Woods Hole Oceanographic Institution

WOODS HOLE OCEANOGRAPHIC INSTITUTION

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SUMMARY OF INVESTIGATIONS

CONDUCTED IN 1971

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

APPROVED FOR DISTRIBUTION _____

Paul M. Fye, Director

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Foreword

This collection of brief "summaries of investigations" has been prepared by the members of the research staff of the Woods Hole Oceanographic Institution and this volume is a continuation of our early traditions. For the first decade or so reports of progress by individual investigators were included as an appendix to each annual report. There were only fourteen such summaries occupying less than seven pages in the 1931 Annual Report; there were but thirteen persons on the research staff at that time.

With the expansion of the Institution during the World War II years it became impractical to include a comprehensive report of progress for each investigator, but the Annual Reports did continue to describe very briefly the work being done by each. With the continued expansion of the Institution the printed annual report has become more and more impersonal and the lack of a comprehensive summary of current investigations has been apparent to all. The *Collected Reprints* of the Institution have continued to provide a record of the scientific results obtained by our staff members, but publication delays make these at least a year out-of-date before they appear.

This report is the tenth in the series of Summaries of Investigations. They are similar in style to the reports of progress included as appendices to earlier Annual Reports and a limited number of copies is available. This collection of summaries is intended not only to supplement the limited information about the scientific investigations included in the Annual Report for 1971, but also to let our friends and associates know what each individual staff member is currently studying.

These summaries have been reviewed by the department chairmen but typed, insofar as possible, without editorial change, adhering strictly to the original manuscript in most cases.

Acknowledgment of Financial Support

A very large portion of the support for our research programs came from agencies and offices of the Federal Government, including:

Atomic Energy Commission
Federal Water Quality Administration
National Aeronautics and Space Administration
National Oceanic and Atmospheric Administration
National Science Foundarion
Office of Naval Research
U.S. Coast Guard
U.S. Geological Survey
U.S. Department of Health, Education and Welfare
U.S. Program International Decade of Oceanographic Exploration

We also received support from many private foundations, organizations, individuals and from the Associates of the Woods Hole Oceanographic Institution.

The help, assistance, and encouragement that derives from this support is deeply appreciated.

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BIOLOGY

DEPARTMENT OF BIOLOGY

Richard H. Backus, Department Chairman

OCEANIC FISHES

Richard H. Backus, James E. Craddock, Stephanie Fofonoff,

Denise Franklin, Richard L. Haedrich and David L. Shores

In furtherance of our effort to describe the distribution patterns of mesopelagic fishes in the Atlantic Ocean, a major portion of our time during 1971 was devoted to the sorting and identification of material collected on *Atlantis II* Cruise 59 (Madeira-Cape Verdes-Woods Hole, Nov.-Dec. 1970), identifying and re-identifying small lots of material from earlier cruises, completing our suite of computer programs to plot distribution charts, and re-checking previously computerized data. In addition, and in part as a contribution to pollution studies conducted under NSF-IDOE, new collections were made in the South Atlantic and in the Mediterranean Sea.

The task of identifying the material from the 119 midwater trawls of *Atlantis II* Cruise 59 is about half finished. Approximately 25 species of lanternfishes (Myctophidae) are completed. These have been punched on computer cards and distribution charts for each, based on our ten years' sampling, have been made using our now operative set of programs. These programs work from essentially raw data--station number, position, depth, duration of tow, time of day, and species name. From these are developed charts (any part of the ocean can be selected) showing reliable negative data as open circles and positive catches as black balls (Fig. B-1). We are collaborating with Basil Nafpaktitis (University of Southern California) in preparation of the lanternfish section of the Fishes of the Western North Atlantic series, and these distribution charts will form a major part of our contribution.

We participated in *Atlantis II* Cruise 60 (Montevideo-Capetown-Luanda-Port of Spain, May-July) to augment collections already made in the tropical and subtropical South Atlantic, and to extend our collecting to the eastern parts of that ocean. One hundred midwater trawl and 160 neuston collections were made. (A number of these were specially preserved for pesticide analyses as part of a project examining baseline levels of pollutants in the Atlantic Ocean.)

Our interest in collecting on *Knorr* Cruise 24 (Ionian Sea, Nov.) was to examine further the effects of season on the diversity and species composition of midwater faunas. Eighteen collections were made, supplying ample material for comparison with fishes collected in the same place during June 1970 (*Atlantis II* Cruise 49). During June, 36 neuston collections and two *Alvin* dives were made on *Lulu* Cruise 3-71 (Slope Water). The dives showed two species of lanternfish, *Lampanyctus macdonaldi* and a *Lampadena* sp. (probably *L. speculigera*), both rarely caught in our midwater nets, to be bottom dwellers.

Near completion is a paper reporting the fishes collected on *Chain* Cruise 85 (Sargasso Sea, Nov. 1967) and comparing them with an earlier transect of the same area (*Chain* Cruise 49, June 1965), a transect similar in all respects except that the season of year differed by about six months. The *Chain* 49 results established that the thermal fronts observed near 27°N in the Sargasso Sea were significant faunal boundaries in early summer. The *Chain* 85 results show that the boundary is equally important in early winter, and that the change in biomass occurring there is similar in both seasons. Of especial interest was the finding that diversity indices, an integrative measure, were approximately constant north and south in both seasons, whereas percent similarity, a measure of overlap which takes into account both species present and their abundances, showed that considerable changes occurred from season to season within a region. The collections made in the Mediterranean on *Knorr* 24 were made specifically to examine whether this aspect of the *Chain* 85 results has general implications.

Jonathan Wittenberg (Yeshiva University and Marine Biological Laboratory) and Haedrich completed a summer project of long-standing--a study of the occurrence of a choroid *rete mirabile* in fishes and, based upon its distribution, some suggestions as to the function of the *rete* and of the pseudobranch.

Haedrich has begun an up-dated version of his "Key to the Stromateoid Fishes" with Michael Horn (California State College, Fullerton) and has almost completed a paper on the nomeid fishes collected by the German research vessel *Walther Herwig* in the Atlantic.

Andrew Jahn, a graduate student, and Haedrich have nearly completed a study of the natural history of a small mesopelagic shark, *Isistius brasiliensis*. An interesting finding is that the diet of this animal, which grows no bigger than 50 cm, consists largely of pieces bitten out of large tunas and swordfish.

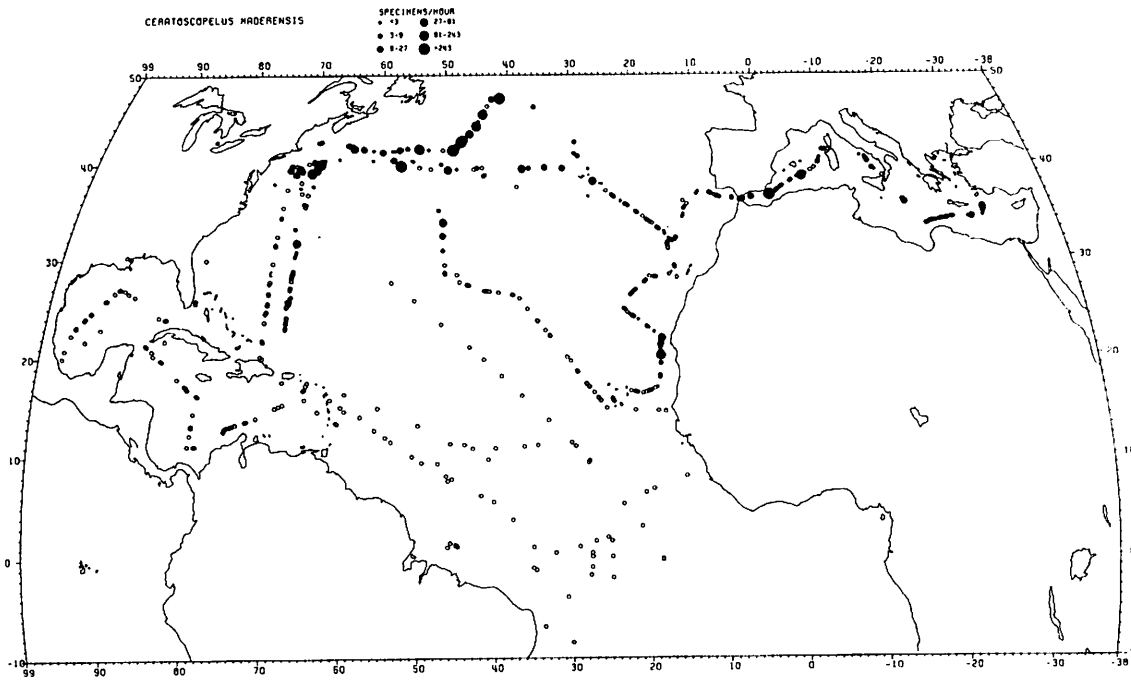

Fig. B-1 (Backus) Distribution map of the myctophid fish, *Ceratoscopelus maderensis* based on W.H.O.I. midwater trawls. The diameter of the black spot is proportioned to the catch per unit of effort. The open circles represent collections made at the appropriate depth for this species, but which failed to take any specimens.

Francis G. Carey

The muscle of tuna has long been known to be warm, and many of these fish have warm viscera. It now appears that they also have warm eyes and brains. Using specimens taken at the Provincetown fish traps, D. S. Linthicum, a W.H.O.I. summer fellow, was able to show that the giant bluefin tuna regulate the temperature of these organs to a fairly constant value over a wide range of water temperatures. This temperature control is probably important in maintaining quality of function in the nervous system during the great temperature excursions these fish experience in their annual migrations and when swimming through the thermocline. A long-line fishing cruise from Wilmington, North Carolina to Woods Hole was made in April on *Gosnold*. We were particularly interested in catching big-eye thresher sharks and mako sharks for telemetry experiments in temperature regulation by free-swimming fish.

In September, several trips were made on a purse seiner to obtain temperature measurements on other species of tuna and specimens for anatomical study.

A long-line cruise out of Yarmouth, Nova Scotia, aboard the *Dorothy and Gail* was made in October. This cruise was sponsored by the Fisheries Research Board of Canada. The vessel was long-lining for swordfish, and we made temperature measurements and prepared specimens for the study of the cranial circulation in this fish.

ALGAL ECOLOGY

Edward J. Carpenter

In the spring, a cruise was made with C. C. Remsen on the *Gosnold* to coastal waters of Georgia and the Savannah River estuary. Our research on competition for urea by bacteria and phytoplankton is described in Dr. Remsen's section of this report. We fortunately obtained measurements of urea decomposition *in situ* by a single species of diatom, *Stephanopyxis costata (Skeletonema costatum)*. We compared this urea decomposition with measurements made in the laboratory with a clone of *S. costata* isolated from Vineyard Sound. Calculation of the *in situ* uptake based on laboratory uptake kinetic measurements was approximately 30% of that observed in the field. We feel that the laboratory estimates agree well with the actual *in situ* data, and this supports the application of laboratory uptake kinetic data to *in situ* conditions.

A study with K. L. Smith of the pelagic *Sargassum* community was started on a cruise in the autumn. Measurements of the production of *Sargassum* and the most abundant macroepiphyte *(Calothrix crustacea)* were made throughout the western Sargasso Sea. Production averaged 65% lower in the southwestern (south of 30°N) Sargasso Sea than in the northwestern. The lower productivity south of 30°N appears to be due to a lack of nutrient regeneration of surface waters resulting from the absence of winter mixing (Ryther and Menzel, 1960).

Epiphytes can contribute an average of 15% of the neuston (*Sargassum* + epiphytes) primary production on the continental shelf off New Jersey and Delaware. In the Sargasso Sea, epiphytes contribute less than 1% of the neuston primary production.

Neuston tows revealed that plastic particles are wide-spread on the Sargasso Sea surface. Plastics were collected in all of 11 neuston tows and averaged 3,500 pieces and 290 g per km^2. Diatoms and hydroids were attached to the plastic particles. Many pieces were brittle, suggesting loss of the plasticizers. Plasticizers contain polychlorinated biphenyls (PCB's), and this could be a source of the PCB's recently observed in open ocean marine life.

References

Ryther, J. H. and D. W. Menzel 1960. The seasonal and geographic range of primary production in the western Sargasso Sea. *Deep-Sea Res.* 6: 235-238.

POWER PLANT ENTRAINMENT STUDY

Edward J. Carpenter, Susan J. Anderson and Bradford B. Peck

This study is being carried out at the Millstone Point Station, a 650-Mw nuclear power plant located on northeastern Long Island Sound. We have completed a one-year study of the species and quantity of plankton that are entrained by the plant's cooling water system. The larvae or eggs of ten species of fish have been observed. The survival of these species as a result of entrainment appears to be low. Similarly, high mortalities of phytoplankton and crustacean zooplankton have been noted. These mortalities are due in large part to application of biocides to control fouling organisms in the plant's cooling water system and to high temperatures experienced by entrained organisms in the summer. We have expanded our study to determine the effects of these mortalities on local plankton populations.

ZOOPLANKTON

George D. Grice and Thomas J. Lawson

Taxonomic investigations of planktobenthic calanoid copepods have continued. Improvement in closing nets has virtually eliminated contamination as a major problem. Samples of plankton collected from near the bottom in 1,000 and 1,500 m from the DSRV *Alvin* have substantiated our earlier findings of a calanoid copepod fauna that inhabits the bottom. Analysis of above and near bottom samples obtained from the continental slope off New York showed that 14 species were restricted to the bottom collections. Of these, five were described as new species, four had been found earlier by us in bottom samples, and five either had been described previously or could not be assigned to known genera with certainty. For comparative purposes, other samples were collected recently from 1,500 m near the Bahama Island of New Providence.

As part of our continuing life history studies of calanoid copepods, one of the smallest and most common species in coastal plankton, *Paracalanus crassirostris* Dahl, was successfully brought into laboratory culture. Its generation time was determined and its developmental stages were illustrated. The nauplii and copepodid stages were compared to comparable stages of related species, and points of taxonomic difference noted.

Taxonomic and zoogeographic studies of the family Candaciidae continues. Over 200 vials of sorted candacids have been received from the Indian Ocean Biological Centre and over 200 collections of zooplankton in the Woods Hole Oceanographic Institution collection have been sorted for candacids. We now have representatives of 27 of the 28 described species in this family and have recently completed a numerical taxonomic analysis using measurements from a single appendage. The results of this analysis indicate groupings of species with morphological affinities and encourage us to proceed with further analysis using characters from several appendages and body parts.

PHYTOPLANKTON PHYSIOLOGY AND ECOLOGY

Robert R. L. Guillard

Hydrocarbon Studies (with Max Blumer, Chemistry Department, and P. S. Moreland, W.H.O.I. Summer Fellow):--Methods were established for assay of the effects of dissolved petroleum hydrocarbons on growth of planktonic algae. A preliminary assay showed that the hydrocarbons were unexpectedly toxic to all algae used, but showed differential toxicity to various species.

Floristic Studies:--We are describing new species of diatoms from our culture collection. Each species is represented by clones isolated from different regions. Ranges of temperature and salinity tolerance have been determined for each clone for inclusion in the taxonomic account.

Carbon Dioxide Uptake by Coccolithophorids (with W. F. Blankley and W. G. Deuser):--Feasibility experiments are in progress for investigating the utilization of inorganic carbon by coccolithophorids. Our previous studies with diatoms suggest that we can use the naturally occurring fractionation of carbon isotopes ($^{12}C/^{13}C$) to distinguish the carbon species (CO_2 or HCO_3^-) taken up by the cells for the production of protoplasm and of coccolith calcite.

Facultative Heterotrophy in Marine Diatoms (completed dissertation research of A. W. White):--Forty-three clones of facultatively heterotrophic marine diatoms, including four centric and five pennate species, were selectively isolated from local waters and established in pure culture. The heterotrophic capability of several species was previously unknown.

Studies of two planktonic centric diatoms (*Cyclotella cryptica* and *Coscinodiscus lineatus*) revealed that (1) there was a high degree of substrate specificity for heterotrophic growth (they grew in the dark with glucose or galactose only), (2) growth rate in the dark followed saturation kinetics with substrate concentration and was appreciable at substrate levels approaching those in nature, (3) active

or facilitated uptake systems for organic substrates developed with time in the dark, (4) several organic compounds were taken up and respired rapidly, and (5) growth in the dark for up to one year, compared to photoautotrophic growth, did not lead to any notable changes in cell morphology, pigment content, carbon and nitrogen content, or photosynthetic ability. It is concluded that facultative heterotrophy is ecologically significant in these two diatoms.

Metals, Algae, and Ion Antagonism (thesis research of W. S. Sunda):--An investigation of ion antagonism between potentially toxic metals, e.g., Cu and Zn, and metal nutrients--Mn, Mg and Ca--is presently being carried out with two species of estuarine algae. The basic premise is that metals will compete with one another for coordination sites in and on the cell, and that such competition will be important in determining both heavy metal toxicity and nutritive metal supply.

Atlantis II Cruise 62:--W. F. Blankley participated in Cruise 62 of the *Atlantis II* to the Sargasso Sea. Investigations included studies of the vertical distribution of the planktonic blue-green alga, *Trichodesmium*, and of the phytoplankton primary productivity, species diversity and nutrient chemistry in the "interstitial" water of patches of the pelagic brown seaweed, *Sargassum*. The maximum abundance of *Trichodesmium* generally occurred at 10-(17 max.)-25 m, and cells were usually not found at depths greater than 35 m. Data processed thus far relevant to the *Sargassum* phytoplankton indicate that primary productivity of the phytoplankton is enhanced by the presence of *Sargassum*; that phosphate and nitrate is higher, and ammonia lower, in the "interstitial" water, and that diurnal changes in these variables are affected by the presence of *Sargassum*.

PHYTOPLANKTON INVESTIGATIONS

Edward M. Hulburt

Phytoplankton investigations included surveys in the New York Bight and Raritan Bay in May, July, September and November, showing a change from a diatomaceous plankton in spring to a scanty flora grossly dominated by the abundant green alga, *Nannochloris atomus* in July and September and then to a diatomaceous flora, with a minor amount of *Nannochloris*, in November. Similar surveys in Buzzards Bay, Vineyard Sound and western Nantucket Sound showed a diatomaceous flora from April through November but with a marked decrease in total density and in number of species and a dominance by large species of *Rhizosolenia* in June and August. The New York Bight summer flora would appear to be the result of enrichment from the city of New York; about Woods Hole such enrichment is lacking, and the diminished summer plankton characteristic of continental shelf waters is the result. The effect of the abundant New York plankton is an abundance of quahaugs in Raritan Bay; in Nantucket Sound a sparse population of quahaugs supports only a marginal industry--a result, it would appear, of marginal food from the plankton.

PHYSIOLOGY AND ECOLOGY OF MARINE BACTERIA

Holger W. Jannasch, Barbara-Ann Collins, Paul E. Holmes,

Parmely H. Pritchard, Jon H. Tuttle, Carl O. Wirsen

Microbial Activity and Degradation of Organic Matter in the Deep Sea:--After the initial observation of an apparent preservation of food materials in the deep sea in connection with the *Alvin* accident, quantitative studies confirmed the general concept of a relative slow-down of microbial activities under deep-sea conditions. The studies were continued and extended to include solid materials and the semi-quantitative measurement of their rate of decomposition. These experiments were aimed at the elimination of closed reaction systems and the problem inherent with them of the difficult interpretability of the data with respect to *in situ* activity. In cooperation with the Department of Physical Oceanography, samples were placed on the ocean floor using buoys in piggy-back fashion.

In addition to studying the behavior of known bacterial species and mixed bacterial populations pre-grown at normal pressure, the indigenous bacterial flora of deep-sea water and sediments were sampled and incubated directly in the environment. For this purpose, a pressurized housing was designed and built that permits an inoculation of sterile medium on the sea floor. In cooperation with the Deep Submergence Group, samples have been placed at the permanent bottom station at 24°35'N, 77°30'W. In principle, this mode of *in situ* inoculation and incubation has offered us the possibility to study the activities of deep-sea microorganisms without prior decompression. Another device for the detection of microbial activities in different layers of deep-sea sediment has been designed and built. With its help, a variety of substrates have been introduced into various depths of sediment at the permanent bottom station. In order to check some of the critical results measured *in situ*, a pressurized sampling vessel is under construction that can also be used as a culture vessel after retrieval.

In February and August, decomposition experiments were conducted in shallow coastal waters to supplement the data obtained from the deep sea. Rates of incorporation and respiration of labeled organic carbon by the natural bacterial population were found (1) to be dependent on the substrate concentration, (2) to be slightly lower in the environment than in the laboratory control, and (3) not to show the expected increase in samples of surface sediment as compared to water samples, and (4) to show strong seasonal differences primarily based on temperature changes.

Pressure-Temperature Relationships in Growth of Marine Bacteria:--Pure culture studies are being continued with a number of psychrophilic marine bacteria isolated from various depths in the Atlantic Ocean. Growth optimum, maximum and minimum temperatures are being determined in batch culture. Incorporation and respiration of radioactive labeled substrates have been determined at 1.5 to 15°C and at pressures of 1 to 400 atmospheres. Specific rates at 15°C are one to two orders of magnitude lower at 400 atm than at 1 atm. At 1.5°C the rates average two to three orders of magnitude lower for the same pressure difference. Certain isolated strains exhibited an asymptotic increase of growth inhibition beyond a characteristic pressure. Chemostat experiments are being conducted for the study of competition between mesophilic and psychrophilic isolates at limiting substrate concentrations and submaximal growth rates. From experimenting within the temperature range where the growth ranges of species overlap, we are able to observe how the substrate concentration in a particular seawater sample will affect the outcome of the competition.

Studies on the Microbial Oxidation of Thiosulfate, Sulfur and Sulfide:--Studies on the distribution of colorless, marine sulfur bacteria were continued. Twenty-five new isolates were obtained from thiosulfate enrichment cultures during a cruise to the Caraico Trench (R/V *Atlantis II* Cruise 60). Preliminary examination of the morphology and heterotrophic growth potential of these bacteria suggest that they are similar to our previously studied Black Sea strains. No obligately chemolithotrophic sulfur-oxidizing bacteria could be isolated from the Caraico Trench. Qualitative estimation of dark $^{14}CO_2$ uptake in water column samples suggests active chemosynthesis near the interface of the aerobic and anoxic zones. Thiosulfate concentrations, determined by iodometry, were as high as 0.022 meq per 100 ml at or below the interface and decreased above it.

A comparative investigation of the autotrophic, heterotrophic and mixotrophic metabolism of 10 representative strains chosen from Black Sea, North Atlantic and inshore isolates was initiated. In aerated batch cultures, all strains were capable of strictly chemolithotrophic growth at the expense of thiosulfate, but cell yields were less than 8 µg cell protein per ml of medium. Yields of three strains were increased approximately 20-fold when the cells were cultured heterotrophically with glucose as the sole energy source. In order to study glucose metabolism under mixotrophic growth conditions, a reducing sugar assay was developed to allow measurement of glucose in the presence of thiosulfate. Isolates which could be cultured heterotrophically on glucose grew under mixotrophic conditions with a concomitant decrease in thiosulfate and glucose concentrations in the medium (thiosulfate and glucose supplied initially at a ratio of 10:1 by weight). The yields increased by 50-100% as compared to growth on glucose alone, and in all but one case, thiosulfate oxidation was stimulated. Two strains which did not metabolize glucose alone were neither stimulated nor inhibited by glucose in mixotrophic media. In contrast, the presence of glucose or yeast extract appeared to suppress thiosulfate oxidation of four other isolates during growth in mixotrophic media. The data suggest several metabolic diversities among our isolates which are being investigated in more detail.

With the purchase of a multichannel pH controller, we have begun experiments to determine growth response and substrate utilization with respect to pH under a variety of conditions. Preliminary results obtained with one of our strains of thiosulfate-oxidizing bacteria suggests that the utilization of organic or inorganic substrates when both are present is pH dependent. Manometric experiments using washed cell suspensions of the isolate show that it is capable of simultaneous glucose and thiosulfate oxidation and that the thiosulfate-oxidizing enzyme system is constituative. Experiments are being designed to extend the oxidation studies to include elemental sulfur, sulfide and polythionates.

Anaerobic growth of several of our facultatively anaerobic strains has been studied in liquid culture. A detailed analysis of the growth, inorganic oxidation and use of various hydrogen acceptors is being undertaken.

Succession of Bacterial Populations:--The experiments on bacterial enrichments in dual-stage chemostats led to the study of successions of bacterial species during the decomposition of certain substrates such as hydrocarbons and fatty acids. The results confirm our earlier findings on the existence and competitive interaction of species exhibiting different kinetic constants for growth and substrate uptake. In principle, successions of bacterial populations are governed by the same laws that determine the behavior of pure and mixed cultures described in our earlier work.

These studies have been extended to include experiments on the effect of inert particulate matter. The first results indicate that the effect on growth and metabolic activity of bacteria is highly selective. Certain morphological and physiological types appear to be strongly stimulated by particle suspensions of certain inert materials while other species are not affected. The significance of these observations for our field of study is evident.

Bacterial Production and Oxidation of Methane:--A study on certain microbiological features of Lake Kivu (Congo) was aimed at (1) the comparative analysis of the role of microorganisms in the formation and maintenance of large anaerobic water bodies, and (2) the specific bacterial population and species involved in the formation and oxidation of methane. From measurements of the primary productivity, the yearly production of methane in Lake Kivu was estimated at 46 liters/m^2 sediment/year. In cooperation with E. R. Leadbetter and R. S. Wolfe, a large number of isolates from both groups of bacteria were obtained and described. Probably due to the unique environmental features, at least one new type of a methane-producing bacterium and several new types of methane oxidizers have been found. A comparative study on the bacterial reduction of nitrate, sulfate, and carbon dioxide in Lake Kivu and the Black Sea is intended.

BIOLOGICAL INSTRUMENTATION

John W. Kanwisher and Kenneth D. Lawson

We have developed small acoustic tags capable of transmitting temperature and heart rate from free-swimming fish. The tags are constructed in three sizes, the smallest being about one cm in diameter by five cm long. It has a useful range of about 100 m and an operating life of one week.

Rapid and accurate bearings on radio-equipped herring gulls have been facilitated by the design and construction of a new UHF direction-finding receiver. The receiver uses a pair of skewed antennas switched alternately at a subaudible rate with synchronous detection at the receiver output. The device was put to extensive and successful use by Timothy Williams and associates during the summer. We intend to apply the same technique to direction finding with underwater sound.

An important addition to our capabilities with oxygen electrodes is the incorporation into the electrode housing of a pair of micropower operational amplifiers and their associated bias networks and batteries. This approach considerably improves rejection of unwanted signals and also minimizes direct leakage problems in cables and connectors. The only equipment required external to the electrode is a voltmeter.

The recurrent need to acoustically telemeter slowly changing data, especially pO_2, has led to development of a narrow band/high deviation phase-locked telemetry system. The central component in this system is a highly accurate and linear voltage controlled oscillator, designed by us to generate a full-scale frequency shift of two kHz on a 22-kHz base. The accuracy of the VCO derives from circuitry which periodically "readjusts the zero" to 22 kHz by means of internal phase-lock and hold to a quartz crystal-derived and highly stable 22-kHz signal. Stability over the range of 0-30 degrees C is better than .025% of absolute frequency, with linearity better than 1% of full scale. Receiving is via narrow band phase-lock (40-hz bandwidth) and an automatic hunting circuit. The telemetered signal is reconstructed within the phase-locked loop by use of a VCO similar to the one used in the transmitter. More than one signal may be transmitted with time sharing. A system of this kind has been constructed for deep ocean bell-jar oxygen studies via *Alvin* placement; its use was delayed by weather. A similar device is being constructed for temperature/salinity profiling of African rift lakes, scheduled in the spring of 1972. We also plan to apply the telemetry system to the study of coral respirometry.

KINETICS OF MARINE COMMUNITIES

William B. Kerfoot

Bioenergetics of Vertical Migration:--Studies were continued on the development of a predictive theory for describing and analyzing the vertical migrations of marine communities. By integrating the potential food energy found along the 24-hour path of isolumes, the relative expected biomass of migrators was predicted and compared to patterns observed in the Gulf of Maine. The peak abundance at noon would occur at depths associated with the position of the 5×10^{-3} and 1×10^{-3} $\mu w/cm^2$ isolumes.

Heavy Metal Transport (with G. G. White):--Last summer, striped bass *(Morone saxatilis)* of different ages were caught near Woods Hole and analyzed for mercury content of muscle. The total mercury concentration was found to increase at a mean rate of .059 µg Hg per gram wet weight of tissue per year, beginning with a negligible amount in fingerling bass and reaching .50 ppm Hg by nine years of age (about 20 pounds weight). The levels of mercury in Woods Hole fish were also compared to those of museum specimens dating back to 1859. Although the total number of museum specimens was small (10) and limited in age and weight due to the limited size of containers in collections, there was no indication that there has been a measurable increase in mercury content of the local striped bass from 1859 to the present.

The amount of mercury in the food necessary to sustain the mercury level observed in the muscle of bass of different ages was calculated from daily metabolism, weight gain, mercury content of the body, and rate of elimination of mercury from the body. An analysis of common prey of the bass revealed sufficiently large mercury concentrations to contribute a substantial portion of the mercury necessary to give rise to the levels found in the muscle of the bass. From these findings, we suggested that while legislation restricting the discharge of mercury wastes into marine waters is desirable, it will result in little decrease in the mercury content of striped bass.

DISTRIBUTION, MIGRATIONS, POPULATION DYNAMICS AND MORPHOLOGY OF LARGE PELAGIC FOOD AND GAME FISHES

Frank J. Mather, III, H. Lawrence Clark, John M. Mason, Jr. and M. Dorothy Rogers

Our effort again centered on data analysis, but the Cooperative Game Fish Tagging Program and other studies, most of which related to the Atlantic bluefin tuna *Thunnus thynnus thynnus* and the fisheries for it, were continued. We furnished much information to international agencies for coordination of fisheries research and management of fisheries, and coordinated a continuing

international tag-testing experiment. A new species of amberjack, genus *Seriola*, was described.

The incomplete data for 1971, with 3,024 releases and 206 returns tabulated to date, brought the respective totals for our Cooperative Game Fish Tagging Program to 40,812 and 2,900. The 1971 releases (denominators) and returns (numerators) for the respective species with the cumulative totals shown in parentheses, were as follows: bluefin tuna, $\frac{140}{430}$ $(\frac{2,199}{11,038})$; skipjack tuna, *Katsuwonus pelamis*, $\frac{0}{45}$ $(\frac{85}{2277})$; white marlin, *Tetrapturus albidus*, $\frac{26}{969}$ $(\frac{116}{8515})$; blue marlin, *Makaira nigricans*, $\frac{1}{115}$ $(\frac{5}{676})$; Atlantic sailfish, *Istiophorus platypterus*, $\frac{1}{1033}$ $(\frac{94}{11,970})$; greater amberjack, *Seriola dumerili*, $\frac{35}{131}$ $(\frac{354}{2982})$; and other species $\frac{3}{234}$ $(\frac{47}{3354})$. Except for the tag comparison experiment mentioned above, all the 1971 tagging was by cooperating sport fishermen.

The returns from small bluefin tuna again indicated very heavy pressure on the local stock. The purse-seine catch of 4,250 tons was comparable to the 4,661 tons in 1970, but the fishing effort was greater and the catch per boat day, 12.5 tons, showed a continued decline from the high of 18.2 in 1969. The return rate for fish which had been at liberty over a single winter reached 24.4% in 1970, greatly exceeding all previous figures, which were below 15%. This parameter is considered to be a more reliable index of fishing pressure than return rates in the season of release, since the latter are biased by differences in temporal and areal exposure to the fishery. In 1971, the return rate from the 1970 releases has already exceeded 25%, although tags have not been collected from a considerable portion of the catch. Thus the changes, both in catch per boat day and in second-season tag-return rate, indicate a decrease in the relative abundance of the stock. These and other data influenced the International Commission for the Conservation of Atlantic Tunas (ICCAT), at its meeting in November-December, to initiate studies on the feasibility of a minimum size limit for bluefin tuna.

White marlin tagging was more successful than ever, with about 900 releases and a record-breaking 33 returns--28 from releases in summer between Cape Hatteras and Cape Cod and five from releases in southern waters. Twenty-six of the former fitted well with the clockwise migratory pattern previously proposed for this stock. Ten of these showed the offshore movement from this area in the fall. The first two recaptures in the Gulf of Mexico from releases in this area were recorded. One of these fitted the above pattern, but the other was the first to suggest a switch from this group to the one which summers in the Gulf of Mexico. The other apparently aberrant return was from off the Carolinas in January, when all other results indicate that these fish are off the north coast of South America.

The five returns from releases in southern waters included three released off the northwestern Bahamas and two released off Venezuela. Two of the former fitted previously proposed migratory patterns from the Bahamas to the Cape Hatteras-Cape Cod area and between the Straits of Florida and the Gulf of Mexico, but the third fish made an unpredictable migration from the Straits of Florida to equatorial waters 600 miles ENE of the mouth of the Amazon. One of the fish released off Venezuela made the second recorded migration from that area in summer to off the Guianas in fall; the other was recaptured locally. More tagging of white marlin in southern waters is urgently needed. The return rate for white marlin is improving, and the long times at liberty for recaptured fish continue to show a surprisingly high rate of survival.

The single returns obtained for blue marlin and sailfish were very interesting. The blue marlin migration from off the northwestern Bahamas in February, 1969, to the north central Gulf of Mexico in August, 1971, is the first significant one recorded for this species. It is consistent with the tendency previously found for sailfish and white marlin to move from the Straits of Florida in the cold season to the Gulf of Mexico in the warm season, and vice versa. The time at liberty of 30 months is the longest yet recorded for the species, and in this period the weight of the fish increased from an estimated 200 to about 400 pounds. The dates of release and recapture for tagged blue marlin favor the concept of separate stocks in the North and South Atlantic, as opposed to that of a single stock which migrates seasonally from one ocean to the other. The sailfish return, from off Cape Hatteras in October, 1969, to off Paramaribo, Surinam, in March, 1971, represents the longest migration yet recorded for this species, and also the most northerly successful tagging and the most southerly and easterly recapture. The migration is consistent with the tendency of the species to

move from temperate waters in the warm season to tropical ones in the cold season, and vice versa. The tag return rate for sailfish was the poorest in many years.

The returns for greater amberjack comprised 32 released and recaptured off the east coast of Florida and the Florida Keys, and three released and recaptured in the northeastern Gulf of Mexico. Eight migrations of from 40 to 125 miles were recorded within the former area, and one of about 80 miles within the latter. Twenty-four of the remaining recoveries were in or near the release locality, and release data were not available for the other two. The return rate was good, and times at liberty ranged up to over four years.

As Convenor of the Working Party on Tuna and Billfish Tagging in the Atlantic and Adjacent Seas under the FAO (United Nations) Expert Panel for the Facilitation of Tuna Research (EPFTR), Frank Mather coordinated the preparation of the Final Report of the Working Party. This constitutes a complete review of all tuna and billfish tagging in the Atlantic, and was used as a working document at the meetings of the ICCAT Subcommittee on Stock Identification at Lisbon in April, of EPFTR in La Jolla, California, in November and of ICCAT in Madrid in November-December.

Frank Mather participated in all of these meetings, and was a scientific advisor to the United States delegation of ICCAT.

A preliminary computerized analysis of our data for small bluefin tuna marked in local waters (8,587 releases and 2,039 returns) was carried out by B. J. Rothschild and Gerald Paulik of the National Marine Fisheries Service, Seattle, Washington. This confirmed on a quantitative and objective basis the patterns of local movement which had been deduced from preliminary studies of the data. It also confirmed very high rates of loss of the stock but, with the available data, could not separate mortality rates from out migration and other sources of loss.

A tag testing experiment was initiated in the summer in cooperation with the St. Andrews Biological Station of the Fisheries Research Board of Canada and the Southeast Fishery Center (Miami Laboratory), National Marine Fisheries Service. This experiment, carried out at the request of ICCAT, was designed to evaluate the effectiveness of the two most widely used types of tags, and also to eventually obtain estimates of relative mortality plus shedding, relative shedding, true shedding and true mortality. Continued tagging will be required to obtain some of the last parameters. Field workers of the three agencies double-tagged 580 small bluefin tuna in the Northwestern Atlantic Bight, alternately using two tags of one type and two of the other. Since the target of 1,000 fish was not attained in 1971, the experiment will be completed in 1972. The results of this effort should permit much more accurate estimates of population parameters through analyses of tagging data.

The analyses of size frequency and body condition for bluefin tuna continued, and a study of the stomach contents of small bluefin tuna was undertaken by John Mason. Qualitative and quantitative analyses showed that fishes of the families Scombridae, Clupeidae and Stromateidae and molluscs of the order Decapoda were most important in the diet of these fishes during their summer sojourn in southern New England waters.

The study of the systematics and distribution of the carangid fishes of the genus *Seriola* was also continued, resulting in the description of a new species, *S. carpenteri* Mather, 1971, from the Gulf of Guinea.

MARINE MICROBIOLOGY AND CYTO-MORPHOLOGY

Charles C. Remsen and Brian W. Schroeder

We have participated in a number of cooperative research projects in addition to our continued collaborative efforts with S. W. Watson on the ultrastructure of marine bacteria.

Cell Envelope of Marine Autotrophic Bacteria:--Our survey on the ultrastructure of the cell envelope of various marine autotrophic bacteria has continued. From this survey we have formed a working hypothesis which, simply stated, says that there are basic arrangements for macromolecular subunits on the cell envelopes of marine autotrophic bacteria, which seem to transcend species and physiological differences. In particular, we have concentrated on the envelope of marine photosynthetic bacteria. Preliminary studies indicate a strong similarity in structure to that of the marine nitrifying bacteria.

Much of this work has involved the use of freeze-etching as a preparative tool in the electron microscopic studies. With Dr. Watson, we have recently submitted a monograph entitled "Freeze-etching Bacteria" for publication in the "International Review of Cytology."

Interaction of Membranes with Staphylococcal Alpha and Delta Toxins:--Our studies on the fine structure and composition of membranes have continued. Membranes play an obvious role in the energetics of biological systems and, in particular, our interests have been centered on the cytomembrane systems found in marine photosynthetic and nitrifying bacteria. As a corollary to these studies, together with S. W. Watson (W.H.O.I.), A. W. Bernheimer and K. S. Kim (N.Y.U.) and J. Antanavage (East. Phila. Psych. Inst.) we have been using bacterial toxins as a label of the phospholipid arrangements in natural and synthetic membranes. The results to date strongly suggest an ordered arrangement of phospholipids within the matrix of the membrane.

Measurement of Urea in Natural Waters:--Some controversy has developed over the determination of urea in seawater. In an attempt to clarify discrepancies that have appeared in the literature, we have spent some time comparing various published methods. We believe that by using shipboard spectrophotometers, we are able to measure urea in seawater with accuracy and precision.

Competition for Urea among Estuarine Microorganisms:--In some previous studies we reported on the ability of marine phytoplankton to use urea as a source of nitrogen. During Cruise 175, leg 10 of the R/V *Gosnold* in the lower Savannah River, Wilmington River and adjacent coastal waters, we studied the roles of bacteria and phytoplankton in the decomposition of urea in the estuarine habitat in collaboration with E. J. Carpenter. Results of this study indicate that competition for urea represents a departure from the general rule saying that bacteria are favored over algae in the competition for dissolved organic compounds. Phytoplankton were responsible for the major part of the urea decomposition in the Savannah estuary. Acknowledgment is given to the Skidaway Institute of Oceanography for their help in this study.

QUANTITATIVE BENTHIC ECOLOGY

Gilbert T. Rowe and Pamela Polloni

Deep-Sea Biomass:--The abundance and biomass of the macrobenthos between Massachusetts and Bermuda have been under investigation in an effort to determine how and at what levels organic energy is dispersed through the deep ocean. Data from this transect and from the northern Gulf of Mexico have been summarized, and the generalization can be made that the abundance of life decreases predictably by about one order of magnitude with every two kilometers increase in depth. A comparison of these data with previous investigations in other basins indicates that the most useful parameters for predicting the abundance of life on the deep-sea floor are depth and the primary productivity of the surface water (Rowe, 1971a; 1971c). Animal life is generally more prolific on the east coast of the United States than in basins at lower latitudes, including the Gulf of Mexico, which is under the influence of the Mississippi River runoff. Exceptions to this generalization are eastern ocean boundaries under the influence of upwelling, and hence intensive rates of primary productivity.

Submarine Canyons:--Submarine canyons are among the most prominent features along continental margins, but little is known of how they were formed or how they affect physical and biological phenomena in the ocean. Earlier work along the east coast has indicated that the usual, narrow zonation of benthic populations (Rowe and Menzies, 1969) is broken in submarine canyons (Rowe, 1971b), but we have little evidence of why this occurs. The presence of particular groups or species and their peculiarly clumped spatial dispersions suggest that food sources in canyons may be somewhat different from typical continental slope conditions. To understand this, we have initiated an investigation of the Hudson Canyon system, and our samples from R/V *Knorr* Cruise 19 in and along the canyon margins will allow us some insights into whether the canyon may be acting in some way to concentrate organic detritus or has acted to funnel organic energy into the deep sea.

New York Bight Pollution:--The head of the Hudson Gorge, the shelf-trough extension of the Hudson Canyon System, is under the influence of sewage sludge and dredge spoils disposal from the city of New York. We have attempted to determine how the intense pollution emanating from the Raritan and Hudson estuaries and the dump sites is affecting life in the Gorge. The common statistical parameters of animal communities indicate that outside the direct influence of the dumps there is an intense fertilization. Diversity decreased slightly, but abundance and biomass were radically increased along the Gorge axis and gradually decreased offshore. The macrofaunal abundance estimates averaged 180,000 animals per square meter for the month of July, and this appears to be a record estimate for offshore assemblages (Rowe, in press).

In association with Kenneth Smith and Hovey Clifford, we have initiated seasonal analyses of the total community respiration in what appears to be the most highly fertilized area. With the successful completion of late winter measurements, we will have estimates of the variations in the flux of energy through the community over a one-year period. We hope to be able to establish with a quantitative carbon budget how the ecosystem is coping with the abundance of organic matter to which it is subjected. A similar investigation has been carried out adjacent to the Woods Hole raw sewage outfall with Dr. Smith and Jean Nichols.

Solid Waste Disposal:--A pressing problem in maintaining the quality of the environment in the densely populated metropolitan areas of New England is the disposal of solid refuse. In response to this, investigations have begun to determine the effects of this material on marine biota. A major part of the research has been the deployment of a block of shredded, compressed refuse encapsulated in plastic. The one-ton bale is in 45 feet of water and so far has produced no ill effects on the environment.

Related work in environmental quality has been an analysis of the benthic community parameters in Boston Harbor's lower Mystic River (Rowe, Polloni, and Rowe, in press). Based on animal densities, diversity and biomass, we concluded that this estuary is highly polluted, but that this pollution decreases downstream. Pollution stress appeared to be less at the thermal effluent of a power generating plant, rather than more as might be expected.

DSRV *Alvin* has been used in the Gulf of Maine and the Tongue of the Ocean south of Nassau for the purpose of assessing the abundance of the macrobenthos and for the development of new bottom-sampling equipment. In conjunction with Harold Edgerton at M.I.T. we have been using a time-lapse moving picture camera which will be employed with our time-series ecological experiments with *Alvin*.

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MARINE AQUACULTURE SYSTEMS BASED ON THE RECYCLING OF DOMESTIC WASTES

John H. Ryther, William M. Dunstan, Kenneth R. Tenore,

Nathaniel Corwin and John E. Huguenin

Laboratory experiments were begun in the summer of 1970 on the growth kinetics of marine plankton algae grown in seawater enriched with the effluent from a secondary sewage treatment plant. A flowing system was developed in which sewage-enriched seawater was pumped continuously into 15-liter algal cultures from which a comparable volume of culture was continuously removed. Although uni-algal cultures were used in some phases of the work, the normal procedure was to use unfiltered seawater as an original inoculum and allow a natural mixed population of phytoplankton to develop.

In general, diluted sewage was found to be an excellent culture medium for marine phytoplankton, comparable to if not better than the artificially-enriched seawater medium used for many years in our laboratory. Freshly-collected chlorinated effluent was found, at times, to be toxic. The toxicity could be removed by aeration or brief aging and is thought to have resulted from residual chlorine. However, chlorinated effluent was found to support better and more consistent growth of phytoplankton than effluent taken from the same plant just prior to the chlorination processes.

In the continuous-flow system, phytoplankton growth and cell density was directly proportional to sewage concentrations up to 10% in seawater, the exact figure depending upon the concentration of major nutrients in the effluent.

At concentrations of 10% sewage, the yield of algae increased with flow rate through the system up to a volume exchange or "turnover rate" of 50% of the culture per day. Higher flow rates washed out the culture. At the 50% turnover rate, densities of 0.5 to 1.0 x 10^6 cells/ml could be maintained for periods of up to one month.

At all concentrations of sewage used (below toxic or inhibitory levels) and at turnover rates up to 50% of the culture per day the algae removed quantitatively all of the available nitrogen. Phosphate, however, gradually accumulated in the culture, reflecting the difference in the N:P ratio in the sewage (ca. 7:1 by atoms) and that in the algae (10-15:1 by atoms).

As the population grew in the continuous cultures, increasing by approximately three orders of magnitude in 3-5 days, there was a general increase in abundance of most of the algal species present. Those that were initially dominant usually retained their position of dominance, and the diversity of the population did not significantly change. After the culture reached its maximum density, there was a gradual decrease in diversity and a tendency for two or three species to dominate the population.

Laboratory experiments were also carried out on the effects of temperature, food concentration, and flow rate on food utilization, growth efficiency, and nutrient regeneration (via excretion) of seed oysters 0.5 to 1.0 cm in length. In one such experiment, a natural population of diatoms grown in continuous culture on 10% sewage was passed through a 10' x 5' x 1.5' tank containing suspended strings of oyster spat attached to scallop shells. Over a period of 30 days at 7-10°C, the oysters removed 77% of the algae entering the system and converted 22% of the filtered cells to new oyster flesh.

During the summer of 1971, the project was expanded in size and moved outdoors where it could be tested under natural conditions of solar radiation, temperature, etc. Using 10% sewage and exchanging half the 400-liter culture volume per day, an average yield of 19 g dry weight/m^2/day of algae was maintained throughout the summer (Fig. B-2). From the 200 liters of new medium passed through the algal culture each day, all available nitrogen was removed again indicating that production was nitrogen-limited.

The algal cultures, diluted with filtered seawater by approximately 100:1, were fed continually into 500 gal. rectangular tanks containing oysters, scallops, or mussels (Fig. B-3). In some of the tanks, sandworms, grass shrimp, post-larval lobsters and juvenile flounder were also added to a sand

substrate to utilize solid wastes from the shellfish. Growth of the animals was determined in a series of different experiments as a function of flow rate and food concentration. The water entering and leaving the animal tanks was routinely monitored for nutrients (N, P, Si), particulate carbon, chlorophyll and species and numbers of algae to determine, under the different experimental conditions, food utilization and nutrient regeneration.

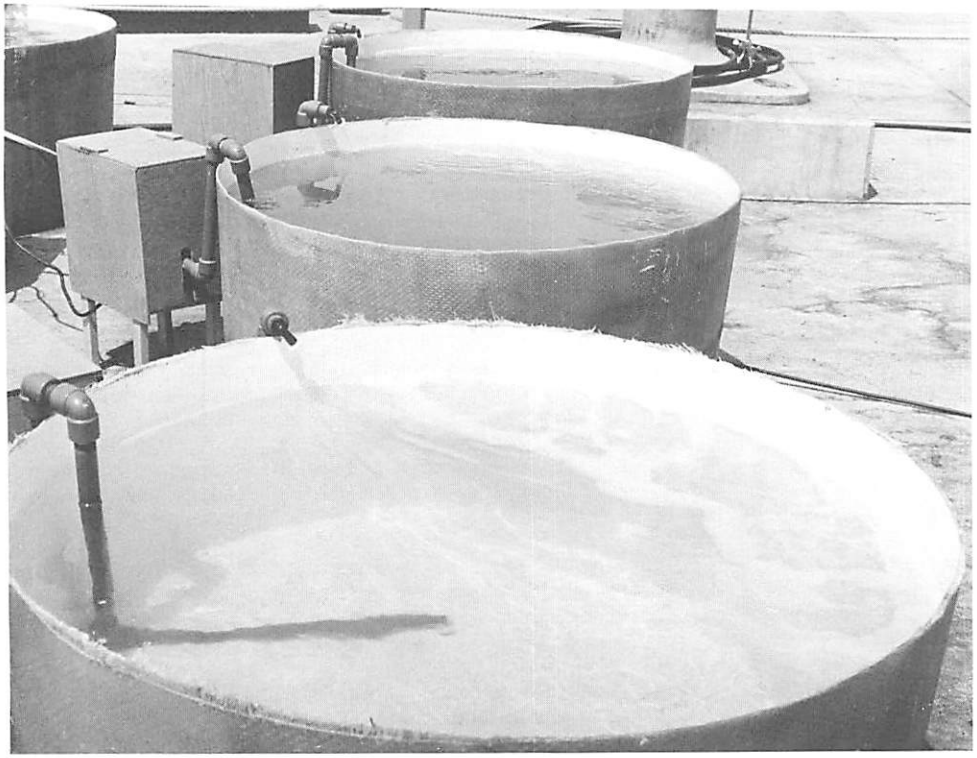

Fig. B-2 (Ryther) Culture tanks (100 gal) in which algae are grown in secondary sewage effluent diluted in seawater.

