Woods Hole Oceanographic Institution

REFERENCE NO. 73-12

SUMMARY OF INVESTIGATIONS
CONDUCTED IN 1972

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

APPROVED FOR DISTRIBUTION _____

Paul M. Fye, Director

In citing this manuscript in a bibliography, the reference should be followed by the phrase: UNPUBLISHED MANUSCRIPT.

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a record of the scientific results obtained by our staff members, but publication delays make these at least a year out-of-date before they appear.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 eleventh 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 1972, 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:

American Petroleum Institute
Atomic Energy Commission
Environmental Protection Agency
National Aeronautics and Space Administration
National Institutes of Health
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
National Science Foundation
Office of Naval Research
United States Coast Guard
United States Geological Survey

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

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DEPARTMENT OF BIOLOGY

Richard H. Backus, Department Chairman

BIOLOGY

MESOPELAGIC FISHES AND CRUSTACEANS

Richard H. Backus, Richard L. Haedrich, James E. Craddock, David L. Shores,
Stephanie Fofonoff, Denise Franklin, and David C. Judkins

A major effort this year was devoted to collecting midwater fishes on *Chain* Cruise 105. This two-month cruise followed a complicated track between Newfoundland, Portugal, the Norwegian Sea, and Ireland. With this cruise we have effectively finished our broad-scale sampling throughout the North Atlantic, a major milepost passed in our long-range goal to describe and understand the distribution patterns of mesopelagic fishes in this ocean. One hundred and forty-six Isaacs-Kidd trawl collections were made, and processing has begun.

Most of the fishes in the 119 Eastern Atlantic collections made during late 1970 (*Atlantis II* Cruise 59) have been identified. All major components, such as myctophids and gonostomatids, have been processed. Late in the year we moved all of our material processed to date into a new storage/workshop area behind the Barn. Here, species are arranged on shelves alphabetically, and have thus become much more accessible, for reference or for further investigation.

A paper reporting the fishes collected on *Chain* Cruise 85 (Sargasso Sea, November 1967) and comparing them with those from another transect of the same region (*Chain* Cruise 49, June 1965) has been reworked and is near completion. The abstract of the paper, entitled "A seasonal comparison of mesopelagic fish distribution in the western Sargasso Sea" reads:

> "The region of east-west tending thermal fronts at about 28°N in the Sargasso Sea is as significant a faunal boundary in the fall as in the spring. As had been true in the spring, north-of-the-front collections in fall were richer (2.0 cc/hr vs. 3.2 cc/hr) and more diverse (overall H = 3.2 vs. 2.6) than south-of-the-front ones. There was little change seasonally in terms of catch-rate, but individual species' abundances and average sizes changed markedly, probably a function of time of spawning. Despite pronounced changes in relative abundances of species, diversities (H) remained relatively constant north and south of the front. Our interpretation is that a dynamic balance between species and relative abundances exists, allowing maximum use of the poor environment of a central oceanic gyre."

Material for a paper on the midwater fishes of the Gulf of Mexico and Caribbean Sea (*Chain* Cruise 60, June 1966) is being assembled into a manuscript. The analyses show the Gulf and Caribbean faunas differ. The Colombian Basin has twice the standing crop of the other two Caribbean basins, but despite this relative richness, the Colombian Basin fauna differs but little from that of the other two basins.

Judkins' attention has been focussed on the decapod crustaceans collected in the midwaters. Up to now, these animals have been almost entirely neglected by us, and it will be of much interest to see whether distributional patterns displayed by the shrimps parallel those found in the fishes. Sorting and identifying these animals has occupied much of his time since arriving here in September; the processing of the Sargasso Sea material from *Chain* Cruises 49 and 85 is well along. Judkins has completed a paper on the malacostracans collected in the Gulf of St. Lawrence and Saguenay River on *Knorr* Cruise 1 (June, 1970).

LARGE MIDWATER NET

Richard H. Backus, James E. Craddock, David L. Shores,
Asa S. Wing, John M. Teal, and David Masch

Our "pop-up" net, a conical free-rising net 100 feet in diameter, is now complete and ready for testing early in 1973. We had trouble finding contractors to work on this large, awkward, special job and ended up doing all of the sewing ourselves.

BIOLOGY OF SALPS

Francis G. Carey and G. Richard Harbison

During R/V *Chain* Cruise 105 (June-July, 1972) preliminary investigations into the biology of salps were conducted, with primary emphasis on laboratory maintenance. *Pegea confederata* and *Cyclosalpa pinnata* were kept alive for six days. It was found that continuous, rather than intermittent, feeding increased survival time. Feeding experiments were conducted, and rates of waste elimination were measured. Salps maintained in the laboratory were observed to reproduce, both sexually and asexually. Salps collected by hand often were found to be covered with extremely dense populations of amphipods, which are now being identified and counted.

PHYSIOLOGY OF PELAGIC FISH

Francis G. Carey

Swordfish have a thermogenic organ which appears to warm their brain. This may be useful in allowing the swordfish to remain active after experiencing rapid temperature change in passing through the thermocline. We have been able to draw certain comparisons between this tissue and the brown fat which serves as a thermogenic organ in young mammals. A cruise on the commercial fishing vessel *Cap'n Bill IV* provided material for metabolic studies of this tissue, and we are preparing an anatomical and histological description of it.

On Cruise 105 of R/V *Chain*, the effects of temperature on the binding of oxygen by the blood of midwater fishes was investigated.

POWER PLANT ENTRAINMENT STUDIES

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

This study concerns the effects of passage of marine plankton through the cooling water system of a nuclear power station on Long Island Sound. The station passes about 500,000 gpm of seawater and heats it 13°C over ambient. Chlorine, applied as a biocide for fouling organisms at the power station, severely decreases (ca. 80-99%) phytoplankton primary production when applied either intermittently or continuously even at concentrations below those required to eliminate fouling organisms. Thus chlorine cannot be used without having undesirable side effects.

Preliminary data on larval fish populations in the Millstone Point area and numbers of larvae passing through the plant suggest that entrainment may harm local populations of fish. For example, about half of the maximum winter flounder larval population in Niantic Bay was passed through the power plant. Survival of the fish after passage was low. Larvae of ten other fish species are entrained through the plant.

Studies on survival of copepods indicate that about 80% of all copepods entering the plant are not returned to Long Island Sound. The copepods are not immediately killed by entrainment but respond by sinking (ca. three times more rapidly than non-entrained copepods) to the bottom of the effluent pond (ca. 30 m deep). Water leaves the effluent pond by passage over a shallow sill and the copepods that sank never rise again to pass out of the pond. Studies are now underway to determine the effects of the loss in copepods on the Niantic Bay ecosystem.

POLYCHLORINATED BIPHENYLS

Edward J. Carpenter and Nicholas S. Fisher

Work with seven inshore and offshore clones of three species of phytoplankton showed that offshore isolates were significantly more sensitive to PCBs than those taken inshore. These results suggest that open ocean phytoplankton may be more vulnerable to abiotic environmental stress than are those found in coastal and estuarine waters.

Chemostat studies with natural plankton communities from Vineyard Sound indicated that 0.1 ppb of PCBs was sufficient to cause inhibition of the growth of the diatom *Thalassiosira pseudonana (Cyclotella nana)*. This concentration of PCBs is within the range of concentrations found in the open ocean.

NITROGEN FIXATION

Edward J. Carpenter

The blue-green epiphyte *Dichothrix fucicola* on pelagic *Sargassum* has been shown to fix atmospheric nitrogen. Input of nitrogen in the spring is about .15 µg $N_2/m^2/day$. This is the first report of nitrogen fixation by a heterocyst-bearing alga in the open ocean and the only algal species not belonging to the genus *Oscillatoria (Trichodesmium)* that has been shown to fix nitrogen at sea.

Measurements of nitrogen fixation by *Oscillatoria* were also made in the western North Atlantic Ocean. These studies indicated that through nitrogen fixation this species can double its nitrogen content (and thus divide) every 47 days (range 12 to 156 days). These estimated division rates, while considerably more rapid than those measured by others, still suggest that a considerable portion of the nitrogen required by *Oscillatoria* must be obtained from sources other than N_2 fixation. High ammonia concentrations (ca. 2.2 µg-at/liter) in surface seawater did not inhibit nitrogen fixation.

PLASTIC PARTICLES

Edward J. Carpenter, Susan J. Anderson, George Harvey,
Helen Miklas, and Bradford Peck

The presence of hard polystyrene spherules in coastal waters from Western Long Island Sound to Vineyard Sound was noted. The spherules are about 0.5 mm in diameter and appear to be what the plastic industry calls "suspension beads". They probably originate from a manufacturer rather than a fabricator since the spherules are not marketed commercially but are molded into a pellet shape before sale. Spherules were observed in gut contents of 8 of 14 fish species (270 individuals) examined and a chaetognath from Niantic Bay, Connecticut.

POPULATION GENETICS OF A MARINE OPPORTUNIST, *Capitella capitata* (Polychaeta)

J. Frederick Grassle

Following the West Falmouth oil spill, September 16, 1969, a marine opportunist species, *Capitella capitata*, increased tremendously in number and subsequently declined. Studies of protein polymorphism of animals collecting during this period have been initiated with Dr. Judith Grassle of the Marine Biological Laboratory. We have looked at a number of proteins, including non-specific esterases, tetrazolium oxidase, leucine aminopeptidase, malate dehydrogenase, and hemoglobin. For the population studies we have concentrated on three malate dehydrogenase loci. Ten months following the spill all individuals were monomorphic at the MDH loci although heterozygous individuals were found in unoiled areas at the same time. Populations three months after the spill had individuals with two alleles and two years after the spill several alleles were found. Of the variety of genotypes settling from the plankton only one type was favored by the oiled conditions. This suggests that selection of one component of the total genetic variability in each local habitat may be the basis for adaptation in opportunistic species.

In conjunction with Dr. Grassle, laboratory cultures and field experiments have been started to study the role of genetic variation in the survival of opportunistic species.

ZOOPLANKTON STUDIES

George D. Grice, Thomas J. Lawson and Coyla B. McCullough

1. Numerical taxonomy. Factor analysis has been used to evaluate phenotypic relationships among 27 of the 28 species in the calanoid copepod family Candaciidae. Twenty-four characters were taken from the first pair of swimming feet, an appendage seldom used in copepod taxonomy. Three factors accounted for 93% of the total variation among species. On the basis of structural patterns exhibited by the first feet, four clusters of species could be recognized. These clusters agree with a phenogram based on correlation coefficients between species as well as with most previously suggested interrelationships among candaciid species that have been based on classical taxonomic considerations.

2. Zoogeography of Indian Ocean species of Candaciidae. Approximately 250 sorted candaciid samples have been received from the Indian Ocean Biological Centre. The species in 150 of these have been identified and measured. Eighteen species have been identified including an undescribed one. These collections plus a group of others which were obtained by *Atlantis II* in the southern Indian Ocean provide sufficient coverage for determining gross distribution, frequency and abundance of candaciid species in the Indian Ocean.

3. Planktobenthic copepod distribution and diversity. The plankton collected by DSRV *Alvin* near the bottom at a depth of 1700 m off New Providence Island, Bahamas, in December 1971 has been analyzed. The collecting area is one of calcareous sediment and low productivity and in these respects contrasts with the continental slope south of Woods Hole where similar collections have been obtained. The Bahamas sample contained no copepod species found off Woods Hole and is further characterized by comparative paucity of animals. The most common species was a large calanoid copepod which possesses characteristics of two families of copepods, Augaptilidae and Heterorhabdidae, both of which hitherto have had only planktonic species assigned them. The species represents a new genus and has been provisionally assigned to the family Heterorhabdidae.

4. Laboratory cultivation of copepods. We have been attempting, so far with limited success, to rear the large, carnivorous copepod *Labidocera aestiva*. Adult animals obtained from Block Island Sound will readily eat nauplii of *Pseudodiaptomus coronatus*, an easily culturable herbivorous copepod and *Artemia* nauplii. *Labidocera* have been kept for as long as a month. Eggs laid in the laboratory appear not to be especially viable as only a few nauplii have thus far hatched.

PHYTOPLANKTON PHYSIOLOGY AND ECOLOGY

Robert R. L. Guillard, Helen I. Stanley and William G. Sunda

Phytoplankton nutrient kinetics (with Peter Kilham and T. A. Jackson):- We have demonstrated silicate-limited growth of two clones of the diatom *Thalassiosira pseudonana* (ex- *Cyclotella nana*) in pure batch cultures. The estuarine clone (3H) had a higher half-saturation constant and maximum growth rate (K_s = 0.98 µM Si; μ_{max} = 3.6 divisions/day) than the clone from the Sargasso Sea (K_s = 0.26 µM Si; μ_{max} = 2.4 divisions/day). The K_s values are such that the silicate concentrations found at certain times in both the Sargasso Sea and in coastal regions can be growth-rate limiting, hence of significance to plant production and to species succession. The clone from the nutrient-poor Sargasso Sea had more efficient Si uptake; this parallels its efficiency in nitrate uptake, studied previously by Carpenter and Guillard.

Quantitative demonstration of Si-limited growth in batch culture makes possible a study of clay particles as potential Si sources for diatoms, an interest of T. A. Jackson, and the study of Si-limited growth of fresh-water diatoms, a continuing project of P. Kilham.

A paper "Kinetics of silicon-limited growth in the marine diatom *Thalassiosira pseudonana* Hasle and Heimdal (= *Cyclotella nana* Hustedt)" has been accepted by the Journal of Phycology.

Copper, algae, and chelators (thesis research of William G. Sunda): - The relationship between the aqueous coordination chemistry of Cu and the toxicity of this metal to algae is under investigation. *Thalassiosira pseudonana* and *Nannochloris atomus* (clone GSB Nanno) have been used as bioassay organisms of ecological interest. A technique is being developed for detecting and characterizing natural copper chelating agents. These agents are shown to protect algae from copper at concentrations low enough to be of environmental significance. The algae themselves produce extracellular chelators that coordinate with and detoxify copper.

Phytoplankton biochemical systematics (with Judith Grassle): - An electrophoretic survey is being made of enzymes from selected strains of marine diatoms grown in carboy lots. A workable system is sought for studying polymorphism (or speciation) on taxonomically difficult groups.

Phytoplankton systematics and morphology (with Charles C. Remsen): - A study of the fine structure of clone GSB Sticho, an alga previously thought to be a chlorophyte (*Stichococcus cylindricus* Butcher) is in progress. The problem is to determine if this alga can be placed in the newly-formed class Eustigmatophyceae (Hibberd and Leedale), as seems indicated by the pigment content (see Guillard and Lorenzen, J. Phycol. 8:10-14, 1972).

SUBMARINE CANYON ECOLOGY

Richard L. Haedrich, Gilbert T. Rowe, Pamela A. Polloni and Lynda Murphy

The Ecology of Submarine Canyons. - Observations from DSRV *Alvin* in Hudson Canyon were undertaken with geologists from the National Oceanic and Atmospheric Administration (NOAA); in all, seven dives were made between 200 and 1800 m and 16 box cores were taken. Preliminary analysis of the biomass in each sample suggests a linear log biomass vs. depth relationship similar to that found in other areas investigated, although abundance and biomass are appreciably elevated in the canyon.

Between July 17 and August 5 we made two ten-day cruises on R/V *Alcoa Seaprobe* to Alvin Canyon and the continental slope along the Gay Head-Bermuda transect. These also were cooperative programs, and involved, besides ourselves, geologists and physical oceanographers. Using *Alcoa Seaprobe's* unique pod assemblage, we made macrofaunal counts along seven transects ranging from 100 to almost 2000 m deep.

During the first part of August we returned to the Alvin Canyon area for trawling from R/V *Gosnold*. All of the fish material from *Gosnold* and *Alcoa Seaprobe*, some 900 individuals in 27 species, indicates that there is no rigid faunal zonation with depth. Each species seems to have its own depth preferences. In general, smaller specimens live shallower than larger specimens of the same species, but the converse is true in the witch flounder, *Glyptocephalus cynoglossus*, and the red crab *Geryon quinquedens*.

A new genus and species of a large terebellid polychaete from the Tongue of the Ocean was captured by DSRV *Alvin*. Animals were resting on and swimming above the steeply sloping walls of the trough, and we hypothesize that the worm's motility may be a requirement for survival on an unstable substratum. The specimens have been deposited in the United States National Museum, Smithsonian Institution and a description of the worm is in press.

Forty-one samples from depths of 240-290 m were taken in the deep basins (Wilkinson-Murray) of the Gulf of Maine from DSRV *Alvin* and R/V *Gosnold* in the summers of 1971 and 1972. Polychaete species were the most abundant, comprising more than 50% of the total number of individuals. The abundance of benthic invertebrates and their biomass were surprisingly low for depositional basins of this moderate depth (240-300 m). We tentatively attribute this to severe seasonal changes. The invertebrate fauna is composed of a mixture of species common both to shallow water and to deeper water in the canyon heads of the open Atlantic.

BIOCHEMISTRY AND PHYSIOLOGY OF MARINE ANIMALS

G. Richard Harbison

Studies on Bivalved Molluscs. - Although temperature stimulates the reaction catalyzed by the adenosine deaminases of bivalved molluscs, at low substrate concentrations, this stimulation is reduced. The theoretical implications of this behavior were investigated, and it was found that the binding of the substrate to the enzyme molecule was insensitive to changes in temperature, and that this could be reflected in higher-order physiological processes.

Studies on Fish. - Preliminary work was conducted on enzymes of the red blood cells of tuna, because of the unique temperature gradient to which they are exposed. Due to the interference of hemoglobin and low enzyme activity titers, procedures will have to be devised to improve assay procedures.

OCEANIC FISHES

Richard L. Haedrich

A by-product of work with Jonathan Wittenberg (Yeshiva University and Marine Biological Laboratory) on the choroid *rete mirabile* in fishes is the discovery of a remarkably-developed septum bisecting the eye of all recent species of osteoglossoid fishes. This feature seems so elaborated in no other group, and provides an additional systematic character useful in the definition of the Osteoglossoidei. This division of the retina into upper and lower parts by the septum may be of use in rapid adjustment to the markedly different light levels that occur near the surface of the water where these fishes live. These results are reported in a paper (with Wittenberg and G. J. Nelson, American Museum of Natural History) to be published in Copeia.

A letter was sent to the Editors of Deep-Sea Research calling attention to the interesting problem of the fate of the creatures entrained in Gulf Stream rings, a physical phenomenon long under investigation here at the Institution by Fuglister and others. An abstract states:

On a transect from Slope Water into the Northern Sargasso Sea during August 1967, one daytime mid-water trawl was made to 210 m in a warm-core eddy (200-m temp. = 16.1°C) at 40°04'N 67°13'W. The fish catch in the eddy, five species at a rate of 0.5 cc/hr, was relatively very poor, for comparable Slope Water trawls (200-m temp.< 12°C) took 22 species at a rate of 20.2 cc/hr and Northern Sargasso Sea trawls (200-m temp.> 18°C) took 11 species at a rate of 1.0 cc/hr. Qualitatively, the eddy trawl was also distinctive, sharing but one species with the five most abundant species in comparable Slope Water collections and one with the five most abundant in the Northern Sargasso Sea.

A report was completed on the nomeid fishes collected by the German *Walther Herwig*. The resolution of certain systematic problems in this group was helped by consideration of the general North Atlantic distribution patterns proposed by Backus *et al.* (1970). A summary of the paper, published in Archiv für Fischereiwissenschaft, reads:

Midwater trawling by FFS *Walther Herwig* from 40°N to 40°S in the Atlantic Ocean during 1966, 1968, and 1971 captured 222 specimens divided among seven species in the genera *Cubiceps* and *Psenes* (Stromateodei, Nomeidae). The largest specimens reveal that, due to allometric growth, maximum depth of the body cannot be used to differentiate between the two genera in specimens larger than 150 mm SL, but the markedly reduced head scalation in *Psenes* can. The distribution of the individual species is zoned with respect to latitude. *Cubiceps gracilis*, a species with knobby teeth on the vomer and tongue and 32-33 vertebrae, occurs only in the northeastern Atlantic and Mediterranean. To the south, it is replaced by the broadly tropical *C. caeruleus*, a species with a single row of pointed teeth on the vomer and tongue and 31 vertebrae. *C. capensis*, with knobby teeth and 31 vertebrae, occurs south of the Subantarctic Convergence. The distribution of *C. pauciradiatus*, a diminutive species with 16-18 second dorsal and anal finrays, is either tropical or Guinean. *Psenes arafurensis*, with knife-like teeth in the lower jaw, 31 vertebrae, and more anal than dorsal finrays, is tropical. *P. pellucidus*, with knife-like teeth in the lower jaw, 30 dorsal and anal finrays and 41 vertebrae, replaces *P. arafurensis* to the north and south; it may be anti-tropical. Only two specimens of *P. cyanophrys* were taken; this deep-bodied horizontally-striped species, though widely distributed, is probably more coastal than its oceanic congeners.

SUFFICIENT AND NECESSARY CONDITIONS FOR PHYTOPLANKTON CHANGES IN THE VICINITY OF THE GRAND BANKS

Edward M. Hulburt

A tongue of very cold water extends from the Grand Banks between a southeastward bending portion of the Gulf Stream and a northwestward flowing portion of a neighboring gyre. This hydrographic structure was "a sufficient condition", that is, a sufficiently marked condition, to bring about a drastic change in distributions of plankton species observed in April and May, 1972. The change was characterized by two types of species, those that were produced in the cold tongue of water and those found in the warm oceanic currents to either side. It is natural to think that the production of the two species types would not have occurred, had it not been for the hydrographic change; that the hydrographic change was "a necessary", as well as a sufficient, condition for the plankton change. But it is not difficult to see that another necessary condition was fulfilled, for each species in both groups changed in abundance with a minimum of interference from others in the same group. This minimum of interference is to be seen in the fact that within a group the biomass was shared between the species and that the distribution pattern of any species within a group overlapped considerably that of every other species.

Although the plankton change can be considered predictable, since all other similarly marked hydrographic changes that we have seen were sufficient to have associated changes in many plankton species, the individual species which emerged as the constituents of each group did so unpredictably. One of the most abundant species in the cold tongue of water, a green, morphologically-changing species belonging to the Euglenineae, we have never seen in abundance outside very shallow, enclosed bays - a most unpredictable occurrence. A minimal interference between species ought to increase the ease with which an unusual species can become abundant, ought to be a part, that is, of the unpredictability of any of the species occurrences. At the same time, minimal interference ought to increase the ease with which species adapted to the varying factors in the water types described can become abundant, ought to be a part, that is, of the predictable change. Seen in this light, minimal interference, a necessary condition for the floristic change, is essential in the transformation of unpredictable species occurrences into predictable floristic change.

PHYSIOLOGY AND ECOLOGY OF MARINE BACTERIA

Holger W. Jannasch, James D. Flanagan, Paul E. Holmes,
Jon H. Tuttle and Carl O. Wirsen

In situ Studies of Deep-Sea Microorganisms. - Research on microbial transformations of organic substrates in the marine environment has been expanded toward a study of the response of the indigenous deep-sea bacteria to nutrient enrichment. Specially designed pressure-tight aluminum cylinders containing racks with 20 sample bottles each were opened on the sea floor by the research submarine *Alvin* at 1830 m depth for inoculation (Figs.1a,b). Sample bottles were left for *in situ* incubation in the deep sea from June 1971 to June 1972. Extremely low rates of microbial degradation of agar, starch, and gelatin were observed with and without the addition of supplementary nutrients. A three-month incubation (June to September, 1972) of ^{14}C-labeled acetate, mannitol, glutamate, and casamino acids confirmed these observations.

Thus, it was shown that the indigenous deep-sea microflora behaved similarly to bacterial populations collected from surface waters and incubated under deep-sea conditions. In both cases, transformation rates were one to more-than-two orders of magnitude slower than those of controls incubated in the laboratory at deep-sea temperatures. From observations on animal and microbial attack of solidified organic materials and from calculations of the amount of non-refractory organic materials reaching the ocean floor, it is suggested that activities of microorganisms in the deep sea may be largely confined to the intestinal tracts of animals where an enriched nutrient milieu will enable them to decompose refractory materials (including chitin, cellulose, etc.) in an endosymbiotic fashion.

Pressure-Temperature Relationships in Growth of Marine Bacteria. - Studies on the activity of marine psychrophilic bacteria as affected by low temperatures and varied hydrostatic pressures are continuing. Using quantified inocula, short- and long-term comparative studies have been made at varied pressures, temperatures, and substrate concentrations. Specific rates decrease with decreasing temperatures and increasing pressures. Increased substrate concentrations result in increased activity independent of pressure. The data indicate that the natural activity of our psychrophilic isolates would decrease with depth in the oceanic environment.

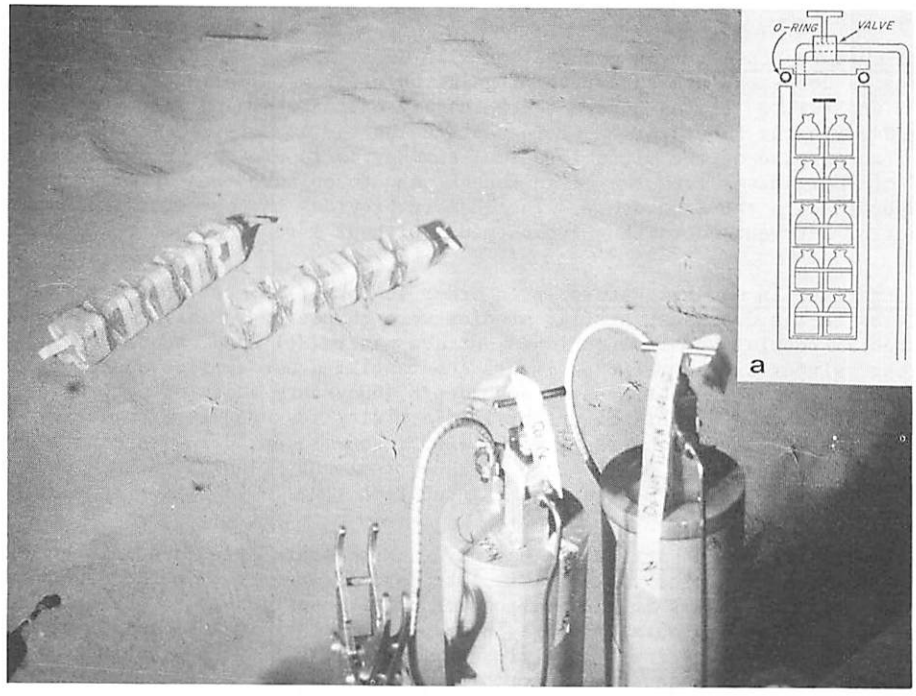


Fig.1 (Jannasch,Flanagan,Holmes,Tuttle and Wirsen) Pressure tight sample housing: (a) schematic; (b) at the deep-sea bottom station at 1830 m depth and two racks of 20 sample bottles each, deposited for *in situ* incubation.

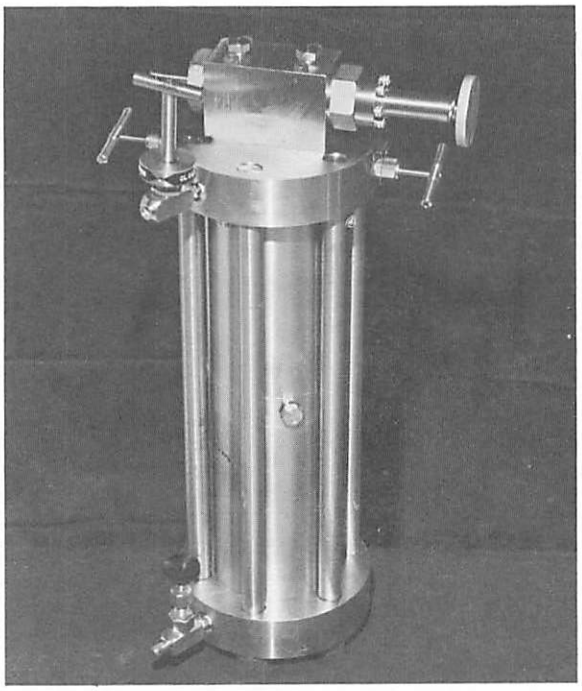


Fig.2 (Jannasch, Flanagan, Holmes, Tuttle and Wirsen) Bacteriological pressure-retaining deep-sea sampler and culture vessel. The unit for the withdrawal and addition of liquid samples (at unchanged pressure) is attached.

Deep-Sea Sampling Culture Vessel. - In cooperation with C. L. Winget and K. W. Doherty (Department of Ocean Engineering), a deep-sea, pressure-retaining microbiological sampling and culturing chamber (Fig.2) has been designed and built. It has passed the necessary operational and safety tests required and is at present being used in the laboratory. Field tests using the submersible *Alvin* are planned for the summer of 1973. The purpose of the microbiological chamber is to prevent decompression during sampling and retrieval of microorganisms from the ocean depths, and to culture them under unchanged conditions of pressure and temperature in the laboratory. The chamber provides the operator with the capability of removing or injecting nutrient-containing liquid media without affecting the pressure conditions within the chamber.

Microbial Transformations in Coastal Waters. - In order to obtain reference data for our measurements of microbial activities in the deep sea, similar studies were completed in shallow coastal waters in 1972. Using active microbial populations from enriched surface water (Eel Pond, Woods Hole) in addition to *in situ* populations, winter and summer experiments substantiated our earlier observations that the conversions of ^{14}C-labeled organic substrates at 40 m depth (buoy farm south of Cuttyhunk) was half of that measured in laboratory controls. This figure of 1:2 (activity measured *in situ*:activity measured in the laboratory at *in situ* temperature) contrasts with 1:200 in our recent deep-sea experiments. The study was expanded to include experiments on the role of added sediment. Inhibiting and enhancing effects appear to vary with the type of sediment and with incubation time. The latter indicates an absorption process.

Microbial Activity as Affected by Particulate Matter. - Experiments have been initiated to study growth and biochemical activities of marine bacterial isolates as affected by suspended inert or detrital particulate materials. This work aims at a clarification of the question as to whether a significant portion of the viable and active microbial biomass in the ocean occurs in association with particulate matter. In chemostat studies the effect of inert particles on the availability of dissolved organic substrates at extremely low concentrations is assessed by microbial growth and conversion of ^{14}C-labeled substrates.

Aerobic Transformation of Inorganic Sulfur Compounds. - Studies on the distribution of colorless, marine sulfur bacteria were completed. Thiosulfate and sulfide-oxidizing bacteria isolated from offshore areas of the North Atlantic and the anoxic basins of the Black Sea and the Cariaco Trench were shown to be

different from the typical thiobacilli. The isolates oxidized thiosulfate to polythionates and, in some cases, sulfide to thiosulfate. Thiosulfate has been found to accumulate near the oxygen/sulfide interfaces in the Black Sea and the Cariaco Trench as well as in pure cultures growing on sulfide. These data suggest that the rate-limiting step in the oxidative turnover of sulfur compounds in the anoxic basins is the biological oxidation of thiosulfate.

Investigations on the heterotrophic and mixotrophic metabolism of several representative isolates under aerobic conditions have been continued. Thiosulfate has been shown to affect the growth rate and possibly the cell yield in organically supplemented seawater media. Mixotrophic growth in glucose-thiosulfate or acetate-thiosulfate media was strongly influenced by pH. Thiosulfate stimulated growth at pH 6.5, but hardly so at pH 8.0, while the growth rate on the organic substrate was higher at pH 8.0 than at pH 6.5. Manometric experiments using washed cell suspensions confirmed that the maximum rate of acetate oxidation occurred near pH 8.0, while thiosulfate oxidation was most rapid at pH 6.0. When both organic and inorganic substrates were supplied to the cell suspensions, oxygen uptake was additive, indicating simultaneous oxidation of the substances. The thiosulfate-oxidizing enzyme system was constitutive in the strains studied and the apparent K_m for thiosulfate was similar for mixotrophically and heterotrophically-grown cells. Thiosulfate was oxidized quantitatively to tetrathionate, independent of pH or the presence of organic compounds. The extent of thiosulfate oxidation to tetrathionate was shown in one strain to be dependent on (i) the population density and (ii) the amount of thiosulfate provided. Neither tetrathionate nor trithionate were attacked by the bacteria, and the presence of these compounds had no apparent effect on the rate of stoichiometry of thiosulfate oxidation. Growth and manometric experiments are being extended to include the oxidation of sulfide and elemental sulfur.

Anaerobic Transformation of Inorganic Sulfur Compounds. - A study of anaerobic growth of several of our facultatively anaerobic isolates has been undertaken. In addition to nitrate reduction, some of the strains also carry out the dissimilatory reduction of inorganic sulfur compounds other than sulfate at the expense of organic substrates. One of our Black Sea isolates reduces tetrathionate, thiosulfate, or sulfite when grown anaerobically in a mineral medium containing lactate or pyruvate as the energy source. From an ecological point of view, microorganisms of this type may contribute heavily to sulfur turnover in certain marine environments by competing with *Desulfovibrio* sp. for partially reduced inorganic sulfur at oxygen/sulfide interfaces in the anoxic marine waters or sediments. The relative abundance of inorganic sulfur intermediates and the redox potential of the environment would be expected to influence this competition.

Bacterial Oxidation of Methane in Lake Kivu (Congo). - Additional determinations of photosynthetic productivity and a new approach in measuring methane oxidation were conducted in Lake Kivu during March and April, 1972. The rates of oxygen uptake and bacterial methane utilization in the zone of oxygen depletion resulted in data useful for the calculation of methane turnover. Work on the isolation and description of methane-oxidizing bacteria is being continued.

BIOLOGICAL INSTRUMENTATIONS

John W. Kanwisher and Kenneth D. Lawson

We have continued the development of instruments for biological research, our interest centering on acoustic telemetry of data. A successful application of these techniques involved the design, construction, and use of a salinity/temperature profiler. This unit provided profiles to depths in excess of 400 m, giving a continuous plot of data. The use of an acoustic carrier frees the experiment from the cost and reliability penalties of conductive wire systems.

Smaller, more efficient, and simpler devices for telemetry of body temperature, water temperature, and heartbeat have been designed. These have been used extensively on free-swimming fish, in open water, and in aquaria.

We have developed a small, simple, and accurate device for telemetry of depth. This device encodes the millivolt level pressure transducer signal as a recurrent ± f, the magnitude of f being proportional to depth. The technique used to recover the signal reduces errors caused by such extraneous factors as ambient temperature and supply voltage variations by at least an order of magnitude.

A reasonably simple and sophisticated receiver for acoustic signals has been designed and constructed. Measuring 8 x 5 x 3", the unit is entirely self-contained, including batteries for 100 hours of operation and a meter for direction-finding. We intend to publicize constructional details in the hope that the availability of such a unit will encourage others to undertake useful field work requiring acoustic telemetry.

WATER QUALITY GUIDELINES FOR A TERTIARY-TREATMENT AQUACULTURE SYSTEM

William B. Kerfoot

The combination of aquaculture and tertiary treatment offers an efficient and potentially profitable means of removal of excessive nutrients from municipal secondary effluent. However, before any commercial aquaculture operation can be contemplated, some serious problems must be resolved. There are three sources of potential contamination: (1) pathogens, such as amoebic cysts, bacteria, and viruses; (2) organic substances, such as pesticides, phenols, or polychlorinated biphenols, which may be toxic to the culture system, contaminate the products, or make the products unpalatable; or (3) trace metals, which even at subacute levels may lead to long-term, chronic disorders and thus render the aquaculture crop unfit for human consumption. This past year, one aspect of the trace-metal problem - the accumulation of cadmium by the artificial food chain of a tertiary-aquaculture system which was developed at Woods Hole Oceanographic Institution - was analyzed in detail. From the study, guidelines for safe cadmium levels in the effluent and dilution seawater were developed.

The procedure of determining safe levels of cadmium employed an extension of the toxicological "critical organ" concept, working backwards through the artificial food chain (phytoplankton-shellfish-man), arriving finally at the original sources of cadmium in the effluent and dilution seawater.

Variations in uptake along absorption and ingestion pathways were analyzed using two forms of phytoplankton culture, one dominated by the green platymonad, *Prasinocladus subsalsa* and another by the diatom mixture of *Phaeodactylum tricornutum* and *Chaetoceros* sp., and two species of shellfish, the eastern oyster *Crassostrea virginica* and the quahog, *Mercenaria mercenaria*. To obtain permissible levels of cadmium in the effluent and dilution seawater, the concentrations in solution sufficient to yield the critical content in three-year-old shellfish were calculated. A daily 40-gm meat weight diet of shellfish, begun by an average man at age 20, with a concentration of 3.0 µg Cd/gm of meat, with a five percent human absorption and negligible elimination, would be enough to elevate the human body burden to 120 µg by age 70. With three-year-old shellfish, a rate of increase of .003 µg/day would yield the critical concentration. A background contamination of .0002 ppm and .0015 ppm in the dilution seawater would raise the Cd content of the meat of oysters and quahogs, respectively, to the critical concentration of 3.0 µg Cd/gm meat in a three-year period. A concentration in the effluent of .001 or .004 ppm Cd would cause the same concentration in oysters, depending on whether *Prasinocladus* or the diatom mixture of *Phaeodactylum-Chaetoceros* is cultured to feed the shellfish. With quahogs, the critical concentrations in effluent were .003 and .005 ppm, respectively, for the culture of *Prasinocladus* and the mixture of diatoms.

A comparison between the critical water concentrations in the effluent and dilution seawater pointed out the importance of maintaining uncontaminated seawater for dilution. Almost an order of magnitude higher concentration can be tolerated in the effluent if the dilution seawater is relatively free of cadmium enrichment. Also, if oysters are raised with a diatom mixture, it is important to avoid contamination of the culture by green algae, such as *Prasinocladus*, since the rate of cadmium uptake by the oysters would increase substantially.

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

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

Our major effort was on data analysis and the publishing of results, but the Cooperative Game Fish Tagging Program and the monitoring of local fisheries, mainly those for bluefin tuna, *Thunnus thynnus thynnus*, were continued. Information was furnished to the International Commission for the Conservation of Atlantic Tunas (ICCAT). The cooperative tag-testing experiment, initiated in 1971 at the request of ICCAT, was continued in 1972.

The 1972 results of the Cooperative Game Fish Tagging Program, as of early December, comprised 1,910 releases and 122 returns, bringing the cumulative totals to 42,841 and 3,040, respectively. The 1972 releases (denominators) and returns (numerators) for the respective species with the cumulative totals, shown in parentheses, were as follows:

bluefin tuna, *Thunnus thynnus thynnus*, $\frac{81}{277}$ $\left(\frac{2,282}{11,319}\right)$; skipjack tuna, *Katsuwonus pelamis*, $\frac{0}{32}$ $\left(\frac{85}{2309}\right)$; white marlin, *Tetrapturus albidus*, $\frac{15}{459}$ $\left(\frac{144}{9025}\right)$; blue marlin, *Makaira nigricans*, $\frac{1}{108}$ $\left(\frac{6}{784}\right)$; sailfish, *Istiophorus platypterus*, $\frac{5}{714}$ $\left(\frac{100}{12,732}\right)$; greater amberjack, *Seriola dumerili*, $\frac{18}{204}$ $\left(\frac{374}{3193}\right)$; and other species, $\frac{2}{116}$ $\left(\frac{49}{3479}\right)$.

The great majority of this tagging was performed, as in the past, by cooperating sport fishermen using equipment furnished by Woods Hole Oceanographic Institution.

The return rates for small bluefin again indicated heavy fishing pressure on the stock. Seventeen percent of the fish tagged in 1971 were recaptured in 1972. While lower than the rates obtained in 1970 and 1971 (about 25 percent of previous year's releases), this figure is much higher than those for earlier years. Preliminary estimates (Mather, Rothschild, Paulik and Lenarz, MS) indicate an average seasonal exploitation rate by the purse seine fishery of about 30 percent, with a maximum of about 55 percent in 1968. Preliminary estimates of shedding rates (Lenarz, Mather, Beckett, Jones and Mason, MS), based on the initial results of the cooperative tag testing experiment, indicate that the actual figures were probably somewhat higher. These estimates take no account of fish which have been rejected, discarded, or lost due to breakage of nets. Such losses probably amount to about 10 percent of the landings.

Preliminary figures indicate that the catch rate of bluefin tuna in tons per boat-day in the purse seine fishery continued its decline from a high of 18.2 in 1969 to about 5.0 in 1972, the lowest figure on record with the exception of 4.7 in the disastrous year of 1966.

A study of the stock structure of Atlantic bluefin tuna (Mather and Jones, MS) shows an almost complete lack of recruitment to the fisheries for large individuals. This is shown by the dearth of medium-sized (75-275 pound) fish in the catches of all the fisheries for which data were available. This situation has resulted in serious declines, or complete failures, in all the northeastern Atlantic fisheries for large bluefin. In the northwestern Atlantic, where there is little commercial fishing for large bluefin, sufficient numbers of exceptionally large individuals are available to provide good sport fishing, but the future looks bleak. Whether the cause of this situation is a succession of poor spawning years, or, as seems much more probable, over-fishing of the young bluefin, it is certain that the species faces grave difficulties if some form of management is not undertaken soon. No measures have been initiated by ICCAT.

The tagging results for bluefin tuna included two returns from small (about 10 pound) fish released off southern New England in the summer of 1966. One was recaptured off the southern edge of the Grand Banks in August, 1972, and the other off Gloucester, Massachusetts, in September. These are the longest times at liberty yet recorded from our taggings of small bluefin. The reported sizes at recapture, 264 and 350 pounds, respectively, are considerably over the 185 pounds which would have been expected on the basis of growth studies.

The tag testing experiment initiated in 1971 was continued in 1972, again with the cooperation of the National Marine Fisheries Service (Southeast Fishery Center, Miami Laboratory) and the Fisheries Research Board of Canada (St. Andrews Biological Laboratory). One hundred and fifty-two small bluefin were double tagged, using two tags of one type, then two of the other, alternately. Last year's taggings have yielded 119 returns, 40 of which consisted of one tag only, indicating considerable shedding.

White marlin tagging results continue to improve the understanding of the distribution and structure of the three stocks we have hypothesized. These stocks are named tentatively for their summer concentration areas - "northwestern Atlantic", "Gulf", and "Venezuelan". Most of the 15 new recoveries support the cyclical migratory pattern proposed for the "northwestern Atlantic" stock (Mather, Jones and Beardsley, 1972). A late report of an August, 1971 recapture in the Gulf of Mexico of a white marlin tagged in the northwest Atlantic gave further indication of an interchange between the "northwestern Atlantic" and "Gulf" stocks. The "Venezuelan" stock has provided the two longest times at large yet recorded for a white marlin, or for any billfish. These fish were released off La Guaira, Venezuela, in July and August, 1966, and recaptured at the same locality in November and August, respectively, in 1972.

A single blue marlin return recorded from the Bahamas brings the total recoveries to six for this species. Released in July of 1971 the fish was recaptured in the same general area in July of 1972.

This particular species of oceanic game fish is one of those about which we know the least. It is important to improve this situation quickly, since drastic declines in longline catch rates and in sizes of the fish being taken in this fishery indicate that the stocks are being seriously affected.

Five sailfish returns have been received thus far in 1972 bringing the recoveries for this species to 100. Port Aransas, Texas, where sailfish tagging has been carried on intensively for many years, has reported its first two near-shore recoveries of our tags. One was released in the same area one year before and the other came from an unreported release off Louisiana. Two other returns were from local migrations along the Florida coastline and the final one showed a northward migration from the Virgin Islands in January to Fort Lauderdale, Florida, in May of this year. The last migration is consistent with the tendency, indicated by previous results, for this species to move from tropical waters in the cold season to temperate waters in the warm season and vice versa.

The returns for greater amberjack continue to emphasize the local migrations of this species up and down the Atlantic coast of Florida.

The collection of catch and effort statistics for the various fisheries of interest, particularly that of the bluefin tuna, has been continued in order to maintain a constant appraisal of the exploitation of the stocks. In addition, length frequency and morphological studies are proceeding to gain better understanding of those stocks of fish with which we are concerned.

Mather presented papers on migration of white marlin and blue marlin in the western North Atlantic Ocean (Mather, Mason and Clark, in press) and results of sailfish tagging in the western North Atlantic Ocean (Mather, Tabb, Mason and Clark, in press) at the International Billfish Symposium, August 9-12, 1972, at Kailua-Kona, Hawaii. A synopsis of biological data on white marlin, *Tetrapturus albidus*, Poey 1860 (Mather, Clark and Mason, MS) will also be published in the Proceedings of this symposium.

Mather also attended the meetings of the Standing Committee on Research and Statistics of ICCAT in Madrid, November 20-25, 1972. Papers on estimation of rates of tag shedding of northwest Atlantic bluefin tuna (Lenarz, Mather, Beckett, Jones, and Mason, MS) (ICCAT/SCRS/72/25), preliminary analysis of bluefin tagging data (Mather, Rothschild and Paulik, MS) (ICCAT/SCRS/72/27) and summary of recent information on taggings and tag returns for tunas and billfishes in the Atlantic Ocean (Mather and Mason, MS) (ICCAT/SCRS/72/31) were used as working documents at these meetings.

FUNCTIONAL AND STRUCTURAL ASYMMETRY IN MEMBRANES OF MARINE PHOTOSYNTHETIC BACTERIA

Charles C. Remsen and Brian W. Schroeder

The marine photosynthetic purple and green sulfur bacteria comprise a variety of ultrastructural types; chief among these are the photosynthetic membranes which are present as flattened vesicles, chromatophores, tubes or chlorobium vesicles. A direct comparative examination of these membranes will permit us to test the validity of current membrane models which in the past have tended to generalize the structure of biological membranes, and will allow us to examine in detail the concept of functional and structural asymmetry in energetically active biological membranes.

