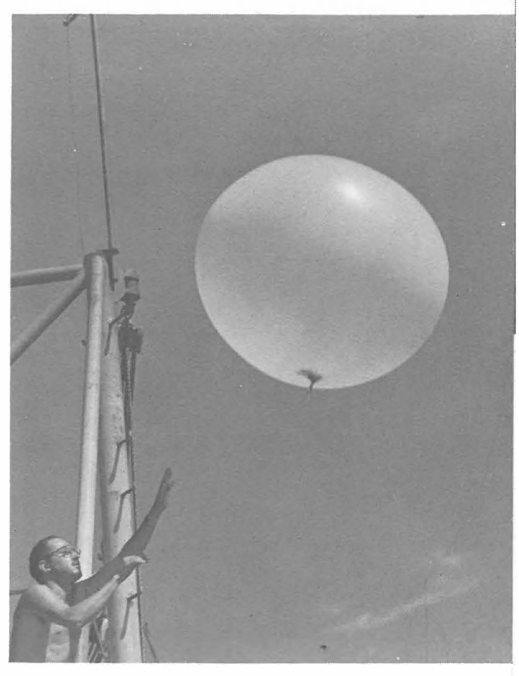
***TROPICAL CLOUDS AND HURRICANES*** Drawing heavily from other Woods Hole scientists, particularly the theoretical group who have provided a language of inquiry from their prototype studies of simple heated fluids, and from the observationalists who have instrumented and calibrated an aircraft to penetrate the real phenomenon and test our ideas in the environment itself, it is now possible to isolate a hierarchy of driving elements and to describe significant facets of their operation quantitatively. Among the most important of these "combusters" are the giant cumulonimbus cloud towers of the "equatorial trough zone" — the firebox of the atmospheric heat engine. Only a few thousand of these ten-mile high thunderheads, actively growing at once in this equatorial belt, are enough to lift and convert all the water vapor fuel needed to balance the global heat budget and supply the small excess which is later used to drive the winds. A quantitative model of these energy transformations was recently evolved by Dr. J. Malkus (in collaboration with Prof. Herbert Riehl of the University of Chicago). As an exciting by-product it also led to a breakthrough in understanding the vicious tropical hurricane, a runaway vortex powered by spiral bands of similar giant clouds—whose release of torrents of rain delivers the heat energy that drives the destructive winds.



***BURSTING BUBBLES AND TROPICAL RAIN*** Rainfall from tropical clouds is thus of more than agricultural importance to man; it is the fuel that makes his air-sea circulation engine go. What makes a cloud rain? More specifically, why, over the tropical seas, do small clouds rain on some days — and on other days, even large ones perish without shedding a single drop? Apparently a few large particles must be introduced to cause small cloud drops to grow big enough to fall. Tossed by the wind, whitecapped waves break upon the sea in foam and spume. As they do, bubbles burst, tossing up tiny salt particles into the air, where warm currents sweep them upward and into the growing cumulus clouds. There they may act as

nuclei for droplet growth. The role of these salt particles in forming the nucleus for raindrops has been under intense scrutiny by Mr. Alfred H. Woodcock and his associates at the Institution, and progress is being made in understanding the complexities of natural rainmaking.

Artificial rainmaking takes on new significance in this background; the discovery that the atmospheric firebox operates with so few and ephemeral cloud towers as cylinders, the elucidation of the role of rain release in hurricanes and even larger wind systems leads to exciting speculations that if this type of basic unrestricted research is patiently continued, man may one day be able to modify these vast energy releases by manipulating key links in the machinery. But first these must be isolated and understood.



***THE GREENHOUSE*** Tinkering with tomorrow's weather, however, is a risky business. Without intending to, man may even now be performing a world-wide experiment that could dangerously increase the rate of warming of his planet. Carbon dioxide, the common gas thrown out of automobile exhausts and factory stacks, is being pumped into the atmosphere at an increasing rate. Distributed throughout the atmosphere, it acts in the same way as the glass roof in a greenhouse, allowing penetrating radiation from the sun to come through it, but trapping part of it on the rebound. This phenomenon is, in fact, called the Greenhouse Effect, and many scientists feel that man is inadvertently raising his planet's heat level to the danger point by the combustion of fossil fuels.

At the Institution, phases of the $CO^2$ problem are currently being studied by Dr. John W. Kanwisher and others; questions being asked include how much $CO^2$ the ocean does absorb, how $CO^2$ is mixed throughout the lower atmosphere, and what the rate of exchange of $CO^2$ is between the atmosphere and ocean. Basic to our understanding of the physical chemistry of the sea, these questions also are important to understanding of the dire predictions of some climatologists.