Fig. B-3 (Ryther) Output of the algal culture tanks are pumped into the white, polyethylene food reservoirs in the background. From there algae, together with filtered seawater, are fed into the rectangular (500 gal) animal tanks.

BENTHIC STUDIES

Howard L. Sanders and J. Frederick Grassle

Our efforts were divided among three research areas; oil pollution biology, the deep-sea benthos, and theoretical ecology.

Certain major taxa of the deep-sea benthic fauna have radiated and diversified far beyond the level known from any other habitat. We have begun to document the great radiation that has taken place on the deep ocean floor within the ancient bivalve subclass Protobranchia. Totally new and unsuspected morphologies have been found. In the initial two papers completed, three new families of protobranchs are erected, the Pristiglomidae, Lametilidae and the Siliculidae. Each constituent species was analyzed on the basis of soft and hard part anatomy, functional morphology, reproduction, distribution, growth, life history and general ecology.

Stimulated by the great variety of life encountered in our deep-sea samples, we have become interested in learning what factors are instrumental in bringing forth high faunal diversity. Much of the confusion relating to diversity and what it implies can be attributed to the fact that an increase in diversity can be achieved by two entirely different and unrelated pathways. The resultant diversities can be differentiated as follows:

> Short-term, non-equilibrium or transient high diversity:--Induced by a low or non-predictable physical or biological perturbation or stress resulting in biological 'undersaturation' of the environment. Because of the at least partial biological vacuum, more species can temporarily occupy the habitat until population sizes build up to densities where the species must intimately interact. The time scale is always short--days, weeks, months or years--and this type of diversity is manifested in the predominantly physically controlled habitats. The increase in diversity is rapid and is brought about by other species in the local surrounding geographic area.
>
> Long-term, equilibrium or evolutionary high diversity:--Increase in diversity is the product of past biological interactions in physically stable, benign and predictable environments. The time scale is geologic, at least thousands of years, and the resultant product is the predominantly biologically accommodated community. Diversity increment is slow, the result of speciation and/or a low rate of immigration into the environment.

The pattern of recovery for the West Falmouth oil spill study is now more evident. Following the catastrophic kills of September, 1969, the affected bottoms remained grossly undersaturated biologically until the summer of 1970. At that time, very heavy larval sets of many species occurred. By September, 1970, the normally occurring species had returned although most of the individuals were hardly more than postlarvae. In the more heavily affected localities, some of the more sensitive species did not return until the winter of 1971. The ability of benthic species to reestablish themselves is intimately correlated with quantitative and qualitative changes in the oil pollutant.

MARINE INVERTEBRATA

Rudolf S. Scheltema

Reproduction and Population Dynamics of some Protobranch Bivalves from the Continental Shelf, Slope and Abyss off the Northeastern United States:--Comparison of the reproductive potential of five lecithotrophic protobranch bivalve species of the genus *Nucula* found off the northeastern coast of the United States shows that the two shoal-water forms have larger gonads and greater numbers of eggs than the three species from the slope and abyss. The numbers of eggs found in the gonads of shoal-water forms are five to twenty times greater than those of the slope and abyss. The data suggest that in order to maintain a stable population, deep-sea lecithotrophic species of the genus *Nucula* must either live longer, survive better or reproduce more continuously than lecithotrophic shelf species of the same genus. Evidence from length frequency analysis (Fig. B-4) and from histological examination of samples collected at various times of year shows that among deep-sea representatives, reproduction is continuous and survival is better than from the shallow shelf species of the genus *Nucula*.

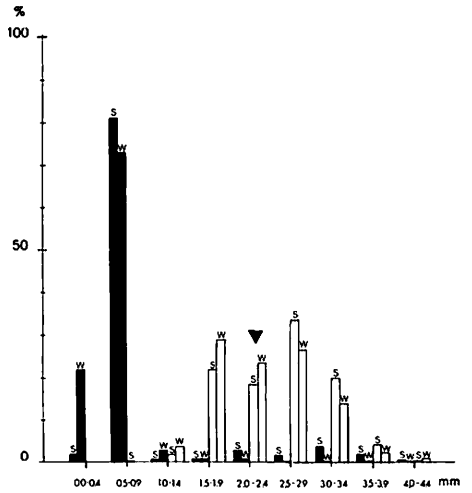

Fig. B-4 (Scheltema) Size frequency distribution of two species of *Nucula*. Solid bars represent *Nucula annulata*, a continental shelf species; open bars designate *Nucula cancellata*. S = summer size distribution. W = winter size distribution. Size intervals along abscissa are 0.5 mm. Ordinate designates percent frequency. Inverted triangle shows minimum size at sexual maturity (2.2 mm). Summer sample of *Nucula annulata* taken in 1963 contained 731 specimens of which 87.3% were juvenile. Winter sample taken in February 1965 consisted of 9,123 individuals. Ninety-nine percent of these were juvenile. The size frequency distribution of *Nucula cancellata*, a lower slope species, is quite different than that of *Nucula annulata*. Summer sample taken in May 1966 contained 352 specimens with 39.8% juvenile; winter collection taken in December 1966 contained 1,017 specimens of which 34.8% were juvenile.

Data further suggest that deep-sea lecithotrophic species of *Nucula* are effectively dispersed, presumably by short-lived non-feeding larvae, and that each generation has an opportunity to extend the range of the species, albeit only a short distance (Table B-I). On the other hand, shoal-water lecithotrophic species (because of their depth restriction) cannot extend their range across oceans in such stepwise fashion. Directly reproducing deep-sea species of *Nucula* are also restricted geographically, presumably because of their lack of a dispersal phase. This work is being continued in collaboration with H. L. Sanders.

TABLE B-I

RELATIONSHIP BETWEEN MODE OF REPRODUCTION AND GEOGRAPHIC RANGE AMONG SPECIES OF THE BIVALVE GENUS *NUCULA* KNOWN FROM OFF THE NORTHEASTERN COAST OF THE UNITED STATES

	Egg diameter μ	Probable development	Geographical distribution
SHELF SPECIES			
Nucula proxima	100	Lecithotrophic	Western Atlantic: NE coast of U.S.
Nucula annulata	120	Lecithotrophic	Western Atlantic: NE coast of U.S.
Nucula delphinodonta	190	Direct	Western Atlantic: NE coast of U.S.
DEEP-SEA SPECIES (Slope and Abyss)			
Nucula subovata	270	Direct	Western Atlantic: NE coast of U.S.
Nucula granulosa	120	Lecithotrophic	Western Atlantic: E coast of U.S. Eastern Atlantic: Bay of Biscay
Nucula cancellata	135	Lecithotrophic	Western Atlantic: E coast of U.S. Eastern Atlantic: Bay of Biscay off W Africa
Nucula verrilli	125	Lecithotrophic	Western Atlantic: NE coast of U.S. NE coast of Brazil Eastern Atlantic: off W Africa

Eastward and Westward Dispersal of Tropical Prosobranch Larvae of the Family Bursidae across the Mid-Atlantic Barrier:--There are in the tropical Atlantic seven species of the prosobranch family, Bursidae. Only four of these, *Bursa thomae, Bursa spadica, Bursa granularis (= cubaniana)* and *Bursa corrugata* are amphi-Atlantic in distribution, i.e., found both in the eastern and western Atlantic Ocean. The dispersal of these tropical prosobranch species is accomplished by means of planktonic larvae.

As no bursid larvae have yet been described, it has been necessary to examine the protoconch of well preserved juvenile and young adult specimens in order to make possible identifications from the plankton. The larvae of the four species being considered here can be separated by size of their embryonic shell (Fig. B-5), the number of axial cords on the first and second whorls of the post embryonic shell (Fig. B-6) and the relative size of the larval spires (excluding the body whorl).

The dispersal of larvae over long distances depends upon the velocity of ocean currents and the duration of planktonic development. Plankton collections made throughout the tropical Atlantic show that the larvae of *Bursa* species from the shoal-water are regularly carried from the continental shelf for long distances (Fig. B-7). The larvae of the stenothermal tropical forms are carried westward from West Africa on the North and South Equatorial Currents and eastward from Brazil along the Equatorial Undercurrent. An estimate of the duration of larval life and a knowledge of the current velocity suggest regular exchange of *Bursa* larvae between the continents of South America and Africa (*vide*, Scheltema 1968). This work was reported at the 4th European Malacological Congress at Geneva, September 1971.

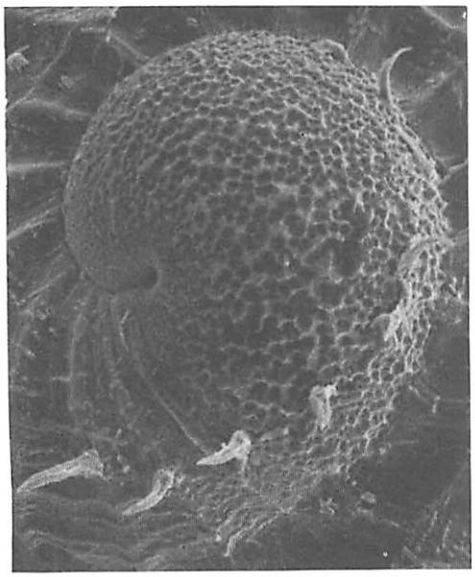

Fig. B-5 (Scheltema) Embryonic shell of the larvae of *Bursa thomae* taken from the plankton. The embryonic shell of *Bursa thomae* and *Bursa corrugata* is smaller than that of *Bursa granularis* and *Bursa tenisculpata*.

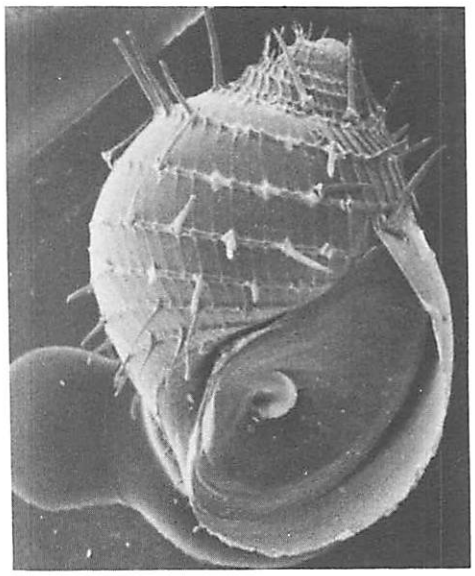

Fig. B-6 (Scheltema) Larval shell of *Bursa thomae*. The embryonic shell is barely visible at the apex. The axial cords in *Bursa thomae* and *Bursa granularis* are more numerous than in *Bursa tenuisculpata* and *Bursa corrugata*.

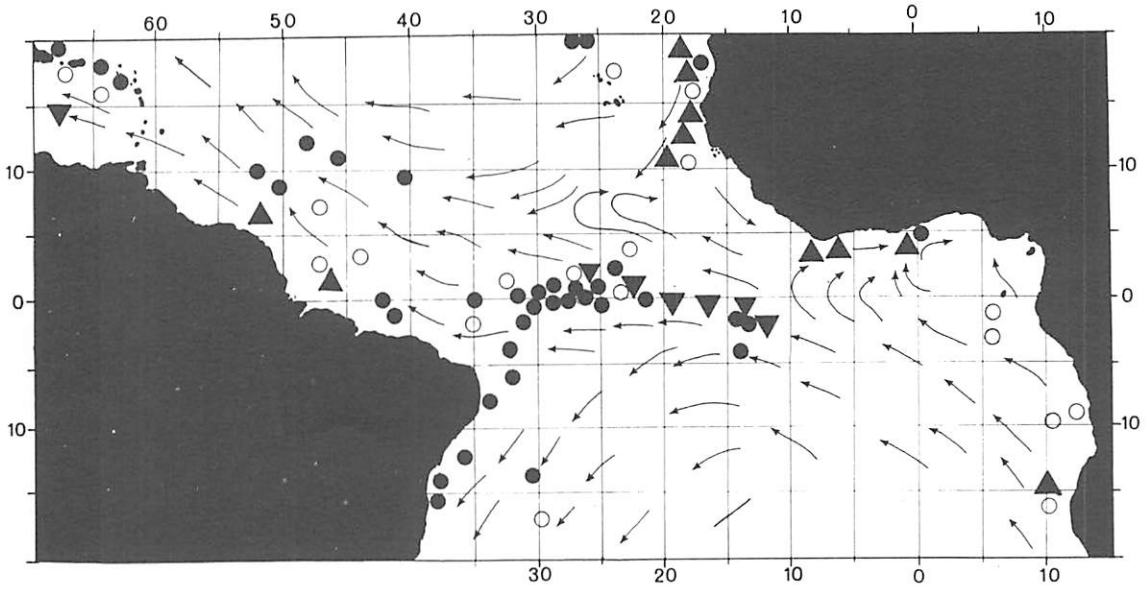

Fig. B-7 (Scheltema) Distribution of veliger larvae from the genus *Bursa* found in the tropical Atlantic Ocean between 20°N and 20°S. Arrows show approximate surface currents. Filled circles equal *Bursa thomae*; open circles equal specimens unidentifiable to species because of poor preservation or small size; upright triangles equal *Bursa tenuisculpata*, specimens found off African coast possibly may be confused with *Bursa scrobiculator* which they closely resemble; inverted triangles equal *Bursa granularis*.

Functional Morphology and Geographical Distribution of Planktomya henseni:--A study of the functional morphology and geographical distribution of the enigmatic bivalve *Planktomya henseni* has led to the conclusion that this form, originally described and figured by Simroth in 1896 from samples taken on the German Plankton Expedition, is actually a veliger larva.

Planktomya henseni is widely distributed throughout the warm temperate and tropical north and south Atlantic Ocean. It is also known from a single collection in the tropical Pacific Ocean. The geographical distribution of *Planktomya* is probably circumtropical.

In the past, *Planktomya* has been regarded as a neotenous species--a holoplanktonic bivalve fully analogous to the pteropods and heteropods. Evidence from detailed morphological observations does not support the view that *Planktomya henseni* is a member of the permanent plankton. It appears rather to have all the characteristics of a teleplanic bivalve larvae, namely, a very light non-calcified shell and a large prominent velum. No specimens during any month of the year showed any evidence of reproductive maturity--no ova or sperm were seen, nor was any gonodal tissue identified.

Evidence from the geographical distribution and abundance of *Planktomya henseni* also suggest that it is the larva of a shoal-water species. Smaller stages are found only in the proximity of land, and the numbers decrease with increasing distance from the coast. Morphological evidence suggests that *Planktomya henseni* is probably the larva of a shallow-water species belonging to the super family Leptonacea.

This research has been done in collaboration with J. A. Allen, Dove Marine Laboratory, Cullercoats, Northumberland, U.K., and will appear in an article in the Journal of the Marine Biological Association, U.K. early in 1972.

The Dispersal of Ciliate Protozoans of the Family Folliculinidae:--The Folliculinidae, a family of sessile ciliate protozoa, constitute one component of the fouling complex found on the shells of larger tropical gastropod veliger larvae (i.e., 2-5 mm). Attached loricate-protozoa are commonly found on the larval shells of *Cymatium parthenopeum, Charonia variegata, Tonna galea* and *Cymatium nicobaricum*. The folliculinid species commonly found attached to these gastropod larval shells is *Folliculina simplex* Dons. This protozoan is apparently part of a species complex and *Folliculina ampulla* of some authors is probably a synonym. Folliculinid species are distinguished largely by the character of their lorica, and the scanning electron microscope has proved useful to determine geographic variations within species (Fig. B-8). Examination of *Folliculina simplex* on larval shells of *Cymatium parthenopeum* from both the eastern and western Atlantic shows no differences in the details of the lorica from these two regions.

The distribution of gastropod veligers in the open ocean suggests that their transoceanic transport is a commonplace event and that the frequency of larval dispersal is directly related to the rate of genetic exchange between eastern and western Atlantic populations (Scheltema 1971, in press). Concomitant with the transport of gastropod veligers is the dispersal of associated folliculinid protozoa across the Atlantic Ocean basin (Fig. B-9). Since folliculinids, as other ciliates, can rapidly reproduce asexually, a favorable genotype once introduced into a new region can become quickly established.

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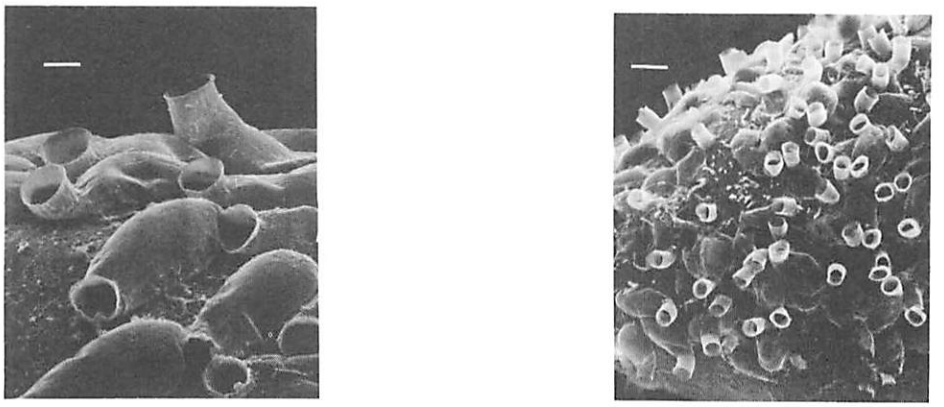

Fig. B-8 (Scheltema) Right: Aggregation of the ciliate protozoan, *Folliculina simplex* Dons on the larval shell of the gastropod *Cymatium parthenopeum* (scale equals 100 μ). Specimen taken from the Gulf Stream, 36°22'N, 67°53'W.
Left: Same as at right but aggregate further enlarged (scale equals 30 μ).

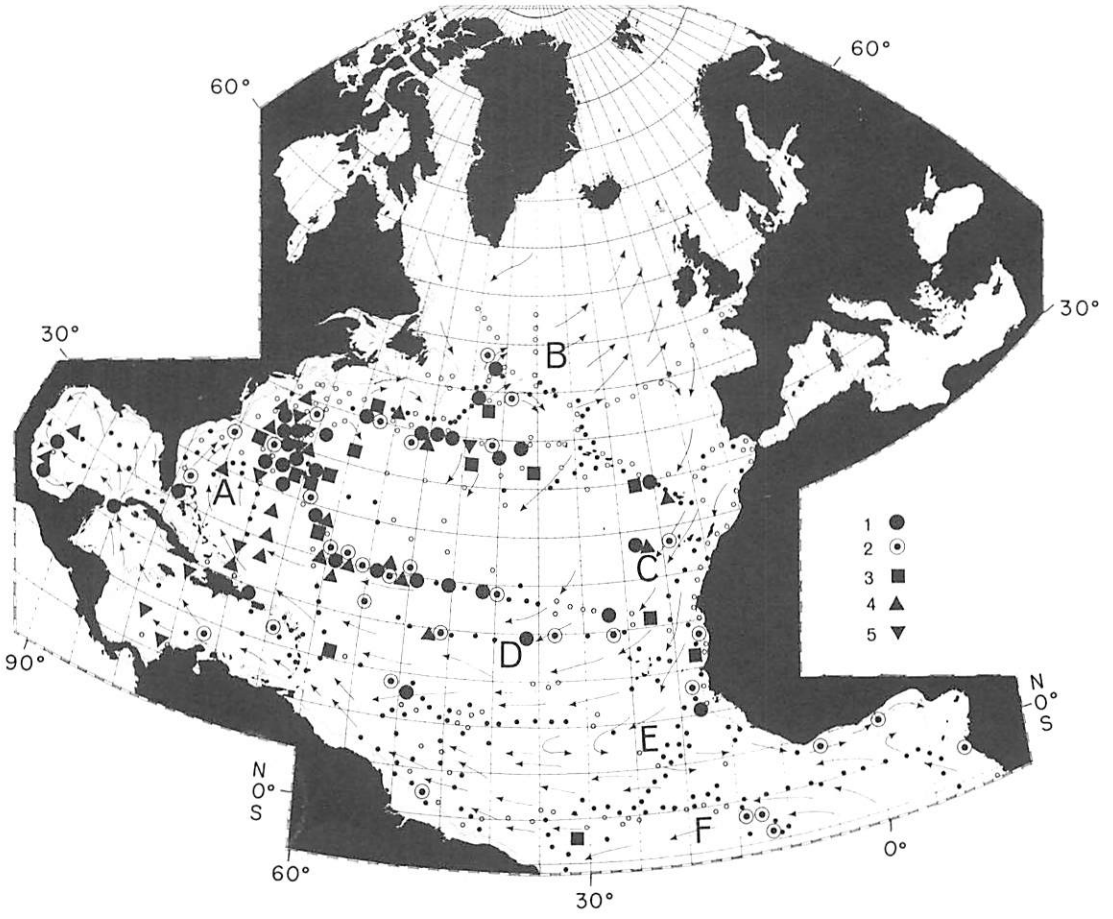

Fig. B-9 (Scheltema) Distribution of gastropod veligers carrying the ciliate protozoa, *Folliculina simplex* Dons, upon their larval shells. Small open circles equal stations where no gastropod larvae were taken. Small filled circles indicate locations where gastropod larvae were captured but their shell did not have folliculinids attached. Symbols 1-5 indicate species of gastropod veligers carrying larvae of folliculinids upon their shell. 1 = *Tonna galea*; 2 = *Charonia variegata*; 3 = *Cymatium parthenopeum*; 4 = *Cymatium nicobaricum*; 5 = miscellaneous unidentified Cymatiidae. Surface circulation indicated by arrows; major currents designated by letters; A = Gulf Stream; B = North Atlantic Drift; C = Canary Current; D = North Equatorial Current; E = Equatorial Counter Current; F = South Equatorial Current.

BENTHIC OXYGEN UPTAKE AND PRESSURE EFFECTS

John M. Teal and Kenneth L. Smith

We have built both shallow and deep-sea bell jar respirometers, which record oxygen concentration under the jars either by recorders in place or via a telemetering link to the surface. Deep bell jars have been put on the bottom with *Alvin* on the shelf station south of Woods Hole and in the Tongue of the Ocean. The bell jar at the northern station is still on the bottom waiting to be recovered, but the southern attempt was successful and is our first *in situ* measurement of benthic oxygen uptake.

The shallow water bell jars were used on a carbonate sediment in Bermuda in April and May where we found uptakes about in the middle of the range reported for *in situ* measurements of oxygen uptake by marine benthic communities. Most of the uptake could be accounted for by bacteria (c. 40%) and microfauna and microflora together (50-60%), (Smith, *et al.*, 1972). The shallow water bell jars have also been used in the marsh enrichment study and in studies of polluted areas in the New York Bight and round the Great Harbor sewage outfall at Woods Hole.

Work was begun on a pressure retrieval system to be used for bringing animals back from the sea bottom with the use of *Alvin*. Engineering was completed, but construction and testing have to wait for further funds.

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BASELINE STUDIES OF PETROLEUM POLLUTION IN THE NORTH ATLANTIC

John M. Teal, Kathryn A. Burns, David Masch and Joyce B. Stratton

A series of collections have been made from various parts of the North and South Atlantic in cooperation with others for the assessment of pollution levels. Special techniques were used to minimize contamination of the samples during collection. However, we have subsequently discovered that plankton nets may contaminate samples and are working on this problem with George Harvey in the Department of Chemistry.

Concentrating our analytical efforts on *Sargassum* and its associated animals, we have produced a hypothetical picture of the biogenic hydrocarbons characteristic of *Sargassum* by comparing analyses from the inside and outside of plants in 11 different samples. Once these biogenic compounds were subtracted from the chromatograms, the remainder could be assumed to be from pollution. The presence of a regular series of straight chain alkanes, of many unidentified hydrocarbons in small amounts, and of an unresolved background in all the chromatograms indicated the universal presence of petroleum in these samples which came from both the surface and interior of the *Sargassum*.

We have also analyzed samples of surface fish, barnacles and benthic animals from shallow coastal waters off the Georgia coast. Every sample showed evidence of petroleum hydrocarbons.

As a part of this effort, we participated in an intercalibration study with John Farrington of W.H.O.I. and James Quinn of U.R.I. Agreement between the three labs was reasonably good.

SALT MARSH STUDIES

John M. Teal, Kenneth L. Smith, Kathryn A. Burns and David Masch

The effects of enrichment of the Great Sippewissett salt marsh with sewage fertilizer were studied intensively during the summer in cooperation with Ivan Valiela and Boston University students. Plots were fertilized with Chicago sewage sludge at two dosages, and controls were done with urea, phosphate and no additions. Measurements were made of the amounts of plant nutrients found in the water draining from the marsh immediately after the application of fertilizer, nutrients in the soil water, standing crop of the grass by clipping, instantaneous rates of photosynthesis by marsh grasses and mud-surface algae, respiration rates of the benthic community both in the treated marsh areas and in the creeks associated with them, biomass of benthic animals in the marsh and creeks, chlorinated hydrocarbons in the sewage and its effects on fiddler crabs, and amount of lead in sewage and its distribution in the marsh muds and organisms. These data are not all analyzed. We are certain that the additions of fertilizer increased marsh production of both higher plants and algae. Preliminary analyses indicate increased production in some animals in the creeks but not in others, e.g., in clams but not in *Fundulus* fry. The overall oxygen uptake of the benthos in creeks from fertilized plots is higher than in control creeks. Most of the added nutrients stayed in the marsh and were incorporated into the biomass during the summer when active plant growth was taking place. The lead in the sewage is apparently all incorporated into the growing *Spartina*. The only harmful effect of sewage so far detected is the killing of crabs by the chlorinated hydrocarbons contained in the sewage.

Preliminary results of the enrichment experiments were presented at the AAAS meetings in December by Dr. Valiela. Analysis of petroleum in organisms in the Wild Harbor marsh as a result of the oil spill were completed. Oil was detectable in all species analyzed from Wild Harbor and absent in the same species collected from an unpolluted marsh three km to the south except for eels which were polluted in both marshes. Total hydrocarbons are expressed as ppm in body lipids in representative organisms at successively higher links in the food chain. Considerable recovery of the marsh occurred in 1971. Photosynthesis was measured and samples taken for hydrocarbon analysis, but these have not been completed.

EFFECTS OF ACID-IRON WASTE DISPOSAL ON THE BIOCHEMICAL CYCLE IN THE NEW YORK BIGHT

Ralph F. Vaccaro, George D. Grice, Gilbert T. Rowe, Peter H. Wiebe and Elaine Hoagland

Periodically over the past 20 years, members of this department have been asked to assess the ecological consequences associated with the disposal of acid-iron industrial waste in the coastal waters off New York City. Some 50 million tons of this material have been disposed of in this manner since 1949. New data obtained during the past year from two identical grids of stations have enabled us to compare hydrographic, chemical and biological conditions within the acid-iron disposal area with the same parameters in a nearby control area. To complete the synoptic picture, supplementary information on benthic communities and sediment composition was obtained at other locations peripheral to the two station grids and in the Hudson Gorge. A recently completed evaluation of these data holds that the disposal of acid-iron waste in the New York Bight has but a minor influence on the local biochemical cycle despite the magnitude and nature of the waste material involved.

At each station, hydrographic measurements included temperature, salinity and light penetration. Chemical observations consisted of dissolved oxygen, dissolved and suspended iron and total inorganic nitrogen and phosphorus. The abundance of standing crops was assessed from quantitative measurements of chlorophyll *a* and the prevailing densities of zooplankton and benthic organisms. Trace metal spectra for iron, zinc, cobalt, lead, chromium, nickel and cadmium were determined on selected zooplankton, benthos and sediment samples. Laboratory toxicity studies were conducted on representative phytoplankton and zooplankton species, using predetermined concentrations of acid-iron waste in seawater.

Distribution of Trace Metals:--Iron accumulation in the sediment was found to be negligible despite a 60% increase in barging activity since 1950. Apparently the distribution of iron on the sea bottom is regulated and limited by the natural flushing characteristics of the area. The heavy metal content of zooplankton, benthos and sediment showed that samples from the acid grid were significantly richer in these elements than the comparable control area samples. However, a broader comparison showed that samples from Hudson Gorge, peripheral to the acid-iron grid, contained the maximum amounts of lead and chromium in benthos as well as the maximum concentration of all eight metals in the sediment. These data are consistent with the possibility that entrapment in gorge sediment may be the ultimate fate of the heavy metal enrichment in the New York Bight area and that sources of heavy metals other than acid iron waste may be substantial.

Benthic Population Densities:--The average number of benthic animals on the bottom of the acid grid area was significantly less than in the sediment of the control grid but there was no difference in biomass or species diversity between the two areas. Notably higher iron-to-carbon ratios in the benthic animals were associated with the iron-rich sediments of Hudson Gorge as well as the acid-iron grid.

Toxicity Studies with Test Populations of Phytoplankton and Zooplankton:--Phytoplankton toxicity studies conducted with an acid-iron waste concentration four times greater than the maximum concentration observed in the field showed no adverse effect on phytoplankton growth or species diversity. On the other hand, similar experiments with copepods caused either failure of these organisms to reproduce or a delay in the time required to transform eggs to adults. Expanded studies on this subject now indicate that the mortality of zooplankton caused by the release of acid waste is negligible for adult copepods because of the short duration of lethal pH conditions in the wake of the barge. Neither laboratory nor field studies demonstrate that the iron floc which persists over the acid grounds adversely affects the viability or development stages of adult copepods.

Zooplankton Population in Densities:--Although the average zooplankton abundance within the control grid exceeded that of the acid grid by 30%, the range of values describing zooplankton abundance in the two areas proved similar. This difference was attributed to transitory large-scale patchiness in the area and not to the toxicity of the acid-iron waste *per se*. As with benthic organisms vs. sediment, a positive correlation was found between the iron-to-carbon ratios in zooplankton and the amount of particulate iron present in the sea water column.

Besides providing important information on the status of current disposal practices in the New York Bight, these data reflect a basic interest on the part of certain of our staff members to interpret small-scale variations of single species populations in coastal zooplankton communities. The derived information promises a useful basis for comparing numerical changes in zooplankton abundance with simultaneous changes in physical-chemical parameters and an additional opportunity to study the variability of community indices in terms of the abundance of single species.

MARINE MICROBIOLOGY

Stanley W. Watson, Charles H. Clifford, Frederica W. Valois, Linda B. Graham and Pamela E. Bowman

Man is interfering with the nitrogen cycle at an accelerating rate. Today more nitrogen is being fixed industrially than by all combined biological processes. This rate of industrial fixation is doubling every 10 years, and as a result of these unchecked activities, nitrates are accumulating in the biosphere. What long-term effect this accumulation may have on the ecosystem is still unknown. Therefore, it is imperative that the rate of nitrate accumulation and the biological processes involved be thoroughly documented. We have been studying the biological conversion of ammonia to nitrate by nitrifying bacteria for a number of years.

In the shallow waters of the ocean a large portion of nitrification must occur in the sediment. We were interested in discovering which nitrifying bacteria were active in this environment, and learned that most of ammonia-oxidizing bacteria in the sediments were similar to those in the water column and belonged to the genus *Nitrosomonas*. However, an entirely new genus of nitrite-oxidizing

bacteria was found in the sediments. The bacteria in this genus have a spiral shape and a unique cell wall. These organisms were isolated from the Gulf of Mexico, the mouth of the Hudson River and the Black Sea. Tentatively named Nitrospira, it is believed to be primarily responsible for the conversion of nitrite to nitrate in marine sediments.

Nitrifying bacteria are Gram-negative and many have unique cell walls and cytomembranes not found in other bacteria. We have continued to study the fine structure of the membranes, demonstrated conformational changes in the membranes, studied the asymmetry of membranes and localized enzymes and electron transport systems on them. We have also initiated detailed studies on the cell walls of nitrifying bacteria and have compared the chemistry and structure of cell-wall components of marine and non-marine species.

Lipopolysaccharides are a major component in cell walls of Gram-negative bacteria. These lipopolysaccharides cause endotoxemia in man, often resulting in death. Most deaths in burn patients, for example, are caused by endotoxemia stemming from Gram-negative infections. Endotoxins are relatively resistant to decomposition and may comprise a significant percent of the dissolved organic matter in seawater.

Until recently, no easy test was available to quantitate endotoxins either in humans or in natural bodies of waters. In the last four years, it was discovered that lysed blood cells of the horseshoe crab, *Limulus polyphemus*, contained a factor which formed a clot when mixed with endotoxins. Using this lysate, a test was developed which detects 10^{-3} to 10^{-4} µgm of endotoxin per ml. Applying this method we found that Vineyard Sound water contains 0.1 mg of endotoxin per liter which represents 5% of the total dissolved organic matter. We plan to use this test in the future to study the distribution of bacterial lipopolysaccharides in the open ocean.

We believe that the *Limulus* test can also be used to quantitate the bacterial biomass in samples of seawater. For this test, bacteria are collected on Millipore® filters and their lipopolysaccharides extracted by phenol. Since bacterial lipopolysaccharides comprise approximately 10% of the cell volume, the total bacterial biomass can be estimated from lipopolysaccharide measurements. This study has been initiated.

Horseshoe-crab blood does not always produce this active compound. We have been studying environmental factors which may control its production and have shown that through holding the crabs in a controlled environment, high levels of this active factor can be maintained in the blood.

During the last year, we have monitored weekly the number of nitrifying bacteria, the rate of acetate and glucose incorporation and oxidation and the rate of urea breakdown by microbes in Vineyard Sound water. The purpose of these investigations was to determine if the microbial populations remain relatively constant or vary seasonally in these waters. The rate of acetate oxidation varied from 7×10^{-4} to 5×10^{-2} µmoles of acetate oxidized per liter per hour. Highest rates were found in July and lowest rates in January. The rates of acetate uptake were similar to the oxidation rates and the same seasonal variations were found. The slowest rate of glucose oxidation was in May (1.5×10^{-4} µmoles/l./hr) and the most rapid in November (1.5×10^{-2}/l./hr). Uptake rates of glucose varied from 1.5×10^{-4} to 1.4×10^{-2} µmoles/l./hr with the highest occurring in August and the lowest in November. Rates of urea decomposition varied from 9×10^{-4} to 6×10^{-2} µmoles/l./hr; the most rapid decomposition occurred during August and December. The number of ammonia-oxidizing bacteria varied from 10 to 1600 per liter. The population of nitrifying bacteria appeared lowest during January through April and highest during May, September and December. These studies have shown that microbial activities in Vineyard Sound waters vary independently and are not related directly to temperature.

ZOOPLANKTON STUDIES

Peter H. Wiebe and Diane Young

Detection and Description of Zooplankton Patchiness:--Continuing effort is being devoted to the study of small-scale zooplankton patchiness, the objectives being to answer such questions as:

1. What is the small-scale structure of zooplankton distribution in different hydrographic areas or water masses? How does a change in this structure, if any, relate to the primary productivity of the region?

2. How do environmental factors such as temperature, salinity, light, depth, nutrient concentrations, currents and turbulence relate to the spatial structure?

3. Are plankton aggregations generally composed of single species or of many species, or is the composition a variable with wide limits? What can be said about the ecological interrelationships between different species found living together in aggregations?

To this end, we have carried out field sampling experiments with the Longhurst-Hardy Plankton Recorder (LHPR) System designed to provide day and night profiles of the vertical and horizontal spatial patterns of zooplankton species on a scale of tens of meters. Sampling took place from the R/V *Knorr* in the Sargasso Sea east of Bermuda in March/April and in the Mediterranean Sea east of Sicily in November. Laboratory processing of the LHPR samples is now taking place.

Effects of Zooplankton Patchiness on Net Tow Sampling Error:--Additional studies designed to test a proposed relationship between size of net, length of tow and sampling error resulting from zooplankton patchiness have been carried out in the Sargasso Sea and Mediterranean Sea (Wiebe 1971a, 1971b). At each location, a series of eight oblique net tows to 100 m were taken in the vicinity of a parachute drogue which was used primarily for navigation but also to mark a parcel of water for sampling. The eight tows consisted of two replicates of each combination of two net sizes (1 m, 1/4 m diameter) and two lengths of tow (2000 m and 500 m). The Sargasso Sea series was taken during the day; the Mediterranean Sea series at night. Laboratory analysis of the samples will take place in 1972 and emphasis will be on counting as many species of copepods, euphausiids, chaetognaths and molluscs as possible.

Ecological Aspects of Molting in Euphausiids:--The role of the intermolt cycle on the ecology of zooplankton which molt frequently, in particular euphausiids, is little known or understood. A necessary prerequisite in the study of molting as an ecological factor is a method by which individuals of a population can be censused as to their position in the molt cycle. In this laboratory, we are working to develop a staining method for use at sea which will selectively stain individuals which are either about to molt or have just finished molting. One method developed here (Jennings and Halverson 1971) which seemed likely to provide useful data on *in situ* molting rates of euphausiids has, upon extensive testing in the Mediterranean Sea, Sargasso Sea and off the northwest coast of Africa, proven to be too insensitive for our purposes.

Another staining technique based on the presence of an enzyme (polyphenol oxidase) at a specific phase of the molt is now being investigated. Shipboard experiments in the Mediterranean were performed in November using this stain on zooplankton samples taken at various times of the diurnal cycle. Cultured animals whose molt cycles can be controlled are presently being used in laboratory experiments to calibrate this technique.

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BIRD MIGRATION AND NAVIGATION

Timothy C. Williams, John M. Teal and John W. Kanwisher

Two principal areas were pursued--radio-tracking and radio-telemetry of free-flying herring gulls and tracking-radar studies of birds migrating over the North Atlantic Ocean.

Radio telemetry of herring gull heart rate revealed constant, elevated rates of about 600/min for flights of up to 10 km in length. Orientation of gulls was tested in releases in Nantucket Sound and 20 miles southeast of Mt. Desert Island, Maine. The results of these releases indicate the use of landmark orientation to orient flights toward the nearest shore, both in the home area and more than 300 km northeast in the Gulf of Maine. In order to obtain long-range tracking of birds, the radio-tracking system was improved, giving an angular resolution of one degree and a ground-to-ground (all weather) range of more than 80 km with the receiver on a mountain 500 m above sea level.

Orientational abilities of gulls were also investigated in releases of blindfolded birds equipped with radio transmitters. We were able to record flights of more than 4 km under these conditions, indicating the ability of birds to fly without the use of vision.

In heart-rate telemetry experiments conducted on the home island of the gulls, behavioral interactions between birds were found to produce heart-rate changes almost as great as those between rest and flight.

Radar studies of bird migration were made during both the spring and fall. Work during the spring at Wallops Station (N.A.S.A.) concentrated on visual identification of radar targets, and we now have over 40 such signatures of migratory birds. During the fall, we were able to obtain the best data on migration over the North Atlantic to date. Search radars were operated by us at Chatham and Otis AFB, Cape Cod, and by the Canadian National Research Council at Halifax, Nova Scotia, Great Barrington, New Brunswick, and Puerto Rico. We operated tracking radars at Wallops Island, Virginia, Bermuda and Antigua. All observations were made during the period September 20 through October 15. In addition, D. R. Griffin and Dr. Teal manned a small tracking radar on the R/V *Atlantis II* cruising between Bermuda and the United States coast. During the passage of Hurricane Ginger through the study area, birds moved away from the storm center at all radar stations south of Canada. These simultaneous observations also revealed that large numbers of birds leave the continental United States coast to the south and southeast, fly across Bermuda to the south-southeast or southeast, continue in this direction for at least 300 km (as detected by the R/V *Atlantis II*) and then appear to shift course in the region of the Sargasso Sea (about 30°N) since birds often arrive at Puerto Rico and Antigua from the northeast.

Improvements in our radar systems consisted in the tracking-radar system for the *Atlantis II* mentioned above and in the modification of a small marine radar for ornithological use and the installation of this radar on a mobile van. This small search radar was used both at Wallops Island, Virginia, and at the S.U.N.Y. Campus at Buffalo for observing bird migration. The unit has an effective range at present of two km, and the very small pulse volume of the unit (0.08 μ sec pulse width) gives it a resolving power far superior to any other radar we have worked with. This fall we were able to observe the movements of low-flying birds around high buildings and towers during migration and the splitting and reformation of single radar echoes into two or more targets which is rarely, if ever, observed with larger radars.

CHEMISTRY

DEPARTMENT OF CHEMISTRY

John M. Hunt, Chairman

CHLORINATED HYDROCARBON POLLUTANTS IN THE ATLANTIC OCEAN

George R. Harvey, Helen P. Miklas and Vaughan T. Bowen

We are engaged, in close cooperation with the Department of Biology (R. H. Backus, J. E. Craddock, G. D. Grice, D. Masch, G. T. Rowe, R. S. Scheltema and J. M. Teal), in determining the concentrations of polychlorinated biphenyls (PCB) and members of the DDT family in organisms collected from the open Atlantic Ocean, north and south. This is the first study of its kind in the high seas and has furnished new insights into transport mechanisms and food chains.

The data strongly indicate that the atmosphere provides the major path for delivery to the ocean of both DDT and PCB. The North Atlantic plankton have almost uniformly high levels (100-900 ppm) in their fat. Thus, the quantities of these pollutants delivered to the ocean by the atmosphere obliterate any concentration gradient from continental run-off. Second, there is little difference in concentrations of these pollutants between the North and South Atlantic. Considering the smaller land surface of the southern hemisphere, the low level of industrialization and the lack of north to south circulation of Atlantic surface waters, the South Atlantic pollution must be transported there by global winds from the northern hemisphere.

Our data appear to offer no support for the widely held view that concentrations of chlorinated hydrocarbons are magnified along marine food chains. Many prey-predator couples (flying fish-plankton, Arctic cod-Atlantic cod, etc.) reveal concentrations just the reverse of what might be expected from biomagnification. Different species which have similar diets and which were collected in the same nets are very different in their concentrations of DDT and PCB. We believe that the levels found within an organism are a result of partitioning of the DDT and PCB between the water and the body of lipids and that lipids of each species have a definite capacity for these chemicals regardless of the position in the food chain. Air-breathing animals must depend on excretion and metabolism which are apparently less efficient than equilibration with water. They therefore accumulate these pollutants. It would have been extremely difficult to discover this in coastal waters where the organisms are subject to sporadic and high doses of pollutants from spills, floods and dumping operations. The open ocean is sufficiently remote so as not to be affected by daily and local inputs.

Finally, PCB formulations must be transported to the ocean by discreet aerosol masses which do not mix with similar formulations during their atmospheric history. This phenomenon is not shared by DDT which is largely transported on atmospheric particulate matter. This must be a consequence of the different modes of injection into the atmosphere: DDT, by slow evaporation from soil and PCB, by distillation from incinerators, dump fires and explosions (aircraft crashes). We are continuing to explore these mechanisms and will soon study the uptake and transfer of chlorinated hydrocarbons in the open sea.

MARINE ORGANIC CHEMISTRY

Max Blumer

The principal long-term goal of our work remains unchanged and can be summarized as follows:

1. What are the sources of organic compounds in the sea and in sediments; what are their concentrations?

2. How great are the taxonomic and regional differences in the chemistry of marine, especially planktonic, organisms? How variable is the chemistry of sea water and of marine sediments?

3. How do organic compounds move through the marine environment, including the water masses and the food web?

4. How do organic compounds interact with other components of the marine environment; what role do they play in the marine ecology?

5. What is the long-term fate of organic compounds in the sea and in marine sediments?

6. How can we apply this knowledge to the study of oceanic processes and to an understanding of the environmental hazards from pollution by organic chemicals?

Our work has progressed along the following major lines:

Biochemically-Derived Hydrocarbons in Marine Organisms (with W. W. Youngblood):--Investigation of saturated and unsaturated hydrocarbons in marine algae has continued with analysis of additional species of benthic algae. Collections were made at different growth stages and morphologically different plant parts were analyzed separately. These analyses should aid in delimiting the coastal food web and thus in distinguishing between biologically and pollution-derived hydrocarbons. The work so far suggests interesting questions about possible biochemical roles of the olefins in algae.

The Long-Term Rate of Organic Compounds in Marine Sediments:--

Isoprenoid acids in ancient sediments. Work reported in earlier progress reports has been completed and two shales of different age and depositional history examined for isoprenoid acid content. Serpiano Oil Shale (Triassic, ca. 210 x 10^6 yr; marine) from Switzerland contains all of the isoprenoid acids from C_{11} - C_{20} (and possibly C_{21}), the n-acids from C_8 - C_{23} and a series of "pseudo" isoprenoid acids. Green River Shale (Eocene, ca. 60 x 10^6 yr; lacustrine) from Colorado, U.S.A., contains the C_{14} - C_{17} and C_{19} - C_{22} isoprenoid acids and the N-acids from C_{12} - C_{34}. The range of α,ω - dicarboxylic acids is extended over previous findings and a series of 2-alkylsuccinic acids is provisionally reported. These results extend known distinctions between acid composition of recent and of ancient sediments and should lead to a better understanding of chemical processes that transform biogenic organic compounds in sediments into the complex mixture in oil shales and petroleum.

The geochemical significance of fossil porphyrins. The fossil porphyrins are a complex mixture of tetrapyrrole pigments derived from a small number of biogenic precursors through extensive transformation reactions in the subsurface. Encoded in their structure is much information about the chemical environment in the subsurface, the mechanisms and rates of transformation reactions and the nature of possible reaction products.

We have suggested that research in organic geochemistry still remains largely descriptive and has yet to answer some fundamental questions about the transformation of biogenic compounds into complex sedimentary organic material occurring in oil shales and crude oil. The fossil porphyrins may be one of the keys to understanding basic geochemical processes.

Evidence for isomerism in fossil porphyrins. The principal low molecular weight porphyrins of the Triassic Serpiano Oil Shale were isolated by extraction, methylsulfonic acid demetalation, liquid partitioning and thin layer chromatography. Eight well-defined pigment bands were resolved. Their molecular weights overlapped. This demonstrates, in combination with mass spectrometry, the existence of isomeric pigments which differ in polarity and mobility on TLC. These isomers may be the products of different diagenetic reaction paths. A study of individual structures by nmr, IR and chemical degradation appears feasible and could provide valuable insight into transformation reactions in sediments.

The Environmental Fate of Fossil Fuels:--

Hydrocarbons from fossil fuels enter the environment in ever-increasing quantities. Past work on their biogenic analogues has revealed relatively great stability, even of chemically unstable hydrocarbons, in the the ocean. This poses a question as to whether oil pollution may not be more persistent and potentially more harmful than was assumed in the past. Our work has proceeded along the following lines:

Methods. We participated in an FAO symposium on the Detection and Monitoring of Pollutants in the Marine Environment in preparing a review of existing methods and a recommendation for further research.

Oil spill identification.

(a) (with M. Ehrhardt). An exploratory study was undertaken to demonstrate the potential of gas chromatography for the identification of oil spills. Chromatograms of a "tar ball" were compared to those of eight known crude oils. Differences in the chromatographic patterns ruled out immediately six of the oils as potential precursors of the tar ball. An additional oil was ruled out on the basis of combined GC and UV data. This left one of the eight oils as the possible parent of the tar ball. However, the relationship was not demonstrated conclusively.

(b) (with O. Zafiriou). The initial attempts at oil spill identification discussed above seemed to have sufficient promise to warrant more detailed work, especially since the previous work and that on the West Falmouth oil spill had demonstrated that characteristic features of crude oil chromatograms are retained in spite of extensive environmental weathering. Routine gas chromatographic procedures for characterizing oil pollutants are being examined. The use of SCOT columns, standard operating conditions and a standard sample improves resolution, reproducibility and inter-instrument comparability. Collection and analyses of samples from ships in Portland, Maine, and from New York Harbor are in progress while a collection of fresh and weathered oils provided by EPA is being analyzed "blind." These will permit evaluation of the method under realistic conditions.

Petroleum-derived hydrocarbons in sediments of Narragansett Bay (Providence River) (with J. Farrington and O. Zafiriou). Extraction of sediments from an upper Narragansett Bay station yielded enough material for carbon-14 analysis. The hydrocarbon fraction, which is rich in branched and cyclic alkanes and poor in straight-chain and aromatic compounds, contains less than 4% of the carbon-14 expected from recently biosynthesized materials. This is consistent with assigning it to a fossil fuel--presumably petroleum--origin, with a minor contribution of recently biosynthesized hydrocarbons.

Biochemically and pollution-derived hydrocarbons in open ocean organisms (with J. Farrington). We have analyzed samples of zooplankton, mid-water organisms, fish and sharks from the North and South Atlantic to determine hydrocarbon concentrations and the ratio between hydrocarbons synthesized by marine organisms and oil-derived hydrocarbons. Concurrently, we initiated a program of intercalibration of hydrocarbon analyses with other laboratories to provide an evaluation of the analytical methods used and results obtained in different laboratories. This program will provide background data on the concentration and nature of biochemically derived hydrocarbons in open ocean organisms and will attempt to assess the degree to which oil pollution has entered the open ocean food web.

