THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

annual report 1960

contents

Dr. Hudson Hoagland " " " "

First name + Title —

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AS OF 31 DECEMBER 1960

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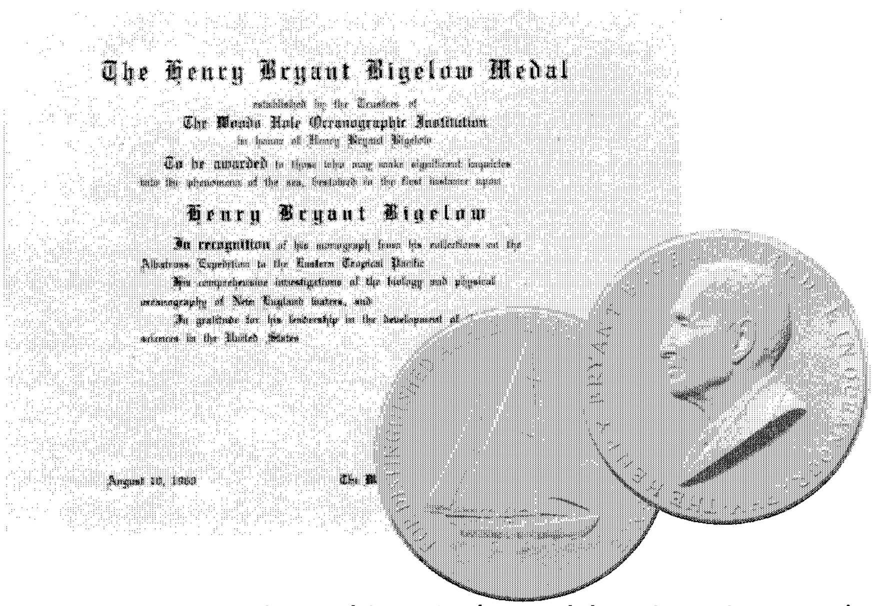
8/1962 YANG, DR. CHEN N. Institute of Advanced Study, Princeton



"The Henry Bryant Bigelow Medal . . . To be awarded to those who may make significant inquiries into the phenomena of the sea, bestowed in the first instance upon Henry Bryant Bigelow, August 10, 1960."

RESEARCH STAFF

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L. Valentine Worthington, Physical Oceanographer

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John M. Zeigler, Research Associate in Marine Geology
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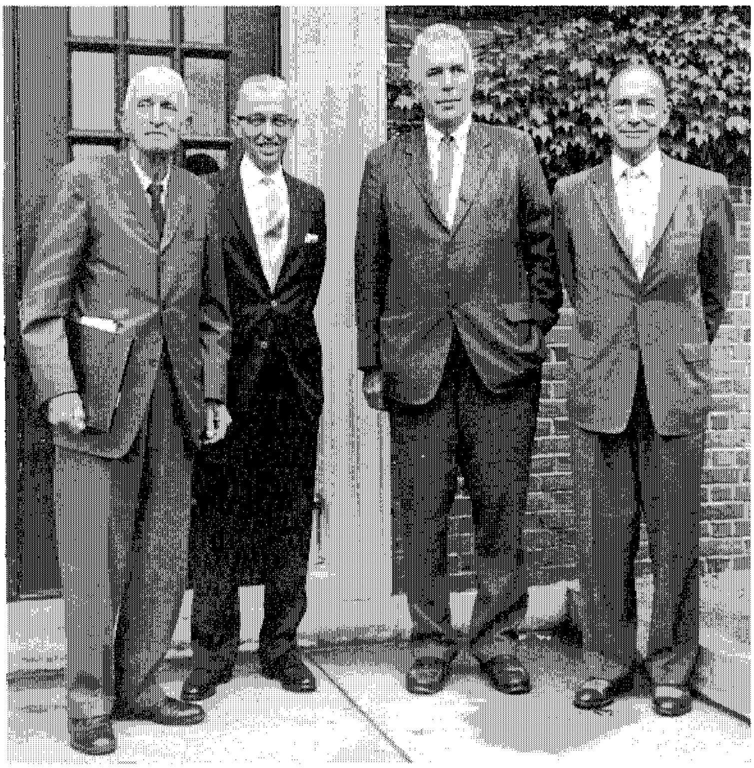
James R. Mitchell	Administrative Assistant to the Director
Ronald A. Veeder	Development Program Manager
W. Redwood Wright	Public Information Officer
Norman T. Allen	Archivist
Harvey MacKillop	Controller
Richard S. Edwards	Marine Superintendent
John F. Pike	Port Captain



SPOONER

Woods Hole Oceanographic Institution Directors during thirty years of outstanding leadership in oceanographic research are, left to right: Henry B. Bigelow, Paul M. Fye, Columbus O'D. Iselin, and Edward H. Smith.

DIRECTOR'S REPORT

oceanography 1930 - 1960

Anniversaries are a time for reminiscing and a time for evaluating past accomplishments and future hopes. In 1960 the Institution completed three decades of oceanographic research and witnessed thirty years of outstanding scientific achievements. Today, in preparing this prelude for our Annual Report 1960, the first Director and present Director have jointly reviewed the accomplishments, triumphs and frustrations during this period.

We have thought of the past three years as heady times in oceanography but so, too, were the first three years of the Institution. From 1957 to 1960 our operating budget has doubled (from 2.4 million to 5.0 million dollars) but between 1930 and 1933 it increased over 2½ times (from $44,600 to $114,900). In comparing budgets it is customary to use a common dollar value. Here we might suggest as the proper inflationary factor for the oceanographic dollar the six-fold increase in operating cost of the ATLANTIS.

In the early years names famous or to become famous were quickly added to the Institution's roster: Redfield, Rakestraw, Rossby, Parr, Stetson, Waksman, Iselin and Wilkins. In like manner, we hope that those recently added to our staff will bring new kudos to our Institution.

Similarly our fleet has changed over the years and the names of at least eighteen research vessels have been enrolled in the pursuit of science at the Institution. None has served more faithfully or brought more renown than the ATLANTIS, which this year has completed one and one-half million miles of cruising and the five thousandth hydrographic station. Indeed, the pace set during the first year and a half of operation which saw 251 days at sea and 450 hydrographic stations has seldom been matched in later years. In the most recent comparable period, however, she has been at sea 389 days.

Perhaps the most revolutionary change in the thirty years has been in the equipment used by oceanographers. A fathometer was not installed on ATLANTIS until November 1932 and the first radio for transmitting and receiving was not acquired until a year later. The Nansen bottle, bucket thermometer and collecting nets have had few basic changes over the years. A heavy bottom dredge was added in 1934 and coring equipment in 1935. The Rossby "Oceanograph" evolved into the Spilhaus bathythermograph. The impact of modern electronics by way of the vacuum tube and of solid-state physics in the form of the transistor has been effective only in recent years. Now the measurement of bottom profiles, of sub-bottom structure, of surface temperatures, down to 400 feet, all computed and controlled automatically, is completely routine. Instruments free of cumbersome wires, that can be programmed to go to the bottom and back, taking data all the way and techniques for recording specific parameters constantly or telemetering data on demand to the laboratory are today becoming commonplace.

In looking over the 1134 papers carrying a Contribution Number from the Woods Hole Oceanographic Institution we appear to have indeed carried out the mandate of our charter " to prosecute the study of oceanography in *all* its branches." Was it prophetic of events to come and of another NAUTILUS that our first paper written by Harald Sverdrup and Floyd M. Soule was concerned with the Scientific Results of the NAUTILUS under the command of Sir Hubert Wilkins? Impossible as it is to evaluate the scientific contributions of this Institution during its first thirty years, we believe the high scientific standards established in the beginning have been maintained.

One aspect of our work of which we are justly proud has remained unchanged. This is the continued excellent cooperation between scientist and sailor and between master and chief scientist. Sverdrup writes in that first paper

> "The interest which Wilkins himself took in the scientific work is illustrated by the fact that on the day when the loss of the diving rudder was discovered and we actually were lying in the ice with a disabled submarine, he had no thought of returning to safety before we had tested our scientific equipment under conditions which were worse than those to be expected on a journey partly under the ice. I can, I believe, safely state that on August 22 every one on board except Wilkins would have been willing to return, acknowledging a complete defeat, but he did not for one moment consider the possibility of returning before every opportunity for scientific work had been taken."

This spirit has been demonstrated on every cruise. The heroic recovery of a deep bottom cast without benefit of winches by the CRAWFORD crew and the difficult sail without engines by the ATLANTIS last December, missing Christmas at home, are only two recent examples.

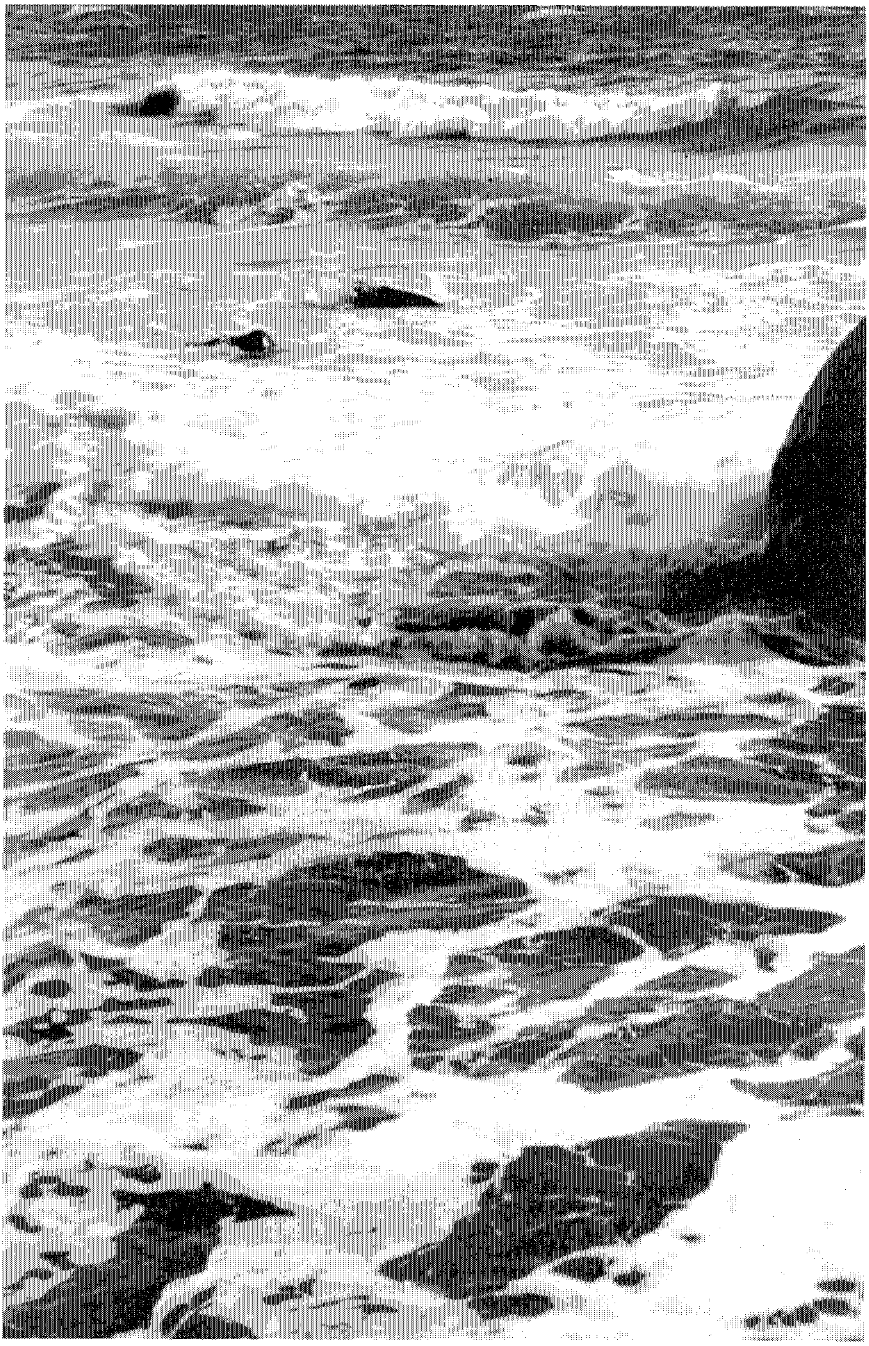
So it is to the people who have sojourned for a time in our Institution, over 4300 in all, that we would at the end of three decades pay tribute. Each one – from Pop Schroeder in the attic to Stan Eldridge in the basement, from Chief Backus in the engine rooms to Virginia Walker in the front office, from the beaker washers to the senior scientists – all have our great appreciation of a job well-done. We sincerely hope that in the days ahead the same spontaneous enthusiasm and unbridled curiosity will continue as the flag at our masthead.

Henry B Bigelow

HENRY B. BIGELOW

Paul M Fye

PAUL M. FYE



HAHN

physical oceanography

The most concerted research effort that was undertaken at the Institution during 1960 was a multi-ship, three-month investigation of the Gulf Stream in the area, Woods Hole, Bermuda and the Grand Banks. During April, May and June the Institution's Research Vessels ATLANTIS, CRAWFORD and CHAIN were fully occupied with this project. In addition, the R/V ARIES was used during the last phase of the work, and the Coast Guard Ice Patrol Vessel EVERGREEN assisted during the initial survey. A long range Navy patrol plane and the Institution's DC-3 aircraft were used for tracking telemetering drift-buoys and for sea-surface thermal radiation measurements.

This major survey, which has come to be known as GULF STREAM '60, was divided into three parts. During the first phase, eleven lines of hydrographic stations were occupied on north-south sections running from the continental shelf to the latitude of Bermuda. Over two hundred stations were taken in this half million square miles of ocean, giving a unique three-dimensional picture of the Gulf Stream system and its environment from surface to bottom. Bathythermograph observations to 900 ft. were made between station positions for a detailed picture of thermal conditions in the surface layer. Bottom topography was recorded by precision fathometers. The Navy patrol plane was used during this phase of the cruise to track the main course of the Stream visually and with the infrared radiation thermometer. At the end of the three weeks required to complete the preliminary part of the survey, the ATLANTIS, CRAWFORD and CHAIN met in Bermuda where data from the various sources were compared and plans formulated for the second phase of the work.

On the basis of pronounced horizontal temperature gradients, the Gulf Stream was found to have formed a very large meander recalling the picture obtained on Operation CABOT in 1950. However, in this case, the southwesterly loop appeared to be much longer than the southern meander of CABOT. The currents and countercurrents found south of the Grand Banks also seemed to be similar to those obtained during CABOT. The more detailed examination of the area during GULF STREAM '60 showed, however, that the CABOT results were an oversimplification of the situation. Even with the long lines of stations spaced only one hundred miles apart, it is apparent that important convolutions of the current system can be missed. During the ten weeks some very marked changes appeared to take place in some areas; yet other portions of the Stream remained unchanged. Although it would appear that the meanders change their dimensions with time, it is very difficult on the basis of the present data to imagine them as moving waves imposed on the general current system.