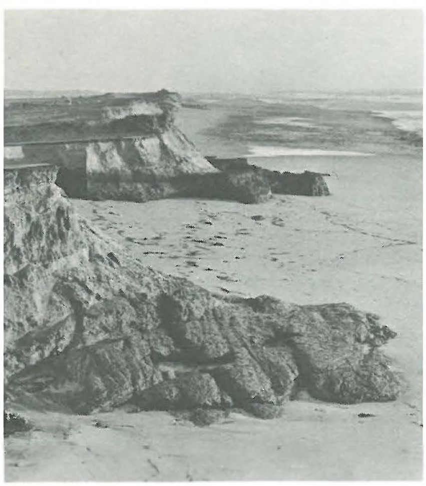
# substrata

Beneath the undulating surface of the sea lies an area more than twice the size of all the Earth's continents put together. Its deeps sink more than 36,000 feet below sea level in trenches large enough to contain the Grand Canyon several times over. Some of its mountains, which range over 30,000 feet in total height, are the largest topographic features on the face of the earth and have a surface expression in island groups such as Hawaii, the Azores and Bermuda. Sedimented particles and decomposing organisms blanket the ocean floor.

This vast province has been increasingly explored in recent years by the Institution's geologists and geochemists, its depths plumbed, its mountains charted and its sediments analyzed. Perched on a floating ice cake in the Arctic Ocean during the IGY, staff members participated in the discovery of a range of mountains which was explored while the ice floe drifted back and forth across the ridge.

Yet little of the topography of the ocean floor has been surveyed in detail. "As far as our understanding of the deep sea floor is concerned," one oceanographer estimated, "we are just about where we were 100 years ago on land, about where we were in 1850." In addition to admitted inadequacies concerning our knowledge of the deep ocean bottom, the study of near shore geological processes has only recently been tackled on a large scale despite obvious material benefits which can accrue from such research.

Charting bottom topography has, until recently, been a laborious business. Well into the 20th Century, it was still being done by lowering a weighted wire into the deeps, then tediously hauling it back. In the recent decades, however, the sonic depth sounder has made bottom charting a far simpler business. By bouncing a sonic pulse off the bottom and timing its round trip, oceanographers can now make a continuous record of the bottom profile. An extension of echo sounding techniques developed at the Institution under the direction of Dr. J. B. Hersey, now permit charting structures beneath the bottom sediment as well. The seismic profiler is such a continuously recording instrument and is capable of recording the structure of the bottom to depths of over 500 feet into the bottom sediment. Seismic refraction is another technique frequently employed, and probing still deeper, is producing exceedingly valuable information concerning the structural relationship of the continents to the ocean basins.