The composition of open ocean petroleum residues ("Tar Balls") (with Byron Morris, Bermuda Biological Station). "Tar Balls" are now ubiquitous on the open oceans. A sampling program has been started and a number of tar balls have been analyzed by gas chromatography on a temperature programmed, packed Apiezon L column of low loading that permits separation of hydrocarbons in the C_1 - C_{40} range. All samples analyzed thus far consist of residues derived from whole crude oils; there is no evidence for the presence of refining products, either individually or in blends. The oils exhibit a wide range of environmental alteration (weathering). Some are extremely degraded with both normal paraffins and isoprenoid alkanes absent. In others, normal paraffins are absent but isoprenoid alkanes are still present while some samples still resemble very fresh and paraffinic oils. In spite of differences in weathering, all oils show remarkable similarity in the degree to which lower boiling hydrocarbons have been retained. In all cases, the boiling point envelope reaches 10% of its maximum amplitude at or very near the boiling point of n-heptadecane (302°C). However, in the less deeply weathered oils, the envelope extends, at lesser amplitude, to lower ones, e.g., to undecane (B.p. 195°C). We believe that the similarity in initial boiling range of weathered oils is the result of rapid decrease in volatility of the hydrocarbons with increasing molecular weight. This leads to the retention of a similar boiling range in the oils, regardless of environmental exposure.

Analyses of the tar balls will continue. The present limited data suggest that hydrocarbon input to the open ocean and its food chain derives principally from whole crude oils that have retained many of their original components in the boiling range above 300°C. Purely from boiling considerations, this residue includes, among others, most of the highly saturated benzenes and naphthalenes and all of the tricyclic and higher polynuclear aromatics.

Petroleum hydrocarbons in polluted shellfish (with M. Ehrhardt). Oysters from a location in Galveston Bay, Texas, were analyzed at the request of Environmental Protection Agency. The hydrocarbons were extracted and separated from other lipids by column and thin-layer chromatography. Gas chromatography and mass-und UV-spectrometry identified complex homologous series of aliphatic, alicyclic and of mono-, di- and tricyclic aromatic hydrocarbons. The presence of most of these compounds and their type and molecular weight distribution indicates petroleum pollution.

The West Falmouth oil spill (with Jeremy Sass and with H. L. Sanders and co-workers). Investigation of the fate and effect of the approximately 600 tons of #2 Fuel Oil spilled at West Falmouth on September 16, 1969, is now in its third year.

Three distinct, though partly overlapping, series of events followed the spill. First, within the first few hours or days after the accident, there was a heavy kill of those organisms which came into contact with the oil. It extended over all phyla and over benthic and intertidal organisms. Next, within weeks or months after the spill, the oil pollution spread to areas that had not been affected immediately and the kill extended, though in some cases more slowly than the spread of the oil, to outlying areas. Oil entered the marine food web and made the shellfish resources of our area unacceptable for human nutrition. The oil showed unexpected persistence in the sediments and in marine life, especially in view of its relatively low boiling range and of earlier assertions that fuel oil pollution was transitory in nature and without long-term consequences. For a considerable time after the spill, oil pollution of the sediments prevented the resettlement by the original fauna. Now, degradation of the oil has become evident; biochemical and physical processes lead to a gradual reduction of the oil content of the polluted sediments. Concurrently with the degradation, there has been gradual reduction in the immediate toxicity of the oil in the sediments. This has permitted resettlement of the polluted region, first by the most resistant opportunists and later by a more varied and more normal fauna. However, oil-derived hydrocarbons have remained at all stations during the entire two-year span for which data are now available and it appears that the life span of pollution, even by a low boiling fuel oil, must be measured in terms of many years.

The eventual aim of this study is documentation of the effects, persistence and eventual disappearance of pollutant hydrocarbons from a relatively small spill in a limited and previously clean coastal area. Of necessity, most of our analytical effort in the past was aimed at a survey of the extent of oiling of the sediments and of some of the commercially important animals. As degradation proceeds, we expect to devote a greater effort to more detailed chemical analysis of the hydrocarbons remaining in the environment in order to define and understand the modes of degradation and to correlate chemical analyses with biological data. Parallel investigations on weathering of different oils under other ecological and climatic circumstances are underway here and should, in combination with the West Falmouth study, give a more realistic assessment of the environmental hazard and persistence of crude oil than has been available previously.

Data are now available for a period two years after the spill. Our present methods distinguish between indigenous and pollution-derived hydrocarbons in sediments and organisms. Further, the gas chromatographic analyses of the sediment extracts that were obtained during this time period give evidence for the environmental weathering of the oil.

Weathering of a stranded crude oil (with M. Ehrhardt). Our work on the environmental alteration of the fuel oil at West Falmouth has been complemented by repeated sampling and analysis of stranded crude oil lumps ("beach tar") from Martha's Vineyard, Mass. This oil has been under survey for 16 months. The changes in its composition vary with the substrate and with the location relative to the high tide line. Here, as in the case of the fuel oil at West Falmouth, the compositional changes can be interpreted in terms of evaporation, biochemical utilization and dissolution. In both instances the oil is expected to survive for several years.

Other Investigations:--

Starfish chemotaxis (with O. Zafiriou). The attraction of the starfish *Asterias vulgaris* to various chemical stimuli is strongly influenced by unknown factors involving their physiological state. We have found that lactic acid, urea, succinic acid and some amino acids are attractive to certain animal groups but not to others. All these groups are attracted to oyster tissue extract. The chemosensory abilities of these animals are thus more sophisticated than had been suspected. We have ceased attempting to isolate the attractant substances from oyster tissue in view of these results.

Photochemistry of the sea (by O. Zafiriou). Attempts to formulate an energy balance for visible light in the sea reveal that the chemical nature of the major converters of light energy to other forms is unknown. Thus, photochemical consequences of light in the sea cannot now be evaluated. Energy transfer processes forming electronically excited oxygen are likely to be important. Metal-organic complexes, water and particles are other likely sites of energy conversion and effects.

EFFECTS OF STRESS AND CHEMOTAXIS IN THE AQUATIC ENVIRONMENT

John H. Todd

Chemotaxis Research (with W. O. McLarney, Joan Mitchell, David Engstrom, Stuart Jacobson and Linda Leffler):--During the past year, two studies on the social behavior and organization of the American lobster, *Homarus americanus*, have been conducted. The first involved a descriptive analysis of small social groups of lobsters in 200-gallon aquaria while the second emphasized agonistic interactions of pairs of lobsters, separated between trials by partitions.

Sexual differences (apart from reproductive activities) were discovered for this species: females used action patterns that were predominantly display patterns to establish dominance relationships while males in conflict tended to rely more upon overt aggressive activities such as lunging and hitting opponents. When females fought males in dominance interactions, successful females adopted male fighting strategies. This behavioral research suggests that lobsters are capable of recognizing sex, apart from mating periods, and we suspect that normal sex recognition is by chemical signals.

The Effects of Stress on the Social Behavior of the Lobster and Several Fish Species:--

Lobster: Thermal studies. An investigation of effects of sublethal temperatures on the social behavior of the lobster was completed. At test temperatures of 21°C, 24.5°C and 27°C, there were no significant changes in their social behavior, and their social organization remained intact up to within 2°C of their lethal temperature (i.e., approximately 30°C).

Lobster: Kerosene studies. The responses of lobsters in small social communities to minute amounts of kerosene and kerosene fractions were investigated. Twenty milliliters of kerosene and its fractions were placed on asbestos strips and added to the test aquaria. Two strips were used per trial with blank strips as controls. Whole kerosene induced feeding, ingestion of strips and an increase in stress-related actions. Polar aromatic fraction caused attraction to the stimulus but no ingestion and a marked increase in stress and agonistic response. Branched/cyclic fractions aroused feeding and the lobsters ingested test strips, but there was no change in stress or social actions. The straight-chain fraction had no effect. At the concentrations used in this study, kerosene and its fractions did not alter the basic social organization of the experimental communities, but all except the straight-chain fraction did influence behavior.

Since, in general, adult organisms have far greater resistance to stress factors than juvenile forms, we are now expanding our efforts to include the culture and observation of larval lobsters to determine susceptibility to heat and oil-contaminated water. This work has been initiated by Joan Mitchell.

Fishes: Social behavior. Descriptions of the social behavior of the yellow bullhead, *Ictalurus natalis*, the pumpkinseed sunfish, *Lepomis gibbosus*, and the golden shiner, *Notemigonus crysoleucas*,

were completed. The bullheads exhibit 98 different activities; the sunfish, 51; and the shiners, 36, exclusive of interactions solely associated with reproduction.

Fishes: Oil studies. A pilot study was completed on the effects of the water soluble fractions of oil on the social activity of the three fish species. Aqueous extract of Kuwait crude was prepared by stirring for 12 hours 100 ml of oil with 15 l. of aged tapwater. Since 50-200 ml of the oil extract had no detectable effect on any of the species, 4 l. of oil extract were used in experiments (initial concentration 80-100 ppb). Feeding for all species was unaffected at this concentration. However, the social behavior of bullheads was altered with a shift in action patterns away from "stereotyped" conduct to high intensity conflict behavior. The experiment (addition of 4 l. aqueous extract) was repeated at one-week intervals with recurring alteration of bullhead social responses. It appears that the most highly social fish, the bullhead, compared with the less complex pumpkinseeds and shiners, is most susceptible to water soluble fractions of oil. The experiments will be repeated.

Fishes: Thermal studies. We continued to observe the influence of various sublethal temperatures on the social behavior of the yellow bullhead. The bullhead's activities seemed temperature dependent, peaking at 27°C and 32°C. Between 30° and 31°C there was a dramatic decline in activity. The agonistic response did not exactly follow the patterns of activity as aggression did not differ discernibly between 24° and 29°C. At 30° to 31°C agonistic action ceased entirely. However, above 31°C it increased rapidly, resulting in several animals being killed in conflict. In one community, cannibalism toward a living, but severely injured, submissive fish was observed. It appears that the bullhead catfish, with its highly evolved social organization, is vulnerable to social disruption and breakdown at levels of oil and thermal stress which are well below lethal planes.

CHEMOTAXIS INVESTIGATIONS

Jelle Atema

The focus of our work remains on chemical communication in the sea. In a multidisciplinary approach, our goal is (1) to identify sensory systems involved in the reception of chemical stimuli, (2) to define biological functions of each chemical communication system, (3) to localize sources of the chemical communicants and (4) to isolate the chemical compounds and identify their structure. As a natural by-product of this work we study the effects of environmental pollutants on chemical communication systems.

Sex Pheromone of the Lobster (with Lauren Stein):--After the discovery of the sex pheromone emitted by the newly molted mature female lobster to attract the male and reduce his normal aggression (Atema and Engstron, 1971)(Fig.C-1), we tried to develop a quantitative bioassay for isolation and structure determination of the pheromone. We found great variability between different males in response to females "in heat" as well as to pheromone-containing water alone. It became obvious that the lobster is a highly evolved animal which uses all its senses at all times and will not respond to sex stimulus under adverse conditions. The pheromone identification program is being continued in cooperation with Bela Ballogh of the Space Research Laboratory at Berkeley.

Taste and Smell in Aquatic Animals:--The biological significance of two anatomically different chemical communication systems, smell and taste, in aquatic animals has puzzled man for centuries. Earlier experiments with specific brain lesions in catfish (Atema, 1971) and recent studies on smell and taste deprivation in lobsters point to a possible solution of the problem. In both animals, representing very different groups in the animal kingdom, the sense of smell was found to be uninvolved in any aspect of feeding behavior whereas the sense of taste contributes in specific ways to noticing, localizing and testing food. We also have rather good direct and indirect evidence that the sense of smell is involved in social communication, providing the animal with information on species, sex, age, family, mood and status as well as on environmental chemistry such as habitat selection and home range recognition, including both territories and homestreams.

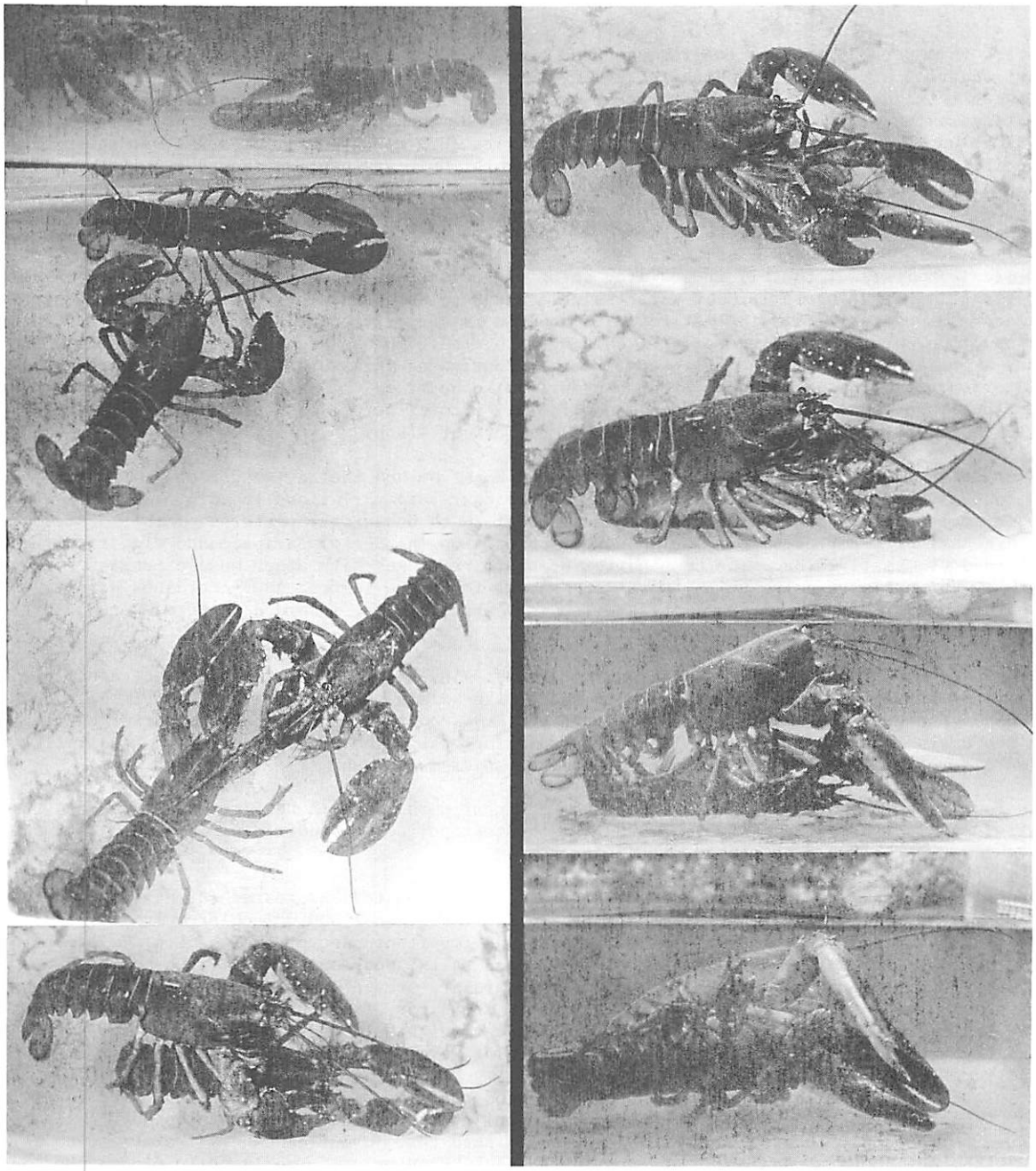

Fig. C-1 (Atema) Behavioral Sequence of Mating Lobsters

Effects of Crude Oil on Lobster Feeding Behavior (with Lauren Stein):--Daily observations of a group of lobsters in a period prior to feeding provided background of normal food anticipating behavior. After introduction of food, the lobster's feeding behavior was carefully timed for three phases: (1) time between introduction of food and noticing its (chemical) presence, (2) time until leaving shelter and starting search, (3) time lapsed before localizing and touching food. After crude oil was introduced at the water surface we found that small quantities (0.9 ml in 100 l. of seawater) interfered with specific aspects of behavior. Analysis of behavioral unit frequencies showed a shift from feeding related behavior to other activities. Timing of the feeding behavior demonstrated that phase (2) was doubled and that phases (1) and (3) were not affected. We concluded that the lobster's motivation for feeding was lowered by the presence of small quantities of crude oil.

Chemical analysis of the oil in seawater solution and suspension showed that one day after oil introduction, a full "fingerprint" of water soluble and insoluble fractions could be recovered from the seawater. Apparently, airstone stirring in aquaria is very effective. However, five days after oil introduction, almost no "fingerprint" could be recovered. In the presence of a lobster and an airstone, degradation seems to be efficient. We are continuing this work for specific fractions of oil. Interference with sex pheromone responses will also be tried. An electron microscopical investigation of possible damaging effects of oil on olfactory microstructures is in progress in cooperation with Helen Ghiradella of the State University of New York at Albany.

Electrocardiogram as a Behavior Indicator (with David Engstrom and Shelley Henderson):--In order to monitor lobster behavior in the field we are trying to correlate variations in cardiograms, which include several muscle potentials other than heart beat, with behavioral patterns of the lobster. Rather large silver electrodes were implanted permanently on the dorsal carapace and electrical events were recorded via small wires. The combination of heart responses with other muscle responses proved successful. Various pure amino acids as well as normal food were tested, and recordings were taken during both agonistic social interactions and feeding behavior. The recorded patterns were sufficiently different to be used in the field in the future.

Home Stream Recognition of Alewives (with David Boylan):--Investigation of the return of adult alewives to homestreams during spawning season revealed that, like salmon, they detect and prefer the homestream odor. The goal of this study is to determine the identity of the homestream marker chemicals and, on the basis of structural analysis, make predictions as to the type of pollutants that will most likely interfere with location of spawning grounds by anadromous fish.

The test apparatus used is a modified Y maze. A continuous background flow in each upstream leg of 5 gal/min of well water is maintained. During the test period, an additional 1 gal/min (stimulus and control water) is added to each upstream arm.

When the Bourne River (homestream) concentrate was fractionated and tested for activity, the active material was heat stable, polar, non-volatile and less than 1,000 molecular weight. Results indicate that basic and acidic materials are probably an important part of the chemical "fingerprint." Non-polar lipids, free amino acids, quarternary nitrogen salts, weak organometallic complexes and inorganic salts are not involved in this, but free sugars are present in the active fraction. However, since no decrease in activity is caused by a change in the sugar "fingerprint," they are probably not necessary to the recognized "fingerprint." Low molecular weight aldehydes, ketones and alcohols and peptides and carbonate polymers less than 1,000 molecular weight have not been studied.

One of the limits of this study is the short period that the bioassay can be performed (April 15-June 10). In order to extend the testing period, juveniles returning to the sea have been collected and trained to respond to homestream water. We established that juveniles can be trained to do this but only with continuous attention of an experienced fish behaviorist. The juvenile program has been temporarily abandoned.

Microtubules as Cellular Information Conductors:--During the course of our work, a theoretical concept was developed to explain the information transduction in sensory cells. The classical concept that receptor potential results exclusively from membrane bound permeability changes in sensory processes was contrasted with a model involving a protein conduction system in ciliary microtubules. The theory was discussed extensively at several national and international meetings and remains controversial. Evidence continually builds up both for and against the proposed model.

Chemical Communication in Aquatic Ecosystems:--Our studies lead us to believe that chemical communication is one of the major links holding aquatic ecosystems together. Although we have scarcely scratched the surface, we find chemical communication is more extensive than we imagined, operating at all levels of biological organization, both inside and outside each organism. Hence, effects of chemical pollution are potentially disastrous. We continually attempt to define "safe" levels of pollution for animals we study. A negligible amount of knowledge is available now. Applications in the field of aquaculture remain a part of our concern.

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SYNTHESIS OF CARBOHYDRATES, LIPIDS AND PYRIMIDINES ON KAOLINITE

Egon T. Degens, George R. Harvey and Kenneth Mopper

Observation of the interaction of aqueous solutions of simple organic molecules with clay minerals is important both to understanding the processes of diagenesis of organic matter in ocean sediments and to gaining insight into the first synthetic processes which led to single-cell organisms.

We have demonstrated that clay mineral kaolinite can serve as a catalyst and template for synthesis of polymerization of several types of biological molecules in totally aqueous systems; i.e., amino acids, peptides, urea, and pyrimidines were formed from carbon dioxide and ammonia (Fig. C-2). Carbohydrates were produced from formaldehyde in the presence of kaolinite and water while glycerides and possibly phospholipids were generated in this system from glycerol, palmitic acid and phosphate. A membrane-type structure was observed on the surface of the clay at the conclusion of the reaction. In view of this, it seems highly probable that minerals, such as kaolinite, played a significant role in the abiotic synthesis of complex organic molecules.

Considering the facility of the reactions described here, any analysis of recent or ancient sedimentary columns for sugars, lipids, etc. for the biological record must take into account the likelihood of post-depositional synthesis within the sedimentary column unless the sample was encapsulated in an inert mineral such as aragonite.

STRUCTURAL MOLECULAR BIOLOGY OF PHOSPHATES

Johan Matheja and Egon T. Degens

The growth of crystalline material on other crystal surfaces is a popular subject in the field of crystallography. The process is commonly described under the heading epitaxis, a term derived from the Greek meaning "to arrange" or "to organize." Minerals may also nucleate on organic templates. For instance, the deposition of bones, teeth, or shell structures in biological systems can be attributed to the specificity of distinct protein or glycoprotein templates. On the other hand, crystal surfaces can act as polymerization agents for organic monomers such as amino acids, sugars and the bases of the purines and pyrimidines. Reaction products include peptides, polysaccharides, and polynucleotides. Finally, organic polymers may introduce crystallization, consequently forming organic crystals. Structural proteins associated with phospholipid membranes are thus derived.

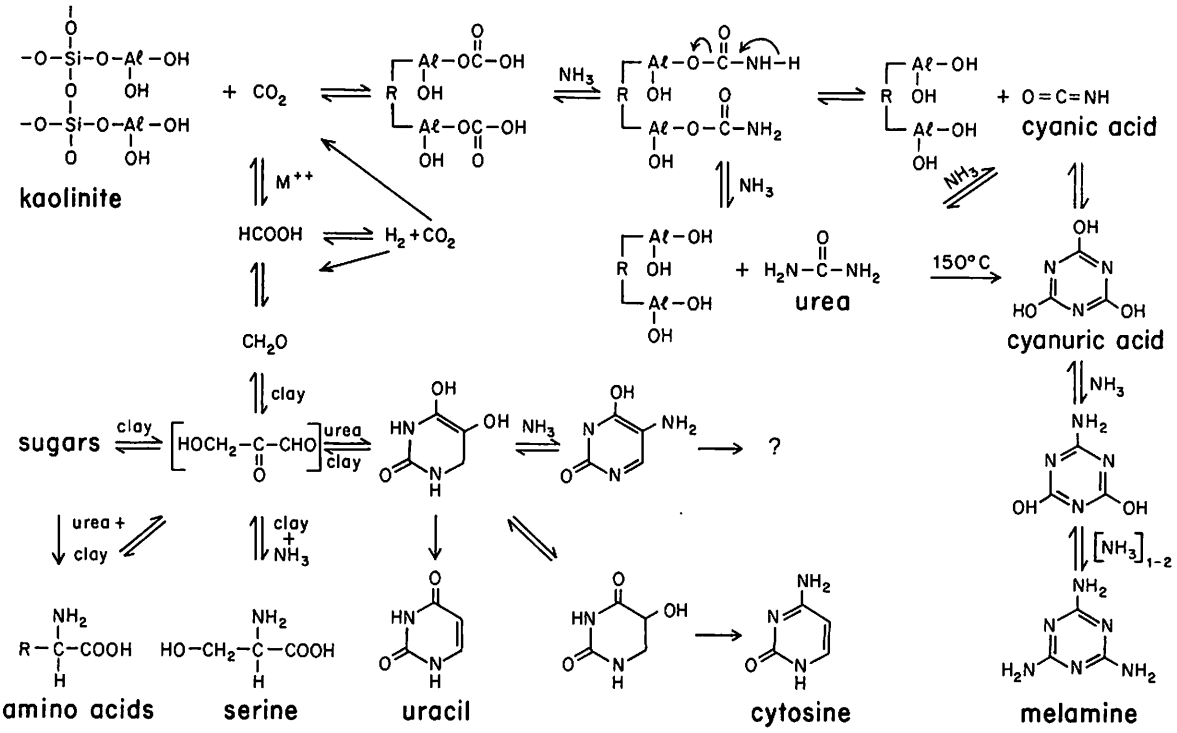


Fig. C-2 (Degens, Harvey and Mopper) Proposed pathways for synthesis of biologically important compounds with kaolinite.

We mention four types of epitaxial growth processes leading to the formation of distinct structures and organic polymers. Boundary and surface phenomena of this type are relevant to (1) mineralization processes in biological systems, (2) prebiotic events leading to the origin of macromolecules, and (3) operation principles in the genetic and metabolic apparatus.

Over the last few years, we have been interested in epitaxis and surface catalysis as they relate to a number of biochemical problems including calcification of molluscs or asymmetric polymerization of amino acids on clay minerals. We became increasingly aware that metal ions represent a key factor in the structural organization of organic molecules and the functional processes operating in biochemical systems. To the extent that nitrogen increases the structural order of macromolecules by allowing the formation of hydrogen bridges, so will oxygen permit the formation of metal ion coordination bridges. The principle of metal ion bonds is the subject of this research.

Our attention is focused on phosphate compounds for two reasons. In the first place, phosphates play a significant role in cellular processes as structural elements in nucleic acids and phospholipids and as functional elements in the oxidative phosphorylation or the photophosphorylation. Secondly, phosphate compounds exhibit a strong affinity to metal cations which is comparable to the affinity metal cations display to ordinary phosphate and silicate minerals present in rocks. A detailed knowledge of phosphate and silicate chemistry and crystallography can thus be used to interpret the structure and function of organic phosphate compounds.

CHRONOLOGY OF THE BLACK SEA OVER THE LAST 25,000 YEARS

Egon T. Degens and David A. Ross

Deep water sediments of the Black Sea deposited during Late Pleistocene and Holocene time are distinguished by three sedimentary units: (1) a micro-laminated coccolith ooze mainly consisting of *Emiliania huxleyi*, (2) a sapropel, and (3) a banded lutite. The base of the first unit lies at 3,000 years B.P., that of the second at 7,000 years B.P., and that of the third at least 25,000 years B.P. Fossils and geochemical criteria are used to decipher environmental events of this time period. Beginning with the base of the section, we witness the final stage of a metamorphosis from anoxic marine to oxic freshwater conditions. By the time this stage ended, 22,000 years B.P., the Black Sea had become truly a freshwater habitat. The lake phase lasted 12,000 to 13,000 years. Sedimentation rates were in the order of 1 m/10^3 years but began to decrease as sea level rose during the last 5,000 years of this phase (9,000 to 15,000 years B.P.). From 9,000 until 7,000 years B.P., Mediterranean waters occasionally spilled over the Bosporus as a consequence of ice retreat and sea level rise. This marked the beginning of a gradual shift from freshwater to marine, and from well-aerated to stagnant conditions. Around 7,000 years B.P. when deposition of unit (2) started, the H_2S zone was well established, and sedimentation rates dropped to 10 cm/10^3 years. Environmental conditions similar to those of today finally became established circa 3,000 years B.P., almost exactly the time when Jason and the Argonauts sailed through the Bosporus in search of the Golden Fleece.

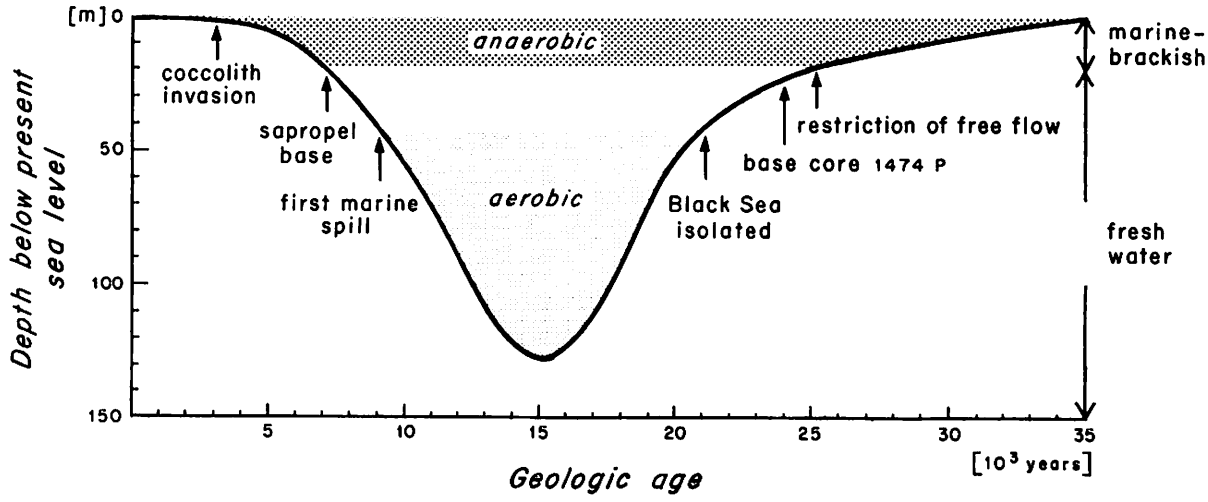


Fig. C-3 (Degens and Ross) Sea level curve (after Milliman and Emery, 1968) showing the important incidents in the recent history of the Black Sea.

EVOLUTION OF ANOXIC CONDITIONS IN THE BLACK SEA DURING THE HOLOCENE

Werner G. Deuser

Based on earlier investigations of the water and sediment of the Black Sea, a model of the evolution of anoxic conditions in the basin was developed. The condition for oxygen depletion was established about 9,000 years ago when, following the last glacial maximum, the first significant influx of Mediterranean Water through the Bosporus caused the development of a density stratification in the basin. Observations suggest that, except for short-term variations, the rate of oxygen consumption decreased logarithmically. For this long-term logarithmic rate a decay constant for the oxygen reservoir of 3.8×10^{-4} yr^{-1} can be calculated, corresponding to a half life of 1,800 years. With the aid of this constant and curves representing the distribution of volume and area versus depth, one can calculate the rise of the O_2-H_2S interface (Fig. C-4) and the growth of the anoxic water in terms of occupied volume and bottom area (Fig. C-5). In agreement with observations, the calculations show the beginning of anoxic conditions in the deepest part of the basin about 7,300 years ago and a continued slow rise of the interface in the recent past.

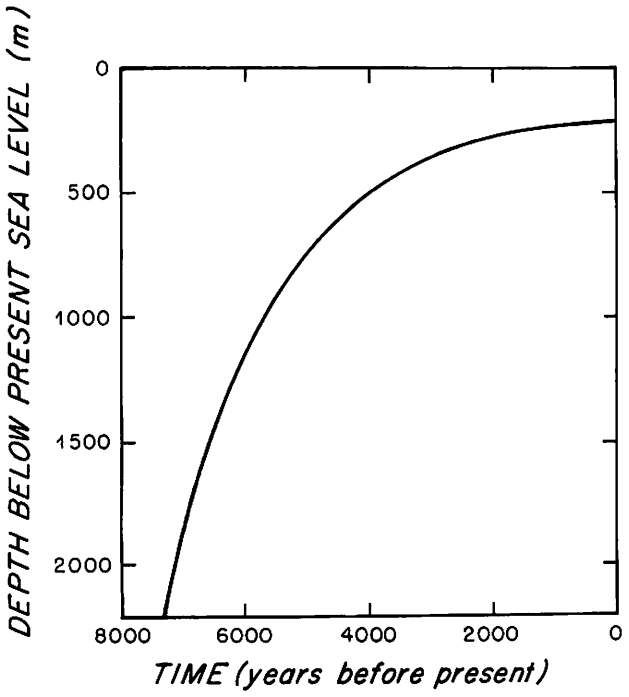


Fig. C-4 (Deuser) Calculated rise of the O_2 - H_2S interface in the Black Sea since its formation 7,300 years ago.

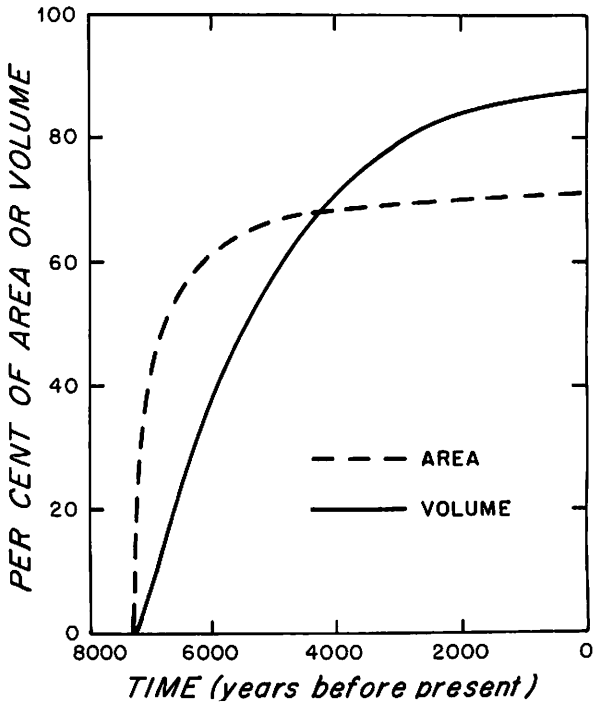


Fig. C-5 (Deuser) The development of the anoxic water in the Black Sea in terms of fraction of basin volume and bottom area occupied.

TRACE ELEMENTS DISSOLVED IN BLACK SEA WATERS

Derek W. Spencer and Peter G. Brewer

Profiles of dissolved manganese, copper, iron and zinc show that distributions of these elements are markedly affected by redox reactions at the boundary between oxygenated surface waters and sulfide-containing deep waters. Copper and zinc are depleted in the deep water by precipitation as insoluble sulfides. Moreover, concentrations of manganese and iron in deep water greatly exceed those of the surface water, principally because of greater solubility of the sulfides and hydroxides of the reduced species as compared with the solubility of the hydroxides and oxides of the oxidized species. The distribution of dissolved nickel and cobalt does not appear to be greatly affected by redox reactions. The profile of dissolved manganese, which shows a pronounced mid-water maximum about 40 meters below the oxygen zero boundary, has been explained with the aid of a vertical advection-diffusion model.

The profile of Mn, in the mixing interval from about 30 m above to 300 m below the oxygen zero, was fitted with the solution of the equation

$$K \frac{\delta^2 C}{\delta Z^2} - W \frac{\delta C}{\delta Z} + J = \frac{\delta C}{\delta t} = 0$$

where K is the vertical eddy diffusion coefficient, W the vertical advective velocity, Z depth and J an *in situ* production rate necessary to account for the production of manganese by the dissolution of sinking particles of MnO_2. We found that it was not possible to fit the above equation to the observed manganese profile (Fig. C-6) unless we allowed the J term to decrease exponentially with depth, and thus we substituted $J = J_o e^{-\mu Z}$ in the equation. From the fit of the stable conservative tracers, salinity and potential temperature, we had previously determined K/W as 0.09 and, assuming the deep water inflow through the Bosphorus (190 km^3/yr) advects upward uniformly through the oxygen zero boundary, we had calculated K as 0.014 cm^2/sec and W as 0.5 m/yr. Using these values, the least squares fit to the manganese profiles gives values of 4.5×10^{-4} for J_o and -0.038 for μ. Hence:

$$J\ (Kg^{-1}yr^{-1}) = 4.5 \times 10^{-4}\ e^{0.038Z}$$

We suggest that the Black Sea basin currently acts as an efficient trap for manganese. A flux of manganese, from surface particulates, of about 200 mg $m^{-2}yr^{-1}$, which is reduced and dissolved immediately upon penetrating to the sulfide-containing waters, builds up a mid-water maximum until the concentration gradient between the maximum and the deep water is sufficient to drive an equivalent diffusive flux of manganese into the deep water. Manganese is not lost by upward diffusion and advection because the reduced species is oxidized and precipitated just above the oxygen zero boundary and hence adds to the total flux of particulate manganese into the deep water. Currently the total flux of particulate manganese going into solution in the deep water is about 875 mg $m^{-2}yr^{-1}$ of which 675 mg $m^{-2}yr^{-1}$ is derived from the precipitation of dissolved manganese. The latter amount will increase in the future until the concentration of dissolved manganese at the mid-water maximum exceeds the solubility product of some salt. Although we have performed no calculations, the shape of the dissolved iron profile indicates that a mechanism similar to that described for manganese controls distribution. In addition, it is likely that sulfide precipitation limits iron concentration in the deep water.

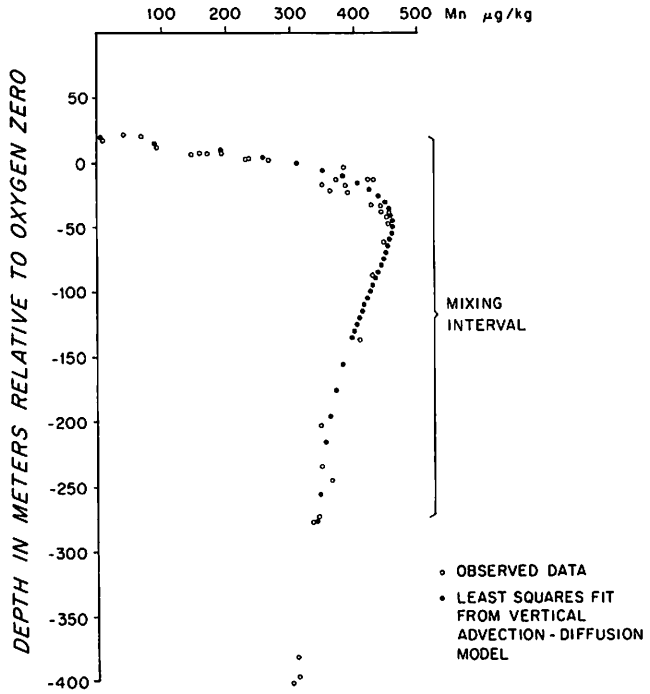


Fig. C-6 (Spencer and Brewer) Profile of dissolved manganese in the Black Sea over the linear mixing interval.

SURFACE CHEMISTRY OF MANGANESE DIOXIDE

James Murray

Results of suspended matter analyses from the anoxic interface in the Black Sea indicate that cobalt and antimony are correlated with manganese. This is not a unique phenomenon for geochemists have frequently found correlations of certain metal ions with manganese in manganese nodules; for example, copper and nickel correlate with manganese and cobalt correlates with iron. Such correlations have usually been ascribed to either surface chemistry or the structure of the iron and manganese oxides. In order to develop a suitable hypothesis for these metal ion correlations, a detailed study of a synthetic manganese dioxide was undertaken. Initial experiments were designed to achieve a basic understanding of the chemical reactions that take place at the MnO_2 interface while later experiments will be made to observe the interaction of metal ions with the MnO_2 surface under sea water conditions.

Results of the initial experiments indicate that the surface of MnO_2 is amphoteric in nature, meaning the surface can be positively charged, uncharged, or negatively charged. Furthermore, it was found the sign and magnitude of the charge is a function of pH. The surface is uncharged at pH 3.0 and negatively charged for pH values greater than 3.0. At the pH of sea water, the surface charge of MnO_2 is an order of magnitude greater than other metal oxides such as SiO_2, Fe_2O_3 and Al_2O_3. This fact alone helps explain the large adsorption capacity of MnO_2. However, it was found that, in addition to the electrostatic attraction, the surface has large specific adsorption capacities for the alkali earth and transition metal cations; thus, adsorbed cations cannot be desorbed by adjusting the pH to 3.0. It is believed this specific adsorption, which is strongest for cobalt, will help explain some of the correlations of metal ions with manganese found in nature.

RED SEA BRINES

Peter G. Brewer

During February 1971, R/V *Chain* revisited the area of hot brine pools (near 21°20'N, 38°05'E) in the Red Sea that had been intensively investigated in November, 1966. The hydrographic observations indicated that the deep water in the Atlantis II Deep has risen in temperature 2.7°C from 56.5°C to 59.2°C in the 51-month period while the water mass overlying this layer had increased 5.4°C from 44.3°C to 49.7°C. There was no observable change in the salinity of the deep water. However, a small ($2°/_{oo}$) increase in the salinity of the 49°water was detected.

These data support Turner's statement (1969) that the stability of the interfaces caused molecular diffusion to predominate. Data given by Turner indicated a net heat flux of 23 μcal cm^{-2} sec^{-1} from the 59° brine to the 49° brine. Using this information together with data on brine volumes and specific heats, we can construct a model of the hydrographic changes. The interface between the 59° brine and the 49° brine has risen 6 m from 2,042 to 2,036 m, indicating an input of new brine of 0.35 km^3. We calculate the temperature of this incoming brine to be >113°C.

An important parameter in describing the stability of these interfaces is $\Delta\rho_s/\Delta\rho_t = D$, giving the ratio of the separate contributions of salinity and temperature to the density difference between the layers. A value of D = 1 indicates neutral gravitational stability. Values for the lower interface are D = 15.7 (1966) and 19.4 (1971) and, for the upper interface, D = 9.1 (1966) and 7.4 (1971). These changes imply that the upper interface is becoming significantly less stable and may overturn within 10-15 years.

Samples of suspended particulate matter in the brines were collected to evaluate rates of redox reactions taking place at the interface, and this work is proceeding.

Reference

Turner, J. S. (1969). A physical interpretation of the observations of hot brine layers in the Red Sea. In: *Hot Brines and Recent Heavy Metal Deposits in the Red Sea*, E. T. Degens and D. A. Ross, editors, Springer-Verlag, New York, 164-173.

CARIACO TRENCH

Peter G. Brewer and Derek W. Spencer

Previous work on the Black Sea led to a significant increase in our understanding of the geochemistry of manganese and iron in anoxic basins (Spencer and Brewer, 1971). In August, 1971, R/V *Atlantis II* visited the Cariaco Trench, an anoxic basin situated on the northern Venezuelan continental shelf. Maximum depth is 1,400 m and, below 300-400 m, the basin is permanently anoxic. It differs significantly from the Black Sea where sulfide concentrations are only about 1/10 as high. Moreover, deep water residence time is only about 200 yrs as opposed to about 2,000 yrs for the Black Sea. There is no obvious inflow of deep water, and it has been proposed that the basin is flushed solely by eddy diffusion.

A θ/S diagram (Figs. C-7 and C-8) has a linear relationship between 200 and 1,400 m depth, and this interval covers the oxygen-sulfide transition zone at about 300 m. Over this linear mixing interval we fitted the data with a vertical advection-diffusion model for the steady state vertical profile of a stable conservative tracer. The solution of the equation is:

$$(C - Co) = (Cm - Co)\ \frac{(e^{z/z^*} - 1)}{(e^{Zm/2^*} - 1)}$$

where Zm is the mixing interval, Co is the concentration at the lower boundary Zo, Z being positive upward and Cm being the concentration at the upper boundary Zm.

The least squares fit to the data gave Z* (= k/w, the ratio of the vertical coefficient of eddy diffusion to the vertical advective velocity) equal to 0.146 for θ, and 0.143 for S, the standard deviation of residuals being ±0.04°C and 0.009 ‰. The fit to the profiles is indicated in Figs. C-7 and C-8.

Analyses of large volume samples for Mn and Fe have been carried out using a combination of ion exchange, atomic absorption spectroscopy and spectrophotometry. The profile of dissolved Mn is shown in Fig. C-9.

Again the data have been fitted to a vertical advection-diffusion model for a stable non-conservative tracer using a production function (J) which was allowed to vary exponentially with depth. The solution to the equation is:

$$C - Co = Cm - Co\ f\ (z) + \frac{Jo/w}{\mu(1 + \mu z^*)} \quad [(1 - e^{-\mu z}) - (1 - e^{-\mu zm})\ fz]$$

$$\text{where } f\ (z) = \frac{(e^{z/z^*} - 1)}{(e^{Zm/z^*} - 1)}$$

The two-parameter least squares fit to the data gives $Jo/w = 3.1 \times 10^{-9}$ and $\mu = -25$; the standard deviation of the residuals is ±1.9 μg Mn/kg and the mixing interval was taken from 300-1,400 m. The fit to the data is shown in Fig. C-9. In order to obtain a unique solution to these equations, either w or k must be estimated. We are now attempting this through the use of ^{14}C data collected on the cruise.

Reference

Spencer, Derek W., and Peter G. Brewer 1972. Vertical advection diffusion and redox potentials as controls on the distribution of manganese and other trace metals dissolved in waters of the Black Sea. *J. Geophys. Res.*, 76, 5877-5892.

INTERSTITIAL WATERS OF MARINE SEDIMENTS

F. L. Sayles, F. T. Manheim and L. S. Waterman

Continuing studies of diagenesis of interstitial solutions of marine sediments have identified a number of reactions which affect the concentrations of several major constituents in these solutions. Detailed sampling on Leg 15 of the DSDP in the Caribbean showed that temperature-induced artifacts affect pore fluid composition in all types of sediments. The fact, known for some time, that the composition of interstitial solutions of sediments is altered by warming samples from ocean bottom to ambient surface temperature has been attributed to ion exchange by the clays present in the sediments. Temperature-induced artifacts affect concentrations of Na, K, Ca and Mg. No significant effects on SO_4 and Cl concentrations in any type of sediment were observed, but minor constituents such as B, Si, and Sr exhibit significant changes of concentration. Average losses and gains observed on warming samples of several types of sediment are given in Table C-I.

The changes induced by the warming of samples is characteristic of the type of sediment. Biogenic sediments exhibit significant but lesser concentrational changes than clayey sediments. Corrections for temperature effects can be made to a few percent or less for Ca, Mg and Na and better than five percent for K. Uncertainties for some minor constituents are much larger.

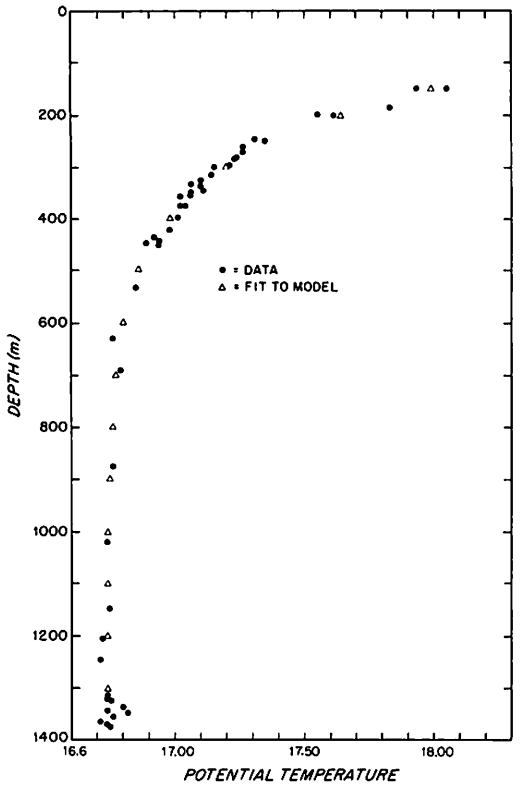


Fig. C-7 (Brewer and Spencer) Potential temperature--depth diagram for the Cariaco Trench showing the fit to a vertical advection-diffusion model.

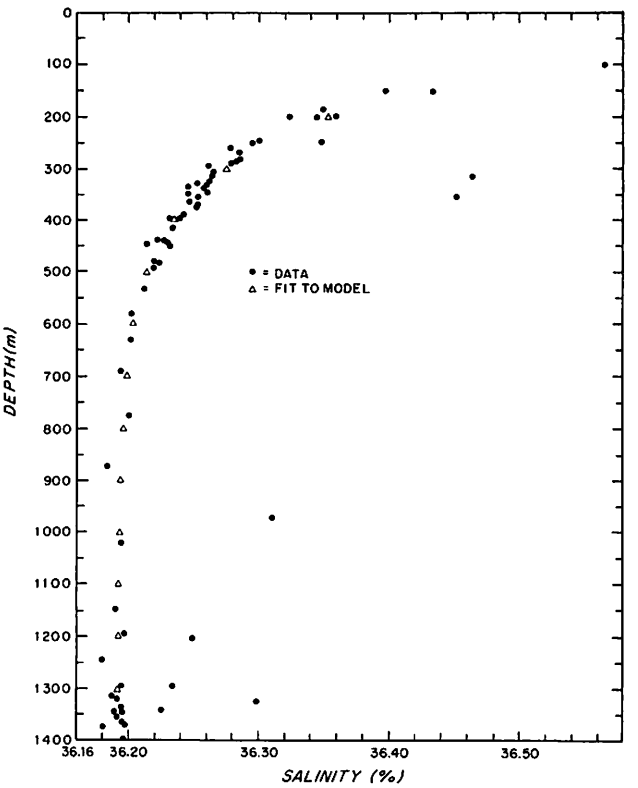


Fig. C-8 (Brewer and Spencer) Salinity--depth diagram for the Cariaco Trench showing the fit to a vertical advection-diffusion model.

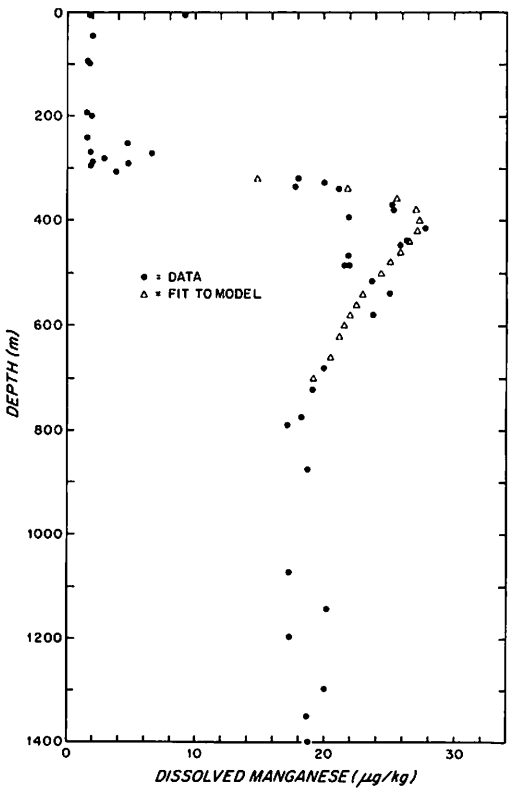


Fig. C-9 (Brewer and Spencer) Dissolved manganese profile in the Cariaco Trench. The data have been fitted to a stable non-conservative tracer model over the mixing interval from 300-1,400 m.