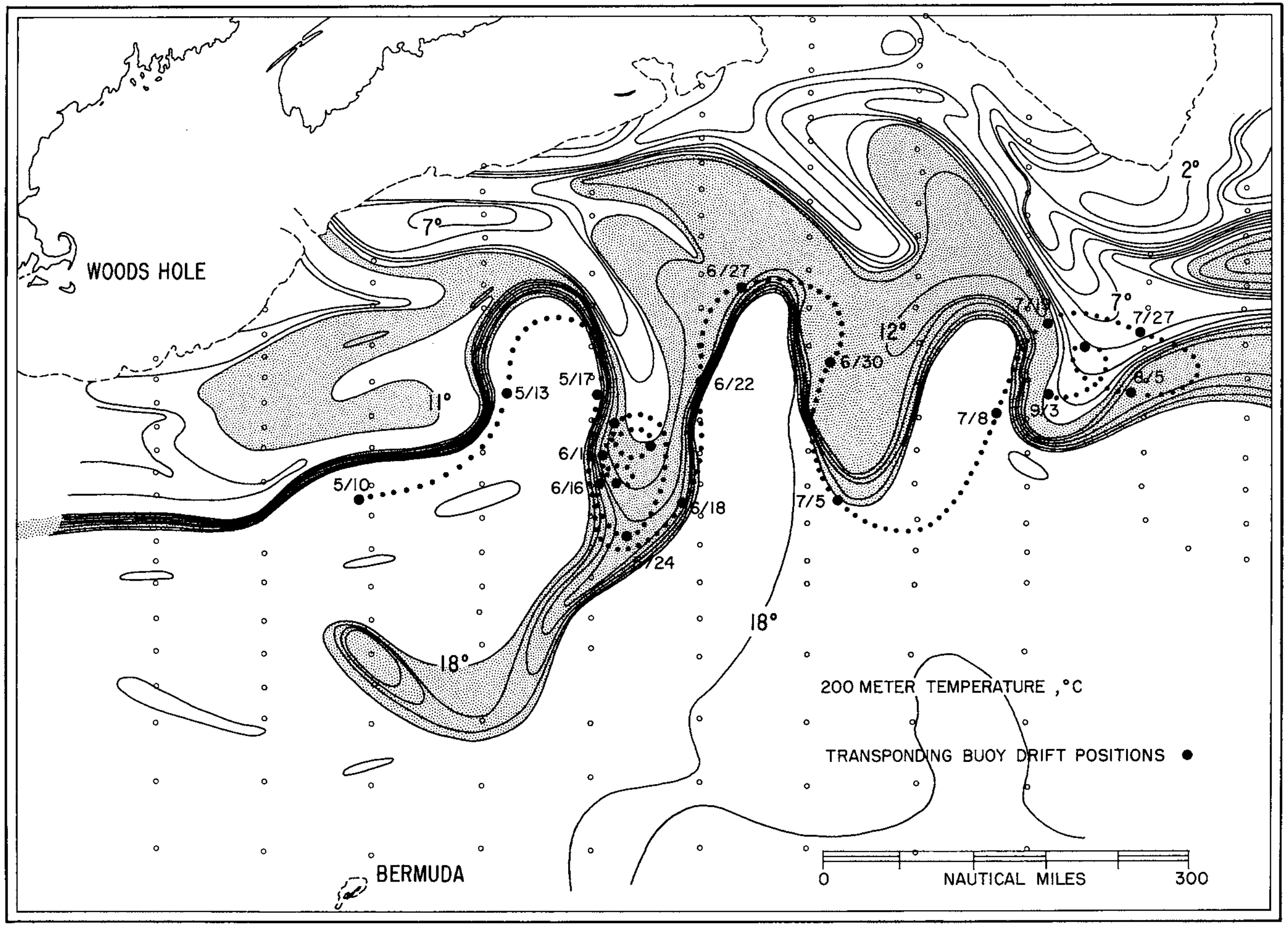
The second period of the study was confined to the western half of the area in the vicinity of the large meander. The work was divided into four principal parts. With vertically buoyant floats, the ATLANTIS observed the deep currents in the main body of the Stream and the CRAWFORD the currents in the upper layers. The CHAIN traced the surface currents, using the geomagnetic electrokinetograph (GEK) and towed thermistor array. The aircraft were used to track radio drift-buoys which were set adrift from the ATLANTIS. In addition, hydrographic and bathythermograph data were obtained, and experiments were also carried out from the CHAIN using free-falling instrumented floats to obtain continuous measurements from surface to bottom.

One of the surprising results, which developed early in the second period of GULF STREAM '60 when the CHAIN made a series of stations through the major loop of the Stream, was the remarkable constancy of this significant feature. This persistent pattern in April and May was confirmed by using the GEK to track the line of zero set of the ship along the major meander. The previous concept of the Gulf Stream meanders had been that they changed rapidly with translatory velocities as large as eleven miles per day. Furthermore, the convolutions in the main current are not shallow phenomena but involve the water to great depths. Hence, the situation is not a simple one. The aerial observations, the GEK results and thermal measurements indicate that in many cases the very surface layer seems to depart from the deeper ones. The correct interpretations of the shifting three-dimensional stream with time are most complex.

During the third period the CRAWFORD and ATLANTIS teams again looked for the loop of cold water extending to the south from about 64°W and found it had moved only some 50 miles to the northwest. The tip of this long boot-shaped loop had closed off into an eddy of about 100 miles in diameter. Both ships launched deep floats at the 3000 meter level on the two sides of this eddy and found currents of about 8 cm/sec moving counter-clockwise in the same general direction as the surface current.

At the same time the CHAIN made a series of stations from 35°N to 39°30′N along longitude 63°W. Then she followed the maximum surface current over 1500 miles through a major loop to the north and another to the south. The data indicated that there had been slow but distinct changes in the meanderings of the Gulf Stream. During this phase of the program the ARIES made deep current measurements in the south-central area.

The final interpretation of the data obtained on this survey will depend largely on the results of the deep-current measurements made by the ATLANTIS and CRAWFORD. Deep-pinging floats were used to follow currents



An interpretation of GULF STREAM '60 using 200-meter temperatures (°C) and surface GEK observations. Red dots show drift positions and dates of one of the transponding buoys used during the survey.

at the 700 m and 3000 m levels during both the second and third periods of the expedition. The CRAWFORD placed buoys in the main current at the 700 m level and found that they moved with a velocity and in the direction predicted by the temperature structure at this depth. Contrary to expectation, the ATLANTIS, with floats set for 3000 meters, found that the one-third knot current at that depth was still flowing in the same direction as the surface current. This result was surprising in view of the usual dynamic calculation of surface currents which assumes a level of no horizontal motion at a depth of 2000 meters. Recent theoretical work had also predicted the thickness of the Stream to be no greater than 1600 meters. The deep countercurrent found earlier, and taken as a confirmation of this theory, was, however, located off the Blake Plateau where it would not be expected to flow directly beneath the Gulf Stream. These, on the other hand, were the first direct measurements of deep current directly under the western boundary current. As a consequence, some revision of prevailing theory may be required.

Several other projects in physical oceanography undertaken during the year illustrate the increased utilization of novel instrumentation. Using such devices as neutrally buoyant floats, telemetering drift-buoys, parachute drogues and a variety of newly designed current meters, several studies involving the direct measurement of specific current regimes were undertaken. Some of these investigations were carried out from the CRAWFORD in the area of the North Atlantic salinity maximum east of the Bahamas. The CHAIN, in conjunction with the Scottish Fisheries Research Ship EXPLORER, likewise used similar techniques on the Iceland-Faroes Ridge and on several shorter cruises off the edge of the continental shelf to the southeast of Woods Hole.

In addition, measurements of horizontal velocity shear near the sea surface by use of towed pitometers were undertaken from the CHAIN during October and November. First analysis of these measurements indicates that the direction of the observed shears agreed quite well with the direction of ship's drift.

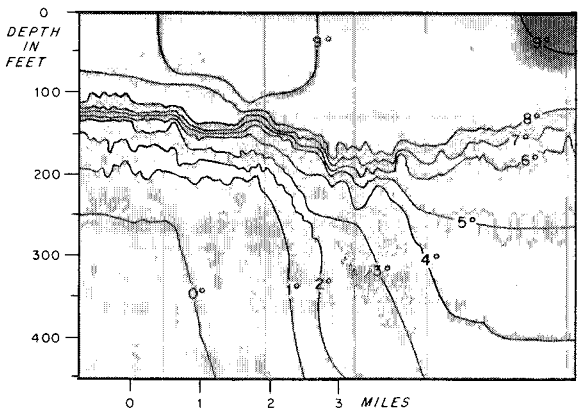
A second instrumented wave tower for telemetering wave height and slope, as well as wind speed and direction, was erected in Buzzards Bay. The data were transmitted by an FM radio link to Woods Hole, recorded and coded for analysis by the Institution computer. The instrumentation system on the buoy functioned as planned, but the project was brought to a halt by the collapse of the tower during a hurricane in the fall.

The oceanographic program on the continental shelf has now been under way for five years and has revealed the need for moored oceanographic stations to measure temperature and current velocity at a network of stations.

Thus, the analysis of the temperature fluctuations on Brown's Ledge over a period of 56 days indicated that abrupt shifts in temperature there are the result of new water masses moving in rather than changes within a given mass. Prevailing winds can contribute to the persistence of one water type in a particular locality for appreciable periods.

As a result of the analysis of the drift bottle returns over the past ten years, the non-tidal surface currents in the Gulf of Maine can now be described. The Maine eddy appears north of 43°N from November to January. It expands southward in February and March to the northern edge of Georges Bank, and it remains there from April through August. Then, in September and October it contracts northward once more. Surface motions on Georges Bank are westward in March, but become a clockwise eddy about the shallower parts of the Bank in April and May. These eddies degenerate in June, and, during the six months, August through January, the currents are generally toward the east and southeast.

South of New England, the surface currents in March and April are closely interwoven with those of Georges Bank, acting as the western extension of the Georges circulation. By May, however, there is a definite indraft at the surface from the outer limits of the continental shelf between South Channel and 71°W. This indraft continues through August after which the circulation turns west and then presumably offshore.



Record from CHAIN cruise 13, August 18, 1960, with identification (°C) overprint, shows Atlantic-Arctic water convergence.

mathematics and theoretical oceanography

The investigations into electrically driven motions in fluids of low conductivity were terminated with a study of the surface motions which are the consequence of the combination of the distortion (caused by surface tension) of the interface between two fluids and a steady applied electric field. It was shown that intense motions could be set up at the interface because of the distribution of charge which results from the distortion of the interface. Values of the electric potential and the scale of motion as functions of the microscopic parameters at the point of onset of instability were derived.

The gravitational instability of a gas mixture was examined for the case when a gradient of component concentration had been set up by the diffusive process. As a consequence of this, it appears that the classical theory of Bénard convection can be applied to this problem provided that the density term in the Rayleigh number is reinterpreted in terms of the actual densities of the concentration gradients. When the diffusion coefficient is much larger than the viscosity, a large stabilizing effect enters. However, there is no evidence that the diffusion coefficient can be much larger than the viscosity coefficient in real gases.

The possible application of information theory to fluid flow was also tested. In particular, an attempt was made to deduce the "preferred" solution in non-linear fluid flow from the principle of maximum uncertainly. This work is being continued.

Studies on turbulence were continued, and it was found possible to deduce the gross qualitative structure of shear flow and thermal turbulence from a new application of similarity theory. It is believed that the simplicity of this formulation will make more complicated fields of motion accessible to analysis. This similarity argument is based on two assumptions, viz., that the mean fields in statistically steady turbulent flows do not exceed the conditions for marginal inviscid stability and that the smallest scale of motion which is unstable on the mean field is the smallest scale which contributes to the transport process. The theoretically deduced mean temperature profile compares favorably with observations. Quantitative agreement is within ten per cent of the observed results.

A laminar jet, in a "shallow layer" of less dense water is in geostrophic equilibrium above an infinitely deep resting layer of denser water. The quasihydrostatic process for releasing energy in this thermoclinic model was compared with other baroclinic and barotropic models. It was shown that a small amplitude disturbance can grow only if there is a transfer of kinetic energy from the horizontal variations in the mean jet, and that conversions of the available mean potential energy can only occur concomitantly with this process. An examination of the characteristic equation, following the arguments of Lord Rayleigh's theory for non-divergent jets, shows that the finite depth of the thermocline inhibits inflectional instability.

A study of the data collected on a detailed survey of the Gulf Stream off Onslow Bay has revealed several interesting features. The largest lateral amplitudes were found to be about 50 kilometers where the meanders exhibited an asymmetric structure at the surface. This may be an indication of the lateral transfer of heat and energy. The pattern of asymmetry is similar, on a much smaller scale, to that for multiple currents found downstream from Cape Hatteras. Because of their periods, the Florida Current meanders are not incipient forms of the larger ones downstream, nor are they induced by a tidal pumping action in the Gulf of Mexico. Furthermore, their surface transfer of momentum is against the mean velocity gradient. Hence, the Florida Current meanders, instead of being a mechanism for the dissipation of the mean current, as had been expected, are actually adding energy to it.

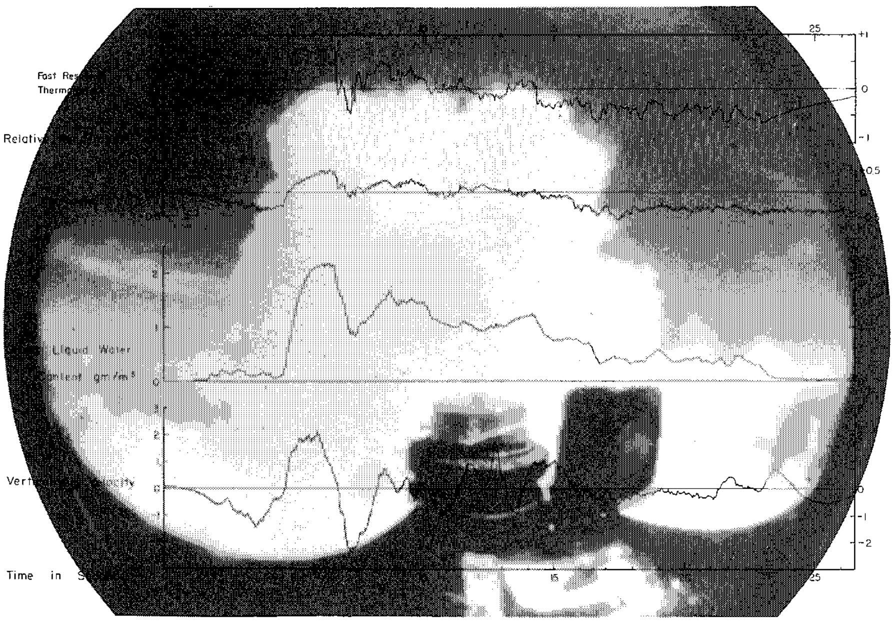
Using additional observations collected by the Marine Laboratory at the University of Miami over an eight-year period, the surface transfer of momentum across the current between Miami and the Bahamas was computed. The results are similar to those found for the current off Onslow Bay; namely, that there is a transfer of momentum by the perturbations against the mean velocity gradient.

marine meteorology

Attacks on the main problem of marine meteorology, the interactions of the atmosphere and ocean, have been pressed from many different angles during the year. Convection and cloud physics have been studied by means of theoretical and experimental models and measurements from airplanes in the clouds themselves. Large-scale studies of the cloud patterns across the Pacific Ocean have been made, as well as studies of the small-scale variations of the water vapor pattern in the trade winds off the Bahamas. Much needed direction and insight into the problems of marine meteorology is contained in a new survey book covering the field of air-sea interaction.

