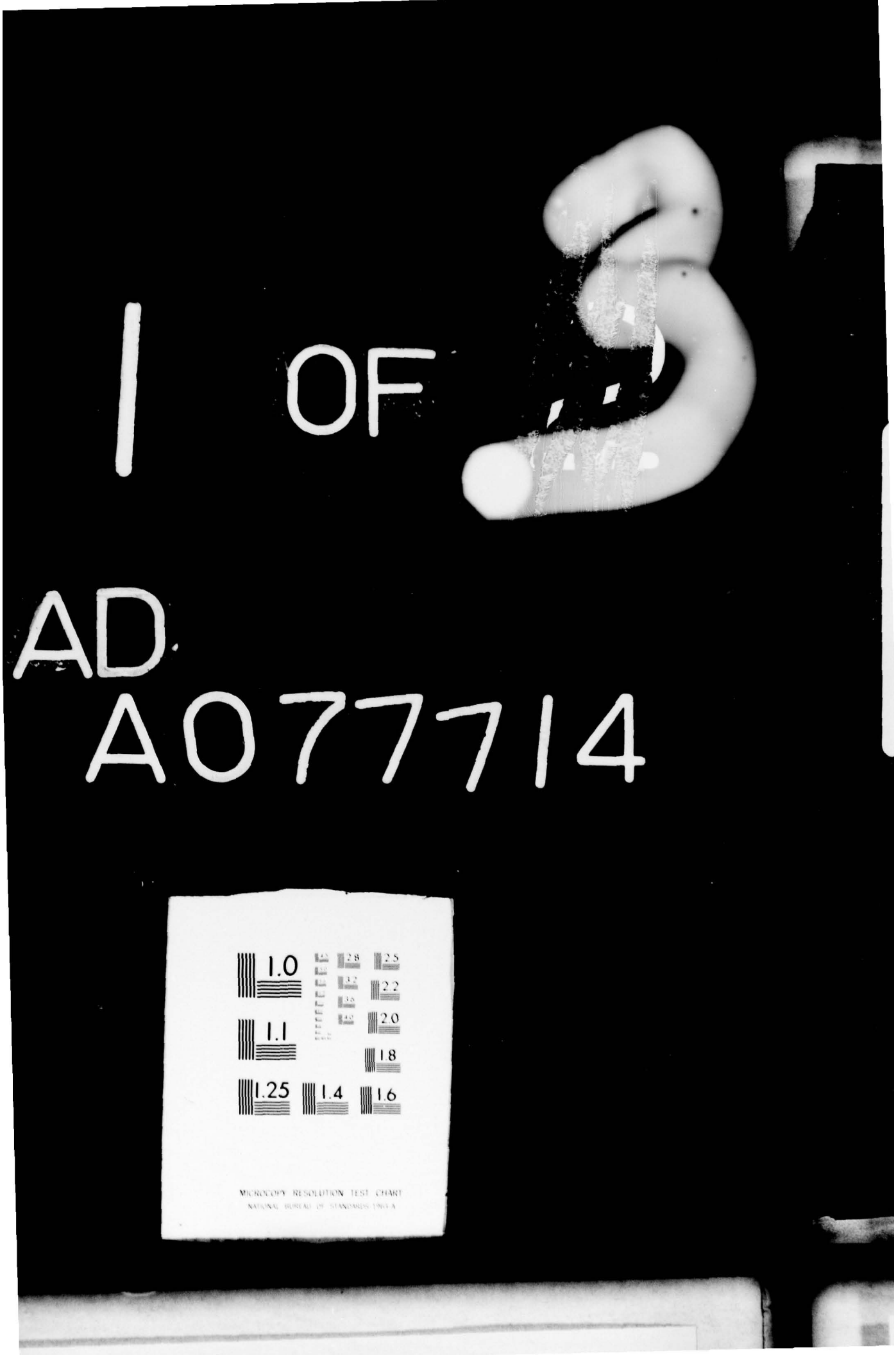
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The source of support of the research reported in each individual article below is indicated in the table of contents by the grant or contract number.

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APPLIED OCEANOGRAPHY DEPARTMENT

Earl E. Hays, Department Chairman

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DEEP OCEAN ACOUSTIC STRUCTURE

Robert R. Brockhurst

We are continuing a program, supported by the Office of Naval Research, to improve our ability to use hydrographic data to provide a detailed description of the acoustic structure of the ocean below the depth of seasonal change. Work during 1962 included classified studies of the Mediterranean Sea and several special small areas of the North Atlantic. Our major interest is to increase the effectiveness of digital machine methods for analyzing hydrographic data and interpreting these data for acoustic purposes.

Recent progress includes the development of a new method for interpolation and curve fitting which is far superior to existing polynomial methods. These methods fit a polynomial to a number of points without controlling the first derivative. The unfortunate result is the frequent occurrence of spurious extrema. The most common forms give two values depending on the choice of points. At best, the resulting curve has discontinuities in the first derivative where segments join. Our new method, while very simple to apply, controls the derivative so that through any set of points a unique continuous curve is passed which has a continuous first derivative. The second derivative is constant except for discontinuities where segments join. Only real extrema are possible so no additional tests of the derived curve are required. The reliability of this method and its ease of application should make it extremely useful for a number of oceanographic problems where the data points are relatively widely separated and the exact equations are not known.

TELEMETERING

Edward H. Chute, George L. Erlanger, Robert M. Snyder, and Robert G. Walden

The development of long-range telemetering buoys has been pursued during 1962. A buoy capable of telemetering, on command, a variety of data in digital form has been used successfully in range tests of over 1000 miles.

In December a deep current telemetry station was set at 32°10'N 64°30'W. The buoy was interrogated from the shore and several hundred recordings were made of scheduled information. These

transmissions were monitored by IT&T at Southampton , L. I. with excellent results.

Two telemetering buoys were set during the ERIKA DAN expedition to measure temperature at the 500-meter depth.

A telemetry receiving and interrogation station has been built at Waquoit to provide a good receiving and transmitting environment.

A telemetering system capable of transmitting twelve channels of multiplexed data on F.M. subcarriers has been completed for installation on the Buzzards Bay tower. This includes the construction of interrogation and command equipment as well as major modification to the Addressor gear which is the readout, digitizing and programming portion of the system.

Design calculation, specifications and some construction was completed for an airborne meteorological data acquisition system for the R5D aircraft. This system will provide a plurality of sensor inputs to a magnetic tape through F.M. subcarrier oscillations. The data, so recorded, can be read out via the Addressor to a computor. A similar system had been developed for beach erosion studies and was used this year at four locations.

The rapid scan three wire circuit developed for the thermistor chain has been included in a design to obtain many depth-temperature data from moored buoys by telemetry. The coded trigger signal from the command station results in all thermistors being scanned in order and the temperature of each transmitted back to shore in digital form. After scanning and transmitting data on all thermistors, the system returns to listen mode to await the next command to scan.

CURRENT MEASUREMENTS FROM MOORED BUOYS

William S. Richardson, Paul B. Stimson, Charles H. Wilkins, Myron P. Howland, Jr., and Nellie E. Andersen

During 1962, thirty-nine current meter buoys were set. The major efforts were two settings along the Woods Hole-Bermuda line in March and June, a five-buoy set in the Pacific in May, and a three-buoy triangular array in December at 28°30'N 76°00'W. In the vicinity of the last array, a controlled comparison of several methods of current measurement, direct and indirect was undertaken. A study

of the data from this experiment will lead to better understanding of the strengths and limitations of the several techniques (hydrographic data, Swallow floats, parachute drogues, current meters).

During the year improvements were made in the mooring system and the instruments. The anchor was reduced to a single piece of cast iron of special design. This increased the ease of handling, and reduced dragging and the expense of the anchoring system.

The data from the buoys analyzed thus far show semidiurnal tides and inertial periods varying appropriately with latitude. The motions caused by the mooring system obscure some of the detail desired and these effects are being investigated.

MECHANICAL SOUND SOURCE IMP MOD. II

Harold E. Sawyer, Arnold G. Sharp, and William S. Shultz

Detailed design and construction of Imp Mod II continued throughout the year. In brief, the "Imp" sound source consists of a mechanical system that derives energy from a hydraulic accumulator drive cylinder, transfers the energy to a moving mass which by impact transfers the energy to a piston with subsequent acoustic radiations into the water.

The large accelerating forces and necessity of precise alignment have resulted in some interesting engineering problems that have been approached both experimentally and theoretically.

The dynamics of a tentative drive system were worked out in some detail and construction started as a result of the analysis.

The guide cylinder design was finished and fabrication began in December 1962.

Castor oil is to be used in a liquid spring configuration in the sound source. Extensive tests were made on the feasibility of using castor oil in this application and its use has been justified by these tests. One of the requirements in this use is that all air and water vapor be removed from the castor oil, and a system for degassing the castor oil and placing it in the sound source was designed and constructed.

ROCK DEFORMATION

Joseph B. Walsh

Since September, Dr. Walsh has devoted 40% of his time as Visiting Lecturer at the Department of Geology and Geophysics at MIT. The major subject of this term is the deformation and fracture of rocks.

A paper "Friction on Griffith Cracks in Rocks under Pressure" (with F. A. McClintock) was presented at the Fourth National Congress of Applied Mechanics in June 1962. A second paper "Some Direct Measurements of the Surface Energy of Quartz and Orthoclase" (WHOI Contribution No. 1273 with W. F. Brace) was published in the American Mineralogist Sept. - Oct., 1962.

A theoretical analysis of the effect of voids in a rock on its stress strain curve, the design of a very stiff testing machine and experiments to determine accurately the tensile strength of rocks, are now in progress.

DEEP SUBMERGENCE RESEARCH VEHICLE GROUP

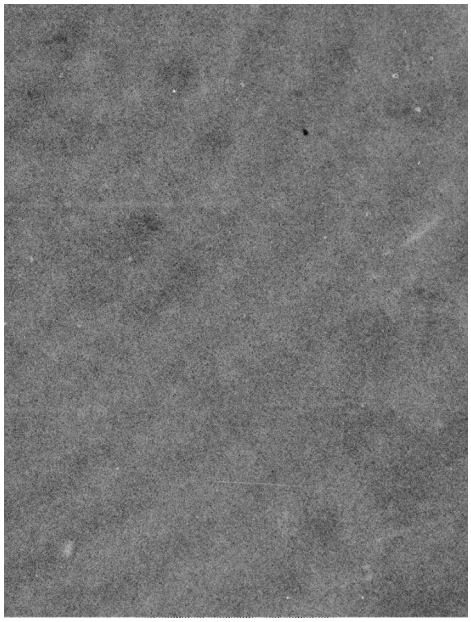
Joseph B. Walsh, Allyn C. Vine, James W. Mavor, Jr., Earl E. Hays and William O. Rainnie, Jr.

During 1962, the construction and design of the submersible 'Aluminaut' was generally monitored and a contract for a mile-deep vehicle 'Alvin' was negotiated. The major concern of the group has not been originating design for the craft but in checking designs in regards to safety and operational feasibility.

Drs. Walsh and Mavor were concerned primarily with the structural analyses of the two craft. A theoretical analysis of the 'Aluminaut' hull has been generally confirmed by the construction and collapse of a 1/16 scale model. Important considerations remain to be investigated in a larger-scale model concerning stress concentration near penetrations, "O" ring grooves and fillets.

As subcontractors for the mile-deep submersible, the Deep Submergence Research Vehicle group has the responsibility to see that the construction meets certain requirements, that necessary instruments are obtained and that an operating group is assembled.

Drs. Mavor and Walsh also participated in some of the analysis and design of the mechanical sound source IMP Mod. II.



BIOLOGY DEPARTMENT

John H. Ryther, Department Chairman

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INFLUENCE OF LANGMUIR CIRCULATION ON BIOLOGICAL PROCESSES

Edward R. Baylor and William H. Sutcliffe, Jr.

Work was continued on the non-random distribution of pelagic plankton in the ocean. Special attention has been devoted to the visual aspects of behavior patterns which probably account for the concentration of plankton in the windrows of Langmuir circulation, and for its dispersion in the intervening water between windrows.

Together with Dr. Alan Faller we have observed several of the physical variables associated with Langmuir circulation to see whether this circulation at the surface of the ocean is a special case of the Ekman spiral. The horizontal spacing of windrows, their angles relative to the wind and to wind speed have been measured simultaneously from small boats on the surface and from overhead aircraft. The downward speeds and directions of convergent circulation have been measured by use of vertical current meters and by observation of dye released in windrows. These studies seem likely to contribute to predictions of the depth of the mixed layer and to rates of productivity.

Because of the apparent importance and interrelations of wind speed, primary production, Langmuir circulation, and depth of the mixed layer, we asked Mr. Duncan Morrill and Mr. William Hoskins to program three years of data on mixed layer depth, primary productivity and wind speed for time-lagged co-variance analysis on the RECOMP II. Preliminary results of the computer calculations indicate that the wind speed for two weeks prior to productivity measurements is of greater importance to productivity than the depth of the mixed layer.

Laboratory experiments have shown that bubbles rising through sea water will concentrate dissolved and particulate organic matter presumably by adsorption to bubbles. Such a system for the recycling of the products of organic degradation near the sea surface could have important effects on the economy of the water column. Further work on this highly interesting organic particulate material is being carried out in collaboration with Dr. Gordon A. Riley and Dr. Peter Wangersky of the Bingham Oceanographic Laboratory.

Work on visual problems in fishes has been continued by Dr. Baylor. Manuscripts on the visual acuity of Bermuda reef fishes and on a special adaptation of flying fish corneas for aerial vision are in preparation.

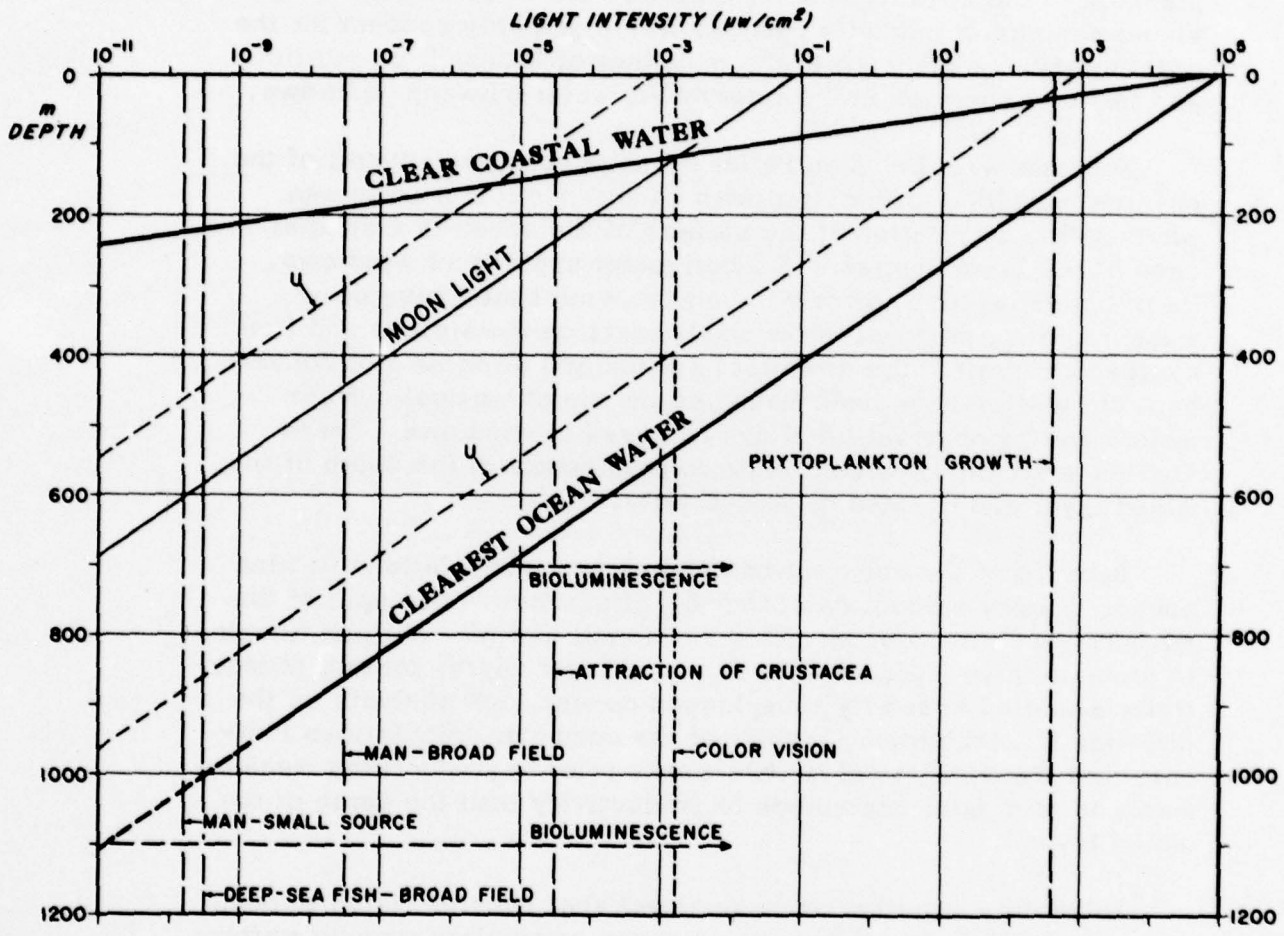


FIGURE 1. PENETRATION OF AND REACTIONS TO LIGHT IN THE SEA.

Dr. Sutcliffe continued research on the applicability of the concentration of ribonucleic acid as an indicator of growth potential in marine organisms. After initial studies on an amphipod, gastropod larvae and brine shrimp, the method showed promise when extended to a marine diatom. Two papers have been prepared on this work. Analyses also have been made on zooplankton samples in an effort to estimate productivity.

SUBMARINE RADIATION AND BIOLUMINESCENCE

George L. Clarke

Investigations have been continued and extended on the conditions of light in the sea, particularly in relation to the activities of marine plants and animals. Additional photo-multiplier photometers have been constructed with the result that we have available two deep-sea instruments, and three "portable" instruments with deck recorders and associated depth meters. Using these photometers it has been possible to measure directly the attenuation of daylight in the sea to a value of 10^{-14} x the surface intensity at noon. In very clear ocean water daylight has been recorded at a depth of 950 m. The accompanying diagram shows generalized curves for the penetration of daylight into the clearest ocean water and into clear coastal water, as well as the penetration of moonlight and the approximate intensity of upward scattered (U) light. Also shown are the minimum intensity values for phytoplankton growth, color vision in man, the attraction of crustacea, and visual thresholds for man (broad field, and small source) and for certain deep-sea fishes.

Our photometers also measure the intensity, duration, and frequency of the flashing of luminescent organisms in the sea. Bioluminescence was recorded at every location investigated in the western Atlantic from Greenland to the Virgin Islands. It occurred at every depth, below the levels at which surface light interfered, down to depths as great as 2-1/3 miles. The intensity of bioluminescence, as shown in the diagram, was found to be greater than the daylight penetrating from the surface below certain depths, and sufficiently strong to be seen by animals at significant distances. Therefore, luminescence can be used extensively to attract other animals for schooling or mating, or to lure prey.

At certain stations two photometers were used simultaneously either at right angles, or one oriented upward and the other down-

ward, to give more information on the spatial distribution of flashing. The spectral composition and other characteristics of the luminescence of animals brought alive into the laboratory, or kept under culture, were measured. Evidence was obtained that some planktonic forms use luminescent discharges to distract, and thus escape, their predators. Bioluminescence has thus been shown to be capable of great ecological significance in the lives of organisms at all depths during the night, and at levels below a few hundred meters during the day.

These findings, together with previous work, strongly indicate that complicated interactions exist between the intensity of light from the surface, the occurrence of bioluminescence, and the reactions of organisms. Both surface light and luminescent flashing are related to the vertical distribution of populations, their diurnal migrations, and the use by animals of their eyes (or of other light-sensitive organs) to find others of the same species, to locate food or to avoid enemies.

ZOOPLANKTON PHYSIOLOGY

Robert Conover

Since particulate carbon or organic matter is the end product of the biological production cycle, the measurement of the rate processes affecting its abundance should be the ultimate measure of production. The C^{14} method is the most direct measure of production presently available, but a method involving confinement of the natural waters to a container, no matter what size, is generally applicable only within these imposed boundary conditions.

During the past year studies of Gulf of Maine plankton populations have been initiated with the aid of parachute drogues as tags to maintain contact with a specific environment. Hydrographic observations showed little evidence of water mass exchange although the drogues had a net movement of over four miles per day on occasion. Rhodamine B dye added to the water near the drogue was detectable for more than 52 hours after delivery at a point source.

Biological sampling was carried out with a Jabsco self-priming pump and suspended garden hose buoyed by an auxiliary float attached to the drogue. Measurements of temperature (bathythermograph), salinity, total particulate carbon (oxidizable material), chlorophyll *a*, particles using the Coulter Counter (R) and net zooplankton

were taken at 4-6 hour intervals. In March and May 1962, carbon, chlorophyll a, and particles, showed daylight increases followed by decreases during the dark. In August 1962, there was no regular pattern of fluctuation in carbon and chlorophyll associated with the daily light-dark cycles but rather a decline over the 48 hours.

Chlorophyll and carbon were positively correlated in March and May. A statistically-fitted curve for the May cruise gave a value for non-photosynthetic carbon of 42.7 μg/L. In August there was no relationship demonstrable between carbon and chlorophyll.

In order to examine the size distribution of the organic fractions, twenty-liter water samples were passed through a column of successively finer filters and the material collected on each filter analyzed for carbon and chlorophyll a. Photosynthesis was carried out primarily by the fraction of organic matter less than 10μ at all seasons so far sampled. However, a considerable fraction of the total carbon (18%) which contained virtually no chlorophyll, was found in the greater-than-30μ size range. This fraction contained considerable detritus and also a population of smaller zooplankton organisms not normally sampled with coarser nets.

Straight lines, fitted to the best portions of the diurnal curves, were used to compute production and grazing rates. During the drogue sampling program, C^{14} measurements of primary production were run at the same depth. Agreement was quite good in March, especially when the C^{14} bottles were seeded with several Calanus finmarchicus at the start of the experiment. In May and August the agreement was not as good, although both methods showed lower values than in March.

The net loss of carbon primarily due to grazing was surprisingly similar on all three sampling dates, amounting to about 75 μgC/L/day. However, due to differences in the standing crop on each date the percentage of the total water mass filtered varied from a low of 33% in May to 59% in March.

NUTRIENT CHEMISTRY

Nathaniel Corwin and David A. McGill

Of the elements in sea water necessary to support the biomass, phosphorus is usually the one available in the most limited amount. The element is utilized by organisms mainly in the form of inorganic

phosphate in the euphotic zone. Regeneration of the element from particulate and dissolved organic phases can occur throughout the water column. It is standard practice at this laboratory to survey the entire water column for the total phosphorus content as well as the inorganic phosphate level. From the difference of these determinations a measure of the organic phosphorus level is obtained and some interpretation of the various stages in the phosphorus cycle can be made. Our data indicate that there is about twice as much organic phosphorus at deep-water levels of the South Atlantic as is found north of the Equator, which in turn suggests that the productivity of the South Atlantic may be accordingly higher.

Since the overturn of water in the area north of Newfoundland contributes most of the North Atlantic deep-water circulation, this area is particularly important. From two recent expeditions in the waters betwen Labrador and Greenland we have obtained several hundred samples. It is hoped that studies of the completed data can be tied to the observations available from further south, where previous data have shown some penetration of high organic phosphorus in deep water which has been ascribed to a northern origin. Charts of the total phosphorus distribution are being prepared; for much of the Atlantic basin and particularly the most northern region, these data are now available for the first time.

Considerable time is also spent on comparison of analytical procedures and techniques. In July 1962, D. A. McGill spent ten days on the Russian research vessel VITIAZ, operating out of Perth, Australia, as part of a UNESCO-sponsored project for inter-comparison of analytical work. Oxygen determinations and phosphate methods were compared on board by Australian, Russian, Japanese and American personnel. An inter-comparison of techniques of oxygen measurement among the major U. S. laboratories was held in Woods Hole in December 1962. The level of oxygen saturation is now being investigated, since preliminary observations suggest that the present literature overestimates the oxygen saturation due to an underevaluation of the Bunsen coefficient.

ZOOPLANKTON TAXONOMY

George D. Grice

Studies were continued in 1962 on the systematics of marine copepods and work was initiated on the distribution and abundance of the bathypelagic species.

In regard to systematics a review and revision was made of the calanoid copepod genus Candacia. This work included a description of a new genus, defined the known geographic distribution of the 24 species of Candacia s. s. and the three species in the new genus and provided an illustrated key for the identification of all 27 species. Other systematic work was the description of two new species of copepods from the Galapagos Islands and an attempt to solve several problems of identification and synonymy, based on the examination of type specimens of two insular-coastal and one oceanic copepod species.

As a corollary to our previous work on epizooplankton, studies were begun on the diversity, abundance and distribution of deep-water copepods. One deep-water series of zooplankton was collected in spring between 42°N and 15°N along the 65th meridian. These have been partially analyzed. A large diversity of species, usually 20-30 was found in samples below 200 m. The number of species in surface waters varied from 5 to 26 depending on latitude, the greater variety being present in lower latitudes. No such marked latitudinal variation in the number of deep-water species has been observed. Most of the deeper living species were usually represented by a few individuals and a small copepod "biomass" was found in deep waters. Some distribution records were of interest. Late copepodids and adults of Calanus finmarchicus, a cold temperature species, have been detected as far south as 30°N at a depth of about 1000 m and C. hyperboreus, an arctic-subarctic species, as far south as 35°N at a depth of approximately 600 m. It is not certain whether these occurrences represent breeding populations, as the presence of juveniles might suggest, or simply populations carried southwards from their northern centers of abundance by deep currents. Neither of these species lives in the surface waters at the indicated latitudes or, for that matter, in the epizooplankton of the Sargasso Sea.

The increasing collections of animals resulting from several Institution investigations prompted us to consider establishing a uniform method of cataloguing and numbering specimens. After discussions with interested WHOI investigators and persons acquainted with cataloguing procedures at the U. S. National Museum and the Museum of Comparative Zoology, a card-type cataloguing system was selected as the most suitable for our purposes. To date nearly 1200 catalogued entries have been made including about 300 copepod species, the largest taxon of the 12 taxa now represented by documented specimens.

PHYTOPLANKTON CULTURING

R. R. L. Guillard

Experimental work during 1962, as in the past, centered about studies of marine phytoplankton species in culture, with the aim of comparing physiological properties of strains from different environments.

The vitamin B_{12} requirement of a number of diatoms from different habitats was studied quantitatively. When these algae were allowed to grow until the B_{12} supply in their medium was exhausted, the amount of protoplasm produced per unit weight of vitamin was about the same for all species and was of the same order of magnitude as is produced by other organisms. However, this should not be taken as evidence that the level of B_{12} in natural waters has no selective influence on the algal populations. A number of observations suggest that the B_{12} requirement for rapid growth or for the production of sexual stages may exceed the minimum requirements found as described above.

A preliminary study has shown that at least one B_{12}-requiring species of diatom cannot utilize the vitamin B_{12} analogue having adenine in the nucleotide portion. Organisms responding differently to the members of the B_{12} family of compounds are of value for the bioassay of sea water for vitamin B_{12} activity.

We have continued our efforts to find out if there are significant differences in the abilities of various phytoplankters to utilize phosphorus compounds at low concentrations. Some results are given briefly in the report by E. J. Kuenzler. Thus far, we can state only that all algae studied can reduce the phosphate concentration to levels undetectable by ordinary chemical methods; it remains to be shown that differences of ecological significance exist. Improved techniques, largely resulting from detailed study of the diatom Phaeodactylum tricornutum by E. J. Kuenzler, should make further study profitable.

The excretory metabolism of a number of species belonging to different taxonomic and ecological groups is under study by J. A. Hellebust (W.H.O.I. post-doctoral Fellow). The ratio of the amount of carbon excreted to that fixed through photoassimilation depends on the state of growth of the algae, being quite low for most algae in the logarithmic phase of growth. However, certain algae excrete a considerable fraction of the photoassimilated carbon even during rapid

growth. Skeletonema costatum has been found to excrete significant quantities of protein under log-phase conditions. Algae grown under moderate light intensity (ca. 8000 lux) excrete little or no glycolic acid, but one species produces small amounts when grown at high light intensity.

Studies were initiated, largely by P. J. Halicki (Ford Foundation pre-doctoral Fellow, University of Kansas) on the cytology and sexual reproduction of planktonic centric diatoms in culture.

A review article on diatoms was completed in collaboration with J. C. Lewin of the Scripps Institution of Oceanography.

PHYTOPLANKTON DISTRIBUTION IN THE OCEAN

Edward M. Hulburt

An examination of the phytoplankton between Nova Scotia and Venezuela in April indicates the following features: a diatom assemblage in the very cold water close to the Nova Scotia coast, a dominance of the diatom Tropidoneis in an assemblage of flagellates at temperatures of 7° - 14° water (> 18°) from latitude 38° to latitude 28° and no marked dominance of any form in the increasingly stratified water on toward the Venezuelan coast. Some distance off this coast large quantities of diatoms were again observed, due to the upwelling that exists there. The divisions of the flora thus appear to be delineated by hydrographic features.

Observations on the growth of fertilized samples of water along this transect were made. When silicate was included in the enrichment, diatoms ultimately dominated the six experiments conducted--even though all but one had an initial population dominated by Coccolithus huxleyi. When silicate, necessary for the diatom wall, was omitted, diatoms dominated in four and a green flagellate in the other two experiments. In general, these experiments indicate the greater growth rate of some diatoms than of the dominant coccolithophore of the western North Atlantic under conditions of enrichment typical along the coast.

The diatom species found along the Venezuelan coast were the same as those found in northern waters. There was only one clear exception, a species previously observed by Cleve from tropical South America. This species, Skeletonema tropicum, has a greater number of spines and chromatophores than S. costatum.

GEOCHEMISTRY, METEOROLOGY AND ECOLOGY

John W. Kanwisher

The first half of 1962 I was away on a leave of absence teaching at Harvard University. The rest of the year I divided my research time among the following topics.

Chemistry of Shallow Marine Bottom Sediments: A general study of shallow bottom ecology has required this work as background in order that the chemical environment of the bottom animals be better characterized. My research and conclusions were presented in two papers: (a) Sulfur chemistry of bottom sediments. Proc. Yale Symp. on Sulfur Geochemistry; (b) Gas exchange of bottom sediments. Proc. U. Rhode Island Symp. on Environmental Chemistry of Marine Sediments.

Gas Exchange across the Sea Surface: I have collected and brought to a reasonable conclusion my work and ideas on this subject. They are presented in two papers: (a) Gas exchange across the sea surface (to be published soon in Deep-Sea Research; this is a general treatment of the topic); (b) Effect of wind on CO_2 sea surface exchange (this is a special treatment of CO_2 because of its chemical reactivity and geochemical importance).

Productivity Measurements in a Salt Marsh: With John Teal I have worked out a method of using a large (6 meters^2) plastic tent over a section of salt marsh in order to follow the net activity of CO_2 in the enclosed community. This has proved feasible and a year's study of the marsh by this means has begun.

I have continued an assorted interest in instrumentat[illegible]. Polarographic electrodes can be used to measure O_2 to better than 1% while drawing samples for other purposes from Nansen bottles. A simple portable logarithmic light meter sensitive to one wavelength (550 mμ) can be used to write out Beers law in a water column. Change in water type shows as a change in slope of the resulting curve. Initial promising results have been obtained on automatically counting copepod size particles <u>in situ</u>. Solid state telemetering gear is in the works for sending data from towed nets and free-swimming whales. An at-sea method of total dissolved organic carbon has been worked out and is being run now on the CHAIN.

Greater than one-third of my time has gone into reports, committee work, lecturing, handling summer students, and other non-directly-productive activities.

PHOSPHATE REGENERATION

Edward J. Kuenzler

Several investigations have been pursued in 1962 dealing with the cycling of nutrients in the sea. A study of the turnover times of several physiologically important elements, iodine, iron, zinc, strontium, cobalt, and manganese was initiated when the U. S. Atomic Energy Commission provided an opportunity to collect zooplankton contaminated during Pacific Ocean tests. Representatives of the most abundant groups, especially copepods, euphausiids, pteropods, pyrasomas, salps and ctenophores, were collected and maintained alive in clean sea water for several hours. The animals were then removed and preserved, and the water was filtered and passed through ion exchange resins. The different isotopes are now being separated and counted to determine the ratios of activity in the feces, on the cation and anion resins, and in the column effluent to the activity in the animals themselves. From these data, turnover times for each element and approximate excretion rates can be calculated. Quantitative vertical hauls of zooplankton nets throughout the day and night at several stations give the vertical distribution of these animals. We hope to estimate the importance of zooplankton in transferring elements across the pycnocline during their diurnal migrations.

A technique was developed (with Dr. R. R. L. Guillard) using phosphorus-deficient unicellular algae for bioassay of sea water for phosphorus. This technique showed that some routine chemical analyses seriously overestimate the dissolved orthophosphate in sea water. This error is greatest in phosphate-poor water, such as in the surface of the Sargasso Sea, and least in phosphate-rich waters. It was also found that phosphorus-deficient Phaeodactylum tricornutum can assimilate a considerable amount of the dissolved organic phosphorus fraction of sea water. We have evidence that these cells excrete a phosphatase and postulate that some of the phosphorus assimilated came from organic compounds hydrolized extracellularly.

The compounds comprising the dissolved organic phosphorus pool are completely unknown. A preliminary study showed that a hydrous zirconium ion exchange column loaded with sea water and eluted with ammonium hydroxide can separate this pool into at least ten different fractions. Further work is necessary to identify these substances and to learn the source, fate and turnover rates of the most important compounds.

DISTRIBUTION OF PELAGIC FISHES

Frank J. Mather and Martin R. Bartlett

Distribution and migrations. Extensive exploratory fishing, frequent examinations of landings, and an increased tagging effort all contributed new information on distributional cycles. Fishing with long-line and trolling gear for large specimens and with nets for juveniles, larvae, and plankton was carried out from 8 vessels which made a total of 11 cruises between the Newfoundland Banks and the southern Caribbean. Environmental data were gathered concurrently. Mr. Martin Bartlett, spending over 100 days at sea, supervised most of these efforts, which were concentrated mainly on the edge and adjacent slope of the continental shelf from Georges Bank to Cape Hatteras, and, to a lesser extent, in the Straits of Florida and among the Bahamas. While the mass of information obtained over the years on tunas was increased, notably for the bluefin and the bigeye, T. obesus, the outstanding results concerned the greatly increased knowledge of the general fall distribution of the broadbill swordfish, Xiphias gladius, along the continental slope, and its apparent differences in habitat according to size and sex. This species was taken in quantity throughout the fall by long-lining at night in the vicinity of the 500-fathom curve from Georges Bank to the Hudson Canyon. The population appeared to center about the 60°F isotherm, with the larger individuals favoring the colder inshore waters and the smaller ones the warmer offshore areas. While available information indicates that the harpoon fishery depends entirely on females, about 37% of the long-line catch consisted of males. Commercial possibilities were indicated when fall long-line catches frequently exceeded on a vessel per day basis the maximum obtainable by harpooning, which is profitable in the summer only. Occasional daytime long-line fishing produced catches of bluefin tuna duplicating the extraordinary ones made in this area from the R/V CRAWFORD in November 1960 (Mather and Bartlett, 1962), but the night sets yielded few of these fish. On the other hand, night sets did produce bigeye tuna in unprecedented numbers, indicating differential feeding habits of these two species. An interesting by-product of night long-lining was the capture of two specimens of the rare gempylid, Lepidocybium flavo brunneum in the Bahamas (Bartlett and Backus, 1962) and nine additional specimens off Georges Bank. The only previous certain record of this species from the western Atlantic originated from the Gulf of Mexico, and specimens in such numbers and covering such a range of sizes have never before been available to an ichthyologist.

Additional distributional information was obtained by examination of the landings of sport and commercial fishermen, notably those of the swordfish long-liners and those of the increasingly-productive tuna purse-seiners, which were sampled on 12 occasions. Seiners netted considerable quantities of skipjack, Katsuwonus pelamis off southern New England, a development of possibly great significance. This species, which has been the greatest contributor to the world tuna catch, had previously been landed in only negligible quantities in the northwestern Atlantic and is believed to offer the greatest potential for increased future production of all the tunas. David Bowen, a summer research fellow, examined landings of a local fish trap from July 4 to August 31, concentrating on the study of the Atlantic bonito, Sarda sarda. Distributional information on northwestern Atlantic Thunnus accumulated to the end of 1961 has been described (Mather, in press).

The continuing growth of the cooperative gamefish tagging program resulted in 2,766 releases and 49 returns in 1962. Of these, three showed migrations of giant bluefin tuna from the Straits of Florida to Norwegian waters, indicating that the two similar migrations recorded in 1961 (Mather, 1962) were not accidental. Other returns increased our knowledge of more local movements of this and other species, notably 29 from great amberjack, Seriola dumerili, and 6 from Atlantic sailfish, Istiophorus albicans.

Biometric studies. Biometric and other descriptive data were gathered concurrently with the above field activities and also through 5 visits by Mr. Mather to museum, laboratories, and a taxidermist's establishment. The great increase in bluefin tuna landings afforded the opportunity for and pointed up the increased importance of obtaining size-composition data for this species. These will be used for studies of growth and population dynamics, as well as distributional patterns. Preliminary analysis indicates that a single-year class of bluefin (4-year-olds) dominated the purse seine landings in 1962. Descriptive data for the size ranges available to date for Thunnus species (Mather, in press) and of virtually the entire known size range of Seriola species are nearly complete for the northwestern Atlantic. Considerable progress has been made toward a world-wide revision of the latter genus.

BENTHIC ECOLOGY

H. Sanders and R. Hessler

Our present quantitative study of the deep-sea benthonic fauna along a transect between southern New England and Bermuda has

revealed a significantly larger number of animals than has been found in previous quantitative deep-sea investigations. Each region seems to support a characteristic number of animals. The outer continental shelf carries about 6000 animals/m^2, the upper continental slope, 6000-23000/m^2, the lower continental slope, 1500-3000/m^2, the abyss north of the Gulf Stream, 400-1000/m^2, under the Gulf Stream, 250/m^2, the Sargasso Sea, 25-100/m^2, the deeper Bermuda slope, 100-200/m^2, and the shallower Bermuda slope, about 800/m^2.

Since we have appreciable numbers of specimens which were collected quantitatively, we can ask what is the nature of a deep-sea benthonic community? All our deep-sea samples contain a large number of species. In addition to this diversity, the bottom fauna can be characterized by a lack of dominance of any individual species. We believe this type of community to be representative of the environments that have been stable for long periods of time and is the product of a long period of biological interaction resulting in biological accommodation.

Sixty-eight species of bivalves were collected along the transect. No species showed a ubiquitous distribution and, in fact, each species was confined to a specific portion of the transect. When a species occurred at more than one station, it was usually present at contiguous stations. These data suggest that in a single ocean basin, despite the apparent uniformity of environmental conditions, pelecypod species are not found throughout the basin, but instead, have restricted and circumscribed distribution patterns. Preliminary distributional data for other deep-sea benthonic groups agree with these findings for Pelecypoda.

In this last year we have continued our efforts to document the phylogenetic position of the subclass Cephalocarida in the class Crustacea. Comparative studies of the skeletomusculature (Hessler, in manuscript) reveal essentially the same picture as that of the external morphology, functional anatomy and comparative naupliology (H. Sanders, in press).

That the skeletomusculature of this subclass is extremely primitive is shown by its great degree of serial homology, a characteristic feature of primitive members of metameric phyla. All the thoracic segments possess the same pattern of tendons, trunk muscles and limb muscles. In the cephalic segments the pattern becomes more specialized because of the unique role of head appendages, but the skeletomusculature still falls within the same basic plan seen in the thoracic region. This serial homology is best exemplified by the carapace adductor muscle which is an isolated muscle specialized

to close the valves in diplostracan branchiopods, leptostracan malacostracans, ostracods, and barnacles. However, in the cephalocarids it is but one of a segmentally repeated series which runs the length of the cephalon and thorax.

Comparison of the Cephalocarida to other subclasses demonstrates that the cephalocarid skeletomuscular pattern is not only primitive, but occupies a central position in the evolution of the Crustacea. For example, the longitudinal trunk musculature is of such a form that the pattern of these muscles in all the other subclasses could easily be derived from it. In no other subclass is this system so generalized.

Further sampling in 1962 has increased the known range of the Cephalocarida (Hessler and Sanders, in manuscript). It was previously known only from the shallow depths of Long Island Sound, Buzzards Bay, San Francisco Bay, and the Caribbean. Recently Hutchinsoniella macracantha was taken at 300 meters on the continental slope between here and Bermuda. It is increasingly evident that the present rarity of this subclass is primarily an artifact of collecting techniques, not distribution.

A large collection of Lightiella incisa, including an abundance of larval stages was made at La Paraguera, Puerto Rico, last winter. This genus possesses the same gradual development already revealed in a study of Hutchinsoniella, indicating that this primitive mode of development is a characteristic of the subclass, not just some of its members (Sanders and Hessler, in manuscript). These specimens were found in a richly organic, flock-like surface sediment trapped by turtle grass. This is the same sort of rich surface sediment known to be the habitat of Hutchinsoniella and is probably also characteristic for the subclass. Certainly this is in line with what is known of the functional morphology.

LARVAL DEVELOPMENT

Rudolf S. Scheltema

The length of planktonic life must be regarded as very important in determining the success of planktotrophic marine invertebrate larvae. A long planktonic life increases the opportunity for mortality and the chances for dispersion into regions unsuitable for metamorphosis and post-larval life. Shortening of the larval planktonic life

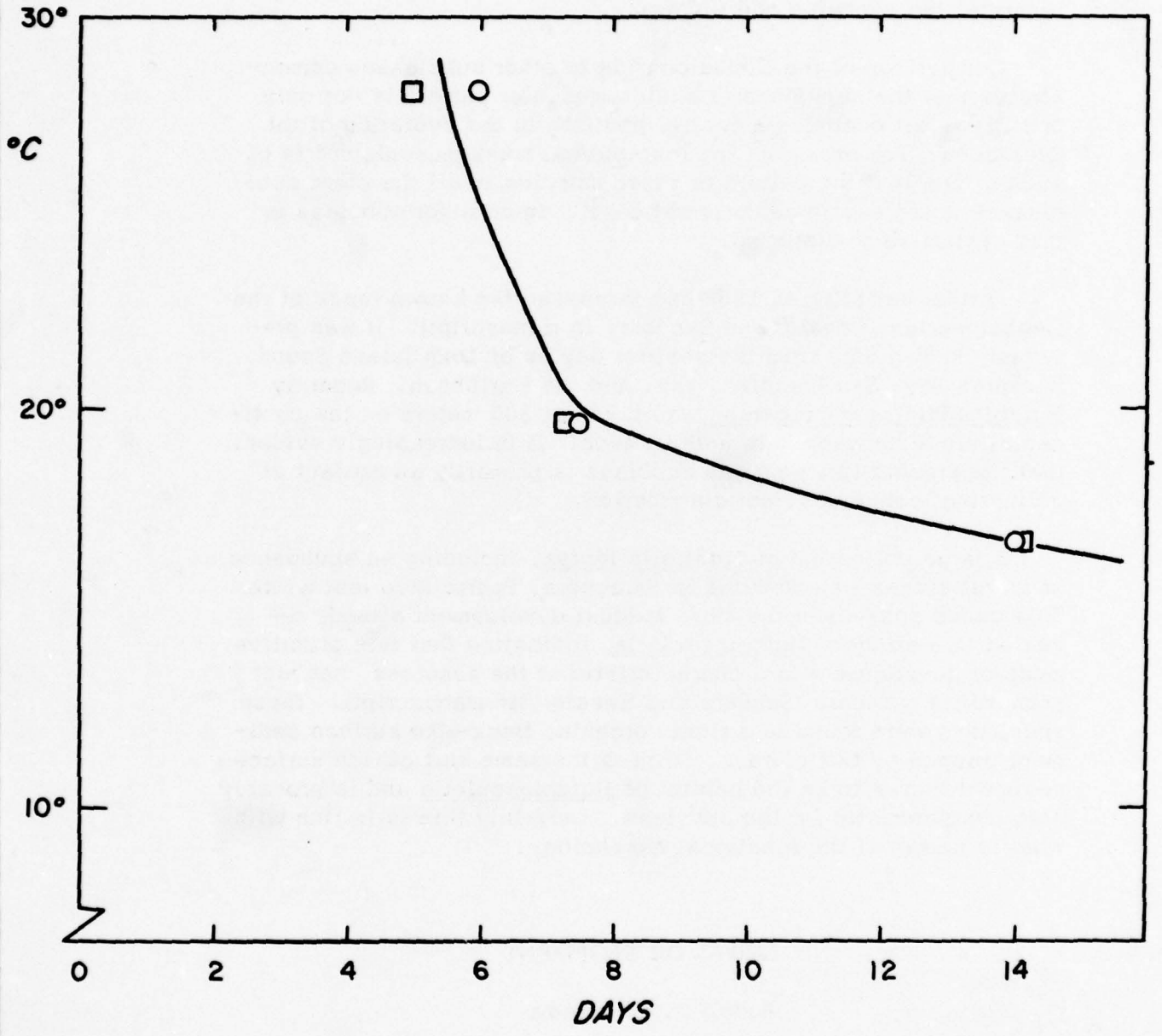


FIGURE 1. EMERGENCE OF LARVAE FROM THE EGG CAPSULE IN NASSARIUS OBSOLETUS AS A FUNCTION OF TEMPERATURE.