TABLE C-I

Summary of Average Changes as a

Result of Altered Temperature of Squeezing

Percent Change, $\frac{\text{(extraction at 22° C) - (extraction at 4° C)}}{\text{extraction at 4° C}}$

Component	Site 147 (marl)	Site 148 (marl)	Site 149 (Carbonate)	Site 149 (siliceous)
B	+30	+61	+ 7 (total site)	
Si (Col)	+26	+41	+27	0
K	+18	+24	+16	+12
Na	+ .9	+ 1.3	+ 1.0	+ 1.0
Li	- 3(?)	0.0	0.0 (total site)	
Ca	variable	- 6.5	- 3.1	- 1.1
Mg	- 7.3	- 7.3	- 3.1	- 1.4
Sr	-19	- 7	0.0 (total site)	
Cl	< .5	< .5	< .5	< .5
	< .5	< .5	< .5	< .5

In reducing sedimentary environments, concentrations of Ca, Mg, HCO_3 and SO_4 appear to be controlled largely by SO_4 reduction and reactions consequent upon this reduction. Bacterial reduction of SO_4 produces HCO_3 and H_2S which precipitate Ca as $CaCO_3$ and Fe as FeS_2. Fe may be replaced in the nontronite component of montmorillonite by Mg. If it is assumed that all of the Mg lost from the system replaces Fe in clays, all Ca losses are due to $CaCO_3$ precipitation and SO_4 losses result from reduction, then these reactions may be represented by the mass balance

$$\Delta SO_4 = 1.33\ \Delta Mg + \Delta Ca - \Delta HCO_3$$

The Δ notation refers to total losses or gains. In a closed system this represents losses and gains of these constituents relative to sea water concentration. Where chemical gradients are not very great and diffusion is minimized, the model appears to adequately explain the observed concentrations (Fig. C-10). In cases where large chemical gradients exist, diffusive fluxes make determination of total losses and gains impossible.

Na and Cl are usually conservative in their behavior, but significant depletions of both elements have been noted in the most strongly reducing sediments studied. Such sediments are characteristically adjacent to continental land masses and are rapidly deposited. They contain a large proportion of terrigenous detritus. It is believed that the observed depletions of Na and Cl reflect dilution rather than chemical removal.

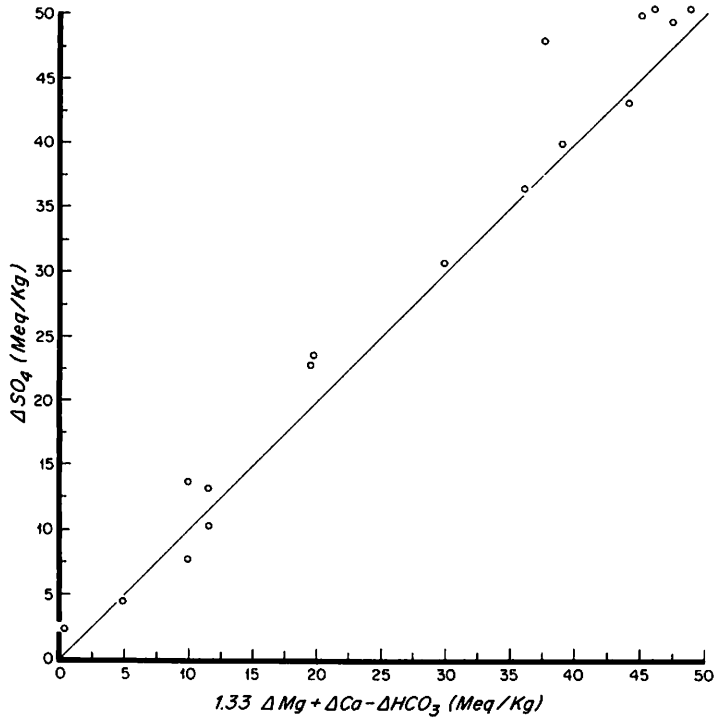


Fig. C-10 (Sayles, Manheim and Waterman) Variation of SO_4 loss as a function of Ca and Mg losses and HCO_3 gains after the equation presented in the text. The straight line represents the relationship described by the equation. Data are from Site 148 (Aves Ridge).

FERROMANGANOAN SEDIMENTS

F. L. Sayles and P. C. Bowker

Unusual sediments composed primarily of an x-ray amorphous material and characterized by high concentrations of Fe and Mn have been found to be widespread in the area between the East Pacific and Galápagos rises. The occurrence of these sediments within this region is controlled primarily by water depth. They accumulate below approximately 4,150 m with little or no admixture of $CaCO_3$. The thicknesses observed vary from one meter to in excess of the core penetration (8 m). Total sediment thicknesses are often in excess of 100 m. Cores from cruises of the *Atlantis II* (54) and *Chain* (100) and several bathymetric profiles of the area suggest that the total area covered by this type of sediment probably exceeds 200,000 km^2.

The sediments are composed primarily of Fe_2O_3 (15-25%), Mn_3O_4 (6-9%) and SiO_2 (30-35%). Al_2O_3 ranges from one to 4% and TiO_2 from 0.1 to 0.3%. There are also unusually high concentrations of Ba (one to 2%), Cu (to 0.2%), Pb (to 0.1%), Ni (to 0.2%) and Zn (to 0.2%). Little of the SiO_2 occurs

as skeletal debris of siliceous organisms or as volcanic glass while the low Al_2O_3 precludes the occurrence of the bulk of the SiO_2 as clays. Precipitates formed by the interaction of seawater and hydrothermal solutions emanating through the sea floor are believed to be an important component of these sediments. These solutions are thought to be the source of much of the Fe, Mn and Si.

Most pelagic marine sediments deposited in the absence of appreciable accumulations of biogenic detritus are composed largely of clays. In the area of the Galápagos and East Pacific rises, however, deposition of amorphous sediment predominates over deposition of normal pelagic clays. At depths of less than 4,100 m where $CaCO_3$ accumulates, the amorphous material is usually only a minor component of biogenic calcareous sediments as demonstrated by earlier work. The amorphous sediments studied thus appear to be analogous to pelagic red clays. Such sediments can be expected to form in other active mid-ocean rise areas where accumulation rates of terrigenous and biogenic detritus are relatively low.

INORGANIC GEOCHEMICAL STUDIES

Geoffrey Thompson

Submarine Igneous Rocks:--Our studies of selected regions of the Mid-Atlantic Ridge were extended to an area about 22°S in the South Atlantic. On a two-month cruise during the summer using bathymetric and magnetic surveys, we were able to delineate a transform fault which offset the ridge axis approximately 100 km. Rocks dredged from the fracture zone included basalts, metabasalts, layered gabbros and serpentinized periodotites, and those from the ridge axis to the north and south of the fracture included basalts and their metamorphic equivalents. Microprobe analysis of basalt glass indicates the rift valley basalts to be typical oceanic tholeiites low in sodium and potassium.

Work on the weathering of submarine igneous rocks was also continued. The stages in low temperature sea-water attack on a basaltic rock exposed on the sea floor range from simple hydration of an olivine-augite-plagioclase basalt to a clay-type matrix composed predominantly of chlorite and seriticized plagioclase. Olivine is the first to be attacked followed by pyroxene and plagioclase. The glass undergoes devitrification and palagonitization. Chemically the alteration is accompanied by enrichment in Si, Na, K, H_2O, B, Ba, Li, Pb and Rb. The iron is oxidized while loss of Mg, Ca, Ti, total Fe, Co, Cr, Ga, Ni, Sr, V, Y, Zn and Zr is noted. Chemical changes are not progressive with alteration but show some redistribution of elements in different alteration facies and are most marked during the latest stages of alteration when mineral reconstitution is greatest.

Our investigation of the variation in composition due to weathering have been complemented by studies of differentiated oceanic basic rocks to indicate control on compositions by fractional crystallization. Concentration variations in basaltic rocks are initially governed by precipitation of either olivine or plagioclase. In those tholeiites characterized by olivine as the first mineral to crystallize, early stages of fractional crystallization show that concentrations of Cr and Ni decrease by factors of two to five for small changes in the FeO/MgO ratio. Those oceanic tholeiites characterized by plagioclase as the first mineral to crystallize do not exhibit systematic trends in trace element concentration in the early stages of fractionation. Tholeiitic gabbros, which show marked differentiation and range from a troctolite through high-iron (15%), high-titanium (9%) gabbro to aplite and diorites in the later stages, also vary markedly in their trace element composition. The differentiation trends displayed by Co, Ni, Cr, V, Y and Zr are very similar to those in the Skaegaard Intrusion, East Greenland. Marked enrichment in Mo (10-fold) and V (5-fold) is noted in those rocks high in titanium and iron.

Marine Organisms:--We examined the elemental composition of a number of sponge species and analyzed for 30 elements in 31 species representing eight Orders from the Demospongiae and one species from the Calcispongiae. Many of the sponges reflect the chemical composition of the surrounding sediment which is often coral debris. Siliceous varieties are somewhat enriched in B but are generally low in other metals. *Dysidea crawshayi* has a high concentration of K; some of the *Haplosclerina*, of Cu as does the *Carnosa* family. The *Poecilosclerina* concentrates Mn. A few samples of sponges are apparently enriched in Ni. However, this may be due to concentration of that element by certain microorganisms inhabiting them.

We are also analyzing diatom species cultured in the laboratory. Specific effects have been noted for the uptake of B, Co and Mn, but Ba is not concentrated by the six species studied so far which is in contrast to a suggested hypothesis of Ba enrichment in some sediments due to concentration by diatoms.

GEOSECS TRACE ELEMENTS

Peter G. Brewer and Derek W. Spencer

As participants in the GEOSECS trace element program, we have undertaken the responsibility for the determination of dissolved iron. Data from the Pacific have revealed the presence of an iron maximum extending from 750 m to 2,500 m. Data now being compiled from the Atlantic reveal two maxima in the water column; one at 750 m, associated with the oxygen minimum, and the second at 3,200 m, associated with the North Atlantic Deep Water. Iron concentrations in the water column at the GEOSECS Atlantic test site (near 35°46'N, 67°59'W) vary from 1-20 μg Fe/kg. These maxima may also be observed in the South Atlantic and indicate that dissolved iron may be an important oceanic tracer.

Data for dissolved copper and zinc show a similar pattern though the precision of our analysis is not as good. The source of these anomalies is not well understood, and this problem will occupy our future work.

IN SITU MEASUREMENT OF LIGHT SCATTERING

Peter L. Sachs

The laser nephelometer developed and used at this institution during the past few years to detect suspended particulate matter in sea water has been incorporated into the GEOSECS instrument package. It consists of a frame holding ten 30-liter Niskin samplers and the mechanism for closing them by shipboard command (Fig. C-11). Attached to the frame are the Brown STD, an oxygen probe developed at Scripps Institution of Oceanography, a bottom proximity sensor and the nephelometer. Fig. C-12 shows the package during a test on the R/V *Melville*. The water samplers are removed, and the STD and oxygen probe are barely submerged.

In the nephelometer, the ratio of outputs from the photo cell, which senses light scattered from the laser beam, and from the reference cell, which senses variations in laser intensity, is converted to an AC signal. This signal is digitized and fed to the STD logic and telemetry circuits which can accommodate additional inputs. Sixteen bits of nephelometer data are part of a 200-bit frame which includes data from all other sensors in the instrument package. Maximum sampling rate is about 33 frames per second. This scheme gives higher resolution over a wider dynamic range at a higher sampling rate than was possible with the acoustic telemetry system used hitherto. The data are accumulated by a shipboard computer system in real-time, then processed and shown on a CRT display with considerable flexibility in selection of axes and scales.

Fig. C-13 is an example of such a plot for a station in the San Clemente Basin off the California Coast. The x-axis represents the ratio of output from the measuring cell to output of the reference cell. The scale cannot be absolutely related to scattered light intensity, but a numerical increase does indicate an increase in scatter. The two superimposed curves were produced by lowering the instrument to and raising it from the bottom at essentially the same location. The general shape of the curve is reproduced well except in the upper 250 m of the water column where the morning downward migration of zooplankton during the time of the scattering produced an offset in the scattering intensity profile. During the six days the instrument was used at this location, that part of the profile below 250 m remained virtually unchanged. This demonstrates that the conditions which produced variation in light scattering, principally in suspended particulate matter concentration, remained stable over periods of many days.

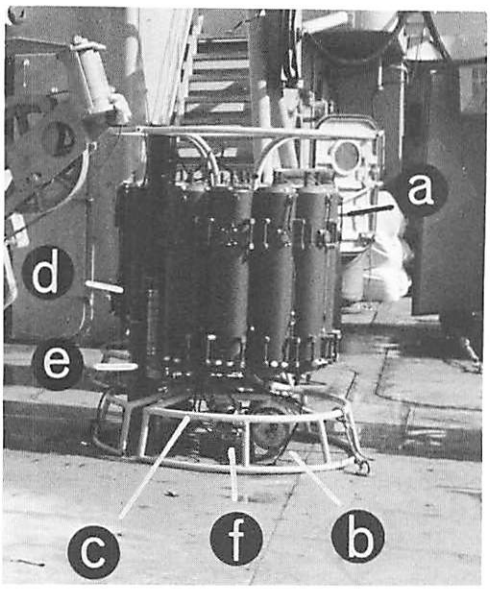
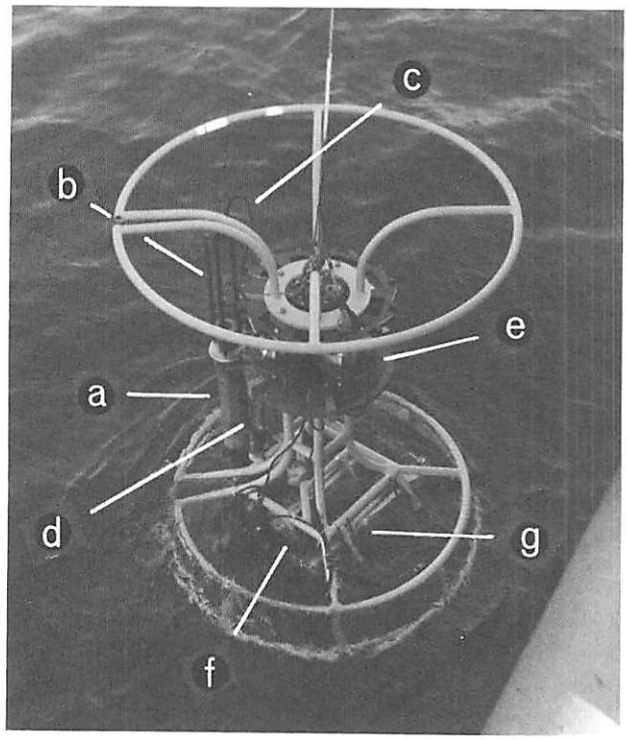


Fig. C-11 (Sachs) GEOSECS instrument package

a. 30 liter Niskin sampler
b. Brown STD
c. Oxygen probe
d. Bottom proximity sensor
e. Nephelometer
f. Telemetry expander



a. Laser housing
b. Optical bench
c. Sensing photocell
d. Nephelometer electronic housing
e. Laser battery supply
f. Telemetry expander
g. Brown STD

Fig. C-12 (Sachs) GEOSECS instrument package over the side. Water samplers have been removed to show nephelometer.

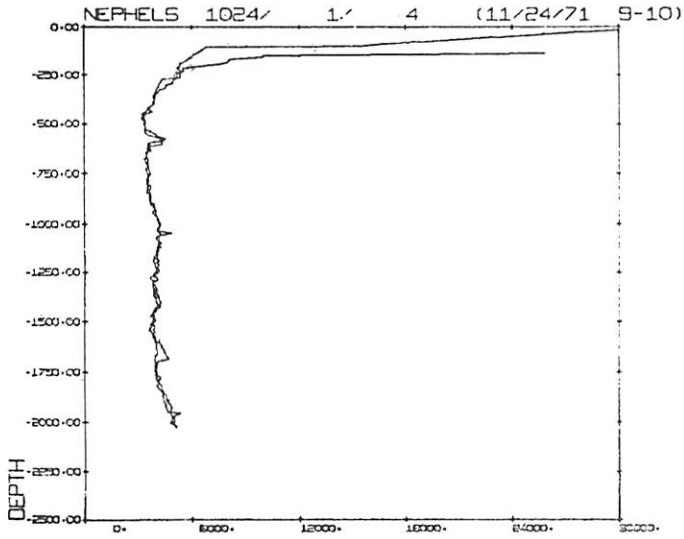


Fig. C-13 (Sachs) Nephelometer profile from third bottom cast, Cal Coast II Cruise, in the San Clemente Basin.

THE GEOCHEMICAL OCEAN SECTION STUDY (GEOSECS)

Derek W. Spencer

The geochemical section survey will be made through the oceans along north-south tracks which follow, as far as is now known, the approximate trajectory of the bottom water current. The United States program will carry out the major survey along this path in the Atlantic, Indian, Pacific and Antarctic oceans (Fig. C-14). Programs now being planned by West Germany, Japan and other nations will supplement our survey. The U.S. program calls for the occupation of 120 oceanographic stations along the main track. At each station, vertical profiles of 50 samples will be taken, each sample measuring about 30 liters. At alternate stations, large samples of 1,000 liters will be taken at about 18-20 depths for measurements of trace constituents and low concentration radioisotopes. The vertical spacing of all these samples will be guided by continuous, on-station recording of temperature, salinity, and dissolved oxygen. Much of the analyses will be done directly on the ships during the expedition. The remaining work on the water samples will be done in the laboratories of participating geochemists throughout the country, and a "water library" of water samples will be maintained for future work.

The parameters to be determined include temperature, salinity, O_2, CO_2, alkalinity, NO_3-N, PO_4-P, Si, Na, K, Mg, Ca, Ba, Fe, Zn, Sr, C^{14}, Sr^{90}, Cs^{137}, H^3, Ra^{226}, Rn^{222}, Ra^{228}, isotopic ratios (C^{13}/C^{12}, H^2/H, O^{18}/O^{16}), He, Ne, Ar, N_2 and measurements of the concentration and composition of suspended matter.

The general plan for station work on the GEOSECS cruises is a series of hydrographic and sampling casts which, on a complete station, will be arranged in roughly the following way:

1. A Nansen bottle hydrographic shallow cast and deep cast with high precision (0.001°C) thermometers on the deep cast.

2. An STD-O_2 profile to about 4,000 m using a salinity-temperature-depth probe, with an additional sensor for dissolved oxygen in order to locate precisely the oxygen extrema. The profiles and TS plots will be displayed immediately by a computer system and used to plan depths and spacing of the following sampling casts in order to guide the sampling program by the water mass structure at each station.

3. Two 30-liter Niskin bottle sampling casts, shallow (0 to about 1,000 m) and deep (about 1,000 m to 100 m above bottom). A total of about 50 samples will be collected on these two casts. The bottles will be housed in 12-bottle sampling rosettes with electrical triggering at desired depths and a temperature sensor with 0.005°C and 0.1% depth precision. Temperature and depth will be recorded by the computer system both continuously and individually for each sample. Each rosette will also carry a reversing thermometer rack to obtain a three-point calibration check of temperature and depth on each cast.

4. Interspersed with the 30-liter sample casts on large volume stations, there will be three casts, each consisting of six samples for a total of 18 large volume samples. We are now working to perfect sampling bottles capable of collecting 1,000 liter samples. However, if this is not possible, we will be limited to 280-liter samples using Gerard-type samplers which are known to be reliable. This smaller volume will be sufficient for all of the radio-isotope measurements that are proposed with the exception of Ra^{228}.

5. Finally, a bottom water cast will be made for detailed sampling of a 12-bottle rosette of 30-liter Niskin bottles which can be tripped and verified electrically. The six bottles will give an excess radon profile for study of the vertical mixing parameters at the bottom, and a temperature sensor will give a detailed temperature profile with a precision of 0.001 C. Additionally, a nephelometer developed at Woods Hole will record continuously the light scattering as a measure of the suspended particulate material, and samples of the particulate matter will be collected by filtration of the water.

This series of hydrographic and sampling casts will require approximately 30 hours on station. At several stations in each oceanic hemisphere, an additional 12 hours cast for Si^{32} and particulate flux will be made using sponge samplers. These are specially designed butterfly samplers containing about 50 lbs of chemically treated natural sponges. By suspending the samplers on the wire and moving the wire up and down about 50 m continuously for 12 hours, large volumes of water are processed and a sufficient amount of Si^{32} is collected for analysis. Absolute quantities of Si^{32} will be determined by measurement of the stable silica that is collected.

Successful operation of the program will depend upon the precise and rapid measurement of several ocean variables aboard ship. For this reason, we are developing automated analysis systems for many of the routine chemical measurements. All physical and chemical measurements made at sea will be coupled with the shipboard computer. Data will be logged from principal and auxiliary sources and brought together in a real-time system to compute final values of the parameters. A large portion of this data will be available for evaluation by the chief scientist before moving off station.

The analytical systems being automated or partially automated and interfaced with the computer are salinometer; alkalinity-total CO_2 titration; gas chromatograph, total CO_2, N_2, Ar; autoanalyzer, NO_3, PO_4, Si; Rn^{222}; pCO_2. In addition, data from the thermosalinograph, various atmospheric parameters, ship speed and heading, satellite fixes, etc. will be constantly added to the computer data bank and will be available for instant recall.

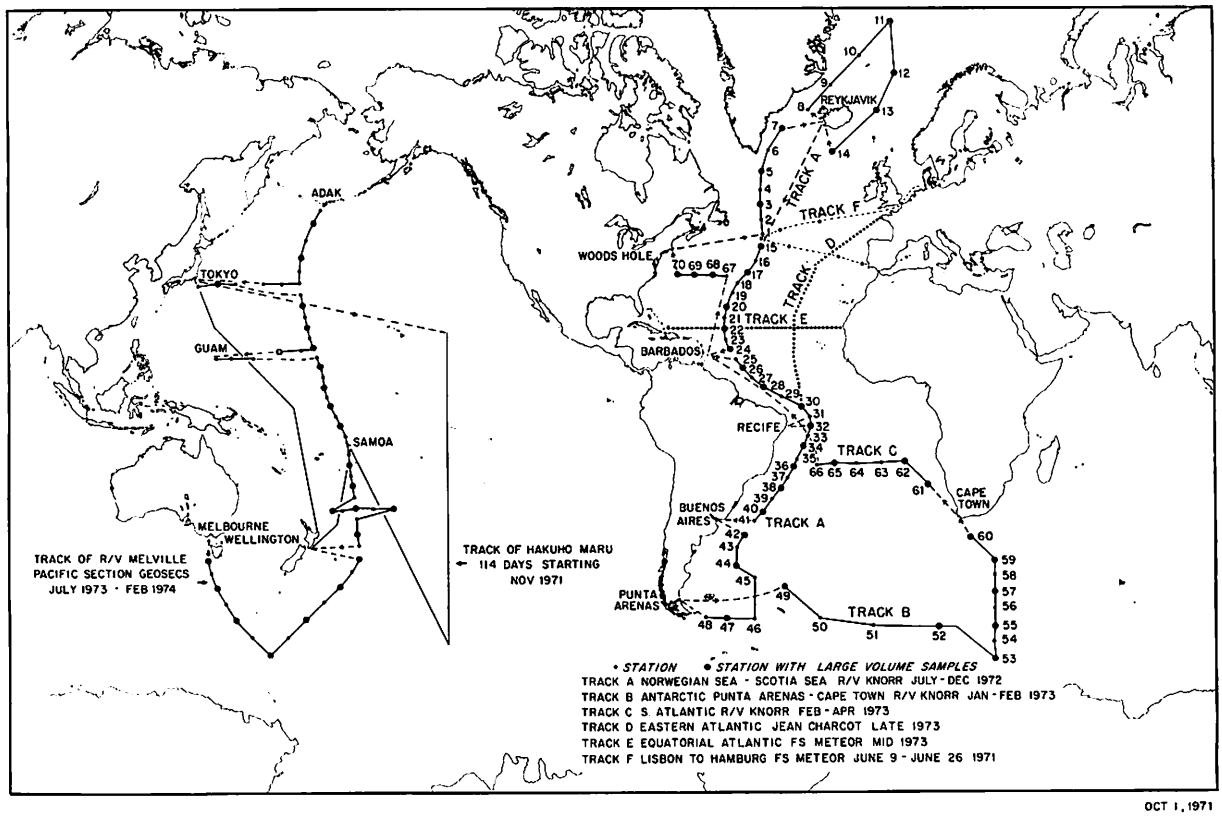


Fig. C-14 (Spencer) Proposed GEOSECS Cruise Tracks

LAKE KIVU: ANATOMY OF A RIFT LAKE

An Interdisciplinary Study of Geological Structure, Water Chemistry and Biological Productivity of an Unusual Lake

Egon T. Degens, Richard P. von Herzen, How-Kin Wong,

Werner G. Deuser, Holger W. Jannasch and John W. Kanwisher

Since their discovery by European explorers in the 19th Century, the rift valley lakes of East Africa have evoked curiosity and subsequent scientific investigations. Until recently, these investigations have been directed largely towards a description and understanding of the hydrobiology and chemistry of the lake waters. As the exposed rift valleys of East Africa became the focus of a variety of geological and geophysical studies about the origin of these unique features, it became obvious that the rift valley lakes constituted an even more striking western branch of the East African rift system. For example, the bottom of the deepest of these, Lake Tanganyika, lies below sea level despite a rather thick infilling of sediments. The similar morphology of the East African rifts and mid-ocean rifts has given renewed impetus toward a more thorough understanding of the way in which these continental features relate to new concepts of plate tectonics developed largely from geological and geophysical studies of ocean basins.

The northern basin of Lake Kivu contains about 0.5 km of sediments overlaying a basement believed to be crystalline rocks of Precambrian age. Volcanic rocks at the northern end of the lake have created large magnetic anomalies of up to 300 γ which have a smaller horizontal extent than that normally observed at sea over mid-ocean ridges. They neither confirm nor refute the existence of the type of tectonics associated with sea-floor spreading. Heat flow varies from 0.4 to 4 hfu. The extreme variability may be due in part to sedimentation or recent changes in the temperature of the bottom water. Sharp boundaries in the vertical temperature structure of the water indicate that individual water layers may be as young as a few to 100 years old.

Concentrations of the major dissolved gases in the deep water, CO_2 and CH_4, approach saturation but do not exceed it at any depth. Concentrations of dissolved salts show strong stratification. The salts are supplied mainly by hydrothermal discharges at the bottom of the lake, calculated to have a salinity about 60% higher than the bottom water. Zinc anomalies in the water are explained by the accumulation of sphalerite-containing globules at certain depths.

Stratigraphic correlation of sediments is possible across the entire lake, based on physical, geochemical and paleontological criteria. Sedimentation rates are of the order of 30 cm/1,000 yr, implying a Pliocene age for the deepest part of the lake. A beach deposit at a water depth of 310 m indicates that the lake reached its present size and level no more than a few thousand years ago. Periods of hydrothermal activities and heightened volcanism, as recorded in the sediments, appear to have coincided with pluvial times.

Several new types of methane oxidizing and producing bacteria were isolated, but bacterial degradation of recent plankton appears insufficient to explain the amount of methane in the lake, implying addition from more deeply buried sediments. While the diversity of planktonic organisms is low, in accordance with observations in other eutrophic situations, quite the contrary seems to be true for the bacteria.

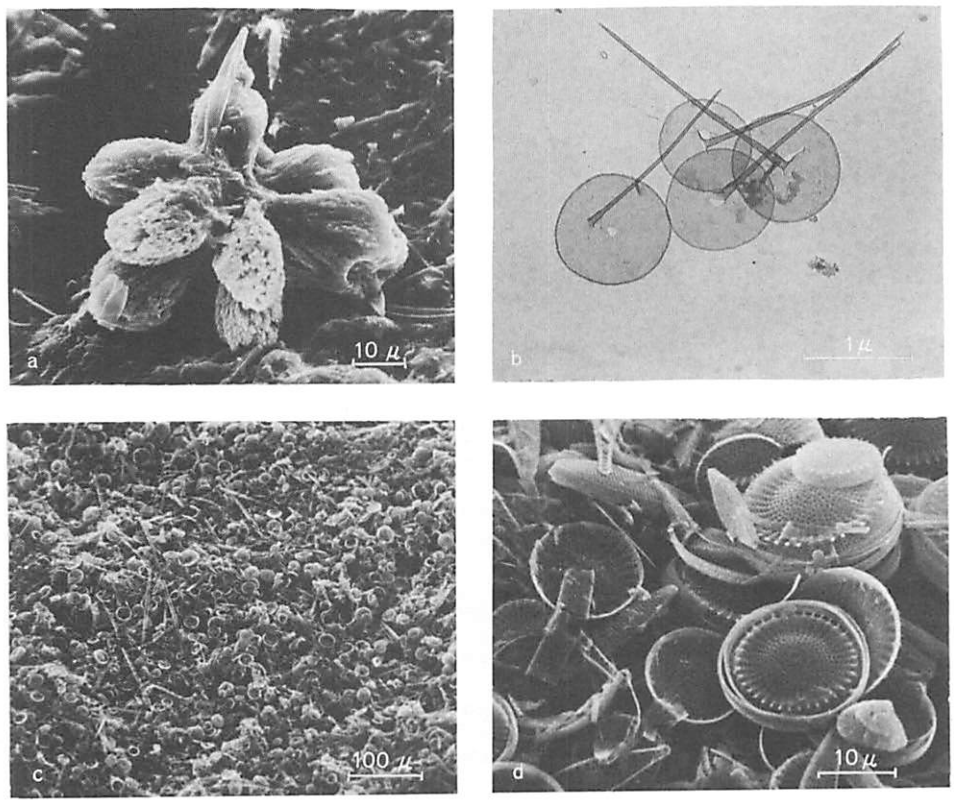


Fig. C-15 (Degens) Electron micrographs of some typical sediment material: (a) high magnesium calcite; (b) scales of unidentified flagellate species belonging to the class Chrysophyceae; (c-d) original sediment surface showing principally *Stephanodiscus astrea*, a disc-shaped diatom, and *Nitzschia fonticula*, a boat-shaped diatom.

MICROCRYSTALLINE SPHALERITE IN RESIN GLOBULES SUSPENDED IN LAKE KIVU

Egon T. Degens, Hisatake Okada, Susumu Honjo and John C. Hathaway

The origin and chemical nature of micron-sized spheres found as suspended particles in Lake Kivu were examined. These hollow spheres, with a wall thickness of 500 Å (Fig. C-16) consist of a complex polymeric resinous material which has little functionality except for hydroxyl groups. The spheres arise in the process of degassing of water samples at depth. Tiny gas bubbles, about one micron in size, act as scavengers of dissolved resinous material. The newly created resinous membrane promotes the selective coordination of zinc dissolved in the water column. In the prevailing H_2S regime, formation of sphalerite crystals is induced. The size range of the crystals, five to 50 Å, corresponds to one to 10 unit cells and suggests that the resinous membrane also acts as a template in sphalerite growth processes.

The sources of the zinc and dissolved gases (methane, carbon dioxide, hydrogen sulphide) are hydrothermal springs seeping from the lake bottom into the basin.

Water discharge is substantial. Less than 1,000 years are required to fill the lake to its present level (ca. 550 km^3 water). The average Kivu water contains 2 ppm zinc. Thus, one million tons of zinc are contained in Lake Kivu in the form of sphalerite.

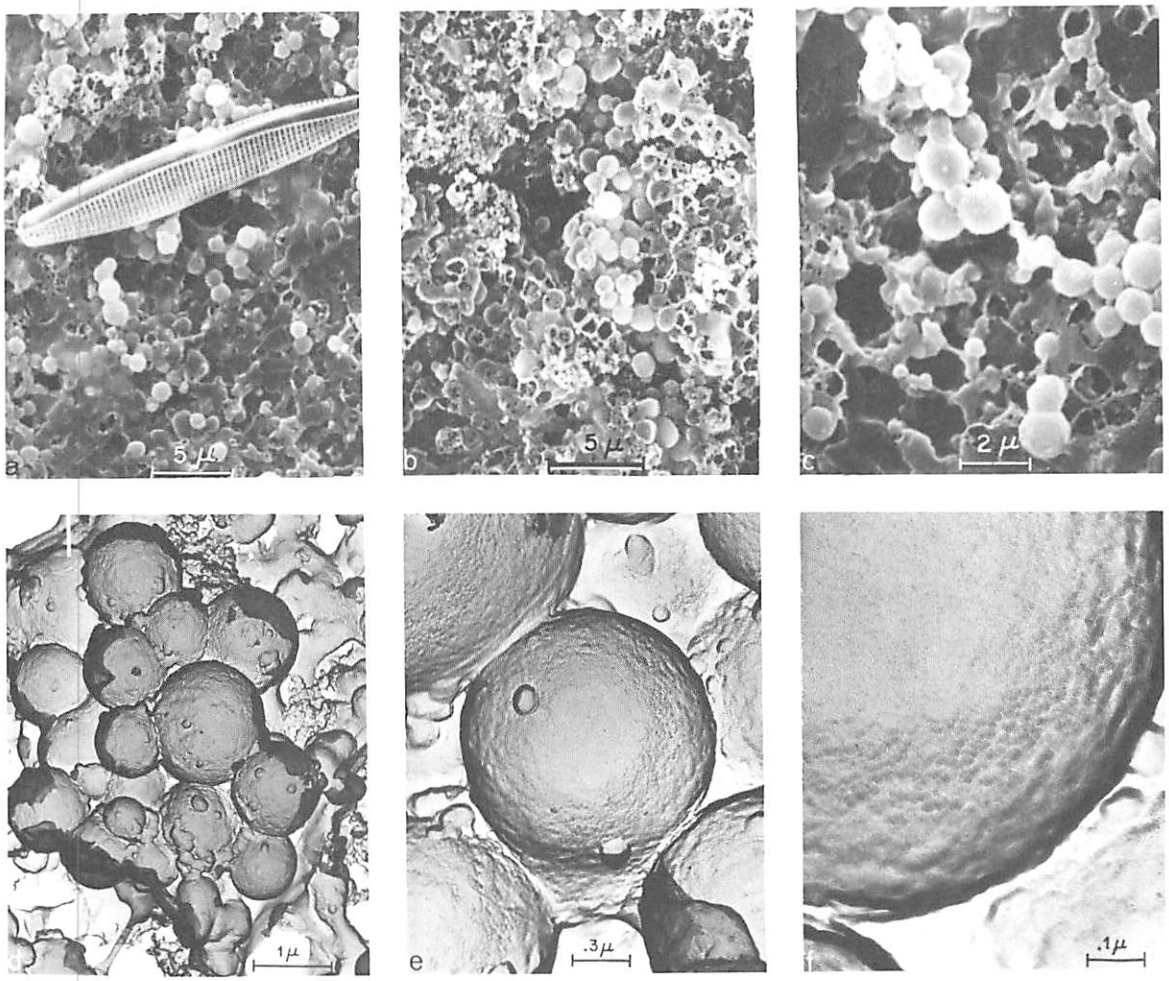


Fig. C-16 (Degens, Okado, Honjo and Hathaway) Scanning electron micrographs (a-c) of a Millipore® filter of a sample from a hydrographic station near the island of Shushu, Lake Kivu, at a depth of 70 m. Note the presence of spheres in all stages from intact globules to open rims. Carbon replicas of globules (d-f). The "blisters" visible on the globule surface (d-e) may have been produced by the leakage of gas entrapped inside the larger sphere; subsequent solidification through resinous material fossilized this event. The position of the sphalerite crystals (black spots) on the globule surface as well as the accretion pattern can be seen in (f).

HYDROCARBON ACCUMULATIONS IN LAKE KIVU

Werner G. Deuser, George R. Harvey, Egon T. Degens, William G. Steinhaver and Edith H. Ross

Lake Kivu, the highest and westernmost of the African rift lakes, is almost 500 m deep. About 20 years ago, it was discovered that its deep waters contain large amounts of methane and carbon dioxide in solution, methane reaching a concentration of half a liter at NTP per liter of water. The lake has pronounced thermohaline stratification maintained by convection within layers separated by sharp boundaries across the lake and methane is trapped in the deeper layers.

The leading hypothesis has been that the methane formed from the anaerobic fermentation of plankton debris. During and after our recent expedition to the lake, we measured concentrations and carbon isotope ratios of the gases and, for the first time, detected small amounts of higher hydrocarbons, up to hexane, in the water. Detailed considerations of all possible modes of its origin (from plankton, volcanism, shallow sediments, deep sediments, flooded forests and swamps) led us to conclude that plankton and deeply buried sediments are the most likely sources of sufficient magnitude. Possibly the gas is a mixture of methane from several sources. A critical factor entering these considerations is the accumulation time of the gas, which is closely related to the residence time of the deep water. Present data indicate that this time is between 100 and 1,200 years. Identification of the principal source of the methane awaits a narrower determination of the accumulation time.

BIOCHEMISTRY OF FALLOUT RADIONUCLIDES AND CHEMICAL POLLUTANTS

Vaughan T. Bowen, Victor E. Noshkin, John C. Burke and Hugh D. Livingston

General:--We participated this year in only one major cruise, *Atlantis II* (60), in the South Atlantic. However, we had people on board and work going for five legs (Barbados to Montevideo; Montevideo to Montevideo; Montevideo to Cape Town; Cape Town to Luanda; Luanda to Trinidad) for a total of 11 man-months at sea.

In addition to this cruise, we "piggy-backed" on *Atlantis II* (66) to collect 300 samples of Sargasso Sea Water (60 l. per sample) to be used by the International Atomic Energy Agency for an interlaboratory comparison of long-lived fallout radionuclides. This collection was partly supported by a small contract from IAEA.

Surface ocean water samples and atmospheric particulates were collected for us by both U.S. and European Ocean Weather Ships and by commercial vessels of several companies.

Our collecting of local marine organisms to be analyzed for their content of plutonium radionuclides has been continued and expanded.

Also, a program to investigate the distribution of plutonium along a fresh water food chain was started. With the assistance of the Environmental Protection Agency, Lake Ontario program office, we undertook a successful summer cruise on Lake Ontario. A number of water, sediment and biological samples were obtained which are currently being radiochemically analyzed by procedures developed in this laboratory.

A cooperative investigation on fresh water intercomparison samples and standards with several laboratories in the United States and Canada was initiated. Both radionuclides and trace elements will be analyzed in water, sediment and biota, a program that will hopefully lead to obtaining better quantitative data for radionuclides released to the environment from nuclear power reactor facilities.

Finally, our stored samples of biological and geological materials have been consolidated in the "Barn Basement."

Fallout Studies:--

Sea water. Analyses have proceeded at a good rate for strontium 90, cesium 137 and plutonium 238, 239. On many of the same samples we have also, cooperatively, had analyses made for carbon 14 and for tritium. As a result, a considerable amount of data has accumulated too rapidly for full evaluation.

The stations from *Atlantis II* (56) in the eastern approaches to the Caribbean have raised some interesting questions about the shallow circulation in that area. In addition to the unexpected finding of a surface low-Sr 90 layer only a few centimeters thick, the "sub-surface salinity maximum" appears responsible for rapid horizontal transport of surface-Sr 90 concentrations from the "surface salinity maximum" (about 24°N from 24° to 53°W) to depths of 100-125 m in the eastern Caribbean. This stimulated us to make some changes in plans for the early 1972 *Knorr* cruise to the northeastern Caribbean and to plan a cruise for 1973 specifically to study rates and directions of movement of this very thin lamina of high-salinity water. Most earlier cruises to this part of the ocean, including the IGY sections, used such wide bottle spacings that the salinity maximum was as often missed as sampled. Clearly STD profiles plus five-meter bottle spacing will be required to give interpretable data.

Sediment samples. Radiochemical analyses of deep open-ocean sediment cores from the North and South Atlantic and the Mediterranean Sea show the presence of Sr 90, Cs 137 and Pu 238, 239 in small but measurable amounts distributed to depth within the sediment column. These measurements are the first which show fallout radioisotopes have reached and penetrated Atlantic Ocean sediments and are the only ones available which indicate the presence of these isotopes in marine sediments obtained from overlying water depths greater than 3,000 m anywhere in the world. Sufficient sedimentary

material necessary for a detailed profile analyses of these radionuclides was obtained only by utilizing as a sampler the 8-inch diameter corer developed in this laboratory several years ago.

The quantities of these radionuclides, which have accumulated in the sediment since their introduction into the environment no later than 20 years ago, and comparison of these values with both the estimated integrated delivery to the sea surface and the measured quantities in the overlying water have permitted derivation of the residence times of the material transporting these isotopes to the sea floor. The computed mean residence times for Sr 90 and Cs 137 are orders of magnitude less than previous estimates made for the isotopes' respective stable element. Plutonium has an even shorter residence time than either Sr 90 or Cs 137. Earlier, we discussed how it is depleted from the water column relative to Sr 90 and Cs 137 by association with sinking particles. The sediment data supports our previous arguments.

Since we find fallout Pu 239 redistributed to depths of at least 29 cm in shallow water sediments from the region of Cape Cod, Massachusetts, the factors principally responsible are being investigated. The total quantity of plutonium found in the bay sediments agrees well with that quantity deposited and retained in terrestrial soils obtained from similar latitudes, but considerable concentration differences are noted between sediment types. The more silty regions of the bay contain substantially more plutonium than do sandy deposits.

Biota. Increased levels of Pu 238, relative to Pu 239, have been detected in a number of nearshore marine species. This additional Pu 238 was introduced to the environment following the burnup of a SNAP-9A Nuclear Powered Satellite over the Southern Indian Ocean in 1964. The isotope provides a unique environmental label of a source originating in the southern hemisphere. From the ratio of Pu 238 to Pu 239 found in the environment it has been possible, in some specific cores, to distinguish the pathways of plutonium uptake by marine species.

Intercalibrations and methods development. We participated in the first IAEA intercalibration of radionuclides analyses in seawater. Our own performance (on Sr 90 and Cs 134, 137) was excellent, but the world situation was revealed--as expected--to be pretty grim: as many as 25% of the laboratories reporting were shown to be unable to perform satisfactory analyses for any radionuclide sought and about half the remainder were unsatisfactory in some respects. Many more intercalibrations are now scheduled.

As a result of some interlaboratory Pu analyses of standards, an error in our alpha-detector calibration was revealed. Our previous results and detector efficiencies were based on an old Pu 236 standard. Comparisons with more recent and better calibrated standards showed the old standard to contain 1.51 times more Pu 236 than the early calibration indicated. Our earlier data have been corrected and our current data based on a Pu 239 standard which seems well calibrated.

Pu 242 is now being used as a Pu tracer in our chemical separation procedures. This has several advantages over the Pu 236 used in the earlier studies, viz.,

1. The long half life (3.8×10^5 yrs) removes the need for decay corrections in data calculation.

2. The location of the alpha-peaks at a lower energy than Pu 239 and Pu 238 means that there is no possibility of tracer interference in the analyses of levels of Pu 239 and Pu 238 close to detection limits.

3. The absence of Th 228 (present with Pu 236 as a decay product) reduces the possibility of the accidental interference in Pu 238 determination--inadequate chemical cleanup of Pu from Th causes interference in Pu 238 measurement because of the close proximity of the relevant alpha-peak energy values.

This latter consideration is of special concern since the introduction of new Pu 238 from the burnup of a SNAP-9A satellite affords us the chance, by measurement of Pu 238/Pu 239 ratios, of distinguishing fresh from older Pu (useful in following Pu movement in the ocean).

Efforts are now being made towards determining levels of other artificially introduced alpha-emitting isotopes in the ocean. Am 241 and Np 237 may well be present in detectable amounts in several types of sample. Development of methods to permit the incorporation of the analysis of these nuclides in our ongoing analytical procedures is well underway, and enough progress should be made in the coming year to allow assessment of marine levels of these nuclides.

Chemical Pollutants:--Our major effort has included the collection of samples of marine organisms and sediments to be analyzed for chemical pollutants and the evaluation of the results of such analyses. Since the most serious pollutants, from the point of threat to open ocean organisms, are those that are delivered via atmospheric pathways, as is radioactive fallout, our studies of fallout distributions are very useful in interpreting the pollutant data. Much of our work on trace element levels in marine organisms is also relevant to these problems.

Gear Development:--Effort has also gone into the design and construction--modifying ideas developed at the IAEA laboratory at Fiascherino, Italy--of a high-speed, multiple-net plankton sampler that can be used for collection of biota and for extraction of DDT or PCB from water sampled. We expect to have this ready for use on the *Knorr* cruise this April.

Also, since this will be our first attempt to collect deep, large-volume water samples from *Knorr*, time was spent on planning racks (for samplers) and procedures. Both her free board and the placing of the main hydrowinch make *Knorr* the least convenient of the large ships for this aspect of our work.

GEOLOGY and GEOPHYSICS

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

James R. Heirtzler, Department Chairman

GEOLOGICAL AND GEOPHYSICAL STUDY OF THE RED SEA

David A. Ross

A detailed geological and geophysical survey was made of the southern and central region of the Red Sea from R/V *Chain* in March, 1971. We completed 34 seismic profiles, most with gravity and magnetic measurements, took 23 core, eight camera and six hydrographic stations.

Among the highlights of this expedition are the following: (1) Discovery of ancient brine deposits also enriched in iron and copper in an area adjacent to the three known deeps; (2) three cored sections from the Atlantis II Deep which completely penetrated the heavy metal-rich sediments and bottomed in basalt; (3) detailed mapping of the brine area which shows that its location is structurally controlled and related to recent sea-floor spreading of the Red Sea; (4) an increase in temperature of the overlying water up to 5°C, and a continuing increase in temperature during the interval (three weeks) of our expedition. The latter temperature increase confirms the work of Brewer and colleagues who visited the area earlier.

Further work is being done by John Milliman and Frank Manheim on the interstitial water of the sediments, by John Hathaway and Peter Stoffers on the mineral composition of the sediments, and by David Ross, John Schlee, and Roger Searle on various aspects of the bathymetry and structure.

Probably the most important implication of our research in the brine area of the Red Sea is that the deposition of this potential ore deposit is a dynamic process still occurring and that older similar deposits may be found.

CRUSTAL STUDIES IN THE NORTHWEST AND NORTH CENTRAL INDIAN OCEAN, *CHAIN* CRUISE 100, LEGS 4 AND 5

Elizabeth T. Bunce

The area covered by Leg 4 lies between Djibouti (in the Gulf of Aden) and the Seychelles Islands. Most work was carried out in the Northwest Somali Basin to investigate further certain structural relationships originally inferred from observations made on an earlier *Chain* cruise (Bunce , 1966, 1967). These included the possible extension of Chain Ridge to the structures of the African margin, forming the southern as well as the eastern boundary of the Somali Abyssal Plain, and the identification of the basement material of the Plain. Additionally, surveys were to be made of four proposed sites for Leg 23 of the Deep Sea Drilling Program (*Glomar Challenger*). Two of these sites are located on the eastern and western flanks of Chain Ridge respectively, the third on a ridge on the western margin of the Plain, and the fourth north of the Seychelles. Other sites on a line east of Mombassa were surveyed during Leg 8 of *Chain* Cruise 99 in late 1970.

The time of the second part of the cruise, Leg 5, was occupied mainly by the passage between the Seychelles and Cochin, India, i.e., no detailed areal studies were possible.

The scientific program for the entire cruise comprised the total geophysical suite of underway and on-station measurements: continuous seismic profiling, echo-sounding with the 3.5-kHz source (the 12-kHz equipment was reserved for on-station pinger use for the major time of this cruise), gravity and magnetic measurements; on-station, piston coring and, on the Chain Ridge, rock dredging (unsuccessful).

The passage from the Seychelles to the 79th meridian, including crossings of the Carlsberg Ridge and the Maldive Island structure, was made along latitude 1°30'N, where no previous geophysical traverses had been recorded.

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JAVA SEA

Kenneth O. Emery

About 7,400 km of geophysical traverses were made in the Java Sea and adjacent continental shelf and trench during June and July aboard R/V *Chain* during Leg 7 of Cruise 100. This was part of a continuing long-term geophysical study of the east Asian continental margin that was begun in 1968 near Korea and proceeded southward in cooperation with the United Nations Economic Commission for Asia and the Far East. In addition to the geophysical measurements of seismic reflection and refraction, magnetics, gravity and bathymetry, data were obtained on surface water temperature, salinity, color, content of suspended sediments, and wave direction and period.