The importance of cumulus clouds in marine and global meteorology is twofold. First, they are the most effective process for transporting water vapor from the thin sub-cloud layer to a thick layer which carries the vapor to the equatorial regions. Second, once arriving in low latitudes, cumulus clouds tower to the stratosphere releasing the latent heat of condensation of the vapor which provides energy for the global wind system of the atmosphere.

Because of the key role of cumulus clouds in the transfer of energy, much attention has been focussed on the physics of cloud drops and cloud formation. Aircraft observations of clouds in the Bahamas and in the neighborhood of Woods Hole have been made. These consisted of nose-camera photographs, wet- and dry-bulb temperatures, measurement of liquid water content and turbulent vertical velocity records in and around cumulus and stratiform clouds. The observations are being reduced for interpretation in terms of a theoretical "bubble" model of buoyant elements in cumulus clouds. A crucial aspect of the work is the empirical evaluation of arbitrary parameters introduced into the "bubble" model with the help of the above observations.



LEVINE

Meteorological measurements while flying through cumulus clouds.

Laboratory experiments complement the direct observations of the atmosphere. For convenience liquids are used rather than gases. A small mass of dyed salt water released into a large mass of fresh water acquires the character of a turbulent vortex ring (and resembles a miniature nuclear bomb explosion). By adding salt to the fresh water in different concentrations at different depths, we change the behavior of this vortex ring. For example, at a level where there is an abrupt change in the salinity (density), the ring can be observed to spread suddenly. Such experiments yield information and concepts for describing the spread of giant cumulonimbi at the tropopause and the penetration of trade-wind cumuli into the trade inversion.

Work on the relation of cumulus to hurricanes has continued, and papers have been published describing the energy transformations and the relations of the diameter of the clouds to vertical velocities.

Before the water vapor and heat can be transported by cumulus clouds, they must first be diffused by turbulence from the ocean to the base of the clouds. This process has been observed from the DC-3 airplane for several years from Newfoundland to Trinidad. A recent paper presents the turbulent heat and water vapor transport through the sub-cloud layer. The variation of these quantities with latitude, the ratio of heat to water vapor flow and the downward flow of heat from the upper air are described. The airborne radiometer was developed and used to determine the net radiational flux in the atmosphere so that the heat budget of the ocean-air system could be established. Observations made in the trade-wind air have been reduced and heat budgets for a few days have been constructed.

The introduction of the Recomp II computer this year allowed an ambitious project to be carried out that otherwise would have been impractical. In order to determine how the water vapor of the trade wind air varies at different heights below the clouds, a three-airplane study of the air off Eleuthera was carried out in August. Values of dry- and wet-bulb temperatures were recorded every three seconds in three airplanes during 10 to 20-minute flights with the airplanes stacked at different levels. An hour of computer time is sufficient to handle the staggering amount of data accumulated on each run.

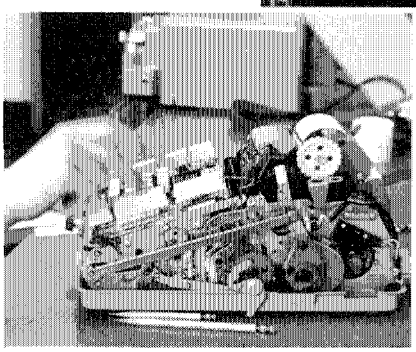
For a better understanding of the shearing stress of the wind on the water surface, a small spherical anemometer is being developed to measure the three components of the turbulent wind.

An empirical study in forecasting the temperature of southern New England winters by means of November pressure distributions has been continued. Of the various features of pressure distribution which have been tested as indicators of our winter temperatures, the most reliable is a welldefined trans-Arctic ridge as indicated by the isobars along the Atlantic side of the ridge. Strong flow from Siberia to the United States, together with the development of a trough off the east coast, are found to be indications of colder-than-normal winters. On the other hand, an ill-defined trans-Arctic ridge with little indicated flow of air from Siberia to the United States and a well-developed east coast high cell often precede a warmer-than-normal winter.

Earlier ideas about the retention of particles immersed in cell-like or vortical circulations in fluids and about the growth of raindrops on a basic nucleus of sea salt led to a much discussed theoretical study of raindrop growth in cloud parcels. This work progressed to some experimentally testable conclusions about the time variability of the numbers, sizes and salinities of raindrops falling from the base of warm shower clouds in maritime air. It also underlines the importance of filling the gaps in our knowledge of the dynamics of cumulus growth if further progress in understanding of the microphysical processes is to be made.

A more detailed study of Project SHOWER data led to the conclusion that tradewind shower rains may be generated in distinct parcels of unusually moist cloud air which are identifiable near sea level prior to the

WRIGHT



Re-comp II has been used to broaden our consideration of many heretofore "impossible" problems.

lifting of the air and the formation of clouds. The total rainfall from showers formed in marine air appears to be related to the amount of salt spray in this sub-cloud.

To further such studies, semi-continuous rain recorders capable of effectively counting all showers and giving their drop sizes are being built. A modified flame photometer for the measurement of sodium concentration in individual raindrops has been designed and tested.

Steam clouds from the flow of lava into the sea during the 1960 volcanic eruption at Kilauea in Hawaii offered a unique opportunity to learn about the potential importance of coastal volcanoes as sources of salt-nuclei in the atmosphere. Particle sampling flights by aircraft through these clouds revealed high concentrations of minute droplets containing sea salt. The salt particle production rate by the action of hot lava in contact with sea water was many millions of times greater than that of an equal area of the sea surface. The size range of these salt particles was from about 0.1 to 10 microns radius. These results are meteorologically important during periods of intensive volcanism.

An extensive and important study of bursting bubbles at the sea surface as a source of electrically charged saline particles in the atmosphere was completed during 1960. Climatic atlases and the extensive data assembled over the years on the distribution of sea salt in marine atmospheres permitted a careful evaluation of the flux of salt from the world oceans as a function of wind force and altitude. The flux of positive charge from the world oceans, carried into the air by the droplets ejected by bursting bubbles, has been found to lie between 100 and 200 amperes. The annual flux of sea salt is about 10^{10} metric tons.

geophysics and submarine geology

The study of the sea floor by means of echo sounding, dredging, underwater photography, coring, geothermal gradient methods and seismic reflection and refraction has continued to be a principal activity. Although, during the year, these have been carried out from the Equator to north of the Arctic Circle, some of the most interesting investigations have been completed in waters adjacent to the Institution. Using the seismic profiler, reflection surveys carried out by the BEAR extended and confirmed earlier work, indicating that two passages in Narragansett Bay are underlaid by sedimentfilled gorges and bed rock. These gorges have exceedingly irregular profiles and in places are over 400 ft below sea level.

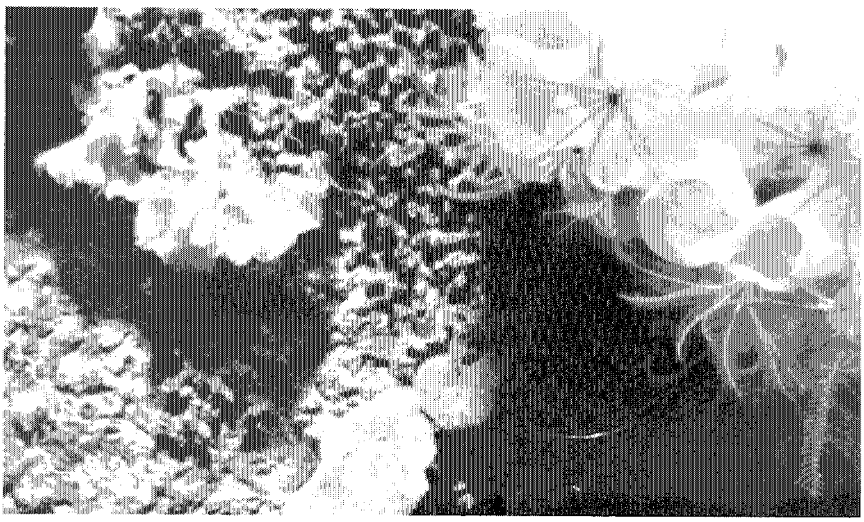
A fascinating correlation of sub-bottom structures in Cape Cod Bay was also completed during the summer. Glacial deposits, preglacial topography and underlying late Mesozoic structures were successfully charted in the bay. As an interesting adjunct to this work, coring operations on the Cape proper and a test well put down in the Provincetown area demonstrated the presence of Eocene sediments at a depth of about 100 ft. These cores have also proven useful in the identification of seismic horizons which were initially discovered with the continuous seismic profiler in Cape Cod Bay.

On the two long cruises during 1960, one to the Caribbean and Bahama area and the other to the Norwegian Sea, a variety of interesting geophysical observations were made. Unlike many of the other geophysical investigations, photography permits a study of results relatively quickly. During the year about 500 stereoscopic pairs of photographs of the ocean bottom were taken from the CHAIN. These pictures, partly in black and white and partly in color, revealed many scenes of rugged rocks, of mud and of sand, often with ripplemarks. Nearly everywhere there was abundant evidence of animals living on the sea floor. The color and structure of rock beds have proven useful in studying submarine canyons and rift valleys. One group of photographs taken at a depth of seven kilometers on the north wall of the Puerto Rico Trench show freshly fractured rock surfaces. In the same vicinity companion photographs show large boulders of native rock. This group of photographs has become especially exciting since the recently completed analysis of seismic profiles taken at the same time strongly suggests that the top of the basaltic layer (the "third-layer" of seismologists) outcrops on the north wall at this depth. This, in fact, may be an area, where due to great tectonic activity, the base of the earth's crust may actually be exposed.

Using a variety of high intersity sound sources, seismic reflection techniques have been used to determine the sub-bottom structure in the Baltic, across the Norwegian Channel, across the continental shelf and slope west of Norway, in the North Sea and in the English Channel. The seismic reflection studies in the English Channel were made in collaboration with British geologists who had previously carried out an extensive coring program there. The series of reflection profiles at the edge of the Norwegian shelf showed nearly horizontal beds outcropping on the continental slope at depths of 700 meters. These were supplemented by dredgings which recovered freshly broken calcareous rock from depths greater than 500 meters. Reflection surveys were also carried out in several Norwegian fjords and outlined the form of the rocky channel in which sediments were deposited. Sedimentary material for biochemical analysis was also collected from the bottom of fjords where little oxygen is present in the water.

On the CHAIN's passage across the Atlantic in mid-summer, vertical temperature gradients were measured in ocean sediments at several locations. Heat conductivity was also measured in core samples taken at the same places to provide data for computing heat flow from the earth's interior. The majority of these measurements resulted in nearly normal heat flow (close to 1.3×10^{-6} cal/cm^2 per sec) but one in the Mid-Atlantic Ridge resulted in a value greater than 6×10^{-6} cal/cm^2 per sec.

The sound velocity of bottom sediments has been measured directly on deep sea cores and compared with high resolution echo soundings which showed multiple echoes. The latter suggest reflections from flat beds only a few feet below the bottom surface. It has been especially interesting to carry out detailed sound-velocity measurements on the cores on shipboard. These velocities are well correlated with other characteristics of the cores and the positions of abrupt changes in velocity correspond well with echo-sequences where the latter persist horizontally over large areas. Less persistent echo-sequences do not correspond with the characteristics identified in the core material.

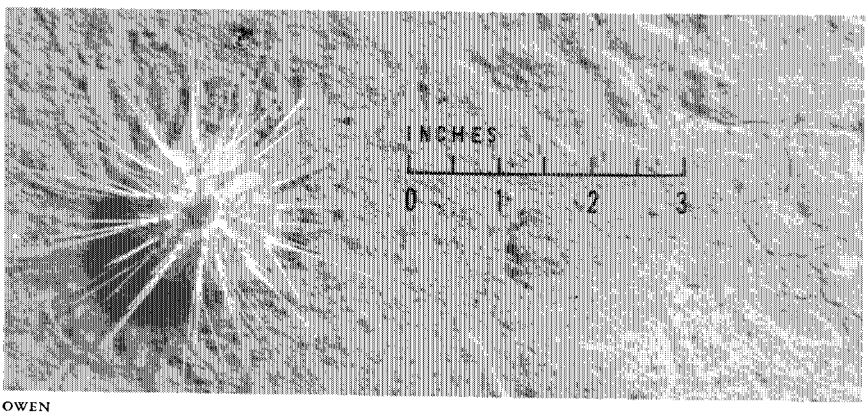


PRATT

In addition, cores were collected in several areas for special geological and geochemical investigations. Two series were collected in the Caribbean during the winter as part of a general program to determine the circulation and sediment patterns there. One set, taken along the downwind side of the Windward Islands, will be used to examine the alteration of volcanic minerals by sea water. Another from a large area of the Yucatan Basin and nearby plateau will afford an opportunity to study the distribution of the biologically derived components of sediments in relation to the physical properties of the environment. Again, special emphasis has been given the low oxygen content in the basins.

In the late summer, the ATLANTIS made a short cruise to a clay area on the continental shelf east of Cape Cod where several new analytical techniques were attempted on freshly collected material. Thus, a higher salinity content was demonstrated in the interstitial water of the sediment in the upper part of the core than occurs in the bottom water iself. In contrast to this, lower interstitial salinities were found deeper down in the core and suggest a transition across a Pleistocene interface. The acidity of the interstitial water was greater than that of the bottom water. This is considered to be due to high CO_2 pressures developed by the bacterial decomposition of organic material.