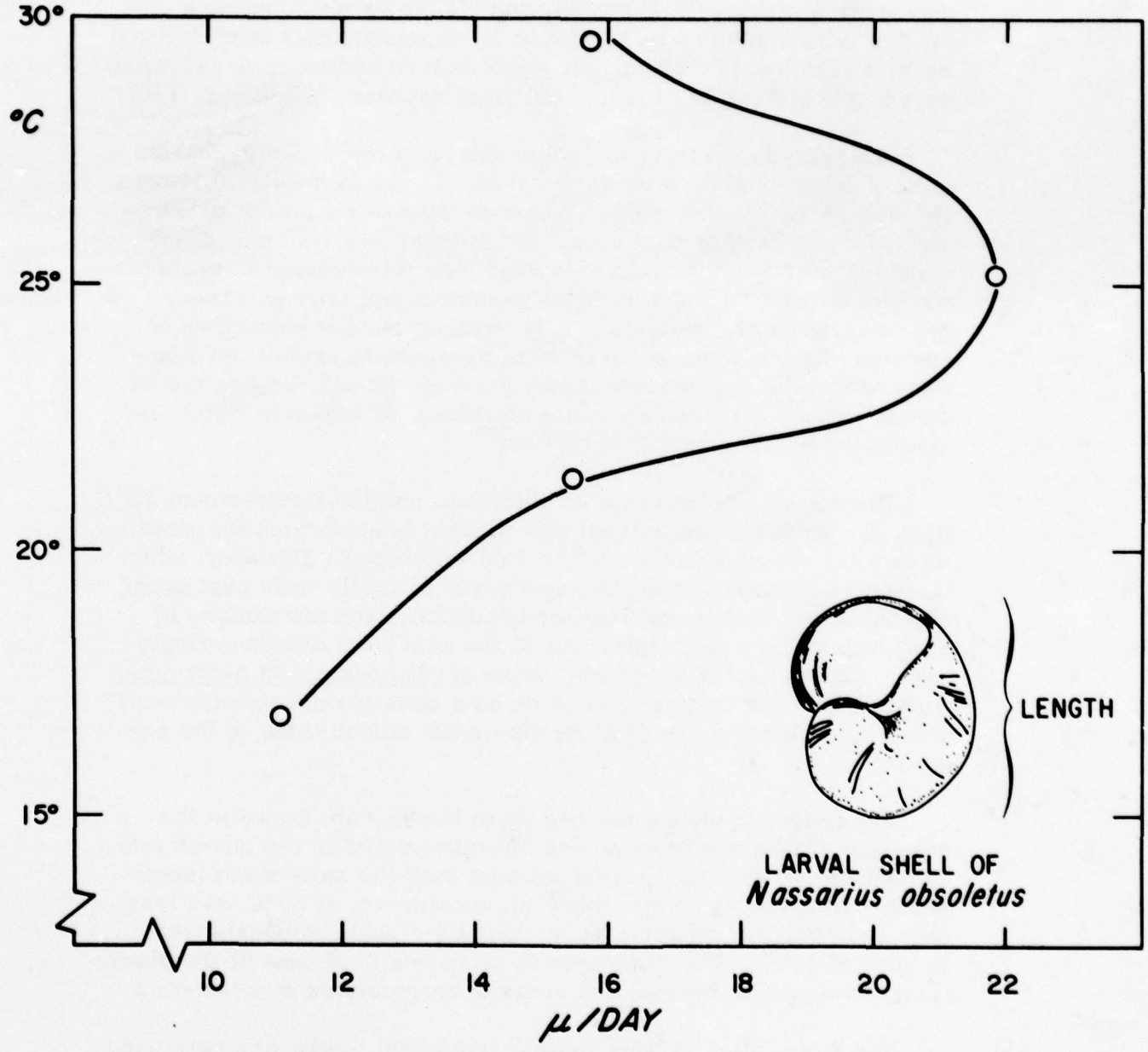


FIGURE 2. MAXIMUM INCREASE IN LENGTH (μ/DAY) AS A FUNCTION OF TEMPERATURE IN THE PELAGIC LARVAE OF NASSARIUS OBSOLETUS.

in the gastropod Nassarius obsoletus depends upon (1) the liberation of the veligers into the sea at a time when conditions are most favorable for growth, (2) continued favorable physical conditions for growth during the free-swimming period, and (3) the earliest possible encounter with a substratum favorable for metamorphosis after development is completed. The importance of bottom sediment for inducing metamorphosis has been previously demonstrated (Scheltema, 1961).

The rate of development of the embryo in the egg capsule was largely determined by temperature (Fig. 1). In cold water (between 10° and 14°C) the embryos never completed development but remained viable within the capsule for at least two months. If egg capsules previously held in cold sea water were placed in temperatures of about 20°C, the embryos developed normally and subsequently emerged as veligers. It is evident that the exact time of spawning by the snail is not critical because the rate of development within the egg capsule is governed by the sea temperature in a manner such that the larvae are not liberated into cold water unfavorable for planktonic development.

The optimum growth rate of planktonic larvae occurred near 25°C (Fig. 2). Between the optimal and minimal temperatures for growth, there was, on the average, a two-fold difference. However, when the larvae originally from the same group of snails were kept under approximately similar temperature conditions, the differences in growth rates from one experiment to the next were disconcertingly high. Change in the nutritional value of Phaeodactylum tricornutum with aging of the culture is considered a possible uncontrolled variable, which may account for the dissimilar growth rates in the experiments.

The length of planktonic life when larvae were grown in the presence of bottom sediment was directly related to the growth rate, except that at 25°C and above, veligers took the same mean length of time to metamorphosis. Since the growth rate at 30°C was less than at 25°C, the median size at the time of metamorphosis was smaller at 30°C. The difference in mean length of time of the planktonic existence at optimal and minimal temperatures was two-fold.

The description of New England gastropod larvae was continued with the laboratory culture of Anachis avara Say. This small snail is commonly found on rocky shorelines. Shortly before the metamorphosis this larva is strikingly beautiful in form and color. A full description is in press.

Interest in the larvae encountered beyond the continental shelf has opened an exciting area for investigation. In the open sea sessile and bottom-dwelling species of most major phyla are represented by larvae. Their origin is of some conjecture, but many are regarded as West Indian or Caribbean forms.

ICHTHYOLOGY

William C. Schroeder

Research in 1962 was devoted chiefly to collections of skates and rays made by U. S. Fish and Wildlife Service vessels operating along our South Atlantic coast, in the Gulf of Mexico, and southward to Brazil. Most of these specimens were trawled on bottom in 100 to 600 fathoms, depths in which no organized exploratory fishing had been done heretofore within much of this region.

Based on the material received up to 1961, the following paper was published: "New and little-known batoid fishes from the Western Atlantic" by H. B. Bigelow and W. C. Schroeder, Bull. Mus. Comp. Zool., Harvard Univ., 128(4): 159-244, December 1962. Included are 8 new species. During 1962 additional collections were received and will form the basis of a subsequent report.

In press is an article by Bigelow and Schroeder on the smelts and capelins to be published in the memoir series "Fishes of the Western North Atlantic" and, completed, an article on the whitings, Family Merluciidae, to appear in a subsequent volume of this same series.

INVERTEBRATE PHYSIOLOGY

John Teal and Frank Carey

Preliminary attempts to use oxygen electrodes for measuring respiratory rates at sea were hampered by lack of detailed information on the characteristics of the electrodes. Consequently Frank Carey and I made a study of electrode currents under various conditions of cathode size and material, electrolyte concentration, membrane thickness and composition, in each case finding the half-wave potential and the extent of the plateau

With the insight gained into electrode function we constructed a set of electrodes combined with a 12-point recorder which makes a very adaptable apparatus for respiratory studies and biochemical measurements. The system was taken to sea and measurements made of the respiration of animals from the surface of the Sargasso and from 2000 meters on the slope.

For the respiratory studies of the bottom animals we also constructed a pressure vessel of 4-inch internal diameter and 12-inch internal height which has electrical connections to the outside which permit measurements to be made of respiration of animals ranging in size from a few milligrams to several grams under conditions of temperature and pressure which can duplicate those found anywhere in the oceans. The apparatus has been taken to sea twice and used successfully.

The respiration of fiddler crabs was studied in regard to their critical tension and to their respiration as oxygen was depleted to zero and restored to 100% of air concentration. Concurrent measurements were made on the lactic acid concentration in their blood and its relation to the oxygen debt contracted during anaerobiosis.

INVERTEBRATE EMBRYOLOGY

Harry J. Turner

The role of nutrition in gametogenesis of the sedentary tube worm Hydroides dianthus was examined. In previous experiments which demonstrated the gametogenesis in this species took place at any time of the year under the influence of elevated temperatures, adequate quantities of phytoplankton had been provided for food. Subsequently, it has been determined that these worms can elaborate as many gametes in filtered sea water without feeding as when they are fed. It can thus be concluded that the reproductive products can be elaborated from reserve materials and that an inadequate food supply during the period when gametogenesis takes place may not be detrimental.

The nutritional requirements of the larvae of Hydroides appear to be more exacting. These larvae begin to feed approximately 24 hours after fertilization. Under experimental conditions these thrive on small algae such as Nannochloris but are unable to ingest any of the larger common algae. After two additional days of development, the

larvae can ingest larger phytoplankton such as Phaeodactylum and continue on such a diet through metamorphosis. The unusual settlements of Hydroides reported from the oyster grounds of Great South Bay, Long Island, during seasons when dense blooms of Nannochloris-like algae occurred, may have resulted from an adequate supply of the right kind of food at a critical time of development.

Observations on the behaviour of mature Hydroides larvae at metamorphosis have indicated that a surface coated with a bacterial or algal slime film is required. This is of little significance in the natural habitat because all solid materials immersed in the sea become slimed rapidly. However, under experimental conditions where it may be desirable to collect metamorphosing specimens on glass surfaces, it is essential that these surfaces be permitted to slime over before presenting them to the larvae.

Reproduction in the sedentary polychaete, Spirorbis, is being investigated. This small hermaphroditic tube worm is found attached almost exclusively to Fucus and similar rockweeds near the low tide mark. It reproduces during the spring, summer and early fall. The lecithotrophic larvae are retained in a special brood pouch through development and, when liberated, must find a suitable substratum within an hour or two or they die. This short pelagic period eliminates the hazards of the larval existence that occur in organisms with planktotrophic larvae. However, the larvae must be liberated when there are no currents that might sweep them out of the narrow coastal band of rockweed to deeper waters where they would be unable to find a suitable substratum for metamorphosis.

Heating, cooling and even vigorous shaking will cause liberation of larvae of Spirorbis in a few specimens. The most successful and consistent stimulus was found to be partial drying of weeds inhabited by gravid Spirorbis and replacing them in sea water. In the natural environment, exposure and partial drying of the worms at low tide would carry them inshore and retain them in the area of the rockweed substratum. Specimens exposed at the extreme low of the spring tide period might respond in a manner that would suggest lunar periodicity. This aspect of the problem will be investigated during the next breeding season in April.

Investigations of the reproductive cycles of abyssal benthic organisms have been commenced with the aid of ship time supported by NSF Grants G-8339 and G-23472. These organisms live in continual darkness and at a constant temperature where environmental variables that might influence reproductive cycles are not obvious. A series of dredgings has been made at various times of the year in depths

exceeding 2000 meters. Specimens of polychaetes, molluscs and nematodes have been preserved in a manner suitable for histological treatment. These are currently being sorted and when sufficient specimens of the same species dredged at different times of the year have been identified, they will be sectioned so that the condition of the gonads can be determined. A preliminary preparation of an unidentified species of the polychaete genus Scalibregma has been made and the location of an undeveloped gonad determined.

Additional studies of abyssal benthic organisms have been initiated with facilities provided by a group from this laboratory operating under an Office of Naval Research Contract No. Nonr-3351. This group, which is maintaining a line of instrumented anchored buoys between Woods Hole and Bermuda has provided facilities and personnel to include panels for the attachment of organisms along with the instruments on the buoy line. In the preliminary trials, some buoys and most of the panels were lost because of unanticipated problems in design. However, one single wood panel suspended for two months in the early fall near the bottom in 3000 meters of water was recovered and found to be heavily infested with wood-boring molluscs of the genus Xylophaga. With continued cooperation of this group and improved design of equipment, any periodicity of settlement of this type of deep water benthic organism can be determined.

DISTRIBUTION OF NITROGEN IN THE OCEAN

Ralph F. Vaccaro

The biochemical exchanges of nitrogen in the sea have long intrigued marine ecologists because of their fundamental relation to all marine protein synthesis. The many and diverse forms of combined nitrogen present at a given oceanic location depend upon the relative importance of a variety of assimilative and regenerative biological transformations. Usually inorganic nitrogen as nitrate, ammonia and possibly nitrite constitute the important nitrogen reserve for primary production of marine phytoplankton. Of the three, nitrate is characteristically the most abundant for water columns of great depth. However, it is not uncommon for the photosynthetic layer of the sea to become depleted of this form of nitrogen.

During the past years studies on the importance of ammonia as a complementary source of available nitrogen during periods of nitrate depletion have been initiated. In off-shore New England waters this

condition is typically encountered during the later summer months. Our measurements at this time show that most of the available nitrogen within the photic layer occurs as ammonia, so that meaningful estimates of the amount of nitrogen available for primary production require accurate ammonia measurements. Apparently there is sufficient ammonia present at such times to maintain algal nitrogen at a more-or-less normal level and above that which has been demonstrated in the laboratory for nitrogen-deficient cultures of phytoplankton.

TAXONOMY OF LARVAL FISHES

Margaret E. Watson

Visceral and skeletal studies. Routinely, records are kept on macroscopic characteristics of viscera; namely, liver, gall bladder, gonads, air bladder and stomach contents. Skeletons are prepared from selected fresh specimens or X-rays taken of preserved specimens. A comprehensive analysis of these records disclosed several errors and inconsistencies in published information on the tunas, genus Thunnus. A key was formulated to provide ready identification of the six species of tunas, genus Thunnus, either by X-ray photographs or by examination of viscera and gill rakers (Watson, in press).

Studies recently initiated on the swordfish reveal two different axial skeletons in this species independent of the size or sex of the fish. Only after examining many more specimens can we conclude whether variation within the norm can account for these two skeletal types or whether the swordfish should be distinguished by two species instead of one.

Maturation studies. Gonads of tunas are examined in the field or preserved for laboratory study in an effort to assess proximity of spawning by macroscopic methods. However, ripe tunas are not readily captured. To obtain more specific information on age at first maturity, time and area of spawning, and number of spawning periods per season, we initiated histological investigations on these gonads. For assistance with the histological processing we were fortunate in obtaining a grant-in-aid from the Sport Fishing Institute, Washington, D.C., for the summer employment of Miss Helen McKenzie.

Increased numbers of swordfish gonads also have accumulated. Males captured by long-lining only recorded a maximum body length of 79 inches, while the longest female recorded was 95 inches.

Early life history studies--the identification of larvae and juveniles. The acquisition of a custom-built radiographic unit in September, 1962, advanced the continuation of these studies. This soft X-ray unit, the only one of its kind in the world, is suitable for contact microradiography of larvae and juveniles as well as conventional radiography of specimens up to 30 cm in fork length. With the advent of an adequately shielded X-ray laboratory in the new biology building, specimens up to 100 cm in fork length can be radiographed. A donation from the Charles W. Brown Jr. Memorial Foundation financed the construction of this equipment which was designed by Dr. Ulf Friberg of the Massachusetts General Hospital.

Four species of larval and juvenile Thunnus are now distinguishable by their vertebral characteristics delineated in contact microradiographs. Specimens of bigeye tuna (T. obesus) and the Pacific longtail tuna (T. tonggol) have not been acquired yet. It is hoped specimens of these two species can be obtained during an expedition to the Indian Ocean on the RV ANTON BRUUN.

Measurements of body temperatures. On eight occasions body temperatures were recorded of fishes taken in traps, purse seines, or by long-line. A thermistor imbedded in the tip of a stainless steel probe was designed and constructed by Fritz Hess of this Institution. It attained a constant reading in 10 seconds with an accuracy of $\pm$ 1°C. The standard position for a deep measurement reading involved the dorsally directed insertion of the thermistor probe at the origin of the pelvic fins thereby piercing the liver. Deep temperature measurements made on active bluefin confined in the seine were identical to those taken on active fish immediately after they were brailled on board.

Eight bluefin, averaging 52 inches long, caught in water at 15°C, measured 24 to 28°C in the liver, 19°C in the superficial body musculature, 29°C in deep body musculature (about 4 inches beneath the second dorsal fin), 24 to 27°C in the rectum and but 16°C when the probe was inserted into the pericardial cavity via the wall of the gill chamber. One bluefin (26-1/2 inches long) and one albacore (size not recorded) registered 25°C when the water temperature was but 8°C. Future measurements will determine the constancy of this warm-blooded characteristic of tunas in warmer waters.

In contrast to the tunas, liver temperatures registered the same as the water for Xiphias gladius, Lepidocybium flavo-brunneum, Sarda sarda, Scomber scomber, and Prionace glauca.

ECOLOGY, PHYSIOLOGY AND BIOCHEMISTRY OF MARINE NITRIFYING BACTERIA

Stanley W. Watson

Available nitrogen is essential for the development of planktonic algae and the major source of this combined nitrogen in deep waters is nitrate. It is estimated that the nitrate ion comprises 60 per cent of all of the oceanic combined nitrogen.

For over 70 years the process called nitrification, whereby ammonia is oxidized to nitrite and nitrite subsequently to nitrate, has been known to be almost the exclusive function of two groups of autotrophic bacteria in terrestrial environments. It was also assumed a priori that nitrifying bacteria must also be responsible for the production of nitrate in the ocean, as in the soil, but until recently there was no experimental verification of this hypothesis.

The present studies concern those autotrophic nitrifying bacteria which oxidize ammonia to nitrite in the open oceans. Last year we obtained crude enrichment cultures of these bacteria but failed to isolate them in pure culture. Within the last year we have isolated one of these nitrifying bacteria, Nitrosocystis oceanus, in pure culture. This bacterium is the first nitrifying microorganism ever isolated from open ocean waters and it is the first member of the genus Nitrosocystis ever obtained in pure culture. Nitrosocystis oceanus has been experimentally demonstrated to be an obligate autotroph which oxidizes ammonia to nitrite as its sole source of energy and fixes CO_2 as its sole source of carbon.

In the past nitrifying bacteria have been difficult to investigate biochemically because it has been impossible to obtain large amounts of these cells for study. We have overcome this obstacle by growing N. oceanus in mass cultures in 14-liter fermentors designed and built in our laboratory. Using this apparatus 20 grams of wet cells per fermentor are obtained, making possible the first biochemical study of any marine nitrifying bacterium, and this work is now in progress.

N. oceanus oxidizes ammonia ion to nitrite in the following manner:

$$NH_4^+ + 1\text{-}1/2\ O_2 \longrightarrow NO_2^- + H_2O + 2H^+ + 66\ \text{K cal.}$$

The simplest possible reaction sequence for the above over-all reaction would be as follows: ammonia ⟶ hydroxylamine ⟶ unknown

intermediate ⟶ nitrite. First we attempted to demonstrate the oxidation of ammonia to hydroxylamine in a cell-free extract of N. oceanus. Although this system is easily demonstrable in intact cells all enzymatic activity for this specific reaction is lost once the cells are fragmented by sonification. Work is continuing on this phase of the investigation.

However, one part of this system can be demonstrated easily in cell-free extracts. When hydroxylamine is added to a cell-free sonicate of N. oceanus, electrons pass through cytochrome c in a normal cytochrome system terminating in cytochrome oxidase, via a "hydroxylamine cytochrome c reductase." Dr. Alvin Nason and Mr. Allan Hooper of the McCollum Pratt Institute have been cooperating in this phase of the investigation. This enzyme has been purified thirty-fold and has been characterized. The results of these studies were reported in the Federation Meetings in the spring of 1963.

Morphological investigations of N. oceanus have developed new information about the submicroscopic cytomembrane system found in nitrifying bacteria. Electron micrographs of thin sections of N. oceanus revealed a complex cell wall, a protoplasmic membrane, ribosomes, nucleoplasm and, most interesting of all, a cytomembrane organelle hitherto undiscovered in any bacterium.

Once this structure was observed in this marine form, we predicted that terrestrial nitrifying bacteria would have the same or an analogous structure. This proved to be correct. When sectioned and examined under an electron microscope, both Nitrosomonas europaea and Nitrobacter agilis were found to have cytomembrane systems. Their cytomembranes were located peripherally in the cell rather than centrally as in Nitrosocystis oceanus.

The function of these cytomembranes is unknown. Their remarkable similarity to chloroplasts leads to speculation that they are in some way associated with carbon dioxide fixation and possibly with ammonia oxidation. It is our hope that these unusual features may serve as excellent tools to correlate structure and function at the submicroscopic level.

As reported last year, this organism was found in the majority of samples taken during the spring and summer cruises of 1961. The new media and culture techniques thus made it appear to be much more abundant than was indicated in earlier studies. In the January cruise of the CHAIN in 1962, N. oceanus was isolated in only two samples of a total of 18 samples from which its culture was attempted.

From these results it is clear that there must be a pronounced seasonal cycle of abundance and that we still have much to learn about the ecology of this organism.

CHLOROPHYLL STUDIES

Charles S. Yentsch

A highly sensitive and precise method for the measurement of chlorophyll and phaeophytin by fluorescence has been devised. Measurements of the concentrations of these pigments are being made daily in Woods Hole waters. Generally, the phaeophytin concentration is quite low, but after a winter gale the concentration of this pigment has been observed to increase greatly. This is the result of plant detrital material being stirred upward from the bottom. Measurements of pigment in bottom deposits have shown that phaeophytin concentrations are quite large there. Observations in the open ocean have shown that the phaeophytin concentration is very low within the euphotic layer. Below this layer all the chloroplastic pigment appears to be in the phaeophytin form. The other site for high concentrations of phaeophytin appears to be in the intestines of herbivorous crustaceans. Coarse net tows, when extracted with acetone, yield considerable greenish pigment. Measurements show that practically all of this is phaeophytin. Factors affecting the formation of phaeophytin in phytoplankton have been studied using cultures. These observations show that when nutrient-deficient, the chlorophyll a does not convert to phaeophytin, even when the culture is incapable of photosynthesizing.

Factors affecting the compensation intensity (photosynthesis : respiration) are being studied using cultures of marine phytoplankton. A culturing apparatus has been designed where phytoplankton population is retained on a membrane filter. This allows the removal or addition of new culture medium without changing the population number. The chamber may be equipped with oxygen or pH electrode, and as the culture per unit volume is low in the chamber photosynthesis or pH responses are quite rapid. These experiments show that as a culture becomes progressively nutrient-deficient, the compensation intensity increases. In most healthy cultures the compensation intensity is about 1/10th the intensity for saturation of photosynthesis. Extremely low compensation intensities have been obtained at temperatures lower than are considered optimal for growth.

Interest in development of more satisfactory and dependable opening closing units for plankton sampling has led to the development of a pressure-operated unit. Actuation is accomplished by a microswitch which is closed by a pressure piston. The closing of the switch energizes an explosive wedge which allows a spring-loaded damper to open the mouth of the net. The damper closes the net at the same depth by a latching relay and a second exploding wedge. Sea trials have been extremely successful and have demonstrated a second desirable feature, the noise of the small underwater explosion which is audible to a conventional submarine hydrophone, and thus signals the operation of the unit.

CHEMISTRY and GEOLOGY

CHEMISTRY-GEOLOGY DEPARTMENT

Bostwick H. Ketchum, Department Chairman

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BATHYMETRY OF THE TONGUE OF THE OCEAN AND COASTAL AERIAL PHOTOGRAPHY

William D. Athearn

During the first seven months of 1962, I completed by contract work on the Bathymetry of the Tongue of the Ocean, Bahamas, for Naval Underwater Ordnance Station, Newport, R. I. This culminated nearly two years of field and laboratory effort. Three detailed bathymetric charts of the area deeper than 100 fathoms were completed, using a scale of 1:50,000 for the northerly half, and one chart using a scale of 1:100,000 for the southerly half. Recorded depths were corrected for sound-velocity variations. Chart contour intervals were two fathoms where relief was low and were increased through several steps to fifty fathoms on the upper, steeper and more complicated parts of the marginal slopes. Reproducible masters of these charts were sent to NUOS as they were completed. A final report for the project (WHOI Ref. Nos. 62-25 and 62-27), submitted in late July, includes a reduced-scale composite chart of the entire area and also a simplified chart, contoured to a fifty-fathom interval, with sediment and photographic station locations included. Topography and surficial sediments are considered, and a supplement is devoted to a discussion and presentation of stereographic bottom photographs from the Tongue of the Ocean. This report has been rewritten for publication and will be submitted to the Bulletin of Marine Sciences of the Gulf and Caribbean. The charts are to be reproduced at a scale of approximately 1:150,000.

With F. Claude Ronne, I made three coastal photographic flights in the R4D aircraft in 1962. Primarily, these, with several earlier flights, were made to record geological changes in shore-line features of the East and Gulf Coasts of the United States, although our growing collection of films also reflects the recent economic development of many coastal areas. In April we photographed the coast between Montauk Point, N. Y. and Miami, Florida, recording the effects of the severe northeast storm of early March. In September, the section between Montauk and Cape Fear was re-run. In general, it was found that the beaches had made some recovery during the summer months, but many severe scars remained which probably will take several seasons to erase. In June we flew the Gulf Coast between Apalachee Bay, Florida and the Rio Grande. This flight recorded the extent of recovery of the barrier island beaches of Texas, after the severe destruction caused by Hurricane CARLA in September 1961.

On December 29, a paper entitled "Aerial Photographic Study of Shore-line Changes at Cape Hatteras and Hatteras Inlet, North Carolina -- 1945 to 1962" was presented at the A.A.A.S. meetings in Philadelphia. In this paper, which is being submitted for publication, use of vertical photographs from more recent flights, with others dating back to 1945 obtained from the Coast and Geodetic Survey, enabled us to make reasonably accurate measurements of beach changes.

In late November I joined a Colombian Survey ship, the BOCAS DE CENIZA, for a few weeks cruise along the western Caribbean coast of Colombia, under auspices of the Colombian Port Authority. The ship stopped at many small coastal towns to explore the practicality of improving or developing port facilities. Beach samples were taken from many places and nine plankton tows were made during the trip. Four tows were made in the vicinity of the Gulf of Darien; one surface tow near the entrance; two tows, one surface in comparatively fresh water and one in deeper, more saline water, at the center of the Gulf; and one subsurface tow, in relatively saline water, near the head of the Gulf. As tests of these pelagic species are found occasionally in the sediments of this area, the object of our tows was to determine whether these normally-marine Foraminifera might be found living within the Gulf, possibly in the deeper saline tongue of ocean water which extends well into the Gulf under an overlying sheet of fresh river water. Preliminary scanning of the samples from the Gulf entrance indicated an abundance of one pelagic species Globigerinoides ruber, but apparently none from within the Gulf. As the tows were restricted to about ten minutes and the diameter of the net is only one foot, possibly the lack of specimens reflects their scarcity, but not necessarily their complete absence. However, it is also possible that the Foraminifera cannot survive in the Gulf in spite of the salinity. This may be due to increased turbidity. The few specimens which are found in the sediment may be carried in as empty tests by currents very near the bottom and therefore would have escaped the net which was somewhat above the bottom of the Gulf.

In cooperation with Dr. John Zeigler, I plan to continue this line of study on the continental shelf south of New England.

ORGANIC CHEMISTRY

Max Blumer

Our efforts to concentrate and analyze some of the dilute organic substances of sea water have led to the isolation of a very complex

mixture of compounds. Some of the components have now been identified even though their concentration lies as low as 1 part in 1000 billion parts of water.

The development of an organic-free water sampler became imperative because of the great difficulty in obtaining uncontaminated surface sea water near a vessel. The apparatus now under construction can be triggered at depth to filter water at a predetermined rate through a Millipore filter. Organic materials other than the filter itself and a minimum number of Teflon seals have been excluded in the construction; the water can be collected in a glass or metal container.

Two alternative methods have been developed for the extraction and concentration of the organic materials from the filtered sea water. The simpler technique, limited in its scope to unpolar, high boiling materials, involves extraction with benzene or pentane and concentration by evaporation of the solvent at low temperature. A more complicated and slower technique extends the recovery to more polar materials and compounds of lower boiling point. It utilizes an extraction process in a stabilized solvent bed and consecutive concentration by recrystallization and zone melting.

At the extremely low concentration levels of interest in this work we find a major difficulty in contamination from various sources. Millipore filters, for instance, contribute an excessive amount of contamination unless pre-extracted before use. Even highly purified solvents appear to produce interfering contaminants when exposed to light for extended periods.

The scope of analytical techniques used in this work includes column chromatography for isolation and separation of the hydrocarbons, urea adduction to obtain the straight chain compounds, spectrophotometry and gas chromatography for final identification. Of great value have been the recently-introduced polar high-temperature gas chromatographic substrates for cross identifications and the electron capture detector because of its extreme sensitivity to certain aromatic hydrocarbons.

We now have established the presence in near-shore sea water of dissolved straight chain hydrocarbons in the C_{14} to C_{35} range. In the aromatic fraction we find as most abundant components the hydrocarbons fluoranthene and pyrene.

The search for biochemical sources of the dissolved marine hydrocarbons has led to a surprising finding; the saturate hydrocarbon fraction

of zooplankton from the Gulf of Maine consists of nearly pure normal heptadecane ($C_{17}H_{36}$). The concentration of this hydrocarbon in the animals is sufficiently high that it would recognizably alter the composition of the surrounding water if it were released from the organism. No such predominance of heptadecane has been found in the zooplankton of the Woods Hole area. We will now try to identify the organism responsible for the high concentration of this hydrocarbon and attempt to search for the dissolved compound in sea water.

The hydrocarbon assemblage in the pigment-rich fossil crinoid Millericrinus has been studied in detail by David W. Thomas. The structure of the most abundant hydrocarbon has been confirmed by mass spectral analysis and by synthesis. Eight additional hydrocarbons have been isolated and the presence of at least 17 more is indicated. The carcinogenic 3.4 benzopyrene, which we previously identified in soils, is also present in the fossil; this finding further extends the known range of natural occurrence of this carcinogen in the human environment.

The hydrocarbon assemblages of soils, shallow water marine sediments, deep sea sediments (e.g. manganese nodules) and fossils resemble each other in many respects; they are also similar to those previously isolated from petroleum, air and various organisms. It thus appears that saturated and aromatic hydrocarbons are of much wider natural distribution than previously thought. At a low concentration level they may indeed pervade any natural material. The relatively high solubility of these compounds in mobile natural media (air, water) suggests the operation in nature of a complex geochemical cycle of hydrocarbons.

INORGANIC CHEMISTRY

Vaughan T. Bowen

Surface samples for studies on the fission products from fallout have been collected on a biweekly schedule from the four Atlantic U. S. manned weather ships. Study of yttrium 91, cerium 144 and promethium 147 in relation to the weather data has elegantly supported our thesis that fallout delivery over the ocean is mediated in different ways from that over the land. The ratio of recent to pre-1961 fallout may be only about half that over land. Especially within the Bermuda-Azores high pressure cell, very large amounts of fallout, especially low in recent material, appear to have been delivered almost in the absence of sensible precipitation. When winds in excess of about 38 mph are reported the samples show strong evidence of dilution by water low in

both new and old lanthanide fission products. This would, of course, not be observed in the situation postulated by some oceanographers, of an upper wind-mixed layer essentially out of communication with the underlying water.

Substantial completion of the analyses on the deep stations taken during CHAIN Cruise 17 in 1961, has shown very similar patterns at stations at 0°, 5°N, and 11°N. Surface Sr^{90} concentrations are identical and values at 100 to 300 m are slightly elevated in the northern stations compared to the equatorial values. Values for deep samples, down to 2500 m, at both 11°N and 0°, are essentially the same. The values at intermediate depth on the equator are only very slightly elevated over those observed in 1958, and are much less than those at 29°15'N, in the southeastern Sargasso Sea where the surface water Sr^{90} is about doubled, and the values at 100 m and 300 m are more than doubled. At present this seems another indication of the especially high delivery of fallout under the Bermuda-Azores High.

Preliminary study of our data from the Chukchi Sea does not support the Russian idea of very considerable transport of Pacific surface water through this shallow sea northward into the Arctic Ocean. The fission product analyses are all consistent with the view that this is an essentially stagnant area, with most of the fallout Sr^{90} delivered to it still in its own waters, and most of the $cerium^{144}$ already in the sediments.

Our program of analysis of trace elements in pure species collections of plankton continues to be fruitful. A major publication of results is in preparation, and collection of samples has been accelerated. From data in hand, two interesting studies have been made: Lithium:Rubidium ratios permit dividing our specimens into two groups - one with ratios greater than 1, and mostly much greater, and one with ratios less than 0.4. By contrast only two collections fall in the range of sea water (Li:Rb 0.85) and one of these, being a two-species composite, is questionable. Chow and Goldberg have recently published several profiles of Li concentration with depth, all showing the minimum Li:Cl ratio at surface; this is not emphasized in their discussion. In fact, however, the activities of both groups of plankton cited above would tend precisely to this effect, since the Li acceptors are in general creatures which withdraw Li from surface waters and the Li rejectors are in general predators which may be thought to excrete more intensively at depth.

Our series of Sr:Ba ratios in plankton also point to the possibility of biological control of the barium concentration profile in the oceans. Goldberg has already postulated this must be the major avenue of removal

of Ba from surface waters. We find, contrasted to a sea-water Sr:Ba ratio about 900, that all our plankton ratios are lower: the highest about 300, the mean well below 200 and the lowest 10. It should be possible by accumulation of more analyses and by culture experiments already begun, to test Goldberg's hypothesis that return to the water column is from sinking dead organisms or fecal material and is controlled by the solubility of barium sulfate. It also appears certain to us that any biological uptake system showing strong Ba to Sr discrimination will show even stronger change, in the same direction, in the Ra:Sr ratio. Instrumentation is about completed to use solid-state alpha spectrometry for radium analysis in organisms to test this hypothesis; an autoradiographic examination of plankton tissues is also underway to explore this.

A major activity of our program in inorganic marine geochemistry during the past year has been organization of our two-ship cruise to the Equatorial Atlantic. As is known, our program was begun and has been carried through independently of the International Cooperation Program, Equalant, which appears to have been sparked by our example. Much of our work will, however, mesh well with the more diffuse program, and their results should expand our interpretation of our own studies.

BIOCHEMISTRY AND PHYSIOLOGY OF MARINE ANIMALS

Francis G. Carey

Some progress has been made on the separate projects described below:

(1) Affect of temperature and pressure on respiratory metabolism of planktonic and benthic animals (with Dr. J. M. Teal). We have built a respirometer using oxygen electrodes recording on a twelve-point recorder, and a pressure vessel for respiration measurements under high pressure. We have taken this apparatus on three cruises. Results were poor for the first two, because of technical difficulties, but a recent cruise of one month's duration was quite successful and we now have a large amount of data on the respiratory rates of scattering-layer crustaceans under various temperatures and pressures.

(2) Anoxic metabolism of fiddler crabs (Uca) (with Dr. J. M. Teal). We have shown that under anoxic conditions Uca produces lactic acid as a major fermentation product and incurs an oxygen debt in doing so.

The rates of lactic acid production and disappearance have been measured and are in fair agreement with the extent of oxygen debt after various periods of anoxia. I have made some measurements of neutral fat and glycogen under anoxic and aerobic conditions and will extend these analyses to a number of other constituents.

(3) Chitin synthesis. An attempt to synthesize chitin in vitro, using an enzyme from the epidermis of soft shell crabs is awaiting the synthesis of some C^{14} uridinediphosphate N-acetylglucosamine, the immediate precursor of chitin. Following published procedures, I have made some C^{14} N-acetylglucosamine phosphate. This labeled amino sugar must now be joined to the uridine nucleotide in an enzyme catalyzed reaction. After a series of pilot experiments I have been able to get a moderate yield for this reaction and will soon synthesize a larger batch of the amino sugar nucleotide. I will then be ready to begin the experiments with chitin synthesis.

CHEMISTRY OF SEA WATER

Dayton E. Carritt

During the past year I have worked (with Mr. J. P. Clarner as a research assistant) on two problems.

The first is concerned with the measurement of trace constituents, both dissolved and suspended, in sea water. It is generally agreed that the geochemical and bio-chemical behavior of a great many of the elements in the periodic table is, at best, poorly known and for many completely unknown. We have taken the rather obvious point of view that a prerequisite to learning the geo-bio-chemistry of these elements is an analytical method that will permit a mapping in space and time of the distribution of the elements with spacing at least as fine as can be done for temperature and chlorinity. Since all of these elements are present in concentrations below the useful limits of most sea-going analytical methods, we have been concerned primarily with developing means of concentrating elements of interest from large volumes of sea water (up to 20 liters), and separating them from the major dissolved constituents, to produce a final solution that can be analyzed by conventional methods.

Our first approach has been to use anion exchange resins (usually in the chloride form) looking for retention on a resin column of elements that should exist, at least in part, as anion complexes when in a

chloride medium of pH approximately 8. We have found that Zn, Cu, and Pb can be so removed from sea water and eluted from the resin column with appropriate acids. During a CHAIN cruise we tested a procedure, using ten exchange columns (run at 70°C) with associated millipore filtering, eluting, and regenerating equipment and solutions for the collection of Zn.

Last summer, Roger Bachmann found that anion exchange resins can be put in the dithizonate form and so made active for the collection of Zn (and presumably other elements that form stable dithizonates). Starting with that observation we have studied the resin-dithizone reaction and the retention of Zn on such a column. It now appears that columns of this kind will be much more efficient as collectors than anything so far studied. We plan to continue these studies and to extend them to see if other organic (and inorganic) precipitants can be utilized on exchange resins.

During December 1962, Dr. Peter Koske, a postdoctoral student from Kiel, Mr. Clarner, and I planned and supervised an intercalibration experiment in which participants from eleven of the major oceanographic laboratories (private and Federal) in this country (one Canadian participant) assembled in Woods Hole for one week to compare the precision and accuracy of measurements of dissolved oxygen by the Winkler method, as currently carried out by the participating groups. The results of this experiment will be reported at the 1963 AGU meeting in Washington, D. C.

ZINC IN SEA WATER

John P. Clarner

Work was continued (under the direction of Dayton E. Carritt) on the development of an analytical method for zinc in sea water. The ability of strongly basic anion exchange resins to take up zinc, as zinc chloride complex, was used as the means of separation from metals such as sodium, magnesium, calcium and potassium which are not taken up by these resins. This, in effect, concentrates zinc and separates it from sea water and metals that would interfere in subsequent analysis.

The analytical scheme for zinc involved the use of strongly basic anion exchange resin in column operation. Measured quantities

of sea water were put through columns, zinc being retained on the resin. It was stripped from the resin by dilute hydrochloric acid which was evaporated down so that final samples of 10 ml were obtained. The zinc in these was determined by polarography. Five-liter samples of sea water were analyzed by this method.

A leg of CHAIN Cruise 25 was used to collect deep ocean water samples and try the column apparatus under sea conditions. Five-liter samples, from Van Dorn bottles, were millipore-filtered, to remove and save particulate matter, prior to going through the resin column. The columns were eluted with hydrochloric acid and these samples brought back to Woods Hole for final analysis. Much useful experience as well as knowledge of modifications to perfect the apparatus was acquired.

The take-up of zinc by anion exchange resin was more thoroughly investigated using zinc-65 tracer technique. Distribution coefficients of zinc on the resin are not constant in sea water, but vary inversely with zinc concentration. Artificial sea water (NaCl, Na_2SO_4 only) did not show this behavior but bicarbonate and iodide ions, added to these simple salt solutions, caused the same effect. Column breakthrough experiments showed chloride ion to be superior for column regeneration over other ions tested. The minimum resin quantities needed to take up all the zinc in a given volume of sea water were established from this work.

PHYSICAL CHEMISTRY

Paul C. Mangelsdorf

The thermodynamic activity of sodium chloride in various mixed electrolyte solutions has been studied potentiometrically using sodium-sensitive glass electrodes and high-impedance circuitry. At a constant ionic strength of 0.7 the activity coefficient of sodium chloride is found to increase in a regular manner when $MgCl_2$, $CaCl_2$, or $BaCl_2$ are added to the solution. The fact that all three have the same effect suggests a simple charge-interaction mechanism, but the fact that the effect occurs at all at constant ionic strength puts it outside the scope of the elementary theories of ionic solutions.

The use of long sea-water salt-bridges for marine potentiometry has been expanded in several directions. The technique of the vertical

salt-bridge GEK has been developed and improved in preparation for use on the Atlantic Equatorial undercurrent during the 1963 Equalant expedition. The use of the towed salt-bridge GEK for direct studies of total oceanic transport has been explored, with two sections across the Gulf Stream indicating much smaller eastward transport than the geostrophic method has been showing.

We have developed a workable method for in situ pH and salinity measurements using long sea-water-filled salt-bridges closed with appropriate selective membranes. Detailed pH and salinity vertical profiles at a number of stations in the shelf waters south of Nantucket during the late summer have revealed some interesting stratification which seems to be fully as intricate as the associated thermal structure.

EQUILIBRIUM BINDING STUDIES OF ZINC-GLYCINE COMPLEXES TO VARIOUS CLAYS

Alvin Siegel

The clay minerals are well known for their ability to bind both polyvalent cations and various organic molecules. The interaction of such binding and the possible binding of metallo-organic complexes to the clays holds much interest both to those interested in the chemistry of trace cations in the sea and those interested in the biological concentration of trace metals. Glycine , being known to bind zinc fairly well, was thought to be a convenient starting material for this course of work.

The stepwise stability constants of glycine to zinc were determined, in 0.7 M NaCl at 15°C, by a titration method of Albert (Albert, A., Biochem, J., 47, 531 (1950)). The stability constant for the formation of Zn-Glycine^{+} was found to be 9.59×10^{4} and the all-over stability constant for the formation of Zn-Glycine$_2$ was 9.48×10^{8}. This compares closely with the published values for zinc-glycine in other systems.

Equilibrium studies of the uptake of zinc on Dowex 50 ion-exchange resin and on nontronite and montmorillonite clays (Ward's Natural Science Supplies) were carried out, both in the absence and presence of various amounts of glycine (5×10^{-3} to 2.5×10^{-1}M). The clays were all ground to pass through a 62-micron sieve. The amounts of clay used ranged from 0.005 to 0.3g per 50 ml sample. The concentration of zinc previous to a run was 1×10^{-6}M. All

experiments were carried out at a constant pH of 8.0 ± 0.2 through the use of dibasic sodium phosphate as a buffer and a total ionic strength of 0.7 (NaCl).

The samples were shaken in a water bath maintained at 15°C. Zinc 65 was used as a tracer to follow the uptake of zinc on the clays. All systems studied were found to come to equilibrium within 6 hours. The samples were shaken for 18 hours, centrifuged and aliquots drawn off for counting.

The three systems studied gave markedly different results. In the Dowex 50 resin system the experimentally-determined distribution constant,

K_D, (K_D equals $\frac{\text{counts } Zn^{65}/\text{gram clay}}{\text{counts } Zn^{65}/\text{ml solution}}$), decreased with increased concentration of glycine, with the results falling about the curve calculated through the use of the previously-determined stability constants for the zinc-glycine system. Since other experiments had shown that little, if any, glycine is bound by the resin or clays at this pH there seemed to be no measurable binding of either the zinc-glycine^{+} or the zinc-glycine$_2$ complex to the resin.

The clays gave results indicating that such binding of complexes do occur in the clay systems. The experimental values of K_D in the nontronite system, throughout the range of glycine concentrations used, were several orders of magnitude greater than would be predicted if no binding of the complexes occurred. In the montmorillonite system, at low concentrations of glycine, more activity was found in the clay phase than in the complete absence of glycine. This is certainly an unexpected result and several possible explanations are under current study.

INSHORE SEDIMENTS

John M. Zeigler

Manuscripts:

1. "A study of sediment distribution in the zone of shoaling waves over complicated bottom topography," with R. L. Miller, is in press.

2. "Hydrography and Sediments, Gulf of Venezuela," completed and should go to press soon.

3. "Geology of Outer Cape Cod" with Tuttle, Tasha and Giese, has been written and will go to critics soon.

At least twenty per cent of my time goes into administrative duties and report writing.