Extrapolation from well data both onshore and offshore indicates that two types of basement are delineated by the seismic reflection profiles: one, an irregular surface in the profiles, consists of pre-Tertiary igneous and metamorphic rocks; the other, a smoother surface, is probably the top of a lower Miocene limestone whose acoustical impedance masks the real basement, particularly where the latter is deep. North of Bangka and Belitung islands, the igneous and metamorphic basement is very shallow, forming a broad platform. In the Java Sea farther southeast, this basement takes the form of a series of ridges and basins or troughs that trend northeasterly from Sumatra and Java to Kalimantan (Borneo), and it is part of the East Indian tectonic ridge complex that has been studied by many authors. Drill hole data, and gravity measurements obtained aboard *Chain*, indicate that the total sediment above the igneous and metamorphic basement may reach thicknesses of 3 km in the basins and troughs between the ridges. Folds, faults and pinch outs in the basin sediments justify widespread expectation that the Java Sea may be a major oil and gas region.

High frequency (3.5 kHz) acoustic profiling shows the presence of many cut-and-fill structures in the uppermost 50 m of the sea-floor sediments. These are attributed to subaerial erosion of the region during Pleistocene stages of glacially lowered sea level. The drainage pattern postulated long ago by Molengraaff on the basis of topography alone is supported reasonably well by the new data of *Chain*.

The cruise occurred during the season of the southeast monsoon which produced currents and swells that moved westward and northward around Kalimantan. The water became warmed as it flowed over the shallow sea floor, and it became less saline along the shores through dilution by run-off from Java, Sumatra and Kalimantan. The same run-off contributed quantities of suspended sediments that caused the blue water of the open sea to become greenish near shore. Large plankton blooms were observed in the western part of the sea and shelf. Similar plankton blooms and contributions of fine-grained sediments during the past contributed to the basin fillings and helped to produce their oil-rich character.

Some of the material is being studied more intensively by Ben-Avraham as part of his doctoral dissertation, and some of it will be reported in other publications with Carl Bowin and Joseph Phillips.

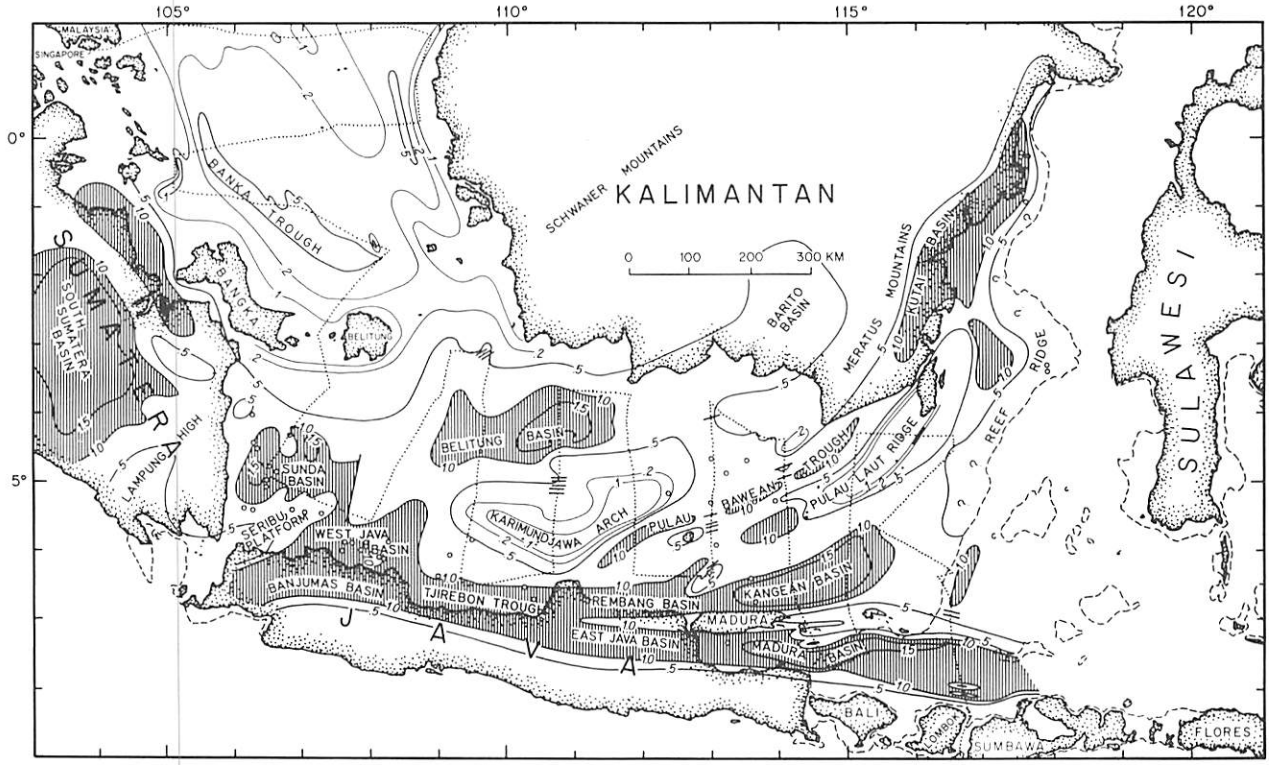

Fig. GG-1 (Emery) Isopach map of thickness of sediments above acoustic basement, with contours in km. Vertical hatching designates basin areas that contain more than 1 km of sediments. Short parallel lines across some traverses indicate crossings of faults of unknown azimuths.

GEOPHYSICAL INVESTIGATIONS IN NORTHERN MELANESIA

Bruce P. Luyendyk and Wilfred B. Bryan

Geological and geophysical investigations of the Woodlark Basin (southern Solomon Sea) and the New Hebrides Island arc - Fiji Plateau region were completed on Legs 8 and 9 respectively of *Chain* Cruise 100 (Fig. GG-1). Geological studies included dredging, coring and island sampling. Geophysical studies included heat flow measurements, sonobuoy refraction, and profiling of bathymetry, gravity and magnetic fields, and seismic subbottom structure.

The Woodlark Basin, which has an east-west trending ridge devoid of sediment, may be a site of active sea-floor spreading. The Louisiade Archipelago and the Woodlark Rise, which bracket the basin on the south and north, show evidence of block faulting under north-south tension. East-west striking magnetic anomalies were charted in the basin; however, they cannot be easily correlated with known sea-floor-spreading-type magnetic anomalies. Thus the spreading rate in the basin is indeterminate. Scattered heat flow stations indicate that the basin has above normal heat flow. An epicenter belt coincides with the center of the basin in the east, but is offset to the north of it, over the Woodlark Rise, towards the west. The reasons for this offset are not clear at present.

The New Hebrides Island Arc occurs at the junction of the Australian lithospheric plate on the west with the Pacific and Fiji crustal plates to the east. The Pacific and Fiji plates join at the east-west trending Hazel Horne Fracture Zone behind the arc near 15°S and serve to divide the arc system in two parts. Heat flow data are generally normal in front (west) of the arc and above normal behind it. The region south of the Hazel Horne Fracture Zone is hotter, reflecting sea-floor spreading on the Fiji Plateau. An area in front of the arc in the extreme south also has a high heat flow which we tentatively identify with the existence of a lithospheric plate fragment beneath the New Caledonia - Loyalty Island region. The trench is devoid of sediment except in the central portion just south of the

Hazel Horne Fracture Zone. Up to a kilometer of sediment is apparent in an archipelagic apron behind the arc. The central islands of the group form two parallel north-south chains. The easterly group has structure which dips to the west and is bounded on the east by steep faults, suggesting that these islands resulted from the island arc system facing in the opposite direction (east) in the past. There are vertical faults in many places on the frontal arc, and a consistent series of step faults on the Australian plate defines the outer wall of the trench. Opposite the central island group, sediments appear to be thick and distorted in compression. North-south trending magnetic anomalies exist over the Fiji Plateau but no clear pattern over the arc system. Gravity data are presently under analysis.

A prominent structural feature of the arc is north-south trending rift structures behind the frontal arc (inter-arc basins). These regions are typified by vertical faulting, lack of sediment cover in the basin floors, and high heat flow. Inter-arc basins are dramatically developed in the south, apparently absent in the central section, and less well developed to the north behind the Santa Cruz Islands. The differences in development may be due to the fact that the arc system includes two different lithospheric plate junctures along strike.

Petrographic studies are in progress on basalt and pumice dredged from the Woodlark Basin; chemical analysis and fission track dating are also planned on these rocks. Comparisons with the petrology of ocean ridge basalts should help to establish whether the Woodlark Basin is an active spreading center and the site of formation of new crustal material. Volcanic ash layers in piston cores from the New Hebrides area are expected to provide a basis for correlation between cores, and tephro-chronology developed in these cores may provide some insight into the frequency and nature of eruptive episodes in the New Hebrides area. Volcanic ash shards have been separated from a foraminiferal limestone dredged from the New Hebrides Trench. Analysis of the ash, combined with paleontological dating of the limestone should provide information on the nature of volcanic products during an early stage of the island arc development. Preliminary results of studies of rocks from Mitre Island near the north side of the Fiji Plateau indicate that they are a very calcic plagioclase-pyroxene basalt similar to the oldest basaltic rocks making up the basement of the Tonga Island Arc. More detailed chemical and petrographic analysis are expected to indicate whether Mitre Island is geologically part of an incipient island arc related to the Vitiaz Trench, or whether it is somehow associated with rift-type volcanism on the Fiji Plateau.

SURFACE AND SUBSURFACE STUDIES

Advanced Marine Technology Program

Elazar Uchupi and Robert D. Ballard

An important part of the geology and geophysics Advanced Research Projects Agency submersible program was to put together a system to define the structural framework of the sea floor where specific studies were to be conducted. Work during the first year included the testing of surface ship mapping techniques, evaluation of a submersible bottom profiling, and calibration of photographs taken from the submersible. The sea-floor mapping system placed aboard the R/V *Lulu* has a 12-kHz echo-sounder and recorder, a continuous seismic profiling system, and a sonobuoy receiver and sonobuoys for oblique reflection and refraction studies. In the profiler system, there is an air compressor, an air gun, a 200-element 30.5-m linear array, a filter, amplifier, and a graphic recorder. The subbottom profiler placed on *Alvin* consists of four 5-kHz oil compensated transducers externally mounted on the submersible with an eleven-inch wet-paper recorder, a programmer, and a transceiver inside. The calibrated photography system which is in the process of being built will include a camera mount for the Nikkormat FTN camera on *Alvin*, and two light sources positioned on the exterior of the submersible in such a manner that the light spots will remain in an optimum portion of the total field of view of the port as the altitude of the port varies from zero to 10 m. Knowing the distance of light spots to the center of a photograph, the altitude and attitude of the submersible can be determined. Once this is known, an overlay grid for the photo can be produced with a computer which makes it possible to determine the size of objects and the distances between them.

SEDIMENTATION PROCESSES IN THE SAMOAN PASSAGE, EQUATORIAL PACIFIC

Charles D. Hollister

During Leg 10 of R/V *Chain* Cruise 100, we attempted to determine the sedimentation processes that have been active since the Mesozoic in the Samoan Passage. This passage is presently one of the most important conduits for the interchange of Antarctic Bottom Water into the North Pacific. The objective of the cruise was to determine the near bottom and bottom conditions in an area scoured by the Antarctic Bottom Water as it flows northward through this constriction. We wanted to contrast this area of erosion with the depositional environment that we expected to find north of the passage. We successfully delineated the areas of erosion and deposition and, using temperature measurements and bottom photography, established that Antarctic Bottom Water is the most important factor governing the bottom environment in this area. The deep (>5,000 m) areas of the Samoan Passage are covered by dense concentrations of manganese nodules which can be correlated with the distribution pattern of vigorous bottom circulation. We determined that the erosion during the Pleistocene was much greater than it is today and that deposition north of the passage is primarily controlled by the Antarctic Bottom Water.

While in the area for approximately two weeks, we recovered 20 cores ranging in length up to 65 ft, a dredge haul, 12 boomerang cores, and obtained bottom photographs at four locations. Underway programs included continuous seismic profiling, 3.5-kHz acoustic profiling, gravity, magnetics and bathymetry. Bottom reflectivity at 3.5 kHz was found to correlate with distribution patterns of manganese nodules, and thus we may be able to map manganese nodule distributions, occasionally checking the correlation with boomerang cores.

SEDIMENTATION PROCESSES - ANTILLES OUTER RIDGE

Charles D. Hollister

To date, this grant has allowed us to make two cruises: one on the NOAA ship *Mount Mitchell* and the other on the R/V *Atlantis II*. On the *Mount Mitchell* we surveyed the Antilles Outer Ridge north of San Juan, Puerto Rico, and deployed three current meters--one on the crest and one on either flank. These were picked up approximately four months later by Robert Heinmiller on the NOAA ship *Researcher*. The data analysis is still in preliminary form, but it appears to substantiate the idea that, at least in the area of thickest sediment accumulation, the predominant current direction is from the west-northwest towards the east-southeast. This current pattern is consistent with the theory that the Antilles Outer Ridge is a constructional feature built of sediment transported from northerly sediment sources.

Results of the *Atlantis II* cruise are also in a preliminary stage. We successfully initiated a new technique of hydrographic casts which consisted of up to 14 hydrographic bottles, four large-volume Nishkin bottles and an underwater bottom contact camera equipped with a core, which replaced the standard hydrographic weight. We were thus able to take bottom photographs and cores with each hydrographic cast. Each station took between two and 3 1/2 hours in water depths of over 5,000 m. Most casts (23) were successful, and those that were not produced either good photographs, good hydrographic data or a usable gravity core.

Bottom current direction inferred from the hydrographic information correlated with the bottom current direction inferred from photographs, thus lending support to the concept that bottom photography can give reliable information about current directions and velocity. The physical properties and clay mineralogy of the 12 long (up to 10 ft) gravity cores are being determined at the present time.

In February 1972, we will revisit the Antilles Outer Ridge with the R/V *Knorr* to obtain large diameter 150-200-ft piston cores with the Giant Corer and make a detailed 3.5-kHz acoustic profiling. These data will allow us to determine the orientation and composition of the internal stratification of the dunes that appear to form along the ridge flanks.

DEEP-SEA ROCK CORE DRILL AND HEAT FLOW INSTRUMENT

Richard P. von Herzen and Bruce P. Luyendyk

A new deep-sea hard rock core drill has been under design, construction, and testing in shallow water. The drill is a completely self-contained package designed to be positioned and released, on the bottom, by *Alvin*. Automatic controls then take over, and the drill conducts its coring and thermal gradient measurement operation. It is capable of obtaining an oriented, one-meter long, hard rock core, through a layer of sediment up to one meter thick. The drilling operation takes less than one-half hour, and the thermal measurements may take one to several hours, at the end of which *Alvin* recouples to the drill and returns to the surface.

The goal is to core and make heat-flow measurements on rock bottoms of the sea floor, particularly mid-ocean ridges, where it is not possible to use standard techniques.

MAGNETOTELLURICS

Richard P. von Herzen, Joseph D. Phillips and James R. Heirtzler

Instrumentation is under development to measure the fluctuating components of the geomagnetic field at the ocean floor. In combination with corresponding simultaneous measurements of the electric field, we expect to infer the electrical conductivity structure to depths of several hundred kilometers beneath the ocean floor. From the electrical conductivity structure, we may infer the temperature and/or compositional structure of rocks to a similar depth.

Several instrumental systems for development as a deep-sea package have been evaluated. A new solid-state, variable-inductance sensor appears to have considerable promise and is presently being extensively tested.

EAST ATLANTIC CONTINENTAL MARGIN

(A Four-Year International Decade of Ocean Exploration Program)

Kenneth O. Emery

Activities consisted of several items that had to be completed prior to the departure of R/V *Atlantis II* for 5½ months' work off southwestern Africa scheduled for 20 January 1972: (1) A new system of seismic profiling using an array of large airguns and a digital processing and recording unit has been built by K. E. Prada for installation aboard *Atlantis II*. (2) The bathymetry of the entire Atlantic Ocean at 400-m contour interval has been compiled by Elazar Uchupi for printing and distribution to interested I.D.O.I. scientists and organizations early in January 1972. (3) Previous measurements of magnetics and gravity have been compiled for the Atlantic between Africa and the Mid-Atlantic Ridge by J. D. Phillips and C. O. Bowin, respectively, in the form of charts and a brief report to be distributed with the bathymetric atlas. (4) One of the W.H.O.I.-M.I.T. joint program students (Brian Bornhold) spent three months aboard *Jean Charcot* off Africa, and one of the French CNEXO people (Jean Mascle) spent six months in Woods Hole. They are investigating suspended sediments and the structure of the Gulf of Guinea, respectively, and at the same time serving as liaison links between the two organizations. (5) Problems of organization of the cruise and of making arrangements for scientific cooperation with African countries and with European countries that are working off southwest Africa have largely been completed. The initial stages for this cooperation was the symposium of SCOR Working Group 31 on the East Atlantic Continental Margin held at Cambridge, England, in March 1970; later stages have continued by conversations at the International Oceanographic Commission meeting in Paris (November 1971) and by correspondence.

HANDLING AND TRANSFER AT SEA

Allyn C. Vine

It has been possible to conduct some paper and at-sea investigations on the fundamental aspects of handling heavy instruments or small boats at sea in rough weather. This work was undertaken for three reasons: (1) our present use of large equipment and the use of small boats is severely handicapped in heavy weather and frequently in normal weather, (2) it is desirable to improve the safety of crew and scientists when handling heavy equipment, and (3) it is important to consider seriously some larger instrumentation to provide new kinds of measurements. Typical examples are higher resolution towed echo-sounders, side-scan sonars, coring rigs, biological sampling frames, work boats and submersibles.

The principal technique under consideration is the incorporation of controlled energy absorption and resiliency into the equipment or small boats in question. Perhaps the most widely appreciated marine application of such principles is the landing of aircraft on carrier decks. Hence, one purpose of the investigation is to determine how similar the physical and operational problems are when airplanes or small boats are being recovered by a ship.

The test boat was a three-ton workboat furnished by the Coast Guard and equipped fore and aft with the entire nose wheel landing assemblies from a Navy S-2 aircraft. This provided some 15 inches of controlled resiliency, and the freely castering wheels provided rolling contact against the side of the ship. Repeated tests in local but choppy waters alongside ships and docks showed that the wheels easily accommodated to fairly rough surfaces and that contact forces when alongside were reduced from being destructive to being fairly inconsequential. Quantitatively an approach or contact had to be quite severe to give 1/10 g acceleration.

This study is continuing to obtain more quantitative data and to try to equip a workboat of 25-30 feet so that it can be readily usable from larger ships in sea state 3 or 4.

Another part of this investigation was to see if large buoys made of resilient materials such as plastic or rubber could be more easily handled and hence more widely used than buoys of rigid construction. Several large tires, 10 feet in diameter and 4 feet wide, were obtained and converted with water-proof bottoms to buoys that could be manned. The Woods Hole based Coast Guard Buoy-Tender *Hornbeam* has been successful using one for transferring inspection personnel from the ship to navigational buoys.

RESEARCH SUPPORTED BY U.S. GEOLOGICAL SURVEY

James R. Heirtzler

Over the last few years, as the regional U.S. Geological Survey office became established, financial support for W.H.O.I.-U.S.G.S. joint projects has diminished. A small six-month final contract was in effect during March-September of 1971. Many details of earlier contracts were finalized.

Six papers were published and 11 more have been submitted under this terminal contract. Publications included papers on interstitial water from the Deep-Sea Drilling Project, Legs 6 and 7, geological observations from the submersible *Ben Franklin*, and the continental margin off North Carolina and the Middle America Trench.

The cooperative and productive efforts with the U.S.G.S. will continue even though there will be no contractual arrangement.

GEOMAGNETISM

Joseph D. Phillips

Field researches in geomagnetism during the last year have included a joint Woods Hole - U.S. Naval Research Laboratory aeromagnetic study over the Mid-Atlantic Ridge and Oceanographer Fracture Zone. The U.S. Navy provided the aircraft at no cost. Shipboard investigations have been carried out in the Indian and Pacific Oceans aboard R/V *Chain* Cruise 100 and in the North and South Atlantic aboard R/V *Knorr* Cruise 22 and R/V *Atlantis II* Cruises 59 and 60, respectively.

Laboratory analysis of previously collected data has also been undertaken, including further refinement of the plate rotation parameters for the African and North American plates (*Chain* Cruises 96 and 99) as derived from the Atlantis Fracture Zone. Our best estimate for the pole during the last 15 million years is at 57.9°N, 31.4°W (Phillips *et al.*, 1971). Prior to 15 million years ago and before 35 million years ago, a pole just north of the Azores at 48.2°N, 33.1°W best fits the fracture trend. Between 35 and 65 million years ago, the pole was near 86.0°N, 36.8°W.

Considerable effort has been made in compiling PROJECT MAGNET aeromagnetic data for the South Atlantic. Delineation of several quiet zones here has been a significant result of this work (Mascle and Phillips, 1971).

A comparison of deep-towed magnetic data from the Gulf of Alaska and off southern California has also been completed during the last year. For this work a digital filtering technique was developed to allow cross correlation and coherence tests between widely spaced profiles. The striking similarity of profiles after treatment strongly supports the idea that paleofield changes are responsible for the short wavelength magnetic anomalies observed near the sea floor.

A plate tectonics study of the ancient configuration of the Atlantic Ocean Basin, as well as all the Northern Hemisphere oceans, has been completed (Phillips and Forsyth, in press). The resulting reconfiguration was combined with a von Arx-type rotating torque experiment to investigate the paleo-circulation of the northern ocean for the period 100 million years ago. Significant changes in the surface current pattern can be expected for these ancient ocean systems, particularly under glacial wind conditions (Luyendyk, *et al.*, in press).

A geophysical data exchange program for data in the Ionian and Tyrrhenian seas has been initiated with the Osservatorio Geofisica Sperimentale (Trieste). During September, 1971, J. D. Phillips visited Trieste and developed a computer program to facilitate the exchange of digital magnetic, gravity and bathymetry data. Present plans call for a joint analysis of magnetic and gravity data for the Ionian Sea.

Included under this program was a geological and geophysical investigation of the central Tyrrhenian Sea (Heezen, *et al.*, 1971; Morelli, Finetti, Zarudzki and Wong, 1971) and a correlation of seismic reflection horizons in the Tyrrhenian Sea with the JOIDES Leg XVII Drillsite #10.

A theoretical analysis of sea-floor spreading-type anomalies, using digital filtering techniques was combined with a field experiment north of the Azores to determine the effect of such anomalies on naval detection systems (MAD). The anomaly field over ridge crests seriously degrades MAD performance under certain spreading rate and depth conditions (Phillips, in press).

Investigation of intensity variation in a 22-meter, 20,000-year-old, core from the Gulf of Maine has been undertaken to infer the behavior of ancient geomagnetic fields, and studies have been made of anisotropic susceptibility of cores from the Barracuda Rise area (Birch, 1971) to determine ancient bottom current direction.

In addition to these field and laboratory analyses a near-bottom magnetometer was developed for use on DSRV *Alvin*. Although this instrument was successfully tested during November in the Tongue of the Ocean area, a more compact, lower power system will be required for routine scientific work. Development of such a new system is underway.

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GRAVITY INVESTIGATIONS

Carl O. Bowin

Our basic aim is to understand better the structure and origin of crustal and surface features on the earth. Our principal contribution is conducting gravity measurements and interpreting gravity data in light of geological and other geophysical information. We are particularly interested in attempting to use the gravity field of the earth to aid in the determination of the processes that may be producing the features identified with the recent hypothesis of global plate tectonics. Emphasis is placed on comparison of trench and island arc regions, spreading ocean ridges, fracture zones, aseismic ridges, and continental margins. We anticipate that a study of the gravity field over sites of active tectonics may help elucidate the stage of development of individual active features.

An example of integrating gravity data with geological and other geophysical information is our investigation of the underthrusting of the Caribbean Plate by the Atlantic Plate at the Lesser Antilles. The underthrusting occurs at the site of the well-known Puerto Rico Trench negative gravity anomaly belt which extends from south of Barbados north along the length of the Lesser Antillean Arc, follows the curvature of the Antilles Arc to the west, and then extends to the west off the northern coasts of Puerto Rico, Hispaniola, and eastern Cuba. The axis of the free-air anomaly minimum along the Lesser Antillean Arc lies very close to the eastern border of a zone of epicenters which apparently mark the commencement of crust--crust faulting along the underthrust. The trend line of historic volcanoes of the Lesser Antillean Arc is equidistant (160 km) from the axis of minimum free-air anomaly. However, the surface trace of the underthrusting diverges more and more from the trend of the Lesser Antillean Arc and the axis of negative free-air anomaly minimum, moving from north to south. Gravity anomalies suggest that the thickness of low density material on the eastern flank of the Lesser Antillean Ridge, probably sediments, thickens southward along the length of the arc. Perturbations of the free-air anomaly profile across the arc and flank suggest that uplift of the sediments has been greater to the south, probably because in that direction a thicker pile of sediments is being affected by compressive forces accompanying the underthrusting of the Lesser Antillean Arc by the Atlantic Ocean crust. Since volcanism and seismic activity are continuing at present, it is inferred that underthrusting is presently active, and thus the uplift is not due to reestablishment of isostatic equilibrium. It is postulated that the squeezing of the sediments is due to differential shifts between the Caribbean Plate and the underthrusting (Atlantic) plate. Such shifts have occurred at least twice: once in the Late Eocene to Early Oligocene during which the outer island chain of the northern Lesser Antillean Arc was formed, and again sometime since the Late Miocene when the

Barbados Ridge, Tobago Trough, Barbados Basin, and associated uplifted topography were formed. This latter deformation resulted in the disappearance of a trench opposite the Lesser Antillean Arc and a displacement of the Puerto Rico Trench axis oceanward from the axis of the negative free-air anomaly belt near the northeast corner of the Caribbean Plate.

We are presently constructing a detailed structure model across the Lesser Antillean Arc that is compatible with available gravity, seismicity, seismic refraction, seismic reflection, magnetic, and geologic information in order to learn what limits may be given to the distribution of mass in a region of crustal consumption, especially in answer to the question as to whether or not the downgoing lithosphere is sinking under its own weight.

The southern border of the Caribbean Plate has different relations. Extensive gravity coverage of Venezuela obtained from oil companies, Cartagrafia National, published and unpublished data and our own land and offshore measurements is being analyzed to determine the deeper crustal structure of the continental margin of Venezuela and Colombia. Where the junction between the Caribbean and South America plates extends east-west, the North Range of Trinidad and the Coast Range of Venezuela are nearly in isostatic equilibrium whereas in western Venezuela the Venezuelan Andes are largely uncompensated. The Maracaibo and Barinas basins that flank the Andes on the northwest and southeast respectively are sites of mass deficiency. Our tentative conclusions are that the North and Coast ranges are relics of an earlier period of compression, that they are bordered now by a transform fault that separates the Caribbean and South American plates, and that the Venezuelan Andes mark a site of crustal collision and result from east-west directed compressive forces. The Andes appear to be the principal site of the boundary between the Caribbean and South American plates. In western Venezuela and in Colombia, a zone of block faulting appears to exist in the southwest corner of the Caribbean Plate to the northwest of the Andes. The zone of block faulting is inferred to result from extensional adjustments in the continental crust to accommodate the relative motions of South America and the Caribbean plates.

Studies have commenced on the gravity field in the north central Indian Ocean where occurs the most negative regional free-air anomaly (-80 mgals) in the world as indicated by the 1969 SAO Model Earth II. Surface gravity measurements are being compiled, integrated over different sized areas, and compared with the regional field deduced from satellite orbit perturbations in an attempt to help define the nature of the source of the regional anomalies. The gravity field and crustal and upper mantle structure at sites of underthrusting are also being studied for the Caribbean Island Arc, the Indonesian Island Arc, and for other island arc/trench regions for which data are available. Compilations and interpretations of the gravity field and structure of the Ninety East Ridge and the west coast of Africa have also begun.

The portable gravity laboratory van, completed in 1970, has been used continuously during R/V *Chain* Cruises 99 and 100 in remote areas. These cruises have provided measurements in the area of the Bahamas, the equatorial Atlantic, the South Atlantic, Indian Ocean, and in the Red, Java, and the Coral Seas, the Pacific Ocean and the Caribbean Sea. In general, this gravity laboratory has operated with good results. A second portable gravity laboratory (jointly owned by W.H.O.I. and M.I.T.) constructed for use on the R/V *Knorr* or other vessels has been essentially completed. The VSA sensor oven originally intended for use with this laboratory was defective, and its replacement is now being completed.

These new portable gravity and data acquisition laboratories include a vibrating string accelerometer (VSA) gravity meter with digital readout, a Sperry Mark 19 Mod 3c gyrocompass which is used as a stable platform for the gravity meter and provides heading information, and a Hewlett-Packard 2114A digital computer which is the heart of the digital data logging system that acquires gravity, geomagnetic, and ship's velocity information. This equipment along with recorders, diagnostic devices, clocks, power conditioning devices, a teletype, air-conditioning unit, spare parts, tools, and supplies are housed in a trailer-type van which may be hoisted aboard and "plugged" into any appropriate ship.

GEOTHERMAL PROGRAMS

Richard P. von Herzen

On *Chain* Cruise 100, heat-flow was measured in the vicinity of the New Hebrides, in the Western Pacific Ocean, to elucidate the complex tectonic history there. Later on the same cruise, additional heat-flow data were obtained within a relatively small region on the lower east flank of the East Pacific Rise to investigate heat-flow variability.

During a multidisciplinary study of Lake Kivu, similar to the investigations of Lake Tanganyika in 1970, several heat-flow measurements were taken. Values varied by an order of magnitude over the lake, although measurements at the same locality repeated well. The same instrumentation was used for detailed vertical profiles of the unique water temperature structure of the lake.

An apparatus to measure the time variation in the vertical temperature structure between several decimeters below to several meters above the sea floor has been constructed. The instrument is a standard heat-flow film recorder modified for intermittent recording, and is designed to be emplaced and recovered by the submersible *Alvin*. Its purpose is to investigate the variability of bottom water temperature and the modes of heat transfer from the ocean floor into the bottom water.

Self-contained instruments were completed to measure *in situ* temperature within drill holes in the sea floor. Measurements were carried out on Legs 19 and 21 of the JOIDES deep-sea drilling project aboard *Glomar Challenger*. Successful measurements were made at several sites on both legs, to depths as great as 500 m beneath the sea floor.

MARINE SEISMOLOGY

Elizabeth T. Bunce and Sydney T. Knott

Field Program:--The major field activities utilizing seismic techniques for investigation of crustal structure were those conducted from R/V *Chain* Cruise 100 in the Red Sea, Indian and Pacific Oceans, and the Yucatan Basin (Fig. GG-2). These seismic observations included echo sounding with sources of 3.5 and 12 kHz and continuous seismic profiling (CSP). Wide angle reflection-refraction measurements using sonobuoys as receivers were part of the routine profiling program.

For CSP either the 100,000-kilojoule (kj) (rated) sparker or a Bolt 600 B air-gun operated at 40 cu in/2,000 psi were used as source. In deep sedimentary structures such as the northwest Somali Basin or on continental margins, the two sources were sometimes used simultaneously to effect deeper penetrations than might be expected from either alone. This usually served at least to enhance the basement structure, particularly where it was both deeply buried (2 sec or more) and topographically rough. The convention of towing two AQ-1 hydrophone arrays and recording their summed outputs has been continued, since the demonstrated improvement in signal-to-noise ratio (Knott and Bunce, 1968) makes this a valuable technique.

The in-hull installation of the 3.5-kHz transducer array gave excellent results. The transducers had been moved about 20 feet forward from their original site in #3 cofferdam (W.H.O.I. Ref. 70-11, p. 106) prior to the start of *Chain* Cruise 99. This resulted in decreased machinery noise and also improved the signal-to-noise at higher speeds (4 engine).

In addition to the in-transit work, there are areas of specific geophysics for which the profiler was a primary tool: the Red Sea, the northwest Somali Basin and Ninety-East Ridge in the Indian Ocean, the Java Sea, New Hebrides Arc and part of the Coral Sea in the Pacific, and the continental margin of the western Yucatan Basin.

In addition to the routine normal incidence profiling and the wide-angle measurements required for determination of compressional wave velocity and thickness of the sedimentary layers, quantitative

measurements of various physical parameters were taken that would yield information on reflectivity and, possibly, sediment classification. To this end we developed the concept of the underway seismic station, which in its simplest form is the process of slowing the ship enough during the data acquisition process so that the information rate is effectively increased. The recording instrument is supplemented by a multichannel tape recorder (Sangamo 3500) to enable later digitization of the data as well as analog playback of both vertical and wide-angle reflections. Experience has shown the value of tape-recording all sonobuoy runs for later, off-line analysis. This is part of the regular shipboard recording program.

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Laboratory Program (with H. Hoskins and A. Baggeroer):--This is a tripartite effort. It consists of: (1) reduction and interpretation of the analog-recorded reflection profiles and their correlation and compilation with the simultaneously obtained geophysical and geological data, (2) reduction and computation of wide-angle reflections, usually from variously filtered playbacks of the taped data, and (3) implementation of a program of seismic signal processing. Under the first category, we are currently working on the recent Indian Ocean data and finishing various previous studies in other areas. In the second category, reduction of sonobuoy data (wide-angle) from *Chain* 99 is about 50% complete; from *Chain* 100, also about 50% complete (both Red and Java Seas data, Legs 2, 3, and 7). Our progress in signal processing, the third category, is summarized briefly.

Applications of digital processing to routine oceanic seismic reflection profiling have proved practical and useful although techniques are neither always required nor equally successful. The following procedures have been emphasized in the past year: (1) the basic step of digitizing with fidelity and assuring a definitive relationship between the original time base of the data and the digitizing rate, (2) signal-to-noise improvement by time domain filtering methods, particularly signal averaging (stacking), (3) elimination of multiple reflections that traverse the water column repeatedly, and (4) examination of the energy budget to help evaluate the possible effectiveness of the averaging or stacking and the multiple removal techniques. Reflectivity, derived from the energy measurements, may also provide a classification of reflection horizon materials by means of the relationship between the reflectivity and the specific acoustic impedance of the materials.

Effective means for the translation of shipboard analog seismic data into digital format have been devised. Minor but significant problems are to be expected in obtaining suitable dynamic range and low equipment noise values with each new setup.

No simple stacking procedure has been found that is routinely applicable to the problem of determining the shape of deep interfaces in such regions as continental shelf, slope and rise. However, stacking a larger number of samples by taking more over a given distance (i.e., slowing the ship) could be a useful technique. Another is the application of stacking along an estimated layer slope. For general purposes we recommend a running average of seven at the regional slope as a second shipboard display, the first being "unprocessed" graphic recording. A running average of seven gives about 8.5 db reduction in random background noise. At a ship's speed of 8 knots, the sevenfold stack minimizes the loss due to the shift in phase (about 2 db) of those returns that are as much as $\pm 1.5°$ off the slope along which the average is taken.

Removal of multiple reflections has been partially successful. Layer reflectivities and the interaction of layer reflections with multiple reflections require further study, particularly in such regions as continental shelves, slopes and rises (e.g., relatively shallow water and thick sediment structures), where the problem is especially complex.

The ability to detect deep layers by processed signals will be determined at any one time by the power spectrum relationships between the energy budget of the whole reflection system (source surface

reflector, transmission mediums, bottom reflectors and receiver) and the signal-to-noise ratio. If measurement of the reflected energy budget and noise spectrum were routinely obtained, a true evaluation of the possible effectiveness of processing would be available. Recognition of the roles played by reflectivity, scattering, absorption, etc. is essential to the success of a signal processing program dealing with these problems and the classification of reflection horizon materials.

Obviously there are other techniques that have yet to be applied in this program. Two are the use of matched filter and deconvolution processes for the purposes of improvement of signal-to-noise and resolution of reflectors.

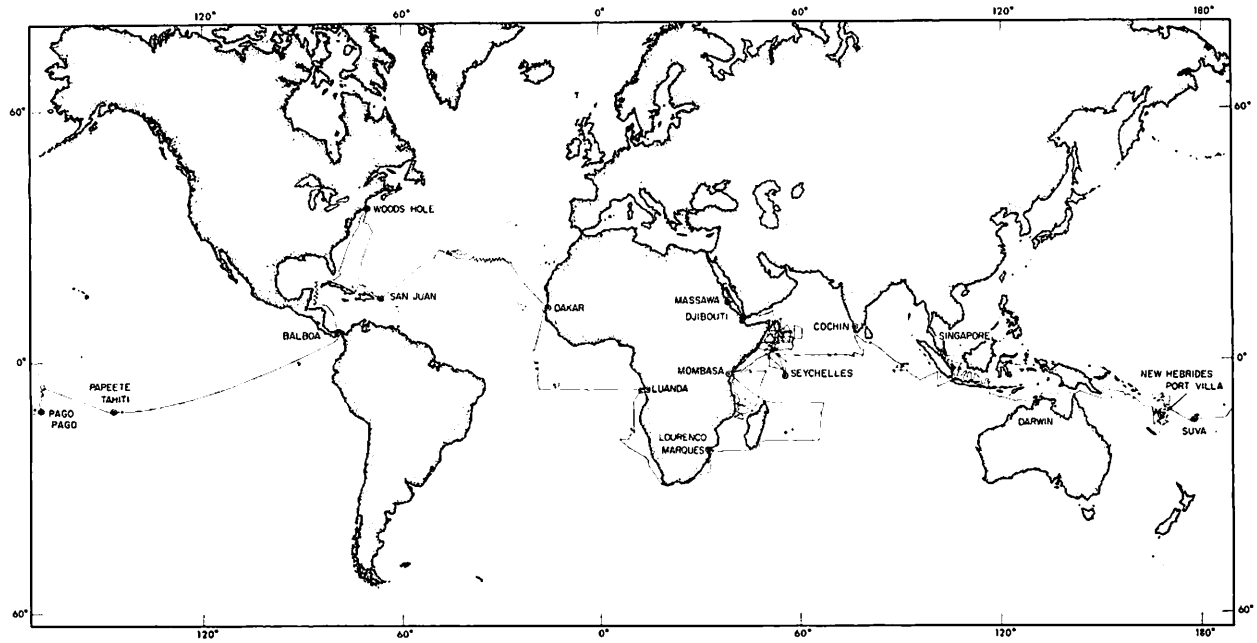

Fig. GG-2 (Bunce) Track chart of R/V *Chain* Cruises 99 and 100. Cruise 99, Woods Hole eastward to Mombasa; Cruise 100, Mombasa eastward to Woods Hole. April 1970 to November 1971, 77,000 nautical miles.

SEA FLOOR ROCKS AND SEDIMENTS

David A. Ross and Joseph D. Phillips

Our research covers many areas of sea-floor investigations. Most of the major field work was on *Chain* Cruise 100, which included geological and geophysical work of the Red Sea, of the northern parts of the Indian Ocean, of the New Hebrides Trench area, of the East Pacific Rise, and of the eastern part of the Yucatan Peninsula.

John Milliman has studied sediment cores collected in the eastern Mediterranean. A significant portion of the carbonate fraction (which generally accounts for about half of the total sediment) is composed of inorganically precipitated magnesian calcite. Previously, the deep-sea carbonate sediment fraction in the Eastern Mediterranean was believed to be almost exclusively biogenic calcite (coccoliths and planktonic foraminifera). The Mg-calcite in some layers can account for more than 75% of the total carbonate, although most average between 10 and 50% of the carbonate fraction. The significance of this discovery is three-fold: (1) it is one of the first reported occurrences of large-scale inorganic precipitation of calcium carbonate in the deep sea; (2) the precipitation has not been constant, but seems to have been restricted mainly to the warmer and more saline periods of the Quaternary, and with this knowledge, cores can be correlated stratigraphically by a comparison of mineralogical distributions; and (3) in some locations magnesian calcite cements bottom sediments into hard slabs; such a hard bottom may present significantly different mechanical and acoustical properties than neighboring uncemented sediments.

Wilfred Bryan has been working on mineralogical and textural features of modern ocean ridge basalts from the Mid-Atlantic Ridge and Red Sea. One objective has been to compare these modern sea-floor basalts with the oldest basalts obtained by JOIDES drilling in the western Atlantic. These oldest rocks are similar to the modern ocean ridge basalts in texture and in mineralogy, and thus support the hypothesis that they were generated at the Mid-Atlantic Ridge and transported to their present position by sea-floor spreading. Modern Red Sea basalts, Mid-Atlantic Ridge basalts, and the oldest JOIDES basalts from Site 105 all share some surprising and unusual mineralogical features, which include hollow, sector-zoned plagioclase crystals and a remarkable variety of skeletal olivine growth forms.

In both the modern basalts and older basalts in the *Glomar Challenger* cores, magnetite may be entirely absent in the rapidly quenched basalt glass of small lava pillows. In more coarsely crystalline rocks, magnetite commonly occurs as skeletal crystals enclosed in interstitial glass. This glass is very susceptible to weathering and deuteric alteration, and probably explains the rapid decrease in thermal remnant magnetism away from the Mid-Atlantic Ridge.

Three distinct sediment types in the Black Sea can clearly be related to environmental changes due to recent sea-level movements. A photographic survey of the Red Sea rift valley revealed broken and angular lava boulders, pillow lavas, and unusual columnar extrusions, similar to those photographed in the Mid-Atlantic Ridge. Color photographs were taken in the brine area, which record areas of no bottom life under the hot (59°C) brine, but mounds, probably made by organisms, were observed in the transitional areas between the brine and normal Red Sea water. Ripples in this transition area possibly indicate strong internal waves.

The paleomagnetic stratigraphy over several deep-sea cores from the Atlantic Ocean and Mediterranean Sea having rapid sedimentation rates have been studied to infer detailed behavior of the ancient geomagnetic field over the last 100,000 years. A 22-meter core from the Gulf of Maine (*Knorr* Cruise 10) has proved most useful. Variation of the remanent magnetic intensity along its length suggests that in addition to cyclic changes there has been a marked decrease in the ambient field intensity over the last 20,000 years.

CORE AND DREDGE STORAGE FACILITY

John D. Milliman

The new Data and Earth Sampling Center (DESC) completed on the Quissett Campus now provides 12,000 sq ft for storage of oceanographic cruise data and samples of the sea floor and laboratories for their examination. The present sample storage in this building encompasses 1,740 sq ft. Of this approximately 550 sq ft is presently used for the storage of more than 800 cores, more than 3,000 surface grab samples and about 360 cu ft of dredge samples. More than 5,000 cu ft are still available for storage of earth samples. Sediment collection operations were, primarily, samples taken aboard *Chain* Cruise 100. A total of 126 cores and 20 dredge samples were obtained, mostly from the Indian and Pacific Oceans.

DATA HANDLING

Bruce P. Luyendyk

Our major effort has been final processing of data from *Chain* Cruises 99 and 100 (Deva Richards, C. Wooding, N. G. Serotkin and R. C. Groman). Considerable time was spent designing a digital library system. Gravity and bathymetric information from more than a dozen cruises and from other institutions has been incorporated into the library. All PROJECT MAGNET data from the South Atlantic (J. Mascle) have been digitized.

"Software" development included program MAN1 to calculate magnetic anomalies from the gravity-navigation format (S. J. Abbot) and program DTOB to merge bathymetry time series with the gravity-navigation format (B. P. Luyendyk). Another program, TRACK, was written to plot all of our data formats as profiles along ships' tracks on Mercator charts (R. C. Groman). The above programs have been implemented on both the HP and Sigma Seven computers. Program TED was developed for use in automatically digitizing PGR records with the Calma digitizing table (Deva Richards). In addition, a significant amount of time was spent making modifications and refinements to existing "software." To aid users, we have stored commonly used programs on discs as element files (R. C. Groman and Deva Richards). To call a program, a user merely punches its name on the load card.

The shipboard information processing system has also been modified for the upcoming IDOE African margin project. These modifications include an improved inventory technique, elimination of processing steps, modification of existing "software," and improvement of system documentation.

BASALT FROM JOIDES DEEP CORES

Wilfred B. Bryan

Petrographic study of selected basalt cores from the deep-sea drilling program is part of a broader geochemical and mineralogical investigation of these cores being carried out in cooperation with G. Thompson, Department of Chemistry, and F. Frey, Department of Earth and Planetary Sciences, Massachusetts Institute of Technology. Work has continued on basalt from Leg 11, Site 105 in the western Atlantic, and has been extended to basalts from Legs 2 and 3 which traverse the Mid-Atlantic Ridge in the North and South Atlantic, respectively. The work so far has been limited to high-resolution optical observations in polished thin sections, but arrangements have been made for electron microprobe analysis and fission track dating of selected minerals and basalt glass in cooperation with F. R. Boyd and P. M. Bell at the Geophysical Laboratory, Carnegie Institution of Washington.

The initial petrographic investigations are intended to define the mineral phases in equilibrium with the basalt liquid, thereby permitting a broad classification into chemical and mineralogical types.

Of the basalts examined so far, one from Leg 11, Site 105, is a plagioclase tholeiite; those from Leg 2, Site 11A, and Leg 3, Site 14, are olivine-plagioclase tholeiites, and the one from Leg 3, Site 15 is a rare plagioclase-pyroxene tholeiite. As modern ocean ridge basalts are typically olivine tholeiites, the greater abundance of plagioclase in the older sea-floor basalts implies a change in composition of the magma with time. Alternatively, these older basalts could represent later extrusive or intrusive igneous episodes on the flanks of the Mid-Atlantic Ridge or adjacent sea floor which reflect genetic conditions entirely different from those prevailing at the ridge. Basalts from Legs 2 and 3 contain unusual feldspar phenocrysts which enclose sector-zoned cores. Examination of the feldspar zoning in modern sea-floor basalts has indicated that sector-zoning typically occurs only in quenched microlites near pillow rims. The sector-zoned cores thus imply an early stage of magma outflow and quenching, followed by backflow and relatively slow intra-telluric crystallization of the remainder of the phenocryst. Such backflow has been frequently observed in subaerial basalt eruptions, but evidence for it in submarine eruptions so far has not been reported.

NODC - CATALOGUING OF UNDERWATER PHOTOGRAPHS AT WOODS HOLE OCEANOGRAPHIC INSTITUTION

Charles D. Hollister

Approximately 1,000 bottom photograph stations have been examined, and the results are tabulated in special bottom photograph data sheets provided by NODC. When the project is complete, we will be prepared to send NODC approximately 1,250 data sheets which tabulate some of the more obvious features observed in photographs stored at this Institution. These data will be catalogued and made available by NODC to all interested scientists. We will use this catalogue at Woods Hole to help retrieve information concerning the visual seascape. Our photographs cover portions of the Indian Ocean, Mediterranean, Caribbean, Red Sea, Black Sea, Atlantic and Pacific Oceans.

DINOFLAGELLATE STUDIES

David Wall, Barrie Dale, Kenichi Harada

Investigations included the application of scanning electron microscopy to dinoflagellate studies, the biostratigraphic distribution of dinoflagellates in sediment cores from the Black Sea, life history of several living genera and continuation of biogeographic distribution of cysts in plankton and sediments, plus several smaller miscellaneous projects.

Scanning Electron Microscopy:--Initially, several weeks were spent in experimenting with sample preparation procedures. These included coating specimens with various combinations of carbon, carbon-platinum alloy, gold and gold-palladium to determine which were most suitable; mounting specimens from aqueous medium onto the specimen holder stub with minimum distortion; examining fossil cysts from Late Quaternary Black Sea sediments and some modern marine sediments as representatives of typical Quaternary and living dinoflagellates, and comparing the results with previous ones that are based on optical microscopy. Scanning electron microscope examination is superlative for the determination of microstructures and is now being used in the preparation of a paper on the systematics of Quaternary species from the Black Sea.

Black Sea Fossil Dinoflagellates:--A detailed study of the distribution of fossil dinoflagellates in several cores from the Black Sea was completed with the examination of the 11-meter piston core 1474P. Sediments deposited in our core sites during the last 7,000 years are characterized by large numbers of cosmopolitan, euryhaline species that can tolerate brackish-water conditions whereas the older sediments (up to 23,000 yrs B.P.) contain a low diversity, low salinity stenohaline assemblage that mainly comprises two unusual new species, *Spiniferites cruciformis* and *Tectatodinium psilatum*. An abrupt change from one assemblage to the other occurs at the base of a sapropelic layer in each of the three cores examined (taken 660 km apart) and can be accounted for by the reëntry of saline Mediterranean water into the Black Sea following the latter's physical isolation during the Würm Glaciation.

Life History Studies:--In cooperation with Elijah Swift (Narragansett Graduate School of Oceanography) we described a new thecate stage in the life history of *Pyrocystis acuta* Kofoid. It has been realized for many years that species of *Pyrocystis* have a flagellated stage in their life histories, but it was not apparent until recently that this stage can be thecate and has a gonyaulacid tabulation. This provides important new evidence for the basic affinities between this genus and the thecate dinoflagellates (Order Peridiniales).

Cyst Biogeography:--Efforts to determine the salient features of dinoflagellate cyst distribution in plankton and sediments have continued with special emphasis on types that in paleontology are referred to as species of *Leptodinium*. These have proved difficult to locate and thus to culture, but specimens of several species have been found at some depth in slope water in the vicinities of Block and Baltimore canyons in the Middle Atlantic Bight region. Sediment sample transects are being examined to determine onshore to offshore gradients in the distribution of *Leptodinium* and other cyst-based genera to ascertain the general ecology of such taxa. This supplements a continuing study of cysts in near-shore sediments along the eastern coast of the United States.