Outstanding examples of high speed photography of the deep ocean floor, near Bermuda, showing various animals. Photo below: Owen stereo camera. Photo opposite: Edgerton camera.



OWEN

underwater acoustics

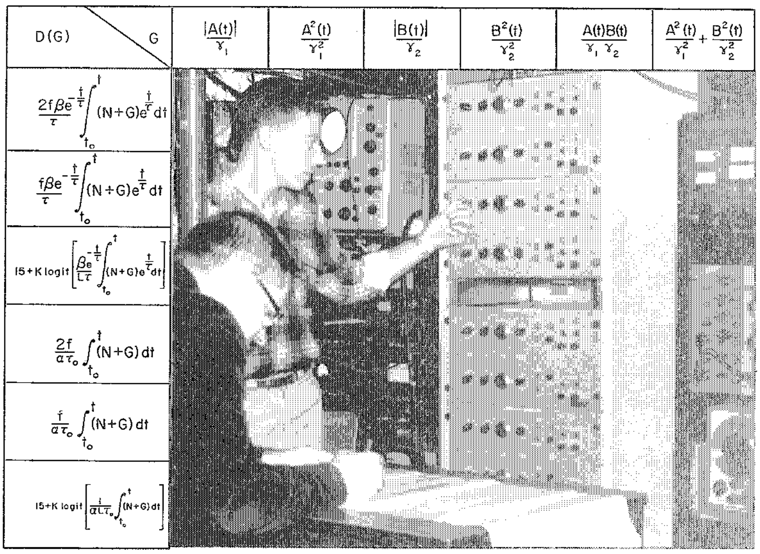
Interest has continued in the animals which through their diurnal vertical migrations form layers in the ocean. These can be detected by the scattering of sound. Using explosives as sound sources, broad-band sound scattering observations were made at about forty-stations from the northern Norwegian Sea to the Bahamas on two ocean crossings. A new sound spectrum analyzer permits better and more rapid analyses while still at sea. The frequency-dependent characteristics of scattering layers at three widely separated localities in the western Atlantic and the changes in the scattering spectrum during vertical migrations will be published shortly. The frequency-depth relationship continues to be compatible with our concepts of the behavior of the swim-bladder in bathypelagic fishes with changes in pressure. These fish are presumed to be the sound-scattering agents.

During 1960 considerable attention was paid to an unusual sound-scattering feature restricted to the slope water off the coasts of the northeastern United States and Canada. This peculiar phenomenon, nicknamed "Alexander's Acres," is located northeast of Cape Hatteras in an area bounded to the north and west by the 200-fathom curve and to the south and east by the Gulf Stream. "Alexander's Acres" is detected at a mid-day depth of about 200 fathoms and migrates up to the surface at night. Unlike the ordinary deep-scattering layer whose reverberation is diffuse and relatively weak, this layer consists of groups of strong scattering agents. Their reverberations cause crescentic patterns on the echo-sounder record much like those found in shallow water over the fishing banks. In 1959 this scatterer had been continuously distributed over thousands of square miles between Cape Hatteras and the latitude of New York. In 1960 it had a rather spotty distribution and was even missing over much of this area. In other words, here is an oceanic population which fluctuates from year to year as do many coastal animals. The identification of this animal, thought to be a fish, would be of great interest. However, attempts to photograph it with the echo-sounder camera apparatus on various cruises of the BEAR have been unsuccessful as were preliminary attempts to catch it with deep-set gill nets and longlines. In the successful fishing trip of the CRAWFORD in November, reported below, there was a good correlation between the appearance of "Alexander's Acres" on the fathometer record and a successful catch of large fish.

An analysis of echo-sounder records made by YAMACRAW and CHAIN in the Strait of Gibraltar and its approaches at times when dynamic studies were also being made there has demonstrated the value of such records in studying circulation problems. It was shown that sound scatterers in the Strait of Gibraltar are useful in determining the boundary between the surface layer of east-flowing Atlantic water and the deep layer of west-flowing Mediterranean water. Moreover, in the Strait, a scatterer was observed whose daily pattern of vertical migration is reversed. It moved upward in the daytime and downward at night. Such a scatterer was not detected on records made in either the easterly or westerly approaches to the Strait. These observations were presented at the meetings of the International Union of Geodesy and Geophysics in Helsinki during the summer of 1960.

Acoustic analyses of whale sounds has continued, as opportunity offered, and so far twelve species of whales and porpoises have been definitely associated with their corresponding sound records. It is extremely difficult to identify the source of sounds heard at sea, and so this apparently small score is in reality a considerable achievement.

A thorough understanding of sound transmission can only be achieved with a knowledge of its relationship to the properties of sea water and the earth beneath. This has required the development of instruments for measuring the environment in greater detail, particularly high-energy sound sources. Sounds received from these sources in the ocean consist of a train of pulses having characteristics of their transmission paths through the ocean. Techniques developed over many years for identifying the transmission paths and measuring the energy flux in these pulse trains have been applied in experi-



New sea-going analog computer, developed at Woods Hole, provides a variety of computations for the scientist.

ments in the North Atlantic Ocean over long, nearly horizontal sound paths. Other observations using short inclined sound paths were made to measure the reflection from the ocean floor. Large quantities of such data collected continuously while under way necessitate the development of automatic data processing aids, now in progress.

Continuous records in over ten thousand miles of towing, made with the thermistor array have delineated the time-space variations in the shallow temperature structure over deep water. In addition, similar studies were made of the "cold wall" of the Gulf Stream south of the Grand Banks, in the Strait of Gibraltar, and in the boundary between Arctic and Atlantic waters in the Norwegian Sea. These investigations were concerned with the effect of tides, of other short-period disturbances acting within the water, and of the local weather on the thermal structure near the sea surface.

"Sound-scattering by Marine Organisms" and three other related chapters have been prepared for the forthcoming book, "The Sea: Ideas and Observations." These are concerned with the physics of underwater sound-scattering, biological sounds and a collection of observational underwater sound data which have been accumulated from the deep ocean.

chemistry

Throughout the year, continued emphasis has been placed upon the use of various radioactive fission products in the general study of ocean circulation. So far, strontium-90 has proven to be the most useful isotope, and its distribution in the ocean has several interesting features.

A North Atlantic station made by the CRAWFORD in March illustrated strikingly the effectiveness of heavy winter winds in vertical mixing of surface waters. For two days an unusually severe storm made hydrographic work impossible in this area, and it appeared to have significantly raised the salinity and temperature in the 500-800 meter water level. Fission product samples taken after the storm from the surface to 500 meters showed uniform strontium-90 values. This evidence of mixing is particularly striking since we have not previously postulated massive storm mixing to depths below about 300 meters.

A Gulf Stream station made late in 1959 showed a very sharp strontium-90 gradient in which a zone of high concentration was found to be between 300 and 500 meters while a year and a half earlier, this zone was between 80 and 250 meters. The 300 meter level is somewhat higher than the surface value and may be a consequence of reduced atomic testing in 1959. The sharp gradient in lanthanide radioactivity remained between 100 meters and 300 meters, confirming earlier evidence that the processes controlling vertical movements are different for strontium and for the lanthanides.

A study of our total strontium-90 data based on the integration of the curves for strontium-90 at various depths indicated both a very considerable mass transport of water to the 300-500 meter depths in periods of only 2-3 years and that the total strontium-90 in the water column in Atlantic mid-latitudes is much higher per unit area than that estimated for comparable latitudes on land. This surprising result is strengthened by the finding that the strontium-90 content is higher in coastal and island samples. This suggests that the simple explanation that the sea-surface is the optimal fall-out collector is unlikely and that instead there is involved a specific phenomenon of marine or near-marine meteorology.

An increasing emphasis has been placed on electrochemical problems, especially those involved in the operation of the GEK (geomagnetic electrokinetograph). An experimental investigation of this, by replacing the long cables and towed electrodes with salt bridges and deck-mounted electrodes, appears to have real promise and is being pursued actively. Using this means, it should be possible to eliminate or compensate for the sensitivity of electrodes to salinity, temperature, pressure and oxygen tension without introducing any new sources of error.

Other electrochemical problems being studied are the determination of the activity coefficient of electrolytes in sea water, the contributions of the various components of sea water to its conductivity, theoretical analyses of diffusion and molecular motion in liquids, the question of instrinsic thermal electromotive force in the ocean and potentiometric frontal analysis in ion exchange chromatography.

Studies of the composition of sea water by use of ion exchange resins in the analysis have been initiated. These resins permit simple separation procedures that should give more accurate results for the major dissolved constituents. These experiments are aimed at testing the validity of the notion of the constancy of relative proportions for the major dissolved constituents in sea water. Earlier work has shown that both calcium and magnesium can each be separated from all other dissolved constituents with an increase in the accuracy of several orders of magnitude. Measurements of the calcium chloride ratio in samples obtained in the Bahamas have been shown to be different than the ratio obtained in open ocean water. At present attempts are being made to measure the total anion or cation equivalents in sea water by determining the acid or base produced by passage through either a cation or anion exchange resin bed. The ratio of these quantities to chlorinity should provide a direct measure of the theory of constancy of relative proportions.

Various techniques have been considered for the isolation of the very dilute organic components of sea water. The most promising is a modified chromatographic method in which the extractant, an organic solvent, is stabilized in a column on an inert carrier, such as a swollen polymer. The concentrating efficiency is much higher than in conventional batch extractions, and organic extracts of approximately 1 milligram per gallon of sea water have been obtained. These extracts were separated by acid-base fractionation, and their absorption spectra and interfacial properties have been examined.

marine biology

Our interests in life in the sea range from the floating microscopic phytoplankton and zooplankton to the largest fish, porpoises and whales and are primarily focused upon the ecology and distribution of species within various populations. These problems invariably require a combination of experimental studies in the laboratory and observations of the populations as they occur in nature at sea.

The ecology, physiology and distribution of phytoplankton populations in both coastal and oceanic waters have been the principal areas of interest. A study of the seasonal and spatial distribution of various species occurring between Montauk Point and Bermuda has been completed. The frequency at which each species was observed at various salinities shows that those species commonly classified as oceanic, often the flagellates, were indeed more frequent in the high salinity waters seaward from the shelf, and those considered as coastal, predominantly diatoms, were more frequent in the lower salinities of the shelf water. It appears, however, that salinity alone is not sufficient explanation for the comparative rarity of the diatoms in the open sea since in the spring bloom observed near Bermuda many so-called coastal diatoms were present in large numbers in waters of relatively high salinity.

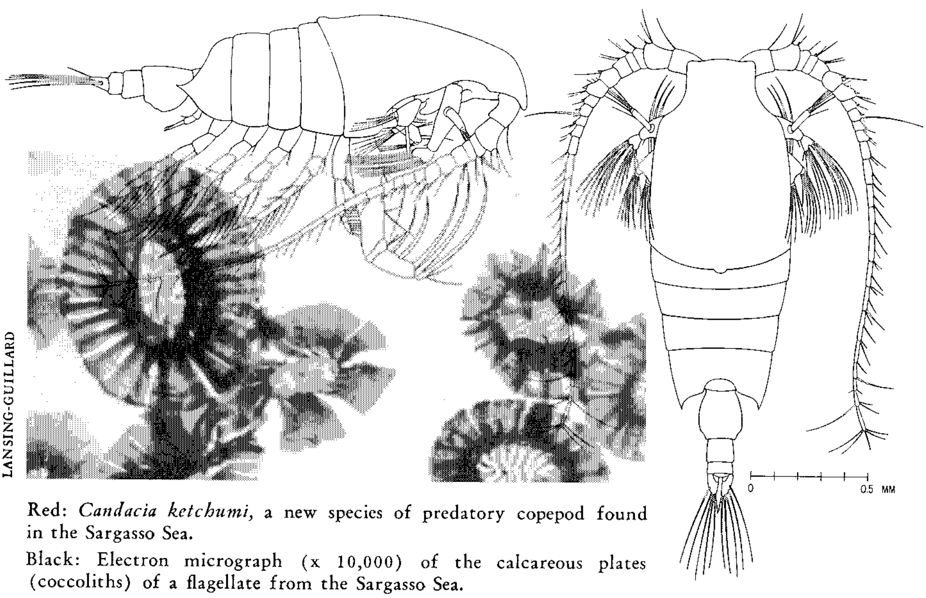
Fortunately our ability to culture these organisms from the open sea has kept pace with our requirements for physiological experimentation. During the last year a number of truly oceanic species of the plankton algae have been isolated and cultured. These include representatives of the green algae, the diatoms and the coccolithophorids. With these organisms in pure culture a number of controlled physiological experiments designed to explain their occurrence and abundance may now be attacked. For example, our controlled studies have shown that coccolithophorids have a lower requirement for iron than diatoms. Thus, the low iron content of the open ocean waters may be one of the reasons why coccolithophores are most successful there than diatoms.

An intensive study of the phosphorus metabolism of unicellular algae has been carried on using the radioactive tracer, phosphorus-32. Algal cells can assimilate phosphorus rapidly from the environment in order to satisfy their needs, and when a cell has assimilated all that it requires, the exchange rate between the phosphorus in the cell and that in the medium decreases ten to a hundred fold. Radioactive tracer techniques have also shown that cells in pure culture are able to reduce the concentration of phosphorus in their environment to 1/10 to 1/100 that which it is possible to detect by ordinary analytical methods. This suggests that a bioassay technique using radiophosphorus may be the only way now available to obtain accurate analyses of the amount of phosphorus left in the ocean at the end of intense phytoplankton blooms. Comparisons of the rates of uptake of phosphorus by different species of planktonic algae may further aid in explaining the distribution of these species in nature.

Studies of the ocean-wide distribution of phosphorus have been continued, particularly on the data obtained during the cruises of the International Geophysical Year. From evaluation of the total water transport in the cross sections of the north Atlantic Ocean combined with the distribution of inorganic and total phosphorus, it is possible to derive a regional estimate of the mean productivity potential of different areas of the ocean. This analysis has now been completed on sections at 40°N, 8°N and 24°S and illustrates the interrelationship between the mass circulation of the oceans and the biological processes which can be carried on in various parts.

Two exciting advances have been made in our studies of the nitrogen cycle of the oceans. Available nitrogen is almost completely exhausted in the surface waters of the Sargasso Sea by the end of summer or early fall, and at this time of year we have repeatedly observed large blooms of the blue-green filamentous alga *Trichodesmium thiebautii* in these waters. The ability of this alga to fix atmospheric nitrogen for use in its metabolism has been studied in natural sea populations and there is only a small nitrogen fixation by this species. This may well explain its success in the impoverished Sargasso Sea waters at this time of year.