During photosynthesis, the purple and green sulfur bacteria require sulfide as a source of reducing power, oxidizing this material to form elemental sulfur. Certain species within these groups of bacteria deposit this sulfur outside the cell, while others deposit sulfur inside the cell in the form of membrane-bound sulfur globules. Whether the sulfur is deposited inside or outside the cell appears to be directly related to the type of membrane system present in the cell.

In the case of *Ectothiorhodospira mobilis*, where the membranes are still attached to the plasma membrane, limitation in the source of reducing power is determined by the concentration of sulfide in the surrounding medium which flows over the surface of the invaginated plasma membrane and sulfur is deposited outside the cell. On the other hand, in the case of *Chromatium violascens*, where the membranes are no longer connected with the plasma membrane, it is our hypothesis that as the chromatophores are formed by the invagination and subsequent pinching-off of the plasma membrane, a certain amount of sulfide is trapped within the vesicle. The amount of sulfide trapped within the vesicle determines the life of the chromatophore as a photosynthetic unit. Oxidation of sulfide to sulfur results in the accumulation of elemental sulfur within the chromatophore. Once all the sulfide has been oxidized, the chromatophore vesicle becomes a sulfur storage granule. A number of these sulfur-filled chromatophores then may coalesce to form the large intracellular sulfur granules common to these cells.

Studies are currently under way to test this hypothesis and to identify and localize enzymes associated with photosynthesis and sulfide oxidation on one or the other side of the chromatophore membrane.

THE ROLE OF UREA IN MARINE MICROBIAL ECOLOGY

Charles C. Remsen, Edward J. Carpenter and Brian W. Schroeder

During the past year we have completed a preliminary study on the role of urea in marine microbial ecology. From our data we have been able to show (a) that urea is present in biologically significant amounts in most natural waters; (b) that phytoplankton play a more dominant role than bacteria in the utilization and/or decomposition of urea in coastal waters, while bacteria play a dominant role in the breakdown of urea in the open ocean; (c) that the rates of urea breakdown are far greater in coastal waters than in oceanic waters; and (d) that since the ability to use urea is not present in all phytoplankton species, it is possible that the presence of urea exerts considerable influence on phytoplankton species composition.

The rate of urea breakdown varies with the location. Most rapid urea decomposition (19.4 mμmoles urea $liter^{-1}hr^{-1}$) was observed in the Savannah River plume. Slowest was in North Atlantic oceanic waters (0.31 mμmoles urea $liter^{-1}hr^{-1}$). It is possible that the variations in urea decomposition are related to the availability of other nitrogen sources, as well as phytoplankton and bacterial standing crops and other variables.

In river, estuarine and coastal waters, phytoplankton were responsible for the major part of urea being broken down to ammonia and CO_2. By using a filter technique to qualitatively remove bacteria from a phytoplankton sample, as much as 86% of the activity was removed indicating that most of the activity was associated with the larger centric and pennate diatoms.

In the case of water samples from the open North Atlantic, bacteria seem to play a more important role. While the absolute activity is comparatively low (0.45 mμmoles $liter^{-1}hr^{-1}$ vs. 23.99 mμmoles $liter^{-1}hr^{-1}$) the amount of activity remaining after filtration is comparatively higher, 51% versus 14%. The relative importance of bacteria in the utilization of dissolved organic compounds in the open ocean is not surprising, albeit the actual levels of activity are quite low. What is surprising is the relative unimportance of bacteria in utilizing urea in estuarine and coastal waters. Our data appear to be contrary to the conclusions of a number of other investigators - that bacteria in both freshwater and marine environments are the most important agent in the utilization of dissolved organic compounds. The decomposition of urea in an estuarine and coastal environment would appear to be an exception to this general rule.

RESPONSES BY OPEN-OCEAN MICROORGANISMS TO ENVIRONMENTAL POLLUTION

Charles C. Remsen, Edward R. Gonye, Anne C. Collins and Cheryl L. Brady

In collaboration with members of the Chemistry, Geology, and Geophysics Departments we are examining the effects of environmental pollutants on open-ocean microorganisms, specifically the bacteria, yeasts, diatoms and planktonic protozoa. Our studies fall into three main categories: a) population ecology, b) cell structure and chemistry and c) effect(s) of pollutants on cell structure and physiology: experimental populations exposed to sublethal levels of pollutants such as PCBs and DDT; uptake studies using isotope-labelled compounds, and study of the change in cell chemistry and structure of exposed populations.

We participated on legs 1 and 2 of *Chain* Cruise 105 from St. Johns, Newfoundland to Lisbon, Portugal, to Cork, Ireland. During this time we were able to collect, make preliminary identifications, and preserve for electron microscopic examination many open-ocean microorganisms. We were able to isolate a number of bacterial and yeast cultures for use in laboratory studies. Sensitivity and resistance to pollutants is being examined, as well as possible cytological effects of pollutants on these cultures.

OCEAN REFUSE DISPOSAL

Gilbert T. Rowe and Charles H. Clifford

The Ecological Impact of Solid Refuse Disposal at Sea. - As a part of our continued investigation of the effects of dumping municipal refuse in the ocean, we have constructed a small reef of six compressed bales with a total weight of approximately ten tons in the shallow (40') water of Great Harbor, Woods Hole. Two more bales have been placed in deep water, utilizing the investigative capabilities of the R/V *Alcoa Seaprobe* and the DSRV *Alvin*. Aboard the *Alcoa Seaprobe* we were able to observe photographically and with television a bale as it progressed through a 1000-meter water column. The second deep-water bale deployment occurred at the Deep Ocean Station, where future monitoring is planned.

At our Great Harbor reef area, we have observed that

1) within a few months after deployment the bales began to evolve a gas mixture including methane, hydrogen, carbon dioxide, and hydrogen sulfide,

2) no oxygen depletion occurred in the cavities formed between bales that were purposefully stacked, and

3) substantial growths of filamentous bacteria, microscopic algae, barnacles, hydroids, and anemones, occurred on the bales. These have attracted starfish, gastropods, decapods and fishes.

ANIMAL-SEDIMENT RELATIONSHIPS

Gilbert T. Rowe and Charles H. Clifford

Animal-Sediment Relationships on the Deep-Sea Floor. - Thirteen Birge-Ekman box cores were taken by DSRV *Alvin* at the 1800 m Deep Ocean Station south of Cape Cod for studying small-scale variation in certain faunal and sedimentary parameters. Woods Hole Oceanographic Institution-Massachusetts Institute of Technology student, Mr. Joseph MacIlvaine, discovered the current velocity necessary to erode two of these undisturbed box core samples was nearly 100 cm/sec. Our time-lapse film, however, taken at the head of Hudson Canyon (300 m) with Dr. George Keller, NOAA, indicates biotic activity initiates erosion at much lower velocities.

Experiments in the relationship of benthic faunal composition to the physical properties of sediments have begun in Buzzards Bay in preparation for similar experiments at the Deep Ocean Stations next season. An *in situ* vane-shear apparatus is being used to determine relationships between small-scale biotic variations and the resistance of sediment to shear. Mr. Robert Young, a WHOI-MIT Geology student, is measuring a suite of sedimentary parameters in preparation for *in situ* flume trials in Buzzards Bay. With Mr. Young's flume, we expect to investigate the relationships between current velocity, sediment incipient motion, and animal activity.

WASTE RECYCLING AND AQUACULTURE

John H. Ryther, Nathaniel Corwin, Kenneth R. Tenore, Joel C. Goldman,
William B. Kerfoot, Valerie Vreeland, Jeffrey S. Prince and John P. Clarner

Research has continued during 1972 in the development of a combined tertiary sewage treatment-marine aquaculture system. In this system, the effluent from secondary sewage treatment, diluted with seawater, is used as a culture medium for the growth of unicellular algae (phytoplankton) and the algae are used as a food for oysters, clams, mussels, or other filter-feeding bivalve molluscs. Solid organic wastes produced by the shellfish as feces and pseudofeces may be utilized by detritus-feeding invertebrates, such as polychaete worms or crustacea, while secondarily-produced dissolved nutrients (ammonia, phosphate, etc.) may be eliminated by final passage of the effluent from the system through a culture of macroscopic algae (seaweed). The seaweed may be grown for its intrinsic value (e.g., such species as Irish moss which has commercial value) or as a food for browsing invertebrates such as abalone. A flow diagram of the system in shown in Fig.3.

During the past year, work on the project was undertaken in three areas. First, controlled laboratory studies were continued to obtain more information on the growth kinetics of mixed and single species cultures of marine phytoplankton reared on sewage effluents, and the effects of algal

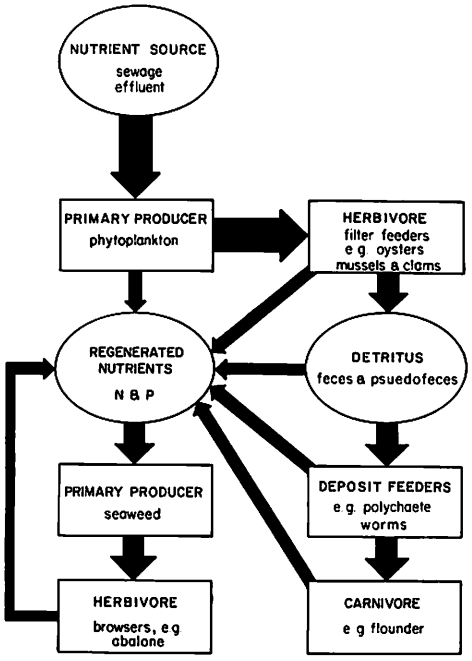


Fig.3 (Ryther,Corwin,Tenore,Goldman,Kerfoot,Vreeland,Prince and Clarner) Flow diagram of a tertiary waste treatment - marine aquaculture system.

species, concentration, and flow rate on the feeding rate, organic deposition (feces and pseudofeces production), assimilation, and growth of oysters (*Crassostrea virginica*), hard clams (*Mercenaria mercenaria*), and mussels (*Mytilus edulis*). A laboratory model of the complete system was also constructed and operated to determine the mass flow and utilization of nutrients in the various components and in the system as a whole.

In a second group of experiments, considerable attention was devoted during 1972 to controlled laboratory studies to determine the rates of uptake and loss of trace contaminants by the various components of the system, with main emphasis on the shellfish. Preliminary results have been obtained concerning the concentrations of heavy metals, PCB's, bacteria, and viruses in the sewage effluent, the phytoplankton grown on the effluent, and oysters and clams which have fed on the sewage-grown algae. In addition, known concentrations of cadmium and PCB's have been added to our flowing system in separate experiments to study the kinetics of uptake of these substances directly from the water (and from the algal food in the case of cadmium) by oysters and clams and the loss of these substances by the animals after the source has been removed.

Finally, a scaled-up version of the system was operated on the Institution dock from June through October, 1972. This involved four algal growth ponds of 2140-liter capacity, the output of which was fed into four 9' x 2' x 2' animal tanks containing tray cultures of oysters, clams, and mussels. A fifth animal tank containing all three shellfish received unfiltered seawater as a un-fed control (Fig.4). The algae ponds were operated in a variety of ways, most noteworthy of which was the successful use, for the first time on a large scale, of an automated, fully continuous flow system in which new sewage effluent-seawater medium was added and the culture harvested on a continual basis at the rate of 50% of the culture volume per day. Output from the shellfish tanks were fed through similar tanks containing cultures of Irish moss (*Chondrus crispus*), sea lettuce (*Ulva lactua*) and other seaweeds. The yield of phytoplankton, assimilation and growth of the molluscs, and utilization and the mass flow and distribution of nitrogen and phosphorus in the complete system were monitored.

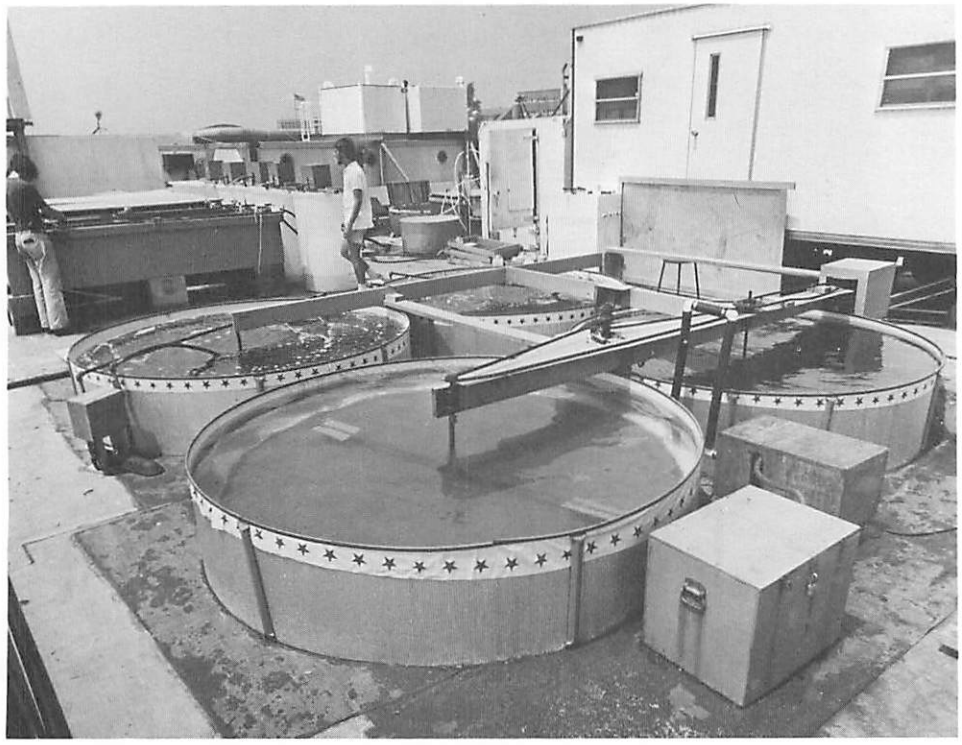


Fig.4 (Ryther,Corwin,Tenore,Goldman,Kerfoot,Vreeland,Prince and Clarner) Algal growth ponds (foreground) and shellfish rearing tank (background) used on W.H.O.I. dock during summer, 1972.

BENTHIC STUDIES

Howard L. Sanders, J. Frederick Grassle, George P. Hampson,
Linda Cole, Susan P. Garner and Virginia Goodrich

With the completion of two transects, one off Surinam and the other off Ireland, we have finished the field work associated with the extensive phase of the deep-sea benthic program. Our objective is to be able to treat the entire deep ocean floor of the Atlantic as a unit. Preliminary findings clearly indicate differing patterns of distribution for various deep-sea taxa. Both the highly diverse isopod and cumacean crustaceans show considerable regional endemism, while the lesser endemism of the protobranchiate bivalves is largely confined to the upper slope. We find that benthic animals living in the relatively 'chemostatic' and poor trophic regime of the deep sea have, on the average, a low reproductive potential and a high proportion of adults to juveniles compared to their counterparts in shallower depths. Circumstantial evidence suggests that they also may be considerably longer-lived, have lower metabolic rates, and be more sensitive to stress.

Using the submersible *Alvin*, thousands of square meters of the sea floor on the continental slope south of New England have been quantitatively surveyed photographically for the larger epifaunal invertebrates and fish. Five species account for 97% of the animals counted in the survey. The faunal components change continuously over the depth interval studied, 495 to 1830 meters. For the most abundant species, the patterns of distribution - aggregated, random, or over-dispersed - were determined over increasing areas of bottom from 20 x 20 centimeters to more than 1000 square meters.

During the recent summer, we were able to place four boxes of azoic (frozen and thawed) sediments by means of *Alvin* at the permanent bottom station in 1830 meters of water. These boxes will serve as temporal markers in the seasonless deep sea. We plan to measure rates of colonization and growth by retrieving one box a year. The findings will be compared with similar experiments in the shallow waters of nearby Buzzards Bay.

The sampling phase of the West Falmouth oil spill study has now been completed and the analyses of these samples are progressing well. Oil-related effects were both evident and severe on components of the benthic biota that settled into the study area a year after the actual spill.

BENTHIC MARINE INVERTEBRATA

Rudolf S. Scheltema and Isabelle P. Williams

During the course of the year we have completed two new major undertakings, (1) an historical study of deep-sea biological dredging in America, 1846-1872 and (2) a field and laboratory study on the egg masses and veliger larva morphology of Woods Hole prosobranch gastropods. The former resulted in a paper read at the International Congress on the History of Oceanography held at Edinburgh, Scotland commemorating the centenary of the *Challenger* Expedition.

On the 7th of December 1872, H.M.S. *Challenger* left Sheerness, England, on one of the great adventures of scientific exploration, a voyage of four years which circumnavigated the globe and visited all the major oceans of the world. Among the principal goals of the expedition was a study of "the distribution of organic life throughout the area of exploration" (*Challenger* Rept., 1(1):iii) and in particular the extent of life on the bottom of the ocean at abyssal depths. The motives and arguments presented to the Royal Society for supporting the expedition were many and varied. For the most part they are reflected by the statement of Dr. W. B. Carpenter who "expressed the earnest hope that the liberal assistance of Her Majesty's Government, which has already enabled British naturalists to obtain the lead in this inquiry, would be so continued as to enable them to keep it for the future" (Nature 1871, 4:187, original italics) and by J. G. Jeffreys who wrote, "...I feel confident that Great Britain, with her vast wealth, naval resources, intelligence, energy and perseverance, will keep the lead which she has now taken" (Nature 1869, 1:168). Events in America which helped precipitate the international competition in deep-sea research were (a) the first systematic study of the deep sea made by L. F. Pourtales (1867, Bull.Mus.comp.Zool. 1:103-120) on the U.S.Coast Survey vessels *Corwin* and *Bibb* and (2) the impending deep-sea expedition of the especially built U.S.Coast Survey research vessel *Hassler* directed by Prof. Louis Agassiz. The *Challenger* represents one of the early government-supported international competitions, a phenomenon which continues into the present day. A full account of America's role in this intriguing bit of history is given in our account presented at the *Challenger* centenary (Scheltema and Scheltema, 1972, Proc.Roy.Soc.Edinburg 72:133-144.)

The larval stages and egg masses of the more common benthic prosobranch gastropods of the Woods Hole region are largely unknown. Among the 42 species most frequently encountered listed in the Woods Hole check list (Smith 1964, pp. 139-141) the egg capsules of only 27 forms presently can be identified. Moreover, the mode of development has been determined for only 30 species; 18 have phytoplanktotrophic larvae, 12 develop directly without a pelagic state, whilst the type of development of the 12 remaining species is unknown. The pelagic larvae of nine species with planktotrophic veligers have been described in published accounts. The larval morphology of the nine remaining species known to have pelagic larvae has not been described. An understanding of the population dynamics and ecology of species having pelagic stages requires that their veligers be recognizable in the plankton.

In collaboration with Dr. Catherine Thiriot, Centre Océanologique de Bretagne, Brest, France, we have been able to identify from the plankton 19 species of gastropod larvae. Of these, 13 have not been previously described including such an ubiquitous form as *Bittium alternatum* and the common *Triphora nigrocincta*. We have made drawings of living larvae, compiled descriptions from our observations and have made scanning electron microscope photomicrographs of the shells (Fig.5). We hope with a few additional summers of work to construct a key for the prosobranch gastropod larvae of the Woods Hole region.

Researches on the dispersal of folliculinid protozoa and prosobranch veligers (*Bursa*) have culminated in two manuscripts which have been accepted for publication.

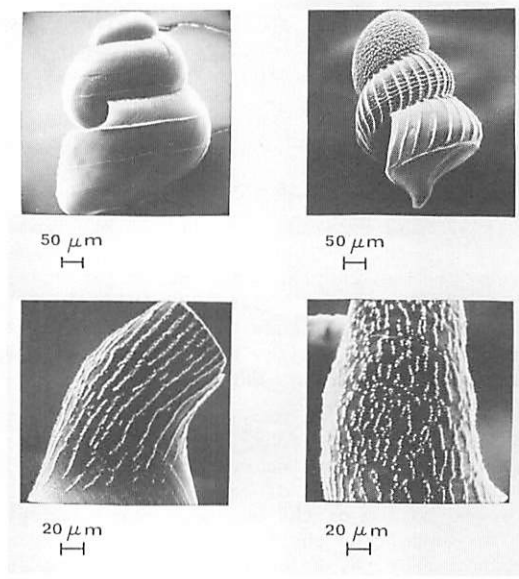


Fig.5 (Scheltema and Williams) Upper left - Larval shell of *Bittium alternatum* taken from the plankton of Woods Hole. Photographed at 280X. Upper right - Larval shell of*Triphora nigrocincta* taken from the plankton in Woods Hole. Photographed at 250X. Lower left and right - Siphons of larval shells of two common species of *Anachis* found in the Woods Hole region and previously described (Scheltema,R.S. and A.H.Scheltema, 1963; A.H.Scheltema, 1969). These two forms are distinguished only with difficulty under a light microscope, but difference in the marking on the siphons is readily seen with the scanning electron microscope. Left - *Anachis translirata* photographed at 420X; right - *Anachis avara* photographed at 690X.

MARINE BIOACOUSTICS

William E. Schevill and William A. Watkins

Detailed analyses have been made of the sounds recorded at sea on several arrangements of the non-rigid, four-hydrophone array. Sound sources were located, tracked, and plotted to obtain information about both the animals and the array. The efforts to reduce the time needed for these acoustic locations has largely been unsuccessful, though we continue to try different ways of automating more steps in the analysis.

A larger 300-m array was attempted during this summer's cruise and hydrophone cable-driving equipment was installed to minimize losses, with the longer cables. Sperm whales and several varieties of porpoises were recorded with this system as they passed within range.

Analysis of the array data from our experiment in Kealakekua Bay, Hawaii Island, provided information about the Hawaiian spinner porpoises (*Stenella* cf. *longirostris*) that in most cases would not have been available through conventional single hydrophone listening. The spectacular serial spin is unimportant acoustically. Bursts of clicks often were answered within a half-second or less by another nearby porpoise. Answering porpoises were separated by no more than 10 m. Their sounds were produced at depths above 10 m. None were heard deeper than 15 m. Of three sound types, only the clicks had highly directional propagation characteristics.

A short trip in Cape Cod Bay and aerial observations provided more information about the right whale (*Eubalaena glacialis*), the finback (*Balaenoptera physalus*), and a porpoise (*Lagenorhynchus albirostris*).

Intense (in excess of 65 db re 1 dyne/cm^2) low-frequency sounds from two minke whales, *Balaenoptera acutorostrata*, were analyzed and reported. These were composed of single downward sweeps in frequency from about 130 to 60 Hz, lasting about 0.3 seconds.

A study of stereotyped repetitive pulse patterns in the sounds of the walrus, *Odobenus rosmarus*, show that these metallic pulsed sounds appear to be dominant in the inshore broken ice areas of the arctic. The spectacular "bell" sound also may be heard from walrus in the springtime ambient sound.

The proceedings of the Shenandoah whale-biology conference are being edited by W. E. Schevill.

In situ MEASUREMENTS OF DEEP-SEA BENTHIC OXYGEN DEMAND

Kenneth L. Smith, Jr. and John M. Teal

We made the first *in situ* measurements of deep-sea benthic community respiration in June and August from the DSRV *Alvin* (Smith and Teal, in press). We placed bell jar respirometers on the bottom at the permanent slope station located 120 miles south of Cape Cod at a depth of 1850 m. Additional measurements were made in July from the R/V *Alcoa Seaprobe* using a drill rig equipped with a 2000-m drill pipe, and television camera pod at a station 20 miles southwest of the permanent slope station at the same depth. Oxygen uptake by these slope sediments was two orders of magnitude less than the uptake of sediments from shelf depths. Formalin treatment indicated no measurable chemical oxygen uptake showing the total to be biological (community respiration). We predict the further decrease of oxygen uptake with increasing depth.

Reference

Smith, K. L., Jr. and J. M. Teal. Deep-sea benthic community respiration: an *in situ* study at 1850 meters. *Science* (in press).

In situ MEASUREMENTS OF BENTHIC OXYGEN DEMAND IN NEW YORK BIGHT

Kenneth L. Smith, Jr., Gilbert T. Rowe and Charles H. Clifford

A seasonal study of the oxygen uptake of New York Bight sediments began last year and continued through April, 1972. We examined the *in situ* oxygen demand of the sewage sludge sediments, using shallow-water bell jar respirometers (Smith, *et al.*,1972), and found significantly greater oxygen demand in these sediments compared to those of a control area. Compartmentalization of the total demand with a formalin treatment revealed a chemical demand of 33 to 46% and a biological demand (community respiration) of 54 to 67%. Macrofaunal abundance in the sludge sediments was significantly greater than any previous measurement of benthic macrofauna. The benthic community is greatly altered by the introduction of sewage sludge but no detrimental effects were observed.

Reference

Smith, K. L., Jr., K. A. Burns and J. M. Teal. 1972. *In situ* respiration of benthic communities in Castle Harbor, Bermuda. *Mar. Biol.* 12:196-199.

PHYSIOLOGICAL ECOLOGY OF PTEROPODS

Kenneth L. Smith, Jr.

On *Chain* Cruise 105 (St. Johns, Newfoundland to Lisbon, Portugal, June-July, 1972), I examined the horizontal and vertical distribution of thecosomatous and gymnosomatous pteropods in relation to temperature and pressure (depth). The respiration of pteropods caught in midwater trawls was measured under varying temperature and pressure regimes. The synergistic effects of temperature and pressure on respiration were very pronounced and correlated well with the distributional patterns of each species. These findings and results obtained on *Atlantis II*, Cruise 59 (Madeira-Cape Verdes-Woods Hole, November-December, 1970) are being incorporated into a manuscript on the ecology of pteropods in the North Atlantic.

Sargassum COMMUNITY RESPIRATION

Kenneth L. Smith, Jr., Kathryn A. Burns, and Edward J. Carpenter

A study of the respiration of the pelagic *Sargassum* community and its component populations was completed (Smith, Burns and Carpenter, in press). Total oxygen consumption by the *Sargassum* community was significantly higher at a Slope Water Station than in the Sargasso Sea. Increased respiration in the Slope Water was attributed to higher concentrations of nutrients and organic matter near shore. *Sargassum* community respiration was two to five times greater than the surface water plankton respiration. Community respiration was compartmentalized into epiphytic, macrofauna, *Sargassum*, and microbial respiration. Microbial respiration was the most important component. Its significance in such an open-ocean environment is perhaps attributable to the extensive surface area presented by the *Sargassum*, which is conducive to adsorption of dissolved macromolecular compounds and to biochemical processes.

In conjunction with the *Sargassum* community study, Burns and Smith examined the energetics of the *Sargassum* fish, *Histrio histrio*. Fish were obtained during *Knorr* Cruise 25 (Puerto Rico to Woods Hole, April-May, 1972). Ingestion, egestion, growth, respiration and production measurements were made on three size-classes in the laboratory and these requirements compared to food availability in the Sargasso Sea. Comparison of the three size-classes showed changes from high growth and low respiration and assimilation in small *Histrio* to reduced growth and increased respiration and assimilation in larger fish. The annual energy requirement calculated for the fish was 1.4 times greater than the food energy available in the environment, which generally consisted of the *Sargassum* shrimp, *Latreutes fucorum* and *Leander tenuicornis*. This discrepancy is attributed to the inadequacy of extrapolating laboratory studies to field conditions and the difficulty in obtaining adequate population size measurements of the *Sargassum* community fauna.

Reference

Smith, K. L., Jr., K. A. Burns and E. J. Carpenter. Respiration of the pelagic *Sargassum* community. *Deep-Sea Res.* (in press).

EFFECTS OF PRESSURE ON RESPIRATION AND ANIMAL ACTIVITY

John M. Teal, Kenneth L. Smith, Jr. and Alister G. Macdonald

Studies of the effects of pressure on animal activity and respiration were carried on with Alister Macdonald of Aberdeen University and with Kenneth Smith. Twelve-hour experiments were performed to check whether accommodation was an important effect in respiration measurements. Respiration was found to be always higher immediately after a pressure or water change in the animal chamber but usually settled down to a steady value within five to sixty minutes. This was sometimes followed by a further decline in rate over the next six to twelve hours.

At pressures of 200 to 300 atmospheres, all of the experimental species (decapod crustacea, amphipods, mysids, and squids) went into convulsions and then became quiescent although in some cases the heart continued to beat. Whether or not the animal died depended upon whether or not it was resistant to anoxia. The mysids and amphipods, which could survive in seawater bubbled with nitrogen for many minutes at surface pressure, survived the pressure treatment. The decapods, crustaceans and cephalopods, which were not resistant to anoxia were killed by the pressure treatment, presumably due to their breathing movements being stopped at high pressures.

BIRD MIGRATION STUDIES

John M. Teal and Timothy G. Williams

In cooperation with staff and students from Rockefeller University, a tracking radar was again taken to sea during the fall bird migration. Tracks of some 1200 birds were obtained. Birds were seen passing Bermuda going eastward again this year. Unfortunately, when *Atlantis II* was in proper position to see where these birds were going, no migration occurred due to unsuitable weather along the North American coast. As in previous years, observations were made with NASA radars at the Bermuda and Wallops Island Stations, and at weather radars in the northeast to try to correlate times of migration at the different stations with observations at sea.

SALT MARSH EXPERIMENTAL STUDIES

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

Studies of salt marsh enrichment, begun two years ago in cooperation with I. Valiela and students in the Boston University Marine Program, (BUMP), were continued. Limitation of plant growth on marshes results primarily from nitrogen shortage, although we still have not observed as much growth in our experiments as naturally occurs on the most productive of marshes. Grasses contribute most of the production. Algal production was enhanced, however, especially in the spring before the mud surface became shaded. Algal diversity was reduced in fertilized plots.

High marsh grass production (*Spartina patena*) in this third year of the study leveled off due to the accumulation of nutrients in plants and soils. Differences in production between the two levels of fertilization in more frequently flooded low marshes (*Spartina alterniflora*) continued, though they were found to be less than in the first two years. Losses of added nutrients in tidal waters remained low. We, with D. Downing of Boston University, progressed in modelling the growth of grass and successfully accounted for some of the variation in grass standing crop during the year, using a model based on the effects of fertilization level, light, and temperature on respiration and photosynthesis.

Studies of the response to increased production on the part of bacterial and animal inhabitants of the marsh are still in preliminary stages. *In situ* measurements with bell jars showed increased oxygen uptake by the benthic community in the fertilized plots as compared with control plots. The increase was due both to bacteria and other organisms. Sorting and preliminary examination of benthic samples from the same sites also show the presence of larger animal populations in the fertilized areas.

Studies of nitrogen fixation and denitrification have been started by BUMP students on the experimental marshes. Nitrogen fixation has ceased in the field plots to which nitrogen containing fertilizers has been added. Denitrification was found to be greater in the fertilized plots. These studies, when complete, will be used with other data to produce a salt marsh nitrogen budget.

The long-term sampling of the Wild Harbor marsh for petroleum hydrocarbons continues. The considerable recovery noted in marsh plants seems to be inversely correlated with the levels of oil residual in the mud. Samples of animal populations were collected. Kathryn Burns is initiating a study of enzyme induction in fiddler crabs from the polluted marsh.

THE USE OF CHELONATED ACTIVATED CARBON TO SEPARATE TRACE METALS FROM NATURAL WATERS

Ralph F. Vaccaro and William B. Kerfoot

Rational management requires precise information on *in situ* effects of pollutants in natural waters. This is especially true for evaluating the envitonmental stress associated with trace metal contamination.

Current analytical goals emphasize an improved ability to sample, isolate and analytically resolve a variety of critical metallic elements whose measurement is typically complicated by high concentrations of masking substances. We are presently exploring a new and promising technique designed to separate, concentrate and analyze a suite of metallic elements present in trace amounts in marine and fresh waters. Briefly the technique uses finely divided activated carbon pretreated with an adsorbable organic chelon to concentrate trace elements. The versatility of the 7-hydroxyquinoline series of chelons has been exploited for this purpose although logical extensions to other aromatic-type chelons capable of being adsorbed in activated carbon is anticipated.

Historically, either liquid-liquid organic extraction of chemically induced organometallic compounds or column chromatography have been the preconcentration methods of choice for trace metal analysis. Comparable results can also be achieved with cocrystallization and co-precipitation. To reiterate, the ultimate effectiveness of these procedures depends upon their ability to separate the trace metal of interest from the more abundant and interfering chemical species.

In recent years the use of chelating resins, i.e., Chelex 100, has added a new dimension to trace metal analysis. Typically these materials are styrenedivinylbenzene polymers which incorporate various chelating agents such as dimethylgloxime or imidodiacetic acid containing functional carboxyl groups. Their behavior is complex in that they introduce two well-known analytically useful processes,

ion exchange and complex formation. Chelating ion exchange differs from ordinary ion exchange in that the former typically displays greater ion selectivity and greater bond strength. However, chelating ion exchange rates are notably slower and appear to be controlled by particle diffusion or some other second-order chemical reaction.

Our activated carbon approach employs two different but complementary physio-chemical phenomena, (1) the adsorptive behavior of potentially useful chelons on the activated carbon matrix and (2) the ability of adsorbed chelons to retain their ionic selectivity.

We have compiled information on the dynamic interactions between selected solid surfaces and external adsorbates of the phenolic type. Typically these studies show a relatively rapid rate of uptake during the first hour of contact followed by a gradual approach to equilibrium over a two-to-three week period. At equilibrium the uptake rate is essentially dependent upon the concentration gradient which controls the diffusion of solute into the internal capillaries of the carbon particle. The long-term equilibrium is predictable according to the Langmuir adsorption isotherm which describes an hyperbolic relation between the amount of solute adsorbed per unit adsorbent and the concentration of solute provided. When adsorbates are competitive, net uptake becomes modified according to the changes in diffusivity introduced by varying molecular size and the cross-sectional configuration of the adsorbent. Finely divided charcoal provides an impressive surface area for adsorptive reactions, 10 mg (Size No. 120/140, U.S.Standard sieve series) possessing an equivalent area of about 2×10^9 mm^2.

Most organic chelating agents are protic acids which act as multidentate ligands and dissociate in a predictable manner. Chelation has been defined as the union of a ligand in which a donor atom furnishes a lone pair of electrons and a metal ion which acts as an acceptor incorporating electrons and a metal ion which acts as an acceptor incorporating electrons into empty levels in its own orbitals. The net effect of the exchange is that each ligand molecule gives up one proton pair.

$$M^{+2} + 2\,HL^{-} \rightleftharpoons ML_2^{-2} + 2\,H^{+}$$

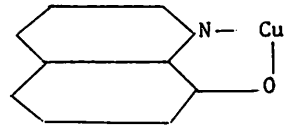
Metal ions which form weakly bound chelates react efficiently only at high pH. Thus pH control presents an option for controlling elemental specificity for analytical purposes.

Our initial search for a chelon adaptable to the chelonated-activated carbon system described above was oriented by the following desirable properties.

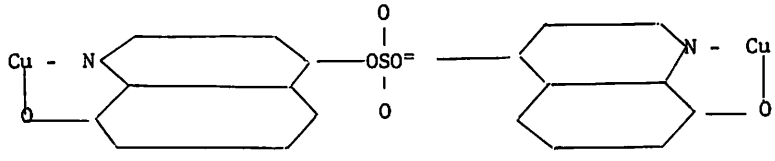
1. Reasonable solubility in seawater.
2. Ready adsorbability on activated carbon.
3. Favorable interaction with metals of environmental interest.

The hydroxyquinolines have long been recognized as powerful chelons, adaptable to a broad range of metallic elements. Members of the series appear to meet the requirements for an effective chelon-carbon system. Their aromatic structure predicts a high adsorptive capacity and the availability of a sulfate dimer, $C_{18}H_{18}N_2O_7S$, insures water solubility. Theory predicts that a transition metal such as copper having a coordination number of 4 will react with such compounds to form a 5-membered ring as indicated below.

Monomer



Dimer



Present indications are that as many as 17 trace elements may respond to 8-hydroxyquinaline in a manner which facilitate their direct analysis by the atomic absorption technique. These include the common elements Al, Co, Cr, Cu, Fe, Ga, Ge, Mn, Ni, Ti, V, Bi, Pb, Mo, Cd, Zn and Be.

MOLECULAR ECOLOGY

Stanley W. Watson, Frederica W. Valois, Robert J. Nairn,
Pamela E. Bowman and Helen L. Quinby

In 1972 studies were continued on structure-function relationships of membranes and cell walls of nitrifying bacteria. In addition a technique was developed for the quantitation of bacteria in the ocean and studies were initiated on nitrogen fixation.

Membrane studies: Membrane studies were restricted to *Nitrobacter winogradskyi* which possesses peripheral cytomembranes (Fig.6) that are studded with particles queued in rows (Fig.7). These membranes were isolated from other cellular components and were morphologically and biochemically characterized.

Cell wall studies: The peptidoglycan layer of nitrifying bacteria both marine and terrestrial, was isolated and chemically analyzed. While the peptidoglycan component of most of these organisms was similar to that found in *Escherichia coli*, two marine strains had a peptidoglycan layer which differed in chemical composition from other gram-negative bacteria. Preliminary results also suggested that marine forms have less peptidoglycan that terrestrial forms.

Determination of bacteria biomass in the ocean: A method was developed in this laboratory to quantitate the number of bacteria in a sample of seawater. This method detects as few as 1000 bacteria in a liter of seawater.

Nitrogen fixation in the ocean: Methods are being developed to determine the number and distribution of marine nitrogen-fixing bacteria in the oceans and their *in situ* rates of reaction. These organisms will be isolated, identified and compared biochemically and morphologically to their terrestrial counterparts.

ZOOPLANKTON STUDIES

Peter H. Wiebe and Diane Young

Detection and description of zooplankton patchiness: Major emphasis over the past two years has been on the field collection of good quality Longhurst-Hardy Plankton Recorder (LHPR) samples. In September, 1972, samples were collected at approximately 90 m in the Sargasso Sea by an LHPR towed from the surface. In addition an LHPR system designed for use with DSRV *Alvin* was used to complete four transects along the seawater-sediment interface at the 1800 m deep ocean bottom station (39°46'N, 70°41'W). The laboratory procedures culminating in species counts of these samples have been started.

Effects of zooplankton patchiness on net tow sampling error: In the continuing study of the relationship between net size, tow length, and sampling error, three sampling experiments were executed, two in the Mediterranean Sea (September, 1970, November, 1971) and one in the Sargasso Sea (March, 1971). Counts of the Mediterranean experiments were completed this year, but the results have not been completely analyzed. Sargasso Sea samples remain to be counted.

Ecological aspects of molting in crustaceans: Experiments have been conducted on two cruises and in the laboratory to develop a chemical technique to differentially stain euphausiids and other crustacean zooplankton at the time of molting. Our attention has been concentrated on a histro-chemical test to detect "phenoloxidase" activity which is thought to peak at ecdysis. In the effort to develop a technique for application at sea, *Artemia salina* (the brine shrimp), has been used as the experimental animal in laboratory batch culture experiments (9) lasting one to three months. In order to test the technique at sea, a total of 30 plankton tows (with approximately 80 experimental treatments) were taken from the Sargasso and Mediterranean Seas. The data have not been completely analyzed but preliminary observations indicate significant differential staining of individuals within several crustacean groups (amphipods, decapods, mysids, and possible euphausiids). It is still unknown whether the technique will provide sufficient sensitivity to yield *in situ* molting rates.

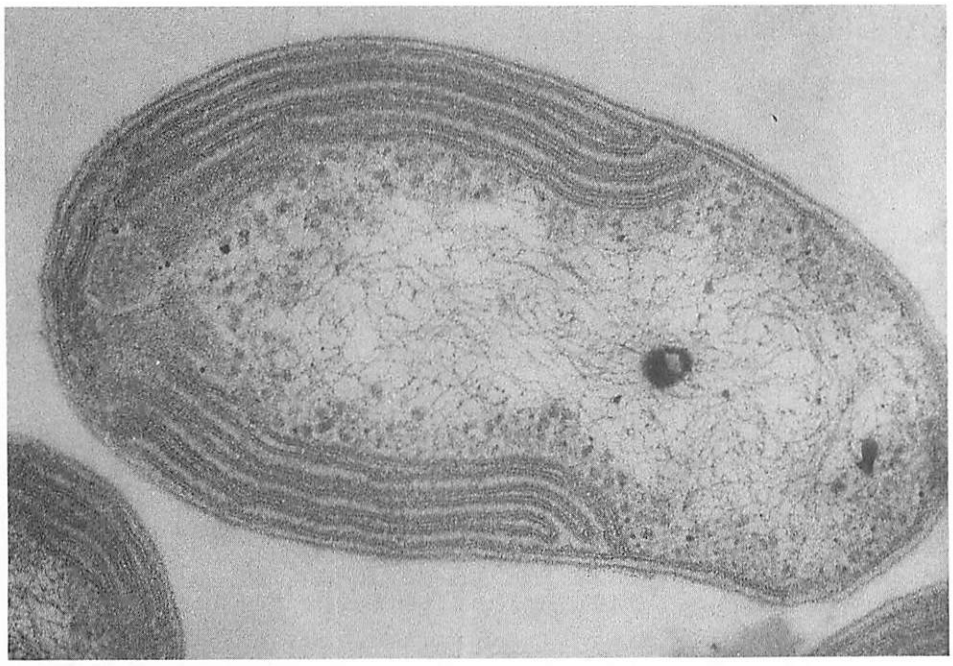


Fig.6 (Watson,Valois,Nairn,Bowman and Quinby) An electron micrograph of a section of *Nitrobacter vinogradskyi* showing cytomembranes in the peripheral region of the cell. Magnification 123,000.

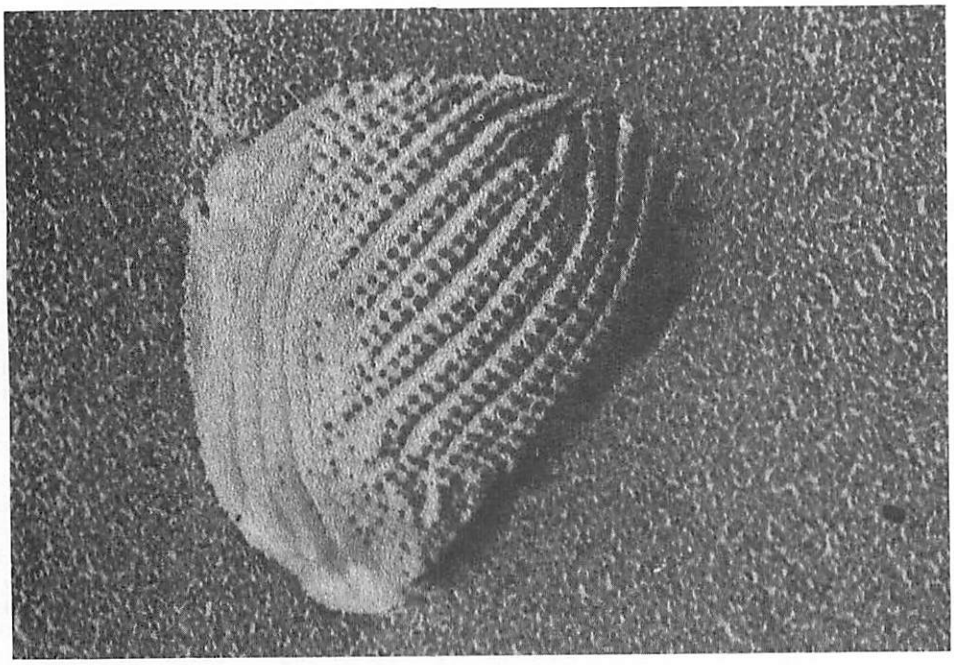


Fig.7 (Watson,Valois,Mairn,Bowman and Quinby) An electron micrograph of a freeze etch preparation of an isolated membrane from *Nitrobacter vinogradskyi* showing the particles which cover the membranes. Magnification 334,000.

Halosphaera viridis IN THE MEDITERRANEAN SEA

Peter H. Wiebe, Charles C. Remsen and Ralph F. Vaccaro

In September and October, 1970, stratified zooplankton collections were made with opening/closing "Bongo" nets throughout the Mediterranean Sea and at a station west of the Strait of Gibraltar. Stratified samples were taken from the surface to 2500 m. In addition to the usual zooplankton, many large ($\sim$ 400 μ diameter) green plant cells were suspended in samples from depths greater than 1000 m. They were later identified as *Halosphaera viridis*, a green alga in the Chlorophyta class Prasinophyceae. Deep water tows in the Ionian Sea in November 1971 verified their presence below 1000 m and some of the individuals collected were used for culture, chemical analysis and electron microscopy.

In 1972 we determined the abundance, size range and distribution of these plant cells in collections in order to gain some insight into their origin at great depths. Supplementary information on their chemical composition (C, H, N) and electron photomicrographs of thin sections and whole mounts suggest their possible role in deep-sea ecosystems.

We have found that in the fall the concentrations of *Halosphaera* cyst cells below 1000 m are 25 to 100-fold more abundant than in the surface layer (0-200 m). In the late spring (May/June), these cells are several orders of magnitude less abundant below 1000 m than in the fall. Based on this and other information, we have calculated that the cells are sinking at a rate of eight to thirty-three m/day and that during some portion of the year they may play an important role in a direct energy flow to the deep-sea benthos in the Mediterranean Sea.