Trips:

Trips to lecture (Chicago), Meetings, Calibration Studies in Washington and field work in the Caribbean.

Field Work (Not including Caribbean):

Four local studies are involved: 1. Acoustical measurements in Narragansett Bay. 2. Wave measurements on Martha's Vineyard. 3. Wave measurements at North Truro, and 4. Field studies of beaches, Outer Cape Cod.

Our general thesis is that field work is greatly needed in coastal work where the usual approach is through wave tanks.

These field studies are the very basis of the coastal research here. The most significant problems are attempts to relate shoaling-wave behavior as measured in the field with the theoretical predictions and to relate sediment movement beneath shoaling waves as measured in the field with either existing empirical equations or with theoretical equations. These field studies require very sophisticated instrumentation and an all-out team effort which begins weeks before the measurements take place. We were most successful in collecting data and have been arranging it into forms more easily digested.

The Cape Cod Geology studies with Tuttle provide the boundary conditions for theoretical work. These studies have emphasized sea level changes more and more.

Laboratory Supervision:

We have a continuing active series of experiments: 1. Environment of deposition determined by measuring the amount of depolarization caused by pits and scratches on sand grain -- a failure, but we finished the experiment. -- Zeigler, Bray, and Chappel. 2. Attempts to develop a new and better sediment analyzer. We had much success, finally, and

the Emery group has a new and improved analyzer. We tried one elaborate device of our own making which failed -- Zeigler, Hayes, Hotchkiss and John Schlee. 3. Testing the accuracy of standard sample-splitting devices. We found the devices could be improved and did so, but even worse, that the general use of the devices in our particular field, has been badly considered and that much of the data presented in the literature are not to be trusted. - Zeigler and Biggs. 4. Measurement of waves - tide gauge , sediment traps, etc., Zeigler, Miller, Hayes, Foley, Hotchkiss.

New Studies or Continuing Work:

Laboratory analysis of samples from the Gulf of Darien, Colombia, ATLANTIS Cruise A-246 A-254. These are almost completed. The general thesis is that planktonic Foraminifera which drift from the open sea are indicators of open ocean water. We have been working on this for two years. We believe that by counting the number of shells in a gram of mud from a good distribution of samples over the shelf, one can describe the hydrographic circulation and its stability through times past. Areas used for study: Gulf of Darien, Gulf of Venezuela, Shelf south of Woods Hole, Massachusetts.

GENERAL GEOLOGICAL SURVEY--WOODS HOLE PROGRAM

K. O. Emery

Work accomplished at Woods Hole Oceanographic Institution between my arrival 1 July and 31 December 1962 can be classed into four main categories: organization of a group for marine geology, water studies, field work in the Eastern Mediterranean, and preparation of reports for publication.

Most time and effort was spent upon organization of the group of men who are to participate in a joint U. S. Geological Survey--Woods Hole Oceanographic Institution study of the continental shelf and slope between Maine and Florida during 1962-1967. The work is financed by the USGS which is interested both for the geological results and for training of selected USGS personnel. Its commitments for the year 1962-63 include a $250,000 contract with WHOI and $60,000 for support of four USGS men at Woods Hole. Personnel consist of these four plus six others from WHOI. During 1963 total man power will reach fifteen or sixteen, the full complement needed. Considerable time was used in making arrangements for these people and in securing space and

facilities for their work. About $40,000-worth of laboratory equipment was ordered and installed in temporary (until June 1963) space at the Marine Biological Laboratory. Sounding, sampling, seismic profiling, and navigational equipment for R/V GOSNOLD was selected and ordered.

Different phases of the planned study were apportioned to the various co-workers and provision made for overseeing its completion. Basically, these phases include topography, sediments, rocks, structure, water, and biology. The group was selected so as to cover well the first four phases; the last phase is jointly covered by one member (for foraminifera) and by Bureau of Commercial Fisheries (for megafauna). Accordingly, I took responsibility for making pertinent studies of the water atop the shelf and slope. Most of this work to date has been the plotting of data and rediscovery of facts described during the past. Little advance was made in such general parts as distribution of temperature, salinity, and sound velocity. However, a cotidal map of the coast (the first one in fifty years) based on records of tide gauges at shore stations and on Texas Towers revealed an unexpectedly great transfer of tidal energy to the shelf--probably partly accounting for the known small percentage of sediment finer than sand on the shelf. Plots of monthly mean sea levels and of water density at a score of shore stations revealed that a seasonal cycle of sea level is probably controlled by seasonal cycles of local water temperature and river runoff. Plots of mean annual sea levels showed the same general relative rise that previously has been reported and which usually is attributed to world-wide rise of sea level or to local submergence of the land. Co-plots of water density indicate that increased runoff (locally lowered salinity) in recent years may account fully for the relative rise of sea level northeast of New York. This suggests that the previously advocated world-wide rise of sea level may be compensated here by local uplift of the land due to isostatic rebound after retreat of the Pleistocene glaciers. Along the coast south of New York the relative rise of sea level appears to be unrelated to local runoff and this probably is due to world-wide rise of sea level.

The third category of work was a field study in the Eastern Mediterranean. During 1961 arrangements were made for use of the NATO ship R/V ARAGONESE for a bathymetric survey of the Nile Delta. During ten days aboard the ship in November the main finding was a northward limitation of bottom-set beds by a series of parallel narrow flat-bottomed trenches. This limitation suggests that the bottom-set beds are deposited by turbidity currents, a conclusion which will

surprise most geologists. During three days prior to arrival of the ship at Beirut, a three-day study was made of the shores of Lebanon with a collaborator at American University of Beirut. The study showed that beach sands from the Nile River, previously traced through Israel, continue into Lebanon. In greater quantities on the beaches, however, are dolomitic and basaltic gravels of local derivation.

Several reports were prepared for publication:

1. Geological Survey--Woods Hole Program for Study of the Atlantic continental shelf and slope, with J. S. Schlee-plans for the joint study--to be published as a special circular of USGS.

2. Characteristics of continental shelves and slopes--the text of an invited keynote address at the annual meeting of American Association of Petroleum Geologists at Houston in March 1963.

3. Oceanographic Factors in Origin and Migration of Petroleum--text of invited talk at Sixth World Petroleum Congress at Frankfurt, Germany in June 1963.

4. Turbidities and Topography of North End of San Diego Trough, California, with B. M. Hand--for Jour. Sed. Petrology--based upon previous work.

5. A Combined Camera and Bottom Grab, with R. J. Menzies and L. Smith--for Int'l. Revue of Hydrobiologie--based upon previous work.

During this period the following were published:

1. Radiocarbon Dating of California Basin Sediments, with E. E. Bray-Bull. Amer. Assoc. Petrol. Geol. 46:1839-1856.

2. Marine Geology of Guam - U. S. Geol. Survey Prof. Paper 403-B: 1-76.

3. Disposal of Low-Level Radioactive Wastes into Pacific Coastal Waters, with others - Nat'l. Acad. Sci., Nat'l Res. Council Bull. 985: 1-87.

4. The Relationships of Sediments, Water, and Life in a Marine Basin, with J. Hülsemann - Deep-Sea Research 8:165-180.

RUNOFF COMPILATION[1]

Donald J. Casey
U.S. Geological Survey
Woods Hole, Massachusetts

As part of the joint U.S.G.S.-W.H.O.I. project, general flow data for streams draining the Atlantic coastal areas were compiled both on a monthly and a yearly basis. These data were then classified and particular drainage basins studied in more detail. These include Penobscott River in Maine, Charles River in Massachusetts, Hudson River in New York, James River in Virginia, Savannah River in Georgia, and the Miami River in Florida. Extrapolations had to be made, both to extend the periods of stream records and to obtain the flow characteristics at the river mouths. These extrapolations were necessary because the stream-gaging stations usually are located above the areas affected by tidal action, and the figures for stream flow are adversely affected by the water needs of large cities such as New York. These stream-flow data were then compared with sea level, salinity, and density at tide gauges of Portland, Boston, New York, Norfolk, Savannah, and Miami; as stream flow increases, salinity and density decrease.

TOPOGRAPHY AND LITHOLOGY

Elazar Uchupi

A set of three topographic charts of the continental margin off the east coast of the United States at a scale of 1/500,000 is being compiled. The northern chart will extend from the Bay of Fundy to Delaware Bay, the central one from Delaware Bay to Cape Fear, and the southern chart from Cape Fear to Key West. A 10-meter contour interval will be used to a depth of 200 meters, and a 100-meter interval beyond that depth. The southern chart, based on 127 U. S. Coast and Geodetic Survey smooth sheets and unpublished data from Woods Hole Oceanographic Institution and the University of Miami, has just been completed. Seven physiographic provinces can be recognized in this region: (1) the continental shelf ranging in width

[1]Publication authorized by the Director, U. S. Geological Survey

from 70 kilometers off Cape Fear to less than 20 kilometers off the Florida Keys (shelf-break ranges in depth from about 30 meters near Cape Fear to less than 20 meters off Key West), (2) the continental slope with an average gradient of 3 degrees and a relief that increases from 500 meters off Cape Fear to 1500 meters off Key West, (3) the Blake Plateau with a declivity of 1 degree, a width of about 1000 kilometers and a depth range from 500 meters on its western margin to 1000-1200 meters at its outer edge, (4) Cape Fear Arch Extension, a 800-meter high ridge extending 600 kilometers in a southeast direction from the base of the slope, (5) Blake Plateau Outer Marginal Escarpment, with a gradient greater than 25 degrees and a relief of about 3800 meters, (6) Florida Strait, a 30-75-kilometer wide trough separating the continental terrace off the east coast from the Bahama Platform, and (7) Pourtales Terrace, a 30-kilometer wide feature off Key West which ranges in depth from 200 meters at its inner margin to 300 meters on the seaward side.

Information on the bedrock geology of the continental margin off the east coast also was compiled. The rocks were classified into (1) bedrock or rocks essentially in place, (2) transported rock or gravel, and (3) authigenic rock (phosphorite and manganese oxide).

Alkaline granite similar to the Quincy granite has been dredged from Cashes Ledge in the Gulf of Maine, and Upper Cretaceous (Upper Campanian), Upper Eocene, Miocene, Pliocene and Lower Pleistocene sedimentary rocks have been dredged from the canyons off the New England coast. Along the walls of Hudson Canyon Upper Eocene and Miocene rocks have been obtained. Lower Cretaceous (Cenomanian), Eocene, and Oligocene have been recovered from the Blake Plateau outer marginal escarpment, and Miocene sediments from the surface of the Plateau itself. Miocene rocks have also been obtained from a series of small banks atop the shelf off the Carolinas.

Transported rock, predominately crystalline in composition, occurs throughout most of the shelf north of Hudson Canyon. Most of these clasts are probably glacial erratics. South of New York what gravel is present atop the shelf is mainly sedimentary in composition. Phosphorite is absent north of Cape Hatteras, but is present on the shelf south of Hatteras and atop Blake Plateau. Manganese oxide has been recovered only from Blake Plateau.

SOHM ABYSSAL PLAIN

Richard M. Pratt

The Sohm Abyssal Plain extends from the base of the continental rise off New England eastward to the foothills of the mid-Atlantic Ridge in about 38° north latitude and 42° west longitude. A T-shaped leg extends south between the Bermuda Rise and the mid-Atlantic Ridge to about 28° north latitude. Precise echo sounding during three cruises of 1962 were combined with previously available echo sounding records at Woods Hole and Lamont Geological Observatory to give a reasonable picture of this area. On ATLANTIS Cruises 280 and 281 bottom samples and photographs were made on the New England seamounts, which rise abruptly from the abyssal plain. On CHAIN Cruise 28 the abrupt abyssal plain contact south of the Newfoundland Rise was delineated, and a continuous high resolution profile from the easternmost end of the plain to Woods Hole gave a good picture of gradients on the plain.

By definition an abyssal plain has a slope of less than 1:1000, but from the standpoint of a graded sedimentary system the Sohm Abyssal Plain can be considered to extend from the lower limit of the continental slope across the continental rise and to merge into the true abyssal plain. Contours of the abyssal plain at a 20-fathom interval show that the gradient and consequently the sediment movement (assuming the reality of turbidity currents) extends eastward from the New England canyons and Cabot Strait to an area south of the Grand Banks and from there southward. The southernmost limit of the plain is indefinite because of poor sounding control and the prevalence of narrow flat channels that become lost in a welter of seamounts. The minimum depth area south of the Grand Banks is at the confluence of a sediment drainage system coming down the Mid-Ocean Canyon from the Newfoundland Basin around the end of the Newfoundland Rise and pouring westward on the Sohm Abyssal Plain.

The sedimentary system of the Sohm Abyssal Plain is intercepted by the New England Seamounts that rise abruptly from nearly flat plains. These seamounts are covered by pelagic ooze and manganese encrustations, and they form anomalous areas of pelagic sediment surrounded by the terrigeneous sediment of the abyssal plain. Ice-rafted material is common on the seamounts near shore, but it is rare on seamounts east of 62° west longitude. Here, photographs and dredge samples indicate that the Gulf Stream controls the nature of sediments on the seamounts. Evidence of current action on the seamounts was photographed at depths as great as 2600 fathoms.

ORGANIC MATERIALS

Jobst Hülsemann

During the Geological Survey--Woods Hole study of the continental shelf and slope several thousand bottom samples must be processed. Prior to the start of field work an opportunity to establish the laboratory routine and to obtain useful data was provided by a large collection of samples obtained by the Bureau of Commercial Fisheries. More than 1000 bottom samples had been secured by this group essentially on the continental shelf northeast of Block Island. Only a few had been analyzed. In order to make the collection most useful to our own program a selection of stations and material was made according to the following two principles: (1) stations as near as possible to a 10-mile grid, and (2) samples recovered from a large "Smith-grab" were preferred over those taken with other smaller instruments. This selection conforms with our own working schedule and tools, and it reduces hard and costly work on shipboard. As a result about 370 samples of the collection were designated for analyses.

Inspection of the sample material at the storage site revealed differences in preservation. Color and consistency are the main properties visibly altered by dehydration. Furthermore, some of the originally homogeneous samples became sorted gravitatively during transport, and a few colonies of fungi had developed. By breaking up and homogenizing the samples and eliminating foreign matter we recovered representative material for the analytical work.

A beginning was made with analyses for two chemical group-constituents which characterize the samples, the environment of deposition, and in part the mode of transportation; hence they hold a firm domain among basic parameters of sediments that serve almost as "standards" for description and history of an area. These two groups are the contents of carbonate and of organic matter. Good analytical procedures for both were developed many years ago. Thus the amount of carbonate in a sample is found by measuring the amount of carbon dioxide liberated as gas upon acidification of the sample. The crucial part of the instrumentation is a special condenser; though a fairly simple piece of glassware, it is not available commercially. Work during the period covered by this report and elsewhere in the past led to a modified condenser even simpler and more effective than the one in use. The new type is presently being built by a glass blower. It is estimated that the new condenser will increase the efficiency of

the method by more than 20 per cent in terms of time per analysis, besides increased ease of manipulation due to (1) faster cooling and (2) shorter cleaning time. The amount of carbon dioxide obtained serves for computing the amount of carbonate present in the original sample. Since the carbonate is essentially that of calcium, no adjustment is made for fractions of magnesium or other carbonates at this time. Analyses were completed for more than a third of the total of about 370 samples. Although the final values are not plotted yet, a brief view indicates a general low content of carbonate in the northern area of the Atlantic continental shelf, of which the Gulf of Maine is the largest part. Typical values are between 2 and 10 per cent calcium carbonate. These low concentrations reflect the cold northern climate which does not permit the growth of calcareous algae or corals in contrast to what we shall find in the southern area. Low values are rather typical for the shelf environment where concentrations of foraminiferal tests or other shell material are important only locally, because dilution of shell debris by detrital material and solution of the finest fractions is general. Only two samples consisted almost entirely of shell debris.

Unique in our procedure of carbonate analysis is the use of the acid-digested residue for determination of its carbon content, i.e., the amount of organic carbon. This eliminates any bias owing to variations between different cuts of the same sample. Since the newly-acquired induction furnace and the attached analyzer required factory repair, too few results are available to be mentioned here.

About one third of the total of 370 samples have been subjected to Kjeldahl-nitrogen analyses as another measure of the amount of organic matter in the sediments. Apart from local variations, the general level of organic matter is low, the order of magnitude being 1 to 3 per cent. However, when we consider what little chance exists for this component to accumulate on the shelf, we realize that these quantities constitute a relatively rich environment compared with other shelves. Since the amount of terrigeneous which dilutes the organic matter is fairly great, we tend to interpret these preliminary results as a reflection of very large primary production in the water of the Gulf of Maine.

Since work on the continental shelf project was started literally from pure ideas, a major part of the time had to be devoted to substantiating the material base. Nearly all parts and pieces for a workable laboratory had to be selected, ordered, installed, and tested. Personnel mainly from the U.S.G.S. who joined the group were introduced to some of the sedimentary techniques and analytical procedures.

TEXTURE OF SEDIMENTS[1]

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Activities on the joint U.S.G.S.-W.H.O.I. project have been concerned with development of a sediment tube analyzer, statistical analysis of textural data, and compilation of surface runoff data. This abstract covers the period from September 1, 1962 to December 31, 1962.

A modified Woods Hole rapid sediment analyzer was built. The tube is constructed of 2-1/2 inch i.d. clear plastic tubing and follows the plans of G. G. Whitney, Jr., except for an increase in the diameter of the tube. Main modification of the analyzer over previous models is in the pressure-sensing device and the sediment-introduction mechanism. Our model uses a bidirectional differential gas pressure transducer to detect the pressure change; the transducer has been adapted for use with water through the addition of O-ring seals in critical places. The signal is amplified and printed on a 2-channel carrier recorder. This recorder has the advantage of fast pen response time and excellent stability; the latter is due in part to the fact that the unit is completely transistorized.

Sediment introduction into the settling tube is accomplished by allowing damp sediment to settle from a porous disk that has been brought in contact with the water just above the tube. The disk is loaded with a 5 to 10-gram sample of sediment and dampened to adhere the sediment to the disk. A semi-circular rotation of the disk brings the sediment to the top of the settling tube where contact with the water causes the sediment to fall off with a minimum of turbulence and as a unit. A similar device was built earlier by F. H. Plankeel based on suggestions of Ph. Kuenen.

Statistical summation of sediment size analysis is being handled by a moment measures program designed at the Woods Hole computer laboratory, and based on formulas given by W. C. Krumbein. The program calculates the median, mean, standard deviation skewness, and kurtosis.

[1]Publication authorized by the Director, U. S. Geological Survey

The main advantage of this type of program is that it computes the above measures on the basis of existing class intervals rather than picking points off the cumulative curve. Approximately 240 analyses from the literature have been summed by the program in order to (1) obtain all the analyses on a common basis of statistical treatment, and (2) survey what is known about the texture of sediments on the continental shelf and slope.

COARSE FRACTION OF SEDIMENTS[1]

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As a part of the joint Woods Hole Oceanographic Institution-U. S. Geological Survey investigation of the United States East Coast continental shelf, a suite of 107 grab and snapper bottom samples collected by the U. S. Bureau of Commercial Fisheries in the northern Gulf of Maine (north of 42° 45') has been examined to determine the composition and texture of the sand fraction (1/16-2mm).

The most prominent characteristic of the samples is the relatively large percentage of rock fragments (commonly as much as 10 per cent of nearly all samples and average 3.5 per cent for all samples). Glauconite is present in 60 per cent of the samples in amounts as high as 2 per cent. Subangular quartz and feldspar grains make up 85 to 98 per cent of most samples, and an average of 18 per cent of those grains show iron oxide staining. Foraminifera are present in 80 per cent of the samples, but they make up less than 1 per cent of two-thirds of the samples in which they are found.

The samples are of two distinct types. The predominant type (80 per cent of samples) has abundant rock fragments, a sand-gravel fraction generally much more than 10 per cent by weight of the total sample, and a biogenic fraction of less than 1 per cent. The other, or biogenic, type characteristically has almost no rock fragments, less than 10 per cent by weight (average 1.2 per cent) of sand and gravel, and a high percentage of biogenic material; the foraminiferal content averages 10 per cent.

The data have not yet been plotted by position, depth, or topography,

[1]Publication authorized by the Director, U. S. Geological Survey

but it would seem safe to predict that the biogenic samples came from relatively flat bottomed and quiet areas of post-glacial deposition, and the rock-fragment samples from areas of rough topography or higher current velocities.

MINERALOGY[1]

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Beginning in August 1962 preparations were made for establishing a laboratory for chemical and mineralogic studies of materials collected as part of the Atlantic continental shelf project conducted by the U. S. Geological Survey and Woods Hole Oceanographic Institution. Principal items of equipment installed were an X-ray diffractometer, a centrifuge and filtering apparatus for fractionation of clays, and a petrographic microscope equipped for photomicrography. Following testing of the equipment and establishing a reference collection of X-ray diffractometer charts of standard minerals, studies were begun of suites of samples collected in the Gulf of Maine and Georges Bank regions by Roland Wigley of the Bureau of Commercial Fisheries. Preliminary identification of the clay and silt minerals of these samples is in progress. Some variations in clay minerals and feldspar content have been noted, but the significance of these variations has yet to be determined.

A study of the mineralogy of Gay Head, Martha's Vineyard, has been completed in cooperation with Clifford Kaye of the U. S. Geological Survey. Essentially, kaolinite is the dominant mineral in the Cretaceous materials, whereas the Tertiary and Pleistocene beds show a clay mineral assemblage of chlorite, mica, and mixed-layered mica-montmorillonite. Tertiary and Pleistocene materials are easily distinguished by the feldspar content of their silt fractions, the Pleistocene showing significantly higher feldspar content. It is hoped that such mineralogic differences will aid in the identification of similar materials obtained offshore in the course of the continental shelf project.

Publications, 1962:

Hathaway, John C., and Schlanger, Seymour O., "Nordstrandite from Guam," Nature, Vol. 196, p. 264-266.

[1] Publication authorized by the Director, U. S. Geological Survey

GEOPHYSICS

GEOPHYSICS DEPARTMENT

J. B. Hersey, Department Chairman

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INTRODUCTION

Before World War II the broad-scale theories of the structure and dynamics of the earth were derived from measurements of the earth's gravitational and magnetic fields, level lines, wave trains from earthquakes, etc. These observations had low resolving power, principally because they were few and the control was sparse. Between 1920 and 1941 techniques of commercial geophysical exploration were being intensively developed to deal with specific local problems of immedicate economic interest. They were also applied to basic problems of geology on land, and in the oceans some important beginnings were made.

When basic research was interrupted by the war many geophysicists with commercial or academic interests brought their experience to naval problems and to the oceans. One of the fields to which they were drawn was mine warfare; others were pro- and antisubmarine warfare. The last two became the principal interests of the a group of geophysicists, under the leadership of Maurice Ewing, who came to the Woods Hole Oceanographic Institution in 1940. The group applied its talents to several wartime problems, especially the use of sound in detecting ships and submarines. This was a natural extension of the significant beginnings in submarine seismology made by Ewing at Woods Hole between 1937 and 1940.

At the end of the war Ewing and part of his group moved to Columbia University; eventually they founded the Lamont Geological Observatory. Those remaining at Woods Hole were joined by other geophysicists, biologists, electrical, mechanical, and civil engineers, mathematicians, and geologists, whose common interest was in making submarine detection more effective. The geophysicists in the group were convinced that a substantial advance could be made only by augmenting our basic knowledge of the influence of the whole oceanic environment on detection systems. Hence, since early 1946 a portion of their research program has been devoted to the solution of problems in hydroacoustics and submarine seismology.

During this same period all basic research on the oceans received very substantial support from the Navy and other Federal agencies. This support has made possible the improvement of such familiar hydroacoustical techniques as echo location and recording and analysis of underwater sounds, as well as newer hydroacoustical means of observing various properties of ocean waters, bottom sediments, and the underlying earth's crust. As a result the ocean is being transformed for us from a

realm of mystery to one that we are daily understanding better through the resolute application of the scientific method. The initial and continuing chief interest of the Geophysical Department is the role of hydroacoustics and interrelated seismological fields in making this transformation possible. Nevertheless, geophysicists recognize the essential worth of employing combinations of geophysical and geological approaches, to limit the inherent indeterminateness of geophysical interpretation. Accordingly, the department has broadened its program by including other fields of geophysical and geological inquiry. Studies of the reflection of sound at the sea floor have required a knowledge of what the sea floor looks like; hence we have used and developed the art of underwater photography. A proper understanding of seismic reflection and refraction requires an identification of the materials of sediment and rock structures; hence we have used and developed dredging and coring. Gravity and magnetic measurements are often critically useful in interpreting and extending seismic results; we have used them in the program whenever we could. In hydroacoustics alone our investigations of sound transmission have required more detailed information about water structures than the physical oceanographers now make use of; hence we have developed and used the thermistor chain and have made extensive investigations to improve methods and make measurements of sound velocity both in sea water and in bottom sediments. For understanding the influence of mass water movement on sound transmission we have studied water currents at great depths. Similar requirements for detail have led us to develop sound sources such as the Sparker and Boomer which emit a complex sound pulse having a broad spectrum and which can be pulsed more often than is feasible in shooting explosives, the long-time utility sound source of the seismologist.

The study of acoustical ambient noise in the sea soon opened up the vastly more significant field of natural sounds, their causes, and significance. In this field we have concentrated our attention on sounds of biological origin - in particular during the past several years, the phonation of whales and related cetological questions.

Another adventitious excursion into biological oceanography came about early in the work of the geophysics group through the discovery of deep scattering layers in the North Atlantic. These layers, first discovered in the Pacific during World War II, are largely responsible for the phenomenon known to the hydroacoustician as volume reverberation. This is the sound scattered back to the receiver from sea water as distinct from similar scattering from surface and bottom. The bulk of the important scatterers in the deep sea are animals living in layers

east of 62° west longitude. Here, photographs and dredge samples indicate that the Gulf Stream controls the nature of sediments on the seamounts. Evidence of current action on the seamounts was photographed at depths as great as 2600 fathoms.

within 800 meters of the surface. We have long been actively interested in identifying these scatterers and learning about their distribution, migrations, and physical properties, and in improving various means of observing their behavior.

Bottom reverberation, another source of interference in the Navy's acoustical detection systems, gives the geophysicist important information about the floor of the ocean. Furthermore, the bottom-reflected sound consists in part of energy which has penetrated the floor and been reflected from sediments and rock below; these sounds are the data of reflection seismology, and illustrate how closely hydroacoustical and seismological interests are intertwined.

It is commonplace now to employ echo-location techniques for controlling oceanographic instruments. Thus Nansen bottle casts are made to come close to the bottom by sound. Cameras, coring rigs, and dredges have all been fitted with pingers for controlling their actions near the bottom, and suspended echo sounders have been developed for measuring the depth of an instrument or for charting complex terrain at great depth. We have adopted some of these techniques and introduced others, but we are continually active in improving various ancillary uses of sound in oceanography.

In presenting an annual report of such a diverse program we have divided it rather arbitrarily into hydroacoustics and related problems of physical and biological oceanography (first section), crustal geophysics (second section), and special geological studies combining geophysical, acoustical, and geological techniques (third section). A final section is comprised of short notes which successfully defied other classification.

the one in use. The new type is presently being built by a glass blower. It is estimated that the new condenser will increase the efficiency of

HYDROACOUSTICS AND RELATED STUDIES IN PHYSICAL OCEANOGRAPHY AND MARINE BIOLOGY

SOUND TRANSMISSION

LONG-RANGE SOUND TRANSMISSION THROUGH THE DEEP SEA

Lincoln Baxter, II and H. S. L. Graham

We have continued experiments to study and identify all important acoustic travel paths from distant sources in deep water to hydrophones situated on the bottom of an island slope. If a single short acoustic pulse is radiated in deep water, a series of separated pulses is received as a consequence of the multiplicity of travel paths. An identifiable portion of the received pattern of pulses is called an arrival, which may consist of a concentrated group of pulses or a single pulse. The time at which an arrival commences is called the arrival time. The times and intensities of arrivals vary with variations in the acoustic velocity structure of the water. It is possible that some features of the ocean now studied by instruments (such as thermometers, sampling bottles, and current meters) lowered from ships may be detected and tracked by long-range sound transmissions between fixed stations. For example, last year we traced the geographic extent of an intermediate-depth sound channel by studying the acoustic arrivals. The range of about 300 miles, at which changes in bathythermograph measurements were observed, agreed with that obtained acoustically.

In many previous sound-transmission experiments, the pulses of sound have been generated by explosive charges. The fastest practical firing rates were too slow to permit arrivals from one explosion to be identified with similar arrivals from the next, except in rather broad groups. To increase our ability to identify particular arrivals and to permit the arrivals at a hydrophone to be plotted automatically by a Precision Graphic Recorder (PGR) as a function of elapsed time and travel time, in 1961 we began to use rapidly-repeating pulsed sources actuated electrically on precise schedules. The Sparker and Boomer discussed by D. D. Caulfield were found suitable for ranges up to 250 miles. More intense sources of the same type would have been better. To compensate for increasing or decreasing travel time of an arrival, as the source ship opened or closed the range, the sweep rate of the PGR was varied manually by a travel-time compensation (TTC) system developed by S. T. Knott and W. E. Witzell.

During 1962, two experiments in long-range transmission of sound were planned and executed. Arrivals at many hydrophone depths from ranges up to 250 miles were plotted automatically, along many tracks in the North American Basin. In the latter experiments, a 20-channel delay line was used to permit a simultaneous plot of inputs from hydrophones

at different locations and depths on the same PGR record. The delays were adjusted to plot corresponding arrivals from successive hydrophones at fixed intervals on the record, showing in this way how changes in arrival pattern and intensity varied with range and hydrophone depth.

The last three sets of long-range transmission measurements were recorded on 14-channel magnetic tape. In studying these tapes, two instruments have been used: the Oceanographic Computer, providing records from which the total energy flux of a wavetrain or of a single pulse can be measured; the PGR, providing records on which travel times, their differences and their correlation from pulse to pulse can be measured accurately, and energy of individual pulses can be compared qualitatively. With the Oceanographic Computer, we have studied (a) relationships between total energy received from an emitted pulse and energies received in various single arrivals in the wavetrain, and (b) relationships between received energy and depth of source. With the PGR, we have studied (c) path identification, (d) range limits over which each order of arrival is received, (e) stability of the received signal from pulse to pulse, and (f) angle of arrival at the hydrophones as a function of range.

These studies, while yet incomplete, nevertheless have shown seasonal relationships connected with oceanographic features and have assisted in relating major permanent environmental factors to characteristics of observed sound reception.

SOUND TRANSMISSION NEAR THE SEA'S SURFACE

David D. Caulfield

The basic research problem of sound transmission in the sea is how the changing physical characteristics of the ocean affect sound propagation. Work in the near-surface field has been proceeding for many years at the Institution, and new data on near-surface temperature structures (WHOI Thermistor Chain), sound-velocity measurements, and surface wave characteristics, have made possible new approaches of value in the analysis of propagation data.

During the last two major European cruises made by the R/V CHAIN, sound transmission data were taken between sources and receivers within 550 ft. of the surface. Detailed measurements of velocity or temperature structure of the water were made in conjunction with the

acoustical observations. Special recording techniques enabled large amounts of data to be recorded on magnetic tape with broad-band frequency response (Caulfield, 1961). These data were processed with the aid of analog computers into a form showing the sound field energy distribution as a function of depth and horizontal range for various frequency bands from 60 cps to 8 kc.

We are pursuing two major directions to determine the relation between the physical characteristics of the sea and the measured sound intensities. The first major program is the application of various approximations of the wave equation to form a semi-empirical model to be compared with the data. To this end, a computer program has been developed which traces sound rays through a generalized sound-velocity profile (approximating the experimental conditions) and obtains the energy distribution in the sound field about an arbitrary source corresponding approximately to that used in experiments at sea. Perturbations made on this generalized sound-velocity profile introduce surface and internal-wave effects. First results suggest that a combination of the ray theory and normal-mode theory might give results closer to the desired model.

A second procedure being used for studying the data is that of comparing the deviation of the data from transmission loss based only on spherical spreading (anomaly studies), to give a means of selecting theoretical models of the energy distribution.

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NATURAL SOUNDS OF THE SEA

CETOLOGY - 1962

William E. Schevill

While it may seem inappropriate to study whales in the Geophysics Department, it turns out to be quite suitable since one of our major interests in these animals is acoustical, and the techniques and equipment of underwater sound are at home among the geophysicists.

In 1962 our major field efforts were directed at Eubalaena glacialis (right whale), which we have been studying over the last six years. These whales appear in our local waters (Cape Cod and the Islands) in

[1]Publication authorized by the Director, U. S. Geological Survey

March, as a rule, and disappear by early May. They are often reported in March along the northern east coast of Florida. Sometimes a few individuals turn up nearby at other times of the year, as in January. This is nearly all we know of annual movements of this species. It was abundant when the first settlers came, but was hunted so relentlessly that it was rare by 1700, and has continued in this precarious status, so much so that the active whalers of the eighteenth and nineteenth centuries have left almost no information on its distribution in the North Atlantic. Since the right whale is no longer hunted, we cannot use the conventional whale marks, which depend for recovery on the processing of the carcass. In other years we have attempted to find this whale along its possible migration routes before and after its local visit, but evidently we have not searched the right place at the right time. This year we tried radio tags, using radios manufactured by the American Electronics Laboratories for the Office of Naval Research (Biology Branch), which generously supplied us with six. Mr. Watkins ingeniously adapted these for aquatic use and contrived an omnidirectional receiving antenna which was mounted on R/V BEAR. The radios, in a pressure case, were attached to a swordfish dart by an elastic warp, designed to permit the dart to toggle just under the blubber while holding the radio snugly against the skin. To make as sure as possible of getting the radio in the middle of the whale's back, we planned to attach it from a helicopter, which Naval Air Station, Quonset Point, most cooperatively agreed to furnish. Since the battery life of the radios was two weeks, we planned to mark the whales shortly before their expected departure, which is usually early May. From mid-April on we had uninterrupted stormy weather, so that we were unable to operate in Cape Cod Bay; when the weather moderated enough for a reconnaissance flight on 5 May, no whales were found, and we feared that they all had left. Nevertheless, we came out on 7 May in a Navy helicopter, the WHOI Helio Courier, and R/V BEAR. To our great satisfaction, we found a single right whale (the last of the season), and we succeeded in planting the radio high on its back. That was the limit of our success, for although we saw the radio still in place twenty-four hours later, it was never heard after landing on the whale. We believe that the antenna failed, and have improved the other radios in this way, but have not had an opportunity to try again.

The same whale, Eubalaena glacialis, is one of the most specialized of the filter-feeding mysticetes. Although we have observed the feeding of this species both from the air and from the surface, we have not succeeded, so far, with underwater observations. Our last attempt with a moving-picture camera was terminated when it was carried off by a whale. This year we chartered Mr. John H. Perry's two-man submarine in the hope of being able to maneuver with the whales while taking photographs. This attempt was frustrated by the same stormy weather

that drove the whales away; during the entire charter period it was too rough to use even R/V ASTERIAS as tender, let alone the submarine, which had too little endurance to use from harbor, and was too low in the water for boarding off shore except in very mild weather. Consequently we failed in this effort, too. It would be neither difficult nor expensive to construct a submarine suitable for such work in these waters; Mr. Perry's boat was designed for Florida and the Bahamas and better weather.

We had better luck on a trip to Quebec in the Helio Courier to record Delphinapterus leucas, the beluga. In conjunction with the Quebec Aquarium and the New York Aquarium, which were trying to catch specimens alive, we operated for two days in June along the St. Lawrence and Saguenay rivers, alighting on the water to make recordings of the beluga sounds. The float plane was an efficient and economical vehicle for this job, being not only quicker than a boat or ship, but also cheaper either per mile or per job. Three men were away from Woods Hole for three days, flying about 22 hours in all. In the operating area, which was about 450 miles distant, we flew 11 hours and were on station (on the water, with hydrophone overboard) for 3 hours.

Whale and porpoise recording and collecting was also carried out at other times during the year, especially during BEAR Cruise 274 and CHAIN Cruise 32.

Publications in 1962 include a description of a portable tape recorder and listening system constructed by W. A. Watkins (1962) and a phonograph record and explanatory booklet by Schevill and Watkins (1962) with samples of the calls of eighteen different kinds of whales and porpoises. Cetology is also represented in a joint paper by Schevill, R. H. Backus, and J. B. Hersey (1962).

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REVERBERATION AND OTHER SOUND SCATTERING STUDIES

BOTTOM REVERBERATION FROM EXPLOSIVE SOUND SOURCES

John K. Hall and J. B. Hersey

As noted above, bottom reverberation merges almost indistinguishably into reflection seismology, since, in the low-frequency spectrum of the bottom echo of a small charge of TNT, discrete echoes are found that have long since been identified with reflecting surfaces below the bottom. Several other articles in this annual report are devoted to the geophysical interpretation of these echoes. But in the high-frequency portion of the reverberation from a TNT shot one expects to find little sound that has penetrated the bottom more than a few meters; most of this sound has echoed and re-echoed from the rough surface of the ocean floor itself, (for an exception, see the article on ponded sediments in the deep sea). To establish the range of variation in bottom reverberation due to scattering from bottom roughness, we have recorded on magnetic tape reverberation received throughout several successive bottom echoes from single explosive shots at many locations in the North Atlantic Ocean and its marginal seas. Omnidirectional sources and receivers, both at depths of about 20 m, have been employed throughout. The recorded sounds have been played through logit filters to the oceanographic computer (see accompanying article on this instrument) and thus presented a graph of the function $\int p^2 dt$ (where p is acoustic pressure and t is time) averaged over 0.1 sec in each frequency band, versus time after the shot.

During the past year our main concern has been the interpretation of the reverberation following the onset of the first bottom echo. We have set up a greatly oversimplified model which assumes single scattering from the bottom, no penetration into the bottom, and a flat attitude (on the average) of the ocean floor. From this model the data yield a back-scattering coefficient which serves as an index of bottom reverberation.

Urick (1961) found that the bottom behaves as a Lambert scatterer at high frequencies (i.e., diffuse scattering) in certain places. It is obvious from our results that such is not the rule either as a function of frequency or location. It seems equally obvious from the variety of frequency- and location-dependent effects that the single bottom-scattering model may not describe the observed scattering in many places. At this writing we have analyzed but small samples of data and must reserve judgment about future plans until further analysis and study is made.

A STUDY OF THE ACOUSTIC REFLECTIVITY OF THE SEA FLOOR

Lloyd R. Breslau and J. B. Hersey

The objective of this program is to investigate the character of the acoustic backscattering of the deep-sea oceanic floor and to study its geological significance. The nature and variability of the backscattering to be found within a single geomorphic province and its change upon crossing obvious geomorphic boundaries are to be determined.

A semiautomatic system has been developed that is capable of making continuous measurements of the reflectivity of the sea floor from a vessel under way. This system has been used for measuring bottom echoes of echo sounding on CHAIN Cruises 19, 21, and 27; BEAR Cruises 281 and 290, and the ASTERIAS cruise and has resulted in 41,000 individual measurements. A block diagram of this system is shown in Figure 1. A functional description of the system follows. The Precision Graphic Recorder keys the Edo UQN Echo Sounder which causes a rectangular 12 kc sonic pulse to be emitted into the water by the UQN-1b Transducer. The echo of this sonic pulse from the sea floor is received back at the UQN-1b Transducer and amplified by the Edo UQN Echo Sounder. The amplified signal is applied to the Precision Graphic Recorder for a bathymetric trace, to one channel of the dual-beam oscilloscope for display of the pressure wavetrain, and to the Oceanographic Computer which squares and integrates the signal and thus provides a measure of its energy content. The output of the computer is applied to the other channel of the dual-beam oscilloscope for a display of the energy contained in the wavetrain. It is also fed to the digital voltmeter and recorder combination which digitizes and prints the value of the complete integral. The face of the oscilloscope is photographed by means of an automatic recording camera capable of obtaining 1600 exposures on a single hundred-foot reel of 35 mm film (Fairchild Model 015). A typical oscilloscope photograph is shown in Figure 2. In addition, the Pulse Width Modulator inspects the value of the complete integral and generates a pulse of time-duration equal to the analogue of the energy in the received echo. This pulse is fed to the Precision Graphic Recorder where it appears as a mark on the record whose length is proportional to the energy contained in the reflected echo, and is generated alongside the bathymetric trace.

On the return voyage from the Strait of Gibraltar a precisely-timed pinger was lowered to the floor of an abyssal plain and its bottom echoes were recorded at several fixed depths during lowering and raising. Analysis

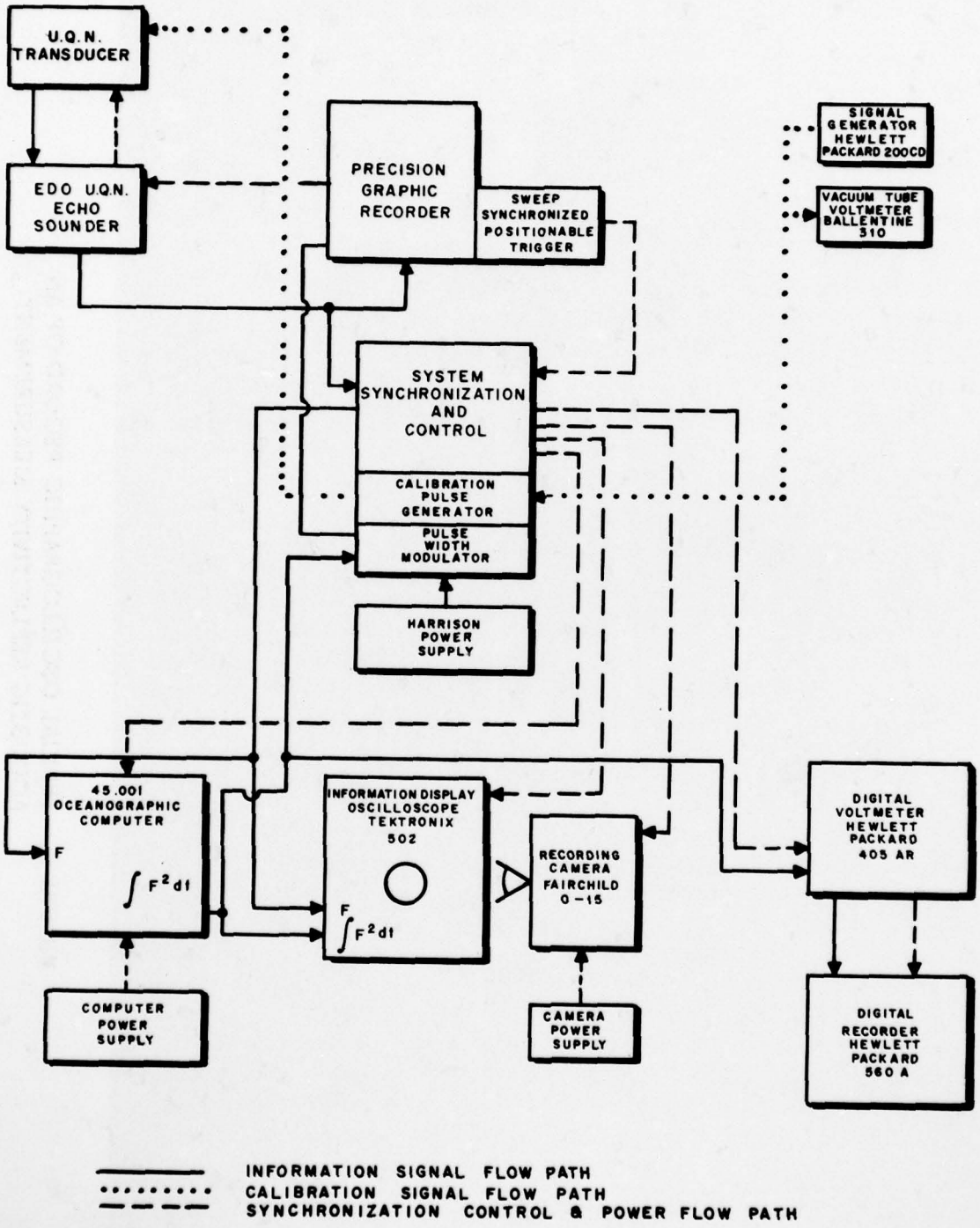


FIGURE 1. BLOCK DIAGRAM OF THE REFLECTIVITY SYSTEM.