The second achievement relating to the nitrogen cycle has been the successful culturing of nitrifying bacteria from the water column in the open sea. For decades unsuccessful attempts to isolate these have led many to assume that all of the nitrifying process must go on in the bottom sediments where the bacteria had been found. The fact that maximum concentrations of nitrite and nitrate are found at intermediate depths is a convincing argument that the nitrifying process must indeed go on in the water column. The successful culture depended upon obtaining large samples of water, which are enriched with ammonia and the cultures started immediately on shipboard. During the last year the presence of these nitrifying bacteria and the process of nitrification has been demonstrated in samples of oceanic water collected from the continental shelf, from the slope water beyond the edge of the continental shelf, from the Gulf Stream and from the Sargasso Sea. This suggests that they are widely distributed in the ocean. The laboratory studies on the physiology of these nitrifying bacteria also demonstrated that they are true chemoautotrophs which use ammonia as their sole source of energy for the fixation of carbon and for growth. The



LANSING-GUILLARD

Red: *Candacia ketchumi,* a new species of predatory copepod found in the Sargasso Sea.

Black: Electron micrograph (x 10,000) of the calcareous plates (coccoliths) of a flagellate from the Sargasso Sea.

marine nitrifiers are euryhaline and can grow over a wide range of salinity whereas terrestrial nitrifying bacteria are unable to survive in full-strength sea water. This, and other differences between the physiology of the marine nitrifying bacteria and the terrestrial ones, suggest that the marine population is indeed different and probably consists of different species.

A study of the zooplankton collections made on cruises taken at four periods during the year between Montauk Point and Bermuda have been completed. Nearly 400 species have been identified, including two which were previously undescribed. Sixty had not previously been recorded in this area of the northwest Atlantic Ocean. The identification of many of these four hundred animals has been confirmed by cooperating taxonomic specialists. A reference collection of these has been established at Woods Hole. The copepods were the most abundant group of organisms in both neritic and oceanic waters. The next most abundant groups were the chaetognaths and euphausiids. In addition to being numerically the most abundant, the copepods, in spite of their generally small size, frequently formed more than half of the total weight of zooplankton. There was considerable seasonal variation in the size of the collections from the continental shelf, somewhat less in the samples obtained from slope waters, and very little in those obtained in the Gulf Stream and Sargasso Sea. The largest concentrations of zooplankton were generally found at or near the edge of the continental shelf with considerably smaller quantities of plankton as the distance seaward from the edge of the shelf increased.

In the Woods Hole region itself, the distribution of various species of zooplankton in the waters of Buzzards Bay, the Cape Cod Canal, and Cape Cod Bay are being intensively studied. This is an interesting area because Cape Cod is one of the temperature barriers to the distribution of northern and southern species of animals, and the presence of many species appears to be related to the temperature changes. The sharp horizontal temperature gradient, often as much as 12°C, between the two bays, permits distribution studies to be correlated with laboratory experiments on the effect of temperature and salinity changes, on respiration and feeding rates.

A knowledge of the structure and taxonomy of each species is fundamental to our distribution studies. Two intensive taxonomic studies have been carried on. First, the study of the functional morphology and musculature of the bottom-dwelling crustacean, *Hutchinsoniella,* and its relationship to the evolution of other major groups of Crustacea has been continued. Second, evidence is also accumulating that two or perhaps three supposed species of the genus *Euphausia* may really be different stages of a single species. At least one of these appears to be a juvenile form and, consequently, not a valid species.

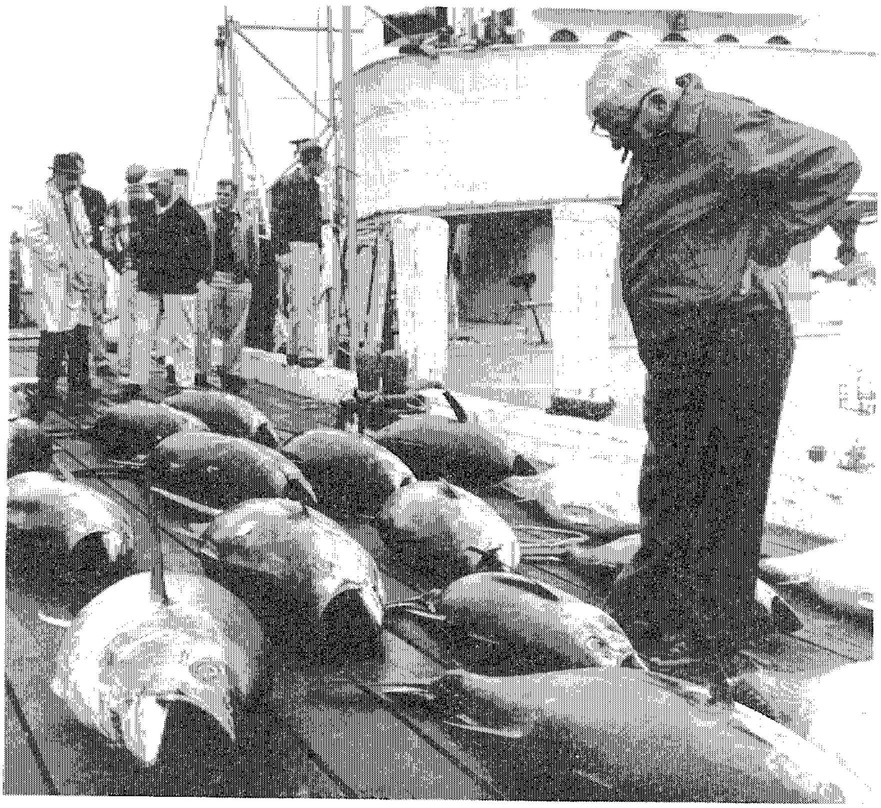
Laboratory studies of the metabolism and nutrition of *Calanus hyperboreus* have suggested that this copepod may have three mechanisms which permit it to survive long periods of starvation. This ability would be particularly important for this species since it is most abuntant in Arctic regions where adequate food material is present in the water only during the brief Arctic summer. These survival mechanisms include the ability to decrease the respiratory rate in the absence of food, the adjustment of the density of the organism so that it is neutrally buoyant with its environment, and the storage of fat in quantities which may exceed 50% of its dry weight. The result of the low food requirements, the elimination of necessary motion and the food storage is that *Calanus* can survive for many months in a dormant state.

Studies of the optical properties of crustacean eyes have been continued. With microphotometric measurement of polarized light transmission, it has been possible to develop a model which confirms a previous explanation of the ability of one species to detect and orient to polarized light in water. Electrophysiological studies of another species make it appear that dark adaptation is a property of the central nervous system rather than of the optical system involving regeneration of the visual pigments.

Measurements of light penetration into the sea carried out in the Brownson Deep 50 miles north of Puerto Rico revealed the presence of the clearest ocean water ever measured. Daylight was detectable to a depth of 950 meters. Comparison with measurements of the visual sensitivity of certain deep-sea fishes indicated that these animals can distinguish between day and night at that depth or even slightly deeper. Bioluminescence was recorded to depths of 3750 m in the Brownson Deep. The brightest luminescent flashes were more than a million times brighter than the probably visual threshold for the deep-sea fishes. Thus, the flashes can be seen for a considerable distance in this very clear water and may be useful in recognition of one animal by another.

Laboratory experiments on the physiology and possible function of bioluminescence were carried out on the marine copepod *Metridia lucens*. This copepod produces a very bright flash which has its peak intensity in the blue-green range of visible light which has maximum penetration in clear sea water. Under normal conditions, *Metridia* does not luminesce spontaneously but can be stimulated electrically or do so when the animal is attacked by a predator. Placing a group of *Metridia* in a flask with an active predator, *Meganycpthanes*, produced a brilliant display characteristic of this copepod. The number of flashes was always greater than the number of *Metridia* eaten. This suggests that bioluminescence in this species may be used in nature to startle or distract an enemy.

Further evidence has been obtained that the breeding cycle of bottom-dwelling invertebrates is closely associated with changes in temperature. Additional species have been stimulated to breed in the laboratory during the winter (when the natural populations are not breeding) by providing elevated temperatures, artificial light to increase the length of day and abundant food. In a species of mud snail, *Nassarius obsoletus*, the growth rate of the larvae is decreased as the salinity decreases below 23‰ or as the tem-



WRIGHT

Tuna specimens brought ashore from R/V CRAWFORD after the successful November long-line fishing investigations. Over two hundred tuna were tagged and released.

perature is decreased below 22°C. The duration of the larval period is also lengthened at the lower temperature. These experiments pose interesting questions concerning the breeding cycle of the deep-sea invertebrates where the environment is always cold and dark. It is hoped to extend these observations by making studies of the development of the gonads of deep-sea organisms at various times of the year to determine whether they have a seasonal cycle of breeding, and if so, whether this is stimulated by environmental conditions or by an internal clock mechanism.

The location of the bluefin tuna in the late fall has long been a mystery. They disappear from our coastal waters in September or October and appear in the spring in the Caribbean area. Little is known about this migration. A most successful cruise on the CRAWFORD in November provides new information about the distribution and migration of tuna by discovering a very large concentration along the 1000-fathom curve off southern New England and Long Island. The catches were made by long-line fishing in which as much as eight or ten miles of multiple-hook lines were set and recovered three or four hours later. Our program of tagging the migratory pelagic fish to determine the extent of their migrations has been continued. Likewise, the study of the maturity and breeding cycle of bluefin tuna has progressed by histological study of the gonads and by tow-net collections and identification of juvenile specimens.

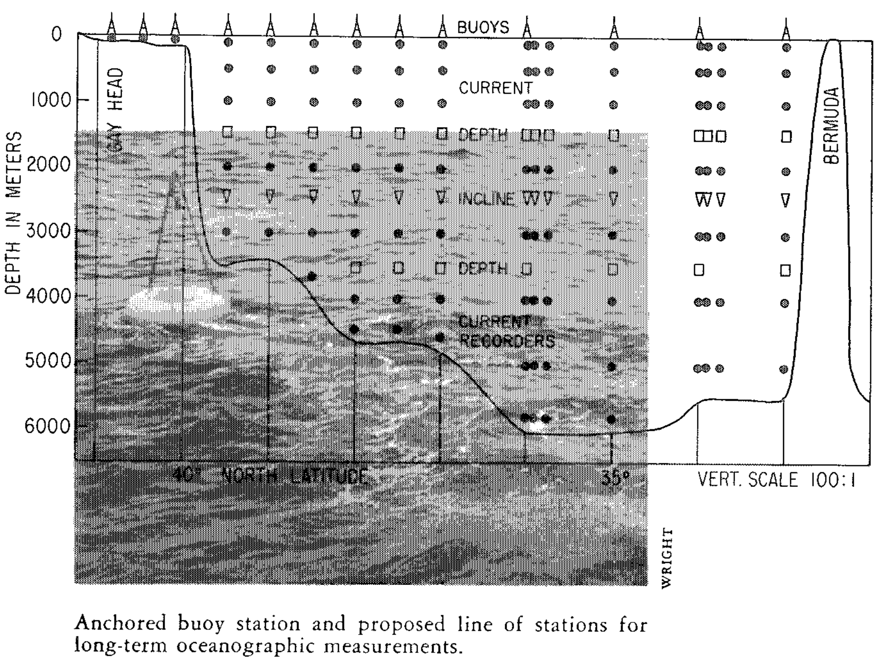
Studies of the schooling behavior of fishes were initiated at the Institution last summer by a visiting investigator and one of our summer Fellows. Why fishes "school," whether this is a learned or an instinctive characteristic of the species, and at what stage in the development of the individual the schooling habit is initiated, have long been vexing and interesting problems. These questions have been attacked by rearing juvenile fishes in isolation from their siblings so that they can be placed with a schooling population at various stages in their development. Such juveniles school very quickly when placed in schools of their own species, but they do not school with a lone member of their own species or with other species. The onset of the schooling tendency in the juveniles appears to be more related to the size of the individual than it is to the age.

The stranding of a live fin whale on a local beach not only caused considerable excitement but made it possible to conduct some physiological studies on a cetacean a hundred times larger than those which had been previously available to our staff. Both studies of thermoregulation by this whale and a hurried electrocardiogram were made before the whale was finally towed out to sea for the last time.

instrumentation

Two major related areas in instrumentation have been emphasized at the Institution during the year. These are the utilization of buoy-supported systems for collecting data and the development of increasingly refined techniques for handling the large amounts of data that are now being obtained.

Although work aboard ship has become more efficient in terms of the amount of research that can be done each day at sea, it is apparent that anchored buoys can provide an economic platform for the collection of oceanographic data. The results of last year's experiments in measuring deep currents in the Bermuda area indicated that observations over a longer period are required. This only appears feasible by using buoy stations. The scientific and engineering problems associated with such a large scale experiment will be studied by establishing a line of twenty-four moored buoys between Woods Hole and Bermuda; three in shallow water, the remainder in deep water. Each station will have a surface float with wind recording equipment and six to eight current meters attached at intervals down the mooring line. This equipment has been designed and built during the last six months. Each of the instruments, some two hundred in all, is self-recording and has a life in excess of 120 days. The stations will be visited every three to four months to recover the records, to refurbish the instruments and to replace the mooring lines.



Anchored buoy station and proposed line of stations for long-term oceanographic measurements.

Transducers, transmitters and receiving equipment for telemetering buoys developed at the Institution over the past few years have been modified in several ways. With a telemetering thermometer, water temperature can be measured on demand to an accuracy of approximately 0.15°C. Not only is this device economical to manufacture, but it has also been designed for direct digital output. The thermistor scanning system is triggered by an interrogating tone. As each of twenty-three thermistor outputs on a buoy is scanned, a servo amplifier is balanced against a reference potentiometer coupled to a shaft encoder. This encoder activates a relay matrix to convert the decimal output of the shaft into a modified binary code. This is then telemetered as one tone or a combination of two tones. The signal at the receiver is reconverted to a decimal code which is automatically typed out as the resistance of the thermistor.

In an attempt to develop a method for tracking drifting buoys from a shore installation, a preliminary investigation into the feasibility of retransmitting doppler shift information from transit satellites was made. As the power output of the satellites is increased, it is anticipated that the doppler shift signal could be recorded in the laboratory upon interrogation of the buoy and thus the buoy's position at the time of the satellite's passage computed.

The early TIROS I pictures made as part of the weather satellite program were difficult to interpret because of the unfamiliar appearance of cloud structures when seen from above. The Institution has cooperated throughout the year with the Air Force Geophysical Directorate by taking time-lapse photographs of the whole sky during those times when the satellite passed overhead in daylight.

The development of a gyro-erected optical navigation system (GEON) shows great promise. With a Mark 19 Sperry Gyro compass, stabilization for optical tracking is provided and a meridional reference maintained. With this equipment, it is possible for a ship to track its position to an accuracy of one nautical mile by celestial navigation continuously day or night whenever the skies are clear. Moreover, with the gyro indication of the local meridian plane, it is possible to obtain a fix by sighting only one celestial object.