MICROPALEONTOLOGY

William A. Berggren

Programs on micropaleontology have been conducted along several fronts: biostratigraphy, paleoclimatology, paleobiogeography, and scanning electron microscopy of foraminiferal wall structures. Utilizing data from the Deep-Sea Drilling Project and surface outcrops from the land areas bordering the Atlantic, an attempt has been made to reconstruct the history of surface and deep-water circulation in the Atlantic Ocean. This investigation has been made within the conceptual framework of sea-floor spreading and continental drift. Among the significant conclusions reached are the following: (1) The relatively cosmopolitan nature of Jurassic marine and non-marine faunas is a reflection of the relative contiguity of land masses and development of extensive shelves. (2) The North and South Atlantic have had separate and distinct histories. The two regions were linked in the Turonian (*ca.* 95 m.y. ago) at which time water mass and marine faunal exchanges were initiated. (3) The final stages in the fragmentation of Eurasia occurred about 50 m.y. ago with the separation of Scandinavia and Greenland and the rotation of Spitsbergen. The immediate effect of this was the formation of cool surface water inflow in the North Atlantic and the gradual development of a Boreal Faunal Realm. Atlantic deep-water circulation was also initiated at this time. (4) The gradual severance and isolation of the Tethys Sea from the world ocean in the Miocene is reflected in the restriction and eventual cessation of faunal exchange between the Indo Pacific → West Tethys and West Tethys → Atlantic Ocean. (5) Significant changes in circulation and faunal dispersal patterns occurred as recently as 3 m.y. ago. The initiation of glaciation in the Northern Hemisphere led to the formation of the Labrador Current which displaced the warm northward-flowing branch of the Gulf Stream to its present position south of 45°N and led to the development of a Polar Faunal Realm. At this time, the gradual, but inexorable, biogeographic provincialization of the North Atlantic was essentially completed.

On the basis of additional radiometric dates on biostratigraphically controlled horizons, an updated and improved version of the Cenozoic time-scale has been prepared. The implications for regional geology and paleobiogeography are discussed at some length. This version of the time-scale is now in use on the *Challenger* by the DSDP.

The results of Leg 12 of the DSDP in the North Atlantic were summarized and include discussions on the Cenozoic biostratigraphy and paleobiogeography of the North Atlantic, late Cenozoic glaciation in the North Atlantic and the basic results of Leg 12 itself (with A. S. Laughton, National Institute of Oceanography, Great Britain).

Paleoclimatic investigations on deep-sea cores are being made in the Mediterranean and Atlantic Ocean. Several climatic cycles have been detected in a late Pleistocene core (*ca.* last 100,000 years) from the Tyrrhenian Sea, and the raw data is currently being processed for computer treatment at Brown University. Another study is being conducted on paleoclimatic cycles in a 10-m core from the central Atlantic. The core extends into the Pliocene, and this represents the first attempt at extending the method of Imbrie and Kipp (1971) into the older part of the Pleistocene. Significant

climatic fluctuations, reflecting glacial/interglacial cycles, are seen that are of comparable magnitude to those observed in the Brunhes. Additional information which supports our original interpretation of the age and position of the Pliocene/Pleistocene boundary has been obtained in this core.

Scanning electron microscope investigations on foraminifera and calcareous nannoplankton are being conducted with S. Honjo and his associates to understand the surficial morphology of planktonic foraminifera. A monograph on this group should be completed during the coming year.

The SEM contract (GB-8767) was terminated in the summer, and a report of the use of the instrument is being prepared for NSF. Basically, the instrument has served a broad spectrum of research interests--geology, paleontology, biology, biochemistry, and metallurgy.

An investigation on the Cenozoic paleobiogeographic history of the Atlantic Ocean was initiated late in the year. It will involve a series of time-scale analyses of faunal and floral diversity from high to low latitudes in an attempt to delineate the gradual biogeographic provincialization of the Atlantic Ocean over the last 65 m.y. We are soliciting suitable materials from DSDP, Miami and various geological institutes and oil companies in Europe, North and South America.

B. Ul Haq investigated calcareous nannofossils and used the SEM, EM and light microscope in order to elucidate details of morphologic structure. The SEM was used, in particular, in the study of lineages of important nannofossil groups such as the helicopontosphaerids, sphenoliths and thoracosphaerids. The following lines of investigation were pursued during the year:

1. The distribution of calcareous nannoplankton in the deep-sea cores collected during Leg 8 of the Deep-Sea Drilling Project was studied in detail and biostratigraphy established for the Eocene to Recent interval.

2. Rates of evolution in the Cenozoic calcareous nannoplankton were estimated. For this purpose the records of the nannoflora for the whole of Tertiary time were reviewed and topotype materials were examined to insure an interval consistency in the taxonomic concepts. Total frequency, rates of origination, extinction and total change were calculated.

3. Tertiary calcareous nannoplankton biostratigraphy was also established for a number of Middle Eastern regions: Paleocene of Persia, Paleocene-Eocene of West Pakistan, Paleocene of Jordan, Eocene of Syria and Lebanon, Oligocene of Syria and Paleocene of Tunisia. World-wide correlation of Paleogene strata was attempted.

4. Lineage studies were attempted on two stratigraphically important groups of calcareous nannofossils, helicopontosphaerids and sphenoliths, and another group of very persistent calcareous nannofossils, thoracosphaerids (Cretaceous to Recent). Both light and scanning electron microscopes were extensively used for this purpose.

Reference

Imbrie, J. and N. G. Kipp 1971. A new micropaleontological method for quantitative paleoclimatology: application to a late Pleistocene Caribbean cave. In: *The Late Cenozoic glacial ages.* K. Turekian, ed., Yale University Press, New Haven, pp. 71-181.

NATURAL SOUNDS OF THE SEA

William E. Schevill and William A. Watkins

The three-dimensional hydrophone array was used extensively for sound source location. As is inherent in the use of arrival-time-difference hyperbolae, although sharp bearings can be obtained, range precision (and consequently sound intensity) degrades with distance. In fact, even relative intensity was not coherent between hydrophones only 30 m apart, which we tentatively ascribe to propagation irregularities in the rather shallow water (greatest depth during tests was about 60 m).

In May, with the support of the Oceanic Institute (Kenneth S. Norris) of Waimanalo, Hawaii, we used the array in Kealakekua Bay where there is a resident school of *Stenella longirostris*. These data have not been fully worked up but promise to give good information regarding the location of animals during sound production. The spectacular spinning leaps of these animals appear to have been acoustically unimportant.

SALT CRYSTALS ON MARSH GRASS LEAVES

John M. Teal and Susumu Honjo

Spartina alterniflora, the principal species living in local salt marshes, can grow in salty water because it can concentrate ions in its cells and remain osmotically superior to the external medium, and because it can secrete excess salt by means of special glands on its leaves. The salt in the transpiration stream within the plant is only about 1/20 the concentration of the medium in which the roots are growing, most of the salt being excluded at the roots. While the above facts about the grass are known, no detailed salt balance has ever been worked out for such a plant.

We began to observe the surface of the *Spartina* grasses with the scanning electron microscope with the hope of seeing the glands that secrete the salt and the crystals of salt that form as the secretion drys. The glands turned out to be situated at the bottom of crevices and invisible, at least without further manipulation. The surface of the leaves showed closely spaced protuberances about 10 microns in diameter covered with a fine fur which we suspect might be the waxes characteristic of *Spartina*.

The salt crystals themselves were all colorless to the naked eye and cubic under the microscope--characteristic of NaCl. The individual crystals on some *Spartina* leaves grown in the laboratory were analyzed by a non-dispersive x-ray analyzer. The lower side of the leaves showed only the cubic crystals which contained nothing but Na and Cl. The upper side had both the pure NaCl crystals and other amorphous or poorly organized materials which contained Na, Mg, Ca, K, Cl, and S. Whether or not the difference between the two sides of the leaves is characteristic of the healthy plants we hope to determine next summer when we will have healthy plants for experimentation.

COCCOLITHOPHORIDS IN THE PACIFIC OCEAN

Susumu Honjo and Hisatake Okada

Horizontal and vertical distribution of pelagic coccolithophorids in the Pacific have been investigated on the basis of 605 Millepore® filtered sea water samples. These were systematically collected from 263 stations and 329 subsurface substations along five traverses throughout the pelagic North Pacific and a part of the South Pacific. A large number from the coastal waters of the Inland Sea of Japan and the Gulf of Carpentaria have also been investigated. Each filtered sample represented 2 to 20 liters of sea water. Transmission and scanning electron microscopes were used for specific identification and counting of coccospheres.

Standing Crop of Pelagic Coccospheres:--Coccolithophorids were ubiquitous in pelagic surface water throughout our traverses which, along the meridians, exhibited (1) high standing crop in the Subarctic Zone, (2) abrupt decreases in the number of cells in Transitional and Central zones, and (3) a sharp increase in the Equatorial Zone. The highest standing crop of pelagic coccolithophorids was 170,000 per liter at 46°N, 155°W, while only a few individuals were found in the South Philippine Sea.

Zonal Distribution of Coccolithophorids in the Pacific Ocean:--Approximately 100 species of coccolithophorids, including several which may be merely phenotypes, were identified. The specific diversity was low in the Subarctic Zone and was highest at the middle of the Central Zone. Five coccolithophorid zones were found in the pelagic surface water in the North Pacific, each with a characteristic species assemblage. Subarctic, Transitional, Central and Equatorial zones can be recognized which are similar to the distribution of some pelagic zooplankton organisms. The Equatorial Zone was subdivided into northern and southern flora. A Southern Hemisphere counterpart of the Central Zone was in the South Pacific. The boundaries of coccolithophorid zones coincide with those of currents.

The Subarctic Zone was almost monopolized by a northern ecophenotype of *Emiliania huxleyi*. *Rhabdosphaera stylifera* was dominant in the Transitional Zone. The Central Zone was marked by the predominance of *Umbellosphaera irregularis* in the epiphotic layer and by *Umbellosphaera tenuis* in the mesophotic layer. The Equatorial Zone is characterized by the abundance of *Gephyrocapsa oceanica* and *Cycloccolithina leptoporus*. The pediphotic layer of the Transitional, Central and Equatorial zones was dominated by *Deutschlandia*.

Vertical Distribution of Coccolithophores in the Photic Zone:--In the Subarctic Zone, coccospheres were concentrated in a surface layer and their abundance decreased drastically with depth. The number of coccolithophorids was maximum at -50 to -100 m in the Transitional Zone. The standing crop was fairly constant throughout the Central Zone except for a drop at 10°N. Their number decreased gradually below -100 m in the Equatorial Zone. Their total number in the photic water column was more evenly distributed than in the surface water. The ratio between the maximum standing crop (in the Subarctic Zone) and the minimum (in the Central Zone) exceeded 500 in the surface water, but was only about 10 for the photic water column.

The photic layer of the Central and Transitional zones consists of three identifiable coccolithophorid layers. The Equatorial Zone may have two such layers, and the Subarctic Zone consists of a single layer. Coccospheres, usually from placolith-bearing coccolithophorids, were found in the mesobathypelagic as well as the abyssopelagic water layer of the temperate and tropical areas.

Hydrographic Parameters and the Distribution of Coccolithophorids:--The water temperature is the definitive character in coccolithophorid distribution; however, this relationship appears to be quite complex when one takes into consideration the vertical temperature distribution. The occurrence of some species, for example, *Deutschlandia* sp. A, appears to be independent of temperature, measured water chemistry or light penetration, but dependent upon depth of water.

The range of surface water temperature was determined in terms of 25 important pelagic coccolithophorid species. Temperature preference of some species changes at different depths. The multiple regression analysis on the mode of occurrence of coccolithophorid species *vs* various nutrients is underway.

The Species Diversity of Coccolithophorids:--The diversities of coccolithophorid species were computed at each station or substation using the formula developed for information theory:

$$H^{11} = -\Sigma^{i}\ Ni/N\ \log_{10}\ Ni/N\ -\ (S-1)/2N.$$

The diversity in the surface water generally increased toward the equator. It was also calculated for the photic profile along the 155°W meridian from 50°N to 15°S, on the basis of 183 substations distributed from the surface to -200 m. The highest observed diversity in the Pacific was found at -10 m to -50 m, and at -130 m of 34°N, in the area between the Transitional and Central zones. The species diversity was generally high in the water column between -20 m to -130 m through the Transition and Central zones. An even higher diversity was maintained throughout the photic water column in the Equatorial Zone.

Coastal and Inland Sea Coccolithophorids:--The electron microscopic study of filtered water samples collected from the Seto Inland Sea, Japan, and the Gulf of Carpentaria is underway. Preliminary results show *Gephyrocapsa oceanica* to be ubiquitous and the major standing crop of coccolithophorid flora. Individuals belonging to this species of abnormal form, suggesting the existence of stressed environment, are frequent. Contrary to the pelagic flora, *Emiliania huxleyi* rarely occurs in coastal regions. Generally, the number of species found in such areas is less than in the open sea.

PRODUCTION, SUSPENSION, DISSOLUTION AND ACCUMULATION OF COCCOLITHS IN THE DEEP SEA

Susumu Honjo and Hisatake Okada

Production of Coccoliths in the Photic Layer:--Living coccospheres occur not only in the surface water but also in the lowest level of the photic water column. The majority of pelagic coccospheres disintegrate into individual coccoliths after their productive life cycles. This disintegration occurs within a relatively short period. The total number and weight of coccoliths--the sum of suspended free coccoliths and coccoliths on coccospheres--at the lowest level of the photic layer is 100 to 10^4 in the Subarctic Zone, 1 to 5 x 10^6 or 10^{-6}g per liter, 2 or 3 x 10^5 or 10^{-7} per liter in the Central Zone and 3 x 10^5 or 10^{-6} per liter in the Equatorial Zone.

Suspended Coccoliths in the Aphotic Layer:--About 10^5 coccoliths were suspended throughout the water column down to 5,000 m in the equatorial Pacific. Fewer were found in the aphotic water column of the Central Zone, where the production of coccospheres in the photic layer also was low. Approximately 10^5 coccoliths were suspended in the meso-pelagic water column of the Transitional Zone. The number of suspended coccoliths decreased with depth, particularly in the northern area in the vicinity of 40°N in Mid-Pacific.

Selective Dissolution of Coccoliths during Suspension:--The total species assemblage of coccospheres throughout the pelagic water column along the 155°W meridian was compared with the species assemblage at various depths. The genus *Deutschlandia* was abundant at all latitudes and depths, except in the northern area near 35°N. *Gephyrocapsa oceanica* and *Cyclococcolithus fragilis* were predominant in the Equatorial Zone. The basic pattern of species assemblage did not change with depth, but the percentage of *Deutschlandia* in the total suspended coccoliths decreased at -4,000 m.

The number of species suspended in the aphotic water column was less than the number of coccosphere species directly above the photic zone. For example, at 25°N, 50 coccosphere species were found in the photic water column, but only 23 species were found in the aphotic water column. Coccoliths with extremely delicate architecture, such as some species of *Syracosphaera*, are probably destroyed as soon as the coccospheres disintegrate. The number of species decreased with depth in the Transition and Central zones. In the Equatorial Zone the number of species is almost consistent throughout the water column down to -4,000 m.

Diversity of Suspended Coccoliths:--Species diversity of coccospheres in the photic layer and suspended coccoliths in the aphotic water column was not continuous. It was highest at 30°N, but it decreased rapidly at the meso-pelagic layer in the same water column, possibly because of severe dissolution and destruction of coccoliths. The highest diversity of coccoliths in suspension occurred throughout the entire water column of the Equatorial Zone down to -4,000 m. There was thus an apparent shift in the center of the coccolithophorid diversity from 30°N to the area between 10°N and 10°S during suspension. As a consequence, the coccolith diversity in pelagic sediments does not reflect that for living coccolithophorids.

Coccolith Sedimentation in the Deep Sea:--Coccoliths are one of the major components of pelagic calcareous sediment Since the water depth along the 155°W meridian well exceeds the carbonate compensation depth, coccolith ooze is distributed only in the Equatorial Zone. The rate of sedimentation per year at a certain level of water is the function of the volume of a coccolith, descending velocity (weight), and the number of coccoliths per liter of water at a given depth. The size of the coccoliths differs with the species so that the potential total rate of sedimentation was calculated by species, and these values were then extrapolated to obtain a total coccolith sedimentation rate.

The potential rate of sedimentation differs significantly from one species to another according to their size and descending velocity. *Emiliania huxleyi* contributes 0.02 mm/ky or 0.5 g/ky/cm^2 to the total rate of sedimentation, while a large species, such as *Umbellosphaera irregularis* accumulates at the rate of 0.73 mm/ky or 1.7 g/ky/cm^2, at -4,000 m in the Equatorial Zone. The total number of coccoliths may contribute at least 3 mm/ky to the deep-sea floor in the Equatorial Zone. A study of the potential rate of sedimentation by coccoliths at various depths and latitudes is underway utilizing computer techniques.

Distribution of $CaCO_3$ as Suspended Coccoliths:--Coccoliths are composed almost entirely of calcite. The weight of a single coccolith was carefully calculated for each species after precise measurement with the electron microscope. There were two species with a suspended weight in excess of 2,000 nanograms per liter of water.

The meso-pelagic layer in the Transition Zone yielded 2,900 nanograms of coccoliths, but this number decreased drastically to 10% at -3,000 m and 5 to 2% at -4,000 m. The meso-pelagic layer in the Equatorial Zone yielded a maximum of 4,400 nanograms of coccoliths. At 0°, the water column maintained 2,000 to 1,000 nanograms of coccoliths to -3,000 m and 360 nanograms at -4,000 m.

A NEW FREEZE-DRY TECHNIQUE FOR THE SCANNING ELECTRON MICROSCOPIC OBSERVATION OF AQUATIC BIOLOGICAL SPECIMENS

Susumu Honjo and Tadashi Otaka

A method which preserves intact the soft anatomy of marine microörganisms and yields undistorted scanning electron microscope (SEM) images has been developed by using a new freeze-dry technique. It does not require a separate freeze-dry apparatus; the entire drying procedure takes place in the specimen chamber of the SEM while an operator observes the image on the screen. The micro-ice crystals, which grow inside cells during freezing, usually destroy surface features; this problem can be avoided by using absolute ethyl alcohol as a matrix. By applying this technique, small and exceedingly delicate individuals or organelles such as *Stentor* cilia, dinoflagellate flagella, cilia which are developed on the mouth parts of copepods, have been observed with minimal distortion.

Marine specimens are fixed in 3% glutaraldehyde (buffered by normal sea water) immediately after collection. They are then decanted on a nylon filter and transferred to a series of graduated ethyl alcohol baths and finally placed in absolute ethyl alcohol.

A newly designed cryostatic specimen holder keeps a copper specimen pedestal at -170°C ± 3°C by means of liquid nitrogen coolant, utilizing thermal feedback. A drop of alcohol containing the specimen(s) is placed on the slightly concave surface of the pedestal. A pair of microthermocouples 0.008 inches in diameter are installed in the neighborhood of the concave so as to keep the microthermocouples close to a droplet. The specimen within the ethyl alcohol droplet freezes immediately. This procedure is carried out in an attached small dry nitrogen chamber to avoid condensation of the ambient water vapor on the specimen holder. The specimen holder is placed in the SEM column, and during vacuum pump-down, the specimen temperature is normally kept at -170°C throughout. The frozen ethyl alcohol matrix sublimates rapidly and embedded specimens are exposed to the matrix outer surface. Solid ethyl alcohol maintains surface conductivity at -170°C and allows us to observe the sublimation procedure by TV or normal mode SEM.

When the matrix disappears, a thin film of solid ethyl alcohol remains on the specimen surface for awhile. The surface conductivity is usually high and homogenous enough to produce satisfactory photomicrographs during such sublimation at an accelerating voltage of 10 kv, 60 sec/frame scan speed. The temperature of ethyl alcohol is rather critical. Specimens tend to crack below -180°C. Ethyl alcohol remains viscous above -160°C, and it tends to damage the specimen during sublimation. No significant contamination problem has arisen when a normal oil diffusion vacuum pump is used for the evacuation of the SEM sample chamber.

PHYSICAL OCEANOGRAPHY

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

Ferris Webster, Chairman

CIRCULATION

North Atlantic Circulation:--L. Valentine Worthington).

The major effort in 1971 was the near-completion of a treatise on the general circulation of the North Atlantic. In the deep water the distinction is made clearly between the currents resulting from water mass formation and the currents which circulate within a water mass. Water transport budgets are presented for five different layers in the North Atlantic from the abyssal depths to the sea surface.

Further investigation has been made into the regions of strong negative heat flux in the northern hemisphere oceans. In these regions the ocean gives up large amounts of heat to the atmosphere on an annual basis. Clearly, warm water must flow into these regions to replace the heat lost to the atmosphere, and it has been assumed that this process is accomplished by such large currents as the Gulf Stream, Kuroshio and North Atlantic Current which transport warm water from low latitudes. It was postulated that in addition to the effect of the currents, atmospheric coldness in the late winter causes surface water to sink to mid depths and to be replaced by warmer southern surface water advected north to replace it. The excessive continentality of the northern hemisphere permits the atmosphere to deliver frigid polar continental air to the sea surface at relatively low latitudes.

Gulf Stream Studies:--(Frederick C. Fuglister, Joseph R. Barrett and Charles E. Parker)

The long-range objective is to describe the Gulf Stream System in the western North Atlantic. From the tracks of 21 drogued floats, 5,000 miles of current trajectories have been plotted. The floats were tracked in a cyclonic current ring in the northern Sargasso Sea for varying lengths of time over a six-month period in 1967. Speeds ranged from about 1/2 knot near the center of the ring to 3 1/2 knots at a radius of approximately 20 miles.

The ring, as a whole, continuously shifted position, generally following an anticyclonic path. The translation speeds averaged 4.2 miles per day, ranging from 1.6 to 6.1 miles per day. After the ring had traveled along a path of 700 miles, it was only 120 miles to the west of where it started.

A study by C. Parker of the distribution of current rings in the Sargasso Sea, using approximately 200,000 bathythermograph records, was made. Identification of 62 rings was possible in the western Sargasso while none were found in the central area. The rings observed formed between 60°W and 70°W longitude and appeared to move south and southwest as far south as 25°N latitude. It is estimated from these data that the rings can still be recognized approximately 1.5 years after formation.

Two "old" rings located south of 32°N latitude were compared with two (presumably younger) rings located nearer their points of origin. The age of the "old" rings was calculated to be about two years, and (based on available potential energy levels) their expectancy was also about two years. The apparent discrepancy between this lifetime estimate and the shorter one comes about from the different methods used. The shorter lifetime estimate is based on temperature changes in the upper layers; the longer estimate considers an entire ring but is admittedly less conclusive in that the age of the older rings was not proved.

An analysis by J. Barrett of transport float observations (free-fall instrument technique of W. S. Richardson) collected in the summer of 1968 has been completed. It appears that the transport of the Gulf Stream near 67°W was between 120 and 180 million m^3/sec. The probability of large transport fluctuations in time intervals of a few days or less is suggested. The exact nature of these fluctuations is not at present deducible.

The relationships between the convolutions in the path of the Gulf Stream, horizontal gradient structures, alterations in the temperature field downstream, and the nature of the currents in the upper 200 m has been studied. Over 2,700 miles of drogue measurements were obtained in three cruises in 1968-69. These data show a continuous flow-streamline downstream. The swiftest currents, in the

cross-stream sense, correspond to the position of the 15° to 16° isotherm at 200 m. This appears to hold true for both anticyclonic and cyclonic stream curvature except where the radius falls below about 50 km in anticyclonic loops north of the Stream.

Bottom Water Movements, Antilles Outer Ridge:--(W. Redwood Wright)

For several years, geologists have relied mainly on bottom photography and sediment analysis while physical oceanographers have preferred hydrography and current measurements to learn about the circulation near the deep-sea floor. Both techniques have been combined to study the abyssal circulation and its effect upon sediment distribution in the vicinity of the Antilles Outer Ridge north of Puerto Rico. The work has been done in cooperation with R. H. Heinmiller of the Department of Physical Oceanography and C. D. Hollister of the Department of Geology and Geophysics.

A likely source of sediment for the Antilles Outer Ridge appears to be the continental slope of North America, and it was suggested that the sediment could be transported to the region by an extension of the undercurrent which has been observed flowing generally southward along the slope.

Bottom current meters were set out at three locations across the ridge, and hydrographic observations were carried out simultaneously with sea floor photography. Gravity cores and water samples for analysis of suspended sediments were also taken.

All the water below about 4,500 m is clearly Antarctic Bottom Water, of southern origin. However, the sloping isotherms and bottom photographs both suggested water movement in a clockwise manner around the northwest end of the ridge and flow toward the southeast in the region where the sediments are thickest. The current meter records were not conclusive. Additional current meters have been set and more measurements are planned for 1972.

Circulation on the Continental Shelf:--(Dean F. Bumpus)

During the period 1960-1970 inclusive, 165,619 drift bottles were released in the continental shelf waters of the eastern United States. Through the end of November 1971, 16,447, or 9.9% have been recovered from the contiguous shores. During the period 1961-1970 inclusive, 75,664 sea bed drifters were released in the same waters; of these through the end of November 1971, 11,951 were recovered along the shores, 1,109 in estuaries, 2,124 from the sea bottom by fishermen, 15.8%, 1.5%, 2.8% respectively, for a total recovery of 14,075 or 18.6%.

We are attempting, through the use of this simple technique of broadcasting drift bottles and sea bed drifters over the whole continental shelf on a regular monthly basis and their eventual recovery by beachcombers and fishermen, to describe the circulations on the continental shelf and to make an adequate estimate of the processes controlling them. We have ceased the active field program and are in the process of producing a comprehensive description of the results over the past 10 years.

Investigation of the Water Entering the Southeastern Caribbean Sea:--(William G. Metcalf and Marvel C. Stalcup)

The flow of water into the Caribbean Sea may be divided into two separate regimes: the relatively rapid inflow at depths less than 1,000 m and the slow, possibly intermittent, flow near the bottom of the deeper passages. The shallow flow enters the Caribbean through various passages between the Antillean islands, flows swiftly westward as the Caribbean Current and passes out of the Caribbean through the Yucatan passage. The course of the deep flow is imperfectly understood though its existence is confirmed by the character of the deep Caribbean water.

Because of friction and/or other effects, the geostrophic approximations are not adequate to describe the flow or to calculate the volume transport through the passages. Direct current measurements from a drifting ship must be relied upon. Only a few navigation systems offer the accuracy necessary for such precise measurements. We have assembled a radar ranging system that provides positional accuracy of ±20 m throughout an area of 5×10^4 km^2 and have tested this system during

170 current meter stations in the eastern Caribbean. These measurements were made during March and April, 1970, and show an average of 26 x 10^6 m^3 sec^{-1} flowing into the Caribbean through the three southern passages of the Lesser Antilles. Hydrographic observations made at the same time show the water types involved in this circulation come from a broad area to the east of the Lesser Antilles.

Although additional measurements are needed to determine the representativeness of our 1970 measurements and to determine any seasonal variations in the flow, we have shown which of the southeastern passages are most important to the Caribbean circulation.

Deep Currents:--(Bruce A. Warren)

Cruises were made in 1969 in the South Pacific on the USNS *Eltanin* and in 1970 in the South Indian Ocean on the R/V *Chain* to map and measure the deep western boundary currents which transport Antarctic water northward into the central basins of those oceans. During 1971, profiles of the observed property distributions have been drawn up, and dynamic computations have been carried out to estimate the volume transports of these currents and the distribution of geostrophic velocity within them. Some maps of horizontal property distributions have also been partly completed for the South Pacific.

In June an attempt was made on the R/V *Knorr* to observe effects of a seamount on the path and structure of the Gulf Stream. This was a joint project with colleagues from Texas A & M University. The work focused on Kelvin and Atlantis II Seamounts, and consisted of following the near-surface Stream path, carrying out a detailed hydrographic survey with 111 STD lowerings to map the temperature and salinity fields above and around the seamounts, and placing seven near-bottom current meters in a line across the Stream to measure the deep flow. We are uncertain now that we can actually infer the effects of the seamount from these data because the Stream path itself changed dramatically during the course of the cruise, making it difficult to combine data into a synoptic picture.

Robert Stanley and George Knapp have participated in all phases of these activities and have done much of the work described.

Studies in the Mediterranean Sea:--(Arthur R. Miller)

The Mediterranean Sea Atlas was published and distributed during 1971: Temperature, Salinity, Oxygen Profiles and Data from Cruises of R/V *Atlantis* and R/V *Chain* with Distribution of Nutrient Chemical Properties. A manuscript has been prepared which describes the distributions from the Atlas and calls attention to phenomena relative to water formations within the Mediterranean.

A data report has been completed on the first phase of the NATO investigation called MILOC-68. This report gives the temperature, salinity, and sound velocity for a 20,000 square mile area east of Malta in the Ionian Sea.

The diurnal variations of temperature and salinity down to depths of 100 m have been studied using MILOC-68 data. A maximum temperature in the afternoon with maximum salinity following three hours later is found.

Somali Current Studies:--(John G. Bruce)

Availability of the *Chain* in the Indian Ocean during the early part of 1971 enabled us to get a further look at the circulation off the Somali coast during the northeast monsoon. The work included 33 hydrographic stations and 135 BT's along three sections, each on the order of 400 miles in length, passing through the position of the summer gyre roughly along diameters of the gyre.

The remainder of the year has been spent working up and examining our data obtained during the two monsoons. The considerable change in the surface circulation (upper 200 m) during the southwest monsoon (a change not found in our previous studies) has made it necessary to divide the measurements into three time periods for mapping of the properties. The mapping has been completed in a series of figures for a paper which discusses the changes in circulation during the season and compares this with earlier work off the Somali coast during the southwest monsoon (Fig. PO-1).

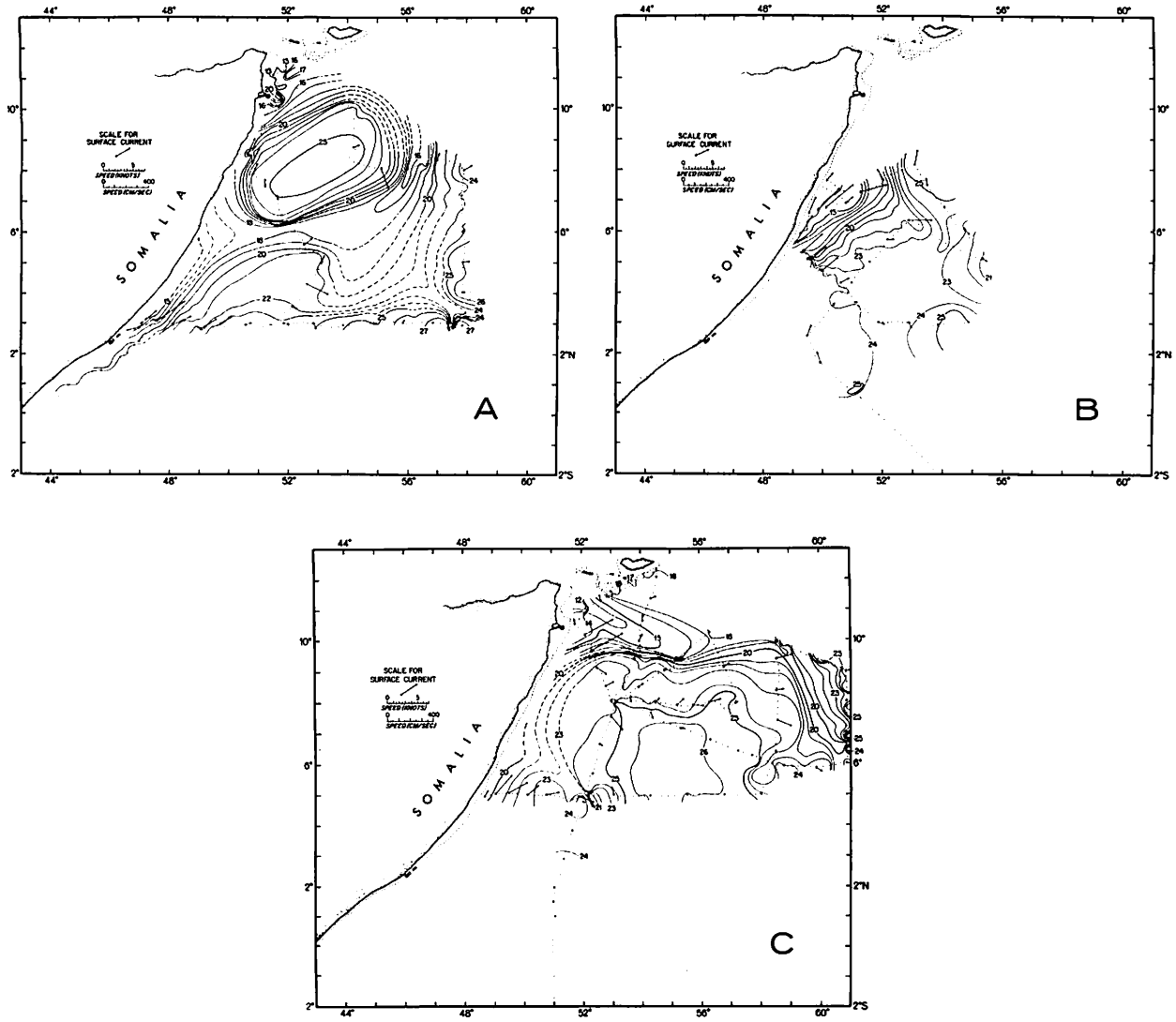

Fig. PO-1 (Bruce) Temperature, °C, at 100 m during the 1970 southwest monsoon in the northwestern Indian Ocean. Vectors show surface current speed and direction. Because of the large changes occurring in the temperature structure during the two months of measurements, the maps are shown in three time periods: (a) August 4-18, (b) August 18-28, and (c) September 6-25.

Development of an Acoustic Dropsonde to Study the Ocean Circulation:--(Arthur D. Voorhis and William J. Schmitz, Jr.)

The acoustic dropsonde is a self-contained acoustic navigation system with conductivity, temperature and pressure sensors. The dropsonde can communicate with up to four bottom-mounted transducers; travel times and sensor signals are recorded internally on magnetic tape.

This instrument was successfully developed, tested, and used in a pilot experiment, consisting of six drops to the bottom over a 40-hour period in the vicinity of a current meter mooring near 28°N latitude, 70°W longitude. Fig. PO-2 is a histogram of range jitter observed during a half-hour period when the dropsonde was moored to the bottom along with three transponders. The standard deviation of the range jitter, nine cm, is probably the upper limit of the relative position stability obtainable with this instrumentation.

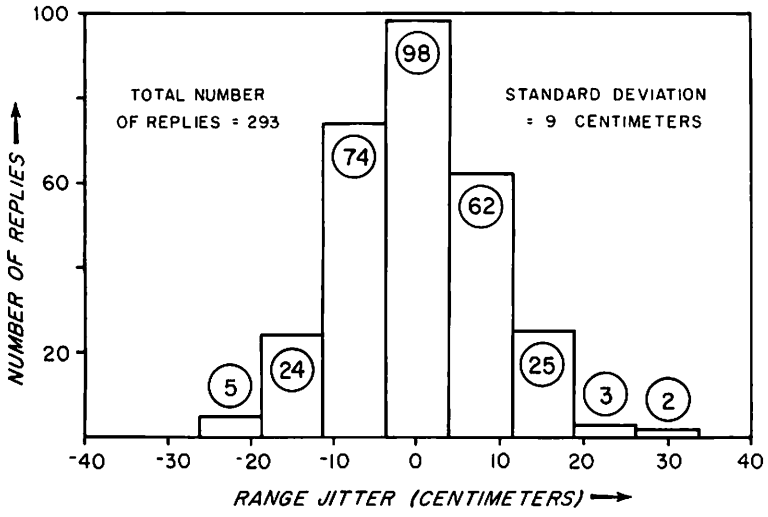

Fig. PO-2 (Voorhis/Schmitz) Histogram of range differences measured while dropsonde and three transponders were moored on the bottom.

A Training Program for Personnel from Developing Countries:--(W. Redwood Wright)

This cooperative program with the National Oceanographic Data Center and the University of Rhode Island is set up to train young oceanographers from developing nations in the acquisition, processing and utilization of oceanographic data.

Two groups of trainees, totaling 11 men, have been through the program in 1971. The emphasis has been on obtaining data at sea with standard techniques such as Nansen bottle casts, and the processing and analysis of such data. The trainees have also talked to marine scientists in a variety of disciplines to learn some of the different kinds of data required for this type of research.

OCEANIC PROCESSES

Vertical Motion and Microstructure:--(Arthur D. Voorhis)

Vertical currents, although usually small, are of central importance in the relatively small-scale and high-frequency processes which affect vertical and horizontal transports of momentum, heat, and material properties within the ocean. Since the development of the neutrally buoyant vertical current meter in 1965 by Webb, we have improved and used these instruments to measure directly and analyze vertical currents in a number of regions.

In February, one vertical current meter was launched from the *Chain* in the Red Sea to measure geothermal convection in the hot brine pools. The instrument sank to an equilibrium depth of 2,010 m in the intermediate hot brine layer which was about 30 m thick and where the *in situ* temperature was approximately 50°C. After 84 hours, the instrument dropped ballast and returned to the surface with a complete record. The vertical flow during most of the period was due to low-amplitude, high-frequency internal waves propagating along the upper boundary of the intermediate layer. On several occasions, however, there were abrupt upward flows of 10 to 20 m lasting about an hour, which we believe were due to convective plumes rising from the bottom of the layer.

In June, two weeks were spent along the edge of the continental shelf south of New England investigating vertical currents in the transition zone between shelf water and the underlying denser offshore slope water. Three vertical current meters were launched, tracked, and recovered a total of 28 times--in shallow water (120 m) and in deeper water (300 m).

The data suggest that vertical motion in shallow water was due primarily to internal waves generated by shear across the density interface between the shelf and slope waters. On the slope the vertical motion had a broader frequency spectrum with periods of several hours being predominant. The amplitudes, 10 to 30 m, were larger than those found on the shelf.

Internal Waves:--(William F. Simmons)

Conversion of the W.H.O.I. towing facility to a year-round internal waves laboratory in collaboration with R. Scotti has been nearly completed. A reliable method for continuously stratifying the tank with a variety of profiles of one or two solutes while gently filling through a false bottom has been designed, installed, and tested. Platinum conductivity probes have been incorporated with a digitizer-recorder to produce a data sensing and recording system. All essential equipment has been installed, and tank calibration experiments are underway.

Preliminary experiments with long-term forcing of high-energized waves indicate energy transfers so extensive that unstable perturbations dominate the forced wave in total energy content.

A new paddle consisting of twenty aluminum slats in the vertical, each able to move independently in the horizontal plane, was constructed. The paddle can generate a nearly pure free-wave mode of any frequency and amplitude for any given, realizable stratification. This generator is scheduled for installation in early 1972.

Ocean Stratification and the Sound Velocity Field:--(Eli J. Katz)

Diverse studies were conducted in collaboration with R. T. Nowak and M. M. Jones to describe the movement of intermediate water in the western Mediterranean and to directly observe a density surface in the main thermocline of the Sargasso Sea.

An STD section and several STD tows, made in the western Mediterranean during July 1970 were analyzed to understand how the saline intermediate layer of Levantine Intermediate Water affects the sound velocity field and how it may influence the ambient noise. A second question examined was how well the section substantiates any of the published descriptions of the flow of the Levantine Inter-

mediate Water between the Strait of Sicily and the Strait of Gibraltar.

Sound velocity as directly sensed by the velocimeter was intercompared with that computed from pressure, temperature, and conductivity. Also considered was the ability to resolve vertical gradients if two similar sensors were to be attached to the tow line with small vertical separation.

A tow exercise was performed in the main thermocline due south of Bermuda during February and March. The density of the water at tow depth was computed on-line, and this depth was continuously adjusted to follow a selected isopycnal ($\zeta_t \approx 26.90$) over two orthogonal tracks. The purpose of the tows was to record the spectrum of spatial variations in the isopycnal depth and to observe the changes in the properties of the water which lie on (or more exactly, constitute) the surface. Combined, they provide an explanation of the horizontal changes in the sound velocity.

Flux of Oceanic Energy having Near-Inertial Frequency:--(Ferris Webster)

The average properties of inertial-frequency motions were studied in collaboration with C. G. Day. Long series of current measurements at Site D were analyzed, using the technique of complex demodulation to obtain time series of inertial-frequency amplitudes and phases. The mean amplitude of the motion was found to diminish with depth and to show a dampening associated with the seasonal thermocline. "Bursts" of inertial energy were also studied. The duration of a burst is statistically correlated with the amplitude of the inertial motion in the burst.

Development of a Wind Stress Model for the North Atlantic Ocean:--(Nicholas P. Fofonoff)

Studies by C. S. Welch of synoptic surface pressure data have continued this year. Specific calculations have been made over areas of the North Atlantic and North Pacific oceans using a formula developed to estimate the curl of the wind stress. In addition, a comparison between geostrophic wind and the observed wind from a buoy-mounted anemometer was performed. The angle between geostrophic and observed wind at Site D was found to be about 17° during October and November of 1968. The speed ratio between observed and geostrophic wind was found to be .75 for the same period.

The wind stress curve formula was used to estimate iceberg drift tracks in the Labrador Current during the year 1959. The estimates were compared with observations of the International Ice Patrol, and significant agreement was found. Finally, mean values of the Gulf Stream and Kuroshio currents for the year 1968 were estimated, using wind-driven current theory. It was concluded that mean values of wind stress were insufficient to drive these major currents.

Physical Properties of Sea Water:--(Alvin L. Bradshaw and Karl E. Schleicher)

This program is concerned with the electrical conductivity and density of sea water. Its object has been accurate measurements of the effect of the variables of temperature, pressure, and composition on these properties.

During the past year, we completed measurements of the isothermal compression of sea water and also of distilled water at 10°C and at pressures up to 1,000 bars. The volume changes were determined precisely in a fused-quartz dilatometer which had been calibrated with mercury. In the case of sea water, the measurements were carried out at approximately the same salinities as those of our thermal expansion work in an effort to combine the two sets of measurements. The result is a new set of tables for the relative volume-pressure-temperature relationship at salinities of 30.5, 35, and 39.5°/$_{oo}$ for the ranges of pressures and temperatures found in the oceans. An interpolation formula summarizing the results is in progress.

The partial molal volumes of the major components of sea water have been measured by others at atmospheric pressure. To investigate the effect of pressure on this quantity, we have completed measurements for sodium chloride, including 35°/$_{oo}$ salinity sea water at pressures up to 1,000 bars and at two temperatures. The complete set of results will make possible the calculation of the effect

of deviations in composition on the density of sea water under pressure. They will also be of value in the study of the chemistry of sea water.

Salinity Measurements of 1970 at Certain Lightships:--(Joseph Chase)

This program of temperature and salinity observations began in late 1955 as part of a study of the circulation and the oceanographic climate of the continental shelf along the east coast of the United States. Observations were made daily by personnel of the United States Coast Guard at 12 lightships and light stations extending from Mt. Desert Rock, Maine, to Frying Pan Shoals, North Carolina.

The data furnished a suitable base for determining temporal changes in the ocean environment, including those induced by the atmosphere. Wind, air temperature and precipitation have all been reflected in the observations. The U. S. Coast Guard has now assumed the responsibility for continuing the program.

North Atlantic Temperatures:--(Elizabeth H. Schroeder)

North Atlantic thermal structure:

The goal of this work is the publication of an atlas showing the average temperature of the North Atlantic at six depths from the surface to 150 meters.

All available Atlantic data were sent to the Scripps Institution of Oceanography to provide, by interpolation, a temperature for each depth, in each month, in each one-degree quadrangle. Distortion of the temperature-depth structure by the computer program necessitated introducing corrections and interpolations, and these changes are now underway.

Panulirus data:

The long-range goal of this program is to describe the temperature-salinity relationship of the waters off Bermuda. This continuing series of Nansen bottle stations constitutes one of the few long-time series and has proved to be valuable as a source for research in diverse fields.

Since June of 1954, the personnel of the Bermuda Biological Station have made a total of 355 Nansen bottle stations. A total of eighteen stations were made and analyzed during 1971. Routine analysis consists of correcting the stations, drawing curves for temperature, salinity, and oxygen versus depth, copying reduced data and geographical file cards, and adding the data to the continuous profiles of the three components.

Temperature anomaly profiles for the second eight-year period of the program have been completed for a study of the steric sea level. These will be compared to the results obtained for the first eight-year period.

Laboratory Models of Oceanographic Processes:--(John A. Whitehead, Jr.)

The Geophysical Fluid Dynamics laboratory has been used since September to study a number of processes related to oceanic phenomena. Among them are a study of Rayleigh-Taylor instability, where a thin viscous fluid layer lies under a heavier viscous fluid, and the generation of bottom-trapped waves that are theoretically predicted for spinning stratified fluids. Also begun are studies of doubly diffusive flows, and of the steplike structure of the mid-Atlantic ridge as a general property of materials whose compressive strength exceeds their tensile strength.

MODE

Introduction:--

There has been increased awareness in the last two decades that the dynamics of the ocean are characterized not only by steady ocean-wide flows, but also by slow variable motions with scales of hundreds of kilometers. This has also been borne out by recent long records from moored current meters. It appears that these important eddy-like or wave-like motions are quasi-geostrophic and make up the bulk of the horizontal kinetic energy of the interior of the ocean.

This year saw the beginning of a multi-institutional program--MODE (Mid-Ocean Dynamics Experiment) to study these motions. The three-year program, funded by the Office of Naval Research and by the International Decade of Ocean Exploration of the National Science Foundation, is designed to generate a synoptic and primarily kinetic description of oceanic motion in a limited area approximately 120 x 120 nm near 28°N 68°W. An intensive cooperative field program, MODE-I, involving 15 laboratories, is planned for the four-month period of March through June, 1973. Among the participating experiments are the following projects in the Physical Oceanography Department.

MODE--W.H.O.I. Current Meter Array:--(Nicholas P. Fofonoff, William J. Schmitz, Jr. and Ferris Webster)

A current meter record of four-month duration was obtained in 1969 from a depth of 4,000 m near 70°W longitude and 31°N latitude. More than 90% of the perturbation kinetic energy was associated with time scales longer than 100 days, and the amplitudes of the motion were similar to those measured with floats in the same region.

A pilot array (Fig. PO-3) was set in October, 1971. This array is scheduled to be recovered in January, 1972. Further arrays have been planned for 1972 to prepare for the MODE-I experiment in 1973. Long-term moored current meter measurements have been begun in the MODE region, and will be continued through and beyond MODE-I.

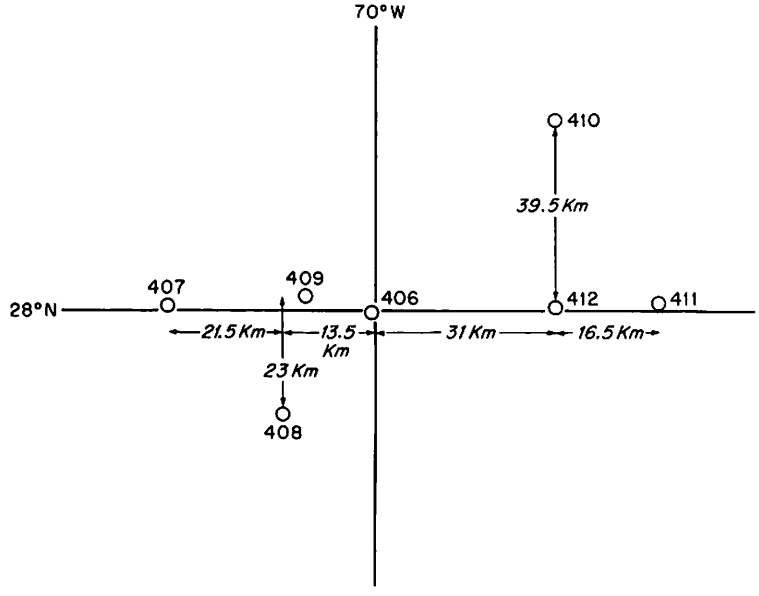

Fig. PO-3 (Fofonoff/Schmitz/Webster) Array 1 positions.

Electric and Magnetic Fields in the Sea:--(Thomas B. Sanford)

This program seeks to understand the generation of electromagnetic (E-M) fields by ocean currents and to develop oceanographic techniques using these fields. Prior to this year, a free-fall instrument was developed to measure the weak motionally induced electric field within the water column. These measurements can be related to the relative or baroclinic velocity profile.

During the past year, field experiments have been performed using both the old model and a later improved version of an E-M current meter. One experiment in conjunction with T. Rossby of Yale University confirmed the interpretation of the electric profile in terms of the velocity profile. A time series of velocity profiles showed an example of the vertical structure of inertial currents. These currents were strongest near the surface and within the thermocline. The vertical structure appears to be of high mode with vertical length scales of 100 - 200 m. Late this year, we were able to collect a similar time series in deep water, using a new digitally recording E-M current meter. The new instrument worked well, producing good profiles throughout the water column.

MODE--The SOFAR Float Experiment:--(Arthur D. Voorhis)

As part of the MODE program, this year saw the initial preparations for a SOFAR float experiment (a joint endeavor between the Woods Hole Oceanographic Institution and Yale University). Over a period of four months, 15-20 large neutrally buoyant floats will be launched at the same depth near the SOFAR channel axis (1,200-1,500 m) and tracked acoustically from land-based SOFAR hydrophones.