TRANSPORT OF ORGANIC MATTER TO DEEP-SEA FLOOR

Peter H. Wiebe

The major pathway(s) of organic matter to the deep-sea floor is largely unknown although potential sources have been delimited. These include (a) sinking of large dead animals such as whales, sharks, and large predatory fish or macroscopic plants, such as pelagic *Sargassum* and neritic turtle grass to the deep-sea floor, (b) transport of organic matter to the abyss by turbidity currents, (c) transfer of organic matter downward by ladders of migrating animals, (d) convection and advection of dissolved organic matter and (e) sinking of small particulate organic matter. This latter source, which includes detrital components such as fecal pellets, carapaces, and animal carcasses, is of particular interest since recent literature indicates these organic particles do sink rather rapidly and in some cases reach great depths. In addition to the potential these fractions hold as a major food source for deep-living animals, they also may be a primary conveyor of surface-introduced organophilic pollutants (pesticides, PCBs, heavy metals) into the deep sea.

In order to document the importance of this pathway, direct measurements of the material falling to the sea floor are needed. Our effort in 1972 has been to design and construct a deep-sea sediment trap for use just above the deep-sea floor. The prototype trap has a base one meter square and a height of 30 cm. At the trap bottom are filters to retain falling particles. Two spring-powered sliding doors, each one meter x one-half meter, are used to close off the lower 2 cm of the trap during ascent to prevent disturbance of the particles collected on the filters. The trap is in the final stages of fabrication and the beginning stages of *in situ* testing.

DEPARTMENT OF CHEMISTRY

John M. Hunt, Chairman

SEA WATER CHEMISTRY

THE GEOCHEMICAL OCEAN SECTION STUDY

Derek W. Spencer

On July 18, 1972, the R/V *Knorr* departed from Woods Hole on the first leg of the GEOSECS (Geochemical Ocean Section Study) Atlantic Cruise. She arrived in Ushuaia, Argentina, December 23, after completing Leg 6 and making a total of 75 stations on a track (Fig.1) from 75°N in the Greenland Sea through the Western Atlantic basins into the Scotia Sea. Future legs will provide additional stations in the Antarctic, the Southeast Atlantic and Equatorial Atlantic Oceans before the completion of the Atlantic cruise in April of 1973.

The objectives of the program are to provide, for the first time, a consistent set of hydrographic and chemical measurements on a series of sections in the world's oceans that will aid the formulation of detailed theoretical models of the large scale ocean circulation. In particular, the program is providing a very extensive set of samples for radioactive tracer measurements that will facilitate model calculations including real time.

The shipboard program is carried out by the GEOSECS operations group under the direction of Arnold Bainbridge. Included in this program are measurements of salinity, temperature, oxygen, phosphate, nitrate, silicate, total carbon dioxide, PCO_2, dissolved nitrogen and argon, alkalinity, radon-222 on discrete samples, continuous measurements of conductivity, temperature, using the CTD (conductivity-Temperature-Depth) sensor developed by Neil Brown, and oxygen and light scattering using probes developed by the G.O.G. (GEOSECS Operations Group) group and ourselves.

In addition to these analyses, samples are being collected for shore-based measurements of trace elements, stable isotopes, particulates and the radioactive isotopes H^3, C^{14}, Sr^{90}, Cs^{137}, Ra^{228}, and Si^{32}.

One of the prime concerns in the shipboard program has been to establish and maintain high precision and accuracy in the measurements. Precision attained during the initial legs was excellent, and similar statistics from later legs confirm that the quality of the data is being maintained.

One of the most important innovations of the shipboard program is the real time data acquisition system and the ability that the chief scientist has to select his sampling depths on the basis of real time information on the salinity, temperature, density, oxygen concentration and light scattering characteristics of the water column.

The underwater package consisting of 24-30 liter Niskin bottles arranged on two Rosette samplers also houses the CTD sensors and oxygen and nephelometer probes. Signals from the probes are transmitted to the surface by a single conductor cable using frequency shift keying. The same cable carries signals that enable the bottles to be tripped in sequence at depth.

In the data acquisition system, raw data is recorded on analogue magnetic tape and is directed to a Nova 1200 mini-computer for preprocessing. Selected portions of the data, normally about one in every sixteen data points, are transmitted to an IBM 1800 computer which maintains processed data files and controls four storage scopes which can be used to plot the data (or any function of the data).

Normal operation has consisted of displaying profiles of salinity temperature, oxygen and light scattering versus depth on two scopes, density versus depth and potential temperature-salinity correlations on a third scope. The fourth scope has been used for temporary displays of detailed "blow-ups" of significant parts of the water column and for review of those laboratory systems that are interfaced with the computer.

Discrete sample data, as it is accumulated, is fed to the 1800 either directly or by punched cards, and station master files are stored which are available for review by the scientists within 24 hours of the start of the station. In addition, master files from past stations may be recalled at any time for comparison with the current data.

The operating console of the system, including the storage scopes, typewriter terminal and various data control and display systems, is shown in Fig.2. Examples of the real time data display are given in Fig.3, which is a reproduction of thermofax copies produced directly from the storage scopes.

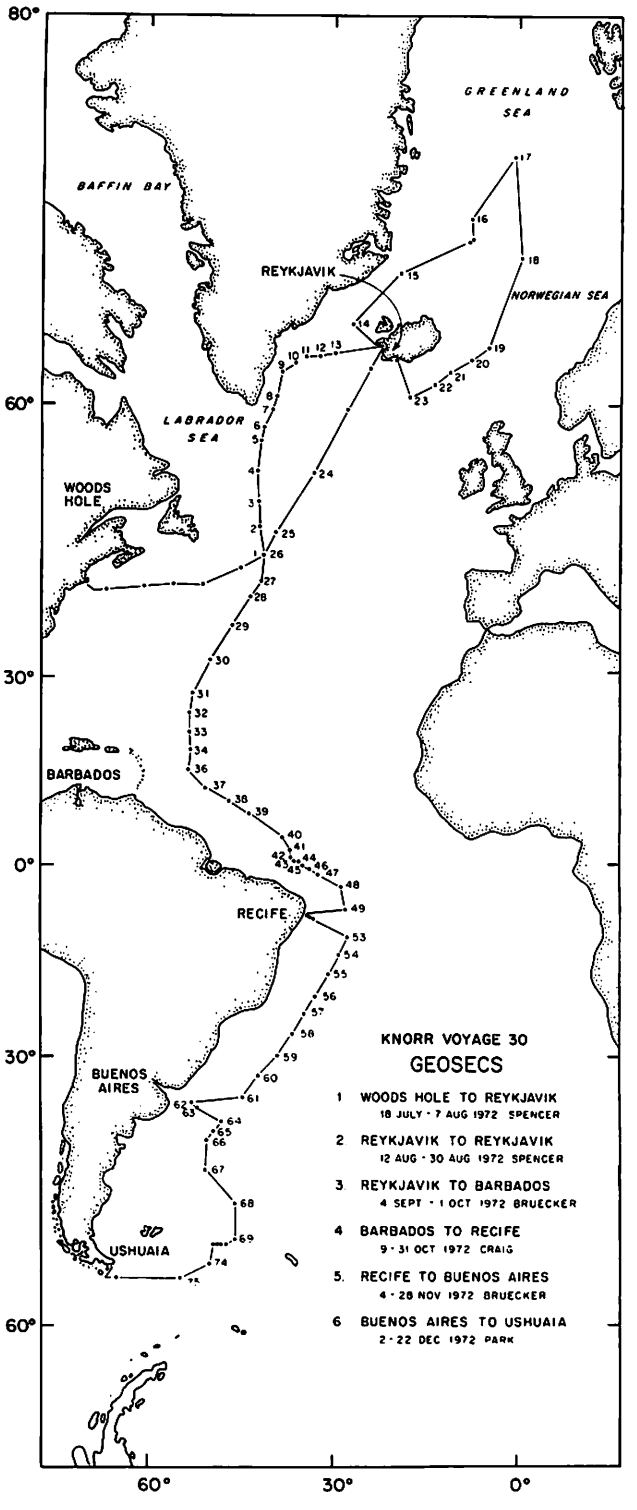


Fig.1 (Spencer) Legs 1-6 GEOSECS Atlantic Cruise

Fig.2 (Spencer) Computer console in operations laboratory on R/V *Knorr*.

Numerous interesting and important features of the Atlantic Ocean water column are being revealed by the data. An example is given in Fig.4 which shows the detail of the relationship between the temperature structure of the bottom water, the *in situ* radon-222, and the light scattering (particle concentration). The radon concentration in the water column above 40 meters off the bottom represents the quantity in secular equilibrium with the present radon-226. The large increase in the bottom 30 meters is "excess" radon derived by diffusion out of bottom sediments. The particles in suspension in the bottom water are principally silicates derived from resuspension of the bottom sediments. The effect of the stability of the water column in controlling the diffusion of these sediment-produced properties is clearly seen in the figure. Similar "bottom" water layers, but with much lower density contrasts, have been observed at many of the stations throughout the Western Atlantic Ocean.

NUTRIENT CHEMISTRY OF THE BLACK SEA

Peter G. Brewer and James W. Murray

We have applied a vertical advection-diffusion model to describe the vertical profiles of total carbon dioxide, ammonia and phosphate in the Black Sea. In Fig.5 we show these data at Station 1466 in the central part of the eastern basin of the Black Sea. Taking a mixing interval over the linear part of the 0-5 °/oo diagram from 75 m above the oxygen zero level to 175 m below it we calculate Z*, the mixing parameter, from the temperature and salinity distributions, and J, the rate of *in situ* production or comsumption for the nutrient species. For total carbon dioxide we calculate

$$J = -1.05 \times 10^{-6} \text{ moles kg}^{-1}\text{year}^{-1},$$

i.e., carbon dioxide is being consumed within this mixing interval, not produced as one might infer from the stoichiometric oxidation model. For ammonia $J = 0.1 \times 10^{-6}$ moles $kg^{-1}year^{-1}$ and for phosphate an exponentially varying J with depth is necessary to fit the profile with

$$J = -9 \times 10^{-9} \text{ moles kg}^{-1}\text{year}^{-1}.$$

We propose that these observed consumption rates are due to the chemosynthetic fixation of carbon, nitrogen and phosphorous by chemoautotrophic bacteria living at the oxygen-sulfide interface.

Direct measurements of chemosynthetic rate by dark uptake of carbon-14 labelled bicarbonate yield estimates of 36 moles C $meter^{-2}$ $year^{-1}$. The surface primary productivity is only

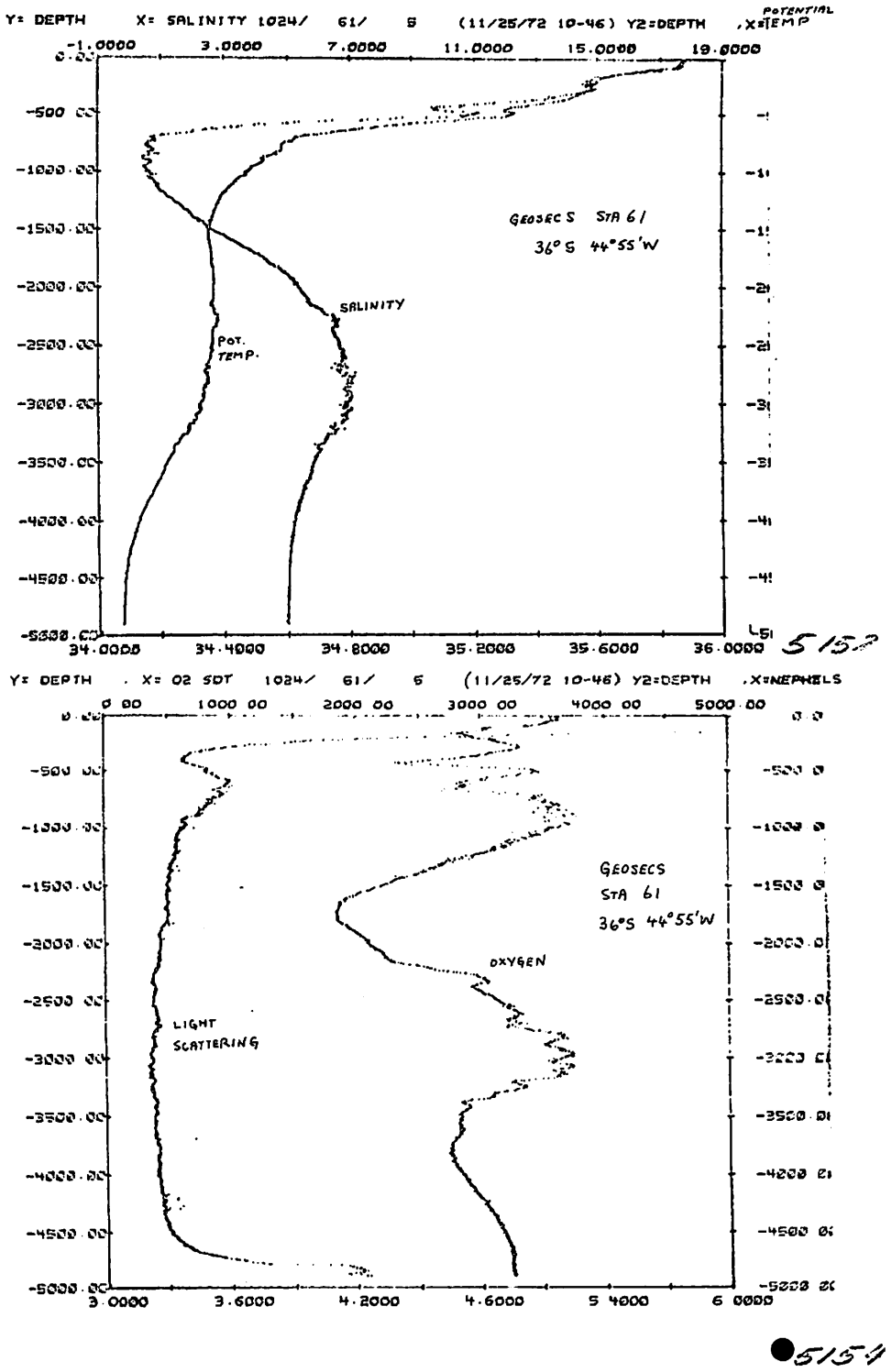


Fig.3 (Spencer) Real time data display.

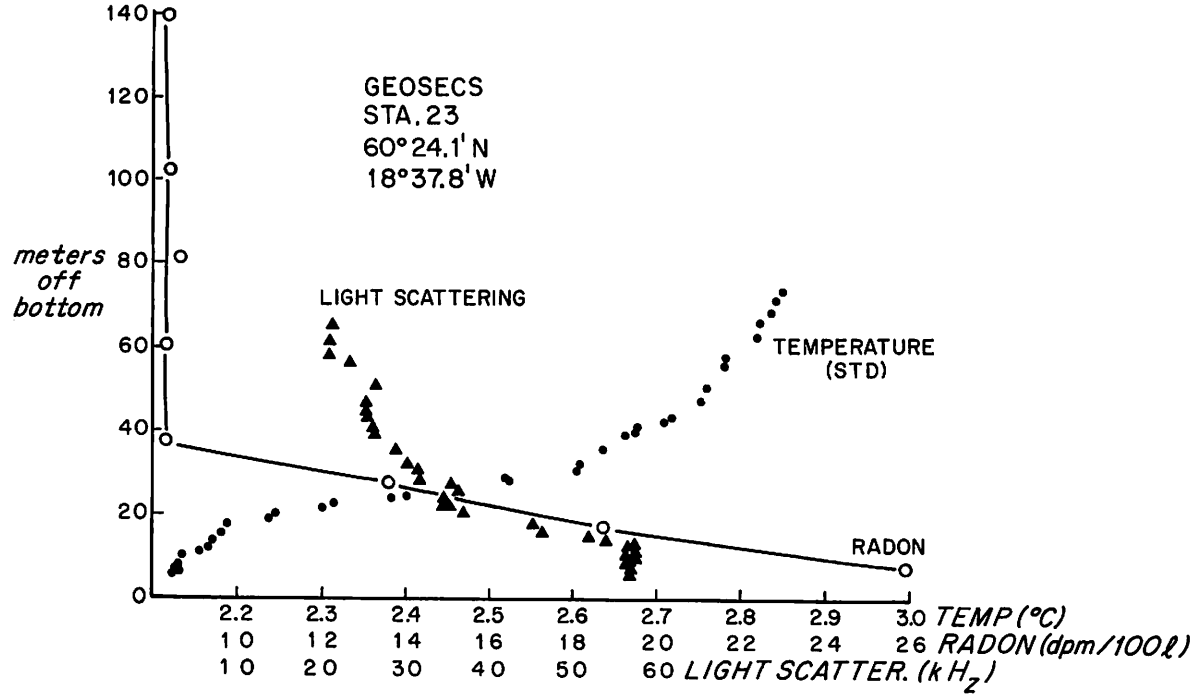


Fig.4 (Spencer) Relationship between temperature structure of bottom water, *in situ* Radon-222, and light scattering.

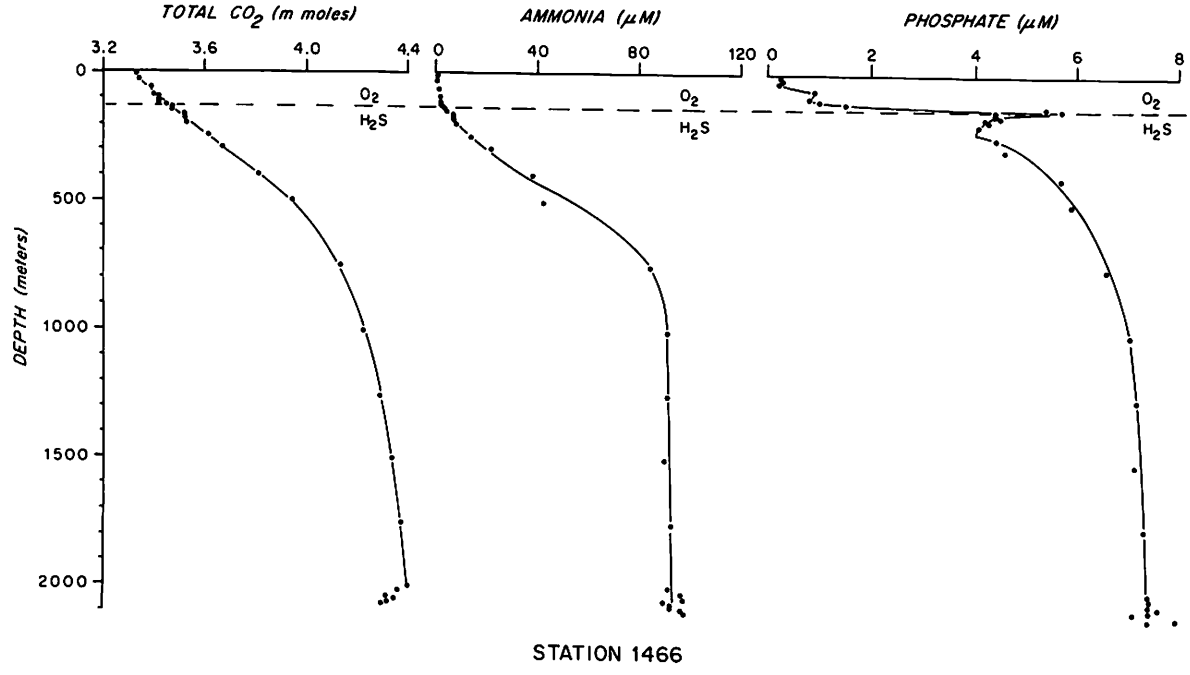


Fig.5 (Brewer and Murray) Vertical profiles of total carbon dioxide, ammonia and phosphate in the Black Sea.

8 moles C meter^{-2} year^{-1} and we suggest the observed chemosynthetic rate is an artifact. We have attempted to set an upper limit to the probable true value by calculating the homogeneous pE buffer capacity, βe, of the water at the lower boundary

$$\beta e = \left(\frac{\delta Cox}{\delta pE}\right)_{pH} = -\Sigma_i \, ri \left(\frac{\delta Mni}{\delta pE}\right)_{pH}$$

Summing for all important reduced species we find βe = 1.6 x 10^{-2} equivalents kg^{-1}. These oxidizable equivalents are available to chemosynthetic bacteria and depending upon the metabolic uses to which they are put various carbon dioxide fixation rates can be calculated. Considering the 24 electron change required to form glucose, at 50% efficiency, we suggest a rate of 0.25 moles meter^{-2}year^{-1}.

The model is strongly dependent upon the assumptions of the vertical advection-diffusion model and has the disconcerting feature that chemosynthesis appears to occur in the absence of oxygen.

TRACE METAL CHEMISTRY OF THE CARIACO TRENCH

Peter G. Brewer

Comparison of temperature data from the Cariaco Trench in August, 1971, with that obtained in 1954, shows that a significant difference exists and that the deep water of the Cariaco Trench has warmed +0.07°C over the 16-year period. If the trend continues the deep water would become unstable in 150 - 200 years. The comparative sets of temperature data are shown in Fig.6.

We have found a significant accumulation of manganese in the deep water of the trench, analogous to that in the Black Sea, with the maximum value being close to 26 μg Mn kg^{-1}. From the temperature and salinity profiles we have obtained the ratio of the vertical eddy diffusion coefficient (K) to the vertical advective velocity (ω) but have been unable to assign specific values to these parameters. We can estimate the next upward flux of manganese from

$$\text{Flux Mn} = K \frac{d\,(Mn(II))}{d_2} + \omega\,(Mn(II))$$

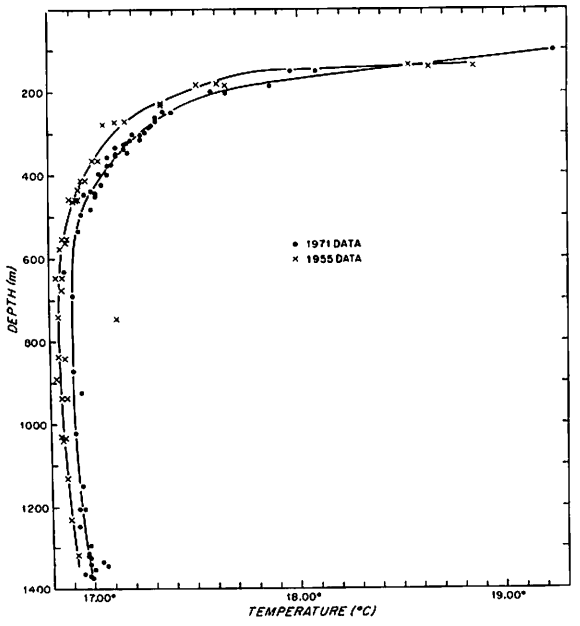


Fig.6 (Brewer) Comparison of temperature data obtained from the Cariaco Trench in 1971 and in 1955.

and the requirement for the steady state condition from

$$\text{Flux Mn} = \int_0^{Zm} Jo\, e^{-\mu z}\, dz$$

The difference between these two estimates, for any μ, represents the amount of fresh manganese transported in particulate form to the basin each year and trapped there by the reduction-oxidation-precipitation cycle. The results are shown in Fig.7. An interesting result is that for reasonable values of ω (e.g. two meters year^{-1}) the annual input of manganese (100 mg meter^{-2}year^{-1}) is not trivial compared to the amount contained in the water column. We suggest that manganese accumulation began about 200 years ago and that the basin must have been flushed at about that time.

KINETICS OF OXIDATION OF MANGANESE IN SEA WATER

Peter G. Brewer and Mark Elert

We have begun a study of the kinetics of oxidation of manganese (II) in sea water. Previous work by other investigators had shown that the reaction was first order with respect to oxygen partial pressure and manganese (II) concentration, autocatalytic and dependent upon the suqare of hydroxyl ion activity. A reaction scheme of the following form has been proposed:-

$$\text{Mn(II)} + O_2 \xrightarrow{\text{slow}} MnO_2\text{(s)} \qquad \text{oxidation}$$

$$\text{Mn(II)} + MnO_2\text{ (s)} \longrightarrow \text{(Mn(II) } MnO_2\text{) (s)} \qquad \text{adsorbtion}$$

$$\text{(Mn(II) } MnO_2\text{) (s)} \longrightarrow 2\ MnO_2\text{ (s)} \qquad \text{oxidation}$$

However few experiments have been carried out in sea water medium and there are apparently no numerical estimates of the rate constant in the literature.

We have followed the rate of removal of Mn(II) in a 2ℓ. reaction vessel at 25°C at a pH of 8.7 and a soluble Mn(II) concentration of 3 x 10^{-4}M. On the basis of a number of experiments we propose that the rate may be described according to the simple expression:-

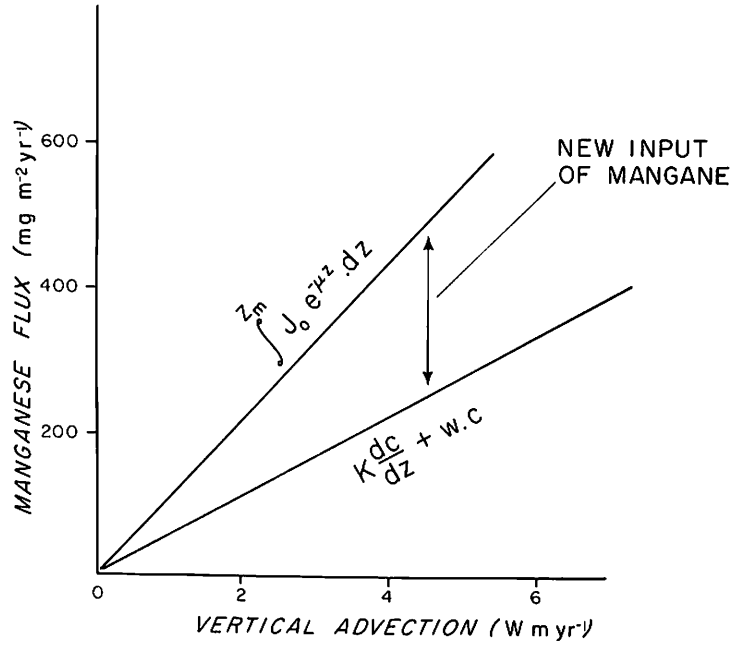


Fig.7 (Brewer) Estimates of the rate of accumulation of manganese in the Cariaco Trench.

$$\frac{-d\,(Mn(II))}{dt} = K\,(Mn(II))(MnO_2)\,(OH^-)^2\,(O_2)$$

Expressing (O_2) in ml liter^{-1} and soluble manganese removal rates in moles minute^{-1} liter^{-1} we find an effective rate constant

$$K = 1.2 \times 10^7 \text{ liter}^4 \text{ moles}^{-3} \text{ ml}^{-1}\text{min}^{-1}$$

The data may be applied to the various manganese removal rates computed from oceanographic observations. As an example we apply the rate constant to the oxidation of manganese at the oxygen-sulfide interface in the Black Sea. The environmental conditions

Temperature	= 8.5°	MnO_2	= 10^{-6}M
pH	= 7.7	Mn^{2+}	= 10^{-6}M
O_2	= 0.2		

Kinetically we predict $\frac{dMn}{dt} \approx 1$ mg m^{-2} year^{-1}, whereas the oceanographic model predicts 875 mg m^{-2} year^{-1}. It seems probable that bacteria are catalytically carrying out the oxidation for the discrepancy between the two rates is large.

MARINE CHEMISTRY OF IODINE

George Wong and Peter G. Brewer

We have developed a technique for the determination of iodate in sea water and have applied it to samples taken at two stations in the South Atlantic on the GEOSECS cruise (Leg 5).

The method involves formation of the tri-iodide ion by acidification and addition of potassium iodide. The sample is then titrated in a microcell with standard thiosulphate solution and the reaction followed photometrically at 353 nm. The method uses 50 ml of sample and has a precision of ±0.5%. An analysis takes 30 minutes.

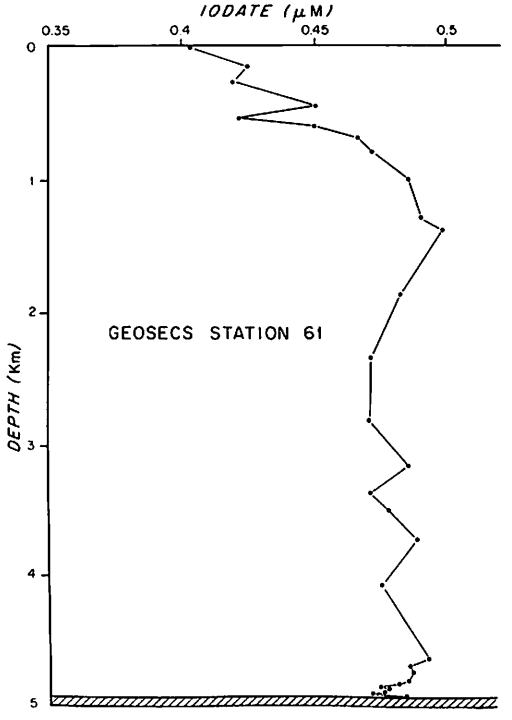


Fig.8 (Wong and Brewer) Vertical profile of dissolved iodate in the Argentina Basin (37°00'S 45°00'W)

In Fig.8 we show a dissolved iodate profile at a location (37°S 45°W) in the South Atlantic. The analyses were carried out on samples frozen, returned to Woods Hole and analyzed immediately upon arrival. The correlation between iodate and the phosphate and nitrate profiles is good, all showing a surface depletion and a mid-water maximum coinciding with the oxygen minimum. From this we would infer that iodate is behaving similarly to nutrient element and is involved in the biological cycles of the ocean. We estimate that only 10% of the deep-water iodate is derived from oxidative decomposition of marine organisms and 90% is behaving in conservative fashion. Work is proceeding on the determination of iodide.

INTERACTION OF Co WITH δMnO_2

James W. Murray

Interesting geochemical relationships have been found between cobalt and manganese. An enrichment of cobalt and manganese was found to exist in the suspended matter of the Black Sea. Sediments from the west of the East Pacific Rise are unusually high in manganese and cobalt as well as other elements. In manganese modules cobalt is one of the elements most enriched relative to seawater. In all of these cases adsorption of cobalt onto the surface of manganese dioxide has been suggested as the enrichment mechanism. Because of this implied chemical relationship the interaction of cobalt with the surface of colloidal δMnO_2 was studied in detail.

Adsorption experiments over a wide range of cobalt concentrations revealed that the amount of cobalt adsorbed by δMnO_2 increases sharply between pH 6 to 8. The pH of this sharp increase in adsorption is lower than the pH at which precipitation would be expected to occur in bulk solution or the Ph at which significant hydrolysis of Co(II) occurs. The increase also occurred when the cobalt concentration in solution was lower than the limiting solubility concentration.

Micro-electrophoresus experiments at some of the higher concentrations indicate that the abrupt increase in adsorption correlates with an abrupt change in the sign of the surface charge from negative to positive. At still higher pH values there is another charge reversal from positive to negative. The pH of this second charge reversal agrees very well with values in the literature for the zero point of charge of $Co(OH)_2(s)$. Thus it appears that the sharp increase in adsorption of Co is due to the precipitation of $Co(OH)_2$ on the surface. This is probably due to the fact that the presence of the charged surface reduces the solubility product of $Co(OH)_2(s)$ thus inducing precipitation on the surface at lower pH values than observed in bulk solution.

TRACE METAL ANALYSIS OF SEAWATER BY MASS SPECTROMETRY

Nelson M. Frew and Peter G. Brewer

A principal goal of our trace metal program is to understand in detail the geochemical cycles of trace metals, their chemical speciation, rates of transport, and behavior as tracers of oceanic circulation. Since precise analytical techniques are required to detect species occurring at the part per billion concentration level or lower, we have integrated a sensitive technique involving mass spectroetry of volatile metal chelates.

The technique combines the high volatility of chelates formed by many transition and heavy metals with fluorinated β-diketones and the extreme sensitivity and accuracy of mass spectrometric isotope dilution. A seawater sample is equilibrated with a suitable stable isotopic spike, simultaneously chelated and extracted using trifluoroacetylacetone or related β-diketones, and is then introduced to the mass spectrometer via a gas chromatograph or direct insertion probe. Detection limits are in the picogram to subpicogram range (10^{-12} - 10^{-14} grams).

We are using a combination gas chromatograph - low-resolution quadrapole mass spectrometer, which is well suited to the metal chelate-isotope dilution technique because of its extremely high scan rates, its ability to simultaneously monitor multiple peaks, and its total computer compatibility. The mass spectrometer is interfaced and controlled by a small digital computer, allowing for data accumulation, digitization, signal averaging, and computation. Isotope distributions calculated from measurements on metal chelate fragments show a precision of two percent or less (depending on sample size).

A test screening of several transition metals indicates that the elements Cr, Ni, Cu, and Zn could be determined at the 1 μg/liter level in seawater mixtures of Cr, Mn, Fe, Co, Ni, Cu, and Zn, using similar extraction conditions and a single, mixed isotopic spike. Interferences can be minimuzed by careful selection of mass range, utilization of differences in fragmentation patterns, and by selective extractions.

We have recently begun a program to apply the metal chelate-isotope dilution technique to measurements of seawater lead concentrations, with the aim of estimating anthropogenic contributions to the lead cycle, and to examine deep-water scavenging and transport processes. We have agreed to participate in a seawater lead intercalibration study sponsored by the National Science Foundation and coordinated by C. C. Patterson of the California Institute of Technology. Nine participating laboratories will cooperate in a program to standardize lead determinations by several procedures, including atomic absorption, anodic stripping, and isotope dilution.

OXIDATION STATE OF CHROMIUM IN SEAWATER

Nelson M. Frew

Attempts to establish chromium speciation have suggested a state of thermodynamic non-equilibrium between the Cr(III)-Cr(VI) oxidation states, which may be significant in determining not only the distribution of naturally-occurring chromium, but also the dispersion of ^{51}Cr introduced to the hydrosphere via nuclear reactor cooling effluent.

A reliable gas chromatographic method sensitive to 10^{-12} gm Cr has been developed for determination of Cr in seawater and Cr(III) analyses have been completed for one entire Sargasso Sea profile to 5,000 m. The measurements show surprisingly high concentrations of Cr(III) at all depths, with a total concentration spread of about twenty percent of the mean value (1.18 µg/liter). Although measurements of total Cr are not yet available, the present data support the suggestion that the oxidation of Cr(III) introduced to the oceans by weathering processes, presumably as $Cr(OH)_2^+$, is exceedingly slow relative to estimated residence times ($\sim$350 yr)[2]. It seems likely that the reduced form is maintained by ineffective coupling with available electron acceptors and a lack of reaction sites, rather than reduction by organic matter, and that polynuclear hydroxo complexes, which are known to be kinetically metastable intermediates in hydrolysis reactions, may constitute a significant percentage of dissolved chromium in seawater.

MAJOR ELEMENT ANALYSES

Paul C. Mangelsdorf, Jr. and Wen M. Chang

The method of Difference Chromatography was developed here for the analysis of small variations in the proportions of the major elements in seawater. The method is now used routinely for analyses of major cations Na, Mg, Ca and K in seawater samples, and thousands of such analyses have been run during the past several years.

For deep ocean samples, such as we are receiving as part of the GEOSECS program the only detectable cationic variation is shown by Ca in the form of substantial enrichment at depth (order of 1% in mid-latitudes) due to redissolution of $CaCO_3$ precipitated biologically at the ocean surface. For the Mg/Na and K/Na ratios in the deep ocean we can find no significant variation with depth or latitude, even though our detection limits for those ratios are .05% and .02% respectively. For Mg/Na and K/Na our deep ocean studies are producing one of the world's finest collections of null results: an important fact, though a disappointing one.

In marked contrast, pore waters in marine sediments show sizeable variations in the proportions of all ionic constituents, even in the top few centimeters of the sediments, and we are now engaged in studying such variations.

Technical improvements of the Difference Chromatograph during the past year have brought a substantial increase in resolution and reliability, and a decrease in noise and drift. A new dual column chromatograph will permit us to proceed with the long-promised development of anion analysis, without interruption of the routine program of cation analysis.

LIGHT IN THE SEA

Oliver C. Zafiriou

Enormous quantities of sunlight are converted to other forms of energy by interaction with molecules in the upper layers of the sea. Nevertheless, the fate of sunlight has been investigated primarily by physical oceanographers interested in the heating of water, and biologists interested in effects of light on organisms.

Under National Science Foundation sponsorship, we have begun a new program exploring light in the sea, emphasizing interpretation in molecular terms. Some of the major questions we are asking are: What are the primary absorbers of light in various types of sea water? How do they convert the energy they receive to other forms? Are there significant photochemical transformations in sea water (other than photosynthesis)? What are they?

Thus far, we have designed equipment to concentrate organic pigments from sea water for study, as well as apparatus for irradiating samples with selected wavelengths in the solar spectral range. An apparatus which can be used to sterile-filter large volumes (to 100 liters) of sea water and concentrate higher molecular weight materials by ultrafiltration, has been designed, built, and was tested successfully on *Atlantis II* Cruise 71 in the Sargasso Sea. The pigments from coastal waters concentrated in this manner will be studied for stability to light, tendency to photo-oxidize, and as sensitizers of other photoreactions.

It has been suggested (Carlucci *et al.*) that trace vitamins in sea water, required for growth by many algal strains, are destroyed rapidly by sunlight but not in the dark. Experiments to verify this effect and explore its chemistry are being designed; work on thiamine (Vitamin B_1) is in progress.

Reference

Carlucci, A.F., Silbernage, and McNally, 1969. Influence of temperature and solar radiation on the solar radiation on the persistence of Vitamin B_{12}, thiamine, and biotin in sea water. *J. Phycol.* 5: 302.

RADIOCHEMISTRY

FALLOUT STUDIES

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

In the last year we took part in two major cruises: *Knorr*-25 to the northeastern approaches to the Caribbean, and *Chain*-105 in the north and northeastern Atlantic. On both cruises our programs of water and plankton sampling were very successful, but we had poor luck in finding bottoms soft enough for the 21-cm diameter corer.

We have continued also the program of surface water sampling from the various United States and European-operated Ocean Weather Ships, as well as from various commercial ships.

In August we had a one-week cruise in Lake Ontario on R/V *Advance II* of the Cape Fear Fisheries Station, as a part of our program to study plutonium distributions in Lake Ontario. Samples of water, plankton and sediment cores were collected at several stations around the lake; at the same time extensive collections of fish and some shellfish were taken for us by the Fish and Wildlife Station at Cape Vincent.

Sea Water: Completion of analyses of the samples from *Atlantis II*-57 about the southeastern approaches to the Caribbean, and availability already of some data from *Knorr*-25 about the northeastern approaches, has cast more light on the question of the high Strontium-90 associated with the shallow salinity maximum in these latitudes. It seems clear now that wherever a strong subsurface salinity maximum is sampled there is also a strong subsurface Sr-90 maximum, but that quite often the highest Sr-90 values are observed slightly below the highest salinity (for instance, at 36.85°/oo below a maximum of 37.10°/oo). We cannot see yet what these data are trying to show us about the circulation of this water mass, and are increasingly intrigued by the problems. It is now evident that we should be able, on the cruise planned for September-November 1973 in this broad area, to examine the extent and positions of salt-fingering underneath the salinity maximum, and to use the ratios of Sr-90:tritium or Sr-90:C-14 as another guide to the source areas of the subsurface high Sr-90 water.

We have shown, in cooperative work with Dr. Wolfgang Roether at Heidelberg and Dr. J. A. Vogel at Pretoria, South Africa, that there are measurable north-to-south variations in surface ocean water in the ratios of Sr-90 (and probably of Cs-137) to tritium or to carbon-14; in the South Atlantic the Sr-90 to C-14 ratio diminishes by about a factor of two, from 34°S 17°E to 07°S 21°W!

In the North Atlantic we have concluded that much smaller, but measurable, differences in the ratios Sr-90:tritium at depth in the water columns at various stations give an indication of the relative latitudes, and possibly in this case of longitudes also, of surface exposure of the water masses represented. Data to extend this sort of analysis to the South Atlantic and to the three-component ratio Sr-90:T:C-14, are now being collated.

Sediments: By examining the ratio between the depth of water over a sediment core and plutonium in the core expressed as the fraction of the predicted total delivery of plutonium-239 to the position sampled, it has proved possible to construct a useful model of the plutonium sedimentation process. Several cores in the Atlantic Ocean, North and South, all show good fit, of their plutonium contents, to a curve predicted for plutonium association with particles of a mixture of sinking rates: 30% sinking at 392 m per year, 40% sinking at 140 m and 30% sinking at 70 m; assumption of no single sinking rate was able to generate a curve fitting the data distribution. It was even gratifying when the mean fraction of the plutonium at or below various depths in the Atlantic Ocean water column was expressed in the same way, the points fitted the same curve, and even more closely than did those from the core samples. Interestingly enough, our data from the Mediterranean, both water columns and one sediment core, do not fall on this curve: much more of the plutonium is still in the water, much less in the sediments. This, we feel, fits well with our original hypothesis, that most Pu sedimentation is biological, and with the fact that the Mediterranean is much less active biologically than the Atlantic. A considerable amount of new data is now being worked up to extend the test of this model. It looks as if we may be able to use the Cs-137 in sediments to make a similar estimate of sinking rates for this nuclide; there is no relationship between depth of sediment cored, and fraction of the Sr-90 in the sediment, from which we conclude that the sediment load of Sr-90 represents "large-particle and hot-particle" fallout, delivered by processes unrelated to normal sedimentation.

Intercalibration and Methods Development: In the past year, in cooperation with a Polish post-doctoral UNESCO fellow, Dr. Ryszard Bojanowski, Dr. Livingston completed development of a workable method for analysis of Americium nuclides in sediment, organisms and sea water. Both Am-241 and Np-237 (by an extension of this new method) are now being measured in some of our samples. It is also possible, by use of the Am-241 method, to analyze, on aged Pu-239 plates, the amount of Pu-241 (not directly measurable, since it is a long half-life beta emitter, and in very low concentration) that was originally present. By a combination of this method, and cooperative mass-analyzer analysis of Pu-239:240:241 ratios, done at Lawrence Livermore Laboratories, we are finding a good deal of interesting isotope-ratio variation.

Several intercalibration exercises, mostly sponsored by IAEA (International Atomic Energy Agency), have engaged our attention in the past year. On the basis of some of these and of our own experience, we are now engaged in preparing, for a forthcoming IAEA publication, reviews and recommendations on reference methods for plutonium and other transuranic elements in environmental samples.

Plutonium in Lake Ontario: Less than 10% of the Pu directly deposited (from fallout) in Lake Ontario is still (1971) in the water column. This evidence for rapid removal of Pu is confirmed by the readily detectable high Pu-238:Pu-239 ratios in water samples; the high Pu-238 derived from the SNAP-9A burn-up in 1966 has been, in the northern hemisphere, only recently deposited. Both horizontal and vertical gradients of Pu in the water columns are exhibited, showing also that the residence time of Pu is short compared with the mixing times of the lake.

In the sediments there is a very complex picture. In the southeastern basin Pu is found down to considerable depths in sediment cores, whereas inshore samples along the south border of the lake show Pu penetration only to a few centimeters. In deeper parts of the lake Pu appears to be controlled partly by bottom morphology and partly by sediment lithology and chemistry. All this variability makes difficult the establishing of an inventory of Pu in the lake sediments. We hope this will be possible with the additional samples obtained in 1972.

CHEMICAL POLLUTANTS

Vaughan T. Bowen, Susumu Honjo, Charles C. Remsen

A new program has been started, investigating the responses of open-ocean microorganisms to chemical pollutants, especially to DDT and PCB. Our attention has been placed first on marine bacteria, phytoplankton algae, and Acantharia. Large numbers of samples were collected at sea last summer and prepared for electron microscopy; this has led to a lot of work to improve the techniques of fixation, embedding or shadowing. We are now collecting a library of electron micrographs of Acantharia, both in section and by scanning, to be examined for possible morphological responses to pollutants.

As a part of this program we had with us at sea (*Chain*-105) and for five months in Woods Hole, Dr. M. G. Andreoli of the University of Parma, Italy. Dr. Andreoli has sorted and identified Acantharia for us, has learned the procedure for preparation of these creatures for electron microscopy, and has spent a good deal of time attempting to culture them. An interesting by-product of her work is the discovery that, although they have never been identified in our near-shore preserved plankton tows, Acantharia are frequent, and often abundant, in plankton tows from just off Gay Head; their non-observation previously has been because of complete dissolution under preservation, as described by Beers and Stewart for tows from the eastern Pacific. This puts us in much better position to continue experiments on Acantharia, but makes even more puzzling the usual good preservation of Acantharia in open-Atlantic Ocean or Mediterranean samples.

GEOCHEMISTRY

GEOCHEMISTRY OF SUBMARINE ROCKS

Geoffrey Thompson

In the summer of 1972, we were involved in a cruise to King's Trough at 43°N, 22°W in the North Atlantic. King's Trough is a 200 mile-long, deep depression (2500 fms) flanked by ridges rising above 1000 fms. We recovered basement rocks in eleven dredge hauls which allowed us to (1) obtain a vertical profile of the oceanic crust in a region far removed from the present ridge center; (2) obtain samples of old oceanic crust (approximately 60 million years), which might have originated at a spreading center, for comparison with modern day rocks; and (3) obtain samples from a later (approximately 30 million years) intrusion and eruption into old oceanic crust.