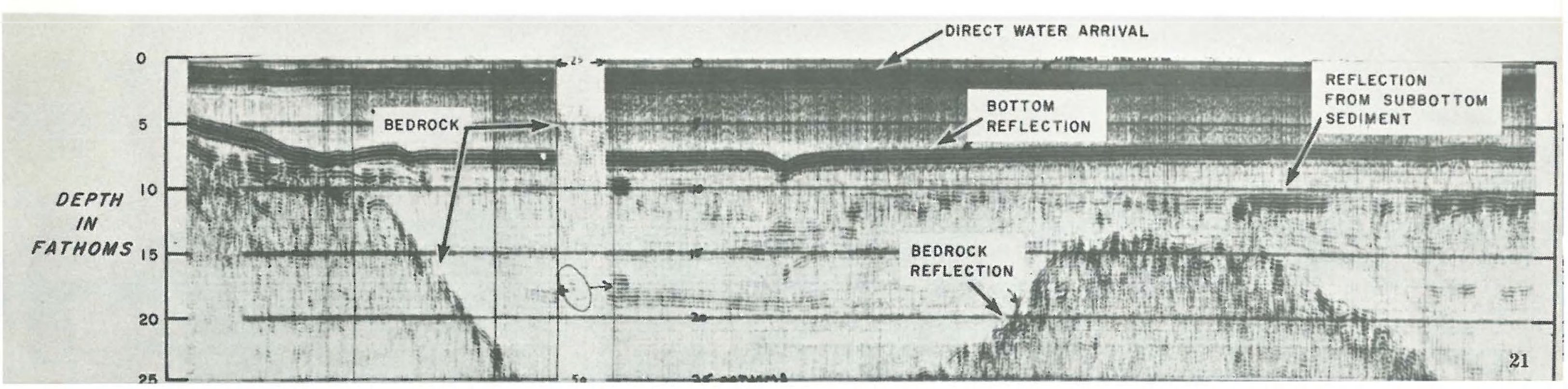


Despite the development of these instruments capable of collecting continuous data, essential information and material still must be obtained by the time honored geological sampling techniques. These range from "hand specimen" collecting of transitory beach deposits to the use of deep-sea coring equipment to obtain an ocean bottom sediment cross section representing thousands of years of the earth's history. Recently it has been proposed to drill a hole through the crust of the earth to obtain rock samples from the mantle below and from the controversial transition zone, known as the Mohorovicic Discontinuity. The collection of such exotic samples has become a concern of submarine geologists since the logical place to drill a "Mohole" is under the sea. The reason the ocean was selected as a possible drilling site, despite the obvious technical difficulties, is that the earth's crust may thin to less than five miles in certain oceanic areas while a twenty-five mile thickness is common under the continents. To find such a thin spot, Woods Hole's BEAR with ships from three other Institutions conducted a highly successful multi-ship seismic operation off the north coast of Puerto Rico during the first six months of 1959.

**DEEP-SEA MANGANESE** The chemistry of sediments has attracted increasing attention in recent years and several research projects at the Institution are directed along these lines. The origin of the manganese nodules which litter the ocean floor is one such problem under study. These manganese, rich deposits, which occur variously as a sprinkling of microscopic particles, in fields of grapefruit size nodules and even as a continuous veneer over large areas of the bottom, are thought by Dr. John W. Graham to be formed as the result of the activity of microscopic marine organisms. He has suggested that these organisms are able to extract from sea water certain heavy metals which are precipitated by metabolic processes as soluble hyroxides. If a suitable nucleus is available — whale's ear bones, sharks' teeth or basaltic fragments are all common — then a deposit of these metallic ions may form. It has often been suggested that these accretions could become an important source of copper, cobalt and nickel, as well as manganese, but the problems of mining the bottom are still considerable.

Other geochemical problems under consideration include the analyses of silica in water squeezed from deep-sea cores, the study of highly organic sediments from the north coast of South America by Dr. Francis A. Richards and Dr. John M. Zeigler, and the geochemistry of certain trace elements in bottom sediments and marine organisms. This last project is being studied by a variety of people at the Institution, many in association with Dr. Geoffrey D. Nicholls, of the University of Manchester, England.

This increasing interest in the chemical properties of sediments and of the particulate content of sea water has in some part been the result of the increasing availability of refined instrumentation which can be utilized for the necessary analyses. It has, however, become evident that many of these problems may have far reaching implications, and this field is one of growing importance to marine geologists.



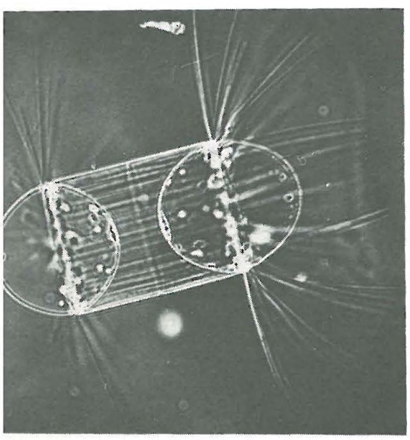
# sea life

Sunlight, by the photosynthetic process supports the life cycle in the sea — as it does on the land. Tiny zooplankton feed upon microscopic diatoms and phytoplankton, small fish upon the zooplankton. The cycle continues until it reaches the large fish and mammals. When these organisms die and sink, their decomposition releases to the water soluble compounds of phosphorus and nitrogen, the fertilizers of the ocean, and these nutrients are slowly brought back to the surface by oceanic upwelling. With the aid of the sun, the ocean plows and fertilizes itself.

Even in the clearest of water, however, sunlight filters down only some 300 feet, and most of the sea is so dark (except to light sensitve photometers) that even the free floating alga-like phytoplankton cannot survive. But marine biologists now know that fish and other organisms somehow exist on the ocean bottom and in such unlikely environments as the underside of Arctic ice cakes, where the dense water is supercooled below the freezing point.