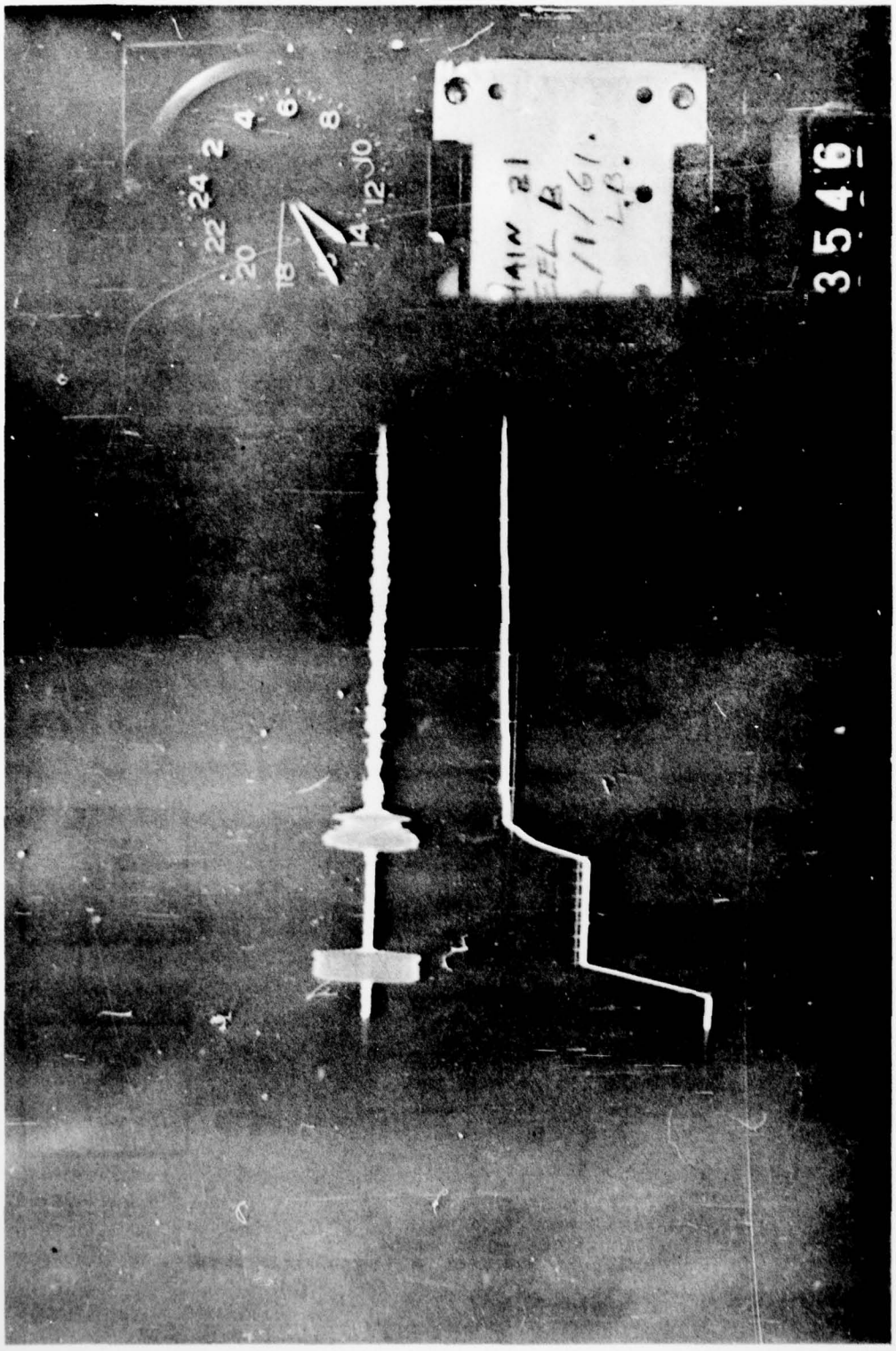


FIGURE 2. TYPICAL OSCILLOGRAPHIC RECORD OF AN ACOUSTIC REFLECTIVITY MEASUREMENT.

of measurements similar to those described above suggests that the bottom there was approximately a scatterer at 12 kc.

These measurements provide the acoustic reflectivity of the sea floor but are taken over areas of poor geological control. In order to remedy this situation, combined acoustical measurements and geological observations were made during the July 1962 cruise of the R/V ASTERIAS and cruises 281, 285, 287, and 290 of the R/V BEAR.

The investigations aboard the ASTERIAS took place in Narragansett Bay, an area whose geology has been well studied by other investigators (in particular, MacMasters of the Narragansett Marine Laboratory). Eight thousand echo-strength measurements were obtained, to be related in detail to parallel geological studies in which the bottom was sampled by means of a Van Veen dredge, and the small-scale surface roughness of the bottom was observed by a lowered stereo camera. A submersible, closed-circuit television camera was occasionally used in obtaining information about the bottom at the same time that reflectivity measurements were made.

The investigations aboard the BEAR took place along two separate north-south profiles over the continental shelf, one stretching from Martha's Vineyard to the fifty-fathom depth contour and the other stretching from Block Island to the same depth contour. These profiles covered a line of stations previously investigated by the late Henry Stetson of WHOI. A section of record obtained with the Pulse Width Modulator is shown in Figure 3. Twenty thousand echo-strength measurements were obtained during these BEAR cruises, to be related to geological studies of Van Veen dredging and deep-sea stereo photographs.

In the course of this analysis 41,000 individual measurements have been made. Apparent reflectivities have been computed and the results have been summarized statistically in 1407 sets, each set corresponding to a location at sea. The results have been made available in tabulations or as geographical plots. Except for the initial measurement, all operations, including the final plots, were accomplished through automatic digital processing machines.

This work is a joint effort with the Massachusetts Institute of Technology inasmuch as Mr. Breslau is being supported under their Contract Nonr-1841 (74) with the Office of Naval Research.

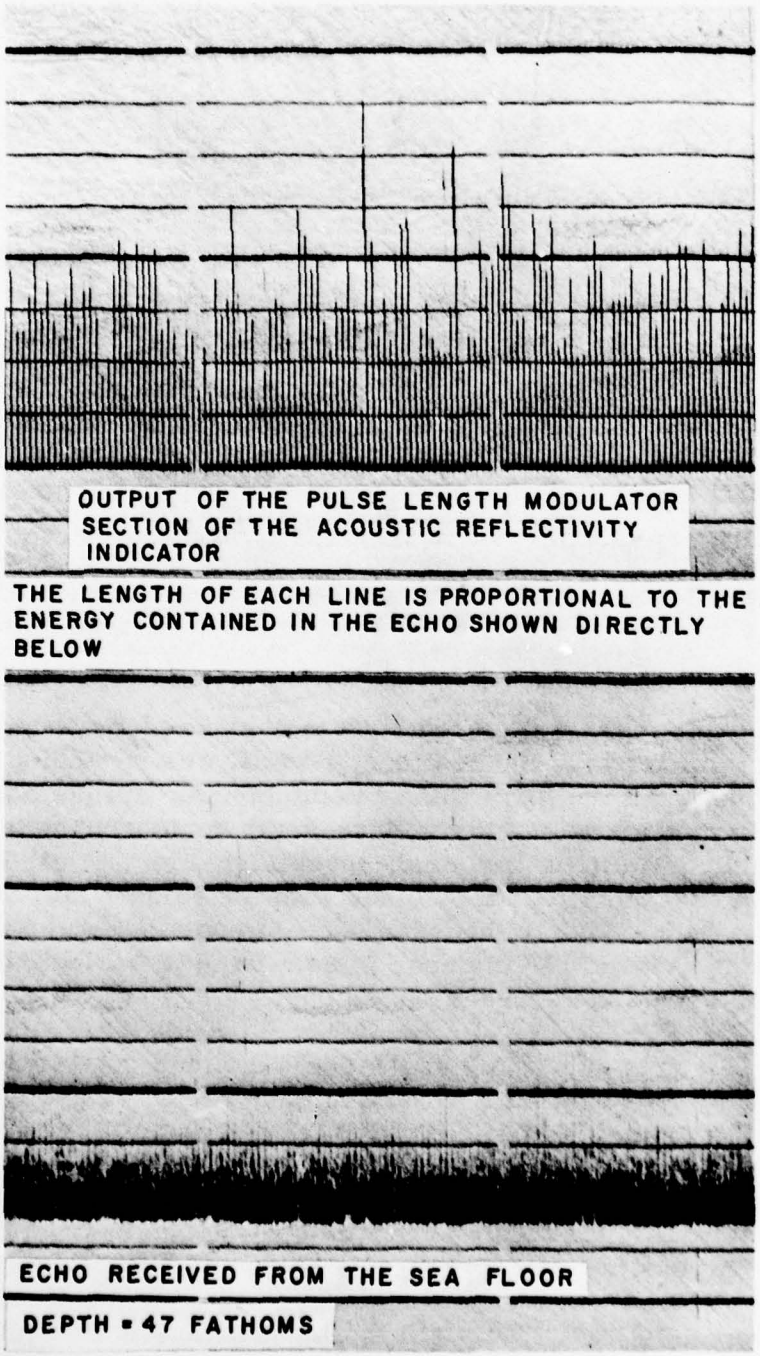


FIGURE 3. A SECTION OF RECORD OBTAINED WITH THE PULSE WIDTH MODULATOR.

SOUND-SCATTERING IN THE SEA AND OTHER STUDIES RELATING TO PELAGIC ORGANISMS

Richard H. Backus

During 1962 the writer continued to study a diversity of problems relating to life in the pelagic zone of the deep sea. The chief of these problems pertained to the high-seas phenomena called "deep scattering layers."

It has been known for a long time that midwater species are nonuniformly distributed throughout the sea's water column, and that some of these species make extensive diurnal vertical migrations. However, the clarity with which underwater sound tools would reveal some of these distributions and migrations was little anticipated.

The so-called "deep scattering layer" was discovered during World War II when workers of the University of California Division of War Research, engaged in sound-propagation experiments, consistently noted reverberation which could only be attributed to a mid-water layer of scattering agents. A diurnal vertical migration of these scatterers was observed and their animal nature therefore demonstrated (UCDWR, 1943, 1946, 1946a, and 1946b; Duvall and Christensen, 1946; Eyring, Christensen, and Raitt, 1948; Johnson, 1948, and Raitt, 1948).

The scattering layer phenomenon was first commonly observed by ship-borne echo-sounder. It appeared to be diffuse, even darkening somewhere in that part of the record corresponding to the upper several hundred meters of the water column. Such observations were made over broad reaches of the deep world ocean, showing that the term "deep scattering layer" was a generic one, and that many clearly separate phenomena were seen to have the general properties of the layer first described (Dietz, 1948; Hersey and Moore, 1948; Johnson, 1948, Tchernia, 1950; Moore, 1950; Boden, 1950; Tucker, 1951; Batzler and Westerfield, 1953).

The prime question that these observations raised was: What are the animals forming these layers? Beyond satisfying a simple curiosity, such identifications were thought desirable (and still are) since it appears that a very large fraction of the macroscopic animals in the deep ocean's water column are concentrated in these widespread strata. By their vertical migrations the layers are important as distributors of energy throughout the euphotic and disphotic zones. Furthermore, such identifications would be useful as stimuli and guides to much physiological

research concerning the problems of vertical migration.

Initial hypotheses were advanced about the identity of the sound-scattering agents, from echo-soundings and net hauls made simultaneously, or from information in the literature about the vertical and geographical distributions of midwater animals. The most reasonable arguments were those made for euphausid shrimp (Moore, 1950; Boden, 1950) and for fishes (Tucker, 1951; Marshall, 1951). Marshall (op. cit.) argued for small bathypelagic fishes with gas-filled swim-bladders as the most likely cause of the sound-scattering. He listed four requirements for any organism to be considered seriously in this role: (1) the organism must be widely distributed, (2) it must exist in concentration at the appropriate depth in the daytime, (3) it must show pronounced powers of vertical migration, and (4) it must be able to scatter sound effectively - specifically, the product of the organism's scattering cross section and its population density must lead to reverberation levels in agreement with those observed for the layers.

Both small bathypelagic fishes with gas-filled swimbladders (such as lantern fishes, family Myctophidae) and euphausids fit well with the first three requirements. With respect to the fourth requirement, the fishes fit better, as the gas-filled swimbladder is a highly efficient sound-scatterer whereas the characteristic impedance of the body of the gasless shrimp differs little from the surrounding water. On the other hand it has been offered that the very presence of the gas-filled swim-bladder argues against fishes so equipped as components of the layers because of the stress that the management of this organ would impose upon its bearers during a rapid and extensive vertical migration (Kanwisher and Ebeling, 1957; P. F. Scholander, in litt.).

About 1950, observation of the deep scattering layers was begun using a broad-band sound source (an explosion) rather than the usual single-frequency devices. This approach showed that several scattering layers were present at each ocean locality studied and that each layer scattered sound best over a rather narrow and distinct band of sound frequencies (Hersey, Johnson, and Davis, 1952); that is, sound-scattering by these layers is a frequency-dependent phenomenon. Later it was demonstrated that the peak scattering frequency of a layer shifted during the vertical migrations of the layer. The narrowness of these frequency peaks and the shift of frequency with changing pressure (as during the vertical migration) suggested a highly compressible scatterer such as a bubble of gas, probably the contents of the swimbladder of a small fish (Hersey and Backus, 1954). During 1962, details of these frequency-dependent effects at western

North Atlantic localities were published (Hersey, Backus, and Hellwig, 1962). One interesting conclusion concerns swimbladder management by the fish during vertical migration. It appears that some fishes simply let the bladder expand and contract with changing hydrostatic pressure (the implication is that the fish is at neutral buoyancy only at the uppermost level of the depth excursion) while others can extract gas from the swimbladder during the evening ascent (we have not yet demonstrated the converse - the addition of gas during the morning descent) and so maintain constant displacement (presumably, constant neutral buoyancy). In September broad-band sound-scattering observations were made continuously at a locality south of Nova Scotia for 24 hours. This body of data will allow us to compare, for the several layers present, the depth-frequency relationships of the evening migration with those of the morning migration and so make further inferences about swimbladder management.

Broad-band sound-scattering data relevant to two problems were analyzed during 1962. One of these problems concerns an unusual sound-scattering feature (dubbed Alexander's Acres) which is confined to the "slope water" region off the northeastern United States. It has the properties of ordinary deep scattering layers save that scattering intensity is unusually high and, more remarkable, individual groups of scatterers are resolved into crescentic patterns on the record of the surface echo-sounder. In 1959, this feature was almost continuous over thousands of square miles between the edge of the continental shelf and the Gulf Stream north and east from Cape Hatteras to the latitude of Hudson Canyon. It was spottily distributed in this area in 1960, 1961, and 1962. Analysis of broad-band scattering data shows that the scatterer is a fish whose sea-level swimbladder volume may be about 10,000 mm^3 and thus an animal ten or a dozen inches long.

In May, 1961, we made broad-band observations along the 3800-mile track from the Romanche Trench (on the equator at 17°W) to Bermuda. Analysis of these data in 1962 showed that there were two uniform patterns of sound-scattering along the track - one to the southeast of the track's crossing of 13°30'N and another to the northwest. The temperature-depth profile constructed from bathythermograph observations made during the ship's passage shows the scattering change to have been coincident with a fundamental change in the temperature distribution in the upper few hundred feet of the water column. At the point of change the thermocline suddenly becomes less steep and the 15°C and 20°C isotherms go deeper. By some standards this temperature change would be regarded as marking the southern boundary of the Sargasso Sea. A number of other ocean properties observed during the passage changed near the break in sound-scattering pattern. These include quantity and quality of plankton and bathypelagic fish hauls,

incidence of whales, porpoises, sharks, flying fish, birds, Sargassum weed, and Portuguese Men o' War, amount of dissolved CO_2, water color, and wind speed and direction. Based on these and other observations, in 1962 we began to examine the hypothesis that the broad-band sound-scattering regimes of the deep ocean may be useful in describing the faunal provinces of the upper 1000 meters.

During the cruise between the Romanche Trench and Bermuda, 14 hauls of bathypelagic fishes were made, partly to study correlations between the fish fauna and the broad-band sound-scattering pattern. These fishes come from a poorly-known region and will be considered as a collection. For this purpose various species groups have been distributed to A. Ebeling (Yale), R. H. Gibbs (Boston Univ.), M. Grey (Chicago Natural History Museum), and G. W. Mead (Harvard), and to the writer (who has conducted this work at Harvard's Museum of Comparative Zoology). The identification of this material (about 140 species and 2500 specimens) was completed in 1962.

For about a decade the writer has been accumulating records of shark captures made by Institution vessels. These captures are mostly concentrated in the deep-water area bounded by lines connecting Bermuda, Cape Romain, South Carolina, New York, and a point in deep water southeast of Halifax, Nova Scotia. There are some hundreds of records involving about a half-dozen species now existing in this area: the blue dog, Prionace glauca; the white-tip, Carcharhinus longimanus; the silky shark, Carcharhinus falciformis; the mako, Isurus oxyrinchus; the dusky shark, Carcharhinus obscurus; and a hammerhead, Sphyrna lewini. In 1962 we began studying these data for whatever they might reveal about the distribution and life history of western Atlantic pelagic sharks.

Several years ago we built an instrument for making one type of measurement of bioluminescent activity due to microorganisms. A stream of water is inspected within a darkened chamber by a photomultiplier tube which is so connected to a counter that bioluminescent flashes are tallied. Observations with this instrument show that microbioluminescence in the surface waters of the sea has a diurnal rhythm (Backus, Yentsch, and Wing, 1961). During 1962 we studied data which reveal a similar rhythm down through the euphotic zone of the sea. We also recorded bioluminescence in Woods Hole harbor throughout the year as part of a study of seasonal variation of this phenomenon.

In 1962 a short paper was published on age and growth in a small sample of bluefish (Pomatomus saltatrix) collected during 1961 (Backus, 1962). This study was continued in 1962 when scale samples and measurements were taken from about 670 specimens.

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STUDIES OF WATER STRUCTURE

THERMAL FRONTS IN THE MIXED LAYER OF THE DEEP OCEAN

A. D. Voorhis and J. B. Hersey

We have noticed from past records of the towed thermistor chain, the occurrence of thermal fronts in the deep ocean mixed layer. By thermal fronts we mean abrupt changes in the mixed layer temperature of 1°C or more in a horizontal distance of less than 20 km. Of particular interest has been the area between Bermuda and the Bahama Banks. In every case in which the thermistor chain has been towed through this area we have observed at least one frontal boundary separating cold

water to the north from warm water to the south. These records were made from 1958 to 1962 and are for the months March, April, October, November and December. When the positions of the front observations are plotted on a chart it appears that they are not strictly a fixed feature. Although they are probably always present they appear to migrate. A front has been studied for many hours at times separated by 44 days, from 28 October to 11 December 1962. The locations and results suggest that the front persisted throughout the period.

During the recent cruise of CHAIN to the Puerto Rico Trench from October to December 1962 two thermal fronts were observed on the passage south and again on the return passage north. The frontal crossings occurred at approximately 27°N 70°W and 31°N 70°W. In both cases the ships conducted a short survey with the thermistor chain to determine the orientation of the frontal boundary and found it to run from northwest to southeast in both cases. In addition, surface current was measured with a towed GEK and it appeared to be unusually strong at the front, indicating that the warmer water in the southern boundary (of the front) was moving to the east with a speed of nearly a knot. We intend to study the properties of these fronts further with the aim of finding why they are there and whether they are truly a near-surface phenomenon or not.

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THE SHAPE OF ISOTHERMAL SURFACES

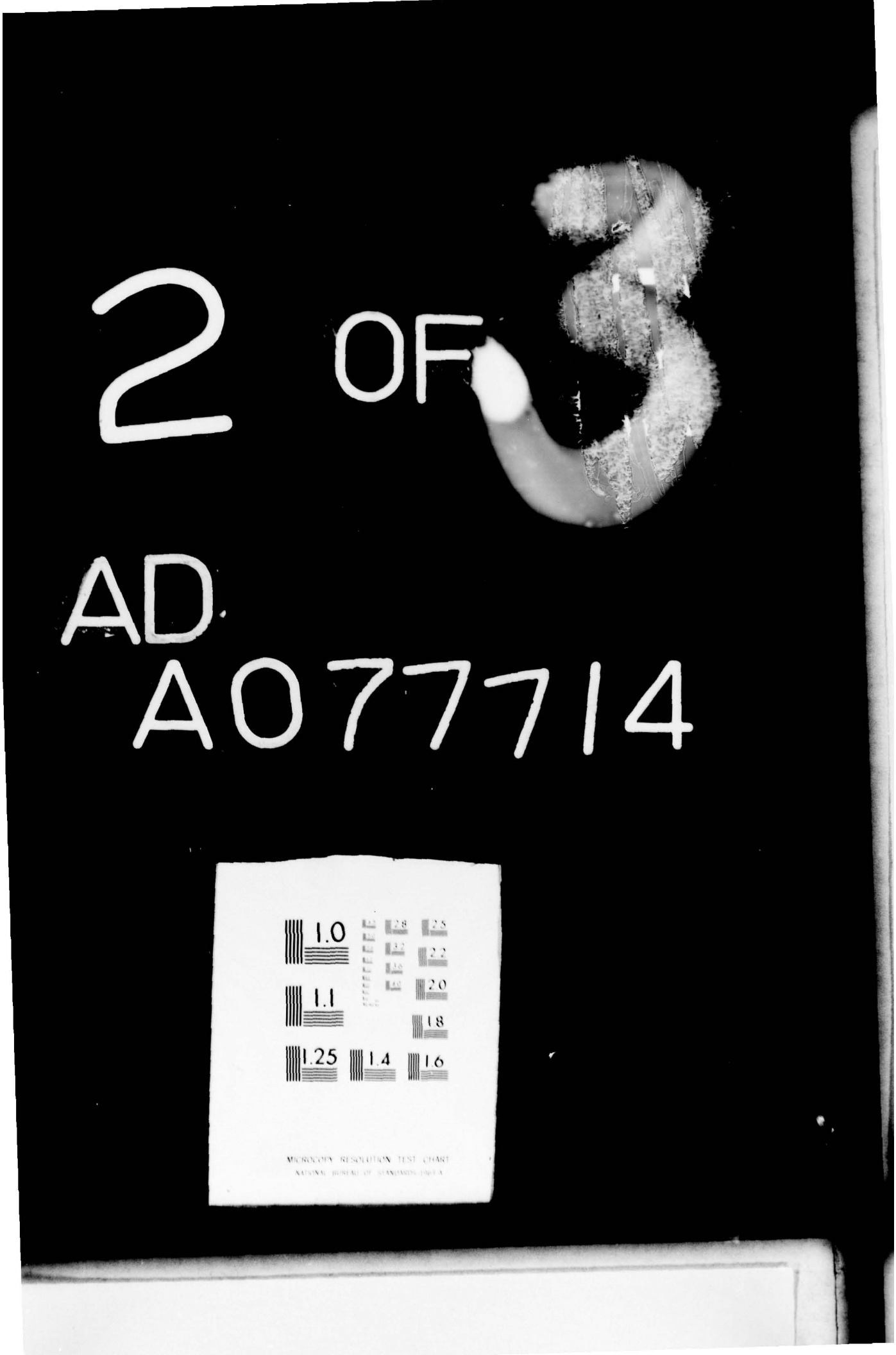
Allyn C. Vine

The string of thermistors which has been towed under and behind our ship has gone well over 100,000 miles and the records have qualitatively shown the complexity and variability of the isothermal surfaces in the top 150 meters. Mr. Perkins, Mr. Vine, and several student record-readers have been analyzing these records, trying to find more ways of achieving a quantitative roughness criteria of the isothermal surfaces.

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

Many individual thermistor records have been analyzed for particular purposes, but the bulk of the records has not been manageable. It was believed that eventually, if a sensible statistical breakdown of roughness criteria could be found, the results would be useful in studies of vertical mixing, energy flow, twinkling of acoustic images, and the vertical migration habits of plankton. Besides the present useful graphic recording there should be a digital recording to simplify study and analysis of future records, and another purpose of the present study was to obtain greater insight into how this could be done.

Because the maximum angular deflection of the isotherms from the horizontal at inflexion points was a conspicuous anomaly, it received early attention. The results of some ten thousand readings from summertime records in the western Atlantic showed that the principal contributors to the slopes at inflexion points were the relatively short, but high-frequency waves associated with the natural period of the seasonal thermocline. Most of these waves were a few hundred meters long and had periods of three to four hundred seconds.

The problem of presenting the statistical distribution has been greatly simplified by the suggestion made by Mr. Mizula of plotting the distributions on log normal paper. These log normal plots of the statistical distribution of slopes fit the straight-line log normal assumption much better than had been expected. One series of observations gave a median value of one angular degree slope, with 10% of the values less than 0.4° and 10% over 2.6°. Such plots may make it possible to compare quantitatively the internal waves at different places or times. It is too early to tell how the different values of the mean and of the variance will correlate with such oceanographic variables as season, wind, and current shear, but present results certainly guarantee the continued interest of the investigators.

OTHER OCEANOGRAPHIC PHENOMENA

OCEANOGRAPHIC OPTICS

Lincoln Baxter, II

Recently the writer has changed his active interest from research in hydroacoustics to optics. Many recent developments and facts indicate an increasing interest in optical properties of the oceanic environment and in radiative transfer theory. Different types of sea

water are known to have different optical properties and optical properties are known to influence the distribution of marine life. The wealth of information contained in optical images has encouraged expanding use of underwater cameras, underwater television, observation chambers (CALYPSO and ATLANTIS II), diving with scuba to shallow depths, and diving by submarines (with windows) to the deepest parts of the ocean. (The program of underwater photography in this department is discussed elsewhere in this annual report.) If these facilities are to be used to their fullest extent by the Woods Hole Oceanographic Institution, detailed information about the physical optics of the oceanic environment should be readily available here.

For several years I have been interested in polarization of submarine daylight in sea water. This subject has received considerable attention in the last few years. In 1958 T. H. Waterman and A. Ivanoff had investigated polarization of the radiance in every direction from positions at shallow depths (some tens of feet), and polarization of horizontally-scattered light at greater depth, but no deep measurements of the polarization of the zenith beam had been made. According to the theory of radiant transfer, the polarized component of the zenith beam at locations near the surface is formed by the contributions of the linearly polarized sky light refracted through the surface and linearly polarized light scattered in the water into the zenith beam. As the depth of the observation point increases, the polarized light from above becomes attenuated by scattering and absorption. The degree of polarization of light scattered into the zenith beam near the observation point varies with the turbidity of the water and the asymmetry of the radiance distribution about the zenith direction, but it eventually decreases as the asymmetry decreases. Thus the polarization of the zenith beam approaches zero at great depths.

In 1959 I made a few experiments to determine the practicability of detecting polarized zenith light at depths greater than those that have appeared in current work and attempted to relate its plane of polarization to the solar azimuth. I found polarized zenith light as deep as 250 ft. in typical Sargasso water, but was unable to relate this to solar azimuth because the compass system failed. These results were reviewed during the year and an opportunity was taken to plan further study.

A subject of intense practical and theoretical interest just opened to experimental investigation in the ocean is that of radiant transfer of coherent light. Lear Siegler's laser Systems Center, Ann Arbor, Michigan, has developed recently a laser which emits a pulse of 10 kw

with a bandwidth of 2 angstroms centered at 5300 angstroms. Other wavelengths of approximately this size may be generated by changing the materials in the laser crystal.

I intend to investigate transfer theory for coherent light in undersea conditions and the commercial availability of such sources, in order to determine how soon and in what way such sources may be used in the study of oceanographic optics at WHOI.

ACOUSTICAL AND OCEANOGRAPHIC INSTRUMENTATION

THE INVERTED ECHO SOUNDER

Willard Dow

The Inverted Echo Sounder is an instrument principally designed to measure continuously and with high precision the depth of other instruments, such as sound velocimeters, as they are lowered with it into the ocean. It was developed primarily because of the current lack of depth-measuring equipment of sufficient accuracy and resolution to satisfy the demands of sound-velocity investigations and other programs requiring that instrument depths be known to within a few feet, regardless of the depth of submergence.

A second use of the Inverted Sounder is in making microsurveys of the bottom in any depth of water to a maximum of 20,000 ft, and in relaying the information instantaneously to a surface vessel. This bottom survey feature has been used successfully in deep water for locating suitable terrain for bottom-mounted instruments.

The equipment is essentially a high-powered, short-pulse 12 kc echo sounder contained in two small cylinders housing the transmitter and receiver, respectively. The device is self-contained, battery-operated, and is lowered into the sea by a single conductor oil well logging cable about one-quarter inch in diameter.

In operation, the transmitter emits a 0.2 msec pulse at 12 kc, either upwards or downwards as desired, and the surface-or bottom-reflected pulses are detected by the deep receiver and then transmitted up the logging cable to the surface. There they are displayed by the PGR, a helix recorder with high-precision time lines and sweep (Knott, 1962). As the time interval between transmitted and receiver pulses is roughly proportional to the distance of the instrument from the surface (or bottom), the approximate depth can be read directly from the recorder record. Corrections for any errors due to sound-velocity variations, etc.,

may then be applied to records covering areas where depth information of great accuracy is required for proper analysis of data. Provision is made in the deep instrument for telemetering sound velocity or other data up the wire together with the depth information. A receiver in the ship's laboratory isolates the signals from one another, amplifies them, and channels them to the appropriate read-out equipment.

Because of the success of the earlier versions of this gear and the current demands of the sound velocity program, it was decided to construct another model in 1962 similar to the 1961 version but incorporating a number of modifications such as: (1) a higher powered transmitter, (2) a high precision electronic timing unit to control the repetition rate of the transmitted pulse, (3) a high-frequency converter type power supply for the transmitter, (4) a more sensitive deep receiver with improved coupling and limiting circuits, and (5) a redesigned receiver-filter unit for unscrambling and channeling data on the ship (as described previously).

This improved unit now has been completed successfully and will be available soon for routine use.

Reference

S. T. Knott, 1962. Precision Graphic Recorder. Marine Sciences Instrumentation, Vol. 1, 1962.

A DIRECTIONAL HYDROPHONE ARRAY FOR RECEIVING SOUND WAVES REFLECTED FROM THE SEA FLOOR

Willard Dow and Hartley Hoskins

Several means are practiced to facilitate the detection from a moving ship of reflections from the sea floor and underlying elastic wave discontinuities. First, the receiver is placed away from the ship and in a streamlined fish so that it tows through the water with a minimum of self-noise. The objective here is to match the receiver assembly density uniformly to that of the surrounding water and then encapsulate it in a vehicle of minimum flow resistance through the water. Slacking the towing cable to reduce the speed of the receiving unit through the water during the recording interval is deemed impractical for the high pulse repetition rates (10 seconds or less) used in the seismic profiler. (Slacking has been highly successful in observations taken every two minutes.)

Another means is to limit the bandwidth of the sound pulse. For reflection seismology this is undesirable as it constrains measurements to determination of travel times alone, is capable of resolving only some fraction of the median wave length, and precludes detecting discontinuities below sediments that strongly attenuate frequencies in the chosen band.

Advantage can be taken of the fact that the sea floor's reflected and refracted energy travels nearly vertically. A directional receiver oriented vertically discriminates against much of the other sound generated by the towing ship and by water waves. The simplest array that can be readily streamed is a series of elements placed in tandem, i.e., a "line array." The resulting directionality or "lobe" pattern is cylindrically symmetric and discriminates against ship-generated sound. Depending on the manner in which the signals from each detector are combined, the array may only be effective over the range of an octave. The exercise of constructing the lobe pattern as a function of frequency and direction shows this. By combining the separately-recorded outputs of each element with a variety of delays so as to effectively vary the dimension and orientation of the array, the coordinate process of "velocity filtering" extends the usefulness of the array.

In practice the receiving array and a Sparker or Boomer sound source are towed over the area of interest, the active portion of the line being dragged at the end of 1000 feet of special neutrally-buoyant cable. The active section was built and later modified by Chesapeake Instrument Corporation to our specifications. It contains five transmitting and five receiving elements in pairs mounted 8 feet apart and in a reinforced neoprene tube ballasted to form a uniformly neutrally-buoyant 40-foot array. The transmitting elements can be pulsed and the surface echo detected by the receiving units, thus providing a continuous depth record of all parts of the array whenever required during operations.

A 5-channel preamplifier cable driver unit is attached to the leading end of this multielement array and provision is made to channel each element separately or to parallel any or all of them, depending on the requirements of the experiment. An electrical calibration circuit for all receiving elements is also provided. The cathode follower preamplifier drives the thousand-foot neutrally-buoyant cable which connects the array to the ship. This cable contains a woven steel braid designed to withstand water drag at all reasonable towing speeds, and the entire array is streamlined as much as possible to keep this drag, as well as cavitation noise, at a minimum. The neutrally-buoyant cable is joined to a multiconductor color television camera cable at a waterproof junction

box mounted on the tow bar on the stern of the ship, and this cable in turn, connects the array to the ship's laboratory. There, the received signals are passed through a distribution panel which channels them to five line amplifiers. The distribution panel also houses the calibration and switching networks. The output of the line amplifier is fed to Precision Graphic Recorders and a multi-channel tape recorder for read-out.

A high-voltage short-pulse transmitter is connected through the distribution panel to the five transmitting elements in the array, for the depth determination described above.

The entire system outlined here, with the exception of the element sections of the towed array, was designed, constructed, and installed on the R/V CHAIN during the few weeks prior to her departure on Cruise 34. This crash program left little time for exorcising and testing prior to departure. Nevertheless, excellent sub-bottom profiles at 1-second travel time beneath the sea floor were recorded in waters deeper than 2500 fathoms and across the deepest water of the Atlantic north of Puerto Rico, proving the superiority of the line over omni-directional systems for this work.

Another outstanding gain over hydrophone assemblies previously used was the low "self-noise" due to towing. The manufacturer propounded that, for minimum towing noise, the assembly should be uniformly and neutrally buoyant besides being streamlined; his thesis proved correct. Some objectionable low-frequency (< 10 cps) noise involved with strumming of the tow cable was encountered, but was suppressed by isolating the cable with shock cord from transient movements of the tow point.

Owing to expediences of fabrication, the spacing of the elements (due to expedients of fabrication), is only 8 feet. The array is therefore directional for frequencies in the range 150 - 400 cps, which is somewhat higher than the range of greatest effectiveness in reflection seismology. To obviate this limitation, the spacing will be increased to 50 feet, making the array 2 wavelengths long for a 50 cps elastic wave in water. There will be additional elements with smaller spacing so that it can be used as a 2 λ array for higher frequencies also. A 5-channel line amplifier, better adapted to this mode of operation, is being constructed and a new transistorized preamplifier is also contemplated. A detailed instrument report is to be prepared.

The authors wish to acknowledge the assistance and cooperation of Thomas Winship of Chesapeake Instrument Corporation in the rapid design and assembly of the array and its subsequent modification, and Carlton Grant, Jr., in the wiring preamplifier and the cable assembly.

THE OCEANOGRAPHIC COMPUTER

Lincoln Baxter, II

An eight-channel analog computer has been developed for hydroacoustic, oceanographic, and other geophysical studies. This computer drives the pens of a direct-writing recorder, producing a deflection proportional to the total energy received at an input after any desired instant. Alternatively, a deflection proportional to either amplitude, rectified amplitude, or power, averaged over a selected time interval or proportional to certain functions useful for studies of the correlation of signals at two inputs, may be produced. The latter functions are the product of the amplitudes at the inputs and the sum of the squares of these amplitudes.

High-gain D.C. amplifiers with pure capacitative feedback are used to integrate, with respect to time, various quantities with or without a time exponential weighting factor. With the weighting factor, the integral approximates a running average over a time interval selected in 2 to 1 steps between 4 seconds and 10^{-3} seconds. Without the weighting factor, all contributions are weighted equally. A deflection proportional to the logarithm of any of the possible integrals may be produced also. Computation to an accuracy of 5% or better is obtained for input signals having all significant components between 20 cycles and 10 kc. Under certain conditions 5% accuracy is obtained for frequencies between 5 cycles and 50 kc.

WHOI Reference No. 61-32, issued at the end of 1962 as a final report on the development project, contains a description and manual of operation of the Oceanographic Computer and, in addition, gives theoretical treatments which relate computer signal processing techniques to information theory and Fourier analysis, and show the relations between pulse and continuous wave signal processing.

Eight Oceanographic Computers have been built. Four of these were purchased for other laboratories and four have been retained by WHOI. They have been used extensively for acoustic studies of transmission, reflection, and reverberation of sound and will probably continue to be useful for a number of years.

UNDERWATER SOUND SOURCES FOR RESEARCH

David Caulfield

The research effort put into pulsed high-energy sound sources has been made for two prime applications: sound transmission studies and seismic profiling studies (see Crustal Geophysics). The two main sources now in use are the 13,000-joule Boomer (E.G. and G., 1962) and the 25,000-joule Sparker (Caulfield, 1962). Each application must be investigated carefully to determine which source should be used.

The Boomer is stronger in the low-frequency range, below 120 cps, while the present Sparker has a broader-frequency spectrum with more energy available at frequencies above 2 kc. Also, each has different changes in operating characteristics with respect to depth. The Boomer operates better when shallow and the Sparker can be operated over a much greater depth range. Studies carried on over the last two years (Caulfield, 1962) indicated that the spectrum of the spark sound source may be controlled to fit desired characteristics.

The first Sparker of high energy (25,000-joule electrical input) was intended both for continuous seismic profiling and for sound-transmission studies. Recent experiments show that it would be desirable to increase the low-frequency response of this Sparker, especially for seismic research. IMP, another sound source under development, holds great promise but so far has not been used in acoustical research at sea.

References

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O'Rourke, R. and C. Dobbie, 1962. Boomer Report. Edgerton, Germeshausen and Grier, Inc., Report No. B-2343, 47 pp.

RADIO ACOUSTIC-TELEMETERING BUOYS

Willard Dow

The primary purpose of the Acoustic-Telemetering Buoys is to aid in obtaining seismic refraction and oblique reflection data. Previously in our program, two ships were required to make these observations, which involve gradual opening and closing of the range between the sound source and receiver. For example, to make a refraction profile, the ship plants a buoy and opens range, towing a sound source such as the Sparker or Boomer over the region of interest. The buoy has a hydrophone suspended beneath it which detects direct, reflected, and refracted arrivals. In the buoy the signals are amplified and transmitted by radio back to the ship. There the data are received on commercial communications receivers, suitably modified for this work, and are displayed on a Precision Graphic Recorder which also keys and therefore controls the pulse rate of the sound source. A properly-synchronized record is thus obtained.

Prior to 1962, attempts were made to convert commercial oceanographic radio buoys for acoustic work, but the requirements of the radio-acoustic buoy were so much more critical and exacting than those required for oceanographic data-handling that the modification was not satisfactory, although some results were obtained with these units. Consequently, in 1962 it was decided to develop at WHOI a new buoy designed particularly for our acoustic work.

In order to use low-frequency, low-noise, transistorized preamplifiers in conjunction with the receiving hydrophone, a new design of hydrophone element assembly was developed and six of these hydrophones were assembled during the summer. Meanwhile, the tentative design of the new buoy was completed and a prototype, followed by two essentially similar units, was constructed in the laboratory.

A series of tests was then scheduled to determine the "ground wave" radio coverage of the buoys operating in the 3 and 6 mc bands. To this end, two commercial communications receivers and audio amplifiers were modified for proper reception and reproduction of the buoy signals, and a 30-foot antenna tower supporting a tuned receiving whip was mounted on the R/V BEAR. Several runs were made which proved the daylight range to be well in excess of 80 miles with no "drop outs," provided the transmission was entirely over a water path. This radio range was regarded as adequate for the intended acoustical observations.

Next, a series of experiments was undertaken to determine the acoustic capabilities of the system. These took the form of oblique reflection runs in shallow water employing a mode of operation similar to that used in the refraction experiment described above. Excellent sub-bottom profiles were obtained in these trials, and therefore the system was transferred to the R/V CHAIN for deep-water operations on Cruise 34 to the Puerto Rico Trench area. Unfortunately, owing to ship scheduling, these deep-water operations had to be greatly curtailed, but some excellent oblique reflection records were obtained using the 6 mc buoys. A representative recording is shown in Figure 1. However, at ranges greater than one mile, atmospherics in this tropical area were such as to render the 3 mc transmissions useless.

The system is a success, and construction of several more buoys is planned for the expedition to the Indian Ocean in the fall of 1963 and for projected acoustical studies in the North Atlantic.

Acknowledgments

The author wishes to acknowledge the assistance and cooperation of the following: (1) Stephen Stillman, who is principally responsible for many elements of the structural design and fabrication of the Inverted Echo Sounder. (2) Dr. Earl Hays, who first used the Inverted Sounder for micro-survey work, developed techniques for using the gear at sea, both for this purpose and for depth determination and made many helpful suggestions for improving the system, (3) Alwyn Carter, who constructed and helped to exorcise the Acoustic Radio Buoys and contributed many desirable improvements and modifications, and (4) Dr. J. B. Hersey, who outlined the desired overall performance characteristics and major design requirements of the systems, participated in their sea trials and supported the entire development program.

In addition, the author would like to point out that successful completion of these projects would have been far more difficult and in some cases impossible without the valuable assistance of a number of other members of the project and the close cooperation of the Captain and crew of the R/V CHAIN.

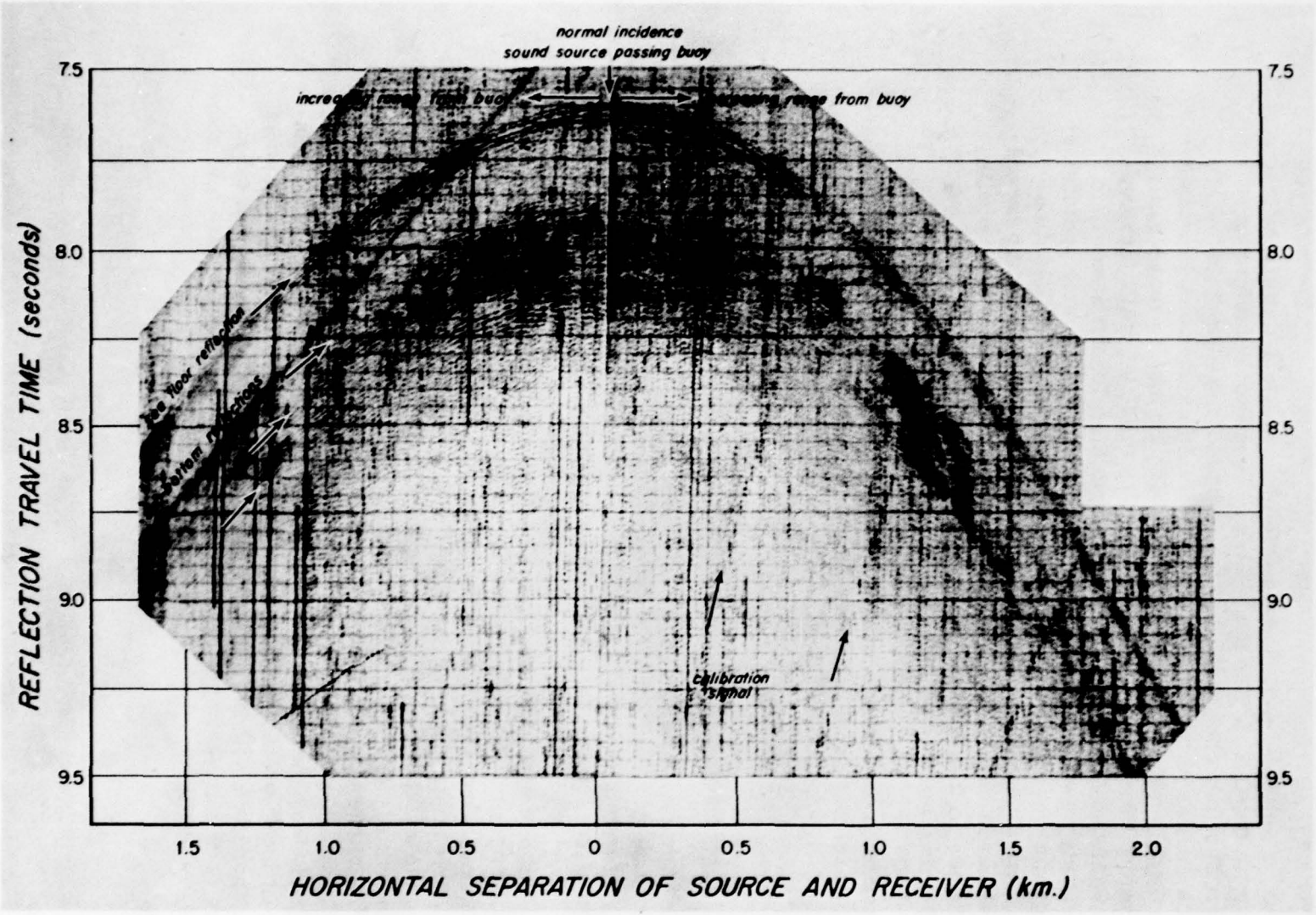


FIGURE 1. SECTION OF PRECISION GRAPHIC RECORDER RECORD OBTAINED DURING THE DESCENT OF THE INSTRUMENT.