We have continued our cooperative work with Dr. Melson of the Smithsonian Institution, on rock samples previously collected from various sites on the Mid-Atlantic Ridge. We have indicated that the chemical characteristics of rocks erupted or intruded into transverse fractures differ fundamentally from those originating in spreading centers. Rocks from 'leaky' transform faults are more alkaline in character and are relatively enriched in Na, K, and such trace elements as Ba, Sr, Rb and Zr.

In our studies of the submarine alteration of rocks from the Mid-Atlantic Ridge, we have demonstrated the formation and chemical composition of different clay minerals formed during weathering. These are mainly potassium smectites. Al is abundant in both octahedral and tetrahedral smectites. Al is abundant in both octahedral and tetrahedral layers, and K^+, Na^+, and Ca^{++}, in order of abundance, are the dominant interlayer cations. The abundance and composition of these clays suggest that they are important traps for K^+ and ions such as Li^+, Rb^+, B^{+++}, and Cs^+, from sea water. We have also studied the chemical weathering of the glassy rind of pillow basalts, compared to their more crystalline interiors. Our work indicates that glass alteration is accompanied by oxidation of iron and enrichment in K^+ and Na^+, as well as marked loss of ions such as Ca^{++}, Mg^{++}, and Si^{++++}. The changes in the interior of the pillow are in the same direction, but to a far lesser degree. Speculations on the role and effects of rock alteration on sea water budgets, that have been made considering only glass and palagonitization, may be seriously excessive.

This past year we were also involved in studies of basement rocks recovered during the JOIDES deep-drilling operations (in cooperation with Dr. F. Frey of Massachusetts Institute of Technology and Dr. W. Bryan of the Geology Department here at the Woods Hole Oceanographic Institution). We were particularly concerned with rocks recovered on Legs 2 and 3 of the *Glomar Challenger*. These rocks were recovered from eight stations at various distances from the crest of the Mid-Atlantic Ridge. The ages, based on magnetic anomalies and the overlying sediments, ranged from 18 million to over 60 million years. We were able to demonstrate, in spite of intense weathering effects, that most of these rocks were similar in composition, at the time of their eruption, to present-day basalts erupt-

ing at spreading centers. That is, they are tholeiitic basalts depleted in large ionic radius elements such as K, Ba, U, and light rare earths. The one sample that differed in composition was evidently intruded as a sill and erupted at a site away from a spreading center. We conclude that eruption of tholeiitic basalts, similar to modern-day eruptives at the Mid-Atlantic Ridge, has been continuous since the initiation of sea-floor spreading, and that much of the Atlantic basin, north and south, is underlain by such rocks.

MINERALOGY AND CHEMISTRY OF METALLIFEROUS SEDIMENTS OF THE SOUTHEAST PACIFIC

Fred L. Sayles and Paul C. Bowker

Iron-manganese-rich sediments have been found to be widespread in the southeast Pacific region. Enrichments of Cu, Ni, Zn and Ba are also common in these pelagic deposits. The sediments are composed almost entirely of nondetrital minerals. Amorphous or poorly crystalline ferromanganese compounds and iron-rich smectite (nontronite) comprise 10 to 20% and 70 to 80% of the sediment, respectively. The ferromanganese compounds contain 95 to 100% of the Mn and Co, 85 to 100% of the Ni, 40 to 50% of the Zn and 40 to 60% of the Cu. The bulk of the Fe(60 to 80%) occurs in the nontronite. The latter also contains a significant fraction of the total Cu (40 to 60%) and Zn (50 to 60%) present. These unusual sediments appear to be related to processes associated with the East Pacific Rise, quite possibly the interaction of hydrothermal emanations with sea water.

FLUXES OF IONS ACROSS THE SEA WATER-SEDIMENT INTERFACE

Fred L. Sayles and Paul C. Mangelsdorf, Jr.

The determination of diffusive fluxes of ions across the sea water-sediment interface requires accurate knowledge of the *in situ* chemical gradients that exist in the pore fluids of the uppermost sediment layer. Studies have shown that solutions extracted from cores after recovery do not provide sufficiently accurate data. Accordingly, a device has been designed to obtain pore fluids extracted from the sediment *in situ*. The sampler collects five filtered interstitial solution samples at 30 cm intervals from the upper 150 cm of the sediment. Tests have demonstrated that *in situ* sampling can be achieved without significant contamination by the overlying sea water. A series of samples has been obtained along a cruise track across the North Atlantic. Analysis of these solutions has shown that significant gradients of K^+ and Ca^{2+} exist in the sediments sampled. K^+ is characteristically depleted one to two percent in the upper 150 cm of all of the sediments investigated. Ca^{2+} enrichments of four to six percent occur in all of the profiles studied. These gradients appear to be characteristic of pore fluids of sediments in the North Atlantic. If similar concentration gradients occur over the world ocean, diffusive fluxes of ions in response to these gradients could be comparable to the annual input of K^+ and Ca^+ by the rivers of the world.

PORE FLUID CHEMISTRY AND DIAGENESIS

Fred L. Sayles, Frank T. Manheim and Lee S. Waterman

Extensive studies of interstitial solutions from the long cores of the Deep Sea Drilling Project have provided data on the long-term trends of diagenesis in marine sediments of the world ocean. In many biogenic sediments Ca^{2+} enrichment in pore fluids is accompanied by Mg^{2+} depletion on a mole-for-mole basis. The absence of any alkalinity changes in these solutions indicates that substitution of Mg^{2+} for Ca^{2+} is occurring, most probably in the carbonate phases of the sediments. These changes are commonly accompanied by Sr^{2+} enrichment (up to 100 ppm) in the interstitial solution as a result of a $CaCO_3$ recrystallization. In some biogenic sediments SO_4^{2-} depletions occur in addition to the above changes in Ca^{2+} and Mg^{2+}. Frequently in such solutions the loss of Mg^{2+} exceeds Ca^{2+} gain. Mg^{2+} depletion above that which can be accounted for by substitution for Ca^{2+} corresponds on a one-for-one basis with the SO_4^{2-} losses. This may be explained either by the precipitation of a Ca-Mg-CO_3, possibly dolomite, or by the formation of an authigenic silicate such as chlorite.

Reactions in rapidly deposited terrigenous sediments such as those characteristic of continental margins are extremely complex. Complete loss of SO_4^{2-} by bacterial reduction is common, often resulting in Ca^{2+} losses through the precipitation of $CaCO_3$. Losses of Mg^{2+} may, as noted above, reflect either silicate or carbonate formation. Losses of Na^+ and K^+ from these solutions requires reactions which consume carbonate alkalinity and appear to involve authigenic silicate formation. The extensive fermentative reaction of organic matter in these sediments commonly results in the production of considerable quantities of methane.

ORGANIC AND BIOCHEMISTRY

OXIDATION OF ORGANIC MATTER IN THE CARIACO TRENCH

Werner G. Deuser

The Cariaco Trench is located on the Caribbean shelf of Venezuela and has a maximum depth of 1400 m. The surrounding shelf is nowhere deeper than 150 m. The consequent isolation of the deep water of the trench from that of the Caribbean is responsible for the absence of dissolved oxygen below 300 m. The extent of anoxic conditions in such a basin is critically dependent on the balance between supply of organic matter and renewal of the deep water. Data resulting from a cruise of R/V *Atlantis II* to the Cariaco Trench in 1971 provide a way of assessing the origin and oxidation of organic matter in the trench and of estimating the renewal time of the deep water.

Measurements of δC^{13} and ΣCO_2 on water samples covering the full depth range of the Cariaco Trench are shown in Fig.9. Both parameters show a progression of values from the surface to the deep water, with minor deviations, especially near the O_2-H_2S interface. This progression is the result of the accumulation of oxidized organic carbon in the water column of a stagnant basin. No change can be detected from 800 to 1400 m, as is the case for temperature, salinity and other chemical constituents. The curves shown in Fig.9 represent the addition of CO_2 of three different carbon isotopic compositions (δ_J) to mean surface water. The one in the middle, labeled $\delta_J = -19.7^o/oo$, represents the addition of carbon of the same isotopic composition as the bulk organic carbon in plankton inhabiting the surface water in the area of the Cariaco Trench. In spite of the scatter of the data it is apparent that, in the upper part of the water column, the measured values correspond well to the addition of oxidized plankton carbon. In the deep water the deviation from the curve for addition of plankton carbon appears to be due to the influx of continental organic matter. This contribution is close to one-third of the total organic matter entering the deep part of the trench. It is thus possible to set limits on the total input of organic carbon into the basin and to set limits on the oxidation rate from analogies with the more extensively studied situation in the Black Sea. Dividing the integrated accumulation of oxidized organic carbon in the water column by the oxidation rate provides an estimate of the renewal time of the deep water. The likeliest value is about 100 years.

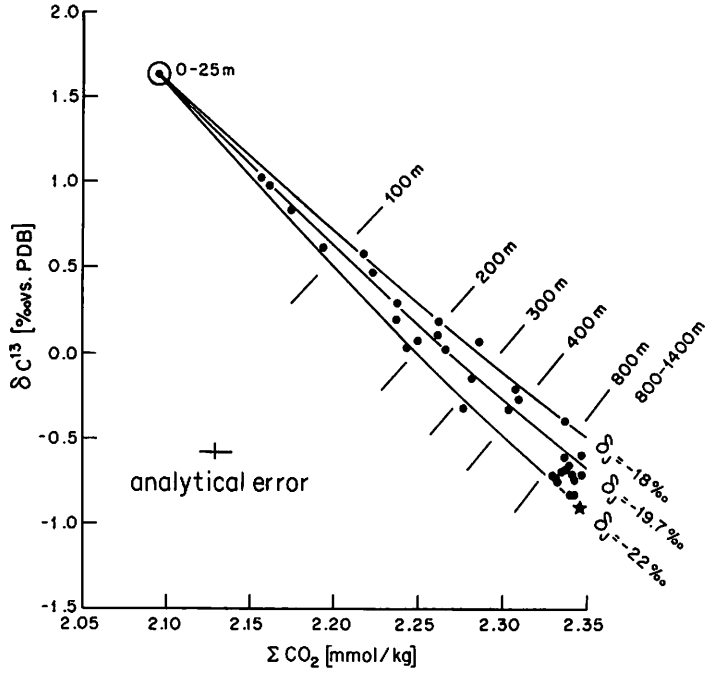


Fig.9 (Deuser) Amount and δC^{13} of total dissolved inorganic carbon in waters of Cariaco Trench. Curves signify addition of carbon having given δC^{13} (δ_J) to mean surface waters.

ORIGIN OF METHANE IN LAKE KIVU

Werner G. Deuser and Egon T. Degens

A second expedition to Lake Kivu, an African rift lake, during 1972 has provided additional information on the source of about 50 km^3 of methane dissolved in the deep water of that lake. By way of comparison, this amount could satisfy the natural gas needs of the entire United States for a month. The principal puzzles remaining after our investigation of the previous year were the accumulation time of this large reservoir and the source of the carbon from which the methane had formed. Various estimates indicate a residence time of the water of several hundred years. The best one, based on calculations of the basin's content and loss rate of Na, indicates a residence time for that element of 350 years. It is unlikely that the residence time of the methane could be greater. Radiocarbon measurements on the gas showed that less than 10% of the carbon is "modern" carbon, the average "age" being greater than 20,000 years. It is thus clear that the methane cannot have formed from the continuous rain of plankton debris during the last several hundred years as had been assumed by other authors. Also, the amount of carbon supplied by that debris is clearly insufficient to yield the methane in the lake. Chemical and isotopic evidence argues against diagenetic or volcanic origin. The only carbon source of sufficient magnitude is volcanic carbon dioxide which enters the lake at several places. Hydrogen is also likely to enter the lake through volcanic vents and is, in addition, liberated during the formation of heavy-metal sulfides which constitute a large part of the sediment. All available evidence suggests that the bulk of the methane was formed by bacteria utilizing carbon dioxide and hydrogen supplied by such inorganic processes. The energy liberated during the production of methane may in part be responsible for the elevated temperatures of the deeper parts of the lake and for an observed temperature increase of 0.2 to 0.3°C during the last 35 years.

THE DISTINCTION BETWEEN INDIGENOUS AND PETROLEUM-DERIVED HYDROCARBONS

Max Blumer

Chemical analysis is essential to the study of oil pollution and of its immediate and long-term biological effects. The analysis for petroleum pollutants is more difficult than that for synthetic organic chemicals where pure individual compounds can be determined (e.g., DDT). Crude oil is a complex mixture of chemicals and it overlaps in composition with the hydrocarbons formed by organisms. Fortunately, sufficient differences exist between the indigenous hydrocarbons of organisms and of sediments and the fossil fuel hydrocarbons.

Analyses of a core taken in the polluted region at West Falmouth show particularly well the transition from almost purely petroleum-derived hydrocarbons at the surface to indigenous sedimentary hydrocarbons at some depth. The uppermost 2.5 cm of the core, taken two years after the oil spill, show the presence of a partly-degraded fuel oil, whose carbon number range and compositional features still correlate with that of fuel oil.

Below 7.5 cm there is little or no evidence for fuel oil hydrocarbons; chromatograms show the odd carbon predominance of the higher (C_{17} and above) normal paraffins which is a common feature of most unpolluted inshore marine sediments.

The intermediate core section (2.5 - 7.5 cm) is intermediate also in hydrocarbon content and appearance of the chromatograms. Both, the indigenous sedimentary hydrocarbons and fuel oil are easily recognized; the latter is less degraded than at the sediment water interface.

This example demonstrates the basis for and the feasibility of the distinction between indigenous and pollutant hydrocarbons in the presence of each other. The distinction by gas chromatography is simple, rapid and in many cases adequate. More sophisticated techniques (e.g. mass spectrometry) may be used for additional characterization of the hydrocarbons.

ARE SUBMARINE SEEPS A MAJOR SOURCE OF OPEN OCEAN OIL POLLUTION?

Max Blumer

Submarine oil seeps are known to occur in some coastal regions. This fact is often mentioned in discussions of oil pollution; the argument is then made that natural seeps might be of equal importance to man's action in fouling the high seas and the beaches - or that organisms which have survived these natural seepages will also survive oil pollution caused by man.

The magnitude of the ultimate world offshore oil resources is rather well known. This represents a total potential source of submarine seepage. Crude oils are geologically ancient and the oil formation potential of the source beds is finite. Thus, seepage would deplete a non-renewable resource at a finite rate.

We have made a comparison of the present oil influx to the ocean from pollution with these ultimate offshore oil reserves. It suggests that seepage, if it equalled present oil influx from pollution, would have exhausted the total reserves of free-flowing offshore oil in less than 20,000 years. This is very short compared to the average known age of crude oil (approximately 5×10^7 years). Thus, there is good reason to believe that the influx of oil from pollution exceeds that from submarine seeps by several orders of magnitude.

THE WEST FALMOUTH OIL SPILL

Max Blumer, Jeremy Sass, Howard L. Sanders

The investigation on 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 fourth 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 very 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 as human nutrition. The oil showed an 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, the oil pollution of the sediments prevented the resettlement by the original fauna. Now, degradation of the oil has become evident; biochemical and physical processes have led to a gradual reduction of the oil content of the polluted sediments. Concurrently with the degradation, there has been a 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 oil must be measured in terms of many years.

The eventual aim of this study is the documentation of the effect, the persistence, and finally the disappearance of pollutant hydrocarbons from a relatively small spill in a limited and previously clean coastal area.

THE ENVIRONMENTAL FATE OF STRANDED CRUDE OIL

Max Blumer, Manfred Ehrhardt and Hubert Jones

The weathering history of two light paraffinic crude oils which stranded on Martha's Vineyard, Massachusetts, U.S.A., and on Bermuda has been studied over a period of 13½ and 16 months, respectively. At both locations the oil has persisted during the entire survey period. We studied the evaporative history, the microbial utilization of the normal alkanes and other physical and chemical changes involved in the weathering of these oils. At the end of the observational period, the spill residues are still far from being inert asphalts. They remain crude oils, modified by evaporative losses of the lower boiling components and by partial microbial degradation; they have not been depleted of their biologically most active higher molecular weight components.

This work complements our West Falmouth study; it confirms the great persistence of spilled fossil fuels, regardless of composition (whole crude oil vs. refined fuel) and environmental circumstances (beach vs. sea bottom; climate of northeastern United States coast vs. Bermuda).

We also have prepared an atlas of gas chromatograms, of analyses of open-ocean tar balls. It documents the composition of these ubiquitous pollutants; the chromatograms are descriptive of the origin of the tar balls (crude oils, products, blends, tanker washings), of the ageing processes (evaporation, dissolution, microbial degradation) and of the relative ages.

ORGANIC COMPOUNDS IN THE MARINE ENVIRONMENT

Max Blumer

Our research aims are being reoriented from pollution problems to some of the basic questions and the urgent research needs in marine and sedimentary organic chemistry (Table 1). Work is now in progress in several of these areas.

To facilitate our GC work we have developed a new method for the preparation of capillary gas chromatographic columns. Silanox 101, a colloidally dispersed hydrophobic silica, is used as wall coating and support for the partitioning liquid. The column performance is predictable, coating is simple and the rapidity of conditioning is unequalled by any other gas chromatographic columns. This permits the conversion of our gas chromatographs to capillary operation; it results in better resolution of complex mixtures, in reduced analysis time, better sensitivity and in coverage of a wider molecular weight range.

Table 1 ORGANIC COMPOUNDS IN THE MARINE ENVIRONMENT

Organic Matter in:	Basic Questions	Urgent Research	Applications
BACTERIA, FUNGI	Origin *Composition* *Variability* Role	Inventory needed, knowledge rudimentary.	Pollution Baselines, Reworking of Organic Matter in Water and Sediments Taxonomy.
	Selectivity and Efficiency in Transfer.	Knowledge rudimentary.	
PHYTOPLANKTON	*Origin* Composition Variability *Role*	*Extend geographic and compositional range.*	Pollution Baselines, Low Level Effects of Pollution, Taxanomy.
	Selectivity and Efficiency in Transfer.	Little known.	Dynamics of Food Web
ZOOPLANKTON	Origin Composition Variability Role	*Extend geographic and compositional range.*	Pollution Baselines, Taxonomy.
	Selectivity and Efficiency in Transfer	Little known.	Dynamics of Food Web, Studies of Fish Populations and Migration
HIGHER FOOD WEB	Origin *Composition* *Variability* Role	*Extend geographic and compositional range.*	Pollution Baselines, Human Nutrition, Public Health, Taxonomy.
RECENT SEDIMENTS	Sources *Composition* *Variability* Interaction	Little known compared to ancient sediments, especially in deep ocean.	Pollution: Baseline, Low Level Identificatio
	Preservation Destruction New Formation	Reaction intermediates and mechanisms.	Geochemical Processes
ANCIENT SEDIMENTS	Composition *Metastability* *Thermodynamic Fate* *Fate after Recycling into Ocean*	Well known in parts, narrow base of knowledge.	Geology, Stratigraphy, Paleontology, Identification of Fossil Fuels
SEA WATER	*Origin* *Composition* *Variability* *Fate* *Residence Time*	Little known	Dynamic Processes, Physical Oceanography, Pollution Studies.

HYDROCARBONS IN OPEN OCEAN ORGANISMS, SEDIMENTS AND SEA WATER

Max Blumer and John W. Farrington

We are currently completing analyses of marine organisms sampled at two geographical locations: the waters near Iceland and East Greenland, and the waters of the Georges Bank area of the New England continental shelf. These analyses for both recently biosynthesized hydrocarbons and petroleum hydrocarbons provide us with information about, (1) Transfer of hydrocarbons within the food web at each location, (2) Baseline measurements of the hydrocarbons in organisms from these areas; these may be used in a future assessment of the degree and trend of hydrocarbon pollution, and (3) Current levels of petroleum hydrocarbon contamination in both organisms from an area traversed regularly by shipping and near a heavily industrialized coast and organisms from an area which is fairly well removed from such sources of oil pollution.

The hydrocarbon geochemistry of the sediments beyond the continental shelves is poorly understood. We are ignorant of the relative importance of the hydrocarbon sources, of the regional variability in composition and of differences in depth profiles that may result from changing sources and from post-depositional reactions. We have initiated work in this area with the analyses of sediment samples taken on a transect from New York Bight to the abyssal plain east of Bermuda.

The hydrocarbon chemistry of water samples reflects a multitude of sources; therefore, it is descriptive of many marine processes. Some years ago we developed methods for the contamination-free sampling and analysis of coastal waters. Recent experience shows that these are still inadequate to deal with the higher shipboard contamination level and the lower indigenous hydrocarbon level encountered in open ocean sampling. The development of improved sampling and analysis methods is in progress.

PRODUCTION AND TRANSFER OF POLYCYCLIC AROMATIC HYDROCARBONS

Max Blumer and Walter Giger

Polycyclic aromatic hydrocarbons are ubiquitous in nature. They appear to be formed by biochemical processes, by combustion and by geochemical reactions in deeply buried sediments. The mechanisms of formation of these, in part biologically active, compounds are not known in detail, nor do we understand their transfer within the environment. Polycyclic aromatic hydrocarbons are relatively stable and can be expected to vary structurally depending on their sources; this suggests their suitability as tracers of dynamic processes.

We have developed analytical techniques and are applying them to the study of the origin and of the transfer of aromatic hydrocarbons between terrestrial, inshore and offshore sediments and the associated water and organisms.

OIL SPILL-SOURCE CORRELATION

Oliver C. Zafiriou, Max Blumer, John Myers and Richard Bourbonniere

We have designed and tested exhaustively a simple, yet highly specific method of correlating unknown oils with their sources by comparing samples with possible source oils. A joint study with the Environmental Protection Agency revealed that high success rates - 80% unique correlations - were obtained for artificially weathered oils. Results were independent of the length of exposure up to 30 days, the water type (fresh or salt) or the presence of spill-control chemicals (other than oil-based formulations). The only important factor in causing indefinite results is the presence of highly similar, indistinguishable, possible source oils. The occurrence of such similar oils in practical situations was estimated by analyzing collections of oils from Greater New York Harbor and from Portland, Maine (which handles 450 tankers/year), and assuming that each oil in turn were spilled, and that any of the remaining oils from that location were possible sources of the "unknown" spill. The results for #2, #4, and #6 oils, and crude oils were very similar. The primary factor (Fig.10) determining the likelihood of success is the number of possible source oils considered.

The success achieved for small sample sizes - the most frequent actual situation - is excellent. The method is in use by several laboratories and is being considered seriously by several agencies with responsibility for water quality management.

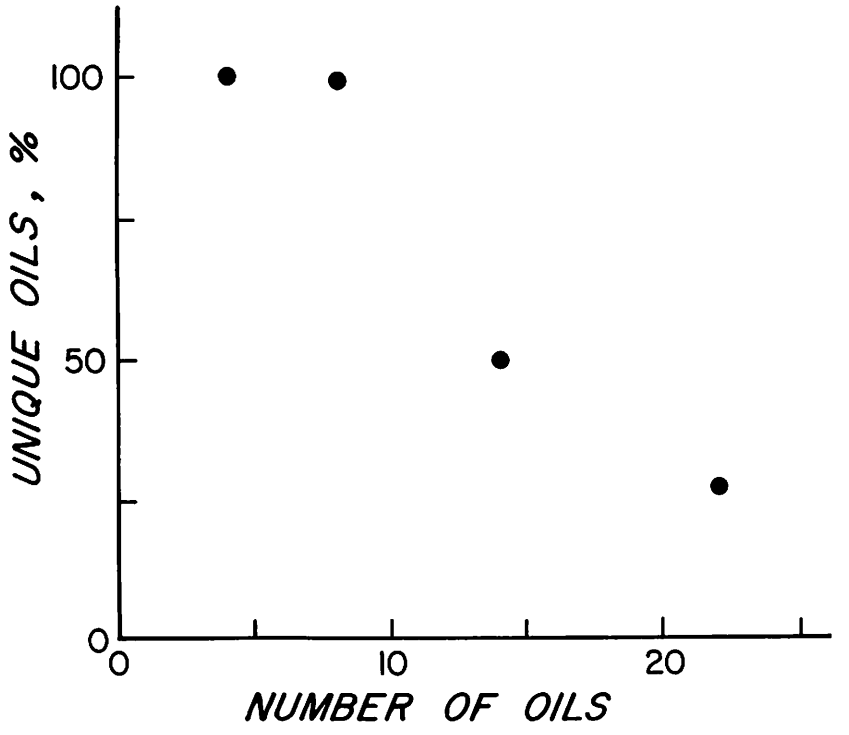


Fig.10 (Zafiriou,Blumer,Myers and Bourbonniere) Percent successful oil characterization for various sized oil collections.

SYNTHETIC ORGANIC COMPOUNDS IN THE ATLANTIC OCEAN

George R. Harvey, Helen P. Miklas, William G. Steinhauer and John M. Teal

Our survey of the distribution of industrial chlorinated hydrocarbons, such as DDT and the polychlorobiphenyls (PCB's), in the Atlantic Ocean has been expanded to include water and air sampling. Earlier hypotheses concerning the movements of these chemicals have been confirmed and new insights have been gained. The results can be discussed in four categories.

Water:- The surface waters of the North Atlantic contain about 20,000 tons of PCB's, but less than 1,000 tons of DDT. This is a surprising discovery in view of their manufacturing and usage patterns. The PCB's were even detectable at 3,000 m depth. There is no decrease in surface concentration as one proceeds from inshore to the open sea. These results confirm the importance of atmospheric transport for these materials. This is further substantiated by our finding lower average concentrations in the Sargasso Sea where the surface evaporation rate is higher than in other parts of the North Atlantic.

Plankton:- Analyses of mixed plankton show relatively constant levels of PCB's (100-500 parts per billion. Figure 11 illustrates the absence of any gradient due to continental runoff. Plankton from the Sargasso Sea near Bermuda reflect the lower concentration of PCB found in the water there. The low concentrations found near Southwest Africa are in the Antarctic upwelling region. The four samples containing more than 1,000 ppb were all rich in phytoplankton, mixed plankton contain higher chlorinated hydrocarbon levels than most higher predators.

Mesopelagic Organisms:- These animals which live below the mixed layer by day, but migrate up at night to feed, are probably responsible for transporting tons of chlorinated hydrocarbons out of the productive zone into the deep sea. The prevailing DDT and PCB concentrations in these species of fish and crustacea have been found to be related to the particular kind of fat or lipid in each species.

Atmosphere:- Our studies indicate that more than 90% of the chlorianted hydrocarbons in the atmosphere are in the vapor phase and not associated with the dust. Thus, the major pathway into the ocean must

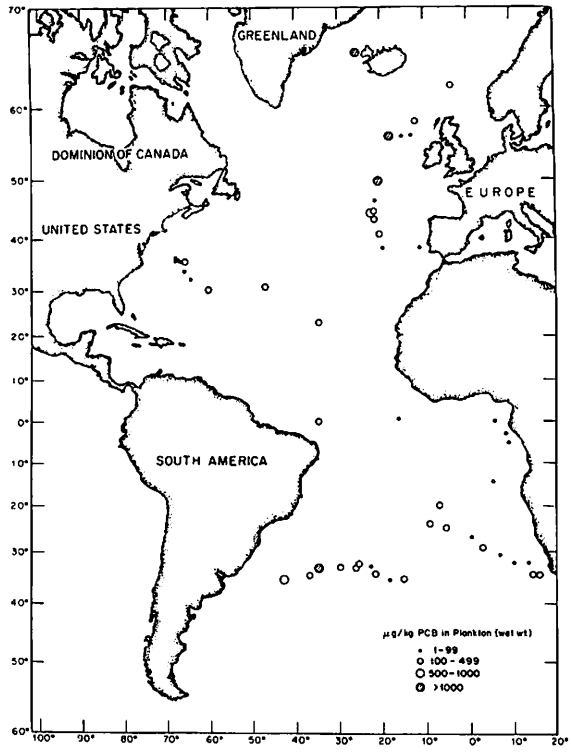


Fig.11 (Harvey,Miklas,Steinhauer and Teal) PCB concentrations in Atlantic plankton.

be by washout during precipitation and not fallout on particulate matter. This finding correlates well with the lower level of contamination in the Sargasso Sea, in which there is a low annual precipitation.

CHEMISTRY OF THE LOBSTER

Robert G. Gagosian and Jelle Atema

We have shown that the female lobster releases her sex pheromone upon molting. In many cases, crustaceans mate just after the female molts. This suggests that the molting hormones of the female could be in some way involved in the pheromone releasing process, either directly or indirectly through a metabolic mechanism. We decided to test organic compounds with molting hormone activity for their sex pheromone activity in the lobster. β-ecdysome, inokosterone, ponasterone A, and cyasterone were tested for their capacity to elicit behavioral responses, especially sexual responses in the male lobster. Of these ecdysones, only β-ecdysone elicited a low-key alerting response. However, no particular type of behavior, such as feeding, aggressive or sexual behavior could be observed. A role of β-ecdysone as a crustacean sex pheromone is not supported by our experiments.

The possibility exists that the catabolic products of the ecdysones act as sex attractants. We have synthesized these compounds and are in the process of testing them for beharioral responses. Preliminary results show no sexual, feeding or aggressive responses.

Not only did we find abnormalities in the behavioral responses to molted females, but in general we observed a gradual physical change in our laboratory-kept lobsters. Up to 25% died during or shortly before molting. Their colors changed from gleaming dark brown with bright orange spots on the spines to a dull pale gray blue color, especially after a few molts. In addition, many of the laboratory-molted animals never completely hardened after molting. We concluded that our lobsters were suffering from an ecdysone (molting hormone) deficiency which showed up in 1) not molting very well, 2) not hardening properly afterwards, and 3) for the females, not giving off the proper chemical sex attractant. The color change may also be related to the ecdysone deficiency.

Since these symptoms were noted in lobsters kept both in running water and in closed system, we concluded that their limited diet was responsible for the changes in biochemistry. When we fed algae to our "deprived" lobsters they exhibited clear feeding responses, were attracted from a distance and fed quite extensively. The vegetarian feeding habits, as well as the general feeding habits of wild lobsters are very poorly understood. We have meanwhile initiated an extensive and long-term nutrition study on immature and mature lobsters in order to assess their need for certain basic foods for molting survival, fertility and growth.

It is possible that it is not ecdysone or a precursor that is taken up from plants, but another essential compound, a vitamin or enzyme involved in ecdysone biosynthesis. It is also possible that a special plant or animal is necessary food during intermolt to insure proper production of ecdysone. We are trying to define this in the course of our work on chemical communication. Recently we have collected results which support the idea, that nutrition is essentially involved in mating success, egg production and survival. Success in lobster culture will depend largely on this type of research.

Analysis of the organic content of both the blood and the urine of the lobster is under investigation by gas chromatography, mass spectrometry. We are using the chemical "fingerprint" of certain organic compounds to initiate a nutritional monitoring system for lobster culture. Several compounds have been successfully separated and their structural determination is in progress. The complete metabolic background of the lobster is being done in cooperation with Bela Balough at the Space Sciences Research Laboratory at Berkeley.

It is well known how important molting is in the life cycle of arthropods. Recently, large efforts have gone into isolating the compounds (ecdysones) from insects. We have adapted many of these techniques to the isolation and structural identification of the lobster molting hormone(s).

CHEMOTAXIS INVESTIGATIONS

Jelle Atema

In our work on chemical communication in the sea some new ideas have emerged. (1) Nutrition appears to be an important factor in the mating success, egg production and molting survival of lobsters. (2) Crude oil has an effect on lobster feeding behavior, but it is not the soluble fraction that causes the changes. (3) Smell and taste in several aquatic animals are anatomically and functionally distinct chemical senses. (4) Evidence is slowly being collected to support the theory that microtubules are intimately connected with the molecular mechanisms of sensory reception and transduction.

LOBSTER SEX PHEROMONE - NUTRITION - METABOLISM

Jelle Atema, Robert G. Gagosian, and Lauren S. Stein

Behavioral tests on pheromone activity and mating behavior conducted in the last year have been ambiguous. Often sexual responses, both to recently molted females and to their molt water, were interrupted by aggressive behavior. In a few instances females were killed by males. Sometimes the males would display a high level of aggression, presumably in the presence of sex pheromone. We further discovered that the seductive behavior of females overrides their chemical abnormalities. Even hard-shell (intermolt) females will be mounted and not infrequently mated by males. This seems to be triggered by a sequence of behavioral cues elicited by the female when she must choose between fighting or being mounted. Upon confrontation even smaller males will respond with similar "invitation" postures and will be mounted - but not mated - by larger males in order to avoid a fight. We have collected evidence that lobsters kept over three months in our laboratory developed chemical abnormalities in their sex attraction.

TASTE AND SMELL IN AQUATIC ANIMALS

Jelle Atema

The theory that catfishes and perhaps several other aquatic animals use their chemical senses for distinctly different purposes - taste for localization and testing of food; and smell for such social behavior as species, sex, individual and status recognition and for home-range recognition was put to a rigorous test at the unique facilities of Professor Kleerekaper at Texas A. & M. University. The two taste senses and the sense of smell of catfish were made inoperative by surgically removing the controlling brain centers. The anosmic and the two types of tasteless fish were tested in their spontaneous behavior and in their search for food for a period of up to three weeks after operation. The test tank was 5 x 5 m and 30 cm deep. A matrix of photocells recorded the swimming pattern of the fish before and after operations. The photocell pulses were stored on a magnetic disc, which preserved their spatial and temporal sequences. Swimming tracks of many animals over long periods of time were stored and compared. Processing of the data is still underway at Texas A. & M. University. Preliminary results confirm the theory of functional separation. Additional information leads us to believe that the sense of smell serves as a stimulator of activity: even simple nose plugs can slow down the swimming of the catfish to almost nil. The rather deep taste brain operation, on the other hand, has no slowing effect.

A fourth lesion is being used now at the Massachusetts Institute of Technology where Thomas Finger is concerned with the neuroanatomy of all catfish senses. We will complement his anatomical investigations on the mysterious *nervous terminalis* with a study of behavioral effects after cutting this nerve, which is so closely related to the nerves of the sense of smell.

HOMESTREAM RECOGNITION OF ALEWIVES

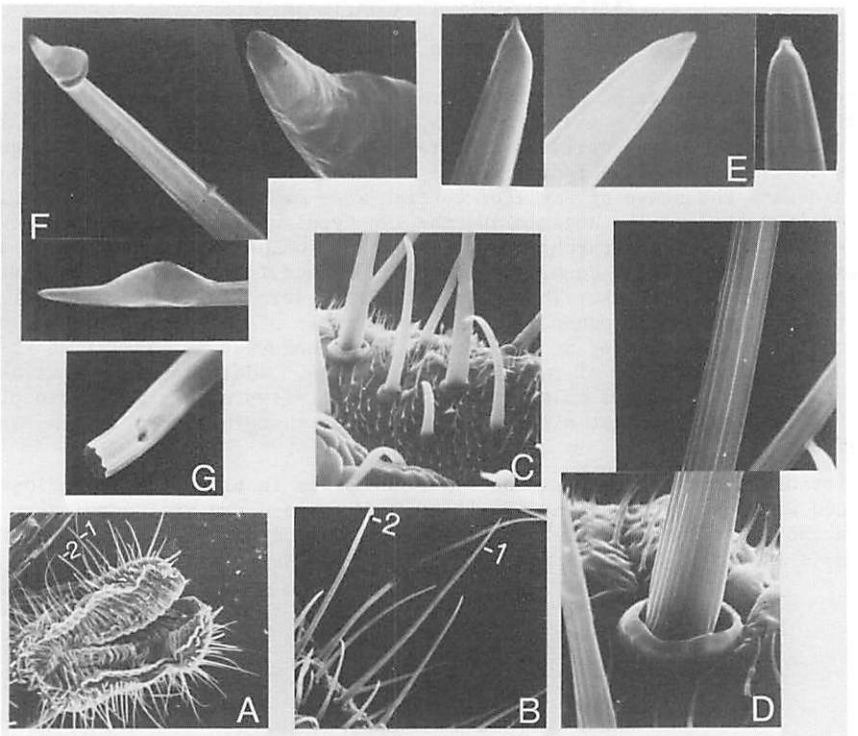
Jelle Atema and David Engstrom

In the third season of alewife testing we have concentrated on a few old questions. We confirmed our early feeling that single fish are behaviorally not suited for y maze testing. Perhaps because they are a schooling species, better results were obtained when five fish were tested simultaneously. This makes statistical data treatment more difficult. However, with the help of Woolcott Smith we arrived at a satisfactory procedure of data analysis. It was not surprising to find that the fish responded more clearly when they were tested with a freshwater stimulus in a seawater background, than when they were tested in a freshwater (well water) background. In general, we confirm that a homestream preference exists in alewives and that it is chemically recognized. Our attempts to identify the groups of compounds involved remain too few to allow firm conclusions. A final report on this work is in preparation.

MICROTUBULES AS CELLULAR INFORMATION CONDUCTORS

Jelle Atema

Supportive evidence has been collected here and elsewhere that indeed microtubules may be actively involved in the reception and transduction of sensory information within the receptor cells. We have shown that microtubules isolated from mouse brains bind to radioactive colchicine and melatouin. Further evidence from other laboratories shows that microtubules bind to many different compounds. Attempts to block sensory transduction in blowfly taste hairs and hermit crab antennules by disassembling their sensory microtubules have so far not been conclusive, due to difficulties in applying the drugs to the sensory cells without damage. Scanning electron microscopy of the blowfly taste hairs was undertaken in an attempt to discover better ways of application (Fig. 12). This facet of our work is at the most basic - chemical - level of biology and the microtubular concept may change traditional thinking in cellular biology and medicine.



Blowfly (Phormia regina) Labellar Taste Hairs
A. Proboscis with taste hairs (1cm=50μm). B. Enlargement of hairs 1 and 2 (1cm=15μm). C. Base of hairs (1cm=7μm). D. Base of hair 1 (1cm=1μm). E. Three views of tip of hair 1, rotated (1cm=1μm). F. Three views of hair 2, rotated, fluid drop excreted (1cm=1 and 3μm). G. Hair broken near tip, central canal visible (1cm=3μm).

Fig.12 (Atema) Scanning electron micrograph of blowfly (*Phormia regina*) labella taste hairs.

EFFECTS OF CRUDE OIL ON LOBSTER BEHAVIOR

Jelle Atema and Lauren S. Stein

This aspect of our investigations on sublethal effects of pollutants on marine life was concluded with Technical Report, 72-74, Woods Hole Oceanographic Institution.

Small quantities of crude oil (0.9 milliliters in 100 liters of seawater) interface with some specific, possibly chemosensory, behavior of the lobster, *Homarus americanus*. Timing of their feeding behavior showed that the delay period between noticing food and going after it doubled when oil was added. The water-soluble fraction of this crude oil alone (in the 50 ppb range) does not have a noticeable effect on behavior and feeding times. Morphological changes in odor receptors after oil exposure were not detected by light and electron microscopy. The results indicate that small quantities of oil mixed into seawater constitute a noxious, bad smell in the lobster's environment depressing his appetite and chemical excitability.

Chemical analyses showed that before the addition of oil a great quantity of lipids was present in the test aquaria. When the water was brought in contact with an oil slick, the lipid concentration dropped considerably. The same effect was seen in the alkane and the naphthene-aromatic hydrocarbon fractions. The fate of oil in seawater followed the usual degradation pattern.

THE BEHAVIOR AND SOCIAL ORGANIZATION OF FISHES SUBJECTED TO SUBLETHAL STRESSES

John H. Todd

During the past year the first set of experiments was completed on the influences of sublethal thermal and oil stresses on the behavior and social organization of fishes representing different levels of social organization from the same ecosystem.

The schooling species was represented by the golden shiner, *Notemigonus crysoleucas* (family Cyprinidae). A territorial and hierarchically organized species was represented by the pumkinseed sunfish, *Lepomis gibbosus* (family Centrarchidae). A socially complex and diverse species (individual recognition, territories, cooperative behavior, etc.) was represented by the yellow bullhead, *Ictalurus natalis* (family Ictaluridae).

The first phase of the investigation involved an analysis of the elements of communicative behavior of species that were representative of different levels of behavioral organization. There were 24 key elements involved in schooling, 33 in territorial and 98 in socially complex and diverse species. With increasing levels of social organization there was found to be a substantial increase in bits of communicative behavoir. This increase is paralleled by a comparable increase in communicative behaviors critical to the maintenance of social organization.

The second phase of the study involved an analysis of the influence of environmental stresses on the communicative behavior and social organization of the selected species. Sublethal stresses induced by high temperatures and exposure to water-soluble fractions of crude oils markedly influenced the behavior of the social complex and diverse species, well below the levels at which they died. Key elements of communicative behaviors were qualitatively and quantitatively altered and the social organization disrupted.

The territorial species were less influenced by sublethal stresses. The thermal study indicated that the range of influence for this species was close to its lethal limits. Within 3°C of their lethal limits territorial behavior was altered and subordinate fish invaded the territories of dominants.

The schooling fishes showed signs of physiological stress at upper sublethal temperatures. Significant behavioral changes were not detected in either the thermal or oil studies.

An environmental ethology concept was developed which links behavioral phenomena with ecosystem strategies and evolution. It was suggested that behavioral studies can provide information that might enable the determination of the fate of aquatic environments under stress.

THE SEX PHEROMONE AND COMMUNICATIVE BEHAVIOR OF THE GOBIID FISH, *Bathygobius soporator*

John H. Todd, Camas Lott and Christopher Reading

Attempts are being made to determine the chemical used by the Gobiid fish in communication. *Bathygobius soporator*, an inshore tropical species, was used as the model because of its known ability to produce pheromones during courtship. Also we suspected that it would be possible to breed them under laboratory conditions. The initial phase of the research involved a study of its courtship behavior and the establishment of criteria for an accurate bioassay. *Bathygobius* were successfully bred and the young raised to a mature size in a simulated marine environment housed within a greenhouse structure with elevated temperatures.

An investigation of the histology, electron microscopy and ultrastructural studies of the ovary and internal sites of pheromone production were carried out during the summer months when the females were in a reproductive state. Minute follicle cells (1-2μ in diameter) lining the follicles were neurosecretory basophiles (B-cells). Steroid enzyme chemistry suggested that these cells contain hydroxysteroid dehydrogenase enzymes in the mature females, but not in the immature animals.

THE ONTOGENY OF BEHAVIOR THROUGH THE FIRST EIGHT STAGES OF THE LOBSTER, *Homarus americanus*

John H. Todd and Joan Mitchell

A study of the development of behavior through the first eight stages of growth for the lobster was completed. The purpose of the research is to determine the biological basis of cannibalism and aggression in this commercially valuable species. The factors underlying behavior are often revealed through ontogeny studies of the type we have embarked upon.

A behavioral dossier was completed for all eight stages and the first three stages (the planktonic stages) were chronicled. Stages four to eight were studied under two contrasting experimental regimes, each designed to reveal unique components of the development of behavior. A. Conflict Resolution experiments involved two individuals per container normally separated by a partition. During the trials the barriers were raised and the ensuing conflicts closely monitored. B. Community Studies: Small communities (five individuals) were maintained in a simulated marine environment for observations on the development of the stage-specific social organization.

There was a progressive decrease in swimming behavior together with an increase in social organization at each stage. By stage seven their behavior was more stereotyped and differences in status were resulting in markedly different rates of growth and frequency of molting. Hierarchical relations play a predominant role in regulating the lobster communities by the eighth stage. Environmental factors including the diversity of substrate and the presence of attached algae also set limits upon the communities.

GEOLOGY and GEOPHYSICS

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

James R. Heirtzler, Department Chairman

DEEP-SEA DRILLING IN THE INDIAN OCEAN: JOIDES LEG 24

Elizabeth T. Bunce

Introduction

Leg 24 (May 3/June 26) of the Deep-Sea Drilling Project traversed 4,500 nautical miles from Djibouti, French Territory of the Afars and the Issas, to Mauritius at the south end of the Mascarene Plateau, with drilling at eight sites and with E. T. Bunce and R. L. Fisher as Co-Chief Scientists (Fig.1). Placement of these holes, the tectonic and structural framework for them, and the problems to be addressed derive in main from the geological-geophysical achievements of the International Indian Ocean Expedition program of the 1960's.

Glomar Challenger sampled three regions: (1) the Gulf of Aden, explored and surveyed largely by geological-geophysical expeditions of the National Institute of Oceanography and Cambridge University, Great Britain; (2) Somali Basin, explored especially by Woods Hole Oceanographic Institution and Lamont-Doherty Geological Observatory; (3) Mascarene Plateau - Central Indian Ridge - Chagos - Laccadive Plateau, a sector explored in large part by United States and Soviet vessels and especially by the Scripps Institution of Oceanography.

Problems examined and elucidated by Leg 24's drilling program have to do with ocean initiation, with the time and direction of movement of the several aseismic and seismically active ridges, and with reassembly of the microcontinents (?) of the western Indian Ocean; these objectives were described in some detail in the July 1972 issue of *Geotimes* (page 26).