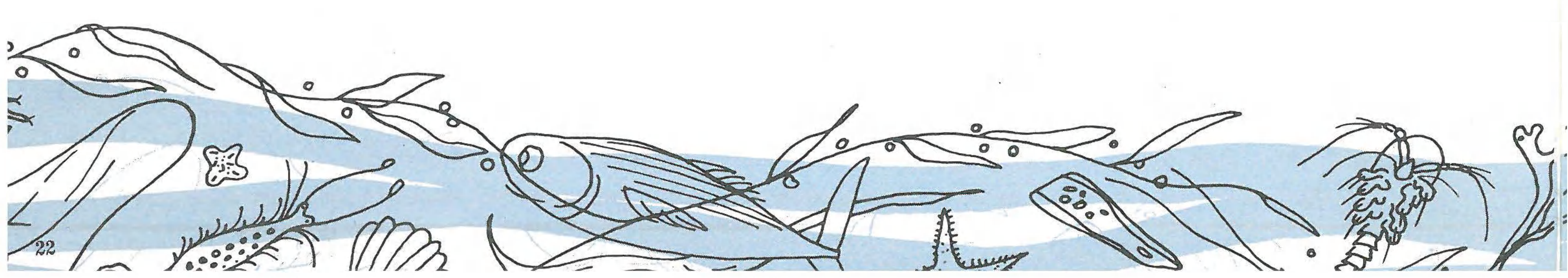
The questions asked of marine biologists are as varying as they are numerous. Some have been asked for centuries: — where is the best place to fish? What causes the sudden shifts in fish populations, and why do cataclysmic disasters such as the Red Tide suddenly strike them down?

Others frame the anxiety of modern medical researchers or population experts: what can I extract from a ground-up jellyfish that might kill cancer cells? What is the built-in thermostat in whales and porpoises that enables them to dissipate and conserve heat? What is the population of the sea, and can it be farmed to feed the Earth's burgeoning population?



The answers to these questions, just as they do in other branches of oceanography, lie in basic research. The Institution's marine biologists are currently studying organisms from diatoms to whales, from phytoplankton to seaweeds. Phosphorus is being used as a tracer to chart the course of the Gulf Stream. A study of bioluminescence in jellyfish and its effect on the ecology of the sea is underway. Snails, horseshoe crabs, clam diets, clam drills, oyster parasites, chlorophyll (more useful in the ocean than it is in toothpaste), and the many-legged, deep-sea red crab (touted as a potential delicacy for man), all are under careful scrutiny. To find out where they migrate, tuna and marlin are being tagged, and the effect of surface winds and water temperature on haddock larvae studied.

***RADIOACTIVE WASTES*** Some projects are more pressing. One such concerns the disposal of radioactive wastes. The peaceful development of nuclear energy may produce an amount of radioactivity each year equal to the explosion of many megaton weapons. It has often been suggested that much of this could be wrapped up and dumped



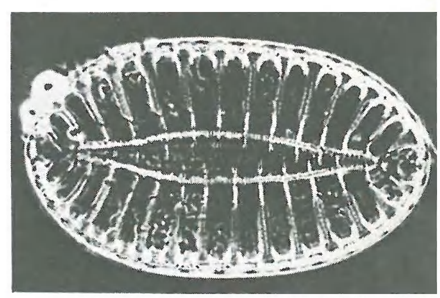
into the ocean's deep "teacups", there to decay until it is no longer radioactive. Oceanographers at Woods Hole are not so sure.

Even though the ocean may turn over only once every 300 years — perhaps not that quickly — and isotopes dumped to the bottom are not likely to turn up by themselves for a long time, the problem is not this simple. Unfortunately plankton have an affinity for certain of the isotopes, and when they are consumed by larger organisms the concentration builds up. Shellfish and other organisms which pump huge quantities of water through their system daily filter out some of the radioisotopes and store large quantities in their bodies.