The acquisition of acoustical data has tremendously increased during the last few years so that improved data-handling and processing equipment is now essential. During the year the first 8-channel analogue computers, developed at the Institution over a period of several years, were delivered. These can provide output functions such as the deviation from the arithmetic mean, the square of the inputs and any time integral of these qualities. Accurate computations can also be made for input wave forms containing Fourier components from 10 cps to 70,000 cps. The unit has already been tested at sea and has proven very effective in reducing the time required to analyze large quantities of acoustical data. Several of these units are being evaluated by us prior to delivery to other laboratories.

A spectrum analyzer has also been designed and successfully used at sea during the year. With an appropriate frequency, a signal can be graphically shown over an 8-kilocycle band between 120 and 32,000 cycles as a function of time. With this instrument the hundred channels are fed to a hundred-and-forty stylus recorder. The time variation of the output from each filter is recorded in order as a brown hue, the darkness of which varies with the intensity of the signal. The original sound is separately recorded on magnetic tape which can be replayed to permit the rapid analysis of additional bands.

Work has continued on the development and use of the National Bureau of Standards sound velocity meter. A very necessary adjunct to this instrument has been some method of satisfactorily measuring its depth as it is lowered in the water. This has been accomplished with an upside-down echo sounder attached to the sound velocity meter which provides the necessary depth information by measuring the acoustical travel time from the instrument to the surface regardless of the shape of the suspending wire. The bottom echo can also be measured so that the instruments can be lowered as close to the ocean bottom as required.

Two devices to produce higher power sound sources have been developed and utilized extensively for the continuous recording of sub-bottom reflections while the ship is under way. One, known as the Sparker, employs a high voltage underwater electric spark; the other, known as the Thumper, produces acoustic power by the eddy current deflection of an aluminum disc held in a plastic core. Since these sound sources produce low frequencies capable of penetrating the bottom, reflections from bodies of rock and layers of sediment below the bottom can be studied. The comparatively weak early models now in routine use have penetrated over a thousand feet of sediments in water of the same depth.

An attempt was made to improve the measurement of bottom slopes at right angles to the ship's path by placing a second transducer at some distance from the hull. To do this, a P5M seaplane wing was hinged to the side of the ship as a 45-ft. outrigger. Tests were carried out in the harbor on the ASTERIAS, in Vineyard Sound on the CRAWFORD, and on the high seas on a destroyer. An initial evaluation of this unusual arrangement indicates that it may provide a technique to determine the slope of the bottom topography on a single traverse of an area.

fleet operations

Although there were no major changes in the Institution's fleet during the year, considerable attention was devoted to the design of the new research vessel which will serve as a replacement for the ATLANTIS. As mentioned in the 1959 Annual Report, this vessel was made possible by a grant from the National Science Foundation. It is expected that the design and construction specifications will be completed in early 1961 and that the ship will be under construction before the end of that year.

In the belief that acoustical tools for general oceanographic studies will become increasingly important in the future, considerable emphasis has been placed on making certain that this vessel will be as acoustically quiet as possible. Low noise, slow speed control and economic maintenance and operation have dictated the use of reciprocating steam power plants. The change from diesel to steam power required an increase in the overall length of the vessel from 175 ft. to 210 ft. This increase will allow us to keep an 8,000-mile range at sea, as well as provide increased deck area and laboratory space for scientific purposes. The other general specifications of the vessel call for a beam of 44 ft, a displacement of 1800 tons, and a cruising speed of 12 knots.

To increase the effectiveness of the Helio-Courier light aircraft which the Institution purchased during 1959, a hangar to protect the aircraft was built on Dyer's dock, adjacent to the Institution. The end of this pier was modified in such a way that the aircraft can be run up out of the water on a ramp. Thus, an aircraft on floats can easily be used from the Institution property on the waterfront at almost all periods of the year. The hangar also facilitates the maintenance work on the aircraft.

The major activity at sea during the year was a 2½-month cruise during the spring, when ATLANTIS, CHAIN, and CRAWFORD were employed in a multi-ship survey of the Gulf Stream in the area northeast of the line between Woods Hole and Bermuda. In addition, the ARIES was also used during the third phase of the work, and the U. S. Coast Guard's Ice Patrol Vessel EVERGREEN participated in the first part of the program. With the exception of a month's cruise to the western Caribbean in the winter, the ATLANTIS served during the remainder of the year in the Bermuda area or in the offing of Woods Hole. In late December, she again proved the usefulness of her sailing rig, as she sailed home from a point west of Bermuda when her shaft was broken and she was unable to use her main engine.

The CHAIN operated in the Caribbean during the winter of 1960 and in the Gulf Stream and vicinity in the spring. She then embarked on a five-month cruise to the Baltic Sea, to the Norwegian Sea above the Arctic Circle between Iceland and the Norwegian Coast, and to the Irish and North Seas, as well as along the northerly track across the North Atlantic en route to Woods Hole. During this cruise to western Europe, a considerable number of foreign scientists participated in the research activities which were carried out on board. As a result of all this, her ability to support a varied and increasing by complex program at sea continues to impress all who participate in the work. The CHAIN visited Helsinki at the time of the meetings of the International Union of Geodesy and Geophysics, and many foreign oceanographers also had the opportunity to visit her there during the meetings.

Although the longest period at sea during the year was the Gulf Stream survey, already mentioned, the CRAWFORD took a long cruise to the east of the Bahamas during the winter. In addition to a number of trips out of Woods Hole, several were made to the continental shelf for various biological investigations.

As during the previous year, the ARIES operated almost entirely in the Bermudas area on the deep-current tracking problem except for her participation in the Gulf Stream survey and a short period in the Bahamas area. This work was completed by the end of the year, and the ARIES was readied for sale. She was sold early in 1961.

The BEAR operated principally in local waters with one long cruise in mid-summer to the Blake Plateau. In the late fall and early winter, however, the BEAR was used in the Tongue of the Ocean for a detailed survey of the bottom topography and sediment characteristics there. Since precise navigation was required for this, a special network of Decca stations was set up. The calibration and utilization of this navigational system posed many unusual operating conditions which had not previously been experienced.

The Institution's fleet put in 963 research days at sea during 1960. This is almost 100 days more than the record in 1959 and is an index of the increased research activity.

The DC-3-type aircraft supplied by Office of Naval Research and the Helio-Courier light plane have both been used extensively for a variety of meteorological and oceanographic problems. The Helio-Courier's slow-speed flight characteristics make it particularly useful for photographic and visual observations, made in connection with some of the biological and geological problems. The DC-3 has acquired more instruments to increase its usefulness as a research tool. In mid-summer both of the aircraft were used in collaboration with chartered light plane in a multi-plane meteorological sampling program to the east of Eleuthera in the Bahamas. Despite the great diversity in the flying characteristics of the aircraft involved, this operation proceeded very successfully and has encouraged plans for similar programs in the future.

ATLANTIS

Cruise No.	Dates	Areas of Operation	Days	Chief Scientist
253	18 Jan. – 18 Jan.	Local	1	Athearn
254	20 Jan. – 12 Mar.	Blake Plateau, Western Caribbean	24	Stetson, Athearn
255	8 Apr. – 15 June	Gulf Stream	69	Miller, Worthington
256	17 June – 30 June	Boston-Yard	14	
257	7 July – 20 Aug.	Bermuda Area	45	Bruce
258	30 Aug. – 2 Sept.	Local	4	Kanwisher
259	4 Oct. – 6 Oct.	Local	3	Stetson
260	11 Oct. – 7 Nov.	Bermuda Area	28	Pratt
261	16 Nov. – 25 Dec.	30°N 50°W	40	Worthington

ARIES

Cruise No.	Dates	Areas of Operation	Days	Chief Scientist
21–32	2 Feb. – 20 May	Bermuda Area	59	Swallow, Crease
33	25 May – 6 June	S. Gulf Stream	13	Swallow
34–36	17 June – 8 Sept.	Bermuda Area	66	Swallow, Crease
37	3 Nov. – 14 Dec.	Bermuda Area	42	Bruce

BEAR

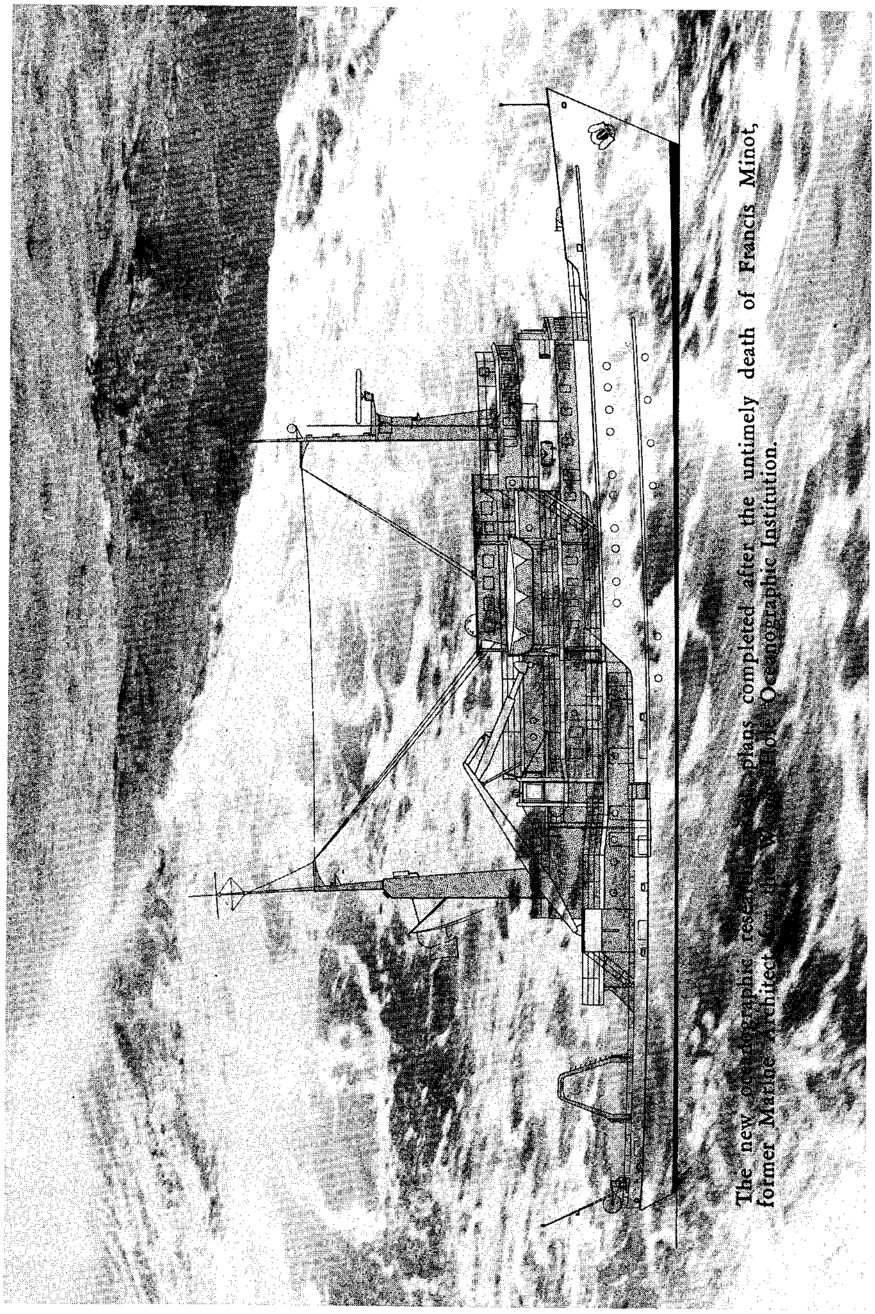
Cruise No.	Dates	Areas of Operation	Days	Chief Scientist
232–249	1 Apr. – 22 June	Local	38	Hersey, Conover, Stetson, Hays, Zeigler
250	8 July – 27 July	Blake Plateau	20	Stetson
251	19 Aug. — 20 Aug.	Boston-Yard	2	
252–253	22 Aug. – 9 Sept.	Local	9	Backus, Knott
254	12 Sept. – 13 Sept.	Boston-Yard	2	
255–257	19 Sept. – 26 Oct.	Local	8	Backus, Knott, Amberseno
258	9 Nov. 1960 – 6 Jan. 1961	Nassau Area	60	Athearn

CHAIN

Cruise No.	Dates	Areas of Operation	Days	Chief Scientist
11	26 Jan. – 22 Mar.	Eastern Caribbean, Bahamas Area	28	Metcalf, Hays
12	5 Apr. – 15 June	Gulf Stream	72	Worthington, Fuglister
13	30 June – 12 Nov.	North Sea, Baltic Sea, Norwegian Sea, North Atlantic	136	Dow, Hays, Hersey, Worthington, Backus
14	21 Nov.	Boston-Yard		

CRAWFORD

Cruise No.	Dates	Areas of Operation	Days	Chief Scientist
37	16 Jan. – 9 Mar.	30°N 50°W	25	Worthington
38	14 Mar. – 19 Mar.	Bermuda-Woods	6	Corwin
39	26 Mar. – 26 Mar.	Local	1	Day Cruise for Science Students
40	7 Apr. – 15 June	Gulf Stream	70	Metcalf
41	13 July – 27 July	Local	15	Volkmann
42	2 Aug. – 7 Aug.	Local	6	Corwin
43	11 Aug. – 17 Aug.	Continental Shelf	7	Ketchum
45	22 Aug. – 23 Aug.	Continental Shelf	2	Watson
46	2 Sept. – 2 Sept.	Local	1	Mass. Science Fair Winners
47	6 Sept. – 9 Sept.	Local	4	Conover
48	12 Sept. – 13 Sept.	Boston-Yard	2	
49	19 Sept. – 23 Sept.	Local	5	Ketchum
50	28 Sept. – 30 Sept.	Local	3	Curl
51	3 Oct. – 5 Oct.	Boston-Yard		
52	12 Oct. – –12 Oct.	Local	1	Day Cruise for Science Students
53	13 Oct. – 17 Oct.	Gulf of Maine	5	Conover
54	19 Oct. – 21 Oct.	Local	3	Curl
55	25 Oct. – 30 Oct.	30°N 70°W	6	Metcalf
56	11 Nov. – 28 Nov.	Continental Shelf	18	Mather
57	29 Nov. –	Boston-Yard		



The new oceanographic research vessel plans completed after the untimely death of Francis Minot, former Marine Architect for the Woods Hole Oceanographic Institution.