The aim of continuous coring of the sediment column at as many of the sites as practical was to build up by this means paleontological reference columns for tropical latitudes in the western Indian Ocean, to attempt to identify and correlate seismic reflectors with lithology in this region where extensive reflection and refraction profiling had been done, and to recover rather complete sections at basement-contact zones where late-stage volcanic effects might be detected. Any igneous rock encountered was to be penetrated deeply enough to establish whether it was basement, to determine

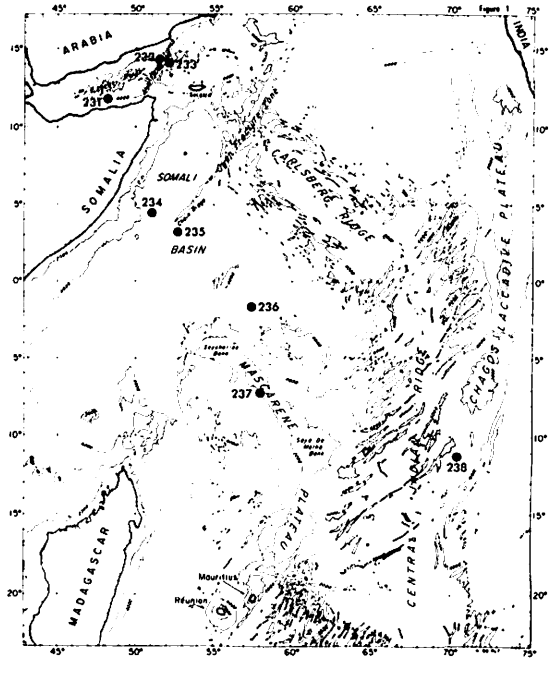


Fig.1 (Bunce) Leg 24 site locations.

possible flow and pillow structure of extrusives emplanted on the deep seafloor and to obtain fresh, if ancient, igneous materials. As a result of this practice Leg 24, in drilling at only eight sites, cored and recovered more sediment than any other leg of the Project; made the greatest total basement penetration, 163 m, and recovered the most igneous core, 74.1 m; at Site 238 penetrated 80.5 m into almost fresh basaltic basement and there recovered 40.6 m, both Project records. Average recovery for Leg 24 was 63.2 percent, with 3,165 m cored and 1,994 m recovered.

Gulf of Aden

The Gulf of Aden is a young and mobile oceanic region of intermediate depth that is bisected from east to west by Sheba Ridge, which marks the spreading center. The ridge is offset by several minor transform faults and, near its eastern end, by a linear NNE-trending cleft, the 5,360 m-deep Alula-Fartak Trench. We drilled three sites in this region: Sites 231, 232, and 233. All were continuously cored to acoustic basement.

Site 231 was drilled south of Sheba Ridge, in an area where evidence for damming of the Gulf, if it had occurred, might appear as evaporite deposits. These speculations proved to be false.

Sites 232 and 233, were drilled on the opposite sides of the Alula-Fartak Trench. Primary results here indicate opening of the Trench may postdate the lower Pliocene.

The drilling results from the northwest Somali Basin are somewhat inconclusive. The western margin, Site 234, was abandoned after the drill string repeatedly seized and stuck. Site 235, east of Chain Ridge, was drilled to basaltic basement, with recovery of 13 m of the 32.5 m penetrated. At both these sites extensive calcium carbonate solution has taken place; the lack of land-derived turbidity material in the section drilled at 234 indicates its removal from the land mass at this time; minor amounts of volcanic ash and glass do indicate Tertiary volcanic input to these two sites.

Sites 236, 237, 238 in relatively isolated localities were variously concerned with time of possible sundering of 'microcontinents', refinement of the magnetic time scale, age and petrology of basement, rates of subsidence of supposed coralline piles on massive foundations, collection of complete paleontological sections to refine Tertiary nannoplankton-radiolarian-foraminiferal zonations, and trend of volcanism that built the Chagos-Laccadive Plateau. Site 236 was drilled into basement in the sedimented outermost foothills southwest of Carlsberg Ridge and about 270 km northeast of Seychelles Bank. It is on or near the oldest cycle (28?) of an ancient magnetic-anomaly pattern associated with Carlsberg Ridge or a proto-Carlsberg Ridge. It was cored continuously to basement, here a veined and chloritized basalt, and thence 21.5 m into igneous rock. The section recovered represents an apparently complete sequence from upper Paleocene through Quaternary and contains common to abundant calcareous planktonic fossils typical of a highly-productive, low-latitude open-ocean environment.

Site 237 terminated short of the basement because chert dulled the bit, was drilled in the intermediate-depth saddle joining granitic Seychelles Bank to volcanic(?) Saya de Malha and the shoal areas to the southwest. The lowest date sediments, about 200 m above the bottom of the section, are early Paleocene (Danian). Inability to penetrate the chert leaves unresolved the question of volcanic or granite structure for this section of the Mascarene Plateau.

Site 238 lies at the extreme northeast end of Argo Fracture Zone, within a partly buried transform-fault cleft athwart the seismically active and spreading Central Indian Ridge. The hole was cored continuously from the seafloor to 506 m where basement was encountered conformably beneath upper Oligocene (Rupelian) sediments. Basement was continuously cored for 80.5 m to hole bottom at 586 m. The site provided abundant sedimentary and igneous material to document the winding-down of a crustal rupture. The data of supposed sundering of the Chagos/Diego Garcia region from Cargados Carajos/Nazareth Bank has been moved back in time, perhaps to the early Oligocene. This calls for reexamination of magnetic lineations between 'Anomaly 5' and the boundaries of transform-faulted blocks.

DEEP-SEA DRILLING IN THE SOUTHERN INDIAN OCEAN, LEG 26

Bruce P. Luyendyk

Leg 26 began when the ship sailed from Durban, South Africa, on 6 September 1972 and ended when we docked in Fremantle, Western Australia, 30 October, with Bruce Luyendyk and Thomas Davis as Co-Chief Scientists. During the course of Leg 26 *Glomar Challenger* steamed 5530 miles and operations were carried out at nine sites, drilling twelve holes in water depths ranging from 1144 m to 5361 m. On Leg 26, 246 cores were cut representing 62 percent of the total stratigraphic section penetrated. Basement was reached at six sites and a total of 69.9 m of igneous rock cores were recovered. Total penetration into igneous rock was 152.7 m. Particular problems investigated on Leg 26 were:

1) The history of the Southwest Branch of the Indian Ocean Ridge and the history of the crust and oceanic sedimentation in that general region (Sites 250, 251, 252);

2) The nature and history of the Ninetyeast Ridge (Sites 253, 254);

3) The age, nature and history of Broken Ridge - Naturaliste Plateau, supposed microcontinents (Sites 255, 258);

4) The oldest sediment in the Indian Ocean and thus possibly the date of the initial breakup of Gondwanaland (Sites 256, 257).

Major tectonic events in the western Indian Ocean are the rifting of Africa - Antarctica and the uplift of the Southwest Branch (SWB) of the Indian Ocean Ridge. A Late Cretaceous age was found at Site 250 which when combined with a middle Cretaceous age at Site 249 (Leg 25) gives a northward age increase south of Africa and implies that the age of the margin, and therefore the rifting, is somewhere in the Early Cretaceous. An age of 17-18 my was determined for the crust at Site 251 which gives a spreading rate on the SWB of 0.93 cm/yr in a direction parallel to the charted fracture zones (NNE).

Two holes on the Ninetyeast Ridge show that the ridge gets younger to the south, being of Lower Miocene age at its southern end, and that it was formed at or near sea level. The Broken Ridge site is at least Santonian/Campanian in age and has been an elevated structure since this time and was uplifted above wave base in the Eocene. Sites in the Wharton Basin are of Early Cretaceous age and are older to the south which is consistent with an ancient north-south spreading ridge now believed to lie to the north. The Naturaliste Plateau is at least 105 my old and has been a deep-sea structure since then and gradually uplifting to its present depth, denying the idea that this structure is a foundered piece of the Australian continent. Major unconformities were found in the western holes; a Santonian-Miocene disconformity of the Naturaliste Plateau, a Cretaceous through Neogene disconformity in the Wharton Basin, and a Santonian-Eocene angular unconformity on Broken Ridge. The disconformities are believed due to the initiation of the Circumpolar Current during the rifting of Australia-Antarctica while the angular unconformity is due to uplift of Broken Ridge from the initiation of the Pacific-Antarctic Ridge at this same time.

DEEP-SEA DRILLING OFF WESTERN AUSTRALIA, LEG 27

James R. Heirtzler

During the period November 1 to December 9, 1972, the *Glomar Challenger* drilled five holes off west and northwest Australia, with James Heirtzler and John Veevers as Co-chief Scientists. Four holes were drilled in an area known to have an oceanic crust and one in an area, just south of Timor, known to have a continental crust. Three of the oceanic holes reached basaltic basement and the fourth had to be stopped only a few meters short of basement because of mechanical reasons. Lowermost Cretaceous/Uppermost Jurassic sediments were found against basement in the Argo Abyssal Plain and are the oldest yet found in the Indian Ocean. The basement age, from this and previous cruise results, tends to decrease in a west-northwesterly direction, to Upper Cretaceous in the Wharton Basin. The general thickness of the Cretaceous sediment layer decreases in a similar direction from a few hundred meters near Australia to near zero thickness in the Wharton Basin.

South of Timor and near the axis of Timor Trough a major acoustic reflector of calcarenite was reached at 442 meters. Salinity of interstitial water increased downward to 53 parts per thousand.

RED SEA STUDIES: SEISMIC REFLECTION

David A. Ross and John S. Schlee

During our 1971 *Chain (Chain* 100) Cruise to the Red Sea we made 34 seismic reflection profiles across the basin. These profiles show that the Red Sea developed in two stages. Initially, an Early or pre-Miocene uplift resulted in crustal thinning and formation of the main Red Sea basin. Evaporite conditions prevailed in the Miocene when the Red Sea was isolated from the Indian Ocean but connected with the Mediterranean Sea, which like the Red Sea was an evaporite basin at that time. A distinct acoustic reflector (reflector S) in the Red Sea marks the top of the Miocene evaporite sequence and is correlative with reflector M in the Mediterranean which is similarly identified with the termination of evaporite conditions in that sea.

In the Pliocene, connection with the Indian Ocean was re-established and the opening to the Mediterranean was closed. This resulted in resumption of normal marine conditions in the Red Sea. During the Pliocene-Pleistocene, sea-floor spreading resulted in the formation of the axial zone.

RED SEA STUDIES: MAGNETICS

David A. Ross, Roger Searle[1], and Joseph D. Phillips

During the *Chain* 100 Cruise, a detailed magnetic survey was made of one degree by one and one-half degree area that included the hot brine area of the Red Sea. The resulting chart of the magnetic anomalies showed two zones of NE-SW trending anomalies, separated by a magnetic "quiet" zone where large anomalies were absent. These results are interpreted in terms of a sea-floor spreading model in which two NE-SW trending spreading axes are offset by a transform fault with a strike of about 015°. Correlating the anomalies with the Heirtzler time scale leads to a spreading rate of 1.6 cm a^{-1} parallel to the transform fault. Anomalies older than 1.7 Ma could not be recognized.

RED SEA STUDIES: BOTTOM PHOTOGRAPHY

Robert A. Young and David A. Ross

Bottom photographs from the axial valley of the Red Sea have documented the varied topography and lithology expected in a tectonically active rift valley. Pillow lavas, flows, and rock breccia, all fresh in appearance and virtually free of sediment cover were observed. Sediment appears to be accumulating only in small local ponds.

A camera station taken within the Atlantis II Deep showed rippled sediment unbroken by rock outcrops. A group of mound-building organisms (polychaete worms?) was photographed in or at the upper fringes of the hot brine (maximum temperature 59°C; maximum salinity 257°/oo). The occurrence of any organisms in such an environment is surprising.

Stations on the eastern flank of the axial valley showed sediment-covered sea floor with no rock outcrops. Evidence of infaunal biologic activity different from that observed at deeper axial valley stations was also noted.

Volcanic and sedimentary features seen in our photographs are similar to those observed in the rift valleys of mid-ocean ridges. This and geophysical evidence indicates that similar processes are active in the Red Sea as in other regions of active sea floor spreading.

GEOLOGY AND GEOPHYSICS IN EAST AFRICAN RIFT VALLEY LAKES

Albert J. Erickson and How-Kin Wong

During March of 1972 a multidisciplinary survey was conducted by a team of investigators from this and other institutions of three lakes within the African Rift Valley as part of an on-going program to study the presence of a branch of the mid-ocean ridge system beneath a continent. Various local boats were chartered and bathymetric, magnetic, and seismic refraction surveys were conducted on Lakes Kivu, Edward, and Albert in Rwanda and in the Democratic Republic of Zaire (formerly known

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[1]Geophysical Observatory, Haile Selassie I University, Addis Ababa, Ethiopia.

as the Congo). In addition, land gravity measurements were made along profiles perpendicular to the axis of the Rift Valley wherever terrain and the road system permitted. Piston cores in conjunction with the hydrologic, geochemical, and biological data also collected on this expedition should provide many clues to the age, origin, and history of these lakes and of the surrounding rift valley.

DIATOM STRATIGRAPHY OF EAST AFRICAN RIFT VALLEY LAKES

Robert E. Hecky

Woods Hole Oceanographic Institution expeditions to the East African lakes - Tanganyika, 1970, Kivu, 1971, and Kivu, Edward, and Albert, 1972 - have returned a comprehensive suite of cores yielding a Late-Glacial and Post-Glacial record from continental Africa. The unique geographical position of these great lakes allows the interplay of tectonic activity, volcanism, and climate to be followed through time by means of the fossil record in these cores. Diatoms are by far the most abundant microfossil in these lake sediments, and they have been the main focus of investigation. Lake Kivu because of its central position in the hydrologic pattern of Africa, having drained into both Lake Edward to the north and Lake Tanganyika to the south during its history, has been examined first. Also this lake and its sediments are under intense geochemical study because of its unusual hydrography and high concentrations of gases and heavy metals. Possible effects of these geochemical peculiarities on the biological populations will be sought in the fossil record.

Detailed investigation of the past 10,000 years of Lake Kivu's history has been completed, and preliminary results for the period between 40,000 and 10,000 years are available. Climate and hydrothermal springs as they affect the stratification of the lake and changes in the chemical weathering rates primarily determined changes in the diatom populations. Ten thousand years ago and for most of the previous 30,000 years Lake Kivu was a shallow, saline lake without a surface effluent. Under the drier and somewhat cooler climate weathering rates were reduced and ground waters tended to move upward and remain in soil profiles. This greatly reduced the ionic input to the lake including dissolved silica, an essential requirement for diatoms, and *Stephanodiscus astraea*, a low silica specialist, predominated in the diatom plankton. The predominance of *S. astraea* prior to 10,000 yr B.P. is characteristic of all the large African lakes so far examined. As the climate became warmer and wetter after 10,000 yr B.P. the lake level rose and total ionic inputs increased. *Nitzschia fonticola* became much more abundant although *S. astraea* was still prominent.

Approximately 5500 yr B.P. the intensity of sublacustrine hydrothermal spring activity increased drastically, most likely as the result of volcanic activity, and the lake became chemically stratified. The density differences between surface layers and bottom layers greatly increased and mixing of nutrient-rich deep and nutrient-poor surface waters was reduced. The lake became more oligotrophic and less suitable for diatoms. Only slow sinking, needle-like species of *Nitzschia* and spiniferous Chaetoceros were able to maintain populations. These needle-like *Nitzschia* are, therefore, good indicators of the stability of stratification in tropical lakes. As stability increases, mixing and nutrient supply decrease and there is selection for slow-sinking diatom species because the fast-sinking species sink out of the euphotic zone before reproduction can occur. This explains the dominance of *Nitzschia* in all deep tropical lakes with perennial deep thermoclines. Changes in the relative abundance of these *Nitzschia* support evidence from other sedimentary parameters especially calcium carbonate which indicate that there have been periodic episodes of intense spring activity followed by reduced activity and mixing of the deep saline waters into the lake surface waters and a general flushing out the Ruzizi River to Tanganyika. The effects of this are quite noticeable in the Lake Tanganyika record. The unusual stratification of Kivu is probably not an equilibrium situation over any great length of geological time. Rather it is a delicate balance between spring input and surface runoff, and it is subject to perturbation by climatic and volcanic events.

CHAIN RIDGE: A STRUCTURAL BOUNDARY IN THE NORTHWESTERN INDIAN OCEAN

Richard H. Burroughs and Elizabeth T. Bunce

The Chain Ridge sector of Owen Fracture Zone, northwestern Indian Ocean, was re-investigated on a geophysical cruise (*Chain* 100, Leg 4). Earlier cruises (*Chain* 43; *Chain* 99, Leg 8) that analyzed major structural features in the area (Bunce, *et al.*, 1966; Bunce, *et al.*, 1967; Heirtzler and Burroughs, 1971) form a background for this investigation. The recent work enabled piston coring of some anomalously old sediments (Oligocene) on the west flank of the ridge (Pimm, Burroughs and Bunce, 1972) and the delineation of the maximum southern topographic extent of Chain Ridge at approximately 1^{o}N.

Analysis of the new geophysical data shows the elevated sector of Chain Ridge and its buried extension to continue south toward the African coast. If layer 2 basement elevation can be used in a method similar to that of Sclater, Anderson, and Bell (1971) to determine age on contrasting sides of the ridge in the area 2^{o} - 10^{o}N then the area to the west of the lineation is at least 30 million years older than that to the east. It may be much older. This age difference is not inconsistent with some continental drift reconstructions and the preliminary JOIDES results from the area (Fisher and Bunce, *et al.*, 1972; Simpson and Schlich, *et al.*, 1972). Hence, the Somali Basin west of Chain Ridge may represent sea floor that existed prior to break-up of Gondwanaland while that to the east evolved subsequently.

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SUNDA SHELF

Zvi Ben-Avraham and Kenneth O. Emery

Seismic reflection and refraction (via radiosonobuoys), magnetic, and gravity data collected by R/V *Chain* during the summer of 1971 were analyzed and combined with earlier studies over the northern Sunda Shelf and with geological and geophysical data from adjacent land areas and deep-sea floors to provide a comprehensive picture of the structural framework of the entire Sunda Shelf and vicinity. An evolutionary scheme that can best explain the structural elements in the Sunda Shelf and adjacent small ocean basins was developed.

The Sunda Shelf consists of three major units: the northern Sunda Shelf basinal area, the Singapore Platform, and the Java Sea basinal area. In the northern Sunda Shelf are two large sedimentary basins separated by a ridge. In the Java Sea are several other basins separated by uplifts. The basins in the eastern Java Sea are narrow and long and seem to result from compressional forces, whereas those in the western Java Sea are more circular and seem to result from tensional forces. Radiosonobuoys revealed small basement features and resolved many strata having different velocities.

Faults are abundant throughout the Sunda Shelf and they clearly control the distribution and shapes of the basins. The faults strike north-south in the western Java Sea and northeast-southwest in the eastern Java Sea. A major discontinuity trending north-south cuts the structures of the entire Sunda Shelf and continues southward across Central Java to the deep ocean floor.

Analysis of magnetic anomalies shows that the area can be divided into several distinct magnetic provinces that do not always follow the major structural units mapped by the seismic reflection data.

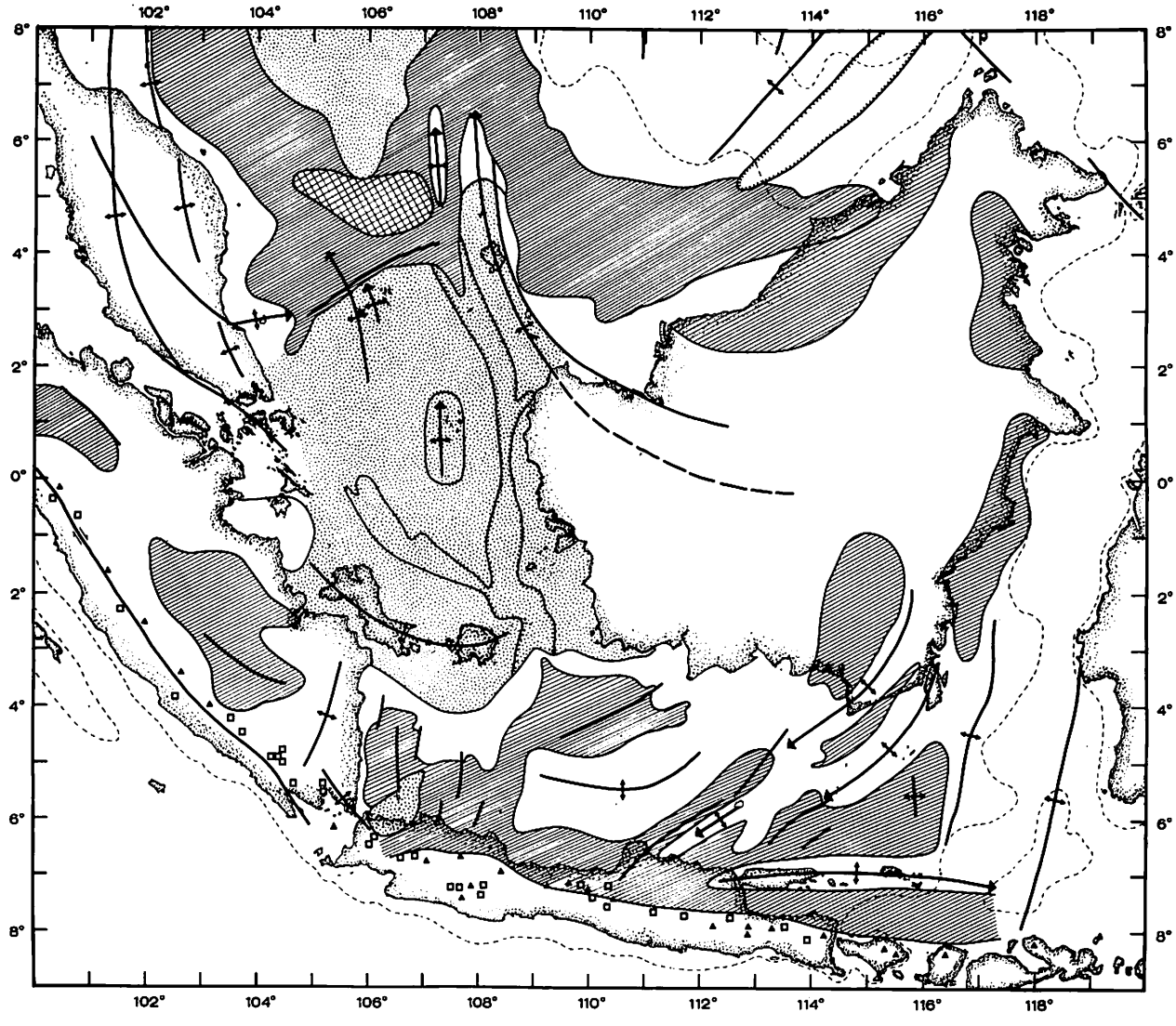

Fig.2 (Ben-Avraham and Emery) General structure of the Sunda Shelf and vicinity. Diagonal cross-hatching denotes basin areas, double-hatching in the northwest - "diapiric"-like intrusions, dots - platforms, solid pyramids - modern volcanoes, and open squares - Quaternary volcanoes.

These magnetic provinces coincide with corresponding lithologic provinces. The gravity field over the central and southern Sunda Shelf averages around +30 mgal. Local gravity anomalies having relative amplitude of 10-25 mgal are superimposed on the regional background level. Although the local gravity anomalies were helpful in resolving the upper crustal structures, the cause for the relatively high regional gravity is unknown.

The structural elements on the Sunda Shelf are interpreted as the result of past interaction between the Indian Ocean-Australian, Pacific, and Asian plates. The evolution of the Sunda Shelf during the Mesozoic resulted from horizontal differential movement in a north-south direction, as both the Indian Ocean and Pacific plates were moving to the north. In Eocene time two major events affected the evolution of the Sunda Shelf: the direction of movement of the Pacific plate changed from north to west-northwest, producing northeast-southwest trending structural elements in the eastern Java Sea, and a spreading ridge that previously existed in the deep sea south of the shelf (Wharton Basin) was subducted along the Java Trench.

SUSPENDED PARTICLES IN ASIAN MARGINAL SEAS

Susumu Honjo, Kenneth O. Emery and Satoshi Yamamoto

The suspended sediments discharged into oceans from the Asian continent are notably greater than those from other continents. Rivers with an unusually large quantity of suspended sediment, such as the Yellow River (with the largest sediment load in the world), Yangtze River and the Mekong River flow from Asia through China and Indochina and discharge into large marginal seas.

The purpose of this investigation was to study the distribution and behavior of suspended particles, particularly mineral grains, in such marginal seas in terms of river discharge and current system. Relation to bottom sediment was also investigated.

Approximately one thousand membrane filter samples were collected on cruises of the R/V *Hunt* and R/V *Chain* between 1968 and 1971. One to three liters of surface water were sampled from systematically designated locations in the East China Sea, Yellow Sea, Sunda Shelf region and Java Sea.

Residue on the filters was weighed with a microbalance and the concentration of suspended sediment in the seawater samples was determined. The inorganic weight fraction was obtained by combustion of selected samples at 500°C.

The following parameters were measured on 185 filter samples and stored on magnetic tape:

A. Non-discriminative measurement of 1) the number of particles per liter and size classification adopting Westworth's scale from 2μ to 64μ; 2) the total projected area of particles per liter; 3) the total length of X-axis projection.

B. Specific particle measurement of 1) the number of anisotropic mineral grains; 2) the maximum diameter and size classification of mineral grains; 3) total projected area of mineral grains per liter; 4) diatom and silicoflagellate counts per liter; 5) a detailed biogeographical study performed on coccolithophorids by Okada.

Mineral grain distribution was examined statistically; the mean size and median size of samples (phi-scale), sample variance, skewness and kurtosis were computed. A contour line was plotted for the results with a newly-developed linear interpolation program.

Following are tentative conclusions: 1) the boundary between marginal sea and pelagic facies was observed in terms of sediment load; 2) the relation of salinity and temperature to the distribution of particles was partly clarified; 3) the mineral grains suspended in surface water were compared with the observed distribution in bottom sediment; 4) the weight of suspended sediments was typically 0.4 to 0.8 mg/l in marginal seas and less than 0.2 mg/l in pelagic areas such as Kuroshio; 5) one to ten percent (in weight) of suspended sediments were anisotropic mineral grains. The percentage was generally high toward the land and irregularly high near distant islands such as Okinawa; 6) the mean size of suspended mineral particles was generally smaller toward land. A 7.5 phi contour runs approximately 100 km off shore in these marginal seas. The phi value was less than 6.5 at locations far from the land. The sorting coefficient (standard deviation in phi-value) was 0.6 to 1.0 and was consistent in the East China Sea. Suspended mineral grains in Sunda Shelf and Java Sea regions were generally less sorted than those in the East China Sea.

OCEANIC COCCOLITHOPHORIDS IN MARGINAL SEAS OF THE PACIFIC AND RED SEA

Hisatake Okada

More than one thousand filter samples have been examined in a study of the ecology and sedimentation of oceanic coccolithophorids in marginal and inland sea environments. The majority of samples were collected from western Pacific regions such as the Inland Sea of Seto, East China Sea, South China Sea, Java Sea, Arafura Sea and Gulf of Carpentaria. Samples were also collected from the Red Sea for a study of comparative environments.

The coccolithophorid distribution is characteristically more patchy in these marginal seas as compared to pelagic environments. Abundant coccolithophorids observed at one station might well be absent in neighboring stations. This phenomena is commonly observed in the distribution of zooplankton in either pelagic or marginal sea environments; it is not observed in the distribution of pelagic coccolithophorids.

Only several of the 400 samples from the East China Sea contained coccolithophorids. These samples were all collected from a narrow area close to the estuary of the Yangtze River. Almost fifty percent of the samples from the western South China Sea yielded large numbers of coccolithophorids; only a few percent of the samples from the eastern South China Sea yielded cells. Coccolithophorid population was generally smaller in these marginal sea environments than in the open seas of equivalent latitudes, where an unusually dense concentration of cells was observed in some samples. A sample collected from the east coast of the Malay Peninsula contained as many as $3.8 \times 10^5/1$ of cells. This value is almost seventeen times higher than the maximum value observed in the tropical Pacific.

The species of coccolithophorids showed extremely low diversity in these marginal seas. Popular species all belong to the placolity-bearing group. *Gephyrocapsa oceanica* was ubiquitous and almost monopolized the entire species assemblage of many samples. *Emiliania huxleyi*, one of the most dominant species in pelagic environments, was often observed in the Red Sea samples, but was scarce in samples from the Pacific marginal seas.

Many of these coccolithophorids showed various types and degrees of deformation of structure and orientation of their coccoliths. Such deformed coccoliths frequently occurred in specimens from the South China Sea and other tropical seas but was negligible in specimens from the Seto Inland Sea, which has been strongly polluted. It may thus be concluded that a stress environment of man-made pollution is not a major factor in determining such deformation.

Hydrographic data have been examined to determine the cause of deformation but a satisfactory explanation has not yet been found. Nitrate measurement showed certain correlation with percentage of deformed individuals in the 40 m level of the Gulf of Carpentaria. The type of deformation seems to have some relation to geographical province.

COMMUNITY STRUCTURE OF COCCOLITHOPHORIDS IN THE PHOTIC LAYER OF THE MID-PACIFIC OCEAN

Susumu Honjo and Hisatake Okada

The mode of population distribution and the community structure of coccolithophorids along the 155^oW meridian from 50^oN to 15^oS were studied based on systematically collected water samples. The contrast between the community in the surface water and in the subsurface photic water was one of the major interests in this study. The latitudinal change of the total assemblage of coccolithophorids throughout the photic water column and the nearest approximation of the assemblage to be deposited on the sea floor along this transect, was also discussed. One hundred and thirty-two water samples were systematically collected from the surface within a limited season. Subsurface samples were collected from 171 substations, located on a matrix of nine levels of depth from -10 m to -200 m, by 19 stations located at every 5^oN or $2^o30'$ of latitude along this transect. A few liters of water samples were filtered through membrane filters with half-micron pore diameter. The coccospheres in the residue were counted and examined by light and electron microscopes. Over 90 coccolithophorid species were found from this profile. The distribution of coccosphere cells in a unit volume of water and the number of species found at a substation were characteristic for each floral zone. Observations obtained from surface water samples were not always applicable to samples of subsurface water. The species diversity index (H') was obtained from every substation. The contour-line distribution of H' value

revealed a definite structure in the photic profile. The percent similarity index was computed to compare the specific content within horizontal or vertical suites of depth levels or stations. This index was most useful for the detection of discontinuity of floral assemblage in combination with conventional species assemblage analysis. The average percent similarity indices were used to examine the uniqueness of the floral content of a substation to adjacent ones. Objective biogeographic provinces of coccolithophorids in the photic water column along the transect were proposed using the available community values.

GEOPHYSICAL STUDIES IN NORTHERN MELANESIA

Bruce P. Luyendyk and Wilfred B. Bryan

During 1972 we have continued data processing and analysis of data obtained on *Chain* Cruise 100, Legs 8 and 9, to the Woodlark Basin and the New Hebrides Island Arc. All geophysical data including bathymetry, magnetic field, gravity field and seismic reflection data, have been reduced along with 29 heat flow measurements and nine sonobuoy refraction stations. Bottom samples including piston cores and dredges have been described and photographed; also preliminary model studies of two strike-normal gravity profiles across the New Hebrides Arc have begun.

A manuscript is in press reporting our work in the Woodlark Basin where we found an east-west striking ridge which is spreading at about 2.3 cm/yr (Luyendyk *et al.*, 1973a). Mapping of the ridge and a transform fault, plus determination of the spreading rate, enabled us to calculate the subduction rate in the Solomon Trench, which is about 11 cm/yr, NE. Another manuscript has been prepared which discusses the relationship between heat flow in Melanesia and seismic transmission anomalies (MacDonald *et al.*, 1973).

Geophysical profiling studies in the New Hebrides Island Arc (Fig.3) have been aimed at a) determining the present plate boundaries in the arc - Fiji plateau region, b) studying the development of

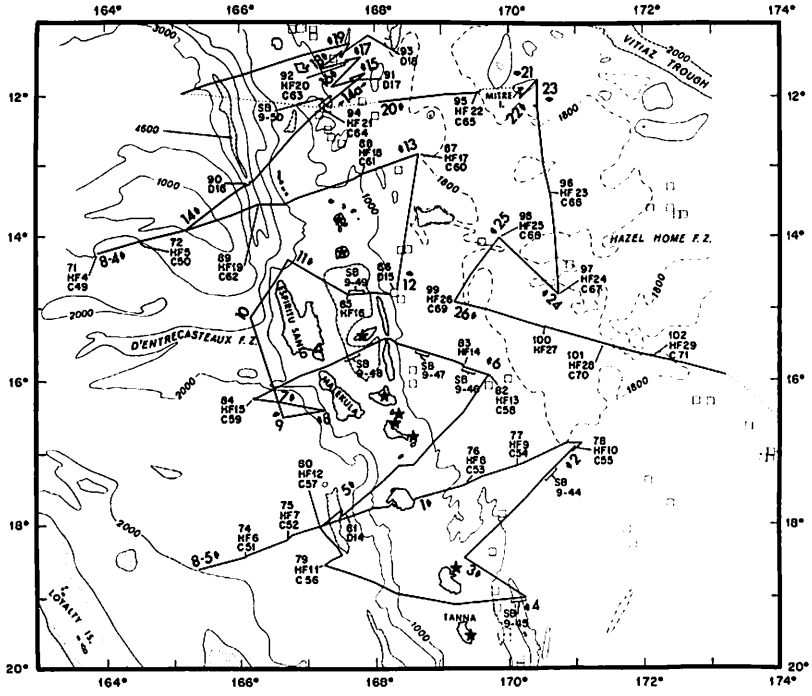

Fig.3 (Luyendyk and Bryan) Geophysical profiles over the New Hebrides Island Arc. Bold numbers on track indicate line number. Stars are active volcanoes and open squares shallow-focus earthquakes. SB indicates sonobuoy stations, HF - heat flow, C - core and D - dredge. Other numbers are station numbers. Bathymetry is in fathoms from unpublished chart of the Scripps Institution of Oceanography.

extensional basins behind the frontal arc and c) looking for evidence of reversal of arc polarity from east facing to west facing at present. A manuscript reporting the results of these studies is now in preparation (Luyendyk *et al.*, 1973b). We have tentatively concluded that the major plate boundaries in the arc system are, of course, the trench, and the Hazel Home Fracture Zone on the Fiji Plateau at 16°S. A north-south spreading center on the Fiji Plateau separates the plate containing the southern part of the arc system from a salient of the Australian plate to the east. Extensional or interior basins are not as highly developed in this arc system as in the Tonga-Kermadec Arc. Behind the frontal arc of the New Hebrides north-south trending basins show evidence of extension by block faulting but the floors of these basins are covered with thick piles of stratified sediments. This suggests that oceanic-type crust is not being formed in the basins, but crustal thinning may be occurring. The eastern island chain of the central group has been thought to be the remnant of an east-facing arc. However, our seismic profiles show that these islands are recently uplifted cuesta-like blocks. Geology on these islands suggests that they represent uplifted sea floor rather than an ancient frontal arc.

Microfossils from the base of the piston cores, and from a random selection of sedimentary rock recovered in dredges 14 and 15, indicate ages of late Pliocene or Pleistocene for all sediment recovered. Volcanic rock recovered in dredges 14 and 16 in the trench is relatively fresh; petrographic and chemical data indicate that it is basaltic andesite of moderately high potash content, resembling material from some of the New Hebrides volcanoes rather than typical oceanic basalt. Rock collected at Mitre Island northeast of the main New Hebrides Arc is petrographically and chemically a moderately alkaline, high alumina basaltic andesite. Jezek and Bryan (1973) have shown that Mitre Island is most likely unrelated to the New Hebrides Island Arc but may be related to an incipient arc associated with a period of subduction along the Vitiaz Trough.

A semi-quantitative numerical study of K_2O/SiO_2 correlations and regression equations for all available good quality volcanic rock analyses from the New Hebrides Arc has shown that the supposed relationship between K_2O and depth which has been demonstrated for other island arcs, is not evident in the New Hebrides. The differences in K_2O levels and in the slopes of the regression lines for individual volcanic centers, are much greater than would be predicted from the rather small differences in depth to the Benioff zone beneath the volcanoes. The oldest known volcanic rocks from the New Hebrides are petrographically and geochemically distinct from both the oldest and youngest volcanic rocks of the Tonga-Kermadec Arc; and thus it seems unlikely that the New Hebrides Arc was ever structurally continuous with Tonga as suggested by some recent reconstructions of Melanesia. The pre-Pliocene volcanic rock data are not really sufficient for unequivocal conclusions about possible changes in arc polarity, but available data do not show the increase in alkalinity from east to west that would be expected by analogy with modern arcs of "normal" polarity such as Japan.

FLOW OF THE DEEP WESTERN BOUNDARY CURRENT (DWBC) IN THE WESTERN EQUATORIAL PACIFIC: HYDROGRAPHY AND GEOLOGY

Charles D. Hollister, Kenneth C. MacDonald, David A. Johnson,
John M. Edmond and Peter Lonsdale

Twelve high-precision continuous temperature profiles in a north-south 100 km section through Reid's Passage northeast of Samoa, obtained on *Chain* 100, show a marked 'benthic thermocline' associated with the DWBC. The maximum temperature gradient is 0.33 degrees in 300 meters. The height of the current (Pot.T. 0.65°C) increases from 450 m (at 120 km south of the Passage) to a maximum isothermal-layer thickness of 880 m in the throat. These pronounced advective features vanish within 50 km north of the Passage. A detailed bathymetric survey shows that the width in the throat at the sill depth (4,800 m) is about 20 km. Three current meters in the throat (for 5-10 days) measured a northerly-flowing current of about 10 cm/sec. Maximum speeds were 15 cm/sec. From these measurements a mean flow of 3-5 Sverdrups for the DWBC is estimated. Data from bottom photographs, piston cores, sparker and 3.5 kHz sub-bottom profiles indicate that the Passage is paved with manganese nodules and has undergone severe erosion during the late Tertiary. Disconformities, of up to 50 my, can be traced throughout the area surveyed. Late Paleocene overlain by Plio-Pleistocene sediment was cored in the axis of the throat at seven meters sub-bottom.

CARBONATE SEDIMENTATION AND ABYSSAL CIRCULATION IN THE SAMOAN PASSAGE

David A. Johnson, Charles D. Hollister and Peter F. Lonsdale

A detailed geological and geophysical survey was conducted within the Samoan Passage, a narrow (50 km width) topographic construction through which the northward-flowing Antarctic Bottom Water (AABW) passes before entering the deep basins of the North Pacific. A primary objective of the study was to examine the depositional record in and around this passage for evidence indicative of the intensity of bottom current flow through the passage during the Cenozoic. Observational techniques included seismic reflection profiling (sparker and 3.5 kHz), coring, sea floor photography, and measurements of bottom current velocities and bottom temperature profiles. Twenty-five sediment cores were obtained, which are up to 20 m in length and range in age from Paleocene to Recent. Many of the cores show striking alternations between highly calcareous ooze and unfossiliferous red clay within the Quaternary and Upper Tertiary portions of the sediment. These alternating lithologies probably reflect major pulsations in bottom current intensity which occurred in response to glacial-interglacial climatic fluctuations and variable rates of production of AABW during the late Cenozoic. Red clay sedimentation corresponds to periods of strong current flow and high rates of dissolution of calcareous microfossils. Carbonate sedimentation corresponds to periods during which abyssal circulation was weakened and AABW production was significantly decreased. The cores suggest that strong bottom current flow through the passage was initiated during the middle Tertiary.

RECENT PHOSPHORITE FORMATION ON THE CONTINENTAL SLOPE OFF PERU

Gilbert T. Rowe, Frank T. Manheim[1] and Dan C. Jipa[2]

One of the most intensely productive areas in the world's oceans is located in the upwelling areas off the Peruvian coast. Beneath the upwelling zone a band of phosphate-rich sediments has been investigated. The sediments are chiefly diatomaceous, organic-rich muds, but contain complete sequences of phosphatized Holocene Foraminifera, such as *Uvigerina striata, Bolivina plicata* and *Cassidulina auka.* Figure 1 shows examples of phosphatization of *Bolivina plicata* ranging from virtually fresh specimens, to complete replacement of the test by carbonate fluorapatite. The sediments occur in the upper slope regions from about 1000 m depth, coincident with both an oxygen minimum ($\leq$ .2 ml/l) and pH minimum (7.4) zone in the water column. There are no rock fragments or other evidences of reworking or dissolution and recementation of pre-existing phosphorite deposits. The phosphorite is apparently formed by the action of phosphate-enriched pore fluids on carbonate tests of benthonic Foraminifera.

The key ingredients for phosphorite formation appear to be: low supply of terrigenous detritus, high organic productivity, and limited (not abundant) supply of carbonate debris to act as nucleation sites and sources of calcium and carbonate. Sea water supplies fluorine and uranium (commonly enriched in phosphorites), as well as its normal component of calcium.

GEOLOGY OF THE BRAZILIAN CONTINENTAL MARGIN

John D. Milliman

The Brazilian continental margin occupies the longest continuous north-south coastline in the world (4°N - 34°S), and yet it is relatively unstudied, both in terms of its morphology and structure and its sediment distribution. In order to gain a better picture of the potential resources on its shelf as well as to train some of its scientists in marine geology, Petroleo Brasileiro (PETROBRAS) signed a contract with the Woods Hole Oceanographic Institution this past January to begin a systematic study of the Brazilian continental margin. This study will also involve personnel from other exploration firms, governmental agencies and universities in Brazil, and hopefully will extend until at least 1976. Present plans call for PETROBRAS to support fully the near-shore phase of the study and International Decade of Ocean Exploration (IDOE) to support the following offshore phase, beginning in 1974.

The first phase of the program involved acquisition of preexisting data on the morphology, sediments, oceanography and structure of the Brazilian margin. These data were presented as a part of

1. U.S.Geological Survay.
2. Institutul Geologic, Bucharest, Romania.

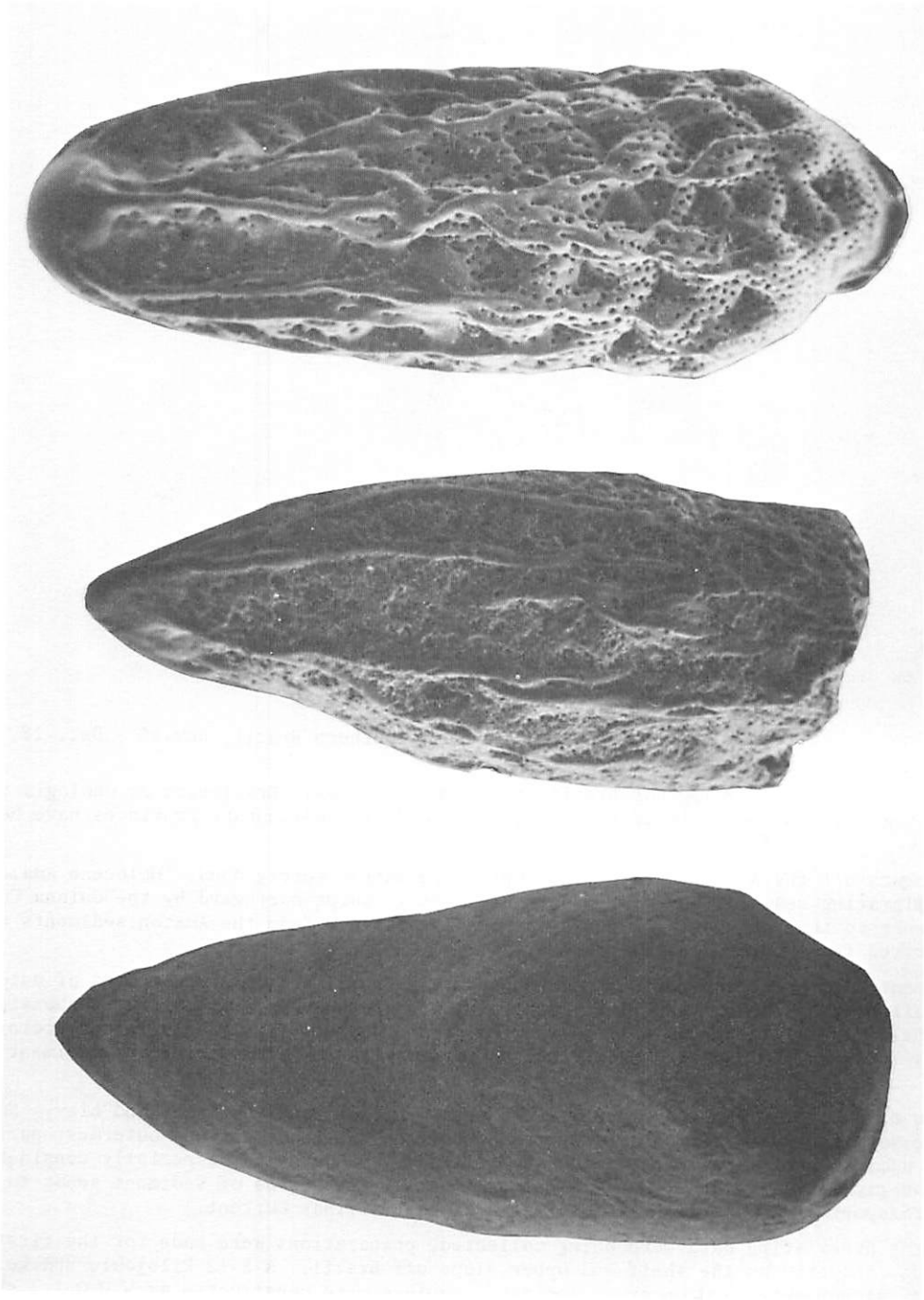

Fig.4 (Rowe,Manheim and Jipa) Microphotographs of *Bolivina plicata* ranging from nearly fresh, partly phosphatized and completely phosphatized specimens from a depth of about 1000 m off Callao, Peru.