The purpose of the floats is twofold. Primarily, they will provide a Lagrangian description of the currents at one depth. The float tracks should reveal the presence of important large-scale features such as eddies and planetary waves. In addition, a moored array of current meters will be used to relate space-time scales at fixed locations with float trajectories.

Secondarily, the floats will monitor and internally record the depth stability of the float, the thermal microstructure and the vertical water motion along the track of each float.

Investigation of Interactions between Short Internal Gravity Waves and Larger-Scale Motion in the Ocean:--(Klaus F. Hasselmann)

The dynamics of larger-scale motions in the ocean such as mean currents and quasi-geostrophic eddies are known to be strongly affected by smaller-scale mixing processes, which cause a transfer of momentum, heat, salt and other quantities. In analogy with similar mixing processes in the atmosphere, the small-scale motions are normally regarded as "turbulence"; following the classical approach of Taylor and Prandtl, the transfer processes are then parameterized by introducing an empirical eddy viscosity and diffusion coefficients. However, existing measurements of small-scale, high-frequency fluctuations in the ocean indicate that these are probably associated with quasi-linear internal waves, rather than strongly non-linear turbulence in the usual sense. If this is the case, many properties of "mixing" processes can be evaluated by rigorously applying the theory of weak wave-wave interactions and weak wave-current interactions. This approach is being pursued with the goal of computing transfer rates quantitatively in terms of the measured internal-wave spectra. The analysis is relevant for an understanding of both the large-scale motions and the energy balance of the internal-wave spectrum.

Theoretical predictions will be tested in part by an analysis of current measurements made at Site D. A conclusive test requires a more detailed experiment designed to resolve both the frequency and directional distribution of the internal-wave spectrum.

Theoretical-Numerical Study of Geostrophic Eddy Motions in the Ocean:--(Pierre Welander)

A numerical model to study the properties of strictly geostrophic eddy motions was formulated at Woods Hole, and the investigation was continued at the University of Washington, Seattle. A time-stepping procedure is used to obtain a steady-state computer solution of the model. The results should provide an improved basis for the interpretation of observations obtained during MODE-I.

The study will continue in 1972 at the University of Gothenburg, Sweden.

MOORED ARRAY EXPERIMENTS

Moored Array Program:--(Nicholas P. Fofonoff and Ferris Webster)

A total of 53 moorings were set during 1971 in a variety of scientific and engineering experiments. Nearly all of these moorings were employed in long-term experiments of one to four months' duration. In addition to the program of long-term measurements at western North Atlantic sites, a series of experiments were undertaken cooperatively with scientists of other departments and of other scientific laboratories. These included experiments in the Pacific Equatorial Undercurrent and the Kuroshio. Measurements were begun in October in the initial phases of MODE (Mid-Ocean Dynamics Experiment)--a large-scale experiment planned for spring of 1973.

Details of the scientific experiments follow in individual summaries. Engineering moorings are described separately in the summaries for the Department of Ocean Engineering.

Array Experiments around Site D:--(Rory Thompson, William D. McKee and Alfredo A. Suarez)

Previous observations indicated that currents at Site D are remarkably incoherent at short periods; even tidal motions are coherent only over separations much less than the ocean depth. The vertical separation over which there is coherence is proportional to period so that simpler oceanic behavior may be hoped for at low frequencies. For periods of a few days to a month, observations indicate that the motion at Site D below the thermocline is essentially barotropic, with high vertical coherence. For periods greater than a month, the motion has high vertical coherence, but is only quasibarotropic. There is evidence in the Site D records for topographic Rossby waves with constant phase lines running WNW to ESE.

A simple array of moorings in the slope water near Site D was begun in August to explore the spatial structure of the currents. This first array was largely destroyed by an eddy from the Gulf Stream. However, three of the deep current meters survived for 45 days. One (3,975) was at 2,500 m depth, near the bottom, and showed a striking oscillation with a two-week period. This oscillation showed strongly in the record (3,974) directly above at 1,000 m depth. Another current meter (3,954) was set 30 km N and 5 km W, so the phase of a two-week period ought to lead by about two days. The record shows an apparent oscillation with period around two weeks, and leading by one or two days.

Bottom-trapped topographic waves in the bottom currents seem to occur. Their theory has been studied, and it is planned to observe their spatial structure by deep hydrographic stations around a current-meter array in January, 1972. These waves have not been previously documented.

A study of the dynamics of topographic Rossby waves has led to a simple model which explains "negative viscosity," and leads one to expect a counter-current north of the Gulf Stream. The model also applies to the atmosphere and may assist in understanding the Site J and L observations.

Low-Frequency Fluctuations in Horizontal Currents in the Western North Atlantic:--(James R. Luyten and William J. Schmitz, Jr.)

Current meter measurements from moored buoys are being used to describe the properties of ocean current fluctuations in the Western North Atlantic, having time scales of days and longer. Between the Gulf Stream and the coast, north of about 35°N latitude and west of the Grand Banks, lies the Slope Water region. It has been suggested that fluctuations in the Slope Water, controlled by bottom topography and associated with Gulf Stream meanders, should make an important contribution to the observed low-frequency energy. The horizontal velocity components are either in or out of phase for any plane-progressive quasi-geostrophic wave.

Topographic waves with sources in the vicinity of the Gulf Stream have negative eddy momentum fluxes below the thermocline. In addition, the orientation of the currents at low frequencies is normally about 30° north of west, as would be expected from the simplest refraction picture. In the presence of perfect reflection, however, one expects that the eddy momentum fluxes vanish. Existing theoretical models do not match the observed fluxes. Modified models have been examined, and further models, taking downstream amplification into consideration, will be studied.

Evidence for the existence and properties of bottom-trapped waves appears confusing. An array of near-bottom instruments set on the slope was recovered in December, 1970. The observed low-frequency motions were predominantly east-west, nearly in phase over 25 km separations along depth contours, and incoherent across bottom contours.

A few long records have been obtained near the bottom in the vicinity of the Gulf Stream. Large-amplitude (20 cm/sec) fluctuations with time scales of 15 days and larger have been observed. An array to investigate the downstream scale showed little visual similarity between records, suggesting that the downstream length scales are shorter than was expected from Gulf Stream path data. An array set across the Current near the Kelvin Seamount yielded considerably more visual similarity at low frequencies.

Tidal Motions:--(William D. McKee and Lorenz Magaard)

The purpose of this investigation is to understand tidal motions at Site D. Moorings 310 and 317 gave nearly two months of continuous measurements at each of six depths in 1969. Hydrographic data for the period were also available.

Each record was divided into two slightly overlapping pieces consisting of 708 hours and the periodograms calculated. Using a piece of this length enables the M_2 and S_2 semidiurnal tides to be separated. The M_2 tide was found to stand out strongly, but the S_2 was barely above the noise level in many cases. Similarly, the diurnal K_1 and O_1 tides were barely discernable. Attention was therefore focused on the M_2 tide.

For each of the two pieces the hydrographic data were averaged to give a time-averaged Brunt-Väisälä profile. From these, the first few normal modes were calculated for the M_2 period and the modes fitted to the computed M_2 amplitudes by a least-squares technique. The baroclinic structure in each of the two pieces was found to be different, but the barotropic mode was found to be remarkably similar. The maximum discrepancy in phase between the two pieces was found to be 13°, and the maximum velocity discrepancy was 0.2 cm/sec. An average over the two pieces gives a barotropic tidal ellipse described clockwise with a major axis of 0.9 cm/sec., a minor axis of 0.3 cm/sec. and with the major axis inclined at about 15°N of E.

Small-Scale Processes:--(Gerold Siedler and Nicholas P. Fofonoff)

Processes in the frequency range between inertial and Brunt-Väisälä frequency are considered in this study, with corresponding vertical scales of tens of meters and horizontal scales of hundreds of meters. The work has been restricted to deep-water motions below the thermocline.

Models of inertio-gravitational internal waves require certain relations to hold for auto-spectral and cross-spectral estimates at given separations. In earlier work at Site D, information was obtained about spectra for single instruments and cross-spectra for vertically separated instruments. There were, however, no data available for horizontal separations sufficiently small to obtain non-zero coherence above inertial or tidal frequencies.

An experiment was therefore carried out in December, 1971, over nine days to supply a set of current and temperature data from two moorings. The horizontal separation was 900 meters, and the array contained a total of six current/temperature meters, four temperature meters and one pressure recorder in the depth range between approximately 500 and 600 meters. The mooring separation was monitored by acoustic transponder measurements for two periods of 19 hours each. Simultaneously, repeated vertical temperature profiles were taken to estimate the high-frequency contamination of temperature data from moored instruments by temperature fine structure. In addition, several hydrographic stations with Nansen bottles were carried out to obtain the vertical distribution of the Brunt-Väisälä frequency during the period of the experiment.

Studies of Coupling between Winds and Near-Surface Currents:--(Joseph A. Gonella and Raymond T. Pollard)

Using measurements collected from moored wind recorders and current meters, the properties of the coupling between winds and surface currents were examined. Dr. Gonella (now at the Museum National d'Histoire Naturelle, Paris) developed a method for expressing spectral relationships between wind and current in a manner that is invariant under coordinate rotation. In the application of the method to data collected at Site D, it was found that the coherence between wind stress and surface current was significant with a phase relationship agreeing with Ekman theory.

Dr. Pollard (University of Southampton, U.K.) examined the results from an array of current meters set in the Site D region in the summer of 1970. Over the 50-km horizontal extent of the array, it was found that the currents were coherent at inertial frequency. Differences in the near-surface currents were related to differences in the wind field over the array.

Current Meter Intercomparison:--(Ferris Webster and Nicholas P. Fofonoff)

Under the auspices of SCOR (Scientific Committee on Oceanic Research) Working Group 21 on Continuous Current Velocity Measurements, an intercomparison experiment involving six different types of current meters was carried out in March, 1970, from the Soviet research vessel *Akademik Kurchatov*. The analysis of the measurements was done at Woods Hole, and a Group meeting at Moscow in August agreed on the final form of the joint report. A further comparison between current meters from the U.S., U.S.S.R., and the German Democratic Republic may be carried out during 1972 at Site D if arrangements can be completed.

Hydrography:--(Gordon H. Volkmann and Robert C. Millard, Jr.)

The Moored Array Program revisits specific locations, and observations can be combined into long time series. The hydrographic stations at Site D were described in last year's summary, but other time series are also being made. Site L at 34°N 70°W has been occupied since June of 1968, offering an opportunity to investigate both seasonal changes in the surface layer and the formation of 18° water. The deep water is being sampled as well, to study long-term changes.

These measurements have been made with serial hydrographic observations and XBT's. More recently, a high-precision Conductivity/Temperature/Depth sensor (CTD), developed by Neil Brown in the Ocean Engineering Department, has been used. The mixing of heat and salt between shelf and slope water has been studied with 112 stations collected on the shelf and shallow slope region south of Nantucket, using both a standard STD (Salinity/Temperature/Depth sensor) and the high-precision CTD in water depths from 40 to 630 meters. A bottom layer, well mixed in temperature and salinity, has been found to occur in a large number of these stations. The bottom layer most frequently occurs and has its greatest thickness (up to 28 meters) at the end of the continental shelf. In September, a set of

hydrographic stations along the shelf south of Nantucket between 68°W and 71°W showed mixed bottom layers at the edge of the shelf along this section. The wide distribution of temperature and salinity for the layer suggests that it is the result of local mixing.

The development of the new Vector Averaging Current Meter has brought with it the capability of measuring temperature continuously at the same time that currents are being measured. Initial measurements, while made primarily to test the new instruments, have encouraged us to fit temperature-measuring circuits to existing current meters.

Instrument Development:--(James R. McCullough)

Five prototype current meters that form vector averages of ocean currents were constructed and compared at sea with conventional W.H.O.I. Savonius-rotor current meters. The vector averaging current meters (VACM's) were tested on two moorings 1 km apart in the near-surface currents at Site D. Fig. PO-4 shows kinetic energy density spectra computed for the one-month test. As anticipated (by computer simulation) the higher sampling rate of the VACM's gives lower energy density estimates at periods of about five hours and less. Construction of an additional 40 VACM's to be used in future experiments is underway.

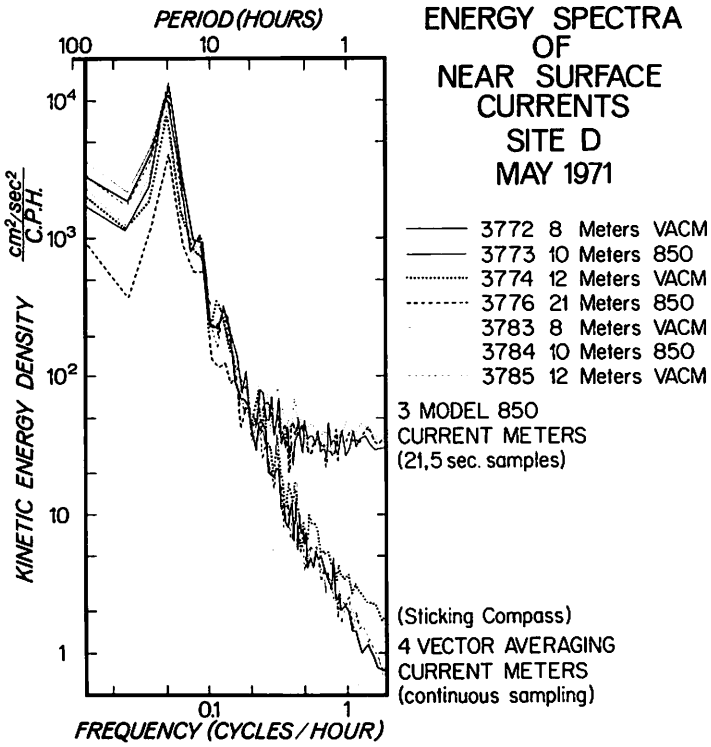

Fig. PO-4 (McCullough)

Moored Array Data Processing:--(John A. Maltais)

Data from 58 current meters and four wind recorders were processed. In addition, records from new vector-averaging current meters (VACM's) produced several useful temperature series.

In the course of the year, new computer programs were developed to handle data from the new VACM and the precision CTD microprofiler. Other new programs were created for interchange of non-standard data forms with existing standard formats. An automated data directory system, maintained on magnetic tape, allows scientists to identify data series having specified properties.

Volume five in a continuing series of data reports was completed. Volumes six, seven, and eight are in preparation, using increasing computer support to eliminate manual tasks in preparing these reports.

Transmittal OF W.H.O.I. Current Meter Data Archives to the N.O.D.C.:--(Ferris Webster)

The current meter archives of W.H.O.I. are being copied onto computer magnetic tape for transmittal to the National Oceanographic Data Center. During 1971 two were submitted, and all data will continue to be submitted routinely in the future. An N.O.D.C. computer programmer visited W.H.O.I. to obtain first-hand information about the Maltais tape format, which has been adopted as the standard for the data transmittal.

Operations:--(Robert H. Heinmiller)

A diversity of moorings was set with a wider geographical distribution than previously undertaken. The basic program was carried out on five regular cruises along the 70°W meridian to Site D (39°1 N), Site J (36°N), and Site L (34°N). Long-term, continuous mooring series were maintained at Sites D and J while Site L was used for engineering tests.

Other moorings were successfully set and recovered as listed in Table I. The percentage of failures was low and due primarily to the intrusion of an apparent Gulf Stream eddy, bringing current speeds well above the design specifications of the moorings. The recovery of practically all gear is the culmination of several years' development of the backup recovery system technique, combined with extensive use of radio beacons and RDF equipment.

Efforts to upgrade the current meters continued during the year, including new checkout techniques and improved circuitry. Initial work was done to outfit the present Model 850 current meters to include temperature measurements. Preparations were made for the new Vector Averaging Current Meters (VACM), expected to enter as standard equipment in 1972.

A number of improvements in the buoy equipment, including a new strobe light, contributed to our operational capability. Changes and improvements were also made in mooring hardware and handling equipment and techniques.

TABLE PO-I

MOORINGS SET IN 1971

No.	Month Set	Location	Type	Duration (Days)	Recovery	Notes
369	Jan.	Antilles Ridge	Bottom	122	Complete	Antilles Ridge experiment
370	"	"	"	121	"	" " "
371	"	"	"	118	"	" " "
372	Apr.	Equat. Pacific	"	-	Lost	Joint W.H.O.I./S.I.O./M.I.T./Harvard experiment
373	"	"	Surface	25	Complete	" " " " " " Failed - part picked up by fisherman
374	"	"	"	7	Partial	Joint experiment, as above - failed
375	"	"	"	188	Complete	" " " "
376	"	"	Bottom	-	Lost	" " " "
377	"	Site D	Surface	27	Complete	VACM evaluation
378	"	"	"	27	"	" "
379	"	"	"	91	"	Four-month current measurements; solar radiation measurements for R. Payne
380	"	Gulf Stream	"	4	"	Engineering test of Gulf Stream mooring
381	May	Site L	"	184	"	Wire and hardware evaluation; solar radiation measurements
382	"	Site J	Intermediate	87	"	Routine long-term measurements
383	"	Grand Banks	Bottom	91	"	Set and recovered from USCGC *Evergreen*
384	June	Kuroshio Current	"	108	"	Joint W.H.O.I./S.I.O. experiment
385	"	"	"	106	"	" " " "
386	"	"	"	-	Lost	" " " "
387	"	"	"	97	Complete	" " " "
388	"	Gulf Stream	"	32	"	Gulf Stream seamount study
389	"	"	"	32	"	" " " "
390	"	"	"	31	"	" " " "
391	"	"	"	31	"	" " " "

MOORINGS SET IN 1971 (continued)

No.	Month Set	Location	Type	Duration (Days)	Recovery	Notes
392	June	Gulf Stream	Bottom	31	Complete	Gulf Stream seamount study
393	"	"	"	31	"	" " " "
394	"	"	"	30	"	" " " "
395	July	Site D	Surface	45	"	Site D Array
396	"	"	"	?	"	" " " - failed in Gulf Stream eddy
397	"	"	"	45	"	" " " - picked up off station in eddy
398	"	"	"	?	"	" " " - failed; removed by dragging
399	"	"	"	8	"	" " " - failed in eddy
400	Aug.	Site J	Intermediate	137	"	Routine long-term measurements
401	"	Site L	Surface	85	"	Fishbite test
402	"	Site D	"	?	"	Failed in Gulf Stream eddy - part of Site D array
403	"	Site J	"	51	Partial	Failed - high current region engineering test
404	Oct.	Site L	Bottom	-	-	One-year test - still at sea
405	"	"	Surface	-	-	Six-month wire test - still at sea
406	"	MODE	"	-	-	MODE-0 array - at sea
407	"	"	"	-	-	" " " " "
408	"	"	Intermediate	-	-	" " " " "
409	"	Site D	"	-	-	" " " " "
410	"	"	"	-	-	" " " " "
411	"	"	"	-	-	" " " " "
412	"	"	"	-	-	" " " " "
413	"	"	Bottom	2	Complete	Acoustic Navigation Mooring - no instruments
414	"	"	"	2	"	" " " " "
415	Nov.	Antilles Ridge	"	-	-	At sea - Antilles Ridge experiment
416	"	"	"	-	-	" " " " "
417	"	"	"	-	-	" " " " "

MOORINGS SET IN 1971 (continued)

No.	Month Set	Location	Type	Duration (Days)	Recovery	Notes
418	Dec.	Site D	Intermediate	10	Complete	Coherence Scales experiment) Set 920 m apart
419	"	"	"	9	"	" " ") at Site D
420	"	"	Surface	-	-	At sea
421	"	Site J	Intermediate	-	-	" "

OCEAN AND ATMOSPHERE

Marine Geodesy and Satellite Altimetry:--(William S. von Arx)

This year's work with the assistance of J. P. Dean, has been a continuation of the program of using an orbiting altimeter to provide geoidal and geopotential topography over the oceans. Ground truth for altimeter calibration is derived from a world-wide grid comprised of the equatorial belt and meridional traverses over which the gravity is known and computations of geoidal topography can be made.

This year the equatorial belt has been completed and data processing is underway.

A re-investigation of the applicability of the Vening Meinesz expansion of the Stokes equation and a comparison of profile gravity surveys vs. two-dimensional surveys is underway. Also a study of the problem of downward continuation of the gravity potential from satellite altitudes to the sea surface is being pursued.

Significant improvements in the equipment have been made as well. The new high-precision equatorial theodolite has been completed. To make room for this instrument on the GEON stabilized platform, a slaved gravimeter platform has been developed and built in our laboratory. This system utilizes the inherent advantages of the GEON horizontal reference in a repeater platform. Work is continuing on development of the data acquisition system.

Air-Sea Exchange:--(Peter M. Saunders)

The space and time variability of currents and temperature in the upper ocean and its connection with variations in the flux of energy across the surface is being explored. An aircraft with an infrared radiometer was used to map the temperature field in the vicinity of six surface moorings in the Slope Water area south of Cape Cod. Unfortunately, a northward meander of the Gulf Stream invaded the area, and associated intense currents broke all but two of the moorings. This led to an incompatibility between the array scale and the sampling interval of the aircraft observations, and the experiment as conceived must be considered a failure. Nonetheless, we are examining the data obtained.

Improved estimates of the flux of solar energy into the upper ocean will result from observations by Richard Payne. He showed that the ocean albedo, the ratio of the upward flux of solar radiant energy to the downward flux--both measured close to the surface--is a function of sun altitude and atmospheric transmittance. The atmospheric transmittance is also a ratio, that of the flux of solar energy reaching sea level to that impinging on the top of the atmosphere; it attains a value near unity in clear weather and near zero with overcast skies. The ocean albedo varies between 3% and 50%,

reaching a maximum with low sun and clear skies (Fig. PO-5). Since the energy not absorbed by the ocean is either reflected from the surface or scattered back from within the upper layers, it is surprising that variations in both surface roughness and turbidity have only minor influence on the albedo.

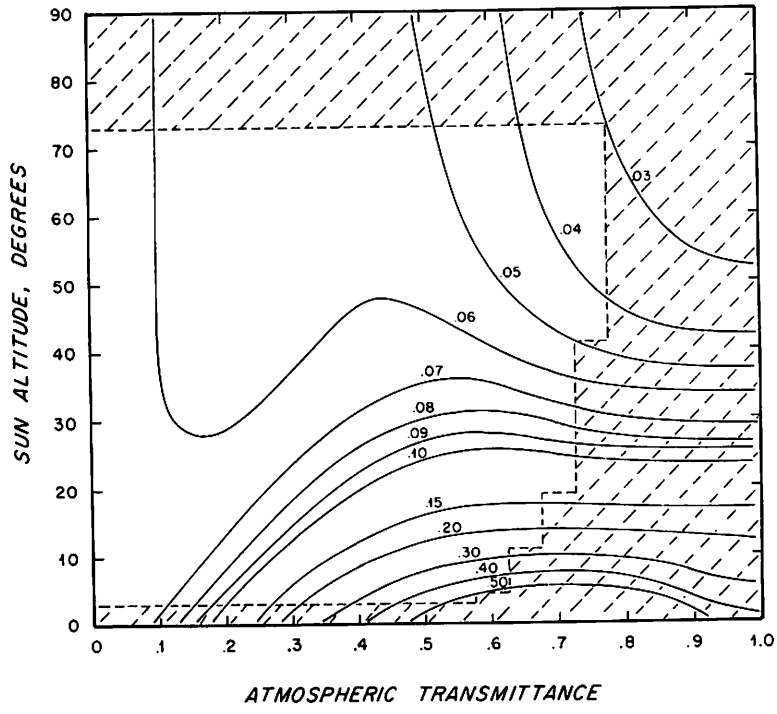

Fig. PO-5 (Saunders)

Environmental Data Buoy Program:--(Joseph Chase)

The United States Coast Guard Environmental Research Buoy (ERB) has been moored off the Virginia Capes at the edge of the Gulf Stream (36.5°N 73.5°W) since February, 1970. Equipped with sensors to sample atmospheric and oceanic parameters, it has been transmitting data to shore with few interruptions since that date.

Analysis of the data has been centered on learning more about the behavior of the Gulf Stream, better understanding of how the ocean and the atmosphere influence each other, and on developing techniques for quality control and the use of data from buoys of this general type in various locations.

The ERB has monitored Gulf Stream meanders, possibly associated with wind patterns. One technique in development is the extrapolation of the heights of upper-air pressure surfaces from surface data and from radiosonde observations over the continent. With suitable refinement the technique might enhance the usefulness of buoys to weather forecasting.

Wintertime Interactions of the Atmosphere with the Mediterranean Sea:--(Andrew F. Bunker)

For many years oceanographers suspected that the cold, dry, mistral winds blowing down the Rhone River Valley caused the Mediterranean water south of France to sink to the bottom. In February, 1969, several research vessels were assembled together with the Institution's research aircraft, and the processes involved in the sinking were studied in detail. The measurements showed that the mistral wind was the primary agent in the cooling of water. The winds from the south and east were ineffective because of their warmth and humidity.

The largest share of the cooling is accomplished by the evaporation of water. A variety of techniques of measuring evaporation were compared. Evaporations were determined from vapor in the atmosphere along flight trajectories as the air blew over the sea, a technique made possible by ship-borne upper-air soundings. Evaporation was computed also from the Jacobs-Budyko formula. This formula and a similar heat-flux formula were applied to climatological data to obtain monthly values of evaporation and heat flow.

To complete the heat budgets of the sea and the atmosphere, radiation fluxes and absorptions were measured or computed. The turbulent and radiational fluxes show that as the solar radiation absorbed by the sea decreases during the fall and winter, the evaporative heat loss increases. As a result, the water south of France is cooled to the neutral stability point by the end of January. The February cooling is enough to make it unstable, and the water sinks to the bottom.

Turbulence and Fluxes in the Boundary Layer of Undisturbed and Disturbed Trade Winds:--(Andrew F. Bunker)

This project was started in November, 1971, hence this report is more a statement of plans than of accomplishments. In broad terms, the problem is to determine the turbulence and wind structure of the boundary layer of the trade winds both in the vicinity of large convective systems and far from such systems. In the case of the boundary layer far from a disturbance, the layer is partially isolated from the upper air by stable air. Contact with the upper air is made by relatively few moderate-sized cumulus clouds. Within the convective system many large cumulus and cumulonimbus clouds occur which disrupt the boundary layer through vertical and horizontal winds with a wide range in size and intensity.

Remote Sensing of Chlorophyll, Pollutants and other Ocean Coloring Agents:--(Gifford C. Ewing and George L. Clarke)

Remote sensing of the ocean from above has as its purpose the rapid scanning over relatively large areas of oceanic features that are inaccessible to immediate measurement either because of rapid fluctuation or because they occur in inaccessible regions of the world. For purposes to which it is well adapted, remote sensing from aircraft or satellite is powerful and efficient. Application of this technology to ocean research was initiated at W.H.O.I. by Henry Stommel in 1950, using thermal radiation measurements to map the warm outcrop of the Gulf Stream. Since then, the method has enjoyed steady growth in a wide variety of uses and is now routinely employed for biological, fisheries and weather investigation, and recently for the detection of pollution.

Beginning in 1964, the present authors have been exploring the feasibility of extending remote sensing to assessing the ocean's chemical and biological constitution by means of spectroscopy. Sunlight falling on the sea is backscattered upward by the air from the surface, and by various underwater reflectors such as bubbles, plankton, detritus, the bottom and the water molecules themselves. While traveling twice along this underwater path, light is spectrally altered by absorption and scattering. The combined effect, or absorbence, produces the color of the sea observed from overhead. In the absence of foreign material, absorbence by water molecules dominates and gives the ocean its blueness, the depth of color increasing with the depth to which light penetrates. A spectrometer operating above the surface receives not only the emergent light but also light reflected from the sea surface and "air light" backscattered from the atmosphere. If the measurements are to be useful, means must be found to discriminate between the underwater light and the extraneous light from the air and surface.

During the past two years, our investigations include a comparison of spectral measurements made by us from aircraft at increasing altitudes with similar measurements made from shipboard at the same locations and time by John Tyler and co-workers from The Scripps Institution of Oceanography. Knowing the absorbence characteristics of various substances found in the sea, their presence can be inferred from color shifts in the observed spectra. We have succeeded in measuring the sea color from low flight altitudes and to correlate this with the presence or absence of chlorophyll and other biochromes associated with plankton blooms. At altitudes as great as 10,000 feet, the color shifts are sufficiently pronounced to be significant in fisheries investigations. It remains to be shown that such observations are possible from hyperaltitudes such as those occupied by orbiting or stationary satellites. Since most of the color degradation takes place in the lowest 5,000 feet of the atmosphere, the outlook is promising.

The ability to detect and identify specific biological and chemical constituents of the ocean (as distinct from its physical state) gives to spectroscopy a unique place in the art of remote sensing of the sea. If perfected, it will complement methods now used to measure temperature and other properties of the upper layers of the sea.

OCEAN ENGINEERING

Department of Ocean Engineering

Earl E. Hays, Department Chairman

OCEAN ENGINEERING ACADEMIC DEVELOPMENT

Albert J. Williams, III

In 1971 eight students were enrolled in a joint program in ocean engineering with Massachusetts Institute of Technology. These students, who are candidates for either the Ph.D. in Ocean Engineering or the professional degree, Ocean Engineer, obtain a somewhat different flavor from their counterparts in the M.I.T. Ocean Engineering Department. Our joint program students are primarily concerned with oceanographic engineering or the engineering required for obtaining knowledge of the ocean. Thus instrumentation, oceanographic engineering systems, and oceanographic science are stressed in addition to the more conventional engineering disciplines studied at the Massachusetts Institute of Technology.

Academic subjects:--Subjects are presented in Oceanographic Engineering Systems, Oceanographic Engineering Systems Analysis, Deep Submergence Engineering Systems, and various special problem topics including electrical field measurements and sediment transport processes. A text is being written by James W. Mavor, Jr. for the Deep Submergence subject. The report of special problems undertaken in 1970 has appeared, and the report of special problems from 1971 is in preparation.

Research projects:--Faculty and student research has proceeded in three areas. James Mavor and Stepher C. Dexter have exposed materials to the environment of the deep ocean. Stephen Dexter has studied the effect of fouling on metals. Ronald C. Gularte has studied the sensitivity of gas chromatography to motion in a seaway.

Single samples and galvanic couples of selected metals have been deployed at a deep bottom research station established in 1,785 meters by *Alvin*. The natural environment, sediment and water column is being closely monitored and the area is to be visited twice a year by *Alvin* over a period of years. The first samples are to be retrieved in June 1972.

Electron micrographs of sea water exposed and unexposed metals have been made to investigate the corrosion pitting under the influence of bacteria. *Desulfovibrio desulfuricans* may grow in the pores of sintered materials under anaerobic conditions, and the effect of colonies on corrosion is being studied.

For *in situ* analysis of hydrocarbons on the sea surface, a gas chromatographic system is being designed, which depends on reducing the observed sensitivity of g.c. detectors to motion. Experiments to identify the source of this sensitivity and reduce it have also been performed with considerable success, and the remaining sensitivity is being analyzed. This work is being done by a student for an Ocean Engineer thesis.

Deep Submergence Oceanographic Engineering - Course 13.995 in the M.I.T./W.H.O.I. Joint Educational Program

James W. Mavor, Jr., Instructor

This seminar course is given in the second year of the ocean engineering curriculum and features academic oceanographic engineering projects of current interest to the scientific community. Six projects completed during 1971 were titled as follows:

1. Titanium for Deep Submergence Application - R. C. Gularte
2. Systems Analysis of Deep Submersibles - D. P. Charnews
3. Deep Sea Rock Drill and Heat Flow Measuring Instrument - D. L. Williams
4. Some Considerations in the Operation of *Alvin* to 12,000 feet - R. J. Jaffee
5. Tow Tank Test of *Lulu* with Cradle Suspended at 100 feet - J. M. Cohen
6. Weight, Buoyancy and Stability of DSRV *Alvin* in its 12,000 foot Configuration - P. F. Poranski.

INFORMATION PROCESSING CENTER

Melvin A. Rosenfeld

The Information Processing Center is responsible for the Institution's central shore-based computers and auxiliary equipment as well as for the shipboard computer systems. The major shore equipment includes the Sigma 7 and PDP-5 computers; auxiliary to these are a Bendix Datagrid Digitizer for paper records and an analog-to-digital converter for magnetic tapes. The major ship equipment includes four Hewlett Packard 2100 series computers with a wide variety of peripherals, and three Magnavox Satellite Navigation Receivers.

The responsibilities of IPC include not only the hardware operation and maintenance but also the development and maintenance of systems software for all computers. In addition, we provide programming and analysis services and consultation for both scientific and Institution business uses. The IPC also develops or assists in the development of hardware and software interfaces between scientific instruments and the shipboard computers.

The shore-based systems functioned reasonably smoothly, and usage was higher than in 1970. There were no equipment changes during the year. The entire Sigma 7 system was purchased by the Institution in November after having been leased since April, 1968. A memory unit of 16,000 words will be added in early 1972 bringing the Sigma 7 to a 48,000 word memory capacity.

Considerable hardware was added to the shipboard systems, greatly increasing our capability to serve the scientists' computing needs at sea.

There were major software advances for the shore-based and shipboard systems.

Sigma 7 and PDP-5:-- Both computers have been extremely reliable. Standards for maintenance and engineering changes were set up and were successful in reducing down time and in increasing reliability. Xerox Data Systems introduced new distribution and packaging methods for engineering changes which insure both completeness of parts and installation instructions. A complete analysis of maintenance procedures was completed, resulting in a step-by-step maintenance program for all equipment throughout the year.

One of the most significant improvements in Sigma 7 system operation is due to the introduction of the F version of the Batch Processing Monitor. This version is the result of a considerable effort by XDS to increase system reliability and efficiency, and our experience has shown that they have been successful. With the prior monitor we experienced system failure regularly. Under F such failures are now a rarity.

The decision to acquire the Sigma 7 and its actual purchase in November were steps toward greater stability of operation in the future. No immediate major change will be apparent until the cost is amortized at about the end of 1973 but, at that time, a substantial reduction in cost-per-hour will occur. The amortization schedule has been arranged to allow for the addition of the new memory in early 1972 and still maintain a decrease in operating costs. Later in 1972, we plan to add a removable disc unit which will increase operating costs only slightly.

The PDP-5 has not changed over the year. Its functions are still to do plotting and conversions for paper and magnetic tapes. Reliability has been outstanding with only a few minor repairs necessary during the year. Usage has increased again, and there seems to be no indication of this trend changing. Because this is a very old piece of equipment the decision has been made to transfer some of its duties to a new shore-based Hewlett Packard computer which will be delivered in the first quarter of 1972.

Shipboard Computer Systems:--A survey was made in the latter part of 1970 to project the needs of shipboard requirements for 1971. The survey showed that the number of shipboard computer users had increased significantly from the previous year and that departments, such as Biology, Physical Oceanography, and Ocean Engineering, were beginning to project plans for continual use of computers at sea. Up to that time, the Department of Geology and Geophysics was the prime computer user and most of the ship computer applications were being tailored to its needs. As in the past, members of that Department found it necessary to supplement the existing shipboard computer system with additional peripherals to assist in acoustic investigations. A Tektronix graphics display terminal was introduced for the first time to the shipboard system. Also, funds were made available through ONR and NSF grants to purchase 9-track digital magnetic tape systems. This was a significant breakthrough for shipboard

processing since up to this time only slower 7-track digital magnetic tape systems were being used. It became evident during the *Chain* 99 and *Chain* 100 cruises that several serious problems had developed with the use of 7-track magnetic tape equipment at sea. The newer 9-track systems are more reliable and easier to maintain. In addition, projects such as NEAT II and ACODAC required the use of a faster, higher density output storage device.

The contribution of hardware by various projects to the shipboard computers has made it possible to operate systems on all three ships simultaneously and to configure the systems most effectively for the intended tasks. Although the three computer systems as yet are not identical in configuration, capital acquisitions have added a graphic display terminal, a high-speed paper tape punch, four 9-track magnetic tape units, a computer power supply, and various acoustic signal processing devices.

In addition to project contributions, ONR contract 241 has provided 1972 funds directly to IPC for a badly needed shore-based computer system to fill the growing need for pre-cruise program preparation. During the last quarter of 1971, the shore computer system was almost non-existent because the components of the small 8K computer had to be dismantled and shipped to the *Chain* as spare parts to repair the computer during the latter part of the world-wide cruise.

The major computer system effort on the *Knorr* was the development and deployment of two acoustic projects, one to measure sound propagation (project NEAT II) and the other to measure ambient noise (project ACODAC). Both systems required extensive instrumentation and programming; the operations were successfully conducted between August and December. In addition, Neil Brown's micro-profiler (STD system) was tested in February when several instrument lowerings were conducted between Woods Hole and San Juan, Puerto Rico. Both the instrument acquisition as well as the computer data processing were successfully tested.

The *Atlantis II* computer system was on shore for the first nine months and thus was available for cruise preparation work and other functions. In September, it was used on *Atlantis II*, on line with a bird-tracking radar, analyzing and logging information whenever the radar automatically locked on a bird. Some STD work was also done on the *Atlantis II*.

The *Chain* computer system was devoted to continuing the processing of Geology and Geophysics gravity and magnetics data, and merging these data with the ship's track. This continued the entire year and was interrupted only when there was equipment failure. A great deal of experience was gained in supporting the *Chain* system through the 19-month world-round cruise.

Computer use time:--Use of both the Sigma 7 and the PDP-5 increased. The chargeable time on the PDP-5 went from 1181 hours in 1970 to 1515 hours in 1971, an increase of 28 percent.

The Sigma 7's chargeable use increased from 1264 hours in 1970 to 1450 hours in 1971, an increase of about 15 percent. This gain in hours is an underestimate of the actual rise in computer throughput because of increased efficiency introduced by the F version of the monitor which was installed in May. It is extremely difficult to estimate the real gain in computer throughput because the monitor-introduced changes in efficiency vary for different kinds of operations, e.g., file handling compared to tape input/output. An exact comparison could be made if we were certain that the job mix has remained relatively constant over the history of the Sigma 7; on the contrary, we are certain that it has not remained constant.

The only guess that can be made is based on the fact that average job time has decreased by 0.3 minutes since monitor F was introduced in May, 1971. This translates to a hypothetical additional 130 hours based on the 1970 level of monitor efficiency. It is possible, then, that the 15 percent increase in actual computer hours represents some 24 percent increase in throughput.

We are always striving for increases in system efficiency, and programmers within the Institution are becoming more sophisticated. These factors work in the opposite direction to achieving more hours and a lower hourly rate. Perhaps, in the near future, the reliance upon use hours and hourly rate will be for financial purposes only and will not be considered a measure of performance.

The distribution of use has changed in 1971, much in the same direction as it did between 1969 and 1970. That is, ONR percentage use has decreased from 76 percent in 1969 to 62 percent in 1970 to 52 percent in 1971. The National Science Foundation use and W.H.O.I. business use remained at essentially the same percentage as last year. There was markedly increased use by the National Marine Fisheries; a large user in 1971, partially supported by the University of Hamburg, was the holder of the Doherty Chair.

The distribution in 1971 was:

Source of Support	Percentage of use
ONR Contracts	52.2
NSF Grants	15.8
WHOI Business	8.2
National Marine Fisheries	8.1
Other Government	4.4
Doherty Chair	4.0
University of Hamburg	2.7
Outside Commercial	2.6
Miscellaneous	2.0
	100.0

Although the Moored Buoy project is still the single largest user of computer time, its percentage of use has substantially decreased from 48 percent in 1970 to 34 percent in 1971. The development of other large users of the computer facilities is a healthy trend.

Annual job statistics are as follows:

	1970	1971
Jobs processed	27,845	36,125
Total job time	1,381.00 hours	1,657.26 hours
Average job time	2.98 min.	2.75 min.

Programming and analysis

A wide variety of programming tasks has been completed by the IPC staff during 1971, both for the Sigma 7 and for the Hewlett Packard shipboard systems. For each of these two computer systems, at least half of the available programming time was spent on systems maintenance and development, user consultation, and other background tasks. The other half was spent in applications programming.

For the Sigma 7, processors to edit, copy, and dump magnetic tapes are continually being improved, as are other general purpose utility routines. Business systems on the Sigma 7 continue to be improved and expanded. The Handbook for Computer Users requires continuous editing to ensure that users have the latest information available. As scientists increase their familiarity with the capabilities of our computing system, they write more sophisticated programs, requiring more help from the programming staff in consultation and trouble-shooting.

Major new programs completed for the Sigma 7 include a general purpose time series analysis program, with special emphasis on spectral analysis using the Fast Fourier Transform, for the Physical Oceanography Department. A program to map and plot distribution of fish species has been completed for members of the Biology Department. Among business systems, a new program has been written for the retirement plan.

New general purpose utility programs have been added to the Hewlett Packard shipboard systems, and shipboard software is being improved. A new shipboard program has been written for real-time digital acquisition of conductivity, temperature, and pressure. The program includes output to digital magnetic tape and plots of salinity and temperature versus pressure. Another program analyzes recorded ambient noise in the ocean.

One Fortran class has been given to Institution employees and summer students.

National Science Foundation Grant GJ-133

This grant of $250,000 was given on July 1, 1968 for three years; we obtained an extension of one year to June 30, 1972. These funds are used to supply computer time for student use (both class work and research) and to unsponsored scientists from both the Institution and the Marine Biological Laboratory. A large amount of the systems programming necessary to maintain the Sigma 7 operations is also supported by this grant. Computer time for student and unsponsored research amounting to 64 hours was used on a wide range of problems covering every area of the Institution's interests. After June 30, 1972, such support will come through the Institution's Education Office.

SUMMARY OF THE 1971 ACTIVITIES OF THE DEEP SUBMERSIBLE ENGINEERING AND OPERATIONS SECTION

William O. Rainnie

Introduction

This year was an active one in the Section with solid achievement the result. The beginning of the period found R/V *Lulu* at the dock in caretaker status due to lack of funds. *Alvin*, on the other hand, was well into the process of rebuilding to be ready for trials in May. Other projects were undertaken by the Section, including a saturated diving experiment from *Lulu* in the spring; an eight-month operating season with *Alvin/Lulu* ranging north into the Gulf of Maine, and south to Key West and Tongue of the Ocean; continued involvement in Project *Titanes*, including procurement of the electrical penetrators, and interface matters, with the new variable ballast system; engineering design and test of an acoustic navigation system; participation in the design and test of several experimental devices for biology, geology and geophysics; and assisting in the planning phase of a major scientific assault on the Mid-Atlantic Ridge in 1973.

Completion of Alvin rebuild

The rebuild was completed on a minimum-cost minimum-change basis because of funding deficiencies, using some of the more expensive spare parts without replacement. For example, the spare set of battery boxes, a high-cost item, is now in use and there is no spare set. The sonar electronics were borrowed rather than procured. Although the situation created anxiety when breakdowns occurred, only about 2% of possible dives were aborted due to *Alvin* deficiencies.

The major modifications made during the rebuild were as follows: (1) The control valves, etc. were moved from the main propulsion box to a new box for the lift props. (2) The mercury trim system was made part of the main propulsion hydraulic system, thus eliminating a separate pump and motor. (3) The battery drop mechanisms were modified. (4) The instrument mounting frame in the pressure hull was modified to permit easy transfer to the titanium hull.

Work was completed in mid-May at which time sea trials and training were conducted in Woods Hole Harbor. Navy material and pilot certification was successfully passed in early June and *Alvin* was declared ready to embark on an ambitious diving program extending into December.

Operating season

In June, *Alvin* supported by *Lulu* commenced operations by establishing a semi-permanent bottom station at 1800 m depth due south of Cape Cod. The first cruise was in support of biology and physical oceanographic experiments. Passive acoustic targets were planted at the bottom to permit return at will. Some instruments were emplanted and recovered; several were left to be picked up later in the summer, but weather subsequently prevented this.

The operating cruises were about ten days in length and were conducted to support various experiments in geology, geophysics, biology, physical oceanography and ocean engineering. Locations included the Gulf of Maine, south and east of Cape Cod, the Straits of Florida from Palm Beach to Key West, and the Bahamas in December at which time *Lulu* departed for Woods Hole ending a record season for number of dives made. They were as follows:

Test, training, and certification	22
Navy work in AUTEC Range	5
Engineering dives	5
Science dives	
Geology	21
Biology	15
Soil Engineering	4
Physical Oceanography	1
A.R.P.A. Instrumentation tests	9
	82

The dive summary shown in Table OE-1, p.17, may be referred to for more details.

At the end of this period, *Lulu* was preparing to depart for Florida to support *EDALHAB* in Project *FLARE* (Florida Aquanaut Research Expedition) sponsored by the National Oceanic and Atmospheric Administration (N.O.A.A.). *Alvin* has been moved into the high-bay area of the Iselin Building to be refitted for operating at a depth of 12,000 feet.

Progress on going deeper

The titanium hulls being built by Mare Island Naval Shipyard (MINSY) are progressing at a pace somewhat slower than originally planned. The expected delivery in Woods Hole of the tested titanium hull for *Alvin* is now early summer 1972, with installation planned for the fall of 1972.

The Institution procured the design of the electrical penetrators and took bids for the production of 23 units. These units are nearing completion and should be delivered for installation by MINSY early in 1972.

The new variable ballast system designed and built by the Naval Ship Research and Development Laboratory (N.S.R.D.L.), Annapolis, Maryland, is in the final testing phase and will be delivered to Woods Hole early in 1972 for installation in *Alvin* at the Institution during the current refit.

The large buoyancy package housing nine titanium spheres will be replaced during this refit by a block of syntactic foam fabricated at the Institution.

During this refit, it is planned to make as many modifications necessary to *Alvin* for going deeper as time and funds available permit. The hulls will be swapped during the fall and winter of 1972. Final trials and certification should take place in early 1973 and provide the scientific and engineering community with the capability of conducting dives to the design depth of 12,000 feet.

Advanced Research Project Agency (A.R.P.A.) progress

The Section was involved in the coordination of this program, design and testing of an acoustic navigation system for *Lulu/Alvin*, and engineering in support of the design and testing of various devices for the Department of Biology and the Department of Geology and Geophysics.

The first phase of the acoustic navigation system composed of surface ship mounted interrogation, receiving and computation equipment, submarine and bottom-mounted transponders, was designed, procured and tested satisfactorily. Transponder nets were planted surveyed and recalled acoustically without failure. The system was used to support some of the experiments conducted by the other Department investigators in the Bahamas and the Gulf of Maine.

Man-in-the-Sea programs

In April successful engineering and scientific experiment was conducted off the Isle of Shoals in cooperation with the University of New Hampshire. *EDALHAB*, designed and built by the University, was deployed and supported by *Lulu*. Three students spent four days saturated at 40 feet. Biologists planted West Coast crustaceans to observe their compatibility with East Coast environmental and biological conditions.

The success of this mission led to further Institution involvement in Project *Flare*. They are planning and coordinating the program as well as supplying the on-scene direction and major support vessel. Twenty-five scientific investigators from a wide list of organizations will conduct ten missions of three-five days at a depth of 45 feet. The program will last from January to April of 1972 near Miami, Florida.