CAULFIELD

personnel

The following persons were awarded grants, honoraria or fellowships during 1960:

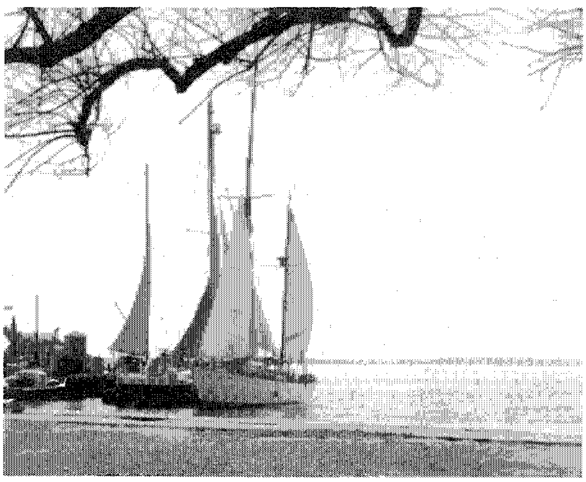
Walter H. Adey	University of Michigan
Michael Bayard	Carl Schurz High School, Chicago, Illinois
Robert A. Berner	Harvard University
Fred Bisshop	Brown University
Duncan C. Blanchard	Massachusetts Institute of Technology
Robert Roy Blandford	California Institution of Technology
William Blumen	Massachusetts Institute of Technology
David B. Clarke	University of Wisconsin
Richard A. Cone	University of Chicago
Richard A. Craig	Florida State University
Robert C. Crowdes	Harvard University
L. A. Earlston Doe	New York University
Ronald L. Duty	Brown University
Walter Eckhart	Yale University
Robert Ellis	Miami University
Michael Emptage	Middlebury College
John S. Farlow III	Johns Hopkins University
Frederick C. Fuglister	Massachusetts Institute of Technology
Augustine S. Furumoto	St. Louis University
Michael Garstang	Florida State University
Kenneth I. Gross	Brandeis University
William R. Holland	University of California at Los Angeles
Louis N. Howard	Massachusetts Institute of Technology
John Polk Kerr	University of Michigan
Robert H. Kraichnan	New York University
Eric B. Kraus	Snowy Mountain Hydro-electric Authority, Cooma, Australia
Joseph Levine	Massachusetts Institute of Technology
David T. Mason	University of California
David A. McGill	Yale University
Dennis Wilson Moore	Harvard University
Norman S. Neidell	Brown University
Gilbert S. Omenn	Princeton University
Bernard L. Oostdam	McGill University, Canada
Joseph Pedlosky	Massachusetts Institute of Technology
Mary Alys Plunkett	Vassar College
John Reitzel	Harvard University
Judith Sandberg	Hahnemann Medical College, Philadelphia Pennsylvania
Peter M. Saunders	Imperial College, London, England
Vincent J. Schaefer	Munitalp Foundation, Schenectady, New York
Alan B. Steinbach	University of Rochester
Bruce A. Taft	Johns Hopkins University
David G. Towell	Massachusetts Institute of Technology
Andrew J. Umen	Williams College
Bruce A. Warren	Massachusetts Institute of Technology

visitors

Distinguished scientists from this and many other countries honored the Institution visits during 1960. These included:

Masateru Anraku	Faculty of Fisheries, Hokkaido University, Japan
Richard G. Bader	Agricultural and Mechanical College of Texas
John P. Barlow	Cornell University, Ithaca, New York
Otis Barton	Palm Desert, California
Neil L. Brown	Commonwealth Scientific and Industrial Research Organization, Cronulla, Australia
William M. Cameron	Bedford Oceanographic Laboratory, Canada
Angelo Campanella	HRB-Singer, State College, Pennsylvania
R. Morrison Cassie	New Zealand Oceanographic Institute, Wellington, New Zealand
Vivienne Cassie	New Zealand Oceanographic Institute, Wellington, New Zealand
Sydney Chapman	High Altitude Observatory, Boulder, Colorado
Keith E. Chave	Department of Geology, Lehigh University, Bethlehem, Pennsylvania
Roland A. Cox	National Institute of Oceanography, England
James Crease	National Institute of Oceanography, England
Ronald I. Currie	National Institute of Oceanography, England
Odd Dahl	Norwegian Defense Research Department, Norway
L. Draper	National Institute of Oceanography, England
I. Engelsen	Norwegian Defense Research Establishment, Norway
Nestor C. L. Granelli	Servicio de Hidrografia Naval, Argentina
David Grant	Department of Biology, Yale University, New Haven, Connecticut
E. M. Hassan	University of Alexandria, United Arab Republic
William E. Hazen	Department of Zoology, University of Chicago, Chicago, Illinois
Koji Hidaka	Geophysical Institute, Tokyo University, Japan
M. S. Longuet-Higgins	National Institute of Oceanography, England
Jacob Hoffman	U. S. Navy Hydrographic Office, Washington, D. C.
Louis M. Lauzier	Fisheries Research Board of Canada
Douglas K. Lilly	U. S. Weather Bureau, Washington, D. C.
Richard S. Lindzen	Harvard University, Cambridge, Massachusetts
Eugenie Lisitzin	Havforskningsinstitutet, Finland
Jacob Magnússon	University Research Institute, Iceland

RAMÓN MARGALEF	Instituto Investigaciones Pesqueras, Barcelona, Spain
WILLIAM E. MEAD	Hudson Laboratories, Dobbs Ferry, New York
C. H. MORTIMER	Scottish Marine Biological Association, Millport, Scotland
MICHAEL M. MULLIN	Harvard University, Cambridge, Massachusetts
H. NODTVEDT	Norwegian Defense Research Establishment, Norway
NECIP OLCAJ	Seyirve Hidrografi, Istanbul, Turkey
B. R. PELLETIER	Department of Mines, Ottawa, Canada
ARTHUR K. SAZ	National Institutes of Health, Bethesda, Maryland
EVELYN SHAW	American Museum of Natural History, New York
WILLIAM B. SNOW	Ramo-Wooldridge Company, Canoga Park, California
JOHN C. SWALLOW	National Institute of Oceanography, England
BERNARD TOBIN	International Business Machine Corporation, Owego, New York
DAVID J. TRANTER	Division of Fisheries & Oceanography, CSIRO, New South Wales, Australia
TJ. H. VAN ANDEL	Scripps Institution of Oceanography
ROMAN VISHNIAC	Yeshiva Medical School, New York
HAROLD P. WEIXTRAUB	Thayer Academy Summer Science Program, Braintree, Massachusetts
KUCHIRO YAMAMOTO	Hokkaido University, Hakodate, Japan



employees and staff

The following personnel were in the employ of the Institution for the twelve-month period ending December 31, 1960.

Allen, Ethel B.
Allen, Norman T.
Allen, Robert W.
Anderson, Nellie E.
Ashmore, Herbert A.
Athearn, William D.
Backus, Cyril
Backus, Harold
Backus, Jeanne M.
Backus, Richard H.
Barbour, Rose L.
Barrett, Joseph R., Jr.
Barstow, Elmer M.
Bartlett, Martin R.
Baxter, Lincoln II
Baylor, Edward R.
Becker, Edward B.
Behrens, Henry G.
Bergstrom, Stanley W.
Betterley, Robert
Blanchard, Duncan C.
Blumer, Max
Bodman, Ralph H.
Bowen, Vaughan T.
Bowman, Warren O.
Bradley, Mabel D.
Bradshaw, Alvin L.
Bray, Winfield S.
Brockhurst, Robert R.
Broughton, Jane F.
Brown, Joseph C.
Bruce, John G., Jr.
Bryan, Kirk, Jr.
Bryant, Edwin T.
Bumer, John Q.
Bumpus, Dean F.
Bunce, Elizabeth T.
Bunker, Andrew F.
Burnham, Charles A.
Cabral, John P.
Cabral, John V.
Cain, Henry A.
Cangiamila, Angelo
Carlson, Alfred G.
Carlson, Ruth H. E.
Carter, Alwyn L.
Carter, Richard J.
Casiles, David F.
Cavanaugh, James J.
Chadwick, Constance W.
Chaffee, Margaret A.
Chalmers, Agnes C.
Chase, Joseph
Christian, John A.
Chute, Edward H.
Clarke, George L.
Clarkin, William H.
Colburn, Arthur D., Jr.
Condon, John W.
Conley, William J.
Conover, Robert J.
Cook, Alden H.
Cook, Hans
Corwin, Nathaniel
Cotter, Jerome M.
Coughlin, Brooks W.
Crocker, Marion W.
Crouse, Porter A.
Curl, Elizabeth L.
Curl, Herbert C., Jr.
Davis, Charles A.
Day, C. Godfrey
Day, Joseph V.
Densmore, Charles D.
Devitt, Howard B.
Dimmock, Richard H.
Dimock, Alan D.
Dow, Willard
Dufur, Dana H.
Dunkle, William M., Jr.
Edwards, Richard S.
Eldridge, Stanley N.
Fahlquist, Davis A.
Faller, Alan J.
Ferguson, Sandra K.
Ferris, Alice H.
Ferris, George A.
Fielden, Frederick E.
Fisher, Stanley O.
Flaherty, John J., Jr.
Frantz, David H.
Fraser, John G.
Fuglister, Frederick C.
Fye, Paul M.
Gallagher, Gloria S.
Gallagher, Rosemary
Gallagher, William F.
Gaskell, Fred
Giese, Graham S.
Gifford, James E.
Gill, Barbara L.
Gingrass, Norman
Graham, John W.
Grant, Carlton W.
Grant, Carlton W., Jr.
Grice, George D., Jr.
Guillard, Robert R. L.
Hahn, Jan
Halpin, William T.
Halverson, Leonard G.
Hannah, Mary Ann
Hart, Arch D.
Hatzikon, Kaleroy L.
Hayes, Carlyle R.
Hays, Earl E.
Hays, Helen C.
Hellwig, Jessica D.
Hersey, John B.
Hessler, Robert R.
Hiller, Emerson H.
Hoadley, Lloyd D.
Hodgkins, Harry L.
Hodgson, Sloat F.
Houston, Leo C.
Howe, Paul M.
Howland, Myron P., Jr.
Howland, Paul C.
Hulburt, Edward M.
Hunt, Otis E.
Innis, Charles S., Jr.
Iselin, Columbus O'D.
Jenkins, Delmar R.
John, Alfred C.
Johnston, Alexander T.
Kahler, Yolande A.

Caron, Henri L.
Karram, Calvin D.
Ketchum, Bostwick H.
Ketchum, David D.
Knott, Sydney T., Jr.
Kostrzewa, John A.
Kuenzler, Edward J.
Lambert, Joseph L.
Langenheim, Anne E.
Leahy, Richard G.
Leiby, Jonathan
Levine, Joseph
Lyon, Thomas
Macaulay, Franklin A.
Mackey, Malcolm R.
MacKillop, Harvey
Maddux, Duane E.
Malkus, Joanne S.
Malkus, Willem V. R.
Martin, George E.
Mather, Frank J., III
Matthews, Francis S.
McCloskey, Margaret E.
McCormack, Eileen M.
McElliott, Joseph M.
McHardie, James
Mellor, Florence K.
Merchant, Floyd L.
Metcalf, William G.
Miller, Arthur R.
Minot, Mary K.
Mitchell, James R.
Mogardo, Juanita A.
Morehouse, Clayton B.
Morrison, Kenneth
Motta, Joseph C.
Munns, Robert G.
Mysona, Eugene J.
Nalwalk, Andrew J.
Oliver, Isabel
Orr, Joseph A., Jr.
Ortolani, Mary
Ostiguy, Betty P.
Owen, David M.
Palmieri, Michael, Jr.
Parker, Charles E.
Pasley, Gale G., Jr.
Foster, Donald B.
Pedersen, Miner, A.
Pennypacker, Thomas R.
Perkins, Calvin F.
Phillips, Helen F.
Pierce, Samuel F.
Pike, John F.
Pimental, John M.
Poole, Stanley E.
Pratt, Richard M.
Richardson, William S.
Rockwell, Robert E.
Rogers, Henry A., Jr.
Rogers, Mary D.
Ronne, F. Claude
Roth, Claës G. H.
Rose, Lawrence
Rossby, Harriet A.
Ryther, John H.
Salthouse, James E.
Sandblom, John D.
Sanders, Howard L.
Sawyer, Harold E.
Schevill, William E.
Schilling, John L.
Schleicher, Karl E.
Schroeder, Elizabeth H.
Schroeder, William C.
Sears, Mary
Seibert, Harry H.
Shaleski, Eleanor M.
Sharp, Arnold G.
Shields, William J.
Shultz, William S.
Siever, Raymond
Slabaugh, Luther V.
Snyder, Robert M.
Soderland, Eloise M.
Solberg, Otto
Souza, Thomas A.
Spencer, Allard T.
Spooner, Charles E.
Stansfield, Richard
Stern, Melvin E.
Stetson, Thomas R.
Stevens, Raymond G.
Stewart, Glenda R.
Kanwisher, John W.
Stillman, Stephen L.
Stimpson, John W.
Stimson, Paul B.
Stommel, Henry M.
Sugihara, Thomas T.
Sutcliffe, Thomas O. L.
Swinhart, Orrin L.
Tasha, Herman
Terry, William A.
Thunberg, Jon C.
Thurston, Theodore G.
Tometich, Louis J.
Turner, Harry J., Jr.
Vaccaro, Ralph F.
Veeder, Ronald A.
Veronis, George
Vine, Allyn C.
Volkmann, Gordon H.
von Arx, William S.
von Dannenberg, Carl R.
Voorhis, Arthur D.
Walden, Robert G.
Walker, Jean D.
Watkins, William A.
Watson, Margaret E.
Watson, Stanley W.
Watt, Helen M.
Webster, Jacqueline
Webster, Thomas F.
Weeks, Robert G.
Whitney, Geoffrey G., Jr.
Wilde, Phillips B.
Wilkins, Charles H.
Williams, George A.
Wilson, Edward
Wilson, Esther N.
Wing, Asa S.
Wing, Carleton R.
Winslow, Elisha F.
Witzell, Warren E.
Woodcock, Alfred H.
Woodward, Fred C., Jr.
Worthington, L. Valentine
Yentsch, Charles S.
Zeigler, John M.

publications

During 1960, seventy-seven papers bearing contribution numbers were published. See Author, Subject-Locality, Taxonomic Index published in 1957 for a complete list through 1956 and subsequent annual reports for the list of publications appearing since 1956.

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No. 1033. HOWARD L. SANDERS. Benthic Studies in Buzzards Bay. III. The Structure of the Soft-Bottom Community. *Limnol. and Oceanogr.*, Vol. 5, No. 2, pp. 138-153. 1960.

No. 1034. J. S. MALKUS and H. RIEHL. On the Dynamics and Energy Transformations in Steady-State Hurricanes. *Tellus*, Vol. 12, No. 1, pp. 1-20. 1960.