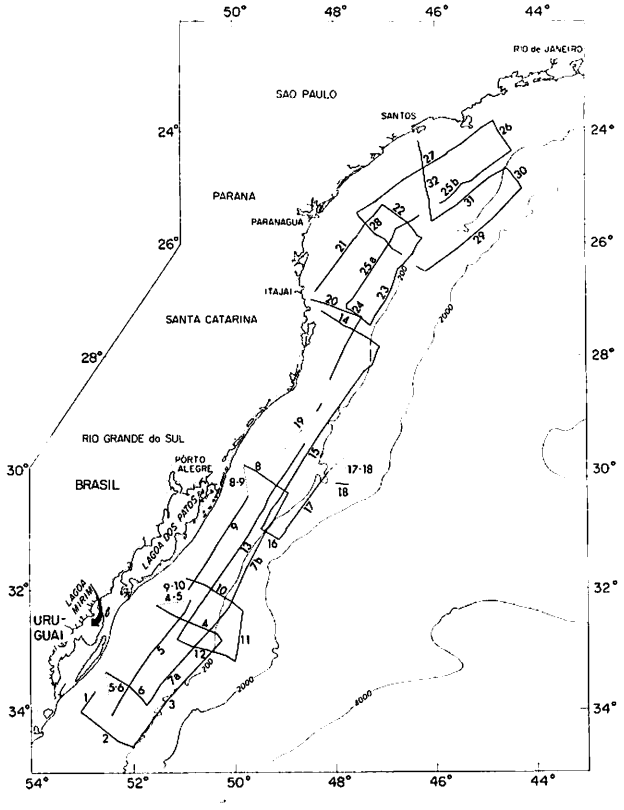

Fig.5 (Milliman) Location of siesmic profile lines off Southern Brazil, Nov.15 - Dec. 18, 1972.

a symposium on the marine geology of Brazil at the 26th Congresso Brasileiro de Geologia in Belem this past November. On the basis of these data, three broad sedimentary provinces have been recognized:

1) Sediments off the Amazon-Para River complex are mainly terrigenous. Holocene Amazon muds are slowly migrating seaward, but most modern sediment is swept northward by the Guiana Current. Shelf sediments to the southeast are petrographically distinct from the Amazon sediments and probably were derived from nearby coastal plain areas.

2) Sediments off northern, northeastern and eastern Brazil are mainly composed of calcium carbonate, coralline algae being the primary contributor. The abundance of calcium carbonate is the result of small fluvial influx as well as tropical temperatures. It is only in the vicinity of major rivers (such as the Doce and São Francisco rivers) that modern terrigenous sediment is deposited.

3) South of Cabo Frio shelf sediments are composed predominantly of silt and clay. Sands, which characterize so many shelf sediments, are present only on the innermost and outermost parts of the shelf. The dominance of this detrital mud is difficult to understand, especially considering the lack of major rivers in the area. At present the most likely source of sediment seems to be the northward transport of Rio de la Plata sediments by the Malvinas Current.

While the preexisting data were being collected, preparations were made for the first series of cruises to be conducted on the shelf and upper slope off Brazil. A 8-12 kilojoule sparker, 3.5 kHz echo sounder, magnetometer and underway sediment samplers were constructed at W.H.O.I., shipped to Brazil, and installed on the N/Oc. *Prof. W. Besnard*, a 165-ft. oceanographic vessel from the University of Sao Paulo.

The first cruise (November 15 - December 18, 1972) covered the shelf and upper slope of southern Brazil (Fig.5). A total of 4500 miles of track were covered, including 3500 miles of geophysical measurements; numerous sediment samples and suspended matter samples were collected in addition to hourly measurements of the temperature and salinity of the surface waters (Fig.6).

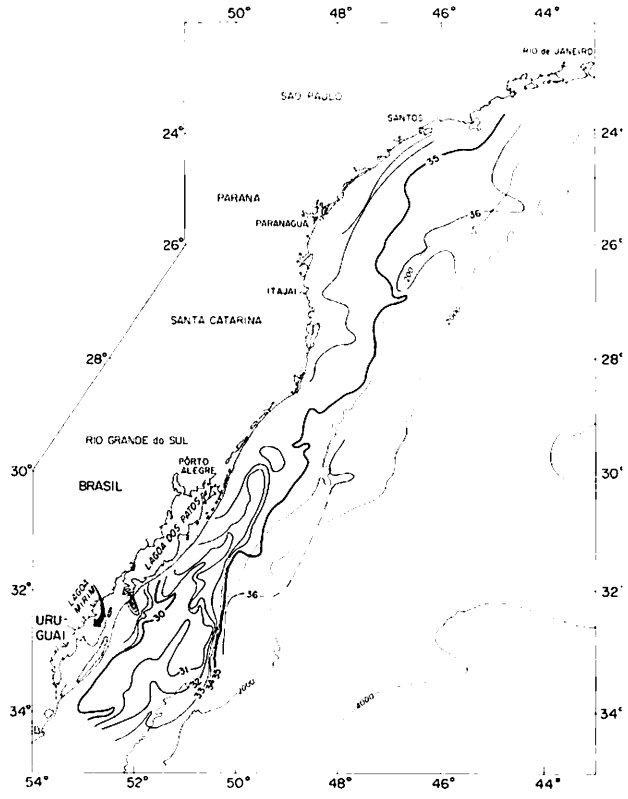

Fig.6 (Milliman) Distribution of salinity values in surface water of Southern Brazil, Nov.15 - Dec.18, 1972. The plume of low-salinity waters to the south is indicative of the Rio de la Plata water transported northward by the Malvinas Current.

Preliminary data interpretation indicates that the southern Brazilian shelf is underlain by two major sedimentary basins, separated from one another by a prominent structural high. Several interbasin arches also have been defined. These interbasin arches appear to provide likely structural traps for the accumulation of oil.

ABYSSAL CIRCULATION AND ITS ROLE IN SEDIMENTATION ON THE GREATER ANTILLES OUTER RIDGE

Brian E. Tucholke, W. Redwood Wright and Charles D. Hollister

Data obtained from hydrographic stations, current measurements of four to six month duration, and bottom photographs are used to infer the pattern of abyssal circulation in the vicinity of the Greater Antilles Outer Ridge north of Puerto Rico. A deep contour-following current of Antarctic Bottom Water with a small admixture of North Atlantic Deep Water flows southeast along the Bahama Banks, counterclockwise around the Silver Abyssal Plain, clockwise around the northwest end of the Greater Antilles Outer Ridge and then eastward along the north flank of the ridge.

The Antarctic Bottom Water enters the basin through Vema Gap, flows counterclockwise around the Hatteras Abyssal Plain and then south along the continental rise into the region of the Greater Antilles Outer Ridge as a deep extension of the Western Boundary Undercurrent.

The deep circulation pattern may provide a mechanism by which terrigenous detritus from the continental margin has been transported to the southeast and deposited to form the thick accumulation of sediment on the Greater Antilles Outer Ridge.

DEEP CIRCULATION AND SEDIMENTATION NORTH OF PUERTO RICO

Brian E. Tucholke, Charles D. Hollister and John I. Ewing

A study of deep hydrographic stations, bottom photographs and six-month current meter records from the Greater Antilles Outer Ridge shows that a contour-following current flows around this deep (> 5,100 m) submarine feature as part of an overall west-to-east circulation pattern. Current speeds up to 20 cm/sec and averaging 5-10 cm/sec were recorded on the northwest section of the ridge. Suspended matter samples show sediment concentrations up to 65 µg/l in the current at the level of the crest and flanks of the ridge and much less (10-20 µg/l) above and below these depths. Thick accumulations (up to 1.0 km) of homogeneous, acoustically transparent sediment blanket the western section beneath zones where shear between opposing currents should cause preferential deposition of suspended sediment. Lesser thicknesses occur on the ridge to the east beneath currents flowing dominantly to the southeast. Minimum sedimentation rates are 1.4 cm/1000 yr. Continuous seismic profiles and data from the Deep Sea Drilling Project indicate the "transparent layer" began to accumulate in late Eocene time. This is nearly coincident with the time when downslope sedimentation to this area from Puerto Rico was terminated by the formation of the Puerto Rico Trench. The deep southward circulation along the western side of the North Atlantic basin was also probably initiated near this time by the introduction of cold, dense water from the newly-formed Norwegian Sea, thus providing a mechanism to transport sediment from the continental margin of eastern North America to the Outer Ridge. This data, together with subbottom profiles showing migrating "dunes" on the ridge, supports a model of current-controlled deposition for the area.

SEA FLOOR ROCKS AND SEDIMENTS

David A. Ross

Continental Slope and Rise Studies.

An 18-day cruise was made aboard *Atlantis II* in late October-November to three areas off the east coast of the United States. In the first area, on the continental slope south of Martha's Vineyard, we made a geological survey using a 10-inch air gun, 3.5 kHz echo-sounder, a towed magnetometer, and an occasional sonobuoy. We sometimes interrupted the survey to take piston cores (sometimes with a core-head camera), bottom photographs, and water samples. Our objectives were to ascertain mechanisms and effects of bottom sedimentary processes. This area had been visited previously by *Alcoa Seaprobe* and includes the Alvin bottom station. The survey showed a series of small gullies and occasionally larger features, including Alvin Canyon, extending normal to the continental slope. At the base of the slope, a scarp at least 40 miles long was mapped.

Area 2 was off Cape Hatteras; here we made a geophysical traverse (air gun, echo-sounder, and magnetometer) and took piston cores (with core-head cameras) and bottom photographs along the track. Our objectives here were to evaluate the relative sedimentological effects of the northeasterly-flowing Gulf Stream and the deep Western Boundary Undercurrent. Bottom photographs showed current-made features, but evaluation of the effects of the two currents awaits mineralogical analysis of the sediments.

Area 3 was in the lower continental rise hill area. Our geological survey showed the "hills" to be linear features parallel to the slope of the continental rise. Seismic profiles of the area strongly suggest a fault and slump origin for the "hills" rather than being due to bottom currents as suggested by some.

SEDIMENTARY PROCESSES ON THE CONTINENTAL SLOPE OF NEW ENGLAND

Joseph C. MacIlvaine

Parts of six cruises have been used to conduct an intensive study of sedimentary processes on the continental slope off New England. The objective of this work is to combine enough complementary types of data to obtain a reasonably complete perception of the sedimentary environment of a limited area of the sea floor. Processes of interest range from the continuous action of bottom currents and animals to the occasional events of slumping and turbidity currents. On the continental slope each of these processes is important, and the problem is to determine how they combine to control sedimentation, form of the slope, and transport of material into the deep sea. The most revealing information has come from a variety of techniques, including current measurement, experimental erosion of undisturbed sediment, seismic and 3.5 kHz profiling, bottom photography, and direct observation and mapping from *Alvin*.

RIFT STRUCTURES OF THE GULF OF MAINE

Elazar Uchupi and Robert D. Ballard

In May and July of 1972 the R/V *Gosnold* made two ten-day cruises to the western Gulf of Maine to obtain information as to the nature of the tectonic setting of the region. Over 2000 km of continuous seismic and magnetic profiles were obtained along the western end of the Fundy fault and in the Murray-Wilkinson Basin complex. In addition, about 30 sonobuoys were used to determine the compressive velocities of the pre-Carboniferous rocks and the sediments filling the Mesozoic tensional basins. Preliminary studies of the geophysical data indicate that the western Gulf of Maine is dominated by narrow northwest trending fault basins of probable Mesozoic age. These structures appear to terminate against the northeast trending Fundy fault toward the northwest, and the northeast trending Acadian-Georges Triassic basins to the east. During the July cruise the submersible *Alvin* was used to sample the pre-Carboniferous rocks along the edges of the rift structures and along the Fundy fault. Rocks exposed along the edges of the rift structures are primarily granodiorites and quartzdiorites, whereas basic intrusive and extrusive rocks predominate along the Fundy fault.

LATE PLEISTOCENE AND HOLOCENE SEDIMENTATION IN THE WESTERN GULF OF MAINE

Brian E. Tucholke and Charles D. Hollister

Sediment analyses and C^{14} dates on cores, together with low frequency (1.4 and 3.5 kHz) subbottom profiles, indicate that the late Wisconsin glacial advance occurred about 18,900 years B.P. off Boston and that a lodgment till was deposited beneath the ice in the present marine basins. During deglaciation, deposition of initial coarse detritus was followed closely by rapid basin sedimentation ($>$ 6 m per ky) from glaciofluvial outwash. Crustal depression of at least 50 m resulted from ice loading, allowing marine transgression and glacial degrounding about 14,500 ybp in Stellwagen Basin. Since that time glacial ice has not grounded in the basin, suggesting the Cambridge-Middleton readvance (about 13-14,000 ybp) was of minor extent. A brief episode of rapid basin sedimentation followed this event, but rates of deposition soon decreased and material reworked from shallower areas became the dominant sediment source. The persistence of frigid marine water until at least 13,000 ybp is indicated by the stratigraphic distribution of the cold water pelecypod *Yoldia arctica*. Cores show strong episodic redistribution of silt-to-sand size sediment into the basins during the past 7,000 years. Recent sedimentation rates are a few centimeters per thousand years.

GEOTECHNICAL PROPERTIES OF OCEAN SEDIMENTS RECOVERED WITH GIANT PISTON-CORER: I - GULF OF MAINE

Armand J. Silva and Charles D. Hollister

A large diameter (14 cm) long piston corer (20-40 m) has been used successfully to obtain relatively undisturbed sediment samples in water depths from 100 to 5,000 meters. Recovery ratios range between 0.76 and 0.87. Calculated and measured coring behavior characteristics show that the corer accelerates during most of the penetration and that maximum deceleration forces occur only near the later stages of coring.

The first recovered core (KN-10-1) was taken in the Stellwagen Basin, Western Gulf of Maine at 81 meters water depth using a pipe length of 33.5 meters and total core weight of 3,500 kg. The 21.74 meters of recovered sediment is black, gray to olive green silty illitic clay with a significant increase in clay content below 13 meters. Visual observations and results of consolidation studies indicate that structural disturbance to the sediments was not severe, that it is normally consolidated and that no post-depositional compaction occurred. Another core (KN-27-1) was taken about 3 km east of the first core location and 19.65 meters of sediment were recovered.

An anomalous zone in core KN-10-1 at 13.0 - 14.5 meters reveals high water content (96%) and high shear strength (260 gm/cm^2). A marked abundance of diatoms may explain the water content and the highly flocculated nature of the abundant clay minerals observed with a scanning electron microscope accounts for the high shear strength. A similar anomalous zone in core KN-27-1 occurs at 16.4 - 19.0 meters where the water content is 53% and shear strength is about 250 gm/cm^2. Preliminary correlations with the 3.5 kHz sub-bottom profiles suggest that changes in both texture and water content may produce reflecting horizons.

PROJECT FAMOUS

James R. Heirtzler, Joseph D. Phillips,
Wilfred B. Bryan and William O. Rainnie

A French-American Mid-Ocean Undersea Study (FAMOUS) was initiated in late 1971. This project has the primary objective of making a detailed study of the rift valley at the axis of the Mid-Atlantic Ridge south of the Azores to determine how new earth crust is formed on the sea floor. Bathymetric, geological and geophysical mapping will be undertaken by various surface ships, deep-towed instruments, bottom-mounted instruments and manned submersibles.

Although cruises by French and American (*Atlantis II*) ships in 1972 have already made the FAMOUS area one of the best known sections of the submerged Mid-Atlantic Ridge more work must be done. Activities have included numerous dredges, extensive photographic coverage, earthquake seismic, magnetic and wide and narrow beam bathymetric surveys all with navigational techniques accurate to a few tens to a few hundreds of meters.

During the year meetings were held in Brest, France, between the French and American organizing groups to plan 1973 work. Along with additional details surveys in 1973 by American, French, English, and Russian ships the French will make a first submersible dive at the location in the summer of 1973. During 1972 training dives were made in the Mediterranean Sea and in the Gulf of Maine. The American dive team has members from several institutions in the United States and Canada.

QUATERNARY SEDIMENTATION ON THE NORTHWEST AFRICAN CONTINENTAL RISE

Robert A. Young and Charles D. Hollister

Quaternary sediments from the northwest African continental rise were analyzed to determine if changes in sediment provenance had occurred relative to glacial-climatic fluctuations on the adjacent continent.

The upper 10 meters of sediment are generally moderately burrowed, tan to cream colored, nannoplankton-foraminiferal lutites, occasionally interbedded with silty sands. Sands were composed of foraminiferal remains, some terrigenous minerals (mainly quartz) and volcanic debris. Some intervals were graded or cross-bedded suggesting emplacement by turbidity currents. Sedimentation rates (based on radiocarbon dating) were calculated to be about 2 cm/10^3 yr during the last 27,000 years.

The clay mineral assemblage consists mainly of illite and montmorillonite with subsidiary kaolinite and traces of chlorite. Detailed analysis of the clay mineral fraction failed to show any correlations between abundance of clay minerals and climatic cycles during the Pleistocene. Montmorillonites are probably derived mainly from diagenesis of volcanic debris. Kaolinite, and chlorite are inferred to be of eolian origin as are the iron stained quartz-silts.

A comparison was made between Quaternary sedimentation on the northwest African continental rise and on the relatively well-studied eastern North American continental rise. High terrigenous input during the Quaternary has probably been responsible for the numerous sand and silt layers (mainly

turbidites) found in cores taken on the North American continental rise. These layers are typically seen as well-defined, parallel, sub-bottom reflectors and lenticular-shaped bodies in the upper 20-40 fm on 3.5 kHz profiles. By contrast, 3.5 kHz profiles taken on the northwest African continental rise show a transparent layer 10-15 fm thick overlain by 5-10 fm of moderately reflective sediments below the sediment-water interface. In some areas sediments below the sea floor were acoustically transparent. Low sedimentation rates and high pelagic carbonate content of African continental rise sediments may be responsible for the observed differences in 3.5 kHz profiles compared to the North American continental rise.

EASTERN ATLANTIC CONTINENTAL MARGIN

Kenneth O. Emery and Elazar Uchupi

Part I of the International Decade of Ocean Exploration program on Eastern Atlantic Continental Margin was completed during 1972. During the first half of that year seismic reflection, gravity, and magnetic profiles were made along most of the 50,000 line-km traversed by R/V *Atlantis II* from Cape Francis (South Africa) to Luanda (Angola). At the same time data were obtained on surface water temperature, salinity, color, and suspended matter. Chief scientists were K. O. Emery, E. Uchupi, and J. D. Milliman. In charge of instrumentation were K. E. Prada, W. D. Nichols, E. M. Young, W. E. Witzell, D. E. Koelsch, R. C. Groman, A. B. Baggeroer and Hartley Hoskins. Also participating were many others from W.H.O.I. and from eight nations besides the United States. The cruise was the first one to use a newly-designed digital system for seismic reflection profiling. Five computers aboard ship permitted onboard analysis and compilation of charts that show many different geophysical parameters.

During the seven cruise legs, five profiles were extended from the inner continental shelf to the Mid-Atlantic Ridge, 20 others extended from the inner shelf to the mid-continental rise, and many others crossed most of the shelf width. Two fracture zones were investigated for azimuth and displacement, several new seamounts were found, a large submerged ancient delta of the Orange River was mapped, a belt of diapirs off Angola was investigated, and the topography and other characteristics of the Congo Submarine Canyon was studied. The main economic advantage for adjacent African nations is the oil potential of the large mass of sediments in the ancient delta and of the sediments that have been trapped and disturbed by the uplift of diapirs farther north. Results of the work are being transmitted as soon as possible to African and other interested countries, organizations, and scientists in the form of profiles and charts so that they can be used even where computers are not available for processing digital tapes.

Preparations for the second cruise, between the Congo Canyon and Lisbon, have largely been completed. Improvements that have been made in methods of removing multiple bottom reflections and stacking give promise of even better seismic results than those of 1972. Participants from about 20 nations of Africa, South America, and Europe are expected during the seven legs of the forthcoming cruise.

GEOTHERMAL INVESTIGATIONS IN OCEANIC REGIONS

Richard P. Von Herzen and Albert J. Erickson

Field programs were carried out in three separate regions in 1972. Heat-flow measurements were attempted aboard a National Oceanic and Atmospheric Administration (NOAA) vessel (R/V *Oceanographer*) in a limited region of the North Atlantic near the Antilles Islands. Unfortunately, due to instrumental problems, only a few of the measurement attempts were successful.

A major effort centered on the Galapagos Ridge and the East Pacific on Legs 7 and 8 of the Scripps Institution of Oceanography (S.I.O.) South Tow Expedition. On Leg 7, approximately 140 measurements were made near the Galapagos Ridge by ourselves and a team from S.I.O. Also two lateral profiles of near-bottom ($\leq$ 20 m height) water temperatures several kilometers in length were obtained. Many of the measurements are precisely located with bottom transponders tied to Deep Tow surveys near the ridge crest on the previous leg. Measured values range from near zero to 30 $\mu cal/cm^2 sec$, with a significant modulation of values over a wavelength of several kilometers. On Leg 8, approximately 56 heat-flow values were obtained over a long profile across the East Pacific Rise from Callao, Peru to Tahiti.

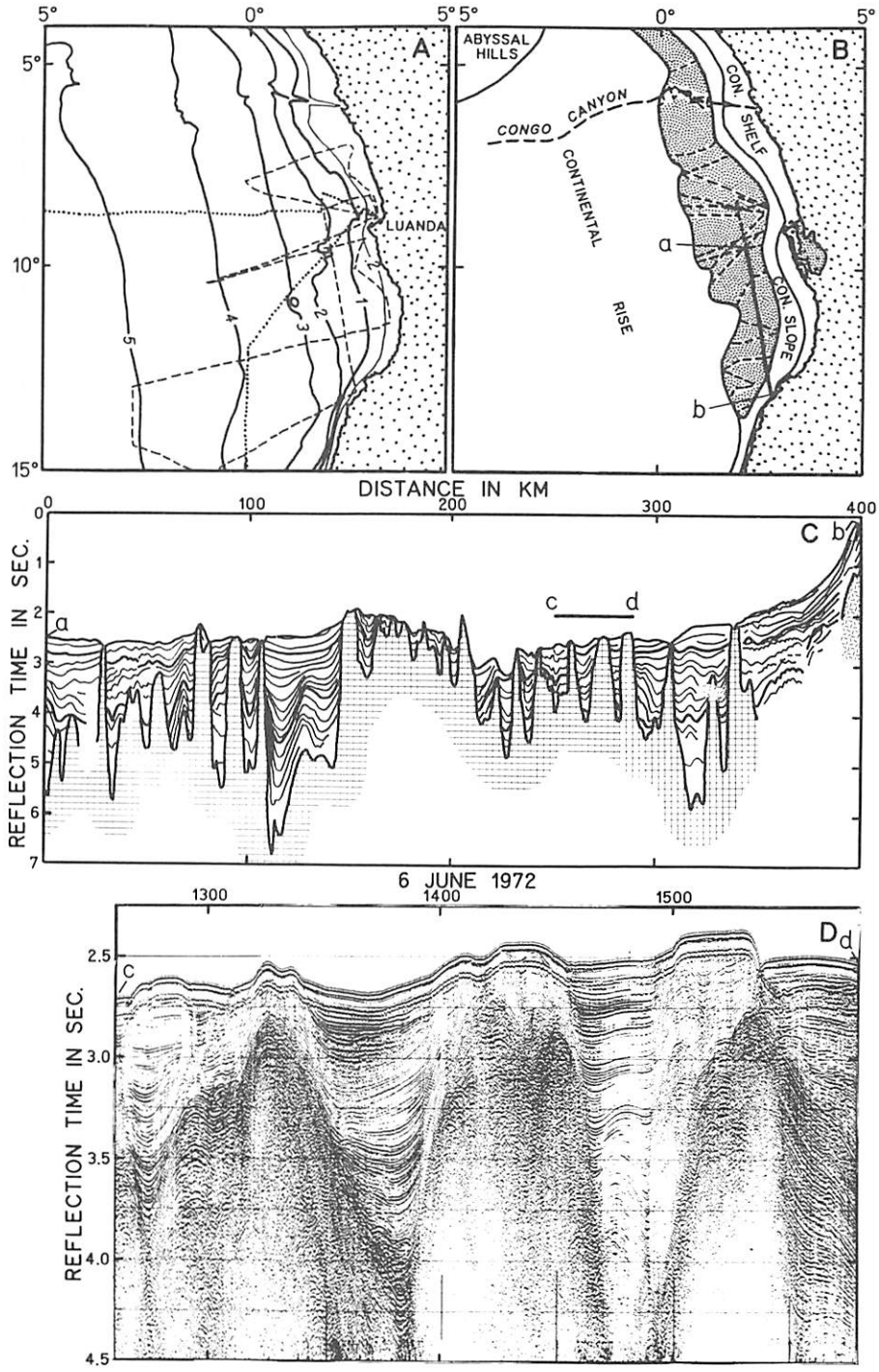

Fig.7 (Emery and Uchupi) Belt of diapirs off Angola. The diapirs are believed to consist of Early Cretaceous salt deformed by the weight of overlying sediments. Profiles to be made during 1973 should determine how much farther north the belt extends.

On *Atlantis II* Cruise #73 to the Mid-Atlantic Ridge south of the Azores Islands, approximately 10 near-bottom water temperature profiles several kilometers in length were made in the axial valley of the ridge and a transform fault. Bottom photographs were made simultaneously with the temperature measurements, and most of the profile lines are precisely positioned from bottom transponders.

Valuable assistance in the field programs was provided by K. von der Heydt, D. Williams, and M. Hobart. During 1972, several papers were published from investigations of previous years.

GRAVITY INVESTIGATIONS

Carl O. Bowin

Field programs included measurements aboard the R/V *Atlantis II* during Cruise #67 to the continental margin of southwest Africa and Cruise #73 to the Mid-Atlantic Ridge near 36°30'N latitude, and aboard the Japanese research vessel *Hakuho Maru* of the Ocean Research Institute, University of Tokyo as part of a United States/Japan cooperative program. Gravity and magnetic measurements were conducted on two cruises of the *Hakuho Maru* this year. One, to the Phillipine, Sulu, Celebes, and South China Seas, and the other to the region of the Ryukyu Island Arc.

The most notable discovery was the finding (in collaboration with Zvi Ben-Avraham of the WHOI/MIT Joint Program and Jiro Segawa of the Ocean Research Institute, University of Tokyo) of an extinct spreading center in the western Philippine Sea during the first cooperative program cruise on the *Hakuho Maru*. The ridge, called the Philippine Ridge, runs 1,500 km from the Palau-Kyushu Ridge towards the southern edge of the Ryukyu Trench along a strike of N 50°W and is located at the site of what had previously been thought to be a major fault zone. The general topography and dimensions - the rift valley, for example, has a relief of 2 km and width of 25 km - resemble those of the Mid-Atlantic Ridge, except that its average depth is greater by about 2 km and the relief from edge to crest is reduced. Magnetic profiles over this extinct spreading ridge reveal almost perfectly symmetry of anomalies about its axis. Also, individual anomalies have a symmetric shape which indicates that the ridge could not have been formed at either its present location or orientation. Either an original azimuth of about N 10°W or a change in latitude closer to the equator would produce the symmetric magnetic anomalies. A northward movement of the Philippine Basin by about 800 km is the preferred explanation. A comparison of the elevation of the Philippine Ridge with empirical depth/age plots determined from active spreading ridges suggests an age of about 58 m.y. for the ridge crest. The depths of the flanks are greater than those found on the flanks of the studied active ridges and thus most likely the 58 m.y. age is a minimum age. The magnetic anomalies do not appear to correlate with known Cenozoic magnetic reversal patterns and hence are thought to have formed in the Mesozoic.

The gravity signature of the Philippine Basin is also similar to that of the Mid-Atlantic Ridge. The free-air gravity anomalies are very near zero; at the central rift valley a maximum value of +42 mgal (and a maximum peak-to-peak relief of 57 mgal) is observed. Elsewhere the anomalies are generally 0 to +15 mgal. The anomalies are slightly more positive in the crestal region than on the flanks as is common for active spreading ridges of the world. Here, however, a shallow free-air minimum is found about 300 km from the crest on the north side, and about 150 km from the crest on the south side. Both these free-air minima are correlated with depressions in the average depth of the flank topography, and the averaged Bouguer anomaly profile shows no associated perturbation. It may be that the ridge has subsided and in so doing the crestal material has acted as a load and slightly depressed the bordering portions of the crust.

The regional Bouguer anomaly gradient at the crest is 0.37 mgal km^{-1} diminishing to 0.17 mgal km^{-1} at about 120 km distance. These values are less than those normally observed at similar distances from the crest of the Mid-Atlantic, and probably indicate that the zone of compensation has both deepened and become less steeply dipping away from the crest as the crest has subsided following cessation of spreading.

The most striking feature of the free-air gravity anomaly field over the continental margin of southwest Africa is the general absence of large anomalies. Over the greater part of the area studied the values lie within 25 mgals of zero, and hence most of the area is in isostatic equilibrium. A large delta occurs on the continental rise off the Orange River. Gravity anomalies suggest that the outer portion of the delta is close to being in isostatic equilibrium whereas positive free-air anomalies higher up the delta indicate that the thickness of sediments there is not completely in isostatic equilibrium, and may be the result of recent sedimentation. Positive anomalies over the Walvis Ridge

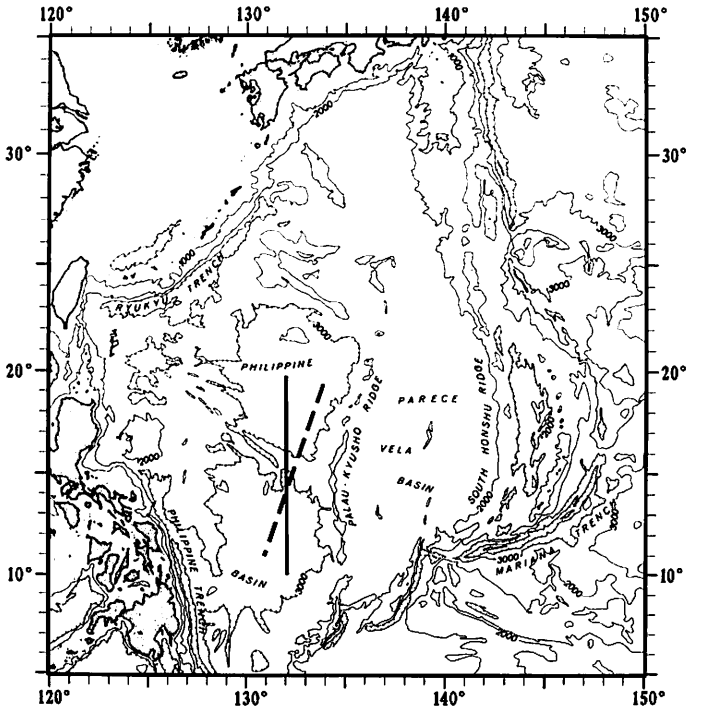

Fig.8 (Bowin) Simplified bathymetric map of the Philippine Sea. Contour interval every 1000 fathoms. Based on Chase and Menard (1969). Heavy line indicates the position of the profile taken by R/V *Hakuho Maru* and heavy-dashed line the position of a profile taken by R/V *Umitaka Maru* in 1963.

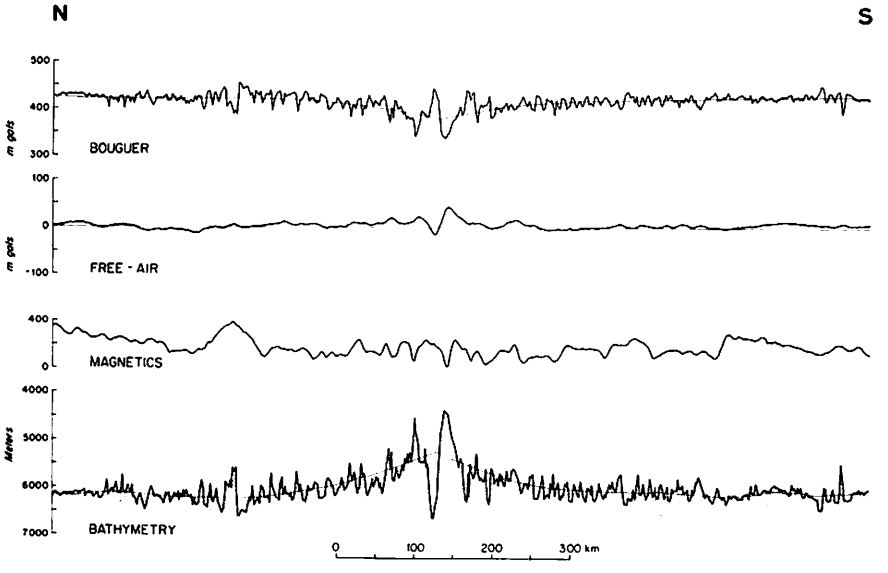

Fig.9 (Bowin) Bathymetry magnetics and gravity profile taken by R/V *Hakuho Maru*. The position of the profile shown in Fig.8.

and Agulas Plateau are inferred to be largely the result of the indirect effect. Negative anomalies on the shelf appear to locate two basins which had not been defined previously by seismic investigations. The free-air anomaly low north of Capetown is inferred to be caused by a basin of deformed sediments of Cretaceous to lower Tertiary age. The second low occurs on the shelf south of South Africa and does not appear to have been previously recognized. It is inferred to indicate the occurrence of a basin of sedimentary rocks. This basin is elongated in a northeast-southwest direction and may be related to the development of the South African fracture zone found to the south.

The pronounced difference in the width of the continental to oceanic crust transition between the western and southern coasts of South Africa, as indicated by both the topography and Bouguer gravity anomaly, is probably owing to a difference in origin of the two continental margins. That off the western coast was probably formed through sea-floor spreading with gradual thinning of the crust and then rifting as the continents of Africa and South America separated. The margin to the south, on the other hand, appears to be related to transcurrent faulting along the South African fracture zone and related fractures which has resulted in a much steeper continental slope and rise than along the western margin.

In addition to the continental margin area of southwest Africa, we have completed compilations of free-air and Bouguer gravity anomaly maps for Indonesia and the Caribbean region. These two regions have a variety of structural and gravity features, and have a complex history of development. Both areas have zones of crustal consumption and island arcs with active volcanoes and high seismicity. We have constructed a detailed structure model across the Lesser Antillean Arc in the Caribbean 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. In particular, to answer the question whether or not the downgoing lithosphere is sinking under its own weight (*i.e.*, a heavy sinker of Morgan). The answer obtained to that question is, perhaps yes locally, but that overall there is a mass deficiency associated with that site of underthrusting. Where the denser lithosphere has displaced lower density asthenosphere it may be sinking, but above that level the downthrust lithosphere appears to result in a mass deficiency rather than a mass excess. This study argues that there is a vertical density gradient in the mantle of the lithosphere and that the downward displacement of the lithosphere during underthrusting results in the mass deficiency just mentioned to occur above the asthenosphere. These hypotheses offer an explanation for the vertical motions that appear to occur at island arcs following cessation of underthrusting which are different than that which would be expected from a traditional view of the mass distribution beneath island arcs.

In the eastern Indian Ocean, a portion of the Ninetyeast Ridge near the equator was examined in 1971 using seismic profiling, gravity and magnetic observations. In the area examined, the topography of the ridge consists of en echelon mountainous masses. A fracture zone trending north-south parallel to the overall trend was found along the eastern margin of the en-echelon topography. This fracture zone probably marks the principal site of dislocation between the Central Indian Ocean plate and the Wharton Basin plate. The free-air gravity anomalies associated with the Ninetyeast Ridge are small and thus the mass of the ridge must in some way be compensated at depth. The Ninetyeast Ridge is inferred to have originated as a result of emplacement of gabbro and serpentinized peridotite beneath normal oceanic crustal layers. The lower density of the gabbro and serpentinized peridotite than of normal mantle at equivalent depths provides for both the uplift of the ridge and its compensation at depth.

Our vibrating string accelerometer (VSA) gravity meter systems have continued to operate with good results. Additional testing has revealed sensitivities to electrical loading and changes in ambient temperature that appear to have been the cause of certain peculiarities in performance. These situations have been rectified. We have also made considerable advance in our ability to manage and utilize the reasonable large gravity library we have in digital form.

An investigation into the possibility of developing a continuous operational gravity meter system for use in the submersible *Alvin* has been discontinued. Although a miniature portable vertically-stabilized gravity meter and navigation system is technically feasible, its cost would be great.

We are also engaged in the study of the gravity field of the moon. The gravity data are obtained by the Manned Spacecraft Center from earth-based Doppler tracking of space vehicles during lunar missions. We are investigating the relationship between the morphological features of the lunar surface and the perturbations of the gravity field in order to help define the crustal structure of the moon and the degree of isostatic equilibrium of its major features.

GEOMAGNETISM

Joseph D. Phillips

Our main research effort during 1972 has concerned analysis of aeromagnetic data collected aboard the United States Naval Research Laboratory's C121 aircraft over the Oceanographer Fracture Zone, analysis of narrow-beam bathymetry, seismic and magnetic data in the FAMOUS region of the Mid-Atlantic Ridge near 36°N, a new aeromagnetic study over the Greenland Sea using a Fleet P3C aircraft as part of a joint Woods Hole Oceanographic Institution/Naval Research Laboratory ocean ridge study program. In addition a detailed study of the Mid-Atlantic Ridge crest near 36°30'N aboard R/V *Atlantis II* (Cruise 73) was completed. These programs together with other laboratory investigations involving personnel from the geomagnetics group are summarized below.

a) The W.H.O.I./N.R.L. aeromagnetic study was conducted during late 1971 over the Oceanographer Fracture Zone on the Mid-Atlantic Ridge between 33° - 37°N and 31° - 39°W. Analysis of these data was completed in 1972. A seafloor spreading interpretation of the magnetic anomalies reveals the ridge crest to be formed of several short, en echelon segments 40-60 km long, each trending about N 15°E. These segments are offset 15-20 km by five transform faults oriented N 80°W in addition to the well-known 100 km offset along the Oceanographer Fracture. A spreading rate of 1.3 cm/yr over the last 10 million years can be fitted to the ridge crest anomalies. Application of plate tectonics theory to account for the anomaly and fracture zone pattern has allowed a new calculation of the rotation pole parameters for the North America - Africa plate systems. A finite rotation pole near 78°05'E with an angular rotation rate of 2.8×10^{-7} dg/yr over the last 10 million years is indicated. This compares well with previous determinations inferred from very widely-spaced fracture zone and magnetic trend information. (Work prepared by Phillips and Fleming.)

b) A detailed magnetic, seismic and narrow beam bathymetric study of the Mid-Atlantic Ridge over the Oceanographer Fracture Zone was made aboard U.S.N.S. *Hayes* during January and February 1972 as part of the joint Woods Hole/U.S.Naval Research Laboratory ocean ridge study. For this work Woods Hole provided a proton magnetometer and seismic profiling systems as well as two shipboard scientists. Analysis of these data is currently underway and is being incorporated with new data acquired in April 1972 with the multi-narrow beam echo scanning system of the U.S.N.S. *Dutton*. The region of this study was located within the area previously studied using the U.S. Naval Research Laboratory C121 aircraft near 36°N. Preliminary results of this shipboard program confirm the fracture zone position and spreading rate history made from the airborne studies. In fact, one additional fracture zone with an offset of five miles was detected. Four fracture zones were found to offset the ridge crest between 36° and 37°30'N. The axial trough was marked by a very narrow central cleft 0.5 km wide and 100 meters deep. At the intersection of each ridge crest (axial trough) segment with a transverse fracture zone deep holes were found. (Work prepared by Phillips, King and Fleming.)

c) Other analysis work was a statistical study of Deep Tow data collected in the northeast Pacific aboard R/V *Thomas Washington*. Deep magnetometer profiles over sea-floor spreading anomalies 9 and 10 were analyzed to determine their statistical similarity. Two 130-km long east-west profiles, separated by about 170 km along strike, were taken in the Gulf of Alaska. Off California, two 40-km long profiles were taken over anomaly 10 only, separated by 20 km. The short-wavelength, high-amplitude anomalies measured at depth were found to be statistically correlated in between the Gulf of Alaska profiles and in between the California profiles. Some visual correlations are possible between the California and Alaska profiles. The correlations over long distances suggest a common, but presently unknown cause. (Work prepared by Luyendyk.)

d) The primary field programs undertaken during 1972 were the aeromagnetic study of the Greenland Sea and Arctic Ocean between Greenland and Spitzbergen and the detailed shipboard study of the ridge crest south of the Azores near 36°30'S. For the former work we adapted the W.H.O.I. towed airborne magnetometer for use in the stinger of a fleet P3C Orion aircraft (VP-24). We also developed a flight control computer program to make optimum use of the high accuracy dual-inertial navigation system of the P3C, as well as writing various programs for extraction of navigation data from the aircraft's computer data acquisition system. The actual flight program is still in progress. Solar flares, aircraft maintenance problems and a 30-day visit limitation imposed by the Norwegian Government for military aircraft have delayed the flight schedule.

In spite of the delays encountered we can report significant new results from this year's work. Specifically, we have been able to infer the Mid-Atlantic Ridge crest position beneath the ice cover from 76°N to 83°N. It appears to be made up of numerous short en echelon spreading axes oriented N 20°E and offset 40-50 km by transform faults, between 78° - 82°N along the Attka Ridge which has a general trend of N 30°E here.

Another important result of the Greenland Sea work has been the precise charting of a large anomaly along the Greenland continental margin. It appears to have a shape and amplitude much like the slope anomaly off the North American East Coast. This Greenland anomaly may follow the continental shelf break. Heretofore the location of the Greenland shelf and the ridge crest was very poorly known beneath permanent ice cover and our airborne study has made a significant contribution to understanding the evolution of the Greenland Sea. (Work prepared by Phillips and Fleming.)

e) A detailed geological and geophysical investigation over the FAMOUS region of the Mid-Atlantic Ridge crest was carried out aboard *Atlantis II* Cruise 73 during November and December 1972. This program included underway magnetic, bathymetric and gravity profiling using radar transponder navigation. The region between 36°47'N - 36°30'N and 33°05'W - 33°40'W was covered with a one km or less line spacing. Two reversed seismic refraction profiles 15-18 km long were made parallel to the ridge crest across the ridge axis. SUSS charges were used for sound sources and signals were received on SSQ41 sonobuoys.

More detailed studies using seafloor acoustic transponder navigation were made at two sites within the larger study area, one over the median valley near 36°44'N and over the transform fracture zone near 36°32'N. The acoustic navigation system allowed precise location of both the surface ship and towed devices with a precision of about 20 meters. Eleven (11) near-bottom bathymetry/temperature and photography profiles up to eight kilometers long and ten (10) dredging stations were made using this system. Over 100 km of rock were recovered in the dredges.

In addition to the *Atlantis II* shipboard studies, preliminary efforts were undertaken in the FAMOUS area to assess the intensity and frequency of microearthquakes and the magnitude and direction of bottom currents. For the former work free floating SSQ-38 sonobuoys were deployed over the median valley and fracture zone regions. During a total recording period of 15 days two earthquakes were observed, both in the fracture zone region. The bottom current studies involved the deployment of Reid-type meters moored for one-day periods about three meters above the bottom at five sites. At two of the sites, on a peak (500 fms depth) west of the ridge and in the narrow trough of median valley (1320 fms depth), currents as high as 0.3 kts were observed. At the other three sites which were located along the walls of the median valley and in the broad floor of the valley near the fracture zone intersection currents were less than 0.05 kts. (Work prepared by Phillips, Bryan, and Erickson).

f) Recent analysis of data collected during *Chain* Cruise 100 near New Guinea indicates that seafloor spreading may be occurring in the Woodlark Basin portion of the Solomon Sea. The basin is characterized by: (1) an east-west lineation of shallow focus earthquakes, (2) extremely rugged bathymetry with an east-west grain and a central ridge structure, (3) lack of sediment in the central portion, (4) grabens and regional block faulting in the Louisiade Archipelago and Woodlark Rise indicating north-south tension, (5) east-west magnetic lineations, and (6) above-normal heat flow as indicated by scattered measurements. In addition, fresh tholeitic basalt has been dredged near the postulated site of spreading. Correlation of magnetic anomalies is somewhat speculative, but suggests a spreading rate of 2.0 to 2.5 cm/yr. Based on the basin width, spreading may have continued here for three my. (Work prepared by Luyendyk, Bryan, MacDonald.)

g) An investigation of available magnetic data from the South China Sea was also completed this year as part of a broader geophysical study of the region. These results showed the central part of the sea to be characterized by east-west trending magnetic anomalies asymmetrical about a line extending along 15°N latitude. The north and south boundaries of the sea are delineated by smooth magnetic zones. This information coupled with seismic profile data showing north-south trending basement ridges (fracture zones?) suggest that the South China Sea may have formed as a result of Borneo drifting southward away from China. The Vietnam continental margin is inferred to be a strike-slip feature. Thus, the opening of the sea is explained by the rotation of a small plate which includes Borneo about a pole near 13°N, 44°E. (Work prepared by Ben-Avraham and Phillips.)

h) A global compilation of magnetic smooth zones has been made to determine their possible modes of formation. No single origin appears satisfactory, but rather three generic origins were considered: 1) those zones resulting from sea-floor spreading during uniform polarity epochs; 2) those originating from relatively slow spreading rates associated with the initial rifting of continents; and 3) those zones resulting from metamorphism of the oceanic basement or from deep sedimentary burial. Smooth zones on the continental rises surrounding the North and South Atlantic Oceans and north and south of the Southeast Indian Rise are attributed to the initial rifting process. Low amplitude magnetic anomalies over the Nansen Ridge are attributed to slow spreading rates as might be found during initial rifting. Some zones found in the South Atlantic Ocean and Pacific north of Hawaii possibly result from uniform polarity epochs. (Work prepared by Mascle,Phillips, Luyendyk, Heirtzler, Poehls.)

i) Development of a magnetometer for use aboard DSRV *Alvin* has continued. During the past year a new, compact, light weight, VARIAN 75/85 unit was modified to operate directly from the submarine's power supply. A novel hydrostatic safety quick-disconnect for the tow cable and fish was designed and was successfully field-tested in the Gulf of Maine during August. (Work prepared by Phillips).