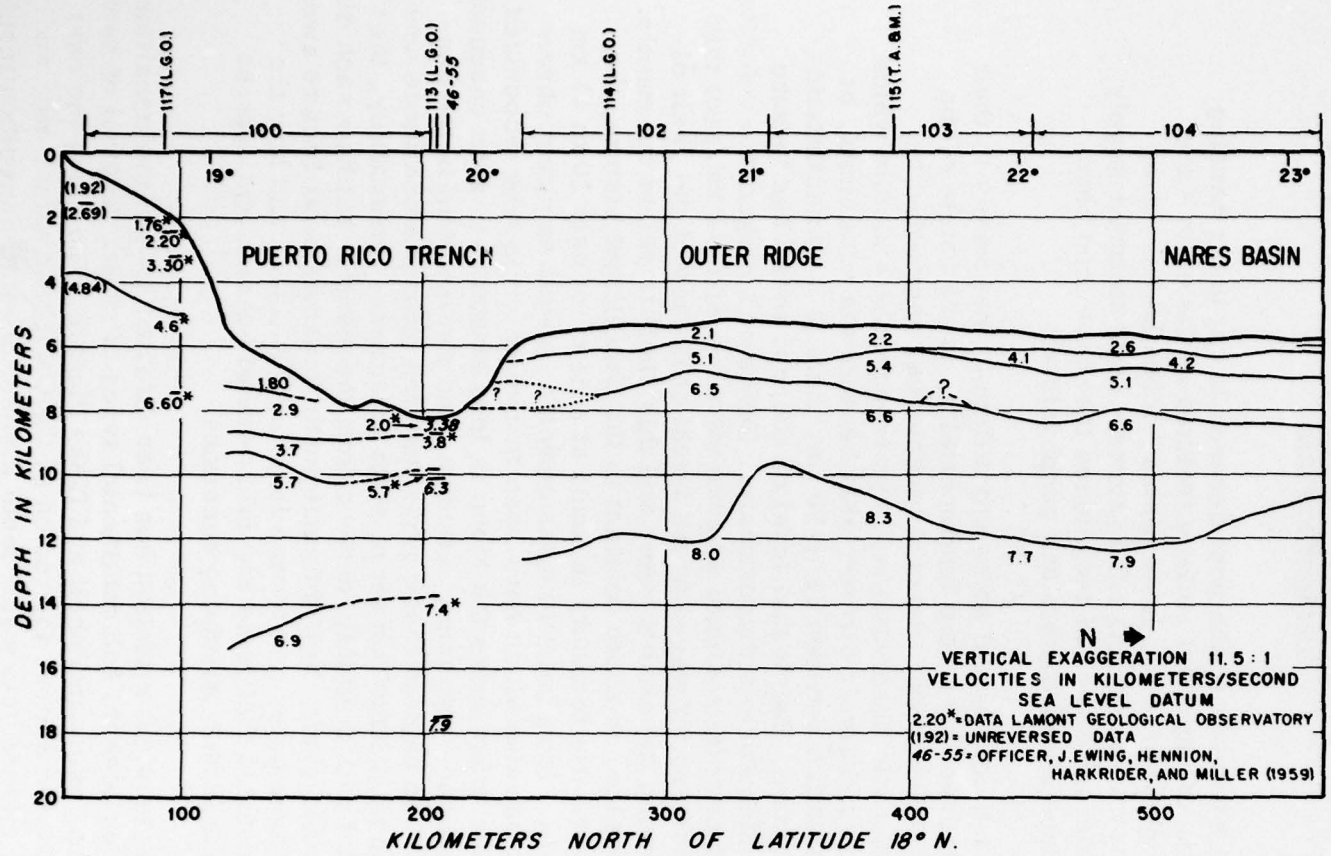
CRUSTAL GEOPHYSICS

INTRODUCTION

The great advances of the past decades in our understanding of the formation of important surface features of the earth - the continents, high mountains, level plains, ocean basins, deep troughs, and world-encircling rift systems - have stemmed largely from the skillful use at sea of techniques that have long been exploited on land by geologists and geophysicists.

Oceanic and continental areas are different, not merely in their relation to sea level but, more fundamentally, in the nature of the material lying below them. Seismic techniques, augmented by gravity and magnetic observations, have brought out a picture which is becoming progressively clearer: that beneath the continents, at a depth which varies between 25 to 50 km, there is a characteristic change of structure. Below this level of change, which has become known as the Mohorovicic discontinuity (Moho or M-layer) the velocity of propagation of compressional seismic waves is about 8 km/sec; this velocity is observed for waves which travel at the top of the shell of material enclosing the earth's core, and this shell is called the mantle. Beneath the oceans, in sharp contrast to the continental picture, the Moho or upper mantle boundary is found at a depth of only 10 to 15 km below sea level. From seismic measurements as well as direct observation of rock samples which have been recovered, it is now recognized that the oceanic crust above the Moho is less abundant in such chemical elements as silicon, potassium, uranium, and thorium than is the continental crust. To explain these gross features affords a challenge now being taken up by a large number of earth scientists. Presumably, the crustal material was originally derived from the mantle, but how such differentiation takes place, how the continental crust material became swept into sizeable aggregates and formed large land masses, and how the forces are generated that raise and fold mountain chains and depress oceanic troughs remain intriguing questions.

For some years our attention has been directed toward the transition regions between oceanic and continental types of crust. Typical of such regions are the continental shelf and Blake Plateau lying along the east coast of the United States, the region of the Caribbean island arc, and such areas of intermediate water depth (neither oceanic nor epicontinental) as the Mediterranean Sea. Frequently these transition regions are areas of geologically recent earth movements, as in the Mediterranean Sea, or of presently continuing tectonic activity as in the Antillean island arc. It



STRUCTURE SECTION-PUERTO RICO TRENCH TO NARES BASIN

LONGITUDE 66° 30' W.

FIGURE 1.

It is to be expected that in those transition areas where the thin crust of the oceans is close to the thicker continental crustal blocks, the contrast in physical and chemical properties between rocks underlying the ocean and those of the continents would lead to complex dynamic behavior.

Our emphasis during the past year has been to exploit continuous seismic profiling and continuous gravity profiling, recently developed techniques of observation which, when used in conjunction with the classical methods of crustal geophysics, have enhanced our ability to make extensive observations of important and fundamental geological features.

SEISMIC REFRACTION STUDIES OVER THE PUERTO RICO TRENCH AND OUTER RIDGE

Elizabeth T. Bunce and D. A. Fahlquist

Results of the seismic investigation of the Puerto Rico Trench and outer ridge, carried out in 1959 by Lamont Geological Observatory, Woods Hole Oceanographic Institution, A. and M. College of Texas, and Hudson Laboratories, published this year, are presented as a crustal section in Figure 1. Three layers above the mantle, having compressional velocities of 2.2, 5.3, and 6.6 km/sec, are defined continuously from the Nares Basin to within 20 km of the north wall of the trench. Extension of the seismic section to the north wall indicates that these three layers may crop out. A layer of velocity 4.2 km/sec is clearly defined in the region of the Nares Basin but pinches out to the south. The depth of the M discontinuity, velocity 7.7 to 8.3 km/sec, varies from 12.2 km to a minimum of 9.8 km. South of the trench a layer of 4.6 km/sec material overlies one of 6.6 km/sec.

Velocities determined under the trench are not concordant with those found under the outer ridge. A layer of velocity 5.7 km/sec overlies material having velocity 7.4 km/sec; depths to these horizons are 10 to 14 km, respectively. Possibly the trench section has been displaced downward at least 2 km relative to the outer ridge, and the materials underlying the trench have been altered subsequently.

A gravity profile has been computed using layer densities and thicknesses derived from the seismic data. The shape of this computed profile agrees well with the measured free-air anomaly, except at the axis of the trench, where the computed values are 50 to 70 milligals too high.

SEISMIC REFLECTION STUDIES OVER THE OUTER RIDGE NORTH OF THE PUERTO RICO TRENCH

Elizabeth T. Bunce and J. B. Hersey

Continuous reflection profiles on the outer ridge north of the Puerto Rico Trench have been made to study in detail the geologic structures there. The purposes of this type of study are (1) to map crustal structure in detail and to as great depth as possible, and (2) to correlate layers determined by refraction with the reflection horizons as a means of reaching a more complete interpretation of structure than is possible with either method mentioned above. The shallower layers are commonly not determinable by the refraction technique because they are thin compared with the water layer.

Preliminary analysis of the data obtained during CHAIN Cruise 34 (October - November, 1962), in the area from the Nares Basin to the north wall of the trench, reveals several distinct structural features which appear to extend east-west and so can be described by north-south profiles. The Nares Basin is characterized by a series of smooth reflectors at shallow depths that lie within the low-speed layer of seismic refraction results (interpreted as unconsolidated sediments). Below the sediments more complicated reflectors, possibly layered, lie within the zone of intermediate velocities, about 4.2 km/sec. Below this zone there is a rough reflector corresponding to the top surface of the layer which has a velocity of about 5.5 km/sec. Immediately south of the basin a series of ridges or steps interrupts the sequence of the layered reflectors, possibly defining the southern boundary of the Nares Basin. South of these hills there is a zone of low relief underlain by complex reflectors suggesting a nearly plane surface as the first major reflector below the bottom. Still farther south the shallowest part of the outer ridge, formed of irregular hillocks separated by complex series of nearly horizontal reflectors, covers the area from about 20°50'N to the north wall of the trench.

Many of these reflection profiles were located to coincide with the refraction profiles established as part of a Mohole site selection survey in 1959 (Bunce and Fahlquist, 1962). Preliminary comparisons clearly show substantial agreement between refraction and reflection results where both show uniform stratification. The principal difference is a consistent tendency of reflectors to show slightly shallower depths than those computed from refraction data. Where the reflection profiles suggest considerable relief in some layers the reflection and refraction results do not agree. At this writing we are only prepared to point out that such a

result has long been anticipated by seismologists dealing with refraction data in regions of complex structure. We are hopeful, however, that some of our data will show how refraction results may be combined with reflection data to allow a much more complete interpretation of structure than is possible from either. In addition, we anticipate that the highly resolved reflection data provided by the Continuous Seismic Profiler will be even more informative when combined with refraction data taken at the same time.

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Bunce, E. T., and D. A. Fahlquist. Recent geophysical investigations of the Puerto Rico Trench and outer ridge. J. Geophysical Research, 67(10), 3955-3972.

A SEISMIC REFRACTION PROFILE ON THE EUROPEAN CONTINENTAL SHELF SOUTH OF IRELAND

Elizabeth T. Bunce and J. B. Hersey, WHOI
S. Crampin and M. N. Hill, Cambridge University

In the course of CHAIN Cruise 13 in 1960, a seismic refraction profile oriented north-south, and 80 km long, was made on the continental shelf south of Ireland in collaboration with scientists of the Department of Geodesy and Geophysics, Cambridge University, and the National Institute of Oceanography aboard the RRS DISCOVERY. A large part of the analysis of the seismic data was completed in 1961 but various delays prevented us from completing a first interpretation until late in 1962.

Earlier seismic work in this area by British geophysicists had provided a measure of structures to depths of about 5 km, which included layers having velocities in the range 1.8 to 6.8 km/sec. These were interpreted by the various authors as sediments and consolidated or metamorphosed sediments above metamorphic basement.

The most significant feature of this new profile is the determination of a layer of high velocity, 7.6 km/sec at depths of 9 to 13 km at the north end and 20 km at the south end. This velocity is lower than that generally associated with mantle material (8.0 km/sec), but it is in the range (7.0 to 7.7 km/sec) found near other continental margins (e.g., Hersey, Bunce, Wyrick, and Dietz, 1959). Whether this velocity

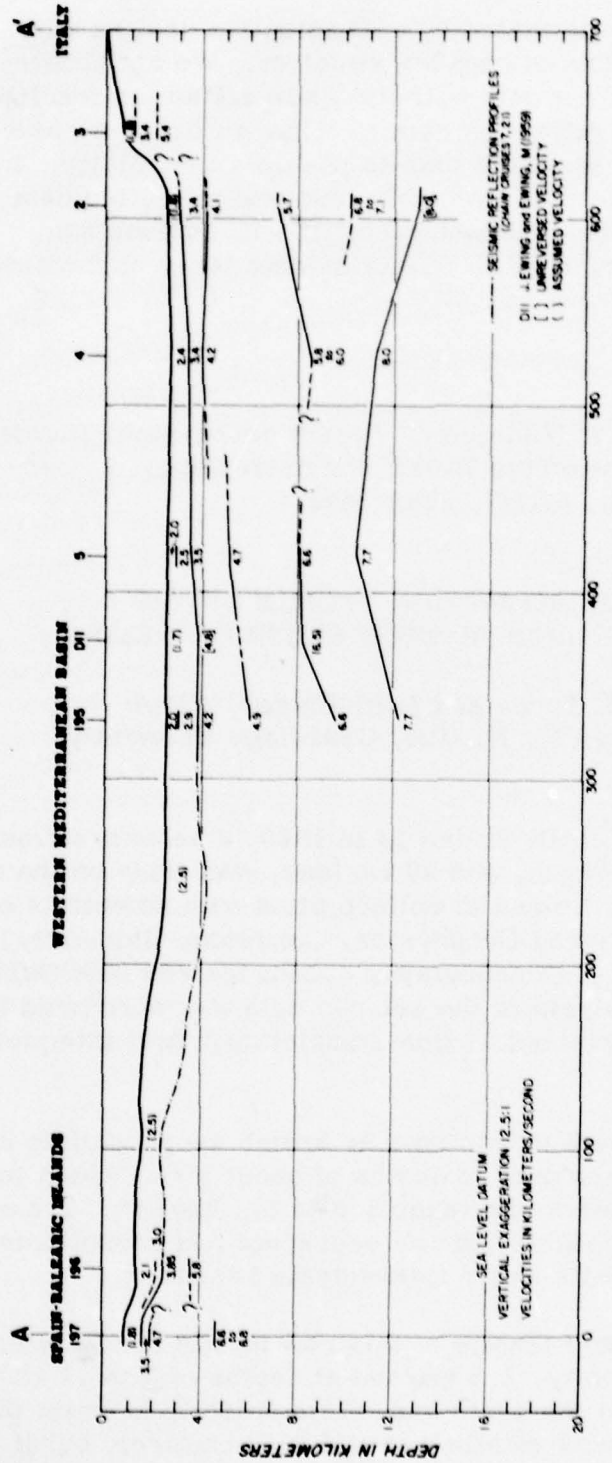


FIGURE 1. SEISMIC STRUCTURE SECTION ACROSS THE WESTERN MEDITERRANEAN.

identifies a zone of transition between crust and mantle with accompanying gradients in composition or whether it is a distinct structural unit cannot be decided from these results. Nevertheless there appears to be relief of about 5 km in the top surface of the layer characterized by the 7.6 km/sec velocity. The velocity determinations for materials lying above this layer agree with earlier results mentioned above and are similarly interpreted by us.

Reference:

Hersey, J. B., Elizabeth T. Bunce, R. F. Wyrick, and F. T. Dietz. Geophysical Investigation of the Continental Margin between Cape Henry, Virginia and Jacksonville, Florida. Bull. of the Geol. Soc. of Am., Vol. 70, pp. 437-466, 1959.

SEISMIC REFRACTION STUDIES IN THE WESTERN MEDITERRANEAN SEA

Davis A. Fahlquist

The Mediterranean Sea effectively conceals from view the tectonic and structural relationship existing between the continental land masses of Europe and Africa. As in the Caribbean, the depth of water is significantly less than that of the deep ocean. Because of the proximity of Alpine mountain chains to this area of intermediate water depth, several geological-geophysical questions can be raised. Is the crustal structure underlying the Mediterranean Sea continental or oceanic in character, or is it intermediate between the two? Is the continental crust of Europe and Africa continuous across the Mediterranean?

Seismic refraction and reflection studies (made during various cruises in 1958, 1959, and 1961) have given new information relevant to these questions. The results are shown in Figure 1; the structure section extends from Genoa, Italy, southwest across the western Mediterranean Basin, and up to the Balearic Islands. Some of the conclusions of this study may be summarized as follows:

(1) Depth to the Mohorovicic discontinuity is less than 12 km in the central part of the basin; this depth increases toward the basin margins.

(2) A thick section of intermediate-velocity material (3.0 - 6.0 km/sec) is present throughout the northern part of the basin.

(3) Toward the northeastern margin of the basin (Italy) the velocities of crustal layers lying at comparable depths decrease: 4.2 to 3.4 km/sec at a depth of 4 km; 4.9 to 4.7 to 4.1 km/sec at a depth of 5 to 8 km; 6.6 to 5.8 km/sec at a depth of 8 km; and 7.7 - 8.0 to 6.8 - 7.1 km/sec at a depth of 11 km.

(4) Under the continental shelf of Europe a layer of 5.4 km/sec material is found at shallow depth.

(5) In the northern part of the western Mediterranean a 3 km downward displacement of the basin, relative to continental Europe, has been deduced from the seismic measurements.

This seismic information, in conjunction with geologic and morphologic evidence, shows that subsidence is the dominant element in controlling the present structural configuration of the western Mediterranean. The fundamental causes of such vertical movements of large portions of the crust are poorly understood. The negligible free air anomaly indicates approximate isostatic equilibrium today. It is difficult to imagine a state of isostatic equilibrium existing prior to the foundering of the basin floor (when its top surface stood at or near sea level) without a corresponding change in density distribution in the underlying deep crust or mantle. No way is known by which the thin crust (relative to the continent), even in compression, could have supported this uplift without fracturing. If the uplift were not compensated for by density changes in the substrata, then forces other than those of isostasy must have played a dominant role in the tectonics of the area. The deep "oceanic-type" structure under the western Mediterranean argues against the occurrence of major changes in density in the recent (Tertiary) geologic past.

SEISMIC REFRACTION OBSERVATIONS OVER THE CONTINENTAL MARGIN, SHELF AND SLOPE SOUTHEAST OF CAPE HATTERAS, N. C.

Elizabeth T. Bunce

In July of 1962 a cooperative investigation was undertaken by scientists of the Woods Hole Oceanographic Institution, the Lamont Geological Observatory, the University of Wisconsin, and Carnegie Institution at Washington, to study the relationship between oceanic and continental crustal structure from deep water off the coast of North Carolina. A seismic refraction profile was made over a line extending about 70 km inland and 100 km offshore from New River, N.C.

In addition, a shorter reversed profile (about 70 km) extending from deep water at the base of the slope (R/V BEAR) to shallower water on the edge of the shelf (R/V CRAWFORD) was completed. The final results of this investigation, when added to considerable information available from earlier Woods Hole refraction stations in this area, will yield more detailed knowledge of the transition from oceanic to continental crustal structure.

SEISMIC REFLECTION STUDIES ON THE CONTINENTAL SHELF, SLOPE, AND RISE SOUTH OF NEW ENGLAND

S. T. Knott, Hartley Hoskins and David D. Caulfield

From the summer of 1958 to the present a collection of seismic reflection data from the continental shelf, slope, and rise south of New England has accumulated. Interpretation of most of the earlier data has been completed during and prior to this year and has served the immediate purpose of guiding further studies. These data have accumulated slowly because many of the recordings were taken incidental to other studies or en route to other areas.

An analysis of the profiles from our earliest work, shown in Figure 1, suggests that the outer shelf and upper slope sediments around New York Bight are from a common source but there are areal differences in the manner in which these were deposited. That the shelf south of Rhode Island and Cape Cod was depressed relative to sea level during the last glaciation and has remained so as sediments accumulated is suggested by the absence of truncated sedimentary strata (Figure 2, profile 25-26). In contrast, data from profiles southwest of Hudson Canyon (Figure 3, profile 7-8) indicate an extensive erosional unconformity with a reflection travel time of about 0.2 sec. Here, apparently, the shelf was built out a great distance while relative sea level remained nearly constant. Although the profiles are presented with a vertical exaggeration of about 40 to 1, it can be seen that the dip of the shallow beds does not differ greatly from that of the present sea floor of the shelf. The dip of the buried sloping beds is close to that of the present continental slope.

In the area south of Martha's Vineyard recent data taken with more powerful sources indicate that buried horizons, deeper than those shown in the profiles discussed above, dip seaward under the present slope, nearly paralleling it, and eventually crop out at depth between 500 and 800 fathoms, in some cases forming steps which have been

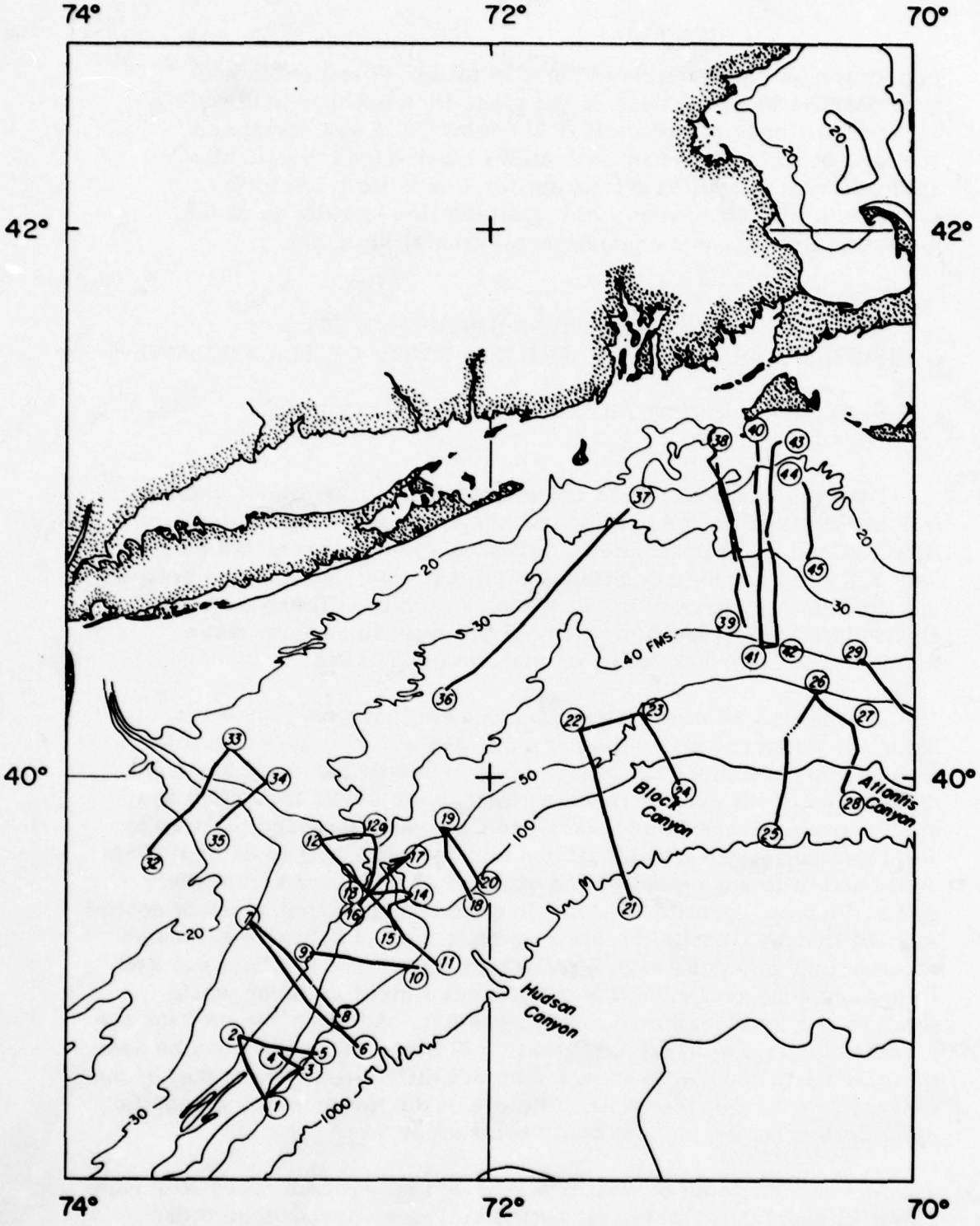


FIGURE 1. LOCATION OF CONTINUOUS SEISMIC REFLECTION PROFILES 1958-1959.

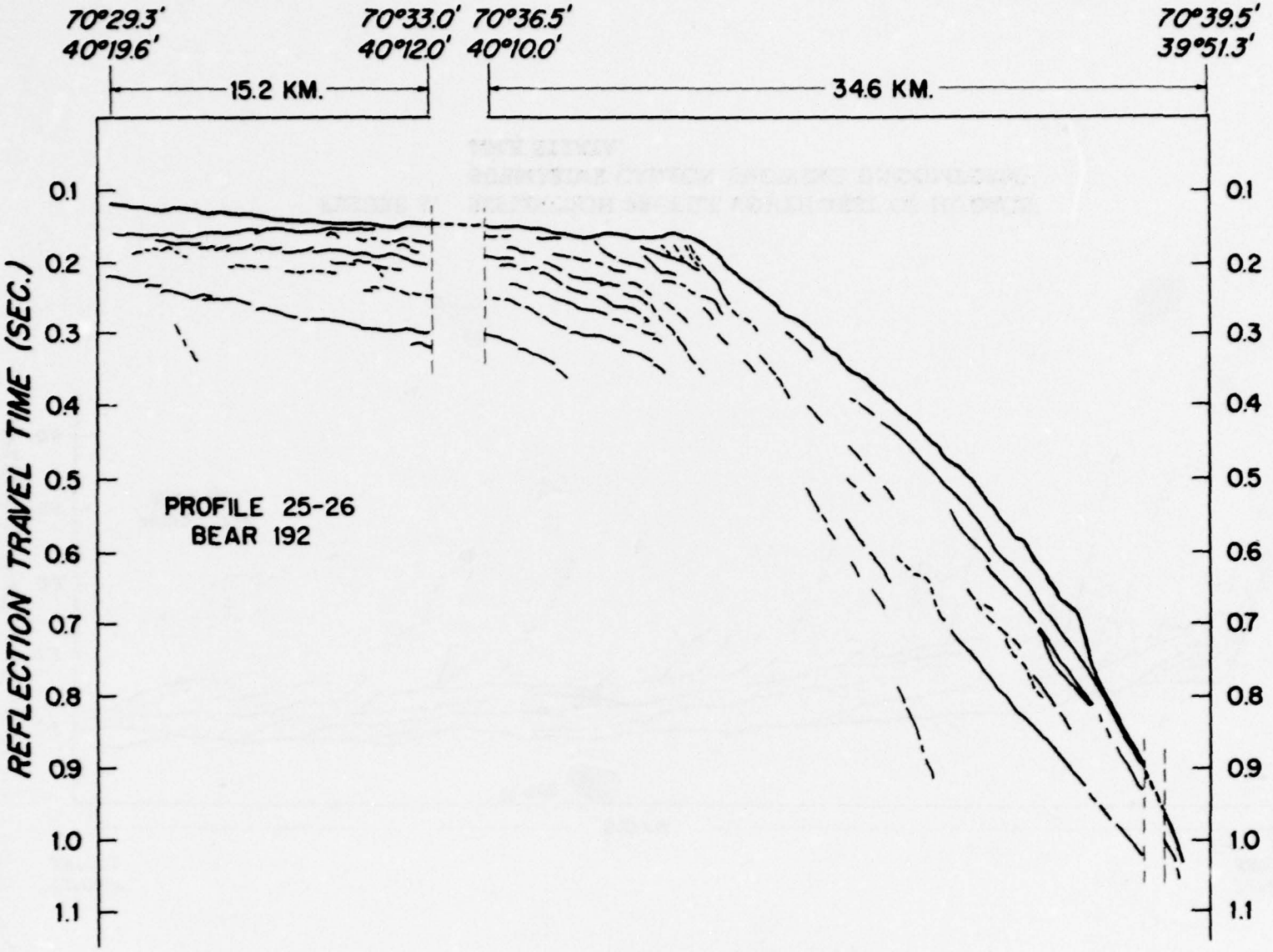


FIGURE 2. REFLECTION PROFILE SOUTH OF MARTHA's VINEYARD SHOWING COMFORMABLE STRATA.

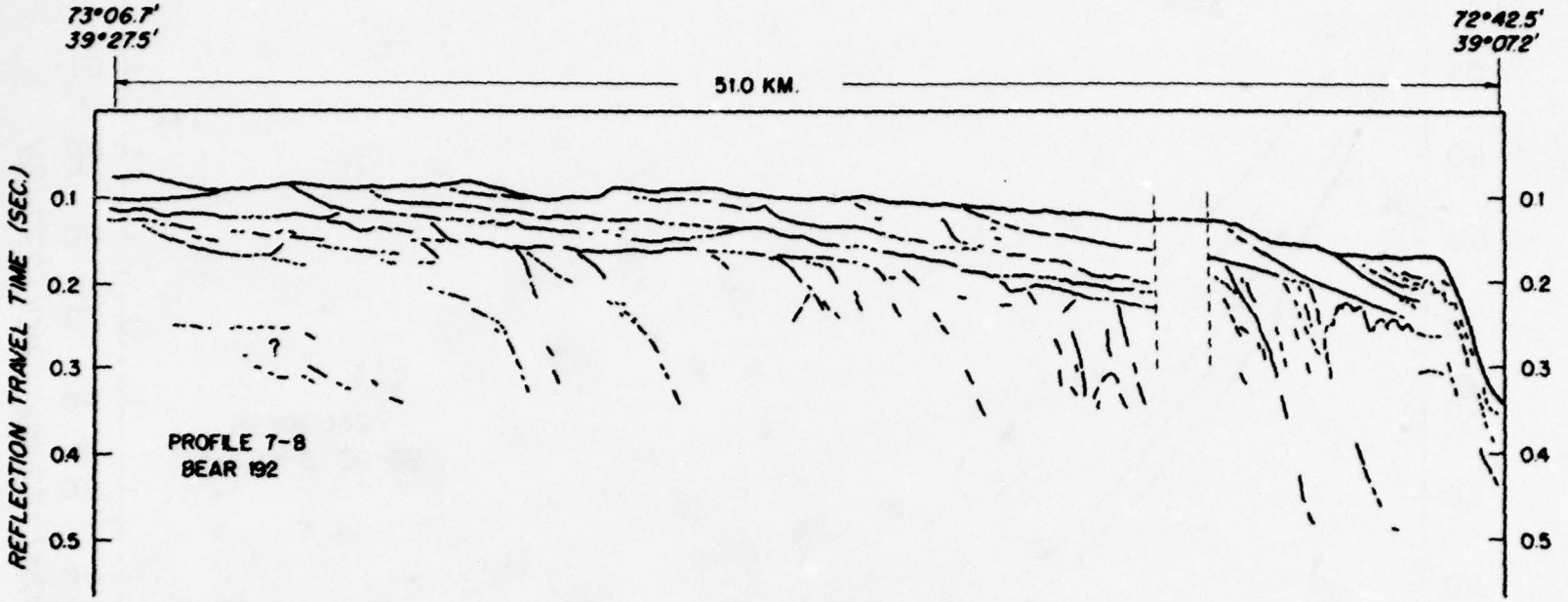


FIGURE 3. REFLECTION PROFILE SOUTHWEST OF HUDSON SUBMARINE CANYON SHOWING UNCOMFORMABLE STRATA.

widely observed with echo sounders on the continental slope. It is suggested that these steps may have resulted from slumping of the more recent sediments which drape the slope or, less likely, the erosion of a sequence of strata of differing resistances (Heezen 1959). As yet no faulting has been observed to be associated with these steps.

Three profiles across the continental rise show layering lapping up on the continental slope; perhaps this has resulted from mass wastage of the slope.

Profiles across Hudson, Block, and Lydonia submarine canyons exhibit reflection horizons truncated by the canyons. That the submarine canyons in this area are the result of erosion is evident from these profiles and confirms the conclusions drawn from the early program of dredging in the canyons by H. Stetson. The new techniques of acoustically monitoring the dredge location help surmount the earlier difficulties in determining the depth of the sample. Systematic sampling with the new deep submersible is envisioned as even more fruitful.

The refraction and oblique reflection observations made on the shelf south of New England with the seismic profiler indicate a small positive velocity gradient for the first quarter-second into the bottom, except for the bedrock near shore, which has elastic wave velocities greater than 4 km/sec. Sub-seafloor reflections on two profiles seaward of Buzzards Bay and Narragansett Bay suggest that these drowned valleys extend a considerable distance to the south.

Most of the data discussed above were taken with a 400-joule (stored energy) underwater-spark sound source. The larger sources now in use (25,000-joule stored-energy underwater spark and 13,000-joule stored-energy Boomer) and improved detection systems (Dow and Hoskins, in this volume) make it possible to obtain profiles to a sufficient depth to correlate with the early refraction work of M. Ewing and others (summarized by Drake, 1959). Our conclusions are yet to benefit either by determinations of the age of the sediments or by extensive measurements of the compressional wave velocities of the layers detected by the seismic profiler. There is not an adequate answer to why the reflecting horizons are often so widely spaced and discrete, nor do we know the means of transport across the shelf, nor why the sediments were eroded in localized areas.

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A THEORETICAL STUDY OF SEISMIC REFLECTIONS FROM A VELOCITY GRADIENT

D. A. Fahlquist and J. A. Doutt*

Deep sea seismic refraction studies (Hill, 1952; Officer, 1955; Katz and M. Ewing, 1956) show the existence of vertical velocity gradients in the deep sea sediment column. The travel time measurements of classical refraction seismology are usually fitted to a layered model with a single velocity assigned to each layer. Such models imply sharp changes in the properties of the medium when passing from one layer to the next. Travel time refraction data seldom rule out alternative interpretations in which the properties of the seismic model are allowed to change continuously from one layer to the next. Experimental evidence at places where well-defined reflections are not obtained from layers showing strong refraction arrivals (Steinhart and Meyer, 1961) lends support to this latter crustal model.

Following the solution of Wolfe (1937), we carried out a preliminary study plane wave reflection at normal incidence from a velocity gradient; the Rayleigh reflection coefficient as a function of frequency was computed for various gradients and transition layer thicknesses. The transmission

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patterns obtained for the model in question suggest that certain frequencies are absent in the energy returned to the surface. The velocity gradient acts as a filter with sharp, harmonically-related rejection characteristics.

Where gradients exist in the crust, transmission through them should leave a marked signature on the frequency spectrum of the transmitted pulse. This effect should be present, not only in seismic reflection data but very probably in seismic refraction information. If so, the frequency spectrum information could be used as a tool for investigation of the deep layered structure of the crust; it may aid in resolving the question whether sharp discontinuities or gradual transition zones between layers characterize deep crustal structure. On a world-wide scale it might be possible to categorize various portions of the crust in terms of its frequency response to transmitted energy.

THE FREQUENCY DISTRIBUTION OF SOME CHARACTERISTICS OF BOTTOM TOPOGRAPHY

Joseph W. Mizula and A. C. Vine

With the advent of precise echo sounding systems (PGR, PDR) the accumulation of reliable sounding records of the ocean bottom has continued at an accelerated rate. Synthesis of this growing body of data will permit the construction of more accurate and detailed contour charts of submarine topography. We feel that this conventional approach to topographic description can be augmented by a quantitative analysis of these same sounding records.

A study is being made to determine whether useful topographic information can be obtained from a single line of soundings. For instance, can one or more parameters be derived that will quantitatively describe different kinds of ocean bottoms and give some measure of how much one area may differ from another? The bottom profile obtained from a line of soundings contains several elements of form or characteristics of the topography traversed which can be measured with varying degrees of accuracy. These include slope, slope length, an estimate of rate of change of slope, depth, change in depth between slope reversals, and distances between slope reversals. The work thus far has been concerned primarily with a frequency distribution analysis of the first four of these properties.

The bottom profile was approximated by a series of closely-fitting

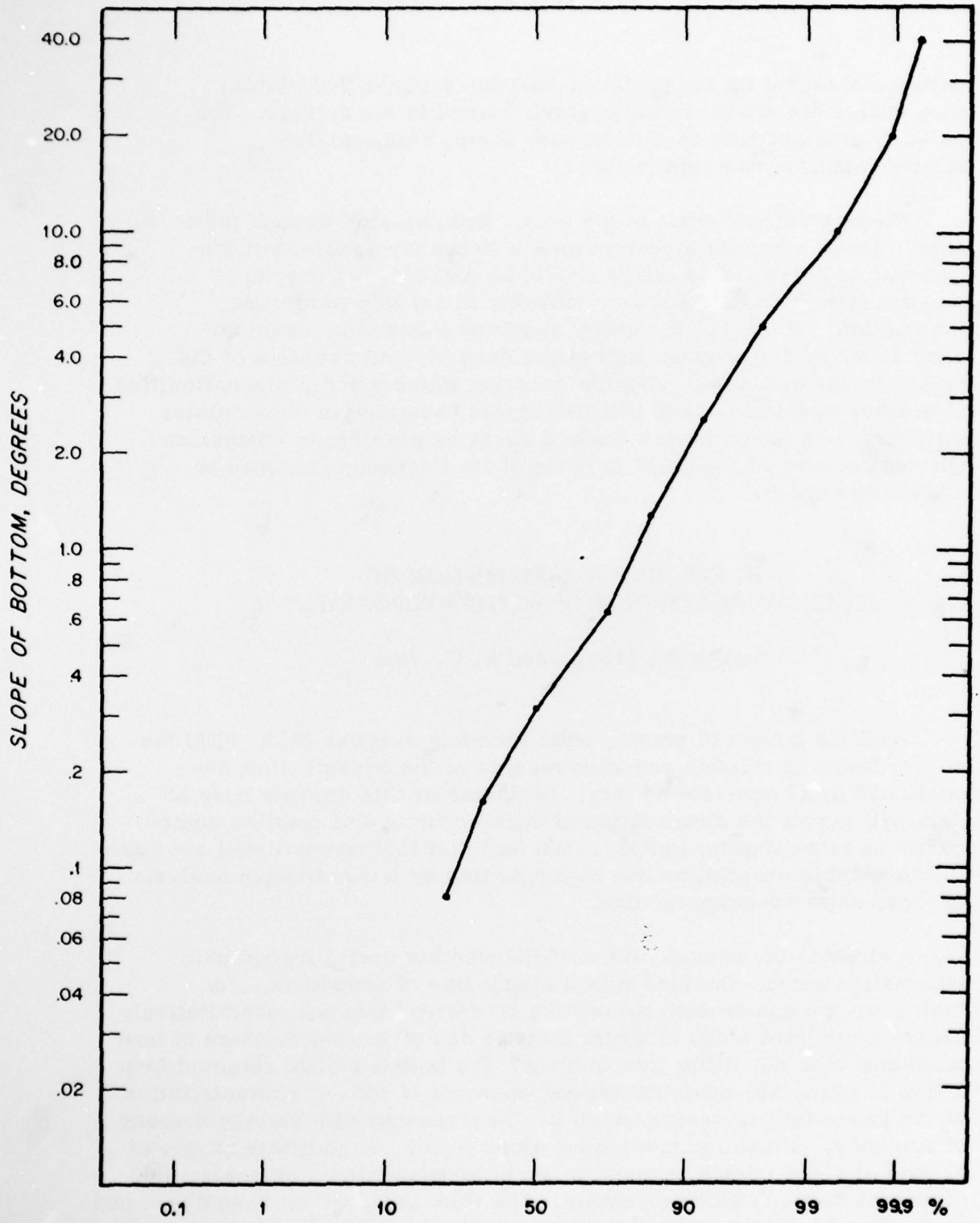


FIGURE 1. CUMULATIVE FREQUENCY DISTRIBUTION OF BOTTOM SLOPES. CHAIN 7 TRACK, BERMUDA TO WOODS HOLE.

straight-line segments of varying lengths. The lengths of the lines and the depths at each end were measured. Depending on the resolution of the records, depths were read to the nearest fathom or half-fathom and the shortest line segments used were around 0.05 to 0.1 mile. Bottom roughness of a scale smaller than this was not measured. The data were then processed by the Institution's Recomp II Computer to yield frequency distributions of the topographic variables.

During this year, some 13,000 measurements representing over 5,000 miles of track were analyzed. The measurements were taken from two Atlantic traverses: one running from Woods Hole to Bermuda and then eastward to Gibraltar and the other from Woods Hole to Bermuda and then northeastward to the northern British Isles. Traverses across different physiographic areas such as the continental slope, or the mid-Atlantic Ridge, as well as complete Atlantic crossings, were analyzed separately and comparisons were made.

A great deal of consideration was given to the types of errors or uncertainties that may be present in the data and to the manner in which they may affect the frequency distributions. Some of these are listed in Table I. The most serious of these is the uncertainty concerning the orientation of the ship's tracks with respect to the slope normal. If a random orientation is assumed, a correction may be applied to the computed mean slope to obtain a corrected mean. Since the tracks were generally normal to the major topographic features traversed, the "true" mean slope can be assumed to fall in the lower part of the interval between the computed and corrected means. Probably the variance of the distribution would be unchanged.

At this writing the frequency distribution of these topographic variables has been analyzed for the two complete Atlantic crossings and for shorter sections across the different types of ocean bottom traversed. A representative result is shown in Figure 1. This is the cumulative frequency distribution of the absolute slope measurements made on the CHAIN 7 traverse from Bermuda to Woods Hole. The data are plotted on logarithmic probability paper, the vertical axis representing the logarithms of the slope angles and the horizontal axis the cumulative frequency of the total number of miles measured, with slopes in the stated intervals. The distribution appears approximately log normal; that is, the logarithms of the slope angles appear to be normally distributed.

Since the depths were read to the nearest fathom or half-fathom, there is some error in the computed slope of each line segment. Obviously,

TABLE I

Errors or uncertainties that may limit accuracy of slope measurements

Orientation of track with respect to slope normal
Slope effect
Navigation
Assumed sound velocity
Measurements on peak and valley crescents
Unmeasured small scale roughness
Failure to measure all of track
Operator error

slope angles, in fathoms per mile, of about the same magnitude as the measurement error, cannot be differentiated unless they continue for several miles. This distribution is considered to be censored at about 0.08° or 1.4 fathoms per mile; that is, the number of observations below the point of censorship is known, but they are not specified further. The methods outlined by Hald (1952) were used to fit the observed distribution to a theoretical log normal distribution with the same mean and variance. The mean and standard deviation of this sample are 9.4440-10 and 0.6669, respectively. The angular values corresponding to the interval one standard deviation below and above the mean are: 0.06° and 0.28° - 1.29°, respectively. The correction for random orientation of track with respect to slope normal would raise the mean to 0.44°. Since most of the track was a traverse approximately normal to the continental shelf, slope and rise, and Bermuda Rise, it is felt that the actual mean slope is close to the computed mean of 0.28°.

The frequency distribution of this sample grouped into equal logarithmic intervals is shown in Figure 2. The mean slope 0.28°, lies just to the left of the class interval containing the largest number of observations, and approximately 23% of the slopes are less than 0.08°, the point of censorship. The distribution apparently has some slight negative skewness.

While this work was in progress, a comparable body of measurements for the South Atlantic was obtained. In addition, a computer program was planned and written to reduce the data to frequency distributions of changes in depth and distance between slope reversals. By combining these vertical and horizontal aspects of the topography, perhaps a useful measure of the grain or texture of the ocean bottom may be derived.

Quantitative topographic information can be obtained from measurements made on echo sounding records, but the present system has certain limitations. Equipment for recording the sounding data directly in a digital format compatible for computer use would permit the rapid and more accurate analysis of vastly greater amounts of data. Since the basis of a statistical approach is quantitative description of a universe by analysis of samples drawn from that universe, it should be feasible to arrive at a useful quantitative description of ocean-bottom topography with less surveying than is required for detail contour charts. For the proper study of complex topography it is essential to use high-power and narrow-beam soundings, to obtain data largely free of errors resulting from slope effect and side echoes.