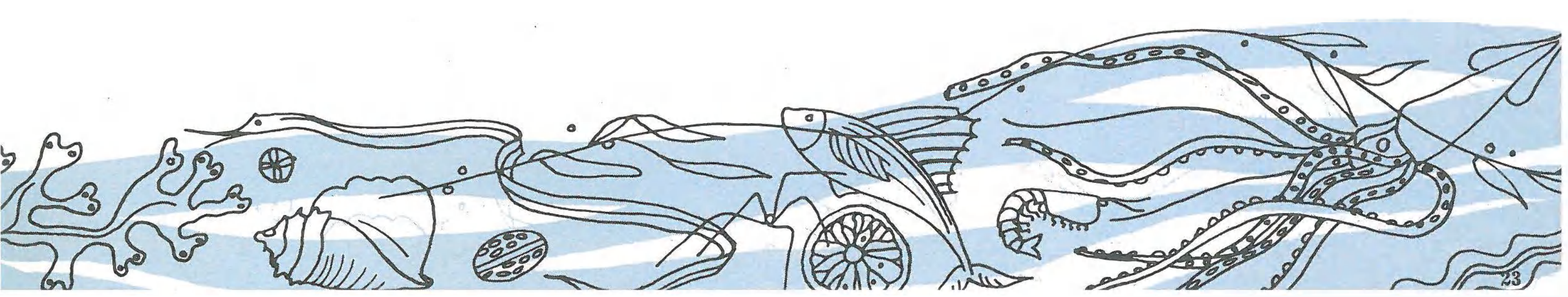
The organisms in the scattering layer, moreover, make a daily migration to the surface at night. To reach equilibrium and sink again during the day, they must squeeze out their bodies. Thus, the waste is neatly transported from lower layers to the surface. "When you consider the number of organisms, from shrimp and squid to microscopic organisms, which make the trip, "reports Dr. Bostwick H. Ketchum, Senior Oceanographer, "the amount of potential radiation being brought up could be considerable — more than the normal circulation of fluids would account for."

A controlled dumping experiment over a well-monitored Caribbean "teacup" may be one way to test the feasibility of burying wastes in the sea. In some way, at least, the Institution's oceanographers would like to assess the results of marine waste disposal before man begins to do it on a large scale.

***SEA FARMING*** An even more pressing project over the next decade may be the possibility of farming the sea. With a world population of over 6.5 billion expected by the year 2000, the relatively untapped pastures of the sea appear enticing. "The sea never supports the dense populations found in forests or grasslands," Dr. Ketchum has written, "but the forests represent an accumulation of 50 years of growth, while maximum marine populations can develop in a few days."



The biggest drawback to such fast farming is lack of fertilizer. In the well illuminated and populated zones of the sea, phosphorous and nitrogen are often completely exhausted. Marine biologists wonder, however, whether ocean bottom nutrients could not be pumped to the surface to turn clear lifeless water into rich sea pastures. They also wonder whether marine organisms could not be transplanted from one region to another, as land plants and livestock are. Such seemingly far-fetched suggestions as these must be studied further if the full potential of the sea as a food source is to be developed. The Institution biologists hope to contribute to a solution of this general problem.



# THE FUTURE

The successes in recent years of international cooperation in oceanography provide hope that in the future many of the world-wide problems in oceanography can be attacked by coordinating the efforts of the research ships of the major maritime nations. In order to perpetuate international cooperation beyond the end of IGY, oceanographers have banded together in an organization known as SCOR (Special Committee on Oceanographic Research). Its parent committee is the International Committee of Scientific Unions.

One of the first projects being planned by SCOR is an international survey of the Indian Ocean, including a joint attack on some of the special problems which can be most profitably studied there. For example, the Indian Ocean is the only ocean where the large scale wind system reverses itself seasonally. When the monsoons set in, how long does it take the currents to reverse themselves? How rapidly do the new currents deepen? One ship alone would find it difficult to secure a clear-cut answer to such questions, but a number of ships working within a well thought-out plan might be very successful.

The instrumentation of oceanography can clearly be much elaborated. Not only will better instrumentation make the ships more efficient in terms of scientific output, but, to some extent instruments can replace ships. The trend to various kinds of unmanned buoys that can secure continuous information will clearly be continued.

Probably the next major development in oceanography will come about through the need for many types of environmental forecasting. Already sea, swell, and surf forecasting has found practical application, both in the Navy and in industry. The routing of ships to take advantage of favorable currents and to avoid head seas has begun to show practical results. Ice forecasts have been quite successful for a number of years. Specialized forecasts for commercial fishing have been shown to be possible.

Unlike meteorology, oceanography has been spared overemphasis on day-to-day predictions. Nevertheless, the proof of our understanding of a system is to be able to predict what will happen next. The ocean changes much more slowly than the atmosphere, so that a rather modest data-gathering network should suffice. The synoptic oceanographer, when he comes into being, will have a somewhat more leisurely time than his meteorological counterpart.

The bottleneck at present in most types of oceanographic forecasts is the limited time scale of the weather predictions. It may well be that by including more day-to-day information about the ocean, better long-range weather forecasts will result. Thus, closer cooperation between meteorology and oceanography is likely to be the path leading to useful predictions about the gradually changing marine environment.

## ACKNOWLEDGEMENT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PHOTOGRAPHS:

Blanchard, Boltz, Curl, Fay, Hahn, Hayes, Holmes, Malkus, Macafee, Owen, Spooner, Von Arx

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