MARINE SEISMOLOGY

Elizabeth T. Bunce and Sydney T. Knott

Laboratory Programs

An important part of our marine seismology effort has been signal and data processing; signal processing to improve the accuracy and clarity of seismic profiles taken in such problem areas as continental margins, and data processing to reduce the oblique (wide-angle) reflection and refraction data collected using sonobuoys.

Much of the signal processing capability developed during the previous year, 1971, was directly applicable to studies carried out during the International Decade of Ocean Exploration (IDOE) supported investigation of the eastern margin of the Atlantic Ocean off Africa (reported elsewhere by Emery and Uchupi). This expedition was outfitted with digital seismic signal acquisition and processing equipment to which the various processing programs were particularly adaptable. For most interpretations of oceanic seismic profiler data, oceanic crustal structure can be determined without processing to the depth of the surface of Layer 2, oceanic basement, if a good signal-to-noise ratio is attained. Since this was the case the processing effort could be concentrated on such major problems as reduction of interference caused by multiple reflections on the shallow African continental shelves and possible determination of deeper structures in the basins by improvement of the signal-to-noise ratio, by stacking. The program development and early tests have been reported by Knott, *et al.*, (1972). An innovative method for reducing the interference of multiple reflections has been discussed by Baggeroer (1972).

For some time we have wished to classify (with the eventual intent to identify) the material or composition of the detected reflection horizons. The now conventional continuous seismic profile generally shows variations in the character of reflectors, but it is basically a profile of travel-time plots. Since it appears that one straightforward way to classify the reflection horizons and possibly to derive some of their characteristics is by measuring reflectivity, we have pursued this route. Reflectivity measurements of the seafloor are a by-product of the process to reduce multiple reflection interference in shallow areas. Programs have also been developed to produce, for deep-water areas, profiles of bottom reflectivity based upon the ratio of the energy received in the second bottom reflection to that of the first. From these measurements and known correlations of the relation of reflectivity to sediment type one may infer seafloor composition with some accuracy. By carrying reflectivity computations further we hope to estimate or to determine the reflectivity of deeper horizons and thus the specific acoustic impedance of the material of these observed interfaces. Correlation of such information with interval and refraction velocities obtained with sonobuoys should improve classification ability.

Our collection of wide-angle sonobuoy data continues. Digital processing, generally done after playback of the original magnetic tapes, is only a part of the interpretation and analysis of the data.

Tape recording is part of the original collection procedure. The original graphic record, while informative, allows no alternative presentations. A playback can be particularly profitable not only for the opportunity it affords to re-examine the data via various filter passbands but also for the ability to record with different vertical exaggerations to define better changes in slope of both reflected and refracted arrivals. Such subtleties as the presence of velocity gradients, and the almost simultaneous arrivals of refraction events are far more easily detected and interpreted when the playback is designed for the purpose rather than relying on the field recordings. No single presentation brings out all the essential information; for example, most interval velocity determinations are made with higher frequency bandpass than is necessary for detection of refraction arrivals while relatively high frequencies are useful for determining the range rate from the direct arrivals.

The digital processing subsequent to interpretation is used primarily to obtain the interval velocities. These various processing steps and programs have been re-evaluated, and are now being simplified, made more reliable, and adapted for use with our Hewlett-Packard computers as well as the Sigma-7.

Field Programs

The major shipboard program to use the standard seismic techniques of 12 and 3.5 kHz echo sounding, continuous reflection profiling with air guns as source, and wide-angle measurements with sonobuoys as receivers was conducted from R/V *Atlantis II* and is reported elsewhere by Emery and Uchupi. In addition, short cruises in the Gulf of Maine (reported by Uchupi and Ballard), and on the continental rise (Ross) utilized some of these capabilities.

A survey of the FAMOUS Mid-Atlantic Ridge area (Phillips) made use of several seismic techniques. Sonobuoys were deployed in the rift area for purposes of monitoring seismicity, and for oblique reflection and refraction measurements using SUSS charges as sources. Normal incidence reflection data were obtained using the standard towed array receiving system and the same SUSS-charge sources. 3.5 kHz was used for the bathymetric work.

In early February an array of twelve 3.5 kHz transducers was installed on *Knorr* for use during giant core experiments (Hollister). The purpose was twofold: 1) to enable determination of sediment structure by acoustic means at the core stations; and 2) to test the feasibility and usefulness of an in-hull transducer installation at the deepest part of the hull on this particular ship. (Both *Chain* and *Atlantis II* have successful in-hull 3.5 kHz installations, Ref. 70-11, 72-23). The experimental installation on *Knorr*, however, was only partially successful and its further use deemed not justifiable, principally because of high noise reception at the transducer array location.

The installation of these transducers requires a three- to four-foot diameter space. The most obvious options available are: 1) a through-hull sea-chest installation with the transducers in salt water or essentially so, flush to the hull as might be done in the forward chamber; 2) inside installation such as that tried; 3) an outside blister-like sonar dome; 4) a towed fish.

Since the in-hull experiment was not really successful, the most promising option appears to be to install the transducers in the forward bow chamber. This then combines many of the features of a sonar dome, a location at a maximum distance from machinery noise sources, and an installation that once made can be serviced without drydocking. This will, however, require hull modifications such as construction of a sea chest in the forward chamber. In average seas the bow chamber offers a virtually bubble-free environment for transmission and reception of acoustic signals, a condition generally not found elsewhere on these and other vessels without deep keel structures. The use of any hull-attached installation (dome or whatever) does, however, become limited in high sea states.

We have recommended a forward-chamber installation and made this part of our ONR proposal for 1973 funding.

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GEOMAGNETIC TIME VARIATIONS

Richard P. Von Herzen and Paul C. Murray

The prototype sea-floor magnetometer under development last year has been constructed and initially tested at sea. The instrument records digitally three components of the Earth's magnetic field with a resolution of approximately 0.1 nT (γ). Sensors are commercially available thin-film inductors modulated by the vector magnetic field. Average power consumption of the instrument is $\leq$ 1/3 watt. The serial recording of the vector magnetic field plus time approximately each minute on standard cassette tape allows for about 43 days of data storage capacity.

A sea test, in October 1972 at 2200 m depth from *Gosnold*, demonstrated the free-fall deployment and recovery techniques, and the telemetry link. The period on the sea floor (two days) was not of sufficient duration to evaluate the long-term stability, which is critical for accurate geomagnetic depth soundings of the Earth. Longer-term tests are being conducted at a remote site on the Quisset Campus, preparatory to field testing at sea in 1973.

STUDIES IN CENOZOIC PLANKTONIC FORAMINIFERA

William A. Berggren and Bilal U. Haq

Several lines of investigation have been pursued under this grant during 1972. These include: a) regional early Cenozoic paleobiogeography of the Atlantic Ocean using planktonic foraminifera and calcareous nannoplankton and b) a study of Pleistocene paleoclimatology of the equatorial Atlantic Ocean; c) Neogene planktonic Foraminiferal biostratigraphy of the Atlantic Ocean; d) the preparation of an Atlas of Paleogene Planktonic Foraminifera; e) Pliocene planktonic foraminiferal and calcareous nannoplankton biostratigraphy of the North Atlantic.

Our major research effort has been towards a delineation of provincialization of planktonic foraminiferal and calcareous nannofossil species distribution during the Cenozoic. We are currently examining samples from selected levels in the North and South Atlantic Ocean in order to obtain a general idea of regional distribution patterns at a given datum level. As a background for our taxonomic concepts an atlas of some 50 Paleogene planktonic foraminiferal species has been prepared.

An investigation on Neogene planktonic foraminiferal biostratigraphy of the Atlantic Ocean is nearly completed (together with Michael Amdurer, a student at Columbia University). This study has yielded significant data on the stratigraphic range and geographic distribution of various Neogene species of planktonic Foraminifera.

The quantitative micropaleontologic techniques for estimating late Pleistocene paleoclimatic conditions developed by Imbrie and Kipp (1971) have been recently applied to an equatorial North Atlantic core which extends into the late Pliocene ($\sim$ 2.3 my ago). A paleoclimatic curve has been formulated for the past 1.75 my and the following general conclusions have been drawn:

1) climatic conditions, in general, were colder and more stable between 1.75 and 0.9 my ago. Climate was generally warmer, but less stable during the past 0.9 my. The climatic changes characteristic of the last 0.9 my were associated with greater ice-volume changes than those in the preceding one million years. A paleocirculation model for the North Atlantic was suggested in which the cool Canaries Current was displaced significantly southwards during glacial intervals. This investigation was done in conjunction with Madeleine Briskin, graduate student at Brown University.

An investigation on late Cenozoic biostratigraphy of the North Atlantic (together with Richard Z. Poore, graduate student at Brown University) has yielded valuable data on the age of the Miocene/Pliocene boundary, on the basis of regional correlation with biostratigraphic criteria occurring in the type section in Italy and in deep-sea cores we have been able, for the first time, to estimate a precise age of five my for the Miocene/Pliocene boundary. This data will have a significant bearing on regional correlations between marine and continental stratigraphies as geologists continue to attempt to calibrate the two stratigraphies to a radiometrically-controlled time scale.

As a result of our current investigation of various aspects of late Cenozoic stratigraphy, a comprehensive review of late Neogene marine and continental biostratigraphy and paleoclimatology has been prepared to acquaint scientists with the rapid advances which have been made in this increasingly complex area of study.

Bilal U. Haq continued the study of the vertical and horizontal distribution of calcareous nannoplankton in the paleogene of DSDP cores from the Atlantic (Legs 1-4, 10-12, 14, 15), Caribbean and Europe. The existing models of the fluctuations in the total diversity of calcareous nannoflora do not satisfactorily explain the observed data and a new model was proposed in a paper under review: Transgressions, climatic change and diversity of calcareous nannoplankton. It is shown that during periods of major transgressions and wide-spread seas (e.g., during Oxfordian and late Maestrichtian in the Mesozoic and in middle Eocene in the Cenozoic) the total species diversity and rates of evolution increased conspicuously and during periods of major regressions and restricted seas decreased proportionally. A review of the temperature tolerances of extant coccolithophore species shows that most of them exist within narrow ranges of temperature and species diversity is greatest near tropics where differences in maximum and minimum temperatures are lowest. During major transgressive periods and maximum spread of epicontinental seas the global climates were changed from the "continental type" climates of the times of restricted seas to more "maritime type" climates with narrower ranges between maximum and minimum temperatures, accelerating the rates of evolution and increasing the overall species diversity of calcareous nannoplankton and dependent organisms.

DINOFLAGELLATE STUDIES

David Wall, Barrie Dale, Kenichi Harada

Studies have been continued with both living and fossil dinoflagellates to gain better understanding of the relationships which exist between extant and fossil members of this group of flagellated organisms. Several different aspects of their study were under consideration during 1972.

Black Sea Fossil Dinoflagellates - Our investigations of fossil dinoflagellates in several deep-water sediment cores from the Black Sea were concluded with the preparation of a manuscript on the taxonomy of new species which were encountered therein. *Spiniferites cruciformis, Tectatodinium psilatum, S. inaequalis* and *Peridinium ponticum* were formally described as new taxa and illustrated with light photomicrographs and scanning electron micrographs for a paper which will appear in *Micropaleontology* in 1973.

Cyst biogeography - A longer term investigation which deals with the distribution of dinoflagellate cysts in modern marine surface sediments was advanced further by the collection of a new suite of samples and examination of previously-collected samples from the eastern coast of the United States. Grabs and short gravity cores were collected from inshore stations between Cape Cod and Machias Bay, Eastern Maine during August together with phytoplankton tows at many of the 41 stations. Work was completed on four onshore to offshore transects which lie between Wilmington Canyon (south of Long Island Sound) and Veatch Canyon (south of Nantucket) and many inshore samples whose ranges lie between Georgia and Maine.

Phylogeny of *Ceratium* - A new project underway currently is an attempt to reconstruct the phylogeny of the genus *Ceratium*, which probably is the largest and most publicized of all the dinoflagellate genera, through a comparison of thecate, encysted and fossilized stages. This investigation is involving the critical morphological study of both marine and freshwater species from sources such as Lake Zurich, local ponds in the Falmouth area, coastal plankton from California and eastern states and fossil material of Mesozoic and Tertiary ages from Britain and Pakistan. Professor W.R.Evitt of Stanford University is collaborating in this investigation and invaluable help has been provided by Dr. R.R.L.Guillard of our Biology Department with the culture of *C. tripos* and *C. carolinianum*.

Miscellaneous - In order to keep abreast of recent developments in dinoflagellate research outside of Woods Hole, a certain amount of time always is devoted to matters which strictly speaking are beyond the intended limits of our project. This year, two such developments were noteworthy. First, a red-tide swept along the coast of Massachusetts, being caused by a bloom of *Gonyaulax tamarensis*. A brief taxonomic study of this organism was performed to verify its proper identification and to study its cysts in samples which were provided by Christopher Martin of the Lanesville Station of the University of Massachusetts. Second, a remarkable assemblage of fossil dinoflagellates was described recently from the Lower Jurassic (Lias) of Germany. These are among the oldest known of all fossil dinoflagellates and thus offer invaluable information about the dinoflagellates during their early evolution. Samples were obtained through the courtesy of Dr. Peter Morgenroth, who discovered these dinoflagellates, and some time was devoted to studying them and making a slide collection of single-grain mounts of these unique microfossils.

PETROLOGY AND GEOCHEMISTRY OF JOIDES BASALT CORES

Wilfred B. Bryan

During the past year petrographic and mineralogical studies were completed on basalts from Deep Sea Drilling Project (DSDP) cores from Legs 2, 3, and 11. This is part of a comprehensive study of basalt mineralogy and geochemistry being conducted in collaboration with Dr. G. Thompson, Department of Chemistry, Woods Hole Oceanographic Institution and Dr. F. Frey, Department of Earth and Planetary Sciences, Massachusetts Institute of Technology. A major objective of this work has been to determine whether certain textural and mineralogical features can be used to classify rocks into geochemical types, and ultimately, whether there is a complete continuity in the types so recognized (implying a genetic relationship) or whether there are distinct compositional groupings (implying existence of distinct and separately derived magma batches). Although the samples examined so far are small in number, there is considerable variety represented. They include olivine-rich dolerite, olivine-plagioclase basalt, plagioclase-pyroxene basalt, and also more weathered varieties of these rocks. In general, there is good correlation between these varieties and their chemical characteristics, with the olivine-rich samples being relatively depleted in the lighter rare earths and their coherent trace elements, and the more feldspathic, olivine-free rocks showing enhancement in these elements.

Some detailed microprobe analyses of sector-zoned augite in a sample of Leg 3 basalt have shown that the compositional and optical zoning effects are very similar to those reported from lunar pyroxenes. The high Al_2O_3 content of the pyroxenes confirms the results of earlier analytical work, which was suspected to be in error due to feldspar contamination. This high Al_2O_3 is apparently a real feature of submarine basalt pyroxenes. There is a strong negative correlation between Al_2O_3 and SiO_2, implying substitution of Al in the tetrahedral site normally occupied by Si. The Al_2O_3 content is relatively higher in quenched groundmass pyroxene than in pyroxene phenocrysts, suggesting that this substitution is favored by quenching and disequilibrium growth.

Microprobe analysis of glass from DSDP Leg 11 in the western Atlantic has shown that the basalt at this site is very similar in major element composition to modern sea-floor basalts. This similarity extends to the textural and mineralogical features of the sample. Basalt from this site, representing the oldest basalt so far recovered in the Atlantic, was sampled in detail late this year and will be analyzed during the coming year. Work was also begun on basalt from DSDP Leg 22 in the eastern Indian Ocean. Comparison of samples from these areas, widely separated both geographically and in time, should help to establish the degree of uniformity of sea-floor basalt compositions in time and space.

Microprobe data on these basalts was reported by Bryan (1972). A more extensive publication is in preparation (Frey *et al.*, 1973).

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MINERALOGY AND DESCRIPTIVE PETROGRAPHY OF SUBMARINE BASALTS

Wilfred B. Bryan

Work has continued this year on mineralogical and petrographic studies of submarine basalts utilizing material in the Woods Hole collection from cruises of the R/V *Chain* and *Atlantis II*. Major objectives in this research are:

1) To define mineral paragenesis (crystallization sequence) in these rocks which may have important implications for genetic evolution of the rocks.

2) To identify mineralogical or textural features which may be unique to volcanic rocks erupted on the sea floor, so that they may be more readily recognized in older geologic terrains, such as island arc basement rocks or continental ophiolite sequences.

3) To define and interpret crystal growth phenomena, zoning, and twinning which are especially well-developed in water-quenched magmas, in order to better understand mechanics of nucleation and chemical diffusion in basaltic magmas.

4) To develop or refine techniques for microscopic study of the very fine-grained volcanic rocks typically recovered from the sea floor.

During the past year, mineralogical studies have been centered on sector-zoned feldspar, which so far appears to be unique to submarine basalts. Chemical analysis of some typical sector-zoned feldspars has been carried out using the electron microprobe at the Carnegie Institution, Washington, D.C. It has been shown that these feldspars contain significant amounts of iron and magnesium, and that distinct differences in concentration of these elements are present in the two sets of sector zones in the feldspar. Between sectors in individual crystals, iron and magnesium are positively correlated with calcium, but within sectors, or between the core and rim of unsectored feldspar, or between phenocryst feldspar and groundmass feldspar, iron and magnesium are negatively correlated with calcium and positively correlated with sodium content in the feldspar. However, iron-magnesium ratios remain relatively constant for all feldspars within individual rock samples. These observations are difficult to interpret in terms of conventional assumptions about crystal-melt equilibria. It is generally thought that iron and magnesium do not occupy specific sites in the feldspar crystal but that they occur as impurities in lattice defect sites. Preference for sector zones related to specific crystal faces, however, implies some structural control over the entry of these cations. Positive correlation between iron and sodium would be predicted from the usual simultaneous increase in iron and alkalies in a

basaltic magma as crystallization progresses, but this should also cause an increase of the Fe/Mg ratio. It is possible that maintenance of this ratio at a nearly constant level in the feldspar reflects an increasing preference for Mg relative to Fe in the more sodic feldspar. Textures and crystal growth forms in many of these rocks were described by Bryan (1972a). Microprobe data on the feldspars, together with some data on pyroxene chromite, and basalt glass, have been summarized by Bryan (1972b). A manuscript on sector-zoned feldspar is in preparation.

During the past year several new microscopic techniques were investigated. Phase contrast and interference contrast methods were expected to improve resolution of zoning and other subtle optical details in transparent minerals, but proved to be less effective than the more conventional polarized light and relief-contrast methods which have been effectively used to date. Reflected light interference contrast, however, does appear to have definite advantages for the study of opaque minerals. Fluorescence techniques using ultraviolet light were also investigated but proved disappointing.

During the year equipment was received on special order from Bausch and Lomb which will permit accurate calibration of refractive index liquids and precise determination of refractive indices of natural rock glasses (such as pillow rims, pumice, and ash shards). This equipment should aid in the quantitative comparison and classification of rock samples, correlation of ash horizons in piston cores, and in mineralogical studies. The equipment includes a high intensity monochromatic light source of variable wavelength, which may be utilized in further experiments in phase contrast methods, and also to obtain more precise refractive index measurements in which phase contrast methods may prove useful.

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LUNAR VOLCANOLOGY

Wilfred B. Bryan

Studies of volcanic morphology and related geologic features are being carried out using stereophotography from the *Apollo* 15, 16, and 17 missions. A major objective in this project is to determine the extent to which volcanic activity has determined the surface morphology of the moon, and to develop geologic models of the lunar surface which may aid the interpretation of other orbital science experiments. In particular, recognition of volcanic phenomena is considered critical to the interpretation of lunar gravity data, which has revealed the existence of large mass concentrations associated with the lunar "seas" (mare).

Work this past year has been centered on stereo strips across Mare Serenitatis, Mare Imbrium, and the Aristarchus Plateau. Features of interest include the sinuous and arcuate rilles, wrinkle ridges, and the "continental shelf" surrounding Serenitatis. The latter is interpreted as a "high water mark" reflecting an early filling of the mare basin by a large lava pond. Isostatic compensation after partial crystallization caused sagging of the solid surface crust toward the center of the basin, producing tensional fractures (the arcuate graben). Intrusion of new magma beneath the crust raised it, producing compressional folds (the wrinkle ridges) and local overthrusting of the crust onto adjacent highland areas. Along the south side of the Imbrium basin, large lava flows were partly ponded against wrinkle ridges and later broken and deformed by them, indicating that wrinkle-ridge development was contemporaneous with filling of the basin by lava.

Important implications for gravity modeling are as follows:

1) The lunar mare morphology does suggest that these are basin-like features filled by basaltic lava.

2) Wrinkly ridges appear to be deformed surface crust and do not imply the existence of shallow, buried "basement" ridges.

3) At least some filling has taken place by lava flows entering the basins from sources outside the mare boundaries. Thus, the basins are sites of surface accumulation but may not represent sites of eruption. Thus, deep-seated mass concentrations representing source magma chambers may be located outside the mare regions.

UTILIZATION OF CONTINENTAL MARGIN SEDIMENTS: ECONOMIC AND ENVIRONMENTAL ASPECTS

Frank T. Manheim

Sand, gravel, and mud represent not only the largest potential, but also the most immediately useful sea-floor resources off the coast of the northeastern United States. Reserves of surficial sand grading 75 percent or more amount to more than 400 billion tons in the upper three meters of the sea floor; this is enough to supply the sand needs of the northeastern states of the United States and Maritime Provinces of Canada for several thousand years at current usage rates.

The New England Offshore Marine Exploration Survey (NOMES) project (SEAGRANT) will supply valuable information on both technological feasibility and the environmental problems associated with dredging shelf deposits. However, an unsolved problem remains: what to do with the mounting quantities of dredge spoils produced in keeping Atlantic coast waterways navigable. Disposal sites are becoming rapidly exhausted. The balance of dredge spoils and need for sediment raw materials for construction is shown in Fig.10. Though dredge spoils are small compared to the need for construction raw materials in the northeast, they pose a serious local disposal problem. New methods for utilizing dredge spoils and organic-rich marine muds have been proposed, and promise possibility of producing cheaper brick and ceramic materials for coastal communities than existing sources. These methods deserve encouragement, for they not only offer a sink for unwanted dredge spoils, but also "surgical removal" of polluted harbor and estuarine muds for construction raw materials could rejuvenate contaminated areas much more quickly than waiting for natural recovery forces - assuming stoppage of pollutant input.

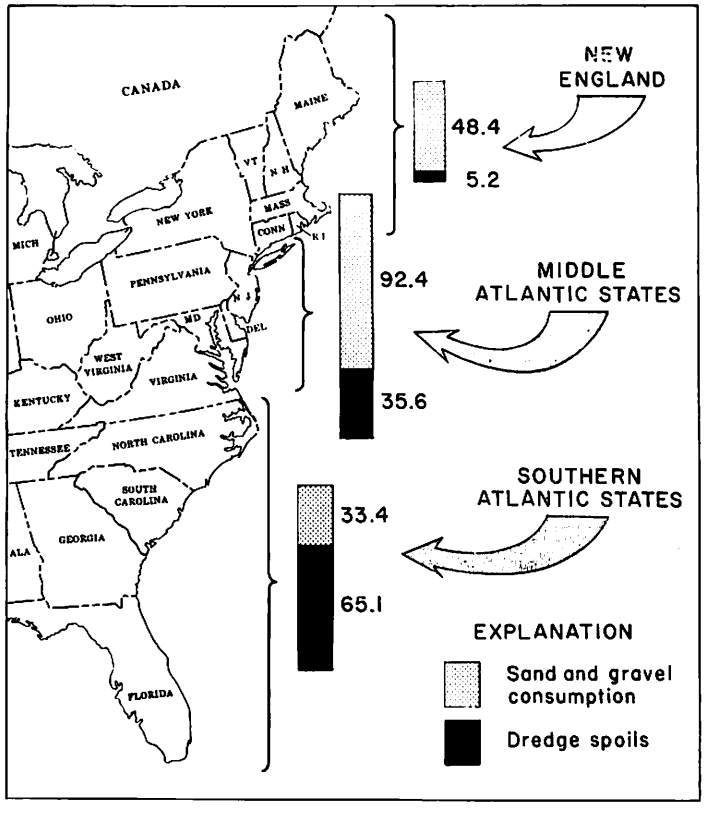

Fig.10 (Manheim) Balance of dredge spoil and consumption of sand and gravel (in millions of tons) in Atlantic coastal states. From F.T.Manheim (1972), U.S.Geol.Survey Circular 669, 28 p.

QUANTITATIVE EVALUATION OF FIXATION AND DEHYDRATION METHODS FOR SCANNING ELECTRON MICROSCOPIC PREPARATION OF SOFT ORGANISMS

Kevin Ulmer and Susumu Honjo

Quantitative evaluation of fixation and dehydration techniques for scanning electron microscopy has been employed in an attempt to optimize preparation of soft marine organisms. Eggs of common sea clam (*Spisula solidissima*) and species of naked dinoflagellate (*Fragelidium heterolobum*, in monospecific culture) were chosen for mainly spherical shape and conformity of size within any given batch of cells. By making use of an electro-optical particle measurement computer system, it was possible to measure individual cross section area, longest and shortest diameter of large number of specimens. Several aldehydes and osmium fixatives were tested both singly and in combination. The concentration of fixative, buffer and artificial seawater were also varied. To each fixative preparation tested, 100 cells were measured and their size distribution compared statistically with that of non-fixed populations of control cells. Each cell serves as a miniature osmometer with any change of size or shape reflected in displacement or skewness of the size distribution curves. In combination with subjective visual examination under light and scanning electron microscope, this technique allowed optimization of many parameters in series of fixation procedure to produce specimens with minimal morphological distortion.

SUSPENDED PARTICLES IN SEA WATER: A COMPUTER SOFTWARE PACKAGE FOR IMAGE ANALYTICAL METHOD

Susumu Honjo, Warren Sass and Dennis Schmidt

Filtration through membrane filters with small pore size has proved to be one of the most reliable methods for collecting suspended particles in seawater samples. The Woods Hole Oceanographic Institution has collected over 4,000 of such filter samples from the oceans of the world. Conventional microscopic measurement of the particles collected by filtration is the most direct method. However, such measurement requires an enormous number of man-hours to obtain statistically meaningful data and accuracy attained is discouraging. A limited amount of such particle measurement has been attempted so far on samples from the ocean.

A packaged computer method to quantitatively study the configuration of suspended particles was developed in 1972. As the result of this effort, efficiency of analysis has been greatly improved and far greater precision has been attained. A large number of measurements of the area which is occupied by each particle is now easily available. Development of automatic shape analysis or shape recognition techniques on particles is underway.

This package is an assembly-line arrangement of computer techniques: 1) automatic particle counting; 2) length and area measurement; 3) shape analysis; 4) raw data editing; 5) processing of data for multiple-power moment statistics, and 6) contour-map presentation of results by automatic plotting.

A filter or a piece of filter sample is first rendered transparent by "hexan" compound and permanently mounted to a glass slide. A prepared microscope slide is submitted to a particle-measurement computer system which is the central module of the package. This hardware consists of a television microscope, an image-analysis computer, and a "command" computer. An enlarged image from a high-power light microscope is received by a videcon tube and displayed on a TV-type display tube. The video bandwidth is 10 MHz and the number of scanning lines is 525 with a scan rate of 30 frames per second.

The particle measurement computer is able to count instantly the total particle number, X-axis project length, maximum chord of particles in Y-axis for any number of particles appearing in a frame, and how far apart they are from each other. Videometric accuracy in X, Y-axis projection and areal measurement far exceed optical resolution; the picture points matrix is 1.1 to 2.2 million and measurement clock frequency is 20-40 MHz. By using a "light-pen" magnetic probe technique, any one of the particles in a frame can be analyzed independently for the longest dimension, hole area measurement and X-axis projected length.

A "command" computer performs data editing and relatively small statistic processing. It operates the particle-measurement computer, designates the range of particle size, and stores raw data. The computer also drives the microscope stage following a preset pattern of transect with variable distance.

Final data obtained are classified as raw data or statistical results; they are stored in the magnetic tape library. Further computation and data retrieval is conducted by Sigma 7 computer. The resulting values are usually displayed on a contour map. A new linear interpolation contour plotting program, an improved version of SENMAP, has been developed in combination with a contour-plotting program.

SUBMERSIBLE OPERATED HYDRAULIC IMPACT HAMMER

Robert D. Ballard and Elazar Uchupi

In addition to visual and photographic missions, small submersibles frequently are required to obtain representative samples from hardrock surfaces in regions having extremely rough terrain. Thus far, previous attempts at sampling from such vehicles have met with limited success. Mechanical arms are strength-limited and cannot break samples off. Small drills are too time-consuming to use, require lengthy periods of ballasting and trimming to attain the necessary attitude, have no tactile feedback leading to frequent jamming, and if successful, samples obtained using such a technique are too small for a variety of experiments. Large drills consume much of the vehicle's extra payload, are awkward to use, require a level and nearly horizontal surface, and can be used on only a few outcrops per dive.

Based upon the above-mentioned experience, it was concluded that the optimal rock sampling system should be light, have a rapid cycling rate, not involve the use of the mechanical arm, not require time-consuming ballasting and trimming, be easy to operate, be self-contained having its own hydraulic and electrical systems, and be functional in rough terrain when the submersible is neutral and hovering in mid-water. To that end a prototype hydraulic impact hammer was designed and constructed in the first half of 1972. The impact hammer consists of five basic subsystems. Two 12-volt batteries emersed in an oil compensated fiberglass box provide power to operate a modified lightweight aircraft hydraulic pump. This pump in turn drives a movable piston which compresses a 1,000 lb. spring. When manually released the spring drives a hammer against a chisel breaking the rock. The hydraulic pump is also used to control a series of positioning pistons which permits the operator to place the hammer in a variety of orientations, depending upon the nature of the rock exposure. During three cruises in the summer of that year, the hammer was used on a series of granite outcrops in the Gulf of Maine. The hammer encountered a variety of problems during its first at-sea tests, some of which were solved on scene and some of which require further engineering consideration. Early tests required a change in the design of the latching mechanism for cocking the spring-loaded piston, development of a rapid cycling capability, minimization of the units overall weight, and optimation of the positioning pistons arrangement. At the end of the summer testing program the major unsolved problem was increasing the overall strength of the impacting device. The hammer was used on test material and its impacting power calculated both in and out of water. This data was compared with known energies needed to break most crystalline rocks. Preliminary results indicate a 10% loss of power in water and a considerable difference between the measured power of the hammer and its theoretical potential, which exceeds that needed to break most igneous rocks. Modifications are presently being made to the hammer coupled with continued testing and later slow-motion photography which hopefully will lead to a substantial increase in the hammer's breaking ability.

DEEP-SEA ROCK CORE DRILL

Richard P. Von Herzen

This year most of the effort centered on completion of major modifications and subsequent testing required as a result of experience with the prototype constructed during 1971. In particular, the control instrumentation, hydraulic system, *Alvin* coupling, and data telemetering system have undergone substantial revision. Dockside testing has generated considerable engineering data on drill performance while drilling rocks.

Sea trials were carried out in relatively shallow water ($\leq$ 100 m) in the Gulf of Maine and Cape Cod Bay. The drill was twice successfully carried to the sea floor by *Alvin* on separate cruises at different locations in this region. On one of these, the drill penetrated more than one meter of granite rock as observed from *Alvin*. In another operation, the drill was run from a surface vessel (R/V *Verrill*). Unfortunately, various minor problems prevented retrieval of a hard rock core during these field trials. We feel that only minor modifications are now required to make the drill an operational tool in the deep sea.

The drill improvements and testing in 1972 were successfully guided by D. Williams and A. Barrs.

GEOTHERMAL STUDIES IN DEEP-SEA DRILL HOLES

Richard P. Von Herzen and Albert J. Erickson

During 1972 reliable *in situ* measurements of sediment temperature were made at more than 11 sites in drill holes on Legs 22, 23, 25, 26, and 27 of the Deep Sea Drilling Project in the Red Sea and in the Indian and Pacific Oceans. Techniques and instrumentation for measuring temperatures in deep drill holes were improved through the close cooperation of personnel of this Institution, of the Deep Sea Drilling Project, and aboard the D/V *Glomar Challenger*.

Studies of the thermal properties of ocean sediment continued in the form of shipboard thermal conductivity measurements. These data, in combination with thermal gradients calculated from the *in situ* temperature measurements, have permitted the comparison of heat flow values obtained using equipment which determines the gradient to a depth of a few tens of meters with highly reliable values calculated using bore hole temperatures over intervals of several hundred meters.

DATA HANDLING

Bruce P. Luyendyk

Routine data processing, together with programming, continued to be our major effort. All geophysical data from Office of Naval Research-funded *Chain* Cruise 100 has been finalized. Other processing of current Woods Hole Oceanographic Institution cruises included *Atlantis II* Cruise 67 (International Decade of Ocean Exploration). Besides current data we have continued our effort in finalizing older Institution data. As of this writing we have finalized 17 cruise legs of digital navigation, six legs of bathymetry, and 11 legs of magnetics. This virtually eliminated our backlog of magnetics data. The backlog of gravity has been completely eliminated by C. Bowin's gravity group. For our bathymetry backlog (which is extensive) we experimented with digitizing old PGR records on the Institution's digitizing table. We found that the annotations on the older records are so inadequate that digitizing speed is slowed so as to be comparable with hand digitizing. Consequently, we are keypunching old bathymetry files from echo-sounding log books, which we have discovered are, in general, quite accurate. The automatic digitizing system will be reserved for newer data records that are more adequately annotated.

Programming efforts during the last year included major streamlining of our at-sea processing system. This included new programs to analyze magnetics and bathymetry data, plus new and revised graphics programs. Concomitant with these developments we have redocumented shipboard processing system procedures. The shore processing system has seen similar improvements. In addition, for the Sigma-7, we have stored 25 commonly-used processing programs as element files on disc. This serves two functions: 1) a standardized set of software is effectively "locked" under our control, 2) interested users are not required to acquire a program deck to run their job.

This past year has also seen growth in our digital data library. All finalized data is stored at the computer center. In addition, quarterly lists of finalized data are distributed to department personnel. We have initiated a new library effort called "MYLAR". This is a graphical reference system for available Institution digital data. We have divided the world into eight sheets at the scale of 0.36"/degree (standard H.O. World Chart). We have four mylar sheets for each area on which will be ships' tracks, and magnetics, gravity, and bathymetry profiles respectively. This project is about 50% complete.

The Digital Data Library System (DDLS) is a project initiated last year to provide interested scientists easy and flexible access to our expanding digital library. In this system our entire library of geophysical data will be stored on a few compressed (blocked - BCD) magnetic tapes. Using programs of the DDLS a scientist can retrieve various data by area, cruise, time, etc., in various formats: lists, plots, etc. The entire system should be available to almost any individual, with no requirement for knowledge of computers or programming. To date, we have completed software developments for constructing the compressed data files and data index-inventory. We are now programming the search routines.

We have continued to disseminate data in accordance with OCEANAV instructions. Bathymetry and navigation files from *Chain* 100 have been distributed plus navigation files from this year's *Atlantis II* African cruise.

ARCHIVING OF GEOLOGICAL COLLECTION

David A. Johnson

The Woods Hole Oceanographic Institution geological collection now contains approximately 2,700 core sections (1 section = 1.5 meters), 8,000 sediment samples from the Woods Hole Oceanographic Institution - United States Geological Survey continental shelf study, 300 dredge samples, and 100 rock samples collected by the deep submersible *Alvin*. This material has been obtained primarily from expeditions within the past 10 years, and has recently been relocated in the new core storage facility (DESC Building) on the Institution's Quissett Campus.

A major project was initiated in mid-1972 for updating the W.H.O.I. geological collection. With the assistance of funds from the Woods Hole Ocean Industry Program, the cores are now being split and photographed on a routine basis, and are being stored in sealed polystyrene D-tubes. Visual core descriptions are being prepared on standard lithologic log sheets, and smear slides are being prepared at intervals of one meter or less within each of the cores. The basic data for each geological sample (location, water depth, sample size, type of material) is being computerized for purposes of rapid retrieval, and this information will be made available to existing sample data banks, such as those at Scripps Institution and at National Oceanographic Data Center (NODC). As the descriptive information for each expedition's samples is completed, it will be made available for general distribution.

As of December 1972, approximately 90% of the core sections had been split and stored, 60% had been photographed, and 10% had been described. These curatorial projects will continue during 1973, under Office of Naval Research and National Science Foundation sponsorship.

PHYSICAL OCEANOGRAPHY

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

Ferris Webster, Department Chairman

INTRODUCTION

The Summary of Investigations conducted during 1972 by members of the staff of the Department of Physical Oceanography is grouped in this report into five sections. For each section there is a central theme as indicated by its title. These themes have been chosen only as a guide to many of the research activities going on within the Department of Physical Oceanography, and it should be stressed that there is extensive interaction between research activities described in several sections of the report.

The section on Studies of Oceanic Processes includes laboratory experiments in geophysical fluid dynamics, laboratory, theoretical, and experimental studies of internal waves, experimental and laboratory studies of oceanic fine-structure and microstructure, studies of the equation of state of sea water, and studies of the vertical fine structure in the ocean. In a sense, the sections on the Mid-Ocean Dynamics Experiment and on Moored-Array Experiments are an extension of the general fields of studies included under Oceanic Processes. General aims include investigations of time and space scales of oceanic phenomena, of the physical properties of eddies and waves, of large and small-scale spatial structure of the ocean, and of the interactions of oceanic processes with oceanic boundaries: the bottom, the shores, and the free surface of the sea.

The investigations described in the section entitled "Ocean and Atmosphere" include studies related to the interaction of the ocean with the atmosphere, the properties of the ocean as observed from the atmosphere, and the properties of the atmosphere over the ocean. The dynamic similarities between the two fluids, atmosphere and ocean, often makes their joint study scientifically profitable.

Circulation studies are and have been a central theme of research carried out in the Department of Physical Oceanography. Although their form has greatly evolved over the years, they still are a major component of the research program and might be considered a connecting thread through most of the studies carried out in the Department. We still want to know more about the general movement of the waters in the ocean. Many of the studies of mechanisms, mixing, and physical properties are directed towards a fuller understanding of the global circulation problem.

STUDIES OF OCEANIC PROCESSES

Laboratory Models of Ocean Processes (John A. Whitehead)

The Hydrodynamics laboratory facilities were used to model strait and sill flows that could be understood theoretically as well as constructed and observed in the laboratory (Fig. PO-1). Such flows are a focal point of oceanographic studies because some of the largest and most intense deep currents occur in the vicinity of straits and sills. The agreement between these recently-developed theories, laboratory models, and some of the more fully studied oceanic sill flows such as the Denmark Straits and the Straits of Gibraltar, encourages pursuit of this line of investigation in more detail in the future.

Mixing processes which can generate the microstructure that has been observed with increasing regularity in the ocean in recent years were also studied in the laboratory. An understanding of the mechanisms that generate microstructure might lead to a more direct understanding of the important vertical mixing mechanisms in the ocean.

The work to date has focused upon double-diffusive processes and their energetics. All processes which generate microstructure were found to have analogs in other areas of non-equilibrium thermodynamics. Consequently our field of study was expanded to construct laboratory models that represent the general behavior of such processes.

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

This program involved measurement of the effects of temperature, pressure, and chemical composition on electrical conductance and specific volume of sea water.

We questioned our earlier data on the effect of carbon dioxide on the specific volume of sea water and repeated the measurements in a dilatometer of improved design. The new results agreed with the earlier ones but are more precise. When combined with partial molal volume data of Duedall and Weyl (1967), they yield (1) the variation of σ_t with pH due to the addition or removal of carbon

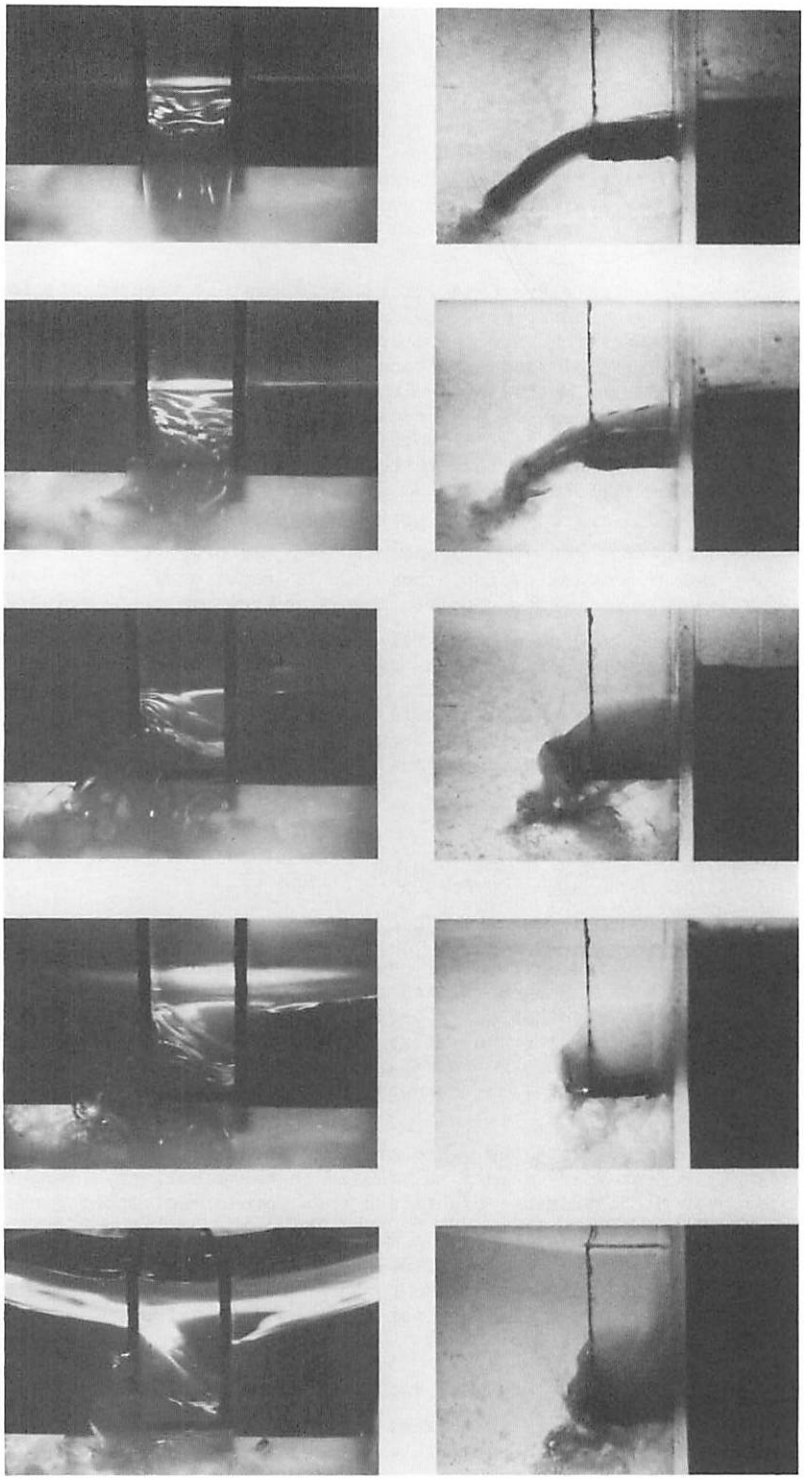

Fig.1 (Whitehead) Laboratory model of flow through a narrow opening, looking in the upstream direction on the left, and from the side on the right. The tilt of the liquid surface across the stream is due to the fact that the entire apparatus is rotating.

dioxide and/or calcium carbonate and (2) estimates of the effect of pressure on the solubility of calcium carbonate.

Measurements of the effect of pressure on the partial molal volumes of the major electrolyte components of sea water were completed. Values for each component were calculated from the measured differences between the mean compressibility of sea water and the mean compressibility of sea water to which known amounts of the salt in question had been added. The experiments were carried out in the same dilatometer used for the sea water compressibility measurements at 10° and 25°C on 35°/$_{oo}$ salinity sea water. The results extend the partial molal volume data obtained by Duedall and Weyl at atmospheric pressure to 1000 bars.

Reference

Duedall, I. W. and P. K. Weyl (1967). The partial equivalent volumes of salts in sea water. *Limnol. Oceanog.* 12: 52-59.