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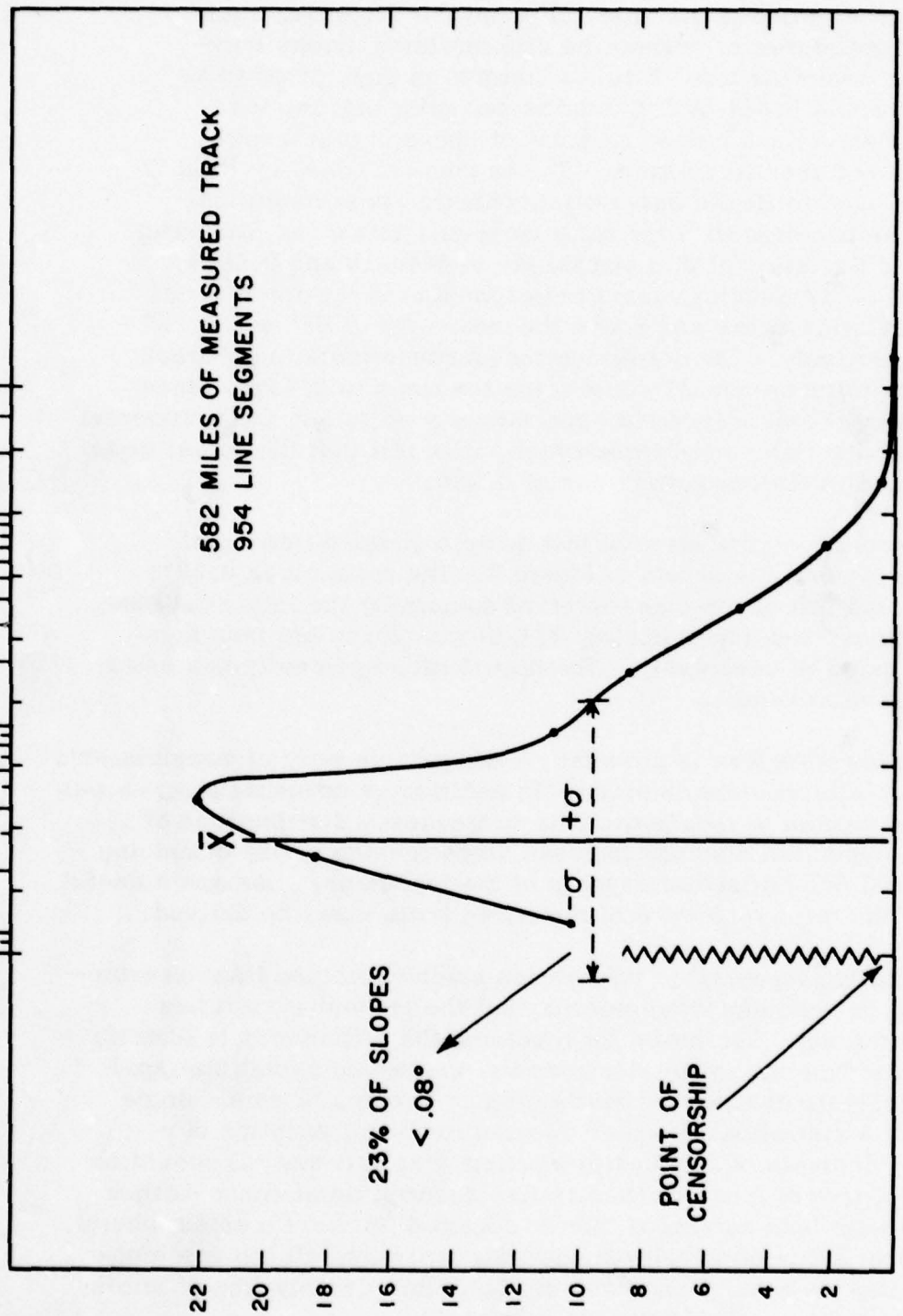


FIGURE 2. FREQUENCY DISTRIBUTION OF BOTTOM SLOPES.
CHAIN 7 TRACK, BERMUDA TO WOODS HOLE.

MEASUREMENTS OF GRAVITY AT SEA: A NEW AUTOMATIC SYSTEM AND SOME RESULTS

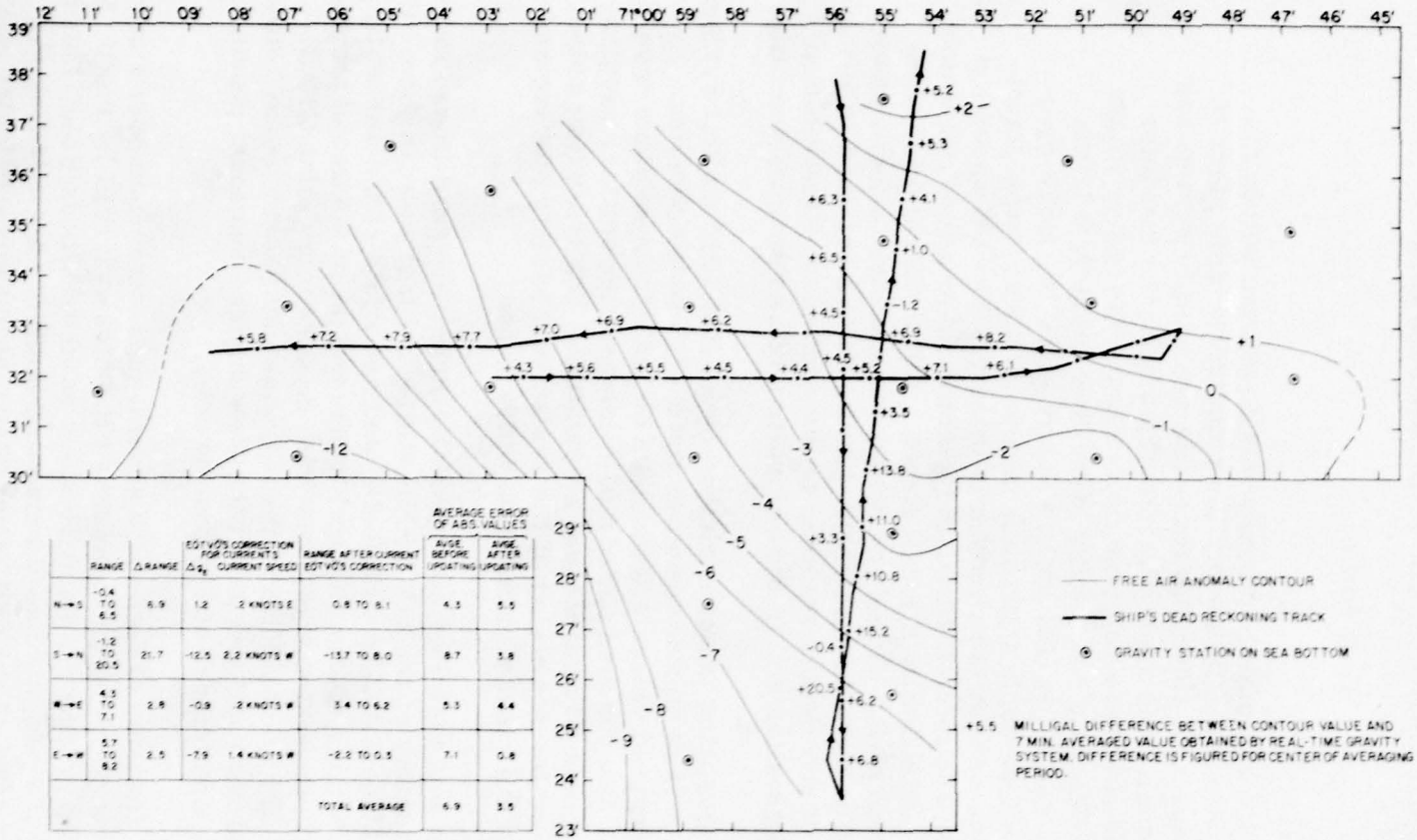
Carl Bowin

During 1962 a sea gravity program was developed within the Geophysics Department. In January the program had only plans to show, but by August an automatic real-time sea gravity system had become operational. The system incorporates a digital computer which processes data received from five inputs. These five inputs are: a LaCoste-Romberg sea gravity meter (two inputs), a Litton electromagnetic speed log (EM log), a Sperry Mark 14, mod 2 gyrocompass and a water-depth input from remote switches. The gravity meter, of course, senses the changes in gravity. The EM speed log and the gyrocompass furnish speed and heading information from which ship's position and velocity are calculated. This information is used in the computation of the Eötvos correction and the International gravity formula needed for the reduction of the gravity values obtained from the gravity meter. Water depths are used in the geological interpretation of the gravity anomalies and in the calculation of sea Bouguer anomalies.

The data processing is accomplished by an IBM 1710 control system which includes a 1620 digital computer and a 1711 data converter. Sampled and computed values are recorded on both punched paper tape and typewriter. The punched paper tape allows recomputation, merging, or sorting of the data without manual preparation. The typewriter output furnishes a record for monitoring of the system and assists plotting and interpretation of the gravity information while at sea.

The system was installed in a specially-built, air-conditioned room in the main laboratory of the R/V CHAIN during the last week in June. On July 6 the CHAIN departed on Cruise 28, and sea trials of the automatic gravity system began. Debugging and improvements in the coded program and in the input conversion equipment were done mainly during CHAIN Cruises 28 and 29. Thus, during CHAIN Cruises 30 (in the region between Woods Hole and Bermuda) and 31 (in the New England Seamount province) the system was operational and in routine use.

During the first day of Cruise 30 several runs were made over a gravity-meter operational check range established in February, 1962 by the U. S. Navy Oceanographic Office, about 60 miles south of Woods Hole, Mass. Figure 1 shows the computed dead reckoning track of the CHAIN as she passed over a portion of the calibration range during this particular test. This track differs from the true track (not shown) because, apparently,



	RANGE	Δ RANGE	EOT V/S CORRECTION FOR CURRENTS Δa_E	CURRENT SPEED	RANGE AFTER CURRENT EOT V/S CORRECTION	AVERAGE ERROR OF ABS. VALUES AVGE. BEFORE UPDATING	AVGE. AFTER UPDATING
N→S	-0.4 TO 6.5	6.9	1.2	2 KNOTS E	0.8 TO 8.1	4.3	5.5
S→N	-1.2 TO 20.5	21.7	-12.5	2.2 KNOTS W	-13.7 TO 8.0	8.7	3.8
W→E	4.3 TO 7.1	2.8	-0.9	2 KNOTS W	3.4 TO 6.2	5.3	4.4
E→W	5.7 TO 8.2	2.5	-7.9	1.4 KNOTS W	-2.2 TO 0.5	7.1	0.8
					TOTAL AVERAGE	6.9	3.5

FIGURE 1. ANALYSIS OF ACCURACY OF GRAVITY SYSTEM OVER U. S. NAVAL OFFICE GRAVITY METER CHECK RANGE.

during part of the test the ship was being set by tidal currents. The EM log measures only the speed of the ship through the water, and this may differ from ground speed because of such currents. Figure 1 gives errors in free-air anomaly values (in milligals) obtained with the automatic gravity system, both as computed in real time and after correction for currents as determined from Loran A fixes. The correction for currents reduced the average error from 6.9 to 3.5 mgls. If Loran A had greater navigational accuracy, one would expect the corrected gravity values to improve in accuracy.

An example of the data computed at sea is shown in Figure 2. This figure is adapted from a profile made aboard the CHAIN during Cruise 31 to the New England seamount province. The correlation of gravity with bottom topography is particularly striking over the three canyons on the continental slope and the three seamounts.

The most significant gravity study made with this system during 1962 was a survey covering approximately 100,000 square miles in the region north of Puerto Rico. Since the automatic system allowed contouring of the free-air and sea Bouguer gravity anomaly values in real time, we were able to modify the cruise plan so that gravity data could be collected in critical places. The main preliminary results of the survey can be summarized as follows:

The free-air values are all negative except over a portion of the outer ridge and close to the islands of Hispaniola, Puerto Rico, and the Virgin Islands. Topography is clearly reflected in the free-air anomaly map; an area of low-gravity relief occurs over the Nares abyssal plain, an axis of positive anomaly parallels the crest of the outer ridge, an axis of gravity minimum occurs along the center of the Puerto Rico trench, and a negative anomaly is associated with the Mona Canyon. Slightly positive free-air values occur where the outer ridge trends east-west, but these values become increasingly negative to the northwest where the ridge parallels the trend of the Bahama Islands. The axis of the negative anomaly is centered over the Puerto Rico trench as a whole and not over the deepest portion, which occurs at the northern edge of the trench. Two distinct minima were found within the trench zone. One is north of Puerto Rico (-380 mgls) and the other is close to the position of the reported Milwaukee Depth (-330 mgls).

Approximate depths to mantle can be derived from the sea Bouguer anomaly map. The approximation becomes less reliable as the trench is approached because of lack of isostatic equilibrium there. The sea Bouguer anomaly map shows rather uniform depths to mantle under the Nares abyssal plain in the northeast portion of the mapped region. The mantle rises in an elongate dome beneath the outer ridge north of Puerto Rico. This position

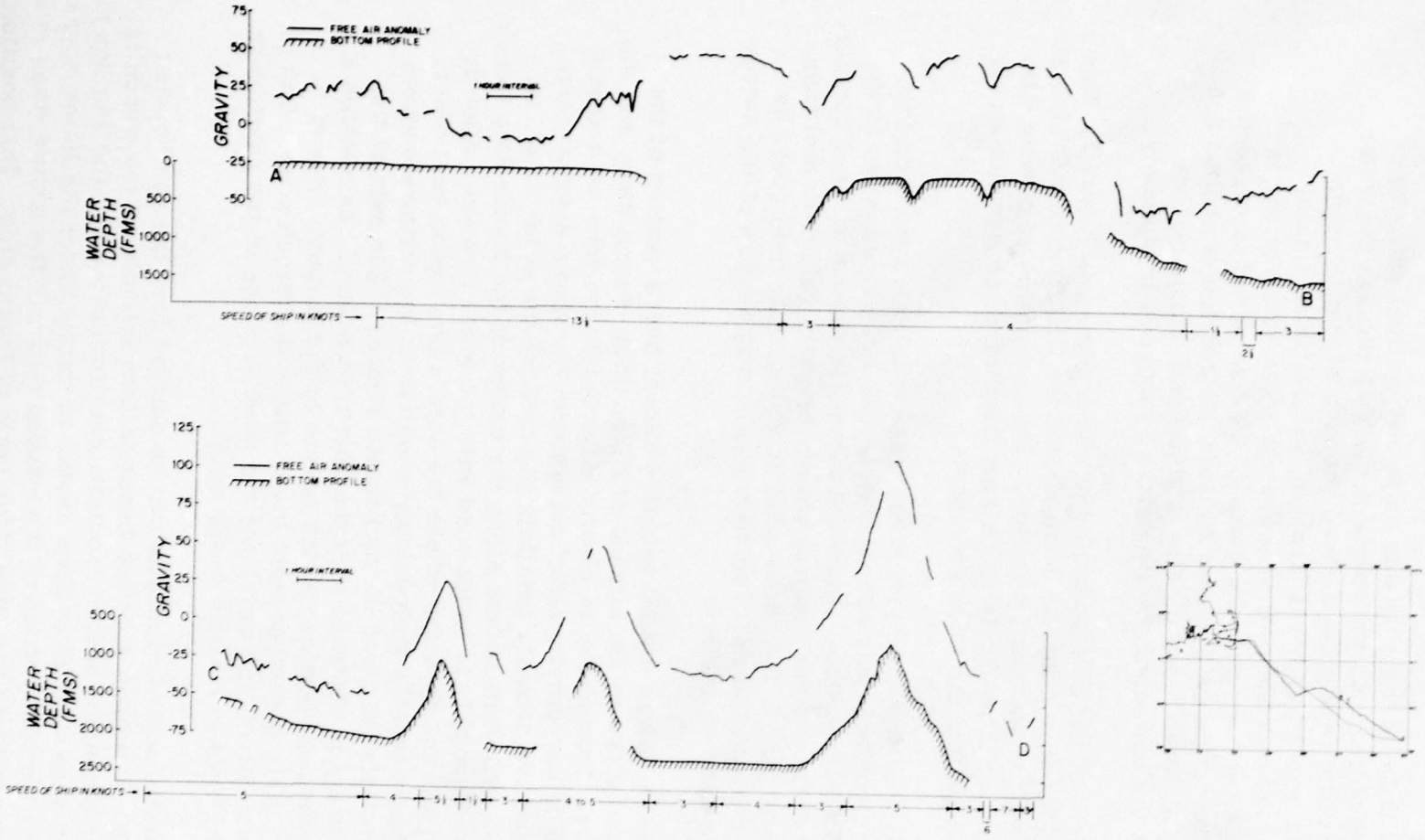


FIGURE 2. FREE AIR ANOMALY AND OCEAN DEPTH PROFILES OBTAINED BY SYSTEM DURING CRUISE TO NEW ENGLAND SEA MOUNT PROVINCE.

agrees well with the position of shallow mantle shown in the seismic profile along 66°30'N given by Bunce and Fahlquist (J. Geophys. Res., Vol. 67, p. 3959, 1962). There is an indication that the dome is antithetic to the free-air minimum north of Puerto Rico because these features are directly opposite to each other and are of similar size. This suggests that the position of greatest upwarping of the crust is associated with the position at which the lack of isostatic compensation is greatest (i.e., in the trench north of Puerto Rico). The outer ridge as a structure, however, does not show on the sea Bouguer map. South and southwest of the outer ridge the mantle deepens under the Puerto Rico trench-Island-arc complex and under the Bahama Islands, respectively.

The success of the gravity computing system is in large measure due to the competence and interest shown by the personnel of International Business Machines Corporation, who were involved in its development and construction under contract to the Woods Hole Oceanographic Institution. IBM also provided maintenance men and a programmer to accompany the system to sea. The continued support of this program by many members of the Geophysics Department of WHOI and others, both on land and in operating the system at sea, is appreciated. Installation of the equipment aboard the R/V CHAIN was made by the WHOI shop electricians, welders, and carpenters. Excellent cooperation was given by the officers and crew of the R/V CHAIN.

INSTRUMENTATION FOR MAGNETIC OBSERVATIONS AT SEA

David D. Caulfield

Many years ago a brief program of total field magnetic measurements was carried out in cooperation with the staff of the Lamont Geological Observatory. The instrument used was an automatically-oriented flux-gate type of magnetometer, and at that time was generally towed from aircraft. It is still used by Lamont, but largely out of lack of active scientific interest, we have not continued a magnetic measurements program at sea until this year. The success of the seismic profiler has made both gravity and magnetic measurements virtually mandatory as accompaniments to seismic reflection profiles. In the past several years a variety of atomic interactions with magnetic fields have been used to measures the earth's magnetic field.

For the immediate purpose, the total magnetic field intensity of the earth at a given location can be measured with the necessary accuracy

by means of a proton resonance magnetometer. When these three devices are used simultaneously, the geophysical and geological characteristics of the ocean bottom are more clearly understood. A prototype of this instrument was constructed at WHOI by Richard Nowak and Howard Kuenzler during the year; it was based on the design used by Vacquier at the Scripps Institution of Oceanography. Preliminary test runs showed that this type of device will work, and at the present time efforts are being made to use this measurement procedure on all geophysical expeditions.

SPECIAL GEOLOGICAL INVESTIGATIONS

ROCKS DREDGED FROM THE NORTH WALL OF THE PUERTO RICO TRENCH

J. B. Hersey, A. J. Nalwalk, and Carl Bowin

Igneous and sedimentary rocks were collected from the north wall of the Puerto Rico trench from depths of 3200 to 4200 fathoms on CHAIN Cruises 19 and 34. These rocks consist of serpentinites, basalts, limestones, cherts, radiolarian cherts, and siliceous shales. The dredging during CHAIN Cruise 19, although successful in yielding rock, suffered (1) because the location of the dredging was chosen entirely on topographic evidence, and (2) because there was no satisfactory means of locating the dredge while it was taking the sample. During CHAIN Cruise 34 the first deficiency was largely eliminated by the use of the seismic profiler to locate outcrops. The second deficiency was partly eliminated by the use of a recently-developed system of vertical triangulation which permits locating the dredge with respect to the ship. Thus the structural associations of different types can be inferred with far greater assurance than formerly.

The Puerto Rico trench, as part of an island arc, is thought to be an Alpine mountain system in its early stages (Hess, 1955; King, 1959). The rocks dredged from the north wall of the trench are comparable to those which commonly occur in typical Alpine mountain systems and were collected from a locality that is thought to be a fracture zone (Hersey, 1962; Bunce and Fahlquist, 1962). Serpentinites collected from approximately 3500 to 4200 fathoms underlie basalts and sedimentary rocks which were collected at about 3300 to 3500 fathoms (based on interpretation of seismic reflection data).

The sedimentary rocks collected from the north wall of the trench are comparable with those often found in eugeosynclines and thus eugeosynclinal deposits may represent a greater submarine depth than

has previously been maintained, for, as suggested by Gilluly (1955), the greywackes and pyroclastic slates present in eugeosynclines, but apparently absent in our dredge hauls, could be accounted for by turbidity currents. The siliceous rocks of the trench are derived in part from siliceous microorganisms, but the greater amount of siliceous material may have been derived from volcanic activity (Hess, 1955; Siever, 1962). Seismic reflection data, together with dredging results suggest that the basalts overlie or are interbedded with the sedimentary rocks. Subsequent dredge hauls and supporting data are needed before these stratigraphic relationships can be defined further.

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ROCKS DREDGED FROM THE MID-ATLANTIC RIDGE

A. J. Nalwalk

A dredge haul taken from the R/V CHAIN in 1961 on the mid-Atlantic Ridge collected a large quantity of basalts and serpentinites. Shand (1949) found basalts and serpentinites in samples dredged by R/V ATLANTIS

from the mid-Atlantic Ridge one hundred miles north of the CHAIN dredge haul. With the exception of Shand's report of the dredge hauls and the one taken from CHAIN, information concerning rocks of the mid-Atlantic Ridge has been based on material collected from the islands that project from the ridge (see Daly, 1925, 1927; Iddings, 1913; Washington, 1930; Smith, 1930a, 1930b). Serpentinites in quantity are not reported from the islands although a serpentinized dunite is reported from St. Paul's Rocks.

The rocks collected from CHAIN are very similar petrographically to those first described by Shand and restudied by Quon and Ehlers (1963). Chemical analyses of the basalts collected from CHAIN (analyst: Professor G. D. Nicholls, University of Manchester, England) show that both typical tholeiitic and alkalic basalt occur on the ridge (Kuno et al., 1957; Murata, 1960). Because the basalts dredged from CHAIN are petrographically very similar to those first described by Shand, the chemical analyses of the CHAIN rocks are probably typical for basalts present on the ridge from 29°N to 34°N latitude.

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CORAL BANKS ON THE BLAKE PLATEAU

T. R. Stetson

The continuing investigations of the Blake Plateau, begun in 1956, yielded exciting information in 1962 with analysis of data obtained on ATLANTIS Cruise 266 (1961). In several localities living coral was found associated with the accumulated remains of earlier generations, forming banks. The term "banks" is used rather than "reefs" as these corals are not associated with calcareous algae and therefore cannot, by themselves, form a rigid framework. The banks are similar to reefs in that they have been built up well above the adjacent sediments.

Over 200 banks, whose average maximum areal extent is found to be 0.5 mile, are found at a depth of about 450 fathoms, in total darkness, and at a water temperature of 7-10°C. One bank has attained a height of 60 fathoms.

The coral species are delicate branching forms, Lophelia prolifera and Dendrophyllia profunda, with the former predominating. These species are believed to form the bulk of the coral found in the banks and appear to have served as a framework to trap fine sediment transported by bottom currents. In this manner, in time, a bank is built up above the surrounding sea floor. Little is known about the age or rate of growth of these banks, but the growth rate of the predominant species, based on submarine cable record, has been reported to be at least 6.8 to 7.5 mm per year.

It is a commonly accepted fact the young coral polyps require a firm substrate on which to attach themselves in order to become established. Samples brought up by dredges have shown much indurated foraminifera ooze to be present in areas where the coral banks are developed. Thus, this rock appears suitable as a substrate for the corals forming these banks. The importance of a firm bottom for establishing colonies of corals is illustrated and confirmed by some of the echo sounding data.

Detailed bathymetric surveys on the Blake Plateau have shown the existence of linear depressions having cross sections shaped like a square root sign. Some of these features can be traced for at least 80 miles and have vertical offset of as much as 20 fathoms. In a typical crossing of a depression the vessel may traverse 0.6 mile. Frequently, coral banks are found linearly disposed along portions of the higher north

or west sides. Here, apparently, the substrate is of such competency that the banks are able to develop, and here also bottom currents were not able to sweep in loose material which would discourage the development of colonies.

Speculation about the cause of these linear depressions was immediately aroused when these features were first detected by echo sounder, both faulting and submarine erosion were postulated. By continuous seismic profiling some data were obtained that showed continuity of subbottom layers beneath the "fault" zones; such data are clearly inconsistent with faulting but entirely consistent with erosion by deep currents. In contrast, other seismic profiles across these features revealed discontinuous beds and complex structures, and thus a fault origin seems to be an acceptable explanation only for these portions.

SEISMIC AND GEOLOGICAL STUDIES OF PONDED SEDIMENTS IN THE DEEP SEA

J. B. Hersey

In 1958 during the cruise of the USCGC YAMACRAW to the Mediterranean echo soundings with very short sound pulses, 12 kc sound, contained extensive evidence of layering in bottom sediments in the deep basins of the western Mediterranean and in the North Atlantic. Many individual layers appeared to be continuous from side to side of the very deepest enclosed basins. The bottom and the underlying bedding appeared remarkably flat (slopes of 1/1000 to 1/5000) in these basins except near margins where the beds thinned out and the bottom gradually became more rugged. In the Algiers-Provencal basin the bedded area was partly flat and partly gently undulating. On several cruises made since 1959 the areas first visited were studied in some detail and many other places have been found both in the Mediterranean and North Atlantic where high-frequency sound pulses reveal layering. Enclosed basins over a wide range of size (from a mile or two to several hundred miles across) exhibit clear acoustic evidence of bedding to 30 m or so below the bottom. No basins have yet been found to lack this property except some of the flat floors of trenches (e.g. the Puerto Rico Trench). On the other hand several extensive areas not now basin-like show similar evidence of bedding.

During 1959 and 1961 cores were taken in one basin in the Tyrrhenian Sea (southeast of Naples). From these the subbottom echoes appear to

be coming from contrasts between graded coarse beds in contact with fine clays. The continuity of the beds implied by the soundings is also found to an even finer degree in the cores.

The graded coarse bedding in the Tyrrhenian Sea has been identified as turbidity current deposit by Norin (1957). We entertain tentatively the idea that the sediments were transported to these beds by deep currents of the proper strength for distributing them more or less evenly over the basin just as a fluid seeks its own level under gravity. The finer materials will have been transported by rather slow currents whereas, in the larger basins at least, turbidity currents seem to be required to transport the coarser material. In the smaller basins it seems possible that sediment slumps which don't develop into turbidity currents would prove sufficient to transport coarse sediments, granted that they were available for transport. Thus under this hypothesis the bottoms of enclosed basins are covered by approximately uniform layers of sediment deposited as a fluid mixture. We plan to test the further idea that extensive, uniformly bedded deposits found outside the basins were originally laid down in ancient basins which have since been uplifted and, in some instances at least, tilted. Evidence of such deposits is available in two distinct separate places on the outer ridge both north of Hispaniola and east of the Blake Plateau. We have not been able to study these deposits completely, but should their structure continue to bear out this interpretation then it would constitute evidence of general upwarping of the outer ridge relative to the present abyssal plains of North America basin in the recent geologic past.

SHORT CONTRIBUTIONS IN ENGINEERING AND TECHNIQUE

SUBMARINE PLANKTON SAMPLER

A. C. Vine

Working with Dr. W. Lyon of the Navy Electronics Laboratory, Dr. S. Galler of the Office of Naval Research, and Dr. J. Mohr of the University of Southern California, Mr. Vine put semiautomatic plankton samplers on submarines SEA DRAGON and SKATE for their rendezvous at the North Pole.

SEA DRAGON left from the Pacific and SKATE from the Atlantic, together covering a considerable area of the Arctic Ocean. Each submarine obtained over a hundred plankton samples that are being analyzed now by Dr. Mohr.

FM ECHO SOUNDER

A. C. Vine

The possible advantages of frequency modulation over short pulses for echo sounding has been given considerable attention. While frequency-modulated echo sounders have several limitations, their inherently high data rate would be most useful and their multichannel method of analysis and read-out suggests a simple side-looking echo sounder that could plot depth contours directly.

TAPE RECORDING SYSTEM FOR SCUBA DIVERS

Lloyd R. Breslau

(This development was completed in cooperation with Dr. John M. Zeigler and Mr. David M. Owen)

A system consisting of a small portable tape recorder, hydrophone, and full-face breathing mask has been devised which enables a scuba diver to continuously record his observations during a dive. Information is effortlessly recorded by the diver by simply speaking into the breathing mask in a conversational voice. The option exists of allowing the tape recorder to run continuously over a maximum elapsed time of 1-1/2 hours or of activating it manually for each individual conversation.

A miniature ceramic hydrophone has been fastened to the inside of a Scott Hydro-Pak full-face mask, and a Mohawk Midgetape battery-operated portable tape recorder has been enclosed in a submersible Plexiglas housing 3 x 5 x 11 inches which is secured to the scuba air reservoir tank. A manual on-off switch is provided on the tape recorder housing as well as visual indication of the tape recorder battery voltage, tape transport, and amount of tape remaining. This system has been designed to perform up to a depth of 150 feet, which is the working range of a scuba diver. The tape recording system for scuba divers has been field tested during a study of beach erosion by scientists using scuba. The instrument performed satisfactorily and therefore no further development work is anticipated.

This system has been described in a manuscript entitled "A Self-Contained Portable Tape Recording for Use by Scuba Divers," WHOI Contribution No. 1282, and has been published in the "Bulletin de l'Institut Oceanographique," No. 1235, 12 June 1962.

This work is a joint effort with the Massachusetts Institute of Technology inasmuch as Mr. Breslau is being supported under their Contract Nonr-1841(74) with the Office of Naval Research.

PRECISION TIME SOURCE FOR REMOTE CONTROL

Lloyd R. Breslau

A miniaturized precision time source for use in submerged instruments has been designed and two models have been constructed. The time source employs a 100-kc crystal as its frequency standard, a silicon transistor oscillator stage, a germanium transistor buffer stage, and five silicon induction transistors as decade frequency division stages. The frequency shift is less than two parts per million per degree centigrade, as determined by the temperature coefficient of a 5° X-cut crystal blank acting as primary standard at ambient temperatures. It has been ascertained that the substitution of a more expensive type of crystal, a GT-cut blank, would result in improved performance at ambient temperatures.

The miniaturized precision time source has been installed in a standard E.G. and G. SP-8 Sonar Pinger, and has successfully completed a sea trial in fifteen hundred fathoms of water. A section of annotated Precision Graphic Recorder record obtained during this pinger lowering is presented in Figure 1. It has been found possible to track an instrument in the sea by employing a Precisely Timed Submersible Pinger and a Precision Graphic Recorder (reported by Breslau, et al., (1962). "A Precisely Timed Submersible Pinger for Tracking Instruments in the Sea," WHOI Contribution No. 1269, Deep-Sea Research, Instrumental Notes, March-April 1962, p. 137-144.

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TRANSFORMATION OF THE INDEPENDENT VARIABLE FROM TIME TO DISTANCE IN OCEANOGRAPHIC OBSERVATIONS

Hartley Hoskins, William M. Dunkle, Jr., and Lloyd D. Hoadley

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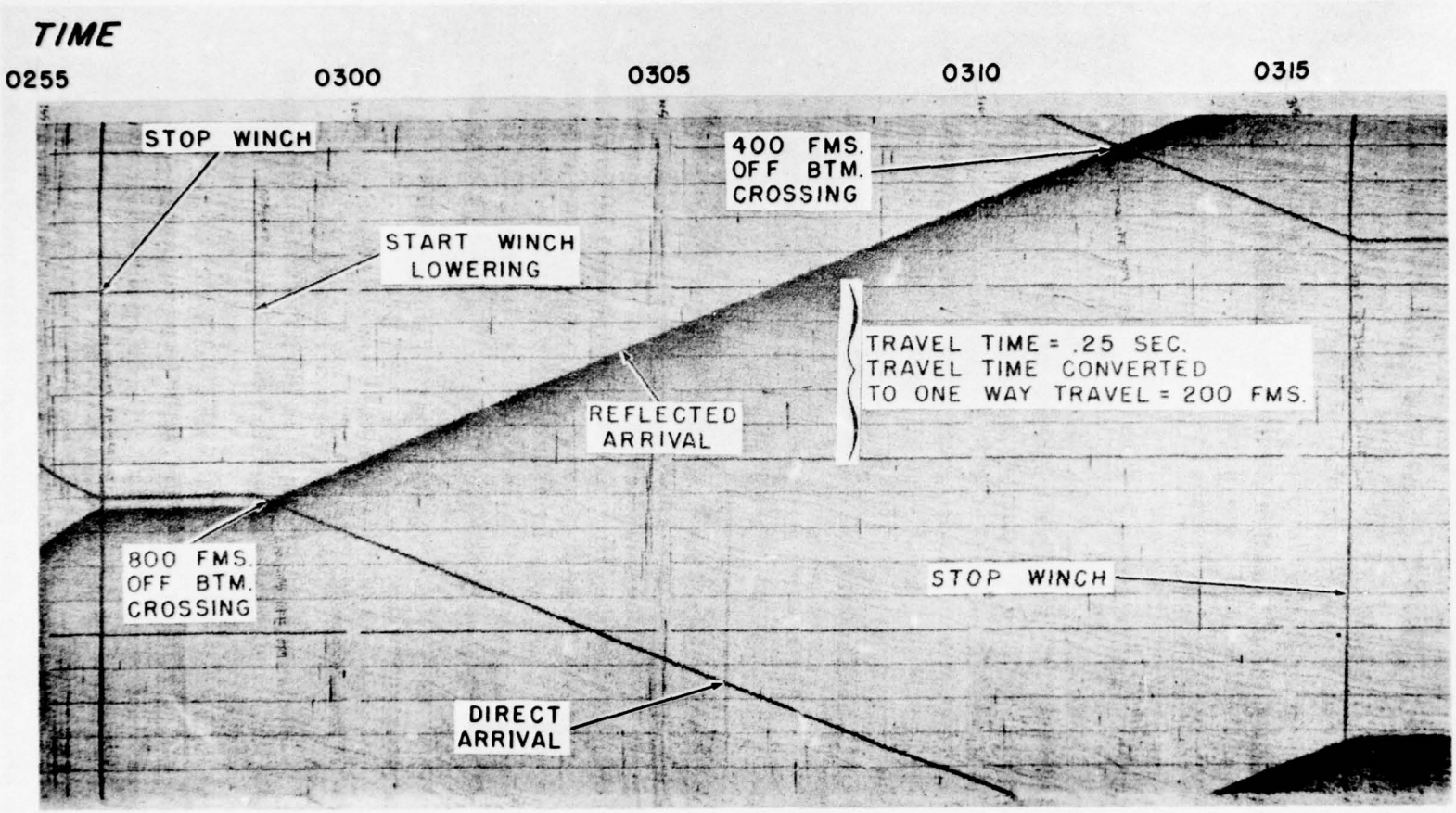


FIGURE 1. SECTION OF ANNOTATED PRECISION GRAPHIC RECORDER RECORD.

location or distance over the ground. The latter presentation is usually desired in the case of continuous echo sounding profiles, continuous seismic reflection profiles, and continuous temperature profiles. Navigational control at sea is at present not adequate to control the speed of advance of the recording paper, which would display the observations as a function of distance. The position of the ship at any time is determined best from the smoothed final navigation plot. The present program seeks a means of accurately converting the independent variables of long strip charts from time to distance. This can be done by recopying the record at a rate inversely proportional to the ship's speed (usually relative to the bottom). Several different scales of the same dependent variable (commonly, depth or travel time) are in use, and it is desirable to convert all recordings to a common scale across the record.

This is being implemented by using "slit photography." It is done as follows: the strip of paper bearing the time-based recording, travelling at a varying speed (ascertained from the navigation plot of the ship), is transported by a set of rollers past a narrow slit, which is viewed continually by a moving strip of photographic film through a suitable lens. Several types of microfilm and "flow-film" cameras for copying, with the relative scale preserved, are commercially available. A machine manufactured by Photocopie GMBH of Berlin, capable of copying onto 35 mm film the 19-inch widths of paper used by the Precision Graphic Recorder, was borrowed through the courtesy of Recordak Division of Eastman Kodak. By a simple modification of the film drive, compressions of 2.5x were made with satisfactory retention of detail. Two conclusions were drawn from our experience with this machine. First, the desirability of working with constant exposure - that is to say, varying the rate at which the copy is transported past the viewing slit, rather than vice versa. Slits as small as 1/32 inch were used and, as expected, the smaller the viewing slit the greater the fidelity of the print. The speed of the film limits the amount by which the viewing slit can be reduced. Second, paper transport is a delicate problem since the recordings are made usually on paper that is readily torn and not dimensionally stable. Making a long strip track pass the viewing slit requires a certain amount of slack in the drive for "steering."

During this exploratory period, a new machine manufactured by Photostat Division of Itek came to our attention. It has a superior paper transport, and a variable-speed drive could be installed more readily in its paper transport. The unit was purchased and now is being used to copy records on 35 mm film, with the ratio of the original dimensions the

same or at three fixed extensions or compressions. The addition of a calibrated, continuously variable planetary transmission to the paper drive will complete the modification. The remaining step will be to introduce such optical systems as will allow variable reductions to compensate for the different sizes of recording papers used.

PHYSICAL OCEANOGRAPHY

PHYSICAL OCEANOGRAPHY DEPARTMENT

F. C. Fuglister, Department Chairman

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DEEP CURRENT STUDIES

Joseph R. Barrett

After the ERIKA DAN cruise to the Labrador Sea led by Mr. L. V. Worthington and a shorter cruise in May to investigate deep currents in the slope water region south of Woods Hole with Mr. Volkmann, preparations were begun for a fall cruise to measure deep currents in the vicinity of Cape Hatteras. This investigation was prompted by the earlier deep current measurements which had been made in 1957 just east of the Florida Current near 33°N, (Swallow and Worthington, 1961) and by observations of deep westward currents made south of Cape Cod by Mr. Volkmann (1963).

The possibility that the southward-moving water offshore from the Florida Current and the westward drift in the deep slope water inshore from the Gulf Stream constituted parts of a continuous deep current similar to that postulated by Mr. Stommel (1957) seemed to merit further investigation. The notion of continuity required that this current pass under the Gulf Stream somewhere in the vicinity of Cape Hatteras and so it was proposed to measure deep currents using neutrally-buoyant floats along the axis of the surface stream as it was beginning to flow over the continental slope and into the deeper water of the western basin after leaving the Blake Plateau.

The plan of operation, which was followed quite closely, called for close cooperation between two ships. The ATLANTIS tracked neutrally-buoyant floats at five locations under the axis of the stream starting near 34°N and thence to the northeast at intervals of about forty km. Two or more floats were followed simultaneously at various depths at each location for about 2 days. Somewhat more than 17 float-days of observations were completed. The location and drifts of the floats are shown in Figure 1 as well as 3 oceanographic stations made by ATLANTIS.

In addition five lowerings of Mr. Bruce's photographic current meter were made to record currents in the very near bottom layers. This device is a large tripod carrying an Edgerton camera and strobe unit which at regular intervals takes pictures of a small rotor-driven counter and a compass a few inches above the bottom. Three of the five lowerings provided useful records, all indicating the existence of currents of a few cm/sec, but generally less than 4 cm/sec. In order to prevent upsetting the tripod, the ship was required to maintain position very precisely in a current that often exceeded four knots - a maneuver accomplished with great skill by the ships' officers.

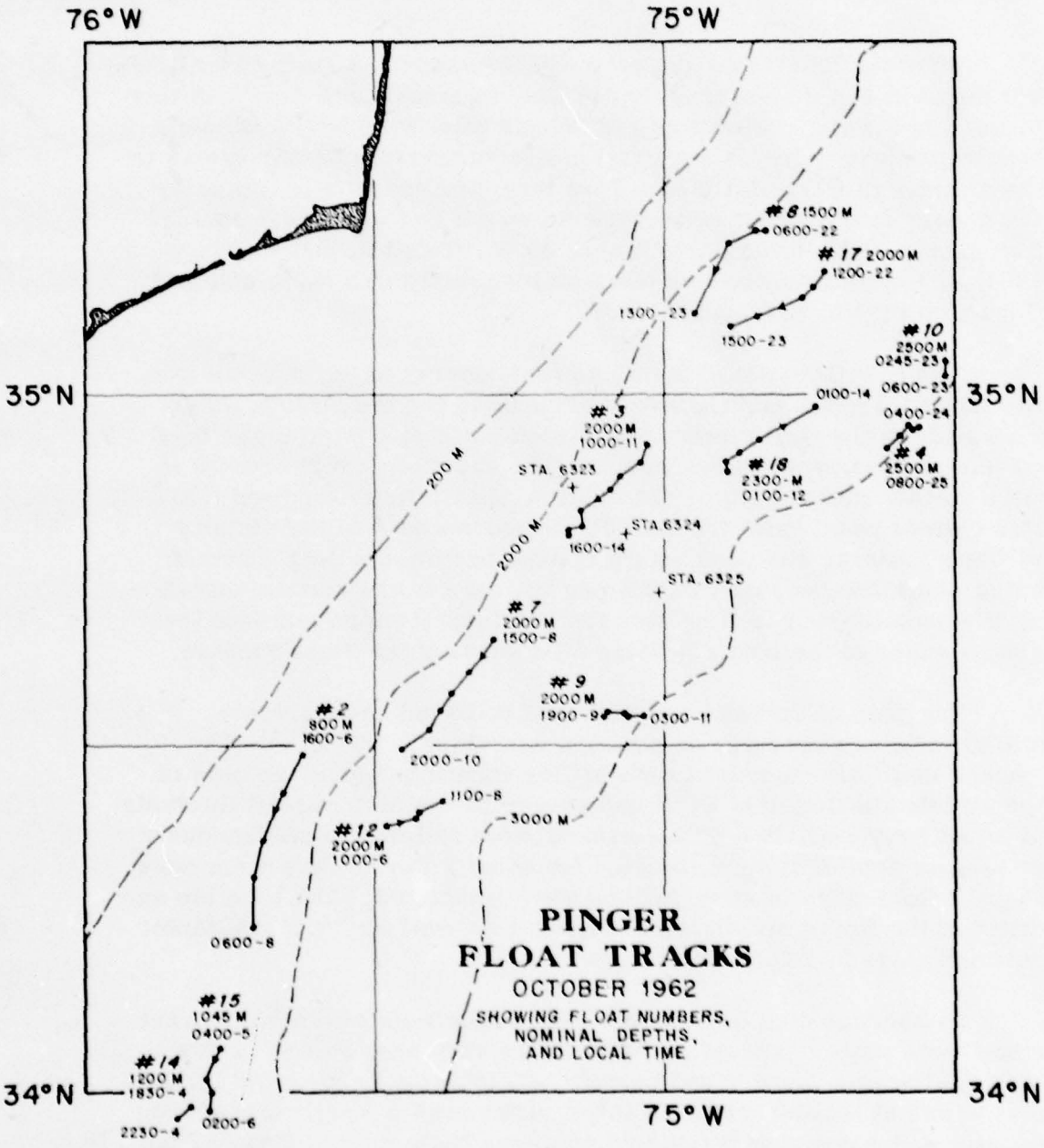


FIGURE 1. PINGER FLOAT TRACKS, OCTOBER 1962.

While these observations were in progress, R. V. CRAWFORD under the leadership of Dr. T. Ferris Webster was engaged in making closely spaced oceanographic sections across the current using the in-situ salinometer. An extensive program of GEK and bathythermograph observations was also carried out on board CRAWFORD. The two ships progressed down stream together from one location to the next in order to maintain as nearly as possible the synoptic nature of the survey.

The data are currently being processed but it seems quite clear at present that an undercurrent of at least the magnitude observed in 1957 will emerge. Swallow and Worthington estimated the southward flow at that time to be 6.7 million m^3/sec. The evidence indicates that the zero-velocity, or reference level occurred at a somewhat shallower depth than that calculated in 1957 and this will probably produce a higher volume transport, but still much smaller than that calculated in 1959 and 1960 by Mr. Volkmann in the slope water region (up to 50 million m^3/sec). Nevertheless, it is clear from preliminary T/S analysis that the source of the water observed to be moving to the south is the slope water region. At a potential temperature of 3.5°C this water is uniformly somewhat fresher than the comparable water of the Sargasso Sea and this freshening is observed on stations in the vicinity of the floats.

A paper entitled "Deep Currents South of Iceland" written in collaboration with Mr. John H. Steele (senior author) of the Marine Laboratory, Aberdeen, and Mr. L. V. Worthington has been accepted by Deep Sea Research and will be published in 1963. Based on a joint cruise of the research ships CHAIN of the Woods Hole Oceanographic Institution and EXPLORER of the Marine Laboratory in which the method of neutrally-buoyant floats and oceanographic sections was employed, this paper describes the deep overflow of Norwegian Sea water across the Iceland-Faroe Ridge into the eastern basin of the North Atlantic. Using a reference level based on direct current observations the volume transport of <u>pure</u> Norwegian Sea water was calculated to be 1.4 million m^3/sec. With this was entrained, according to a T/S analysis, about 4 million m^3/sec of "Atlantic-Irminger" water. Because this mixture is noticeably more saline than the deep water of the North Atlantic it can be traced to the southwest whence it passes through a gap in the mid-Atlantic Ridge and into the western basin. A transport of 1.4 million m^3/sec may seem quite small, but is comparable to the calculated Mediterranean outflow of 1.7 million m^3/sec (Sverdrup, Johnson and Fleming, 1942). It is suggested that the spreading of the Norwegian Sea outflow has not been so widely observed as that of the Mediterranean because its salinity anomaly is smaller and because it is largely dissipated in

a region where observations have been sparse.

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CURRENT STUDIES

John G. Bruce

ATLANTIS Cruise 274 was made to examine the current structure in a region bordering the northern Antilles island arc. Stations were made approximately on a line between San Juan, Puerto Rico, and 23° N., 66°W., there being ten locations for hydrographic stations along the line. Each location was sampled twice with a three-week interval between the samplings. At three locations along the line (21° 34'N., 20°56'N., and 20°10'N.) Swallow floats and drogues were set at various depths from 200 m. to 5500 m. Hydrographic stations were also bracketed about these locations. The floats and drogues seemed to indicate a fairly steady flow toward the E to NE from 1500 m. down to 4500 m. The depth of greatest velocity, approximately 8 cm/sec, seemed to be at 2000 m., while at 4500 m. the velocity was 2-3 cm/sec. Above 1500 m. the movement seemed turbulent in nature with no strong surface currents. These general conditions appeared to continue over the three-week period of the study. In one case, using a float and a drogue, continuous tracking was made at 2000 m. for 10 days indicating a steady flow E to NE. If continuity is assumed both vertically and horizontally in the region of three locations, it may be possible for a transport of approximately 50 million m^3/sec to have existed for this period.