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No. 1052. J. B. HERSEY. Acoustically Monitored Bottom Coring. *Deep-Sea Research*, Vol. 6, No. 2, pp. 170-172. 1960.

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No. 1064. G. G. WHITNEY, JR. Procedure for and Comments on Ice Point Tests of Deep Sea Reversing Thermometers. *Limnol. and Oceanogr.*, Vol. 5, No. 2, pp. 232-235. 1960.

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No. 1067. JOHN H. RYTHER and DAVID W. MENZEL. The Seasonal and Geographical Range of Primary Production in the Western Sargasso Sea. *Deep-Sea Research*, Vol. 6, No. 3, pp. 235-238. 1960.

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No. 1070. ANDREW A. FEJER and RICHARD H. BACKUS. Porpoises and the Bow-Riding of Ships Under way. *Nature*, Vol. 188, No. 4752, pp. 700-703. 1960.

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No. 1083. RAYMOND WEXLER and RUTH WEXLER. Cold Clouds over Tropical Oceans. In: *Cumulus Dynamics*, Pergamon Press, London and New York, pp. 129-134. 1960.

No. 1084. HENRY STOMMEL. Wind-Drift near the Equator. *Deep-Sea Research*, Vol. 6, No. 4, pp. 298-302. 1960.

No. 1086. DEAN F. BUMPUS. Sources of Water Contributed to the Bay of Fundy by Surface Circulation. *Jour. Fish. Res. Bd., Canada*, Vol. 17, No. 2, pp. 181-197. 1960.

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No. 1090. GEORGE L. CLARKE and LLOYD R. BRESLAU. Studies of Luminescent Flashing in Phosphorescent Bay, Puerto Rico, and in the Gulf of Naples Using a Portable Bathyphotometer. *Bull. Inst. Océanogr., Monaco*, No. 1171, pp. 1-32. 1960.

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No. 1092. FRANK J. MATHER, III. Recaptures of Tuna, Marlin and Sailfish Tagged in the Western North Atlantic. *Copeia*, 1960, No. 2, pp. 149-151, 1960.

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No. 1095. VAUGHAN T. BOWEN and THOMAS T. SUGIHARA. Strontium-90 in the 'Mixed Layer' of the Atlantic Ocean. *Nature*, Vol. 186. No. 4718, pp. 71-72. 1960.

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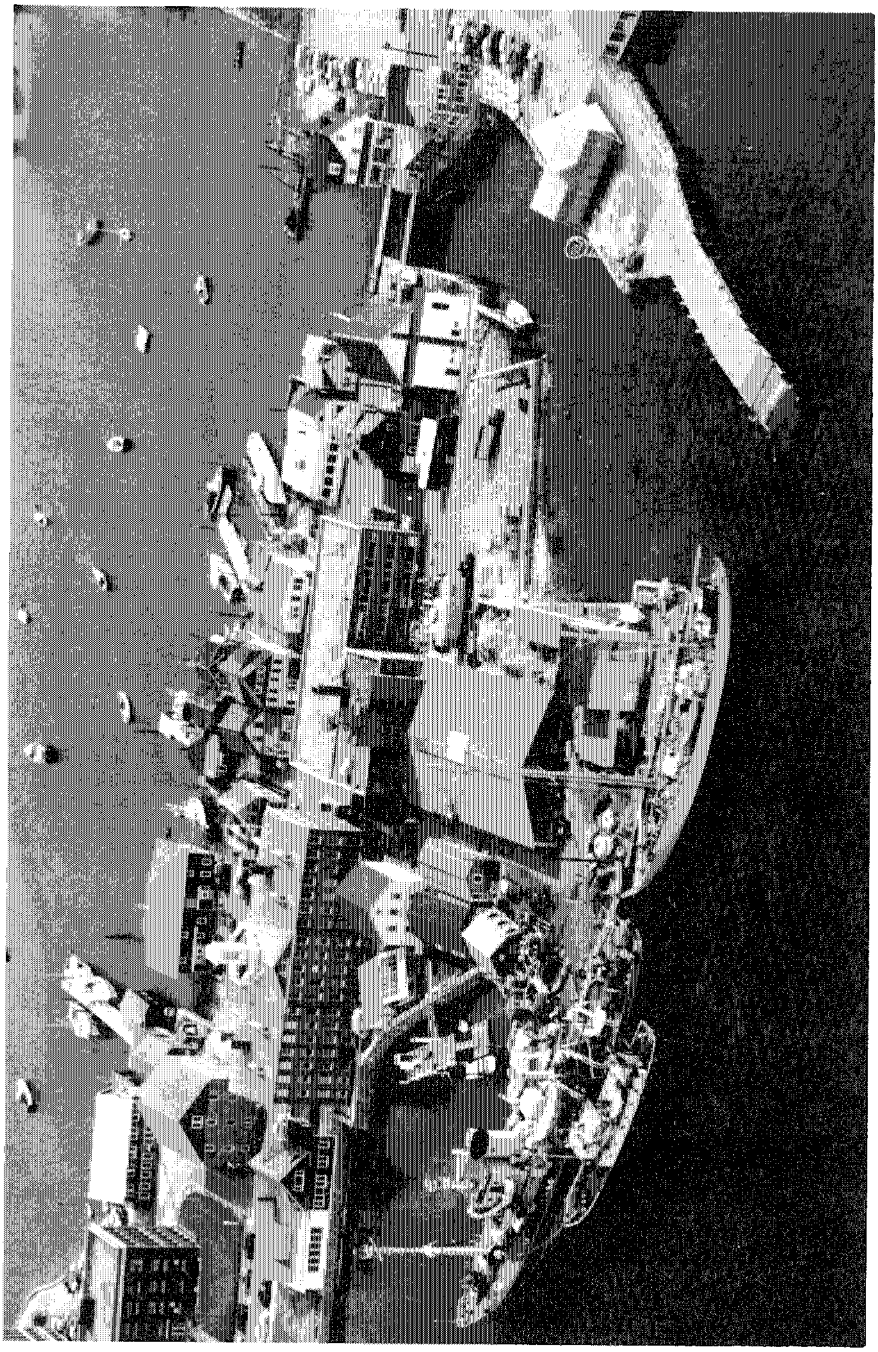

SPOONER

TREASURER'S REPORT

FOR THE YEAR 1960

The financial statements for the year 1960 have been audited by Lybrand, Ross Bros. & Montgomery.

The book value of endowment funds at December 31, 1960 was $3,483,053 of which $1,028,349 represented accumulated net gains from sales of investments. The market value of endowment assets on the same date, including real estate at book amount, was $5,288,653. Endowment fund investments and income received therefrom are summarized in Schedule C.

Income received on endowment assets was $192,354 for the year ended December 31, 1960, compared with $188,639 the previous year. Included in endowment income was $6,024 of real estate income representing a 5% return on this investment. The balance of real estate income, $6,177 was transferred to endowment assets to amortize cost of property. Endowment income represented a return on endowment fund assets of 3.6% at year-end market quotation, 5.5% on the book amount and 7.8% on the contributed amount of the endowment fund.

Endowment income was allocated for 1960 operating expenses at the rate of 6% of the book amount of original endowment funds, or $146,079. Of the balance of endowment income, $46,275, there was transferred to the income and salary stabilization reserve $45,375 and to unexpended balance of gifts from Oceanographic Associates as income from investment of life memberships $900.

The Institution's 1960 contribution to the Woods Hole Oceanographic Institution's Employees Retirement Trust amounted to $98,574. The trust is administered by three trustees. The balance of the old Retirement Fund, administered by the Treasurer, amounted to $73,060 as of December 31, 1960. This balance consisted of amounts on deposit in sixteen savings bank accounts held in trust for ten members of the plan. No contributions to the Old plan were made in 1960. Interest totaling $2,622 was credited to the savings accounts during the year.

In the financial statements that follow it is interesting to note that for each dollar spent 80 cents was spent for direct costs of research activity, 15 cents for general and administration expenses and 5 cents for plant operation and miscellaneous. Administrative salaries amounted to only 5 cents of each dollar of total expense. Included in the 15 cents of general and administration expenses was 3 cents for staff benefits (group insurance, social security taxes, and contributions to retirement plan).

BALANCE SHEET

AS AT DECEMBER 31, 1960

ASSETS

Endowment Fund Assets:		
Investments (Schedule C):		
Bonds (market quotations $1,858,977)		$1,933,381
Stocks (market quotations $3,288,768)		1,408,764
Real estate		114,293
		3,456,438
Cash		26,615
		3,483,053
Plant Fund Assets (note):		
Laboratory plant and equipment		879,032
Vessels and equipment		812,998
Other property		161,541
Vessels under construction		151,816
Total plant		2,005,387
Expenditures in anticipation of funds		49,685
Advance to current funds		303,688
		2,358,760
Current Fund Assets:		
Cash		753,818
Time deposit		50,000
Marketable security		246
Accounts receivable:		
U. S. Government	$193,552	
Other	32,356	225,908
Unbilled costs on research contracts:		
U. S. Government	476,954	
Other	3,254	480,208
Supplies inventories		40,258
Deferred charges		25,094
		1,575,532
Less advance from plant funds		303,688
		1,271,844
		$7,113,657

Note – Since 1945 the Institution has provided for depreciation of plant assets other than vessels at annual rates of 2% on buildings and 5% to 33-1/3% on equipment, carrying the amounts to general plant and equipment reserve.

LIABILITIES

ENDOWMENT FUNDS:		
Unrestricted		$2,033,284
For upkeep of plant		419,420
Henry Bryant Bigelow Chair of Oceanography		2,000
Accumulated net gain on sales of investments		1,028,349
		3,483,053
PLANT FUNDS:		
Invested in plant		2,005,387
Unexpended:		
Fund for acquisition of capital assets		300,000
Fund for construction of a small vessel		49,868
General plant and equipment reserve		3,505
		2,358,760
CURRENT LIABILITIES AND FUNDS:		
Accounts payable and accrued expenses		384,599
Contribution payable to employees' retirement plan and trust		98,574
Unexpended balances of gifts and grants for research:		
Government	$448,107	
Other	25,442	473,549
General fund:		
Income and salary stabilization reserve	311,457	
Unappropriated	3,665	315,122
		1,271,844
		$7,113,657

STATEMENT OF INCOME, OPERATING EXPENSES AND UNAPPROPRIATED GENERAL FUND

FOR THE YEAR ENDED DECEMBER 31, 1960

INCOME:		
Receipts for sponsored research:		
For direct costs		$3,733,013
For indirect costs		807,235
Fees for use of facilities		138,613
		4,678,861
Endowment income (Schedule C)	$192,354	
Less amounts added to income and salary stabilization reserve ($45,375) and to unexpended balance of gifts from Oceanographic Associates ($900)	46,275	146,079
Miscellaneous		18,266
Total income availed of		4,843,206
OPERATING EXPENSES:		
Direct costs of research activity (Schedule A):		
Salaries and wages		1,198,870
Vessel operations		1,115,952
Materials and services		1,398,766
Travel		107,730
		3,821,318
Indirect costs:		
General and administration (Schedule B)	697,962	
Plant operation (Schedule B)	209,531	
Miscellaneous	16,597	924,090
Total operating expenses		4,745,408
Excess of income		97,798
Additions to plant from current funds — books and equipment purchased		37,789
		60,009
Unappropriated general fund, January 1, 1960		43,656
		103,665
Appropriated for acquisition of capital assets		100,000
Unappropriated general fund, December 31, 1960		$ 3,665

SCHEDULE A
DIRECT COSTS OF RESEARCH ACTIVITY
FOR THE YEAR ENDED DECEMBER 31, 1960

	Salaries and Wages	Vessel Operations	Materials and Services	Travel	Total
U. S. Government Contracts.	$1,158,950	$1,110,942	$1,326,125	$95,560	$3,691,577
Other Sponsored Research....	5,816		33,732	1,888	41,436
Total direct costs of sponsored research	1,164,766	1,110,942	1,359,857	97,448	3,733,013
Institutional Research:	34,104	5,010	38,909	10,282	88,305
Total direct costs of research	$1,198,870	$1,115,952	$1,398,766*	$107,730	$3,821,318

*Includes grants and fellowships: $64,226.

SCHEDULE B
GENERAL AND ADMINISTRATION EXPENSES AND EXPENSES FOR PLANT OPERATION
FOR THE YEAR ENDED DECEMBER 31, 1960

General Administration:		
General Expenses:		
Staff benefits:		
Contributions to retirement plan		$98,574
Social security taxes		49,100
Group Insurance		6,056
		153,730
Shop services		134,467
Housing, net		7,731
Administration Expenses:		
Salaries and wages	$259,391	
Insurance, travel, supplies and other	142,643	402,034
		$697,962
Plant Operation:		
Salaries and wages		58,169
Provision for depreciation (credited to general plant and equipment reserve)..................		55,510
Other repair costs	26,859	
Heat, light and power	24,952	
Other..................	44,041	95,852
		$209,531

SCHEDULE C
SUMMARY OF INVESTMENTS

AS AT DECEMBER 31, 1960

	Book Amount	% of Total	Market Quotation	% of Total	Endowment Income
BONDS:					
Government	$587,768	17.01	$588,399	11.18	$18,701
Railroad	451,147	13.05	423,428	8.05	18,710
Public utility	341,050	9.87	321,695	6.11	17,994
Industrial	408,519	11.82	381,855	7.26	13,485
Financial and investment	144,897	4.19	143,600	2.73	7,075
Total bonds	1,933,381	55.94	1,858,977	35.33	75,965
STOCKS:					
Preferred	259,746	7.52	235,551	4.48	12,242
Common:					
Public utility	356,869	10.32	992,306	18.86	28,305
Industrial	556,061	16.09	1,610,667	30.61	52,962
Miscellaneous	236,088	6.83	450,244	8.55	16,856
Total common stocks	1,149,018	33.24	3,053,217	58.02	98,123
Total stocks	1,408,764	40.76	3,288,768	62.50	110,365
REAL ESTATE	114,293	3.30	114,293*	2.17	6,024
Total investments	$3,456,438	100.00	$5,262,038	100.00	$192,354

*At book amount.

LYBRAND, ROSS BROS. & MONTGOMERY

ACCOUNTANTS AND AUDITORS

Woods Hole Oceanographic Institution

Woods Hole, Massachusetts

We have examined the balance sheet of Woods Hole Oceanographic Institution as at December 31, 1960 and the related statement of income, operating expenses and unappropriated general fund 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; however, it was not practicable to confirm receivables from United States Government departments, as to which we have satisfied ourselves by means of other auditing procedures.

In our opinion, the accompanying financial statements present fairly the position of Woods Hole Oceanographic Institution at December 31, 1960 and the results of its operations for the year then ended, on a basis consistent with that of the preceding year.

Boston, Massachusetts

May 16, 1961