TABLE OE-1

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
N.A.	5/17/71	309	Off WHOI Pier 41°31.4'N 70 40.3'W	ONR / Tethered trim and electrical check	V. P. Wilson E. L. Bland	W. Marquet	1602	1746	1^h44^m	13'	First Dive 1971
"	5/18/71	310	Off WHOI Pier 41°31.4'N 70°40.3'W	ONR / Tethered trim and inclining experiment	V. P. Wilson E. L. Bland	A. Medeiros	1040	1510	4^h30^m	13'	Not all time submerged for inclining experiment
"	5/20/71	311	Great Harbor 41°31'N 70°40'W	ONR / Untethered trim dive and system checks	E. L. Bland V. P. Wilson	R. Weaver	1138	1335	1^h57^m	13.7/ 45	Launched and recovered from LULU. First free dive 1971
"	5/22/71	312	Great Harbor 41°31'N 70°40'W	ONR / Dummy battery drop, trim instrument test	V. P. Wilson E. L. Bland	G. Meier	1130	1211	0^h41^m	14/ 50	
"	5/25/71	313	Great Harbor 41°31'N 70°40'W	ONR / Sea trials	E. L. Bland V. P. Wilson	R. Picard	1517	1642	1^h25^m	13/ 42	
N.A.	5/26/71	314	Great Harbor 41°31'N 70°40'W	ONR / Orientation	V. P. Wilson E. L. Bland	J. Miller, N.O.A.A.	1142	1225	0^h43^m	13.7/ 45	
"	"	315	Great Harbor 41°31'N 70°40'W	ONR / Orientation	V. P. Wilson E. L. Bland	J. Miller, N.O.A.A.	1316	1339	0^h23^m	15.2/ 50	
"	"	316	Great Harbor 41°31'N 70°40'W	ONR / Orientation	V. P. Wilson M. J. McCamis	J. Donnelly, O.N.R.	1409	1452	0^h43^m	15.2/ 50	
"	"	317	Great Harbor 41°31'N 70°40'W	ONR / Orientation	V. P. Wilson	P. Wiebe J. Phillips	1521	1554	0^h33^m	17.8/ 58	
"	5/27/71	318	Great Harbor 41°31'N 70°40'W	ONR / Orientation	V. P. Wilson E. L. Bland	CDR. N. Brodeur, Canadian Navy	1021	1102	0^h41^m	19/ 62	

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
40	6/2/71	319	S.W. of Martha's Vineyard 41°09'N 71°00'W	ONR / Navy Pilot Certification	W. O. Rainnie V. P. Wilson	W. Sutter, SUBDEVGRU ONE	1640	1719	0^h39^m	30.5/ 100	
"	6/2/71	320	S.W. of Martha's Vineyard 41°09'N 71°00'W	ONR / Navy Pilot Certification	M. J. McCamis E. L. Bland	R. Whitaker, SUBDEVGRU ONE	1802	1901	0^h59^m	31.5/ 103	
"	6/3/71	321	39°44.3'N 70°58.7'W	ONR / NAVSHIPS MATERIAL CERTIFICATION	V. P. Wilson E. L. Bland	R. Gaites, NAVSHIPS	1141	1730	5^h49^m	1840/ 6000	First Deep Dive
"	6/11/71	322	41°31.3'N 70°40.3'W	ONR / System Check out	V. P. Wilson M. J. McCamis	A. Medeiros	1105	1220	1^h15^m	70	

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
41	6/17/71	323	39°46'N 70°40'W	ONR / Survey bottom station and Benthic Biology	V. P. Wilson	J. Grassle P. Smith	0929	1512	5^h43^m	1805/ 5900	Established bottom station No. 1. Had V.B. problem. Cause for termination of dive.
"	6/18/71	324	39°47.7N 70°40'W	ONR / Plankton tow on bottom	V. P. Wilson E. L. Bland	T. Lawson	1346	1943	5^h57^m	1450/ 4750	Propulsion acted up at higher amperage (75.5A).
"	6/19/71	325	39°50'N 70°40'W	ONR / Plankton & DSL observations	E. L. Bland	J. Craddock R. Beamis	1012	1639	6^h27^m	1025/ 3350	Propulsion same.
"	6/20/71	326	39°47'N 70°40'W	ONR / Benthic Biology	V. P. Wilson	J. Grassle P. Smith	1257	1949	6^h52^m	1440/ 4710	Propulsion same.
"	6/21/71	327	39°47'N 70°40'W	ONR / Physical Micro-Structure	E. L. Bland A. Medeiros	J. VanLeer, M.I.T.	1102	1812	7^h10^m	420/ 1520	
"	6/22/71	328	39°46'N 70°40'W	ONR / Survey bottom station & Benthic Biology	V. P. Wilson E. L. Bland	J. Craddock	1038	1940	9^h02^m	1810/ 5918	V.B. tested ok Visit all 4 towers. Still have propulsion problem

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
42	7/2/71	329	Wilkinson Basin 42°38'N 69°36.5'W	ONR / Benthic Biology	V. P. Wilson/ M. J. McCamis	G. Rowe	1104	1842	7^h38^m	275/ 902	
"	7/3/71	330	Wilkinson Basin 42°32.5'N 69°32'W	ONR / Benthic Biology	M. J. McCamis	G. Rowe D. Bumpus	1539	1951	4^h12^m	267/ 876	
"	7/4/71	331	Murray Basin 42°25'N 69°45'W	ONR / Benthic Biology	V. P. Wilson	G. Rowe G. Keller- N.O.A.A.	0802	1155	3^h36^m	245/ 804	Search for lost hydro-phone
"	7/5/71	332	Province-town Harbor 42°02'N 70°11'W	ONR / Penetrometer Test	V. P. Wilson/ M. J. McCamis	T. Nixon- Lehigh	1641	1743	1^h02^m	18/ 52	
"	7/7/71	333	Murray Basin 42°25'N 69°45'W	ONR / Bottom Sed-iment Data	M. J. McCamis	A. Richards L. Van Siver Lehigh	1758	1056	7^h02^m	248/ 814	Search for lost hydro-phone
"	7/8/71	334	Wilkinson Basin 42°48.2'N 69°46.5'W	ONR / Bottom Sed-iment Data	M. J. McCamis	M. Perlow T. Terry- Lehigh	1138	1808	6^h30^m	244/ 800	

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
42	7/9/71	335	Wilkinson Basin 43°34'N 69°31'W	ONR / Bottom Sed-iment Data	V. P. Wilson	J. Parks P. Dzwilewski Lehigh	1114	1614	5^h00^m	245/ 804	Shortened by weather
"	7/10/71	336	Cape Cod Bay 41°57'N 70°18'W	ONR / Bottom Sed-iment Data	V. P. Wilson	A. Richards- Lehigh W. Schneider- USNRDL	0957	1026	0^h29^m	30.5/ 100	Aborted for leak indi-cation

LOLO Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
43	7/16/71	337	Murray Basin 42°25'N 69°45'W	ONR / Search for lost array and pilot training	V. P. Wilson W. O. Rainnie	R. Weaver	1209	1630	4^h21^m	242^m	CTFM failure
"	7/18/71	338	Cashes Ledge 42°51'N 68°52'W	ONR / Outcrop geology	V. Wilson E. Bland	R. Ballard	1036	1756	7^h20^m	150^m	Hard rock cores
"	7/19/71	339	Sigsbee Knoll 43°01'N 69°06'W	ONR / Outcrop geology	E. Bland A. Medeiros	Lou King, Bedford Institute	1153	1250	0^h57^m	82^m	Aborted by ship's gyro failure
"	7/20/71	340	Sigsbee Knoll 43°01'N 69°06'W	ONR / Outcrop geology	V. Wilson A. Medeiros	Lou King, Bedford Institute	1540	1958	4^h18^m	40^m	Hard rock drill failed
"	7/21/71	341	Jeffreys Bank 43°26.5'N 68°37'W	ONR / Outcrop geology	E. Bland	R. Ballard M. Kane, USC&GS	1217	1828	6^h11^m	128^m	
"	7/22/71	342	Harvey Black Knoll 43°04'N 69°15'W	ONR / Outcrop geology	V. Wilson J. Donnelly	Lou King, Bedford Institute	1132	1740	6^h08^m	139^m	

LOLO Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
44	8/5/71	343	Corsair Canyon 41°12.5'N 66°04'W	ONR / Geology	V. P. Wilson F. Medeiros	David Ross	1153	1444	2^h51^m	1604^m	Aborted due to ground #2 battery
NA	8/10/71	344	Woods Hole Harbor	ONR / Test and trim dive	V. P. Wilson E. L. Bland		1355	1459	1^h4^m	47 ft.	
45	8/13/71	345	39°46'N 70°40'W	ONR / Biology	V. P. Wilson E. L. Bland	Ruth Turner	1038	1849	8^h11^m	1810^m	First deep science dive with female observer
46	8/25/71	346	39°46'N 70°40'W Bottom Station 1	ARPA / Navigation Biology	E. Bland R. Weaver	John Teal	1140	1944	8^h04^m	1825^m	
NA	8/31/71	347	Woods Hole Harbor	ONR / Check out Navigation System	V. P. Wilson J. D. Donnelly	W. Marquet	1103	1302	1^h59^m	70 ft.	
47	9/4/71	348	Parker Ridge 42°43.5'N 68°50.6'W	ONR / Geology	E. Bland	R. Oldale R. Ballard	1157	1725	5^h28^m	111^m	Core samples northern portion Parker Ridge

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
47	9/5/71	349	Parker Ridge 42°39.3'N 68°50.5'W	ONR / Geology	V. Wilson J. Donnelly	R. Ballard	1036	1443	4^h7^m	115^m	Rock samples southern portion Parker Ridge
"	9/7/71	350	Wildcat Knoll 42°23'N 70°00'W	ONR / Geology and A.R.P.A. Navigation	E. Bland	W. Marquet R. Oldale	1355	1730	3^h35^m	210^m	
"	9/8/71	351	Wildcat Knoll 42°23'N 70°00'W	ARPA / A.R.P.A. Navigation	V. Wilson J. Donnelly	W. Marquet	1017	1138	1^h21^m	89^m	
48 Leg I	9/21/71	352	Site "D" 39°10'N 70°00'W	ONR / Buoy line recovery	V. Wilson E. Bland	None	1132	1527	3^h55^m	525^m	Line not recovered. Too much current.
48 Leg II	10/10/71	353	Straits of Florida 23°53'N 82°47'W	NOAA/ONR Bottom Geology	V. Wilson J. Donnelly	G. Keller, A.O.M.L.	1406	1417	0^h11^m	70^m	CO_2 blower failed.
"	10/12/71	354	Straits of Florida 23°54.5'N 82°47.5'W	NOAA/ONR Bottom Geology	E. Bland	R. Ballard J. Kofoed, A.O.M.L.	1109	1802	6^h53^m	1115^m	

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
48 Leg II	10/13/71	355	Straits of Florida 24°05'N 82°47'W	NOAA/ONR Bottom Geology	V. Wilson J. Donnelly	G. Keller, A.O.M.L.	1024	1710	6^h46^m	873^m	
"	10/14/71	356	Straits of Florida 24°16.5'N 82°23'W	NOAA/ONR Bottom Geology	E. Bland	G. Hershorn-hous, AOML G. Lapiene, AOML	1015	1305	2^h50^m	461^m	
"	10/14/71	357	Straits of Florida 24°16.5'N 82°23'W	NOAA/ONR Bottom Geology	E. Bland	D. Florwick, A.O.M.L. D. Lambert, A.O.M.L.	1317	1623	3^h06^m	452^m	
"	10/15/71	358	Sink Hole 24°15'N 81°50'W	NOAA/ONR Bottom Geology	V. Wilson	G. Keller, A.O.M.L. J. Kofoed, A.O.M.L.	1015	1634	6^h19^m	408^m	In sink hole there was no observable fresh water.
48 Leg III	10/21/71	359	Miami Terrace 25°35'N 79°50'W	NOAA/ONR Bottom Geology	E. Bland	J. Kofoed, A.O.M.L. C. Neumann, U. of Miami	1233	1845	6^h12^m	692^m	
"	10/22/71	360	Straits of Florida 25°00'N 79°15'W	NOAA/ONR Bottom Geology	V. Wilson	J. Kofoed, A.O.M.L. G. Keller, A.O.M.L.	1035	1648	6^h13^m	658^m	

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
48 Leg III	10/23/71	361	Straits of Florida 24°54'N 79°13'W	NOAA/ONR Bottom Geology	E. Bland	G. Keller, A.O.M.L. G. Hood, A.O.M.L.	1130	1701	5^h31^m	427^m	
"	10/24/71	362	Straits of Florida 27°04'N 79°22'W	NOAA/ONR Bottom Geology	V. Wilson	J. Kofoed, A.O.M.L. C. Neumann, U. of Miami	1334	1816	4^h42^m	666^m	
"	10/25/71	363	Straits of Florida 27°09.5'N 79°22.5'W	NOAA/ONR Bottom Geology	V. Wilson	G. Keller, A.O.M.L. C. Neumann, U. of Miami	1131	1804	6^h33^m	675^m	
"	10/26/71	364	Straits of Florida 27°20'N 79°25.2'W	NOAA/ONR Bottom Geology	E. Bland	G. Keller, A.O.M.L. J. Kofoed, A.O.M.L.	1035	1758	7^h23^m	668^m	Marlin struck sail.
"	10/27/71	365	Straits of Florida	NOAA/ONR Bottom Geology	V. Wilson	G. Keller, A.O.M.L. J. Kofoed, A.O.M.L.	1005	1535	5^h30^m	639^m	
"	10/28/71	366	Straits of Florida 27°14'N 79°13.5'W	NOAA/ONR Bottom Geology	E. Bland	G. Keller, A.O.M.L. D. Lambert, A.O.M.L.	1113	1741	6^h28^m	504^m	

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
48 Leg IV-A	11/6/71	367	Autec Range 24°20'N 77°31'W	ONR/ Bottom Recon.	V. Wilson E. Bland	None	0912	0947	0^h35^m	260^m	Surfaced to check hatch gasket.
"	11/6/71	368	Autec Range 24°20'N 77°31'W	ONR/ Bottom Recon.	V. Wilson E. Bland	None	1001	1658	6^h57^m	1536^m	Recovered one sample.
"	11/7/71	369	Autec Range 24°21'N 77°29'W	ONR/ Bottom Recon.	E. Bland V. Wilson	None	1050	1507	4^h17^m	1562^m	
"	11/8/71	370	Autec Range 24°16'N 77°30'W	ONR/ Bottom Recon.	V. Wilson E. Bland	None	0930	1455	5^h25^m	1525^m	
48 Leg IV-B	11/12/71	371	24°56.9'N 77°39.2'W	ARPA/ ARPA Navigation & Biology Recon	E. Bland J. Donnelly	W. Marquet	1136	1731	5^h55^m	1770^m	Searching for suitable location for bottom biology station

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
48 Leg IV-B	11/13/71	372	24°57'N 77°39'W	ARPA/ ARPA Navigation & Bottom Biology	V. Wilson	T. Smith J. Houbrick (Smithsonian)	1003	1704	7^h01^m	1799^m	Unable to locate triplane dropped from surface
"	11/15/71	373	25°00'N 77°35'W	ARPA/ Geology and Biology	E. Bland	R. Ballard G. Rowe	1042	1718	6^h36^m	1048^m	Hard rock bottom very steep hills
"	11/16/71	374	25°00.2'N 77°35.5'W	ARPA/ Wall Geology	V. Wilson J. Donnelly	R. Ballard	1151	1536	3^h35^m	650^m	Climb up cliff face to 16^m
"	11/17/71	375	25°00'N 77°35'W	ARPA/ Bottom Biology	E. Bland	G. Rowe J. Teal	1251	1736	4^h45^m	662^m	Unable to find transponder. Took box cores
"	11/18/71	376	25°00'N 77°34'W	ARPA/ ARPA Navigation and Bottom Biology	V. Wilson J. Donnelly	J. Teal	1115	1638	5^h23^m	749^m	Placed Bell Jar near transponder anchor
"	11/19/71	377	25°00'N 77°34'W	ARPA/ ARPA Navigation and Bottom Biology	E. Bland J. Donnelly	W. Marquet	1027	1523	4^h56^m	687^m	Recovered Bell Jar took box cores

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
48 Leg IV-C	11/24/71	378	25°00.2'N 77°32.5'W	ARPA/ ARPA Rock Drill Test	V. Wilson J. Donnelly	None	1532	1615	0^h43^m	18 ft.	Tested submerged release of rock drill on bottom
"	11/25/71	379	25°00.2'N 77°32.5'W	ARPA/ ARPA Rock Drill Test	V. Wilson J. Donnelly	None	1025	1354	3^h29^m	42 ft.	Unable to back clear of drill
"	11/26/71	380	24°58.2'N 77°34'W	ARPA/ ARPA Gravity Test	E. Bland J. Donnelly	T. Aldrich	1406	1712	3^h06^m	309^m	Tested ability to take gravity profiles
"	11/27/71	381	24°58.6'N 77°59.6'W	ARPA/ VB Test, Compressibility Test & Precision Navigation Depth	V. Wilson J. Donnelly	None	1200	1633	4^h33^m	1821^m	Test Dive
"	11/28/71	382	24°58'N 77°39'W	ARPA/ ARPA Biology	E. Bland	P. Weibe R. Steer (Frequency Devices Inc.)	1210	1722	5^h12^m	1830^m	Test of plankton net at deep depth

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
48 Leg IV-C	11/30/71	383	24°57.8'N 77°37.7'W	ARPA/ ARPA Magnetics and Navigation	V. Wilson	B. Luyendyk A. Eliason	1127	1140	0^h13^m	15^m	Ground in magnetometer
"	11/30/71	384	24°57.8'N 77°37.7'W	ARPA/ ARPA Magnetics and Navigation	V. Wilson	B. Luyendyk A. Eliason	1408	1622	2^h14^m	373^m	Magnetometer not functioning
"	12/1/71	385	25°00'N 77°33'W	ARPA/ ARPA Rock Drill Test	V. Wilson	A. Barrs	1252	1708	4^h16^m	53 ft.	Successful test of Rock Drill
"	12/2/71	386	25°00'N 77°34'W	ARPA/ ARPA Magnetics and Biology	E. Bland	R. Steer D. Williams	1351	1657	3^h06^m	301^m	Successful test of towed magnetometer. Plankton net not functioning properly
48 LEG IV-D	12/5/71	387	25°10'N 77°25'W	ONR/ Biology	E. Bland	G. Grice (NSF) Mary Johrde (NSF)	1019	1557	5^h38^m	1733^m	Plankton tows

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
48 Leg IV-D	12/6/71	388	25°00'N 77°34'W	ONR/ Bottom Geology	V. Wilson J. Donnelly	R. Dill (NOAA)	1245	1516	2^h31^m	740^m	Climb up escarpment
"	12/8/71	389	24°21'N 77°30'W	ONR-NAVORD/ AUTEC Recovery	V. Wilson E. Bland	R. James (LCDR, USN)	1349	1916	5^h27^m	1583^m	Night Recovery
"	12/9/71	390	24°20'N 77°31'W	ONR-NAVORD/ AUTEC Recovery	V. Wilson J. Donnelly	P. Looney	1154	1706	4^h12^m	1545^m	Made attachment of lift line to weapon on bottom

OCEAN STRUCTURES, MOORINGS AND MATERIALS SECTION

Robert G. Walden, Henri O. Berteaux, Paul B. Stimson, Clayton W. Collins, Jr., Stephen C. Dexter and Allan R. Davison

The major section activities this year continued to be in support of the moored array program. New mooring types were designed and tested, the mooring design and analysis program expanded and laboratory tests conducted. Section members participated in the joint education program (H. O. Berteaux, S. C. Dexter) and certain phases of ACODAC (H. O. Berteaux, A. R. Davison).

Shallow water mooring tests:-The environmental evaluation of candidate materials for mooring applications was continued at the shallow water test array "Buoy Farm" (H. O. Berteaux, A. R. Davison). Three new samples were set, bringing to 34 the total number of samples evaluated since the beginning of the test series. Seven samples failed during this period. The endurance of torque-balanced jacketed wire ropes was found to be much greater than the endurance of bare wire ropes. Two glass filament rod samples were set in 1970. One failed after 485 days, the other is still on station. A bare titanium rope sample failed after 27 days. The new epoxy-filled wire rope terminations seem to perform as well as swaged fittings. A new buoy antifouling and protective coating has been evaluated with great success over periods of two years.

Deep-sea moorings:--A number of surface and sub-surface deep-sea moorings for engineering and scientific purposes were designed (H. O. Berteaux). The quality control of the wire rope for these moorings was systematically pursued. Three engineering surface moorings were set at Site L for long-term (six months) evaluation. One failed (cause unknown), one was successfully retrieved after six months, one is still on station. Two short-term engineering moorings were set for measuring engineering parameters in regions of high currents (R. G. Walden, H. O. Berteaux). A total of 20 deep-sea surface moorings were deployed for scientific and engineering purposes from December 1970 to December 1971. Eight of these moorings failed. Most of the failed moorings were retrieved with the use of their recovery back-up systems. The following table is a list of the failed moorings and the cause of failure.

Table of Failed Surface Moorings 1971 (Table OE-1)

Mooring Station Number	Site	Mooring Purpose	Failure Identification
356	L	Engineering,six-month evaluation of	Lost. Unknown
373	Pacific	Scientific	Failure of U bolt of current meter plate
374	Pacific	Scientific measurement of equatorial currents	Wire rope pulled out of termination
396	D	Scientific current and temperature measurements	Broken wire rope termination (swaged fitting)
398	D	Scientific current and temperature measurements	Surface buoy pulled under by strong currents
399	D	Scientific current and temperature measurements	Current meter rotor and cage vibration leading to bolt shear
402	D	Scientific	Failure of bolts of current meter cage
403	J	Engineering. High shear current experimental	Broken wire rope termination (swaged fitting).

It should be noted that (1) most failures occurred in regions of high current and (2) near the surface. This unprecedented increase in the number of failed moorings points out the precariousness of the present surface mooring systems, and stresses the necessity for a continued effort in 1972 for the correction of the yet unsolved mechanical and structural problems.

ACODAC:--The analysis and design of six complex *ACODAC* buoy systems was completed (H. O. Berteaux). Buoy Engineering participation helped in the successful deployment and retrieval of these systems (A. R. Davison).

Analysis

A new computer program for the static analysis of surface and subsurface single point moored buoy systems was developed and extensively used (H. O. Berteaux and N. K. Chhabra).

Handling machinery

A new launching winch for deep-sea mooring lines has been constructed, and was tested at sea during October (P. B. Stimson). It features a hydraulic system for dissipating the large amount of heat generated by the launching of a mooring under high tension, and a low-speed rehaul capability. Its twin shafts are vertically mounted, and there is a built-in davit for lifting full reels on and empty reels off. Faults in the hydraulic system and the davit have been corrected, and the winch is scheduled for a second sea trial in January, 1972.

A machine for measuring synthetic fiber ropes under constant tension is under construction (P. B. Stimson). It is expected to improve the accuracy and repeatability of length measurements of mooring lines.

Instrumentation

A more reliable transmitter, tension keyer and antenna installation has been developed and tested (C. W. Collins) for use on our toroid buoys. Development and testing of a more sophisticated telemetry system with a digital command function is in progress (R. G. Walden, C. W. Collins). Engineering instruments to measure and record tension, inclination, depth and current speed for up to eight months have now been standardized and routinely used on our moorings.

Fishbite research:--The mechanical requirements for an effective thermoplastic armor for mooring lines are now well established, and a quest for a suitable formulation is in progress (P. B. Stimson). Most plastics which are hard enough to withstand fishbite prove to be too brittle to meet the flexural requirements. A slightly softer material, applied with somewhat greater wall thickness, may prove satisfactory.

Polycarbonate, previously found to be susceptible to chemically induced stress cracking when extruded over synthetic-fiber ropes, appeared to be compatible with wire rope, so 2,000 meters of 5/16" wire rope were jacketed with polycarbonate, and installed in Station 401 in August, 1971. Upon recovery two months later, the armor was found to be effective in preventing fishbite penetration, however it was severely cracked. Testing of polycarbonate for this service has been discontinued.

A portable instrument for measuring the penetration resistance of plastics has been designed and constructed. It proves to be most useful for the rapid screening of new materials, and ranks them in the same order as does our more elaborate laboratory apparatus.

Corrosion testing:--A number of materials are being evaluated (S. C. Dexter, P. B. Stimson) for future use in the buoy program as buoy line components including pressure cases and general hardware. Table OE II lists the metals and alloys that were exposed on moored buoys during 1971. After exposure, the samples are examined both macroscopically and microscopically to determine the types and rates of deterioration experienced as a function of depth in the water column.

Corrosion research:--Oceanographic instruments are now being maintained at sea routinely for periods of two to four months, with the trend being toward longer exposures of up to one year duration. In order to obtain valid information from these instruments their sensor elements must remain free of both biological fouling and corrosion for the entire exposure period. The fouling process begins on most surfaces with the formation of a primary microbiological layer or film during the first 300 hours of exposure. This film interferes with sensor calibration in a number of ways: (1) increased thermal time constant of temperature sensors, (2) damping of acoustic surfaces, (3) reduced transparency or reflectivity of optical surfaces, (4) binding of mechanical moving parts and (5) altered electrical conductivity. There is also reason to believe that microorganisms in the film are active in nucleating local corrosion cells on metallic surfaces.

In this context a program has been started (S. C. Dexter) to improve our understanding of the relation between the initial stages of microbiological fouling and marine corrosion. The scanning electron microscope is being used to directly observe the interactions of bacteria with metallic surfaces. Materials are being exposed both in the laboratory and in natural pelagic conditions.

Table OE-II

Duration	2 Mo.	4 Mo.	4 Mo.	12 Mo.
Mooring No.	401	407	407	404
Site	Sta. "L"	MODE Site	MODE Site	Sta. "L"
Nominal Depths	10m, 1000m 3000m, 5000m	10m, 1000 m 3000m, 5000m	3000m and 5000m	5400m
MATERIAL				
316 Stainless (Bulk)		x		x
316 Stainless (Sintered)	x			
6X Stainless (Sintered)	x			
Alloy 20			x	x
6061-T6 Al			x	x
7075-T6 Al		x		x
90-10 CuNi		x		x
70-30 CuNi		x		x
Monel 400		x		x
Inconel 625			x	x
Incoloy 825			x	x
Incoloy 718		x		x
Ti-6Al-4 Va		x		x

MICROSTRUCTURE STD SYSTEM

Neil L. Brown

This system was completed in January 1972 and underwent its first sea trials in February aboard R/V *Knorr*. Subsequently, it was used at sea on five additional cruises aboard Institution and Scripps vessels. The equipment performed satisfactorily on five of the six cruises. On one cruise leakage problems caused the conductivity sensor to malfunction.

The system consists of an underwater sensor unit which measures conductivity (C), temperature (T), and pressure (P) and a deck unit to process the signals from sensor unit. C, T and P information is transmitted digitally from the sensor unit in the form of 16 bit words, 30 times per second. The information is transmitted serially via a cable to the deck unit which provides the following outputs:

(1) serial or parallel outputs to a computer
(2) digital display of C, T and P in engineering units
(3) analog outputs to a 2-pen X,Y plotter

The high sampling speed, high resolution and small sensors are designed for both classical hydrographic observations as well as specialized microstructure studies.

During the year numerous improvements were made and deficiencies corrected. The deck unit (demodulator) was completely redesigned to simplify its use and to permit operation with a mini-computer.

Normally a computer is used to process the C, T and P information to obtain values of salinity, depth and other derived parameters, and show the raw data on computer magnetic tape. Since the usual shipboard computers are too large and expensive to be consistently available for use with the microprofiler, a program to interface a mini-computer to the system was commenced.

Construction of a second microprofiler and deck unit is well advanced. Also three general purpose versions of the system are being constructed for the GEOSECS program. These units are simpler

and less expensive and have the same performance as the microprofiler with the exception of sampling speed. The microprofiler has three digitizers (one for each parameter) and operates at 30 samples per second. The general purpose version has only one digitizer which samples all three sensors 10 times or less per second.

AUTOPROBE

Kenneth H. Burt

Autoprobe was successfully operated for a series of vertical shear flow experiments near Bermuda. The experiments in cooperation with H. Thomas Rossby of Yale University required that the Autoprobe operate in the vertical excursion mode. Autoprobe functioning as a magnified sinking float was cycled between 500 m and 800 m at a rate of 4 cm/sec. Autoprobe was fitted with a 2kHz acoustic transducer, that was used to signal bottom-mounted hydrophones in the Bermuda area. The acoustic travel time data was recorded in Bermuda on an analog tape recorder and was processed at W.H.O.I. and Yale. The results of these experiments, presently being processed, will yield detailed measurements of the vertical scale and magnitude of the shear associated with the microstructural layering in the main thermocline.

Autoprobe was operated from the *Panulirus II*, and from the *Sir Horace Lamb* for a total of six dives. Improvements were incorporated in the overall operation, the control system, acoustic telemetry system and mechanical system. Care was taken to insure that additional instruments and measurement equipment could be attached easily, increasing the versatility and ease of obtaining pertinent oceanic data.

The operational use of the Autoprobe will be pursued during 1972, resulting in participation in three independent field programs, the Current System Southeast of Newfoundland, Coastal Upwelling Experiments, and Microstructure Studies.

The overall specifications of the Autoprobe are as follows:

Depth: 2,000 meters max.
0 → 1700 meters operating

Duration: Hours → 10 days (depending on desired function)

Payload carrying capacity: ~ 50Kg (unlimited, with the addition of syntactic foam flotation)

Accuracy of controller: ±10M or ±0.1°C (depending on the energy/time available)

Acoustic telemetry: temperature, pressure data (additional information possible)

Sensors: temperature ±0.01C
±0.5 meters repeatability

Control modes: isothermal
isobaric
programmed vertical excursions
remote controlled from the surface
A rate feedback control system is used.

Safety devices: AMF Acoustic Command System
independent timer that blows blast
overpressure release weight-dropping device
self-contained timer/pressure actuated
weight release
collapse depth ~ 6,000 meters

SALT FINGERS

Albert J. Williams, III

The oceans of the world have large areas in temperate and tropic regions where salty water overlies fresher water. Temperature gradients stabilize this situation, but it appears that salt and heat are transported downward faster than is predicted by molecular diffusion. It has been proposed that this occurs through salt fingering. In such a case, it is expected that the buoyancy flux of the sinking salt and rising fresh water produces mixed layers separated by fingering regions. Steps in temperature and salinity profiles are frequently observed in regions with negative salinity gradients so it is tempting to assume fingering is occurring there. However, there are other proposed sources of layers (and layers have been observed in fresh-water lakes), so it is not certain that the layers are formed by fingering. To resolve this question and learn more of oceanic microstructure, we have planned an experiment to detect oceanic salt fingers optically.

The planning of an experiment has encompassed three parts: optical design, optical testing, and site selection. An optical detector depends on the difference in index of refraction between the up- and down-going fingers. The design then depends on how large the angular deviation of a ray will be. The second question is essentially how large an index difference can be expected in a natural situation. This is derived from tests in a large tank. Finally, a site in the ocean must be selected from hydrographic data where the odds favor fingers.

Carl S. Albro has computed the deviation of a ray of light traversing a field of salt fingers, using as a model for the ordering of the array of fingers a square array in plan with 10 fingers on a side. This model was suggested by experiments done in 1970 and by shadowgraphs of sugar-salt fingers taken in plan by F. Claude Ronne in the spring of 1971. With an index of refraction difference between up- and down-moving fingers of 5 ppm, the deviation is 10 μradians per centimeter pathlength.

As the angular deviations from different regions in the finger field vary in a regular way, a pattern can be produced either by an angle sensing system or by an intensity sensing system. The shadowgraph is an example of an intensity sensing system in which a screen is placed at a critical distance from the fingers. This critical distance becomes very long as the fingers get weak. An imaging system can shorten the actual instrument and by adding an eclipsing aperture, a schlieren system sensitive to angular deviations directly is produced. Both of these systems are being explored.

In the summer of 1971, Charles C. Eriksen obtained measurements of temperature and salinity while observing the presence of fingers with the shadowgraph technique in a tank of sea water heated from above. Evaporation at the surface produced a salinity gradient which gave rise to fingering and mixed regions. A fingering region was observed from 20 cm to 40 cm below the surface having a salinity gradient of .003 °/oo/cm and a temperature gradient of .16°C/cm. Light collimated to reduce stray ray directions to 40 μradians was passed through the fingers by a periscope immersed in the tank. The deviations in the experiment were significantly greater than this 40 μradians; probably 10 times as much. It is expected that using a schlieren system, fingers arising from gradients one-tenth as strong can be detected.

A map of vertical salinity gradients in the Atlantic has been compiled from hydrostation data by C. S. Albro. The strongest gradients are observed off the bulge of South America where differences of 1 °/oo over 50 meters are often reported. In the Caribbean, 0.3 °/oo over 50 meters is reported. Bermuda has 0.15 °/oo /50 meters. These are reflections of mean gradients and do not uniquely indicate probability of finding fingers. However, this map may be useful to others studying microstructure.

EXPOSURE OF MATERIALS AND MONITORING OF ENVIRONMENT AT DEEP-BOTTOM STATION OF THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

James W. Mavor and Stephen C. Dexter

A deep-bottom research station was established in June on the Atlantic continental rise at a depth of 1,785 meters at 39°46'N, 70°30'W.

Three dives to the site were made by the deep submersible *Alvin* in June and August, and it is planned that *Alvin* will visit the station twice yearly in the future to place and retrieve instruments and material samples. In June, a group of metals in galvanic couples were placed for corrosion

study, and will be returned at one and two years. Wood samples were exposed within and above the sediment, and instruments were deployed for injecting nutrients into the sediment. In August, more sophistocated galvanic couples, designed after a suggestion of the ASTM Corrosion Committee, were placed by *Alvin* for long-term exposure. During the summer, a student project initiated the record of performance of structures placed at the deep station and gathered oceanic and sedimentary properties from all available sources. In August, galvanic couples of selected metals were placed on a deep-moored buoy system at Site L at a depth of 5,000 meters. Recovery was made in October.

MODIFIED RAY THEORY

James A. Davis, Edward L. Murphy, James A. Doutt, Frederick R. Hess,

The investigations reported previously on the development of a modified ray theory have continued. This theory provides a ray representation for some of the diffraction effects encountered in underwater sound propagation problems. These effects can be formulated as beam displacement and leakage phenomena which can combine to provide models for the formation of wavelength-dependent shadow zones and caustics, the so-called "leakage arrival", and attenuation in surface sound channels.

The result of extending this theory to include boundary conditions corresponding to a pressure release surface and to a rigid boundary was presented at a meeting of the Acoustical Society of America in Washington in May. While a pressure release surface represents one physical boundary of the water column, the sea surface, a rigid boundary is an idealized situation not encountered in the oceans. For this reason, more general boundary conditions have been considered in order to represent the other physical boundary of the water column, the ocean bottom. For a simple case of a homogeneous medium in contact with an inhomogeneous medium, the preliminary analysis indicates that while special treatment is required for source angles near either a critical angle or an angle of intromission, the overall effect is the introduction of a caustic in place of the shadow boundary predicted by ordinary ray theory. The theory has also been extended to include the effect of a discontinuity in the sound velocity gradient. A discontinuity of this type in ordinary ray theory gives rise to an infinity in the derivative of the range with respect to the source angle. Modified ray theory however predicts no such infinity. Problems involving discontinuous sound velocity gradients in ordinary ray theory can also give rise to "false" caustics. Preliminary indications are that at sufficiently low frequencies these caustics will not be present in the modified ray theory solution.

In this last year, due to the development of computer programs, it has been possible to analyze some of the pertinent aspects of the modified ray representation. In particular, the range (for a given source-receiver depth) as a function of ray parameter (angle at the source) has been investigated numerically for a variety of sound velocity profiles for unbounded problems and for problems in which there is a pressure release surface or a rigid boundary. The results of this investigation can be summarized as follows: (1) modified ray theory predicts a caustic whose location and strength is dependent upon frequency and problem type (unbounded, pressure release, or rigid boundary) whereas ordinary ray theory predicts a shadow boundary whose location is independent of frequency and problem type, (2) modified ray theory shows less sensitivity to the details of the sound velocity profile than does ordinary ray theory, and (3), as expected, at sufficiently high frequencies the modified ray theory results approach those of ordinary ray theory. These results have been presented, in part, at a meeting of the Acoustical Society of America in Washington in May, and in more detail at a Conference on Geometrical Acoustics (Ray Tracing) held at the SACLANT ASW Research Centre, La Spezia, Italy, in September.

While range *vs* ray parameter information gives one an insight into the nature of the effects predicted by modified ray theory, this information is more qualitative than quantitative. The importance of these effects can be determined only by calculation of the sound intensity. This is also the only way in which a comparison with experiment can be made, since the usual result of an experiment is a sound intensity. For these reasons a computer program is being prepared which will calculate intensity. This program will compute intensity as a function of range for the three problem types (unbounded, pressure release surface, rigid boundary), using either a sound velocity which varies linearly with depth, or an index of refraction whose square varies linearly with depth. Special techniques are employed to permit calculation of the intensity in the vicinity of caustics. Although this program is not yet complete, a comparison of preliminary results with an exact answer is encouraging.

The theoretical work during 1970 provided the groundwork for the sound propagation experiments which were performed on the March *Knorr* 19 cruise. These experiments were designed to test the validity and limitations of modified ray theory with respect to low-frequency sound propagation. Experiments were performed in the Caribbean Sea, employing sonobuoys modified for propagation use (F. R. Hess, Summary of Investigations conducted in 1970), and in an area near Bermuda in cooperation with the *Sir Horace Lamb*. Unfortunately, weather and equipment problems coupled with having poor sound velocity conditions left these experiments marginal with respect to testing the various aspects of the theory. The analysis of the experiments has been carried out using analog methods, with the interpretation of the results being facilitated by pressure-time plots obtained during the course of the experiments by digital methods.

LONG-RANGE SOUND TRANSMISSION

Richard T. Nowak

R/V *Knorr* made her maiden Atlantic crossing while participating in a series of sound transmission experiments conducted by Woods Hole and the Naval Research Laboratory. From mid-August until the end of October, measurements were made in the Northeastern Atlantic in the region where the outpouring subsurface Mediterranean waters create a double sound channel with the resulting complexities in the transmission channel. Structural problems with the main winch drum of *Knorr* almost became a stumbling block for the cruise, but they were quickly remedied, and good reports of the ship returned to Woods Hole.

The sound transmission and ambient noise data confirmed the complexities of the sound channel, and the data are now undergoing analysis.

ACOUSTIC DATA CAPSULE (ACODAC) PROGRAM

Scott C. Daubin and Earl E. Hays

The Acoustic Data Capsule is an instrument package for collecting acoustic data throughout the deep ocean water column while unattended for extended periods of time. The outputs from six hydrophones in a submerged vertical array are recorded according to preset time instructions which depend on the mission.

The completed ACODAC systems were deployed at sea at three locations: near Bermuda, west of Madeira, and in the Ionian Sea. While the sea-going expeditions were not faultless, ambient noise and sound transmission data were recorded in satisfying amounts.

The behaviour of the system is being analyzed, and engineering modifications are planned to make launch and recovery easier and to improve the reliability.

AMBIENT NOISE

Lincoln A. Baxter II, James A. Davis, Richard T. Nowak, James A. Doutt, Stanley W. Bergstrom, Willard Dow, Samuel T. Simkins, Frederick R. Hess

In February and March, at three sites in the Venezuela Basin of the Caribbean Sea, R/V *Knorr* was employed in a series of ambient noise measurements. Multichannel analog magnetic tape recordings were made for three depths simultaneously, using SSQ 57 and Modified SSQ 41A sonobuoys as in our Mediterranean Sea measurements reported last year, and a ship-supported deep hydrophone with a specially designed cable suspension to reduce strum and surge noise. Sites were occupied for 24 hours. The data were processed by analog computer and, in addition, a digital program utilizing the shipboard 2100 series H/F computer was tested and evaluated. Machinery noise from passing ships and biological sounds believed to originate from whales were recorded.

Selected samples of ambient noise from the 1970 cruise of *Atlantis II* in the Mediterranean Sea were analyzed with 1-Hz resolution on an analog digital spectrum analyzer located at the Naval Research Laboratory in Washington, D.C.

Reports on both the above projects were completed and submitted.

The digital programs developed on the above-mentioned *Knorr* cruise were utilized on *Knorr* cruises in September and October for ambient noise in the Iberian Sea on Project NEAT II.

Preparations are now underway for ambient noise measurements about 400 miles east of Bermuda, utilizing sonobuoys at several depths and a ship-suspended deep hydrophone.

LONG-RANGE ECHO RANGING

Robert C. Spindel and James R. Heirtzler

Side-scanning sonar techniques present an attractive means of obtaining bathymetric data over extended areas of the ocean bottom, in contrast to conventional echo-sounding methods which yield topographic data only along a single traverse, directly beneath the survey vessel's track. Almost all side-scan systems to date have operated at relatively high acoustic frequencies, thus giving high resolution but restricting maximum lateral ranges. With the development of acoustic receiving arrays having narrow beams, some of the objections to low-frequency operation have been eliminated. Although long acoustic wavelengths limit very high resolution, accurate bathymetric mapping is even more limited by the navigational uncertainties on the numerous tracks required of short-range systems. Successful testing of a long-range side-looking echo-ranging technique has demonstrated the possibilities of low-frequency echo sounding.

A long-range low-frequency system was employed in the Bahama Islands-Blake Plateau area. Explosive charges, detonated at depths of 800 and 1,500 feet, and fired at a rate of one every eight or ten minutes, were used as a source of omnidirectional, wideband acoustic energy. Echo returns were received on a 100-foot discrete hydrophone line array towed at depths approaching 2,000 feet. Echoes were monitored on a special flatbed graphic recorder and were recorded on magnetic tape for off-line processing. In addition, velocity profiles were constructed from XBT data to enable accurate ray tracing.

Strong echoes were received from the Bahama Islands-Blake Plateau escarpment at ranges of approximately 200 nautical miles. Spectral analysis of received echoes show that sound attenuation during propagation, and diffuse scattering upon reflection limit the amount of high-frequency energy received. Array tow noise can mask the echo at very low frequencies, thus pointing to an optimum receiver passband whose upper and lower cut-off frequencies respectively are functions of these parameters. The echoes can often be correlated with known topographic relief, and can delineate structure that is not obvious from inspection of contour maps of the area. In general, the survey area presents an acoustic picture dominated by distinct highlights that correspond to articulated topographic features. However, some highlights do not appear to be associated with structure discernable on bathymetric maps.

The echo signals tend to be diffused with no clear-cut time of arrival. Coupled with multipath propagation, this places a lower bound on the accuracy of reflector positional determinations. In these experiments, an uncertainty in reflector location of about three percent of the range to the reflector is obtained. There are frequent large variations in echo energy from shot to shot during the tracking of a single reflector. This observation places serious limitations on the reliability of a single-shot path.

Convergence zone detection of several small seamounts was achieved, indicating that this mode of operation may also prove valuable.

The results of this test show that similar systems have the potential to map submarine features at long ranges and over extensive areas with relatively little effort. The simplicity of array configuration, the ease with which it can be deployed, and the uncomplicated method of towing are factors that make this technique particularly attractive.

ACOUSTIC VOLUME REVERBERATION

Paul T. McElroy

Our efforts were largely directed to processing data collected in earlier cruises. Some instrumental upgrading was carried out. In addition, the applicability of level-crossing techniques to volume scattering was examined.

Use of a Coherent Frequency Synthesizer in Echo Sounder Studies of the Deep Scattering Layer (with Richard T. Nowak, Maxine M. Jones and Robert C. Spindel):--During Cruise 59 of *Atlantis II* in December 1970, simultaneous measurements of scattering returns at 9.5 kHz and 17 kHz were recorded using the frequency synthesizer. This is a broad-band system under computer control. The recordings were repeatedly played back to generate the best possible facsimile-recorder display of a vertical migration of the scattering layer occurring at sunset. Differences included different migratory patterns at the two frequencies and the occurrence of layers at each frequency not evident at the other.

These differences were striking enough to warrant an expansion of the system with considerably upgraded equipment. During the latter part of 1971 we started to carry out these changes which will include an improved transducer system with flat response (W. Huckabee, 1971), a broad-band power amplifier, more flexible pulse generation programs allowing rapid sweeps over frequency, and computer-controlled signal filtering. An early goal is measurement of the resonant frequency of a scattering layer. The system will also be used in level-crossing experiments conceived by Robert Spindel.

The Spectral Level of Explosive Charges fired very near to the Ocean Surface (with Stanley W. Bergstrom, Samuel T. Simkins and Harold K. Lim:--In the course of measuring broad-band scattering levels during recent cruises, explosives were fired at shallow depth (18"). Other workers have assumed that the spectral levels of such shots are described by the shock pulse alone, the bubble pulse being destroyed by blowout, and that there is no significant reflected signal, it being lost by cavitation.

The spectral levels of these shots recorded during Cruise 59 of *Atlantis II* were analyzed for sea states 0 to 5, and found to deviate considerably from that for the shock wave. The actual spectra were well-described by a theoretical study which used a pressure-time curve made up of the shock pulse and a truncated fraction of the reflection, truncation being caused by cavitation. Since the amount of truncation of the reflection was dependent on the range of the reflected signal to the surface, and that range was determined by the angular position of the receiver, the spectral levels have non-omnidirectional directivity patterns which vary as a function of frequency. This last point will be experimentally checked in an upcoming cruise.

These measurements have particular significance for scattering layer studies since investigators in this field have assumed that the spectra are (1) described by the shock pulse alone, (2) unaffected by surface reflections, and (3) omnidirectional. All three assumptions are incorrect, and bear on the analysis of scattering returns from explosive charges.

Scattering Levels in the Mediterranean and Eastern Atlantic (with Stanley W. Bergstrom and Harold K. Lim):--Scattering data collected during Cruise 49 of *Atlantis II* have been analyzed to give the volume scattering column strength in third octave bands extending from 1.12 kHz to 22.4 kHz. The data had been collected at 25 stations extending from the Eastern Mediterranean to the Azores. The spectra for each station have been plotted and display peaks in three frequency ranges: near 2 kHz, between 6 and 8 kHz, and above 12 kHz. The peaks are presumably due to resonant phenomena.

An initial attempt has been made to compare these acoustic data with the biological provinces noted by Backus *et al* (p.B-3), based on faunal collections made during the same cruise. The spectra cannot be easily segregated into acoustic provinces solely on the basis of similarities immediately obvious to the observer. Consequently, we are attempting to apply objective standards, such as those given by the technique of factor analysis, to see if the spectra can be grouped in a meaningful way.

Plots of the spectral levels of one frequency versus distance along the ship's track show peaking at numerous sites, including the southern Tyrrhenian Sea, the Strait of Gibraltar, and around 20°W, 33°N in the Eastern Atlantic. Scattering is stronger in the Western Mediterranean than in the Eastern in the frequency range from 2.82 to 7.10 kHz and from 14.1 to 17.8 kHz. At other frequencies there is generally too much scatter to note a trend.

Column strengths at particular frequencies for all such sites are being compared with fish collections made at nearby sites. Preliminary indications are that there may be rough correlations at certain frequencies, but the scatter in the data is high.

The Integrator (with Samuel T. Simkins, Asa S. Wing, Harold K. Lim and Frederick R. Hess):--The Integrator is an analog computer designed to measure volume-scattering strength and column strength over a selected depth range at 12 kHz.

Scattering levels recorded at least once a watch during Cruise 59 of *Atlantis II* have been computed and await a detailed study.

The Integrator has been upgraded. A tuned, differential input amplifier with low noise and wide dynamic range has been built. The task of digitizing the timing circuits is complete, permitting measurements over precise depth intervals. Components have been added to simplify the tasks required of a scientific watch in collecting data with this device.

A Theoretical Study of the Level Crossing Structure of Volume Reverberation Signals (with Robert C. Spindel):--The level-crossing structure of volume reverberation signals using a point scatterer model has been investigated. When the number of echo arrivals/unit time at a receiver (whose superposition constitute the reverberation) is large, either by virtue of high scatterer density or by insonification of a relatively large volume of water, this model leads to a reverberation signal whose statistics are gaussian. The computational convenience introduced by gaussian statistics has been exploited to compute the statistics of the level crossings and maxima of the reverberation.

In the case of narrow-band insonification, it has been shown that counting level crossings of the signal itself, or of its envelope, can provide a convenient scheme for determining the mean square reverberation level. In the case of wide-band signals the frequency response of the scatterers has been incorporated in the model. For a spectrally flat source, or a source whose spectrum decreases by 6 dB/octave (e.g., explosive sources) expressions have been derived relating scatterer Q, resonant frequency and expected number of zero crossings. The number of zero crossings is unaffected by attenuation or spherical spreading losses so that measurements do not require time varying gain (TVG) and attenuation correction systems. Using level crossings to determine the mean square reverberation level can also be accomplished without a TVG system since the technique can be applied at a precisely known range, thus reducing spreading correction to multiplication by a known constant.

The theoretical study suggests that level and zero crossing measurements may provide a means for determining scatterer density. In theory, gaussian statistics are realized in the limit of infinite scatterer density, but in practice there is a finite density which results in an effectively gaussian process. The size of correction terms to the gaussian distribution for even smaller densities can be determined from an Edgeworth series expansion. Experimentally we can adjust the ping length of a transmitted signal so that the received reverberation includes regimes of both gaussian and near-gaussian behavior, as determined by monitoring level-crossing information. If the effect proves to be pronounced, the correction terms, and therefore scatterer density, can be determined.

SAFETY PROGRAM

James W. Mavor

"Research with safety" continues to be the motto of the Institution safety program which depends primarily on individual responsibility and line supervision. The safety engineer reviews, advises, investigates and enforces where necessary. Safety problems were treated in several basic areas of operations at the Institution:

Submersible operations: *Lulu* hoist system certification, *Lulu* cranes, *Alvin* titanium hull review, *Alvin* certification review, *Lulu* sea-keeping ability analysis, review of "*Alvin* going deeper", swordfish hazard to *Alvin* windows, *Alvin* steel hull review.

Ships: *Knorr* hydraulic crane failure, *Knorr* acceptance board review, *Atlantis II* hydraulic crane review, *Knorr* vibration problem, *Knorr* stern strength, *Knorr* forward propeller foundation reenforcement, SWL specifications on all ships, *Knorr* trawl crane racking problem, *North Seal* seaworthiness, review of critical part replacement policy in handling equipment, shipboard tensiometers, *Knorr* DRV crane capability, *Atlantis II* trawl block failure, *Knorr*

trawl winch drum failure, membership on vehicle committee, planning new ship.

Operations at Sea: Giant coring, handling larger buoys on shipboard, *North Seal* loading and operations review, portable liquid nitrogen plant and storage, review of buoy handling procedures, long wire rope problem.

Pressure Test Facilities: 200,000 psi pressure installation review, pressure vessel code review, membership on ASME Pressure Vessel Committee on ocean applications, procurement and analysis of large Dahlgren pressure facility.

Government Safety Regulations: Accumulation and review of new federal and state safety codes especially new far-reaching federal legislation.

Laboratory Safety: Faulty heating systems, acquisition of Draeger gas samples and vials for five gases, laboratory mercury spill, compressed gas cylinder review, glass panel failures in Flume and Chemotaxis buildings, fumes and dust problems in ships and laboratories.

Diving Safety: Diving cascade system planning, diving regulations, membership diving board, EDALHAB review, gas analysis for diving.

Planning Safety Features of New Laboratory Facilities: Quissett Campus, gas cylinders.

Contractual Commitments of the Woods Hole Oceanographic Institution in Safety Area: Review of selected proposals, review of industrial contract.

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