A cruise of 10 days was made in the Tongue of the Ocean

(central region) to study water motion within and below the main thermocline using parachute-type drogues. Measurements were made at 50 m., 200m., and 500 m. depths and in general indicated turbulent flow (with speeds of 5-10 cm/sec). An exception was the movement at 200 m. which flowed nearly parallel to the contours of the east bank for approximately three days at velocities of 30-35 cm/sec while the current at 50 m. and 500 m. in this region showed a much slower and more turbulent flow. Other measurements made during a previous year seemed to show a similar weak vertical coupling between layers of water within a region.

A cruise was made on the ARAGONESE (SACLANT ASW Research Center, Italy) in conjunction with the ATLANTIS cruise 275 (A. Miller) to study effects of cooling and sinking of winter water in the eastern Mediterranean. Hydrographic stations were made by ATLANTIS and direct current measurements with drogues were made with ARAGONESE in the southern Aegean Sea. Most direct measurements were made at 200 m. as oxygen data seemed to indicate marked sinking of water to that level. Direct current measurements indicated a large amount of horizontal turbulence. In one case a large counterclockwise gyre persisted for approximatley three days with a radius of ten miles and perimeter velocity of 40 cm/sec. No simple flow in or out of the Aegean basin seemed to be indicated by the direct measurements made during this cruise.

A study is continued of data from previous years obtained in the Bermuda region. Current measurements from two cruises seem to indicate a general steady flow (of at least 2-3 week periods) around Bermuda and its banks with a marked turbulent region in the down-current portion of the banks, producing an "island wake" effect.

Design and construction of current meters was continued mainly with the objective of developing a meter for obtaining a vertical profile of currents.

COASTAL OCEANOGRAPHY

Dean F. Bumpus

A program has been conducted on the continental shelf concerned with the circulation and the annual cycle of temperature and salinity since 1955. Presently, this is being supported by contracts with the Bureau of Commercial Fisheries,

the Atomic Energy Commission and the National Institutes of Health.

The main features of the program have been (a) the establishment of a series of observation posts from Maine to Georgia at selected lightships and shore locations where daily temperature and salinity measurements were made and drift bottles were released; (b) the release of drift bottles and sea bed drifters by our own ships and ships of cooperating agencies over the continental shelf from Cabot Strait to Florida, in an effort to examine the seasonal and year-to-year trends in the surface and bottom circulation; (c) the commencement of a series of current measurements by means of moored current meters and drogued telemetering drift buoys at selected locations. Cooperators have been: the Biological Station at St. Andrews, New Brunswick, of the Fisheries Research Board of Canada; the Bureau of Commercial Fisheries Laboratories at Boothbay Harbor, Maine, Woods Hole, Massachusetts and Beaufort, North Carolina; the Bureau of Sport Fish and Wildlife Biological Laboratory at Sandy Hook, New Jersey; the U.S. Weather Bureau Atlantic Weather Project, the U. S. Air Force Weather Observers on the Texas Towers; the U. S. Coast Guard lightship crews; and the Virginia Institute of Marine Science at Gloucester Point, Virginia.

The temperature and salinity data from the oceanographic observation posts together with an interpretation of the data are published annually in the Special Scientific Reports - Fisheries. Mr. Joseph Chase is currently readying the 1961 and 1962 reports.

About 23,000 drift bottles and 7800 sea bed drifters were released during 1962 with about 10% and 15% returns respectively. The drift bottle data are being combined together with that from previous years into a series of 12 charts depicting the direction and speed of the non-tidal drift and the % recovery from 30-minute rectangles for a 12-month series covering the east coast of North America extending from Cabot Strait to Florida. Much additional Canadian data will be included in this work. Dr. Louis Lauzier of the FRBC Biological Station will collaborate.

There is considerable variation in the circulation from season to season and from one season one year to the same season another year. Notable are the alternation in the circulation off the South Atlantic states, where an offshore component apparently prevails during the winter, a northerly component prevails during the spring and early summer and a southerly component during the late summer and autumn; and the higher per cent return and northerly component off the mid-Atlantic states during the spring and summer of 1962

in contrast to the predominantly southerly drift during the same period in 1961.

The sea bed drifter program has not gone on long enough to establish any satisfactory understanding of the bottom circulation. They appear to drift at about 1/3 to 1/10 the speed of the surface drift bottles.

Experiments with moored current meters on the continental shelf south of New England were conducted by Dr. Malcolm Howe as were experiments with drogued telemetering buoys between Cape Cod and Cape Hatteras. We expect the results of the moored current meters to be analyzed during the first semester of 1963 by Julien Goulet, a senior at M. I. T., as part of a senior thesis. The results of the experiments with the drogued telemetering buoys were reported by Dr. Howe in Deep Sea Research , Vol. 9. In essence he found that the resultant velocity profiles across the shelf are related to the density field, that the salinity distribution almost completely dominates the ultimate shape of the density distribution, but during the summer months the temperature distribution plays a more important role in the density distribution than during the other seasons. Land drainage can have an appreciable effect on the salinity distribution over a period of from two to five months after peak runoff.

Two sets of experiments have been conducted on the continental shelf off Cape Canaveral in cooperation with the Chesapeake Bay Institute during March-April and August in which advection and diffusion were measured. Analysis of that data is presently under way.

FORECASTING WINTER TEMPERATURES IN SOUTHERN NEW ENGLAND

Joseph Chase

The chance reading of a review was the introduction to Dr. Franz Baur's work on a relationship between November pressures and temperatures at selected stations and the subsequent average winter (December, January and February) temperature in southern New England. The availability of monthly mean pressure maps at the Institution made possible the examination of the pressure field for the entire hemisphere month by month.

The examination revealed the similarity (allowing for normal seasonal changes) between the patterns of November and those of subsequent winter months. The similarities were found to be closer in high latitudes and especially along the trans-arctic ridge, the path which connects Siberia, the wintertime cold pole in this hemisphere, with the United States. It is down this path that our coldest air masses travel and the stronger the flow of cold air the colder the winter will be.

A template was devised to gauge the cold air flow in November and its readings are translated into average winter temperatures by means of a regression equation derived from experimental data.

The method gave a correlation coefficient of +0.77 when applied to twenty years of independent data and this is significant at above the 0.1% level.

The forecast of average temperature for this winter was 29.4°F or 1.8°F below the normal, currently in use by the U. S. Weather Bureau. The observed figure will be about 3°F below normal, giving a forecast error well within normal expectations.

GULF STREAM '60

F. C. Fuglister

The evidence from the multiple ship survey in 1960 indicates that the Gulf Stream reaches to the bottom of the ocean. The meander pattern of the current appears to have a sharp line of demarcation near 65° west longitude, the longitude of Bermuda separating the area of relatively small amplitude meanders in the west from the eastern area of much larger north-south meanders. Since a direct deep current measurement showed flow deflected by Kelvin Sea Mount, it seems probable that the shapes of these large meanders may be influenced by the various sea mounts in this area. The path of the Gulf Stream changed very little over a period of 10 weeks; all observed changes in position could be accounted for by lateral movements of less than 2.5 miles per day. The large meanders observed thus formed a nearly stationary wave front along the northern border of the Sargasso Sea. The slope water current was observed but appeared to be a weaker flow than in the past.

Profiles across the Gulf Stream spaced 100 miles apart do

not give an unambiguous picture of the pattern of currents. Following the maximum surface currents downstream with the GEK is a rapid method of delineating the current position, although streakiness occurs in the velocity distribution to such an extent that occasionally the current is lost. Where a cyclonic eddy is being formed to the south of the stream this method of tracing the current may also produce ambiguous results. The possibility exists that the surface currents at these points are quite complicated and perhaps separated from the deeper flow. A telemetering surface float, for instance, was observed to take a month to pass such a location.

It is evident from this study that the volume transport of the Gulf Stream in the area between Cape Hatteras and the Grand Banks is still unknown. The deep current measurements indicated that the transport may be as great as twice the generally accepted value of around $70 \times 10^6 m^3/sec$, although many more deep direct current observations in the Gulf Stream are needed before the actual transport values can be obtained.

A paper entitled "Gulf Stream '60" by F. C. Fuglister has been accepted for publication by the Pergamon Press, for the Progress in Oceanography, Volume I.

Mediterranean Outflow

The spreading of Mediterranean water from the Straits of Gibraltar over the Atlantic is a well-known characteristic of that ocean. The highly saline Mediterranean water flows out of the Straits along the bottom and then down the continental slope until it reaches a depth where it is no longer more dense than the surrounding water. It does not spread out evenly over the Bay of Cadiz but tends toward the northern slope, that is, along the Portuguese south coast, not actually on the shelf but where the depths range around six and seven hundred meters. The salinity and the density of this water rapidly decreases as it mixes with the fresher water of the Atlantic so that by the time it reaches Cape St. Vincent at the southwest corner of the Iberian Peninsula the maximum observed salinity has changed from over $38.0^o/oo$ to $36.5^o/oo$ and the sigma t from 29.0 to 27.7.

Using the water above the sill depth immediately inside the Mediterranean as 100%, several attempts have been made to determine the percentage of Mediterranean water in the core of high salinity off Cape St. Vincent. Percentages varying from as low as 8% to as high as 60% were obtained. It appears that the most probable value will turn out to be near 35%. If this value is a realistic one

then the influence of the Mediterranean water in the Atlantic cannot be as shown by Wüst[1] (1935).

[1]Wüst Georg (1935) Die Stratoshore. Deutsche Atlantische Exped. Meteor. 1925-27 Wiss. Erg. Bd. 6, 1 Teil, 2 Lief

ABYSSAL CIRCULATION IN THE WESTERN BASIN OF THE NORTH ATLANTIC

Hideo Kawaii

With the aid of certain direct current measurements, a study of the abyssal circulation in the Western Basin of the North Atlantic is being made based on the hydrographic station data from "Gulf Stream '60," the IGY survey and other deep hydrographic observations made by WHOI since 1954. The physical idea of this study is that stream lines in a steady state might be indicated by intersections between constant potential temperature surfaces and isohaline surfaces, because except in the bottom boundary layer mixing seems negligibly small. Since this kinematical relationship cannot determine the sense of the flow, the geostrophic relation was used in some restricted regions.

The main charts prepared for this study are isotherms of potential temperature at the bottom and at levels of 4800 m and 4000 m, and isobaths and isohalines on selected potential temperature surfaces (1.85°, 2.0° and 3.5° C) in the "Gulf Stream '60" area. In addition to these, isobaths and isohalines on the 1.85°C surface have been prepared for the entire Western Basin.

Contouring on a horizontal or nearly horizontal surface involves much interpolating. To approach a consistent and systematic interpretation of the data, a double interpolation was made for the main contour lines by imposing certain conditions on them. For instance, the 1.85°C isotherm at 4800 m must coincide exactly with the 4800 m isobath on the 1.85°C potential temperature surface because no significant inversion of potential temperature occurs in deep waters. An isohaline on a constant potential temperature surface must not turn far aside from an isobath on the same surface, if it is assumed that a stream line does not change its level abruptly.

The 1.85°C potential temperature surface is, in steps of 0.05°C, the deepest one which covers the whole Western Basin. This special surface lies at depths of 4500 to 5000 m close to the bottom in the basin off New England, and tends to rise to the south and to the east. It intersects the American continental slope and the western slope of the mid-Atlantic Ridge. No 1.85°C water is found in the Eastern Basin except in the Cape Verde Basin. An outstanding feature of the 1.85°C surface is that a narrow thermal trough stretches nearly along the deepest part of the floor, adjacent to the foot of the continental slope, from the Antilles Arc north

beyond Cape Hatteras and then east to the Grand Banks. If the Gulf Stream extends to the ocean bottom, it may run along the northern edge of this trough in the basin off New England.

Isohalines on the 1.85°C surface indicate a tongue of extremely fresh water, the so-called Antarctic Bottom Water, lying generally along the western slope of the mid-Atlantic Ridge, but branching out to the west in some places. After reaching the southern slope of the thermal trough, south of the Grand Banks, it turns to the west. A band of relatively saline water, the so-called Labrador Bottom Water, seems to extend along the continental slope from the Grand Banks to Georges Bank. Another region of deep saline water appears near the axis of the thermal trough and reaches down the basin to a point north of the Puerto Rico Trough. Accordingly, the main abyssal circulation pattern in the Western Basin may consist of a large cyclonic gyre.

A comparison between the dynamic topography chart, referred to the bottom, and several measurements of deep current in the "Gulf Stream '60" area suggests that no significant bottom countercurrent exists beneath the Stream or south of it in the basin north of Bermuda. In accord with this result, the current direction on the southern side of the thermal trough in the "Gulf Stream '60" area was estimated from the density stratification under the 1.85°C surface, and a reasonable direction of flow for the fresh water obtained. There is a possibility, however, of a meridional countercurrent on the continental slope if the bottom slopes down sharply to the south. To ascertain the character of the gyre over the whole Basin, studies of the bottom currents with reference to bottom topography are required.

The distributions on the 2.0° and 3.5°C surfaces show some different features; conclusive interpretations have not yet been obtained because they should be made with relation to the circulation in the Eastern Basin.

EQUATORIAL CURRENT SYSTEM

W. G. Metcalf and M. C. Stalcup

It is a little surprising that the Equatorial Undercurrent in the Atlantic remained obscure for so long in view of the large number of hydrographic observations in the Equatorial region, and especially when one remembers that Buchanan reported the current

in several papers between 1886 and 1895. At least two later authors mentioned Buchanan's findings, but for some reason they seem to have been largely ignored until recently.

The CRAWFORD section along the Equator made during the International Geophysical Year in 1958 failed to detect the current primarily because the section ran parallel to the current.

The chief reason why this undercurrent failed to come to the attention of many oceanographers who studied the region, is that the sampling bottles were not placed closely enough together in the shallow water to give the true magnitude of the salinity maximum which occurs at less than 100 meters along the Equator.

The startling wire angles on stations plus the reporting of the Equatorial Undercurrent in the Pacific by Cromwell, Montgomery, and Stroup in 1954 combined to make us aware of the Atlantic version. The data collected on CHAIN cruise 17, in the spring of 1961, gave conclusive evidence of an Equatorial Undercurrent in the Atlantic; it was measured at some 2 1/2 knots flowing to the ast in a thin subsurface stream below a slow moving westerly drift (Metcalf, Stalcup and Voorhis 1961).

It is with this background that the coming multi-ship survey has been planned. Under the name of Equalant I, studies by various ships and agencies of the U. S., USSR, Brazil, Argentina and several African nations are being coordinated by the U. S. Bureau of Commercial Fisheries. These studies will extend across the Tropical Atlantic from the coast of Brazil to the Gulf of Guinea.

The CRAWFORD will be engaged primarily in physical oceanographic observations. It is hoped that the in-situ salinometer will enable us to measure the temperature and salinity against depth continuously through the current, something never before attained. The major part of the CRAWFORD's work will consist of closely spaced hydrographic stations in the quadrangle between 10° North and South and between 25° and 35° West. Five north-south sections and two east-west sections, will be surveyed. The CHAIN will set Richardson current meters near the Equator on most of these sections. In addition a wide variety of biological, geological and chemical observations will be made from that ship.

At the time of CHAIN Cruise 17, preliminary evidence led to the idea that the deepest passage across the mid-Atlantic Ridge was well east of the Romanche Trench and was entirely unassociated with that feature. However, detailed studies of the combined bathymetric

and hydrographic evidence indicate that a passage extending in a nearly easterly direction from the Trench itself leads the deepest coldest water from the Western Basin to the Eastern Basin via the Trench. The effective sill depth appears to be approximately 3750 meters.

References

Metcalf, W. G., Stalcup, M. C., Voorhis, A. D. The Atlantic Equatorial Undercurrent. Journal Geophysical Research, Vol. 67, No. 7.

MEDITERRANEAN CIRCULATION

A. R. Miller, C. D. Densmore, R. G. Munns

The last of a series of three cruises to the Mediterranean Sea was completed early in 1962. These cruises had as objectives the determination and observation of the processes involved in vertical circulation and the formations of deep or intermediate waters. Circumstances promoting these processes required that investigations be carried out in the winter season.

The ATLANTIS Cruise 275 departed Woods Hole early in January and returned in late April after a stormy two and one half months' work in the Mediterranean area. One hundred and nineteen hydrographic stations were occupied, some of these in conjunction with other work carried out by the Yugoslavian vessel BIOS in the Adriatic Sea and with the Saclant Research Vessel ARAGONESE from La Spezia, Italy, in the Aegean Sea. Cooperating foreign scientists aboard the ATLANTIS during this cruise were P. Tchernia, P. Guibout and A. de Quay from the Laboratoire d'Oceanographie Physique in Paris, A. Skrivanic of the Instituta za Oceanografiju i Ribarstvo at Split, H. Kolokythas, director of the Greek Hydrographic Service, and A. de Maio of the Naval Institute in Naples.

Aside from the standard oceanographic stations, other work was aimed at determining surface phenomena such as the surface circulation and exchanges across the sea surface. Drift bottles were set out throughout the cruise as part of a cooperative program with the French Hydrographic Service. Radiation measurements were made aboard ship and evaporation observations were carried out with the use of a sling-mounted evaporating pan. Comparative tests were made between the Woods Hole and Brown salinometers and samples were retained for silver nitrate titration to be done in Paris. Samples were taken for National Institute of Oceanography for the general program of determining the constituents of sea water. It should be noted that liaisons were made with various oceanographic interests at the Mediterranean ports-of-call. A short movie was made in cooperation with the U. S. Information Service in Athens for distribution in Greece.

The accompanying chart (Figure 1) shows that with the exception of areas off Tunis and Libya, the entire Mediterranean Sea from Gibraltar to the Black Sea is represented in the Woods Hole observations taken in 1961 and 1962. In particular, such

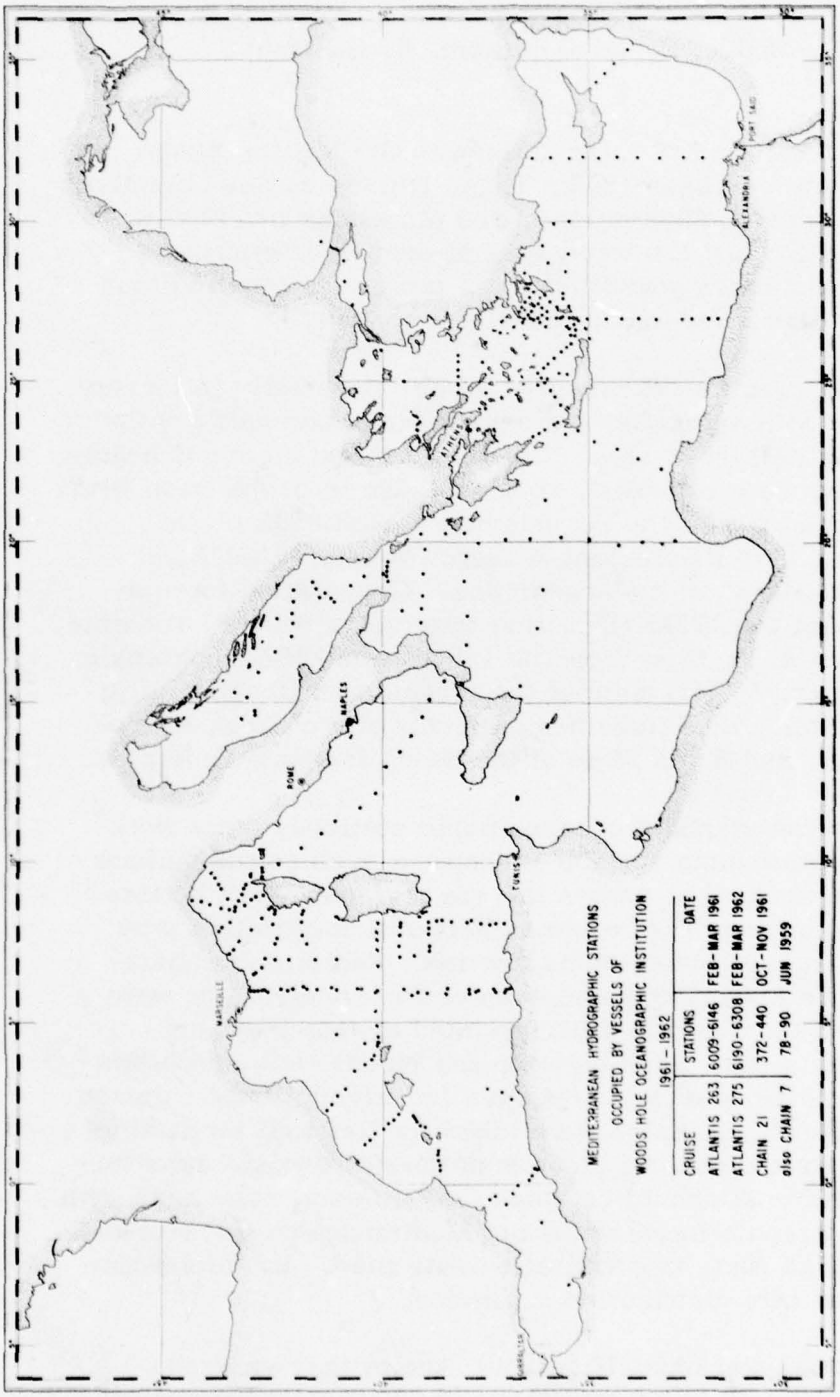

MARSEILLE
ROME
NAPLES
TUNIS
ALEXANDRIA
PORT SAID
MEDITERRANEAN HYDROGRAPHIC STATIONS
OCCUPIED BY VESSELS OF
WOODS HOLE OCEANOGRAPHIC INSTITUTION
1961 – 1962
CRUISE | STATIONS | DATE
ATLANTIS 263 | 6009-6146 | FEB-MAR 1961
ATLANTIS 275 | 6190-6308 | FEB-MAR 1962
CHAIN 21 | 372-440 | OCT-NOV 1961
also CHAIN 7 | 78-90 | JUN 1959

FIGURE 1.

key areas as the Ligurian, Adriatic, and Aegean Seas are reasonably well sampled. It is in these Seas where Mediterranean water makes its final transformations before sinking below the surface. These key northern regions are the initial meeting grounds between dry polar continental air and warm maritime air masses. Here the water is transformed by cooling and evaporation to sufficient density to sink and disappear from the surface.

Temperature and salinity profiles from ATLANTIS Cruises 263, 275 and CHAIN 21 have been drawn and the T/S characters of the waters have been determined (Figures 2 and 3). A significant feature from the T/S analysis is the deep seasonal change occurring in the lower Aegean Sea. A smaller degree of seasonal change occurs in the Western Mediterranean. Periodic and aperiodic large-scale changes occur in the Adriatic, which is a strong contributor to Eastern Mediterranean circulation. In a recent meeting of the International Commission for the Scientific Exploration of the Mediterranean Sea this facet of variability in the deep circulation was recognized.

Oxygen values from these cruises have been compared with previous work and plotted. The oxygen minimum layer in the Western Mediterranean appears to be the source for water passing into the Atlantic. Assuming this layer to be the nutrient-rich layer from the inverse relationship between oxygen and phosphate, the Mediterranean is impoverished by this outflow.

The Mediterranean Sea gets little fresh water contribution from run-off and rainfall, hence a dominant part of its complicated circulatory system depends on the transfer of energy at the sea surface through evaporative processes and incoming radiation. Evaporating pan measurements show that, in terms of salinity increase, a rise in surface salinity of 0.1‰ per hour is normal for the area due to evaporation. Incoming radiation may offset the instability of surface conditions to some extent but evaporation is a strong influence in the vertical circulation of the Mediterranean where the range of density is relatively small.

Experiments were carried out to observe evaporation by determining the changes in salinity in various containers under a variety of conditions.

Concurrent with the demand for direct observations of evaporation is the need for radiation measurements. Net radiation is somewhat difficult to measure from a moving ship. Attempts were made in this direction and the results are now being analyzed and evaluated.

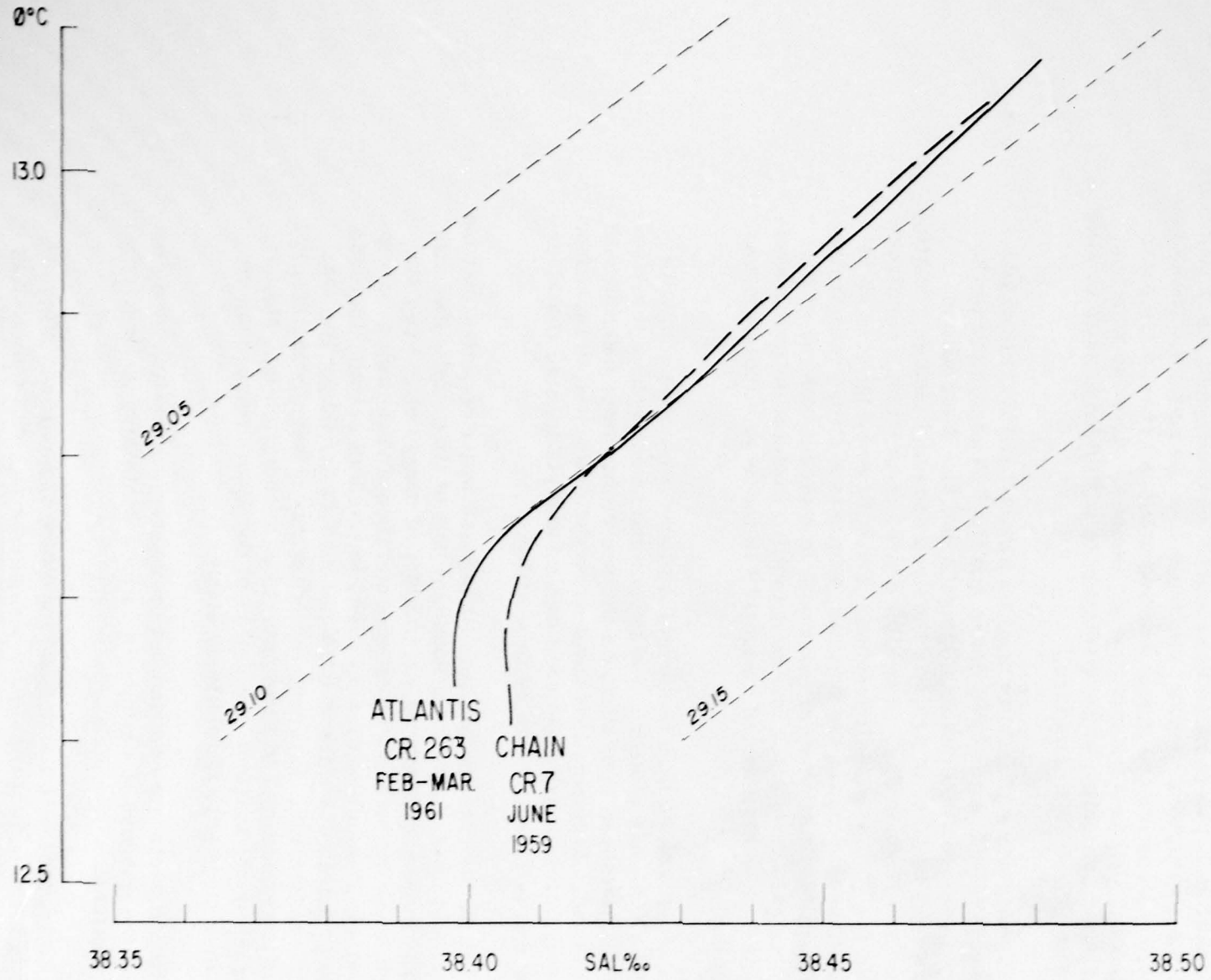


FIGURE 2. POTENTIAL TEMPERATURE-SALINITY CURVES FOR WESTERN MEDITERRANEAN.

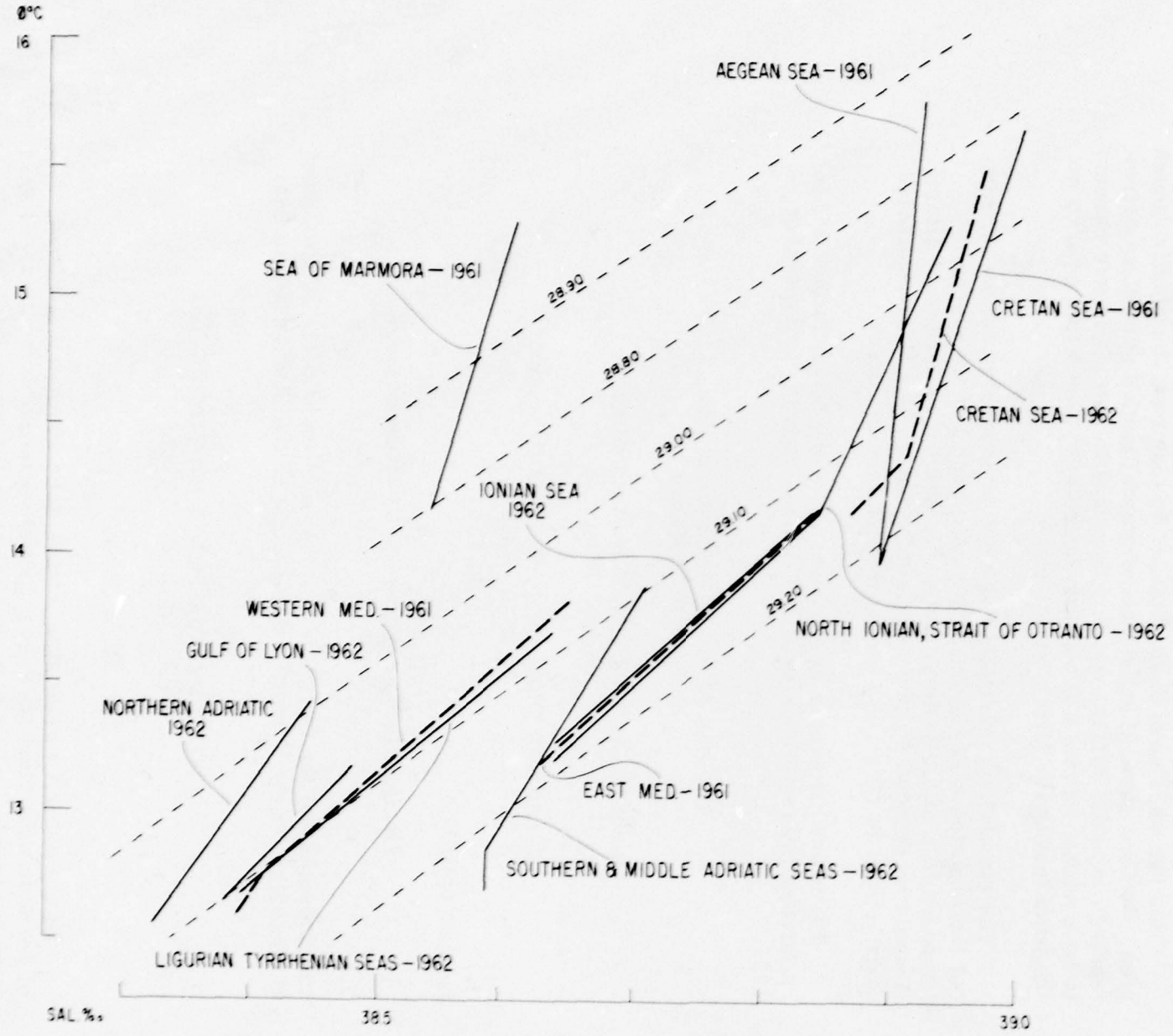


FIGURE 3. POTENTIAL TEMPERATURE-SALINITY CURVES FOR ENTIRE MEDITERRANEAN SEA.

Weather maps have been obtained on loan from the Mediterranean area. Surface streamlines are being drawn together with comparative readings of vapor content. It is interesting to note that there appears to be a normal increase of surface water vapor from 4 to 8 gms/kg as the wind leaves the land area.

The circulatory scheme of the Mediterranean Sea serves to point out the importance of the seasonal influences and the extremely important role of air-sea interactions. Without the seasonal effects it would be difficult to find satisfactory reasons for the complicated distributions of properties found in these recent cruises.

The following papers were presented at the NATO Summer School on Air-Sea Interaction at Imperial College, London, in September 1962.

The Use of Net Radiometers at Sea
by Robert G. Munns

Direct Observations of Subsurface Currents
by John Bruce

Circulation Problems in the Mediterranean
by A. R. Miller

A paper entitled

Physical Oceanography of the Mediterranean
by A R Miller

was presented at the October congress in Monaco of the International Commission for the Scientific Exploration of the Mediterranean Sea.

CURRENT MEASUREMENTS EMPLOYING THE RADIO DROGUE SYSTEM

C. E. Parker

Direct current measurements were made south and southeast of Bermuda with three sixty-four foot diameter radio drogues. They were set in mid-June at a depth of about 1000 meters near 29° 50' N, 64° 41' W, and subsequently tracked with the Navy R4D. Eighteen search flights were made in all, up to 18 October; during this

period the drogues moved over an area of approximately 72,000 square miles. Figure 1 gives positions of each drogue and dates sighted.

Drogue No. 4 moved in an elliptical path, returning after 110 days, to within three miles of its initial position. It was picked up on 24 October by the U. S. Destroyer WILLARD KEITH at $30^{\circ}00'N$, $64^{\circ}00'W$.

When unit No. 5 was recovered (3 November), only twenty-five feet of its original cable remained attached to the buoy. It is supposed that, after following closely the tracks of Nos. 4 and 6 for 85 days, No. 5 lost its drogue chute, and that the buoy was then carried westward by relatively intense surface currents. Its subsequent track should therefore be regarded as indicating surface motions, rather than those at 1000 m.

No. 6 was last sighted on 18 October, moving NNE. A later attempt to locate it was thwarted by severe storms.

For nearly three months Nos. 4 and 6 moved at comparable speeds on nearly parallel tracks, apparently around a great anticyclonic eddy, about 34,000 square miles in area. Then their tracks diverged abruptly: No. 4 continued around the eddy, but No. 6 seems to have entered a new eddy, just east of the first one. It is suggested that a strong disturbance in the southwest quadrant of the area studied initiated this second eddy pattern. Figure 1 depicts one of the possible flow patterns associated with these motions.

The meridional components of the buoy drifts were plotted against time. Portions of these fluctuations appear to correlate with the 27.5 day lunar tide cycle. Possibly tidal effects induce both undulation on the main flow and large-scale oscillations which shift the entire eddy system.

A total of 170 hours actual flight time was used during this program to obtain 2,460 miles of drogue track. The observed points were separated on the average by eleven days, although on occasion by as much as twenty-five days; much is therefore not known of the actual tracks and speeds. It was gratifying, however, to obtain results in such good agreement with so few units. It is hoped that with more drogues, greater operational life, and an increased sampling rate, a more detailed survey will reduce the uncertainties found in this test program.

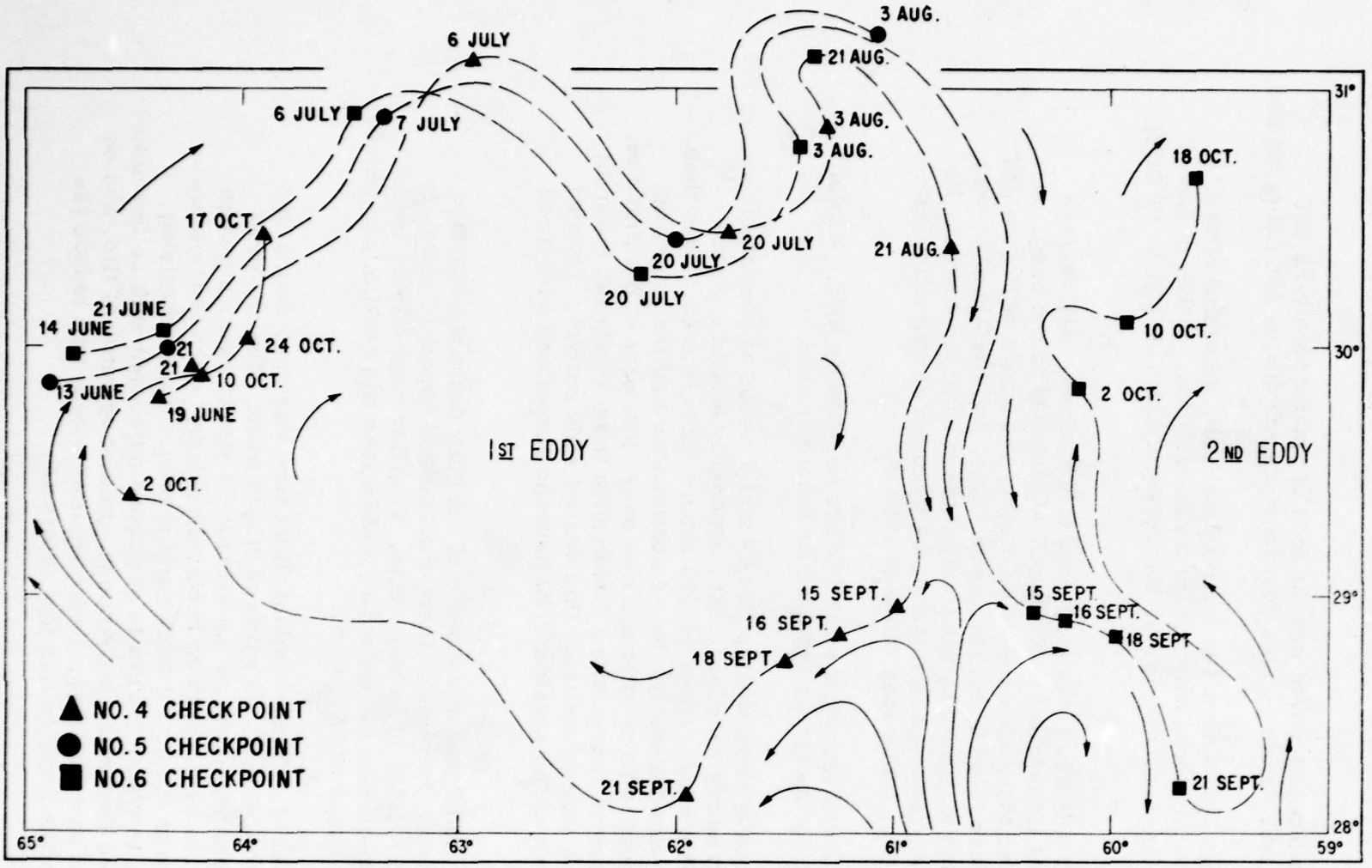


FIGURE 1. SPECULATIVE FLOW PATTERNS AT 1000 METERS.

THE IN-SITU SALINOMETER

Alvin Bradshaw & Karl Schleicher

The WHOI in-situ salinometer is an instrument for recording continuous salinity, temperature and depth. An inductive-type conductivity cell is used for the conductivity sensor of the salinity-measuring system, while an electrode-type cell, electrically insulated from the surrounding sea water but sensitive to changes in its temperature and pressure, compensates for the temperature and pressure effects on conductivity. Pressure-protected thermistors and a vibrotron-pressure gauge serve as the temperature, and pressure-sensing elements, respectively. The sensors are incorporated in oscillator circuits in such a way that changes in the measured quantity produce proportional changes in frequency. These three frequencies, lying in separate frequency bands, are telemetered to the surface along a single conductor logging cable. On deck, this signal, along with a standard frequency, is recorded on magnetic tape for future reference and computer data input. In parallel with this recording, the three frequencies are separated and converted to proportional d. c. voltages for the presentation of salinity and temperature versus depth on an XYY' recorder. Also, by rearranging the inputs to the recorder, temperature vs. salinity curves may be recorded directly, if desired. Since its completion, the instrument has been used on several cruises where continuous recordings of salinity and temperature at frequent intervals were required. Details of salinity and temperature structure were found that would not have been detected with Nansen bottles and reversing thermometers. However, the instrument is not yet in its final form. Some modifications were found necessary from the results of the earlier cruises and have been made, but further changes are required in order to improve the salinometer's accuracy and ease of operating.

Important to the in-situ measurement of salinity by conductivity methods is the study of the effect of pressure on the specific conductance of sea water. This effect is not small for great depths, but amounts to an increase of about 10% at 10,000 meters. Furthermore, it varies greatly with temperature and to a small extent with salinity. A study of the pressure coefficient of conductivity was made by Hamon ("The Effect of Pressure on the Electrical Conductivity of Sea Water", B. V. Hamon, Journal of Marine Research, Vol. 16 , 1958, page 83), for a sea water of 19.7‰ chlorinity at several temperatures from 0 to 20°C and

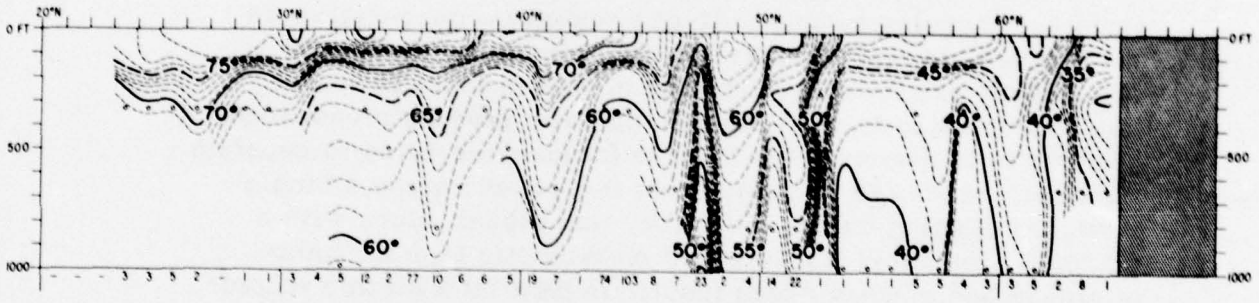


FIGURE 1. PROFILE FOR AUGUST AVERAGE.

found in the Eastern Basin except in the Cape Verde Basin. An outstanding feature of the 1.85°C surface is that a narrow thermal trough stretches nearly along the deepest part of the floor, adjacent to the foot of the continental slope, from the Antilles Arc north

the pressure interval equivalent to 0-1000 meters. A series of measurements extending the results of Hamon is now almost complete for 31, 35, and 39 °/oo salinity water at temperatures of 0, 5, 10, 15, 20, 25° for pressures up to an equivalent depth of 10,000 meters.

TEMPERATURE VARIATIONS IN THE NORTH ATLANTIC

Elizabeth H. Schroeder

A paper presenting average temperature conditions in the North Atlantic at a depth of 200 meters has been completed. It is being published by the American Geographical Society as Folio 2 of the Serial Atlas of the Marine Environment. There are nine charts which show average temperature, the range of observed temperature, deviations from the mean, and seasonal distribution of data. It is shown that the major currents of the North Atlantic are represented by the temperature distribution at 200 meters. The data used in compiling the charts are presented in an appendix. Given in tabular form for each one-degree quadrangle are the average, maximum, and minimum temperatures, the number of observations which make up each average, and the seasonal distribution of data.

A study of average temperatures from the surface to 1000 feet in the North Atlantic is summarized in a series of monthly profiles along eight arbitrarily chosen meridians. These profiles are based on the monthly averages of bathythermograms and Nansen bottle stations in our data collection. Because all basic work was completed before the decision to use the metric system for published papers, these sections are in feet and Fahrenheit. The accompanying illustration depicts the average temperatures for August at 40° 30'W. The North Atlantic current can be seen between 47° 30'N and 52° 30'N and the East Greenland Current is north of 59°30'N. This clearly shows that though the averaging process tends to smooth any given values, major ocean currents can still be recognized easily. The entire series of profiles shows the average month to month changes in temperature and in the positions of the currents.

MEASUREMENT OF DEEP OCEAN CURRENTS

Gordon Volkmann

The primary instrument used in these particular studies is the neutrally buoyant float or Swallow pinger. The commercially manufactured models while satisfactory are still not as good as those

the Atlantic remained obscure for so long in view of the large number of hydrographic observations in the Equatorial region, and especially when one remembers that Buchanan reported the current

made at the laboratory. It was only during December of 1962 that progress appears to have been made in the commercial units. Whether this progress is real or promised will have to await field-work testing.

The early part of the year was spent with Mr. Worthington on board the icebreaker M/S ERIKA DAN during which both the anchored Richardson current meters and neutrally buoyant floats (under the direction of Dr. Swallow) were used.

In May a two-week cruise into the deep water area inshore of the Gulf Stream was made along the line of Richardson current meters between Woods Hole and Bermuda. Hopes to compare the two types of measurement during this cruise were frustrated by difficulties in ship scheduling, in that the meters ran out of film before the cruise began. This was the third trip into this general area which has been made using both a hydrographic section for the computation of geostrophic current and Swallow floats for direct measurements. A report on the first two cruises has been submitted (Volkmann, 1963). This indicated that the water inshore of the Gulf Stream was generally moving opposite to the Gulf Stream but that there were wide variations in the velocities and transports. There seems to be some reason to believe that the large transports might be associated with small changes in the potential temperature-salinity relationship. The May 1962 current measurements show smaller velocities than either of the other two years. Oxygen determinations were made on this cruise in hopes of further detecting small changes in the properties between eastward and westward moving water. Analysis of this cruise is proceeding slowly.

Two other assistance cruises were made. One with Mr. J. Barrett to the region off Cape Hatteras to study the area where the Gulf Stream leaves the continental shelf. The water which is moving counter to the Gulf Stream in the inshore areas must either join the Stream or flow under it to continue. The measurements showed some water moving southward under the inshore part of the Gulf Stream. The last cruise of the year was made with Mr. P. Stimpson to a region 400 miles north of Nassau for the purpose of obtaining comparisons among a number of methods of measuring currents. Stations for the computation of geostrophic velocities were made and direct current measurements using anchored Richardson meters, Swallow floats, Ekman meter, and a free-fall horizontal displacement technique.

observations will be made from that ship.

At the time of CHAIN Cruise 17, preliminary evidence led to the idea that the deepest passage across the mid-Atlantic Ridge was well east of the Romanche Trench and was entirely unassociated with that feature. However, detailed studies of the combined bathymetric

PATHS OF THE GULF STREAM

Bruce Warren

Since the Second World War several surveys have charted quasi-synoptic segments of the path of the Gulf Stream between Cape Hatteras and the Grand Banks of Newfoundland. These revealed extensive meandering in the Stream paths, which for long has been regarded as associated with some sort of instability in the current structure. Taken together, however, the path segments correlate in a very rough way with the distribution of isobaths on the continental rise. Since current measurements made in 1960 (Fuglister, in press) suggest that the Gulf Stream--east of Cape Hatteras--extends to the ocean bottom, it seems at least possible that bottom topography might impose a fundamental control on the path of the Stream at all depths; and that this control, rather than an instability would be responsible for the observed meander patterns.

The possibility was confirmed by an order-of-magnitude analysis of the gross vorticity balance of the Stream, for parameters appropriate to the current dimensions east of Hatteras, far from the continental slope, and to the deep velocity measurements of 1960. The analysis revealed that a Stream path must represent approximately a combination of a stationary Rossby wave and a "topographic wave", dynamically analogous to the former, but produced by forced variations in the depth of the current; in other words, that, at least in an integrated sense, steady-state conservation of absolute potential vorticity prevails.

With a number of reasonable approximations, e.g. treating a curved ocean bottom as a sequence of planes of varying slopes and orientations, it became possible to transform the gross vorticity balance from a sum of integrals to a non-linear (but tractable) ordinary differential equation describing current paths controlled by the mechanisms of the Rossby and topographic waves. By introducing actual bathymetric data and initial conditions appropriate to the observed current paths, a solution was obtained corresponding to each observed path. Since the topographic wave generally dominated over the Rossby wave, the calculated paths tended to meander about isobaths; they agreed sufficiently well with the observed paths to confirm the consistency of the Gulf Stream meander patterns with the idea of topographic control.

Because of a disturbing tendency for rapid error amplification,

and present inadequate knowledge of the bottom topography and current parameters, the method of computation is suitable at this time only for demonstrating consistency, not, unfortunately, for making actual predictions of the Stream path. Computations are further limited by the New England Seamounts, which are of too small horizontal scale to be treated by the method. Just in the neighborhood meanders of very large amplitude have been observed which tended to separate from the Stream as eddies. No way has been found to determine even crudely the effect of such small-scale features on a current like the Gulf Stream.

Very few data are available pertaining to time changes in meander patterns. Mathematical difficulties, moreover, have frustrated attempts to understand how they might occur. Probably the simple topographic and Rossby-wave effects dominate the flow at least as far upstream as Cape Hatteras, where the Stream departs from the continental slope, so that changes in the path downstream can be related to changes in its characteristics near Hatteras, but neither the reason for such changes nor the manner of their propagation downstream has become apparent.

Reference

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Sea from Gibraltar to the Black Sea is represented in the Woods Hole observations taken in 1961 and 1962. In particular, such

INTERNAL WAVES

Arthur D. Voorhis

During the year 1962 studies were made of internal wave data which had been collected the previous year on a cruise of the R/V CHAIN to the Mediterranean Sea. First, an attempt was made to compute the spatial power spectrum of internal waves observed in an area to the east of the Island of Madeira. The waves were detected at a depth of 70 meters beneath the oceanic wind mixed layer, by recording continuously the variations of temperature from one of the thermistors mounted in the towed thermistor chain as the ship steamed at a speed of 11 knots along various headings. On each heading the temperature variations were sampled over a distance of about 10 kilometers. During each run these variations were also recorded on magnetic tape as a frequency-modulated signal in such a format that power spectra could be easily computed using the Addressor program with the Recomp II computer at Woods Hole. About ten spectra have been computed from this data and in all cases show that the internal wave power increases with wave length from the minimum resolvable wave length of about 100 meters to the maximum resolvable length of about 1000 meters. No spectral peaks were found within these limits. In order to find such peaks, measurements would have to be made over considerably longer horizontal distances in order to resolve the spectra at longer wave lengths.

The second study made was of the large tidally-driven internal waves observed in the Straits of Gibraltar. These waves propogate along the large density gradient between Atlantic water at the surface and the heavier more saline Mediterranean water lying beneath. This study was done in cooperation with R. Frassetto, now at the NATO Laboratories in La Spezia, Italy, who has been interested in these waves for several years. From the pressure recorded from several pitotmeters mounted in the thermistor chain, it was possible to measure, while the ship was underway, the water velocities associated with these large waves and in some cases it was observed to be as high as 100 cm/sec.

Summer Course in Introductory Physical Oceanography.

A total of nine students, at the senior college and first-year graduate level, were accepted for the course which was constructed around a three-week cruise in July to the area southeast of the Grand Banks. Prior to the cruise the students attended lectures and received

laboratory instruction for two weeks in order to acquaint them with some of the standard experimental techniques used at sea and which they would be using during the cruise. On the cruise Mr. L. V. Worthington was chief scientist. At sea a large area southeast of the Grand Banks was studied in order to determine the course of the Gulf Stream and to obtain evidence for a two-gyre circulation system which had been hypothesized by Mr. Worthington. The temperature at a depth of 200 meters was measured over a large area, using the bathythermograph and surface currents were measured regularly with the GEK. Two hydrographic sections were made, each of which extended for a distance of several hundred miles from the Gulf Stream northeastward across the Newfoundland Rise into cold water. At several of the hydrographic stations lowerings were made with the recently-developed in-situ salinometer under the direction of Mr. K. Schleicher. After a short time most of the measurements were made by the students. After the cruise they analyzed the data and in discussions attempted to integrate the results. Twice a week the students attended hour lectures given by various scientists at the Institution, in which they could hear about other research being done at Woods Hole.

FLORIDA CURRENT STUDIES

T. Ferris Webster

The study of eddy momentum transports in the Florida Current was continued. An analysis of velocity measurements off Jacksonville, Florida, taken during CRAWFORD Cruise 70 (Oct. - Nov., 1961) has shown a surface eddy flux of momentum which is fundamentally similar to earlier observations off Onslow Bay and in the Straits of Florida. The pattern of all these calculations is that on the shoreward side of the Florida Current, there is a transfer of kinetic energy at the surface from the perturbations of the current (the "shingles") to the time-average current. A possible conclusion concerning the role of the shingles is that they are an important mechanism whereby the energy of the basic flow is maintained.

Two dozen hydrographic sections across the Florida Current using the in-situ salinometer were made during CRAWFORD Cruise 70. It is apparent that the proportion of water originating from sources in the Caribbean with respect to that from the Sargasso Sea may vary widely in the course of one or two days.

Concurrent with the demand for direct observations of evaporation is the need for radiation measurements. Net radiation is somewhat difficult to measure from a moving ship. Attempts were made in this direction and the results are now being analyzed and evaluated.

Measurements of the total volume transport of the Florida Current were made both by standard dynamic methods and by the geomagnetic method of Malkus and Stern. The geomagnetic measurements were in good agreement with the dynamic computations, but it is evident that improved techniques of directly measuring surface current velocity are required before the geomagnetic method can have general application.

A spectral analysis of some records from Richardson current meters moored between Woods Hole and Bermuda has shown the existence of time variations having periods of the semi-diurnal tide and of the inertial period corresponding to the latitude of the observations. It was apparent from the analyses that long-period motions, having periods of a week or longer, are important. However, a closer resolution of these long-period transient motions requires much longer current meter records than have been obtained yet.

In October, 1962, a cruise was made off Cape Hatteras in the R/V CRAWFORD (Cruise 88) in conjunction with an ATLANTIS Cruise under the direction of Joseph Barrett. The temperature and salinity values in the region indicate that the water which flows off the edge of the Blake Plateau (water depth 800 meters) into the deep water beyond Cape Hatteras (water depth 3500 meters) does not deepen signi icantly, and maintains its separate identity. That is, it remains about 800 meters deep, and is underlain by water of northern origin. The study of this problem is continuing.

WATER MASS DISTRIBUTION AND THE NORTH ATLANTIC CIRCULATION

L. Valentine Worthington

From 17 January to 4 May the M/S ERIKA DAN was under charter from J. Lauritzen, shipowners, of Copenhagen, Denmark. The purpose of this charter was to investigate late winter conditions in the Labrador Sea and Davis Strait. None of the Institution's ships is capable of this work as none is suitable for navigation in the vicinity of ice. It was of course necessary to ship all the necessary equipment including the hydrographic winch to Denmark for installation. The scientific equipment was installed at Aalborg Waerft, a Danish shipyard, with great skill and despatch, and the ship sailed from Copenhagen 20 January 1962.

During the cruise two sections were made across the Atlantic

at latitude 53°30'N and 59°30'N. These were similar to the I.G.Y. sections reported on by Fuglister (1960). In addition 7 sections were made across the Labrador Sea and Davis Strait. In all a total of 213 oceanographic stations were occupied and a total of 4,825 readings of temperature, salinity and oxygen were obtained. A lesser number of samples for total phosphate were taken. Dr. J. C. Swallow of the National Institute of Oceanography participated in this cruise and current measurements were made under his supervision in the deep water off Cape Farewell, Greenland and off Labrador. In addition Dr. Swallow supplied the echo-sounding equipment used; continuous echo-soundings were made throughout the cruise.

It has been clear for many years that any formation of new deep and bottom water in the Atlantic must take place within the Labrador Basin. One purpose of the cruise was to determine if any large scale, deep convection of this sort was taking place. The conclusion from the ERIKA DAN cruise is that no deep convection took place during the winter of 1961-1962, and that is it unlikely that any convection to depths greater than 1500 m has taken place in recent years.

On the other hand it appears that the overflow of cold water from the Norwegian Sea into the North Atlantic is considerable. Steele, Barrett and Worthington (1963) calculated that 5 million m^3/sec are contributed from this source through the Iceland-Faroes Ridge. Of this 5 million, however, only 1.5 appears to be of pure Norwegian Sea water, the remainder being of Atlantic water entrained into the overflow.

By means of its temperature/salinity relationship the overflow water can be traced on the ERIKA DAN cruise as far as 53°30'N, flowing to the south along the eastern slope of the mid-Atlantic Ridge. At some point, slightly to the south of ERIKA DAN's section this water evidently passes through a gap in the Ridge and subsequently can be traced flowing northward along the western slope of the Ridge.

A further deep overflow from the Norwegian Sea occurs in the Denmark Strait between Greenland and Iceland. This overflow has distinctly different temperature/salinity characteristics from the first. It can be traced from the Denmark Strait along the east coast of Greenland. At Cape Farewell it doubles back and flows in a north-westerly direction up the west coast, subsequently flowing to the south along the continental slope off Labrador as

far as the Grand Banks. The flow of this current was measured on two occasions on the ERIKA DAN cruise, once off Cape Farewell and again to the north of the Grand Banks. Volume transport calculations have not been completed but it appears that a rapid and regular flow was taking place during the periods of observation.

The ERIKA DAN results are undergoing more careful scrutiny at the present time but the large volumes of Norwegian Sea water overflowing into the Labrador Basin present a problem that will require further field work. The dilemma in the case of the Denmark Strait overflow is that from current measurements made in ERIKA DAN it is evident that a large volume of water colder than 2^{o} is entering the Labrador Basin and none penetrates much further south than the 50th parallel. It could be argued that this cold water is mixing with warmer water at a rapid rate but the temperature/salinity relationship does not support this view; or that this overflow has not been taking place until recent years, but the Ice Patrol's sections show that the bottom temperatures found off Cape Farewell have not changed significantly since 1948 or, indeed, since the Marion and General Greene expeditions of 1928-1935. Finally one could assume that the current measurements made on this cruise ocurred at a time of exceptionally strong flow and at other times the flow is lesser or even in the opposite direction but this assumption is dangerous and verges on the disingenuous. Since the arrival of the neutrally-buoyant float on the oceanographic scene nearly all current measurements throughout the Atlantic have shown us a more lively ocean than had been suspected from the distribution of variables such as temperature, salinity and oxygen.

In April 1962 a paper (Worthington, 1962) was published indicating that the Gulf Stream could not be traced as a continuous current flowing from the Sargasso Sea into the Labrador Basin around the Tail of the Grand Banks. The strong currents found to the east of the Grand Banks appeared to be constituents of a separate anticyclonic circulation system confined to the Labrador Basin. The basis for making the distinction between the two gyres was the far higher oxygen concentration found at all levels in the waters of the northern anti-cyclonic gyre. A simplified Atlantic circulation scheme, consistent with the distribution of oxygen, is presented in Figure 1. Each contour line represents 10 million m^3/sec. An essential feature of this scheme is a trough of low pressure separating the two opposed currents in the region to the southeast of the Grand Banks.

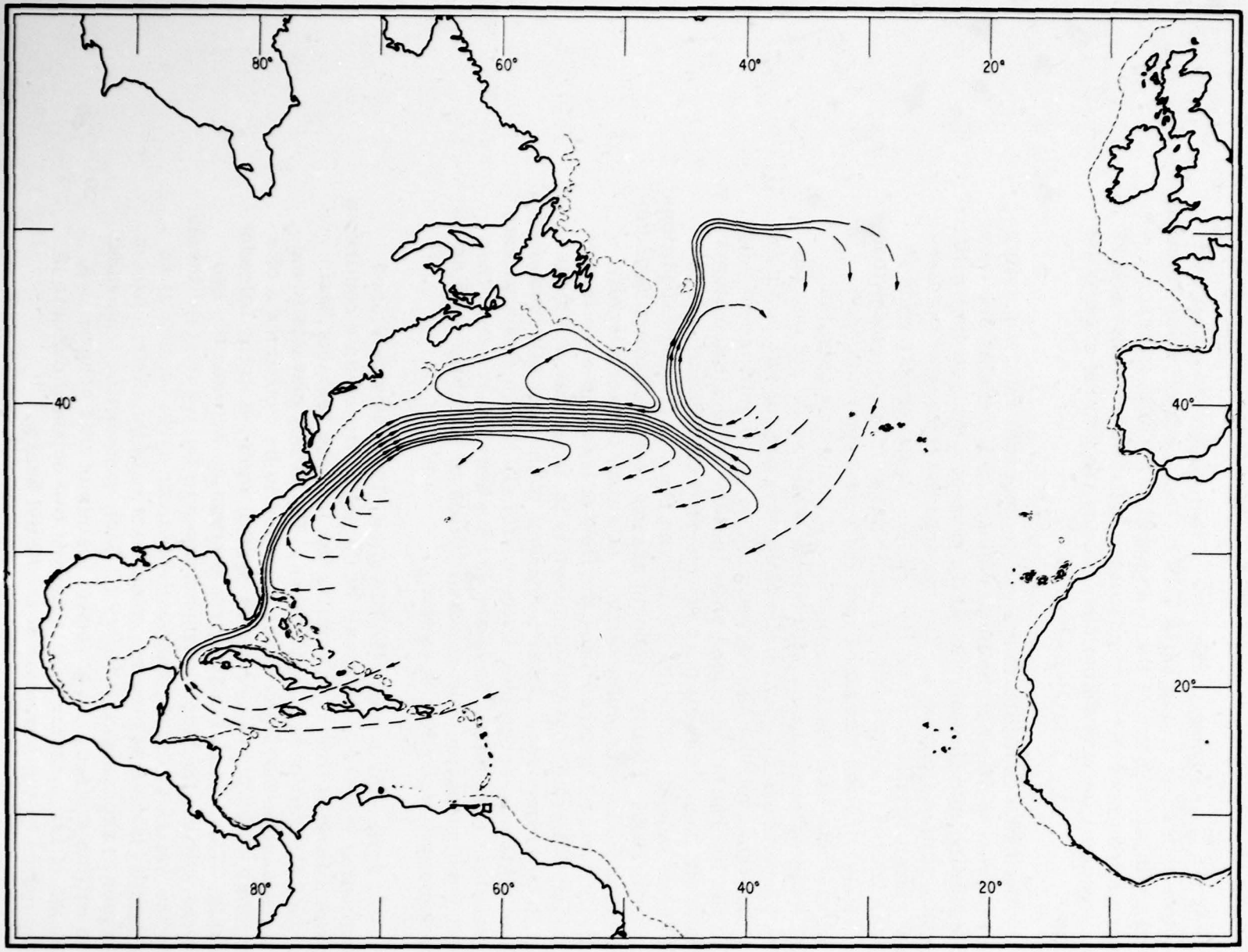


FIGURE 1. WATER BUDGET, RELATIVE TO THE 2000 METER SURFACE FOR THE NORTH ATLANTIC. EACH STREAMLINE REPRESENTS 10 MILLION M^3/S.

In July a short cruise was made in CHAIN to see if such a trough existed. Six bathythermograph sections and one deep oceanographic section were made on a grid oriented northeast/southwest. In addition current fixes were obtained hourly with the geomagnetic electrokinetograph. As usual, the ocean when asked a simple question gave us an ambiguous answer. A definite low pressure trough (consisting of cold water) was found on four of the six bathythermograph sections and on the oceanographic section. On the two remaining bathythermograph sections there was an abrupt transition from the warm Gulf Stream to the cooler water typical of the northern gyre without an intermediate trough of extremely cold water. Possibly if the bathythermograms had been deeper and more closely spaced the trough might have been observed on all six sections. Certainly neither the temperature nor the current field suggested that any considerable volume of Gulf Stream water passed across a line drawn between the Tail of the Grand Banks and the intersection of the 40th parallel and the 40th meridian.

On the other hand the currents were weaker and more diffuse than the hypothesis indicated and the oxygen measurements gave evidence that a considerable exchange of water must have taken place across the trough in the recent past. The oxygen values in the Gulf Stream were considerably higher than they had been during the "Gulf Stream '60" (Fuglister, in press) or in any previous section. Further work in this interesting and little-known area is planned for the early months of 1964; in addition a Canadian cruise under the leadership of Dr. C. R. Mann of the Bedford Institute of Oceanography is planned for the spring months of 1963 which will be of great help in formulating future plans.

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THEORETICAL OCEANOGRAPHY and METEOROLOGY

THEORETICAL OCEANOGRAPHY AND METEOROLOGY DEPARTMENT

Columbus O'D. Iselin, Department Chairman

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THE AIR-SEA FLUX OF ELECTRICITY AND PARTICLES

Duncan C. Blanchard

In general, my activities during 1962 can be put into three categories: field work, reduction of data obtained in the field, preparation of papers, and experimental investigations in the laboratory.

One of my prime interests during our Hawaiian field trip last spring was to determine the amount, if any, of space charge that was being carried by the sea salt particles that rose from the ocean. I selected a region along the shore where a great amount of bubbling was taking place and, consequently, dense clouds of particles were rising from the sea. Using a 6-foot cubical Faraday cage and a surface potential gradient meter, I was able to show that a positive charge was associated with these particles. Space charges were measured up to 2000 fundamental units cc^{-1}. These findings more or less confirm my work on air-sea charge transfer of the past few years. I expect to prepare this work for publication during 1963.

The flux of organic material from sea to air may have some bearing on the charge transfer mechanism. A number of experiments, carried out in Hawaii, indicated that a simple technique could be used to sample the airborne particles from the sea and as a test for the presence of surface active organic material. This material was always present in such quantities as to suggest that particles from the sea carry at least a monolayer, on the average, when they are ejected into the air. I hope to prepare a paper for publication describing the results to date on this interesting problem.

In conjuction with Mr. Woodcock and Mr. Spencer, I monitored the electricity carried by the precipitation and obtained simultaneous data on the surface potential gradient. It was found that the rain current was generally positive, but that negative surges were noted at the beginning and end of showers. This finding is of great interest as the electrical properties of the rain from such clouds as these, which do not reach the freezing level in the atmosphere, have been investigated very little. Perhaps the mechanism of rain formation in these clouds is more complex than we have thought.

Laboratory work indicated that great quantities of positive charge are associated with the salt particle cloud that forms when non-charged saline drops are allowed to fall onto a hot surface. This work will undoubtedly throw some light on the problem of charge separation from bubbles breaking at the surface of the sea, and I hope to be able

to say something about the charge separation that should occur when hot lava from volcanic eruptions flows into the sea. In certain geological ages in the past, when volcanic activity was much more intense than today, there may have been sufficient charge separation at the lava-sea contact zone to increase significantly the positive charge of the atmosphere.

MARINE METEOROLOGY

Andrew F. Bunker

A preliminary report of the water vapor distribution over the Bahaman waters was presented to the Navy early in the year 1962. Further analysis of the material was continued through the year to make a more detailed spectral study of the water vapor variations and to prepare the study for publication. Spectral analyses of the turbulence and turbulent fluxes observed in the trade winds have been computed and are being studied further for their significance.

The greatest amount of time has been spent in planning a meteorological expedition to the Indian Ocean, in preparing our new C-54Q aircraft, and in building new equipment for the work. The aircraft was assigned to WHOI in May and officially bailed to us in July. After considerable negotiations with the Office of Naval Research and the National Science Foundation, and adjustments of the modification and overhaul to be accomplished, work was started at American Airmotive Corporation, Miami, Florida, late in December. In addition to the inspection and repair of the aircraft, the following features and instruments are being installed: an APS-42 search radar for meteorological studies, buoy location and navigation; a gust probe; parachute radiosonde; radios for buoy location; an airscoop for geochemistry; a belly-port for radiometry and coastal photography; psychrographs and a search blister; and a Doppler radar set for the determination of winds and geographical location.

HYDRODYNAMICAL MODEL STUDIES

Alan J. Faller

During 1962 the major portion of construction and furnishing of the new Hydrodynamics Laboratory was completed. This work included

construction and installation of the rotating tank and drive mechanism, installation and wiring of the control panel and lighting, and installation of the air-conditioning system. The accompanying photograph shows the rotating tank and the observation platform above, with the control panel and closed-circuit TV monitor in the left-center of the picture.

After preliminary tests and calibration of the apparatus, experimental studies were begun at the end of March. These initial studies were concerned with the effects of wind stress on the rotating mass of water, studies of thermal convection in the rotating system, and extension of earlier work on the instability of laminar boundary layers in rotating systems.

In conjunction with the laboratory measurements of the instability of the laminar Ekman boundary layer, the following proposal was made: that the Langmuir circulation cells in the ocean are a manifestation of the instability of the spiral boundary layer near the surface of the ocean. To test this hypothesis, measurements of the angle between the surface wind and the directions of the wind rows were attempted. In some cases these observations were made from a small boat and in other cases these angles were observed by scattering papers over the surface of the ocean to indicate the wind rows and by using smoke flares to show the surface wind direction. In all cases the observations indicated that the wind direction was to the left of the row direction in agreement with the theoretical prediction.

The analogy between the laboratory results and the Langmuir cells was presented at the meetings of the American Geophysical Union in Washington, D.C., April 1962.

A paper entitled "The Instability of the Laminar Ekman Boundary Layer and Its Application in Geophysical Fluid Dynamics" was presented at the joint symposium of the American Meteorological Society and the American Physical Union in Boulder, Colorado, September 1962. A manuscript entitled "An Experimental Study of the Instability of the Laminar Ekman Boundary Layer" was accepted for publication by the Journal of Fluid Mechanics.

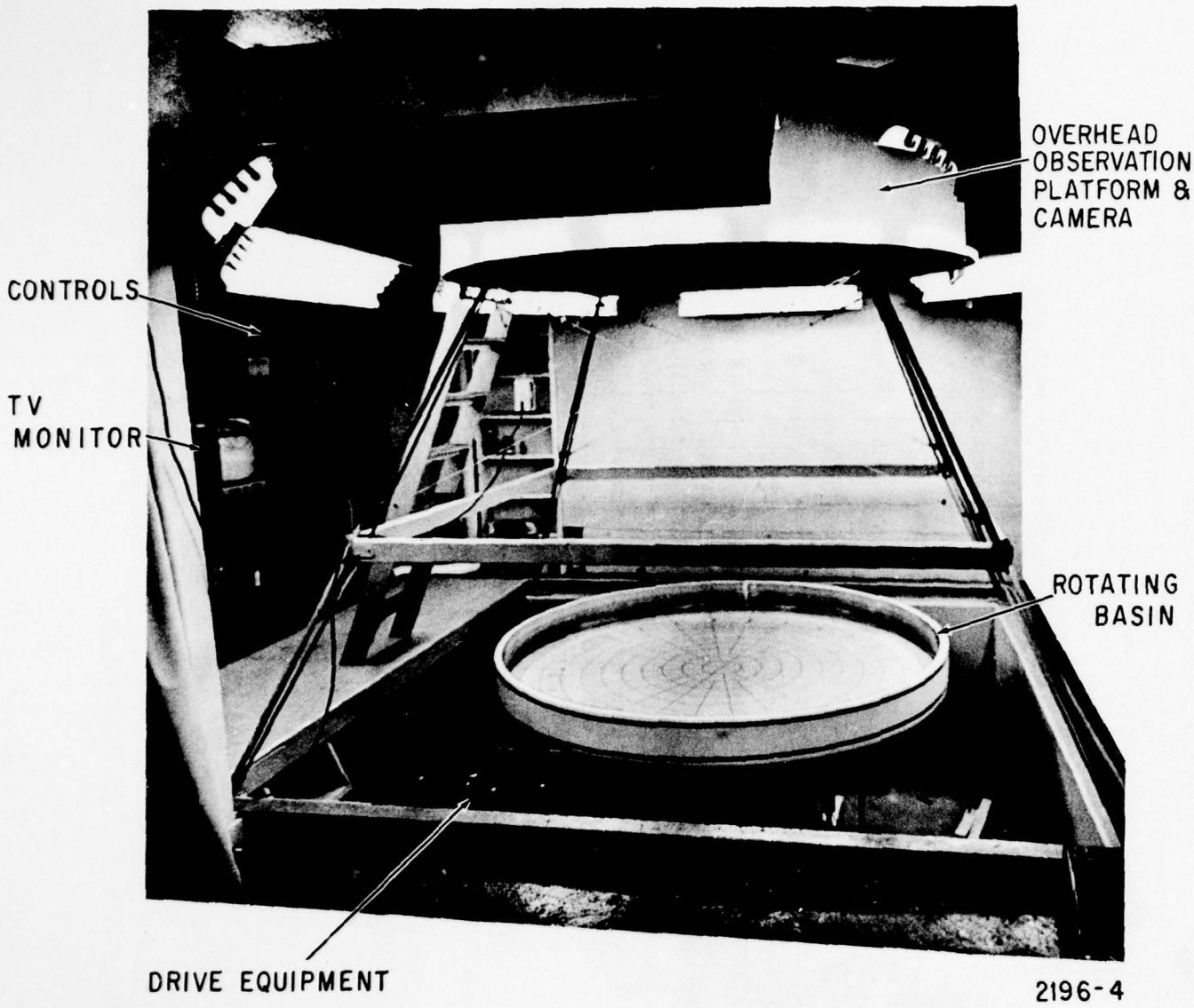


FIGURE 1. THE NEW ROTATING TANK INSTALLATION.

DYNAMICS OF OCEAN CURRENTS

N. P. Fofonoff

The period from September to December 1962, after my arrival at Woods Hole, was spent in examining three problems related to steady flows in the simple homogeneous and two-layer oceans. In two of these problems, the vorticity equation was studied to determine the effects of bottom topography and side boundaries in deflecting and intensifying the flow. The third problem was related to the decay of relative vorticity in steady unbounded flow. An exact two-dimensional solution has been found that incorporates both driving forces and friction. Its characteristics are being examined further.

AIR-SEA INTERACTIONS and CLIMATIC CHANGE AND CIRCULATION CHANGES

E. B. Kraus

Air-Sea Interactions

Theoretical studies of the vertical heat flux led to an explanation of the depth and temperature of the convective, isothermal surface layer. Both quantities were related to a balance between the absorption of visible radiation within the layer and the loss of heat by evaporation, conduction and infra-red radiation at the surface. Variations in the profile below the isothermal layer are caused primarily by vertical motion.

Much work was carried out in preparation of a project to investigate stress and heat flux in different sea surface conditions. This will be done by studying transfers on the windward and on the sheltered side of an island across the trade-wind stream, with buoy and mast-mounted instruments. New instrumentation developed for this purpose included a wave recorder, which consists of a magnet-carrying float that rides a vertical pipe. Inside the pipe is a series of reed switches which are actuated by the magnet. Recording is carried on film. Instrumentation has also been developed for the digital recording of temperature fluctuations.

Climatic Change and Circulation Changes

Statistical studies have shown a world-wide return to wetter conditions after a relatively dry period that lasted half a century. The change paralleled the terminal or reversal of the world-wide warming trend reported by other investigators. It is reflected also in a re-advance of glaciers, on Jan Mayen, for example.

Dynamic studies included work on a model with unequally-heated sea and land surfaces at its lower boundary.

CLOUD DYNAMICS

Joseph Levine

The combined theoretical and observational approach to study of buoyant elements in cumulus clouds, initiated about two years ago, was continued. A crucial part of the program was the development and calibration of liquid water content instrumentation. The two hot wire instruments, which in combined use yield an indication of drop size distribution and had already performed successfully on earlier field trips, were still not properly calibrated at the beginning of the year. To interpret the observational data of temperature, vertical velocity, and liquid water content in clouds in terms of my model of a buoyant element, which relates the above quantities physically, the liquid water content had to be measured to an accuracy of about 10%.

During the early part of the year a rough calibration of the cloud size instrument was achieved by Pearson in a rotating-arm apparatus enclosed in his chamber. The rotating-arm equipment had originally been built for use in fog out on the dock, but I thought that an alternate to wind tunnel calibration should be explored. Also I succeeded in making a commercial nozzle array, which gave a reasonable approximation to uniform spray distribution across the tunnel test section.

After the above work, the instruments were mounted in the C-47 aircraft for field work in the spring. The principal reason for undertaking field work at this time was a question that had been raised earlier by Bunker concerning the possibility of higher measured liquid water contents due to fuselage splash. The instruments had in the past been mounted on the cabin roof just aft of the windshield. To

evaluate the magnitude of the splash effect a duplicate set of instruments were mounted on a nose boom.

Field trips were made to San Juan, Puerto Rico, towards the end of April and also during the last two weeks in May to evaluate splash effect and to obtain data not subject to it.

Then during the summer a thorough calibration of my liquid water content instruments was undertaken at a wind tunnel at Hanscom Field larger than mine. A fast spark source was used to photograph the spray droplets in the tunnel to relate instrument response to liquid water content and maximum drop size.

The remainder of the year was spent on deriving the best possible calibration curves and starting the consolidation of my work for the last three years in a rough draft of my Ph.D. thesis.

MARINE METEOROLOGY

F. Claude Ronne

For the first three months of 1962 I was on a leave of absence from the Institution.

Originally, I had intended not to return before the first of May. However, the intense storm of March 1962 caused such extensive damage to the East Coast of the United States that William D. Athearn, of our Geology Department, and I decided to resume our coastal flights to record photographically these changes before either man or Nature should have modified or eradicated them.

This flight was made in April. A subsequent flight was made over the same area in September for purposes of comparison. The results of these observations have been written up in a paper recently submitted for publication in the Naval Research Reviews.

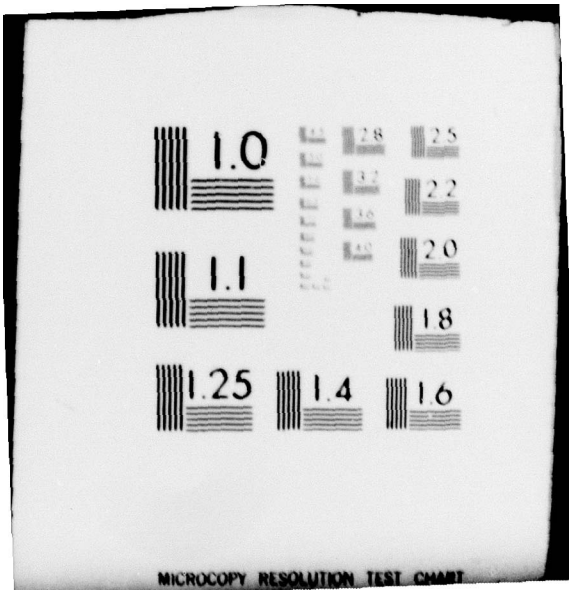
The entire summer was spent in working with Dr. Joanne Malkus in the reduction of the photographic data for the third and final part of the Pacific report, "Cloud Structure and Distributions over the Tropical Pacific." This rather expansive report has been accepted for publication by the University of California Press. This necessitated re-making an entire new set of photographs and drawings of such size and type as to be amenable to their printing processes.

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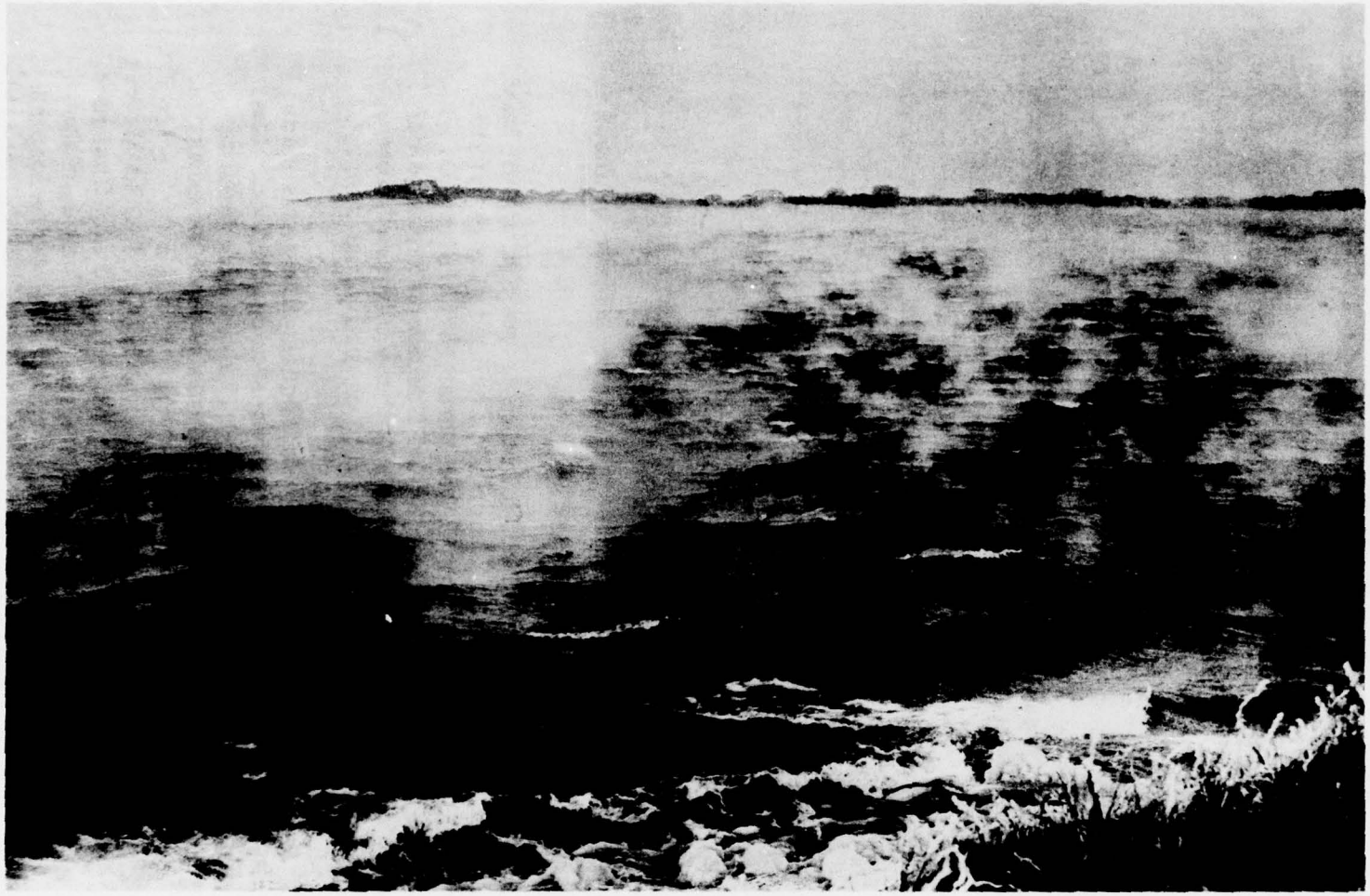


FIGURE 1. SEA SMOKE, WOODS HOLE, 31 DECEMBER 1962. AIR TEMPERATURE 3°F.

Since the completion of this work I have been engaged in modifying and testing cameras and equipment which will be required for Andrew Bunker's Indian Ocean Program in May and June of 1963, and for the Barbados "Weather Modification" project of Dr. Joanne Malkus scheduled for next August and September.

SEA SMOKE AND CONVECTION

Peter M. Saunders

When very cold air flows over a relatively warm ocean the surface steams and gives rise to "sea smoke" (See photograph). From a study of ship reports and other literature it is found that sea smoke is globally distributed--from poles to tropics--and occurs in calm or gale winds. The intensity of the steaming increases as the sea-air temperature difference increases, so that its vertical extent ranges from a meter to a thousand meters. In sea smoke the visibility may be as low as 100 m, whilst its liquid water content of up to a few tenths of a gm/m^3, if supercooled, represents an icing hazard to shipping.

In the region of large temperature lapse close to the sea surface it is assumed that the characteristics of the air result from the mixing of the overlying cold air with air which, by intimate contact with the sea surface, acquires the temperature and equilibrium vapour pressure of the surface. By simple thermodynamic argument it is then possible, for example, to compute the conditions for the onset of steaming of a given water surface; the critical air-sea temperature difference (likely range 7 - 18°C) is found to increase with increasing water temperature and salinity but decrease with the increasing humidity of the overlying air. These values, as well as other conclusions of the above hypothesis, have been substantially verified by observation.

From what is known of convection over land, profiles of the distribution of temperature with height in the air over the sea have been computed and it has been demonstrated that, for a given air-sea temperature difference, the thickness of the thermal boundary layer increases with increasing wind. It is concluded that for air and sea with given properties the height of sea smoke increases with increasing wind.

Another type of convective phenomenon that has been studied is the cold outflow associated with the release of precipitation from showers and severe local storms. Employing surface autographic records, 10 cm weather radar observations, and time-lapse photography, a detailed analysis was made of the cold outflow from a Florida thunderstorm observed by the author and F. C. Ronne in 1961. A series of model experiments is now underway in order to learn what factors control the spreading of the cold air over the earth's surface and hence what controls the severity of the squall.

GEOPHYSICAL FLUID DYNAMICS

Melvin Stern

The past year has seen the publication of "On the Stability of Internal Baroclinic Jets in a Rotating Atmosphere" in the Journal of Atmospheric Research (in collaboration with J. G. Charney). This theoretical study bears on the problem of cyclogenesis in the earth's atmosphere and meandering of the Gulf Stream.

"The Joint Instability of Hydromagnetic Fields which are Separately Stable" has been accepted for publication by the Physics of Fluids and is in press. This theoretical study bears on the origin of geomagnetism.

A theoretical study entitled "Trapping of Low Frequency Waves in an Equatorial Boundary Layer" is being prepared for publication. In it the author suggests the possibility of looking for long-period (1 month) oscillations in the water beneath the equatorial thermocline.

WIND-GENERATED WAVES

Raymond G. Stevens

During the past year two major undertakings have been pursued in the study of wind-generated waves. Both of these efforts have been concerned with the measurement of the directional characteristics of wind-generated ocean waves. When wind blows over a large body of water, waves are generated which seem in general to

progress in the direction of the wind. However, when viewed from near the surface, such as on board a vessel, the waves seem to be traveling in many different directions at rather broad angles to the wind. The objective of measuring the directional spectrum of waves is to characterize the relative intensities of waves as a function of both their angular frequency, or wave length, and their direction of travel.

One approach to the measurement of the directional spectrum of waves was undertaken by Dr. Norman F. Barber, Chief Physicist, Dominion Physical Laboratory, New Zealand, during his visit at W.H.O.I. from March through September 1962. Dr. Barber constructed and tested a method of measuring sea-wave spectra by their diffraction of radio waves. The apparatus consisted of an airborne radio transmitter and receiver installed aboard the Helio-Courier aircraft. The transmitter was designed to radiate over a range of wave lengths appropriate to the lengths of important sea-wave lengths. The radio energy returned from the sea surface at any given radio wave length should be proportional to the intensity of the sea waves of comparable wave length. By sweeping over a broad range of radio wave lengths the full spectrum of ocean waves can be examined. By changing the heading of the aircraft the relative intensity of sea waves progressing in various directions can be determined.

Because of the limited duration of Dr. Barber's visit it was not possible to carry the project to a successful conclusion. However, the tests which were conducted appeared promising. This technique when fully developed would provide a very rapid means of surveying the wave state over the open oceans where no satisfactory method is presently available. The theory and experimental equipment are described in W.H.O.I. Reference No. 62-39.

Another approach to the measurement of directional wave spectra is to use an array of surface height detectors arranged along a line and fixed in space. Such arrays have been constructed and used in Buzzards Bay beginning in 1959. A great deal of time and effort has been spent in developing accurate means of measuring the waves, reducing the data for use in digital computers and in carrying out the actual analysis of directional wave spectra. The line array method is similar to that of radio direction finding except that all the functions of the radio receiver are simulated by the digital computer. In fact, not only are the various wave frequencies "tuned in" and examined by the computer but the array is also caused to "look" in various directions by the computer program, even though the

actual array remains fixed. While this method is not as rapid as Barber's airborne technique it is capable of perceiving very fine detail in the directional spectrum with accuracy and reliability.

The first analysis of the directional spectra of sea waves has just been completed, and the results are somewhat exciting. The measured results, which have been reinforced with visual observations, indicate that sea waves are not, in fact, a random and chaotic process, as is generally assumed, but that the directions of travel of various waves are closely related to the wave frequency. Thus waves of a particular frequency appear to travel only in specific and discrete directions relative to the wind.

During the past year work has been completed on a new radio telemetry and command system for installation on the new Buzzards Bay Observing Tower and the automatic data reduction machinery has been extensively rebuilt. This new equipment is expected to accelerate vastly the study of wind-generated waves during the coming year.

ATMOSPHERIC CONVECTIVE PROCESSES

J. S. Turner

During the 2-1/2 months after my arrival in Woods Hole I spent most of my time meeting members of the Institution, and discussing their work and my own with them. I also continued the theoretical work on the mechanism of convection in which I was engaged in Sydney, Australia, and made some preliminary laboratory experiments designed to simulate the effect of evaporation on convective processes.

THE ROLE OF SALT NUCLEI IN ATMOSPHERIC PROCESSES

A. H. Woodcock

During the year 1962, my efforts were centered about three interrelated activities concerning the role of sea-produced particles in atmospheric processes.

In the spring I traveled to Hawaii with Duncan Blanchard and A.T. Spencer to continue our long-term study of the physics and the chemistry of the orographic rains and of the airborne sea salts over the sea in the region of Hilo. Mr. Spencer had worked for a long time and most effectively on the extensive preparatory instrumentation which was required to carry out our planned studies.

Upon returning to Woods Hole, the massive accumulation of observations from this two-month field trip and that from a similar one made during the fall of 1961 were partially reduced and studied. Much of this material is now ready for analysis in terms of the shower model and other ideas which we hope to test.

The third activity was the completion of a paper, titled "Salt-Induced Convection and Clouds," in collaboration with D. C. Blanchard and C. G. H. Rooth, and the writing of a second paper with Dr. Irving Friedman of the U. S. Geological Survey, titled "The Deuterium Content of Raindrops." Two other papers about new instruments (a flame photometer for measuring the sodium in raindrops and a new type rain recorder) were begun, in collaboration with A. T. Spencer. The first paper mentioned above has been accepted for publication in the Journal of the Atmospheric Sciences and will appear in the March 1963 issue.