North Atlantic Thermal Structure (Elizabeth H. Schroeder)

The aim of this work is an atlas of monthly average temperatures of the North Atlantic at six depths from the surface to 150 m.

All available Atlantic temperature data were sent to the Scripps Institution of Oceanography at La Jolla for a two-dimensional smoothing and Fourier analysis to provide a temperature for each depth, in each month, in each one-degree quadrangle. Distortion of the thermal structure by the method necessitated subjective correction and interpolations which were completed in October. The final computer run is under way and should allow completion of the basic charts early in 1973.

Panulirus data: This continuing series of Nansen bottle stations was started in June of 1954 and was designed to allow a complete description of the waters off Bermuda, including seasonal, yearly and long-term changes. This is the only such deep station in the North Atlantic and has proved to be valuable as a source of research data in diverse fields.

Since the inception of the program, a total of 373 Nansen bottle stations have been made; eighteen of these in 1972. None were made in January or March because of mechanical problems with the *Panulirus*.

In addition to routine analysis of each station as it is received, approximately twice a month, steric sea level is being studied for the second eight-year period of the series. Also under way is analysis designed to determine changes in temperature, salinity and oxygen over the period of the station.

Acquisition and Use of Temperature-Salinity Data (Elizabeth H. Schroeder)

During the eleven months of 1972 ending November 30, this section has processed 833 mechanical bathythermograph slides, 1,993 expendable BT traces and 13,395 BT prints received from outside sources. A total of 17,878 BT and Nansen bottle station cards were averaged by month at standard depths and were added to our data collection; 2,890 of these were stations copied from various sources.

In addition to reading and checking these data to ensure accuracy, 27 BT reading grids were made for instruments calibrated at W.H.O.I.

Coastal Upwelling off Northwest Africa (Arthur D. Voorhis)

On invitation from the Institut für Meereskunde, Kiel, Germany, we participated for three weeks in February on board the F/S *Meteor* in an investigation of upwelling off the northwest coast of Africa. Our program was to measure the upwelling current using the freely drifting, neutrally buoyant, vertical current meters developed here over the last five years. Four of these instruments were launched repeatedly along the shelf edge off Mauretania, between Cap Timiris and Cap Blanc. We tracked them for periods of two to five days as they drifted at depths of 50 to 100 m and recorded, internally, vertical currents. The instruments usually drifted shoreward and two went aground. All instruments were recovered. In none of the records was it easy to identify a steady upwelling current. Instead, the vertical flow was mainly oscillatory, large, and highly variable. On one occasion an instrument at a depth of 100 m recorded a downward and upward displacement of over 100 m of water in a period of five hours. The records suggest that upwelling is sporadic, occurs near the bottom, and is strongly influenced by the submarine canyons which cut across the shelf in this region.

Time Series of Vertical Profiles from the MODE Area (William J. Schmitz, Jr.)

A 40-hour time series of 12 vertical profiles of horizontal current and temperature was made near the center of the Mid-Ocean Dynamics Experiment (MODE) area (28°N, 70°W) to test the assumption that the low-frequency (less than one cycle per day) variability is concentrated on the largest vertical scales. This assumption has been basic in the design of the MODE-I experiment.

The time series was obtained with an acoustic dropsonde, a free instrument moving vertically at terminal speed and horizontally with the current. 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. The conductivity data were of low quality.

The results show that the low-frequency variability is dominated by the longest vertical scales. Smaller vertical scales, vertical wavelengths of several hundred meters in a depth of 5400 m, are apparently dominated by time scales near the inertial period (about 24 hours at this latitude) and have amplitudes of 3 to 5 cm/sec. The results also show evidence for a barotropic (i.e., constant with depth) semidiurnal tide of amplitude 1-2 cm/sec.

Studies of Microstructure (J. Stewart Turner)

Laboratory work on double-diffusive ("salt finger") convection has been continued, using the sugar-salt analogue developed at W.H.O.I. in 1968. The effect of horizontal non-uniformities of fluid properties followed earlier work which showed that a variable depth can have an important influence on both vertical transports and the quasi-horizontal circulations produced by them. A source of salt solution,released continuously into an initially homogeneous sugar solution close to the same density, first produced a remarkably vigorous vertical convection. This, in time, led to the formation of a stable density stratification in which both layers and fingers were prominent in different parts of the tank. Experiments were also carried out in a long tank, and the concentrations of the solutes measured as functions of position. Large, nearly compensating horizontal gradients of sugar and salt (c.f. salinity and temperature) can be set up in this way while the net density remains substantially constant in horizontal planes. Similar variations of properties have been observed in the ocean, and found to be associated with the formation of layers.

Some exploratory experiments on convection in glycerine, whose viscosity depends strongly on temperature, showed some of the features characteristic of convection in the earth's mantle, which do not appear in previous experiments using fluids of nearly constant properties.

Internal Wave Interactions (William F. Simmons)

Experiments were continued this year using the Institution wave tank with conventional wave generators and sensors to study interactions between internal waves. Free and spontaneous energy exchanges to lower frequencies and higher mode numbers were found that almost certainly were of the type associated with nonlinear instabilities. However, using these conventional techniques, we were unable to produce high enough quality data to make the convincing identification of spectral components necessary for comparison with theory. Most of the scatter in the results is due to sluggish viscous response of the small conductivity sensors used to sense the motion in the weakly stratified tank. Much time was devoted to developing and testing a new sensing device, built at W.H.O.I., which successfully overcomes this sluggishness.

The W.H.O.I.-built mixed-mode wave generator has undergone two major design modifications as a result of wet tests. Final changes have been completed, and wave experiments await only the installations of stable low-frequency signal generators.

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

This program is a continuing study of motionally induced electromagnetic fields in the deep ocean. The emphasis for much of 1972 has been on evaluation of the performance and results of the free-fall current meter completed in 1971.

The first use of the new current meter produced a brief time series of profiles at site J (36°N, 70°W). These data (Fig. PO-2) show velocity structure having vertical scales of 50-100 m and longer. Most of this small-scale structure is with motions of period one day or less. This result can be seen in Fig. PO-3 where pairs of profiles taken 1/2-inertial-period apart have been superimposed.

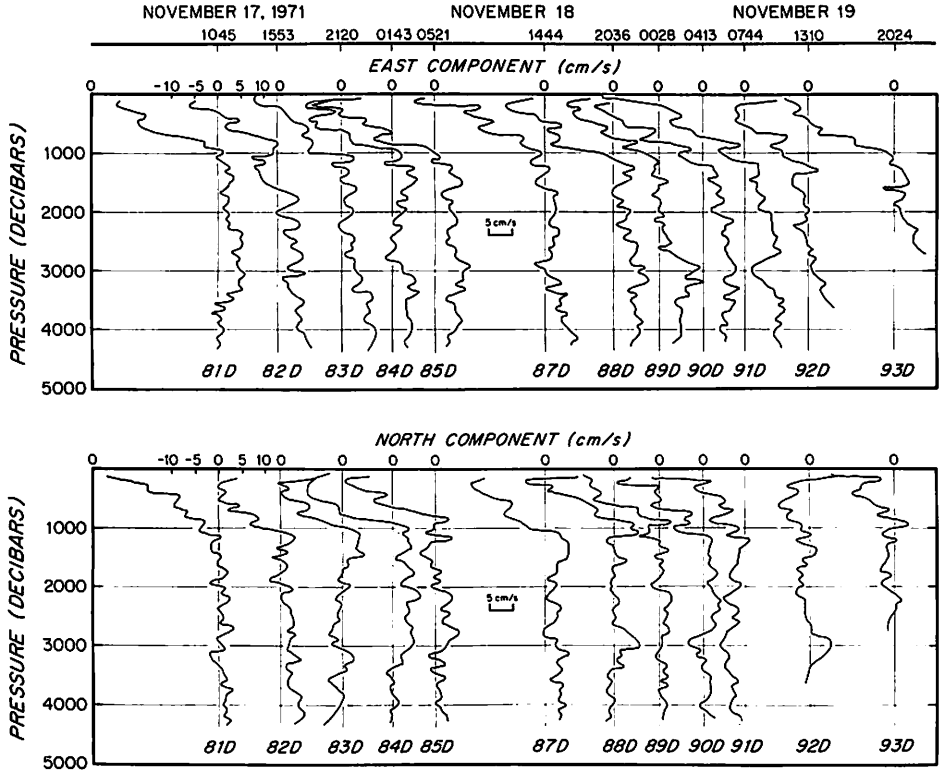

Fig.2 (Sanford) East and North components vs. time and depth at 36°N 70°W.

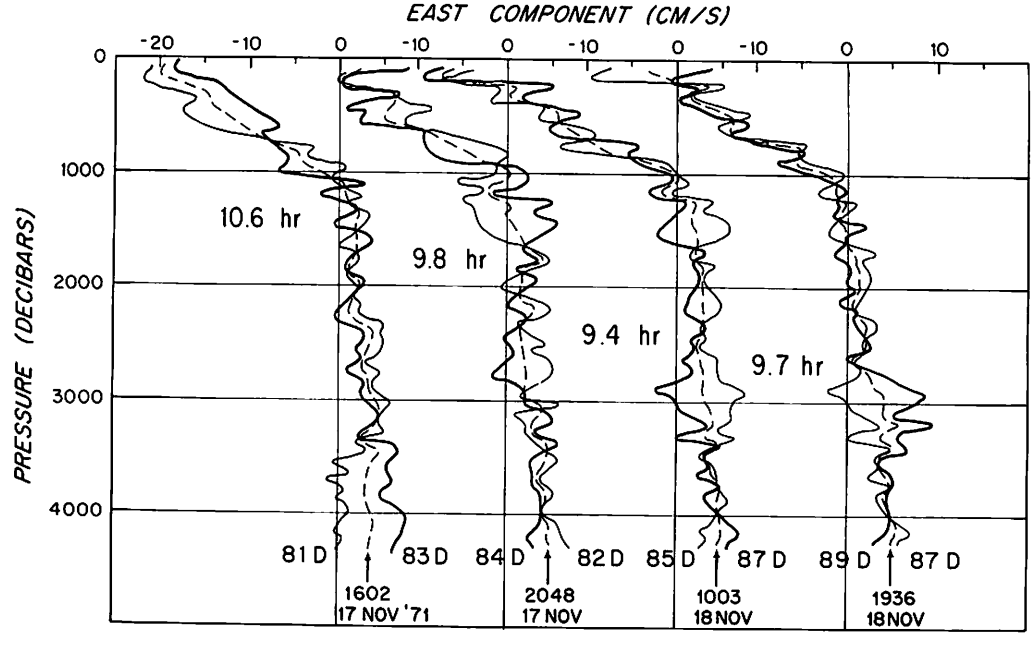

Fig.3 (Sanford) Velocity profiles paired at time separations of about ½ inertial period.

During August and September of 1972, 80 velocity profiles were obtained at and around Site D (39°10'N, 70°W). This work was part of an effort to understand and observe bottom-trapped waves. A further discussion of this experiment appears elsewhere in this report (Luyten, *et al*).

Because velocity profiling is a new approach using new instrumentation, a considerable effort has been spent on the development of a data processing system and on the evaluation of instrument performance. The amount of data collected on each deployment is large, consisting of two velocity series along with other variables such as temperature, conductivity and pressure. In most cases these data are treated in ways different than those followed using current meter or other time-series data. As this system developed, we have used it to examine not only the nature of ocean currents but also the performance of the technique. Of special interest have been studies to determine the appropriate averaging needed to produce profiles showing maximum resolution with acceptable accuracy.

The instrument development effort has continued on the improvement of the free-fall devices and on the design of a stationary electric field sensor. The latter device is to be used to monitor the ambient electric field in the sea for the purpose of measuring the barotropic component of the flow. Fabrication of this instrument began late in 1972.

Internal Wave Experiment (Terrence M. Joyce, Melbourne G. Briscoe and Claude J. Frankignoul)

Although considerable effort has gone into studying internal waves in the ocean, the spectrum of internal wave energy with respect to frequency (time) and vector wavenumber (length) have not been adequately determined. The Internal Wave Experiment (IWEX) proposes to determine the four-dimensional energy spectrum over the time and length scales associated with internal gravity waves. The field experiment will be conducted for a two-month period beginning in August 1973 at a site in the main thermocline over the Hatteras Abyssal Plain in the vicinity of 28°N, 70°W. Seventeen current meters will be placed on the mooring at horizontal and vertical separations from 2 m to 400 m; each will be modified to measure, in addition to the horizontal current, temperature differences over a two-meter vertical separation.

The temperature (T) and temperature-difference measurements will be used to infer the vertical velocity (w) through the relation $\frac{\partial T}{\partial t} + w \frac{\partial T}{\partial z} = 0$. Simultaneous measurement of both horizontal and (inferred) vertical velocity should provide sufficient information to estimate the energy spectrum as well as checking on how self-consistent is the hypothesis that the motion is predominantly due to quasi-linear internal waves. The importance of various complicating factors such as nonstationarity, temperature microstructure, and time-dependent doppler shift upon quasi-linear internal waves is being evaluated prior to the field experiment using both real and model data.

Claude J. Frankignoul has found from his analysis of Site D (39°10'N, 70°W) current-meter data that part of the internal-wave band of frequencies appears as bursts or wavepackets whose energy propagates up and down past the horizontal current sensors in a vertical string of current meters. There is also an indication that for high-frequency horizontal kinetic energy a difference exists between the measurements parallel and transverse to the low frequency currents.

A study of the effect of temperature microstructure upon measurement of vertical current and its time integral (displacement) was begun by T. M. Joyce using both real and artificial temperature-versus-depth data. A probe oscillating in a prescribed manner through a known temperature profile provides a means for computing an error spectrum without assumptions regarding the relative vertical scales of microstructure and internal wave displacement. One possible outcome of this study may be the ability to "decontaminate" a measured temperature spectrum if some statistics of the microstructure field are known.

Energy Balance of Quasi-Geostrophic Flow and Internal Waves (Klaus F. Hasselmann, Peter K. Muller and Dirk J. Olbers)

The interaction of an internal wave field and a quasi-geostrophic flow were studied for the case of weak coupling. The effect of the interaction on the quasi-geostrophic flow field can be described by the diffusion terms in the mass and momentum balance equations. The diffusion tensors can be calculated rigorously as functionals of the spectrum of the internal waves and their relaxation time. Both are poorly known, but calculations based on existing models yield diffusion coefficients that are comparable to empirical estimates.

The dynamics of an internal wave field is governed by competing interaction processes. Starting with the investigation of the nonlinear resonant transfer of energy within the internal wave spectrum, the source function of this process was calculated numerically for various model spectra. The associated relaxation time is of the order of a few weeks which indicates that this process may be important.

Internal wave measurements with moored current meters yield energy spectra with good frequency resolution but a limited wave-number and directional resolution. In order to gain insight into the three-dimensional structure of the energy spectrum, an experiment is being planned with current meters and temperature sensors attached to a tripod mooring. This experiment will be carried out shortly after the Mid-Ocean Dynamics Experiment (MODE) in the same area. (See the next summary.)

Bottom-Trapped Waves at Site D (James R. Luyten, Alfredo A. Suarez and Thomas B. Sanford)

Extensive current measurements with moored instruments at Site D (39°10'N, 70°W) suggest an increase in the low-frequency kinetic energy near the ocean bottom. The kinetic energy of fluctuations in the velocity field shows a two-fold increase between 2000-m and 2500-m depth, predominantly in the north-south component of velocity. These observations are consistent with the theory of quasi-geostrophic bottom-intensified topographic waves. The inferred spatial scales are of the order of 5 to 10 km, although the observations from a single position can give no direct information about spatial scales. A theoretical model based upon local generation of this small-scale variability has been developed. Large-scale barotropic topographic waves interact with small-scale bottom topography, scattering a fraction of their energy into bottom-intensified topographic modes with small spatial scales, and correspondingly smaller phase speeds. The particular mode excited depends upon the local topography. At Site D, the local topography would excite predominantly the mode for which the velocity is directed north-south, consistent with the current meter observations. Since the motions are quasi-geostrophic, a corresponding distortion of the density field should be evident.

A spatial grid of deep hydrographic stations was made from the USCGC *Evergreen* near Site D in February 1972. The results of these observations are not clear due to difficulties arising from poor weather and spatial variability associated with internal waves of corresponding horizontal scale. An array of four near-bottom moored current meters was set in July 1972, three of which were recovered in December 1972. These moorings, embedded in the large-scale array at Site D, were placed to examine the spatial variability on scales of 5 to 20 km. The analysis of the data is in progress.

A series of 80 vertical profiles of the current was made with a free-fall electromagnetic current meter near Site D between 21 August and 15 September 1972. The profiles were obtained over a variety of spatial and temporal scales. Much of the high-mode vertical structure can be associated with near-inertial currents. The lower vertical-mode structure, associated with longer time scales than inertial, was observed to vary over horizontal scales as small as a few kilometers, indicating that this variability may be dominated by advective, rather than wave-like processes. Without the intercomparisons with the current meter data and further analysis, we are as yet unable to establish the existence of bottom-intensified topographic waves.

MID-OCEAN DYNAMICS EXPERIMENT

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

Data obtained prior to 1971 from the interior of the Northwestern Atlantic appeared to demonstrate the existence of energetic, low frequency, mesoscale motions (amplitudes of about 10 cm/sec., periods of tens of days, and horizontal wavelengths of tens of kilometers). To obtain a broader data base for the design of MODE-I, several pilot experiments (collectively called MODE-0) were carried out in 1971-1972. The preliminary choice of location for MODE was in the vicinity of 28°N, 70°W. This area is centrally located in the Western North Atlantic out of the immediate influence of the Gulf Stream, has both smooth and rough bottom topography, and is compatible with SOFAR float-tracking requirements. The pilot experiment referred to in the following as Array 1 was carried out over flat topography. Another experiment, called Array 2, was carried out over rough topography with an E-W trend.

A major result from both Arrays 1 and 2 is that low-frequency motions were coherent over the depth and horizontal scales sampled. We found what we were looking for: energetic motions at roughly

the anticipated time and space scales (Fig. PO-4). These scales are:

Time Scale. Fluctuations with periods longer than one day (low frequency) contribute 50 percent or more to the total kinetic energy. Dominant low-frequency motions have periods from 50 to 150 days.

Vertical Scale. About three-quarters of the low-frequency energy is associated with vertical wavelengths of half the ocean depth and longer.

Horizontal Scale. Data from Array 1 and the U.S.S.R. Polygon Array in the Eastern Atlantic indicate that the low-frequency horizontal flow field exhibits a coherent pattern that is at least the size of the arrays (200 km in each case). There is a striking similarity in pattern between Array 1 and the Polygon Array. A gross description of the pattern would be a closed circulation or eddy translating (maybe) with a westward component, having a residence time over the array of about 60 days, followed by a similar pattern with a reversal in sense of circulation. The sense of circulation above 1000 m is opposite to that at 1500 and 4000 m.

The interpretation of the results from Array 1 is impeded by questions on the effects of mooring motion on velocity measurements. Two types of moorings were used in the arrays. Surface moorings use as buoyancy an eight-foot diameter toroidal buoy at the sea surface. Subsurface moorings use buoyancy below the sea surface in an effort to decouple the mooring line from surface wave motion. The records from Array 1 show that for any depth the values for the mean magnitude of the current vector and for the vector variance are greater for records taken from surface buoys. The energy differences are not confined to any dominant frequency band, but are spread over the spectrum. It is well known that records from surface moorings contain more high-frequency fluctuations than those from subsurface buoys, but differences at low frequencies (in this experiment) were an unexpected result. Data from Array 2 gave a similar result. Data acquired after Arrays 1 and 2 were retrieved suggest that intermediate mooring motion is not the source of the discrepancy at low frequencies.

Eddies, Waves, and Turbulence (Peter B. Rhines)

The long-term object is to study the interplay of wave propagation and turbulent interaction in the ocean and atmosphere, particularly in flows of large (geostrophic) scale. This step is dictated, in part, by the obvious limitations of the linear theory of wind-driven ocean currents and waves. The studies to date have included, via theory and computer experimentation: the beta effect (due to the earth's curvature and rotation), sloping or rough bottom topography, geostrophic turbulence (i.e., strong currents), and density stratification.

Some of the more striking effects: if started off with a definite length-scale and allowed to evolve freely without forcing, a simple pattern of eddies will (1) propagate (sloping topography or beta), (2) fragment into smaller eddies (rough topography), (3) "cluster" into ever larger eddies (strong currents, no beta, no topography, small initial eddy size), (4) fragment to release potential energy (density stratification, large initial size), or (5) intensify and fragment near the sea bed (rough topography, density stratification). There is thus a dismaying number of fates that the flow field may have. Eddies can grow either smaller or larger, become faster or slower, and their location in space vary widely, depending on the relative balance of these effects. Smooth restoring forces like beta, or a sloping bottom can, however, halt the changes in eddy size; in particular, turbulent eddies which have clustered to a diameter of about π x (r.m.s. fluid speed/beta)$^{\frac{1}{2}}$ $\simeq$ 200 km in the ocean will assume the character of Rossby waves, and later changes of scale will be slight.

Such study is aimed at understanding the transient flows in the western Sargasso Sea, being observed in MODE. At the same time, efforts have been made to apply theory more directly to sea-going measurement problems, for instance, suggesting array design over rough topography, placement of pressure gauges relative to current meters, and inference of length scales from time-series of currents obtained at a single location. Other strictly theoretical studies are under way: the deepening of the wind-mixed layer, simple models of wave-turbulence interaction, and of wave-wave interaction.

Structure of the Main Thermocline (Eli J. Katz)

A study of the spatial description of a density surface in the main thermocline south of Bermuda was continued. Additional observations were made in February and October 1972 that concentrated on defining the constancy in time of the vertical displacement of the density surface, the amplitude of the mean trend in the depth of the density plane and the shorter, wave-like, vertical displacements from that plane, and the directionality of these latter displacements. The spectra of the vertical displacement from the February observations were compared to those obtained in 1971. Combined, they

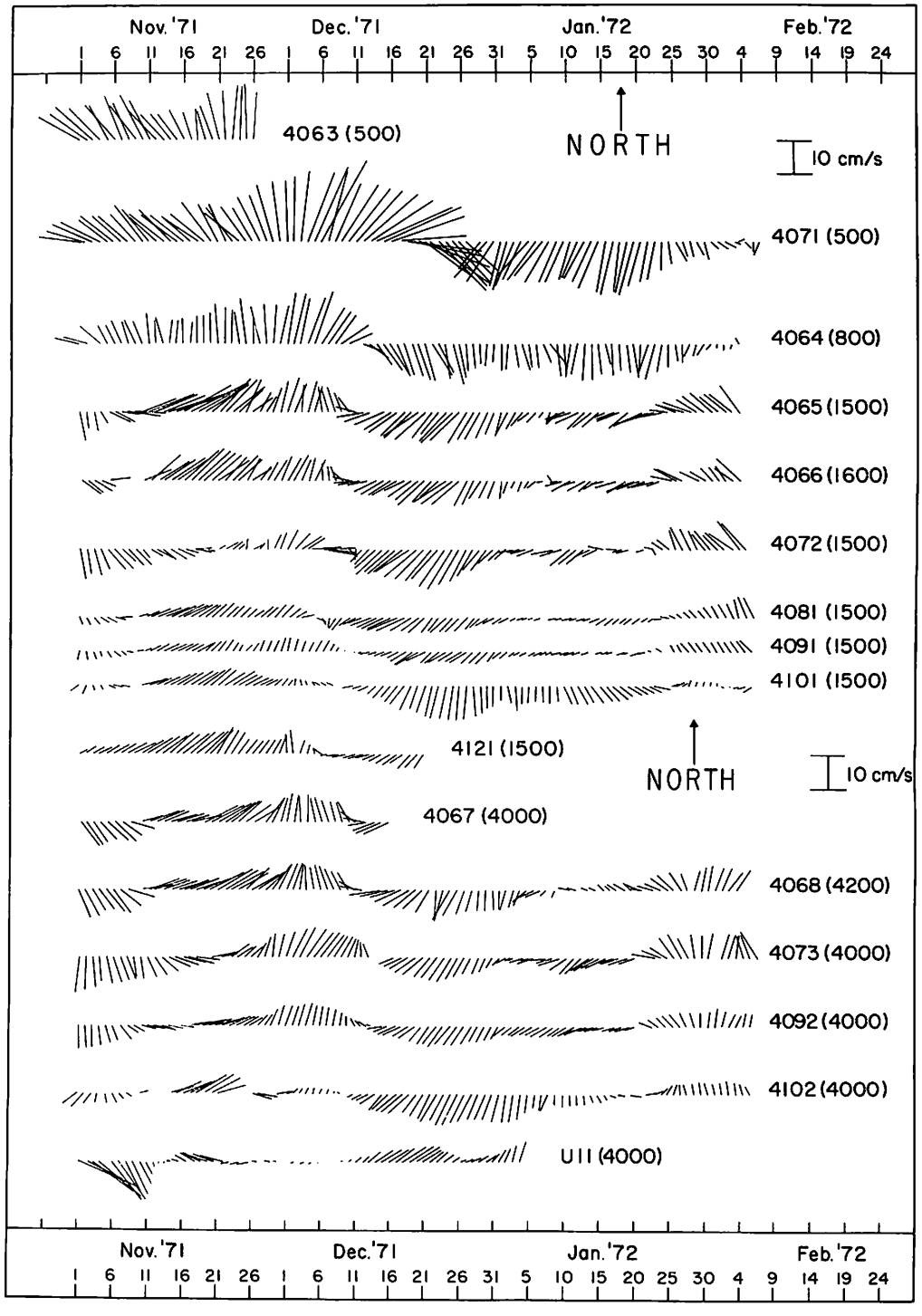

Fig.4 (Fofonoff, Schmitz and Webster) Sequential horizontal velocity vectors for the good data from Array 1. The first number identifies the record; nominal depths are in parentheses.

cover a range of wave numbers, K, of 0.02 to 5.0 cycles/km. The level of the spectra are closely comparable, and no statistically significant energy peaks appear. The spectra approximate a wave number dependency of $K^{-3/2}$, which differs substantially from a recently hypothesized -2 dependency based on a small sample of previously reported data.

The above measurements were made by towing STD sensors on a tow cable above a dead weight "fish". By placing two sound velocimeters 20 m apart on the cable, measurements were made of the vertical temperature gradient about the isopycnal surface. The distribution of the gradient was found to be near to Gaussian with a deviation equal to 1/4 of the mean value. This result complements other reported work from vertically separated sensors on mooring lines.

In an effort to refine the observations of the shorter wavelength vertical displacements, a new tow body was developed (described elsewhere by R. T. Nowak). Its essential feature is a variable lift which can be controlled from shipboard and, eventually, by computer.

SOFAR Float Program (Arthur D. Voorhis)

In the spring of 1973, we plan to launch 20 SOFAR floats in the MODE area (centered near 28°N, 70°W) to measure currents for at least four months over horizontal scales of several hundred kilometers. These floats are large, neutrally buoyant, vertical cylinders, ballasted to drift freely at a depth of 1500 m near the axis of the SOFAR sound channel. Each float contains batteries and is equipped with a sound projector that radiates sufficient power for the float to be detected and tracked acoustically for four to six months at shore listening stations in Bermuda, Puerto Rico, Grand Turks Island, and Eleuthera. The design, construction, and testing of these floats is under the direction of D. C. Webb in the Department of Ocean Engineering.

Ten of these floats have been equipped to sense and record pressure, temperature, and vertical current as they drift. In November, this sensing system was tested successfully on a cruise to the MODE area. At present, two SOFAR floats are being tracked successfully from shore as they drift through the MODE area. They will be recovered in March 1973, their data removed, batteries recharged, and then relaunched for the MODE-I experiment.

MODE Hot Line News (Ferris Webster and Kathleen Daly)

The *MODE Hot Line News*, a biweekly newsletter, was begun in March to disseminate information about the scientific progress of the Mid-Ocean Dynamics Experiment (MODE). It also acts as a forum for timely discussion of MODE problems and is composed almost entirely of contributions from the scientists participating in MODE.

The *MODE Hot Line News* has been issued to a steadily growing circulation list, now comprising about 80 oceanographic institutions and groups throughout the world. It is a new form of scientific communication and, to judge by submitted contributions, fills a useful role in helping to unify the complex activities in the Mid-Ocean Dynamics Experiment.

MOORED ARRAY EXPERIMENTS

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

A total of 58 moorings were set during 1972 in a variety of scientific and engineering experiments. About a third of the moorings were devoted to preliminary measurements for MODE-I (Mid-Ocean Dynamic Experiment to be carried out during March-July, 1973). Major experiments were conducted to examine low-frequency variability at Site D and the deep-water motions of the Gulf Stream south of the Grand Banks.

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 and James R. Luyten)

Previous observations indicated that currents at Site D (39°20'N, 70°W) are remarkably incoherent at short periods; even tidal motions are horizontally 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 quasi-barotropic. There is evidence in the Site D records for topographic Rossby waves with constant phase lines running NNW to ESE.

An array of moorings in the slope water near Site D was resumed in February to explore the spatial structure of the currents. Since the motions of interest have periods of about a month, the experiment was planned to last 18 months, so results at present are preliminary. The first three sets of moorings, through December, have been recovered, and the data has been processed for the first two sets, through August. The preliminary results are consistent with the previous picture, though more data are necessary before firm statements can be made. Low-frequency current measurements 50 km apart at 1000 m depth appear to have considerable coherence though phase lags cannot yet be distinguished. Three Gulf-Stream eddies passed through the array (in April, August and December), which is good for studying the physics of eddies, but obscures the physics of the topographic Rossby waves. Some remarkable inertial oscillations have been associated with the eddies.

Further study of the dynamics of Rossby waves has made the theory more coherent. It has been shown that for arbitrary stable stratification, and including the beta-effect, upward slope of the bottom toward the pole causes Rossby waves of arbitrary frequency to have opposite poleward components of group velocity and momentum flux. Thus, "negative viscosity" becomes a simple property of Rossby waves. The theory seems consistent with observations around Site D, as well as in the atmosphere.

Small-Scale Processes (Gerold Siedler)

An experiment was carried out late in 1971 to study spatial scales of internal waves in the deep ocean. Two identical moorings were set at Site D on December 10 and 11 and recovered on December 20. In order to measure horizontal coherence of the currents in the internal gravity wave frequency band, a mooring separation of less than 1 km was estimated to be necessary. The actual mooring separation was measured over two periods of 20 hours using acoustic techniques. Although the moorings moved with inertial period as indicated by a recording pressure meter, the mooring separation of 920 m changed less than ± 10 m.

Six current/temperature meters and four additional temperature meters were placed at 50 m vertical separations at depths between 500 and 600 m. Good records were obtained from four current/temperature meters and from all temperature meters.

In addition to the mooring work, hydrographic data were taken by Nansen casts and a Bissett-Berman STD to obtain the Brunt-Väisälä frequency distribution and to study the temperature fine-structure in the depth range where the moored instruments had been placed. The local Brunt-Väisälä frequency was approximately 1 cph.

The current/temperature data indicated high coherence and zero phase at low frequencies in the internal wave range. The horizontal coherence dropped below 0.5 at frequencies between 0.3 and 0.4 cph. It was low at higher frequencies except for a small additional peak at 0.55 cph. The results for vertical coherence are similar to those obtained at Site D from earlier measurements (Webster, 1972).

The coherence for horizontal separations was compared with the internal wave model developed by Garrett and Munk (1972). Data and model only agree by reducing the number of modes in the model.

Furthermore, it was possible to study the fine-structure contamination of temperature records from moorings using repeated temperature profiles from STD lowerings. When computing the vertical wave number spectra of the temperature fine-structure, it appeared that these spectra could be described by a power law with an exponent close to -3 over a range corresponding to wavelengths between approximately 100 m and 1 m. Following the ideas of Phillips (1971) and Garrett and Munk (1971), the above power law and the results from current and temperature frequency spectra could be used to develop a model describing the influence of fine-structure on the determination of vertical velocities from temperature time series in the presence of internal waves. The model indicated a considerable fine-structure contamination at frequencies in the middle of the internal gravity wave band and less contamination at lower and higher frequencies.

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SCOR WG21 Current Meter Intercomparison Experiment (Kirill A. Chekotillo, William J. Gould and Stanley Hayes)

Under the sponsorship of the Scientific Committee on Oceanic Research (SCOR) Working Group 21, the comparison of current meters was continued in 1972. Two current-meter moorings, one with surface buoyancy, the other with a subsurface buoy, were set at Site D in August 1972. The moorings carried groups of Alexaev (USSR), Geodyne (USA), LSK (GDR) and VACM (USA) current meters at 50 m on the surface buoy and at 200 and 1000 m on both buoys. The moorings were separated horizontally by 400 m and were in place for 11 days.

Severe damage was sustained by the deepest instruments on the surface buoy. Preliminary comparisons between instruments show good agreement within the groups on the subsurface buoy. In every group on both moorings there is a clear relationship between values of mean velocity, speed and vector variances and tidal and inertial energies for the various instruments. The results show that the Alexaev instruments give the highest values, VACM next and Geodyne lowest. The LSK data have not yet been analyzed.

Studies of Tidal Currents (William J. Gould, William D. McKee and Lorenz Magaard)

Current meter data from two locations, Site D and a position on the continental slope in the north of the Bay of Biscay, have been used to investigate the modal structure of horizontal ocean currents. The results from both sites give data for the barotropic component that are in good agreement with theoretical predictions of Pekeris and Accad. The data from the Bay of Biscay reveal very different distributions of energy between the modes for the solar and lunar semidiurnal species with the former having mostly baroclinic energy and the latter mostly barotropic.

Muir Seamount Experiment (Carl I. Wunsch and Ross Hendry)

A four-month experiment was carried out with two current meters on a single mooring during the fall of 1972. The mooring was placed near Muir seamount at 32°N to study the time-dependent baroclinic motions associated with the seamount. Two primary phenomena are of interest. (1) Baroclinic diurnal tides are usually absent or very small in most of the current meter records collected to date. Two reasons for this can be identified. The ordinary surface diurnal tides are weak in the north Atlantic, and most currents have been measured north of 30 degrees latitude where the baroclinic tide cannot propagate as free internal waves. However, near topographic features like seamounts, the baroclinic tide can exist as a trapped mode, trapped vertically and horizontally. The current measurements will be used to compare the diurnal and semidiurnal (not trapped) tidal energies near Muir seamount. (2) Seamounts should also have a spectrum of trapped oscillations at non-tidal frequencies. A comparison of energies near the seamount and at some distance away should indicate whether these additional trapped modes are indeed excited.

The Influence of Mooring Type on Current Measurements (William J. Gould and Edmund Sambuco)

The statistics of current measurements at Site D at all depths have been studied. The data represent some 2800 current-meter days since 1965, and show differences in the mean magnitude of the current vector between observations from moorings with surface and subsurface buoyancy. In every case the surface-buoy data results in larger values, the ratio of the vector magnitudes typically being about 2:1. At the deepest level, 100 m above the sea-bed, the ratio becomes smaller than in the mid depths; the same is also true at the uppermost level observed, 100 m depth.

The origin of the velocity differences may lie in the rectification of high-frequency motions present on the surface moorings by the Savonius rotor current speed sensor. The mechanism is not clear, and further investigations of this phenomenon are in progress.

Hydrographic Data (Nicholas P. Fofonoff, Robert C. Millard, Jr. and Gordon H. Volkmann)

Vertical profiles of temperature and salinity are taken at each site following setting or recovery of an instrumented mooring. The purpose of these observations is to provide environmental data to aid in the interpretation of the time-series data from the moorings.

The observations have been carried out with both standard water-bottle stations and conductivity-temperature-depth (CTD) profiling instruments. Series extending over several years are available for Sites D and L. Observations in the MODE region (28°N, 69°40'W) were started over a year ago.

As a part of the SCOR current meter intercomparison experiment, a special series of stations was taken to compare geostrophic and measured vertical current shear.

Progress has been made in developing a precise, high-resolution profiling system using the conductivity-temperature-depth digitizer developed by N. L. Brown (CTD microprofiler). The CTD has been in use for one year on an experimental basis. A total of 115 stations has been made during eight cruises; and in many cases, Nansen bottles or Rosette samples were taken to determine the stability of the conductivity sensor.

Procedures are being worked out to use the CTD microprofiler routinely. These are being compiled into a manual for future use.

Comparisons with reversing thermometers showed that equilibrium *in situ* temperatures given by the CTD agreed within limits of reading error (±0.005°C) of the thermometers. However, corrections for the finite lag of the temperature sensor must be applied to the measured temperatures to maintain acceptable accuracy at normal lowering rates.

The conductivity sensor has not shown acceptable stability for dependable routine use. The drift can apparently be minimized by adequate cleaning of the sensor. Because of the special handling required, the CTD remains in an experimental status and has not yet replaced the Nansen bottle stations for routine observations.

The potential of the CTD microprofiler for examining microstructure has just begun to be explored. Preliminary calculations of wave number spectra of temperature variability yield power laws of the form $E = k^{-2.5}$ with energy density varying approximately as the square of the mean temperature gradient (Fig.5).

The bottom homogeneous layer along the Continental Shelf margin was studied with the CTD. Examination of bottom sediments using TV and 35 mm cameras from the *Alcoa Seaprobe* showed coarse-grained sediments in the mixed bottom layer and fine-grained sediments where the layer is absent. This suggests that stronger currents are associated with the mixed layer that inhibit deposition of the fine-grained sediments.

Instrument Development (James R. McCullough and Richard L. Koehler)

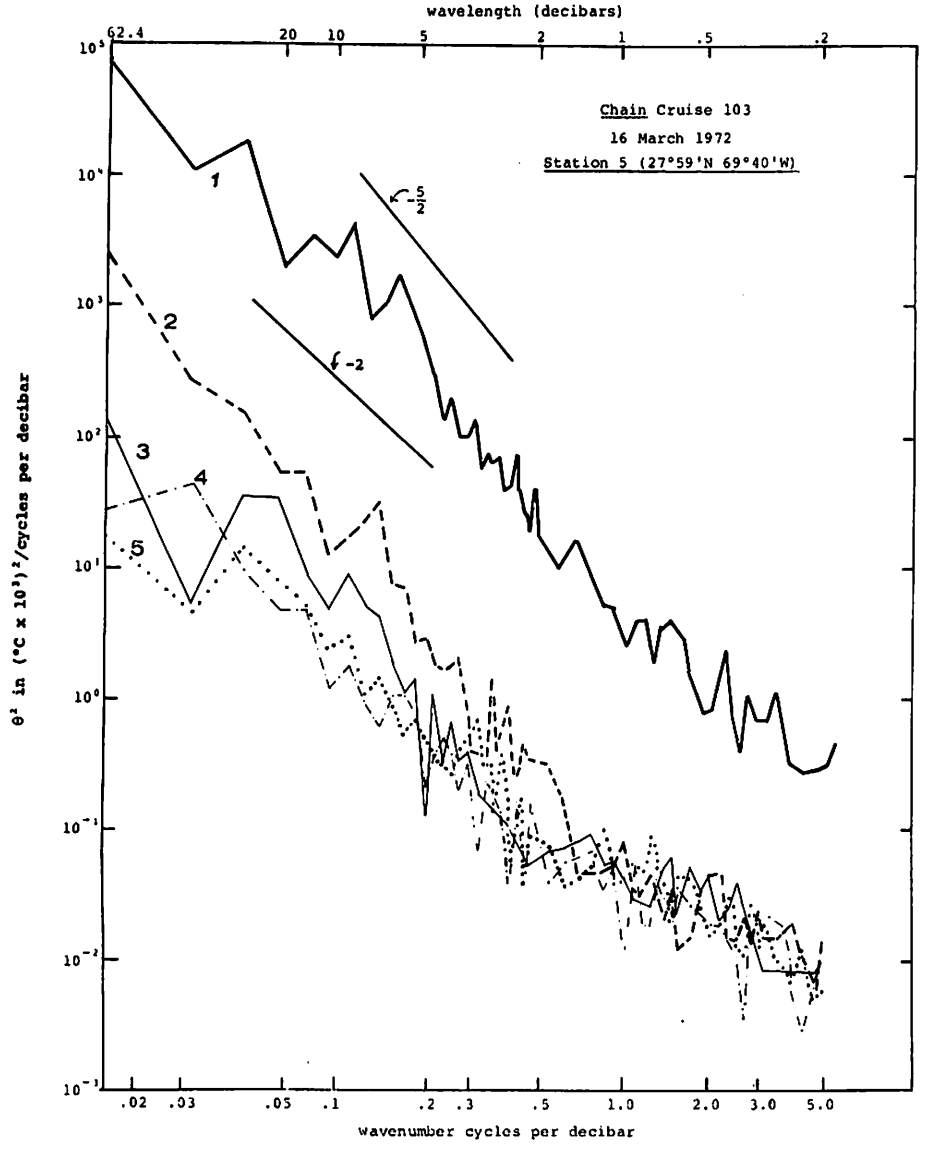
Work with the new vector-averaging current meter (VACM) continues. During the year, 46 instruments were constructed and are now used routinely at sea.

A new cassette tape recorder with a capacity of 10^7 data bits was developed and tested at sea. It is now being used in the VACM and other oceanographic instruments. Two tape playback systems and associated computer programs for the recorder were developed. Test equipment, test procedures and an operating manual for servicing the VACM's have been completed. Studies of the rotor and other current sensors were started. Techniques of precision temperature measurement from moored instruments are being developed and tested at sea.

Moored Array - Data Processing (John A. Maltais)

Data from 110 current meters and three wind recorders were processed, representing a two-fold increase in data volume over the preceding year. Thirty-four percent of all current meters also recorded temperature.

Several new programs were developed in the course of the year for assisting the operations group in the quick evaluation of instrument performance, for decoding the new vector-averaging current meters (VACM's), and for the processing of non-time-series data.



	water type	pressure interval (decibars)	$\langle\theta^2\rangle \equiv$ total temp. variance, $(°C \times 10^3)^2$	temp. grad. variance, $\langle T_p^2\rangle$	temp. grad. T_p $\left(\frac{°C \times 10^3}{\text{decibar}}\right)$	Brunt-Väisälä N (cph)	A $\frac{\langle\theta^2\rangle}{N^4}$	B $\frac{\langle\theta^2\rangle}{\langle T_p\rangle^2}$	C $\frac{\langle T_p^2\rangle}{\langle T_p\rangle^2}$	D $2\pi\sqrt{\frac{\langle\theta^2\rangle}{\langle T_p^2\rangle}}$ decibars	E $\frac{\langle\theta^2\rangle}{N^{-1}\langle T_p\rangle^2}$
— 1	Western North Atlantic Water	570-882	1.982×10^3	1378	26.0	2.74	35.2	2.9	2.04	7.54	7.95
-- 2	Mediterranean Water	1532-1844	5.15×10^1	23.7	1.16	.78	139.2	38.3	17.6	9.24	29.87
— 3	North Atlantic Deep Water	2432-2744	4.38	18.7	.84	.56	44.7	6.21	26.5	3.04	3.48
- - 4	North Atlantic Deep Water	2972-3284	1.73	14.7	.60	.45	42.2	4.81	40.4	2.16	2.15
.... 5	Antarctic Bottom Water	5000-5312	1.20	17.1	.21	.42	38.7	27.2	388.0	1.67	11.46

Fig.5 (Fofonoff, Millard and Volkmann) The vertical wavenumber spectra and summary table.

Operations (Robert H. Heinmiller)

The Operations Group participated in a total of fourteen cruises during 1972. Moorings were deployed primarily at Site D (39°10'N, 70°00'W) and the adjacent New England Slope, the Gulf Stream and the MODE Site (28°N, 70°W). Long-term, continuous mooring series were maintained at Site D and in the MODE region.

All moorings set in 1972 are shown in Table I. Three moorings were lost. No trace could be found of mooring 425, a surface mooring, and there were no acoustic contacts with moorings 457 or 461, both with subsurface buoyancy.

TABLE PO-I

MOORINGS SET IN 1972

No.	Month Set	Location	Type	Duration (Days)	Recovery	Notes
422	Feb.	New Eng. Slope	Intermed.	108	Complete	Long-term slope array
423	"	"	"	108	"	
242	"	MODE	Surface	112	"	Site maintenance moorings
425	"	"	"	-	Lost	
426	Mar.	Caribbean	Bottom	39	Complete	Caribbean overflow (Metcalf and Stalcup)
427	"	"	"	39	"	
428	"	Site D	Surface	1	"	Engineering test--faking box
429	"	"	"	172	"	Routine long-term measurements
430	"	MODE	Intermed.	68	"	MODE 0, Array 2
431	"	"	"	68	"	
432	"	"	"	1	Complete (Aborted)	
433	"	"	"	68	Complete	
434	"	"	"	67	"	
435	"	"	"	67	"	
436	"	New Eng. Slope	"	71	"	Engineering test--Syntactic Floats
437	Apr.	Gulf Stream	Bottom	59	"	Gulf Stream array (Warren and Worthington)
438	"	"	"	58	"	
439	"	"	"	56	"	
440	"	"	"	56	"	
441	"	"	"	56	"	
442	"	"	"	56	"	
443	"	"	"	55	"	
444	"	"	"	54	"	
445	"	"	"	54	"	
446	"	"	"	53	"	
447	"	"	"	52	"	
448	"	"	"	52	"	

TABLE PO-I (continued)

MOORINGS SET IN 1972

No.	Month Set	Location	Type	Duration (Days)	Recovery	Notes
449	May	New Eng. Slope	Intermed.	102	Complete	Long-term slope array
450	"	"	"	102	"	
451	"	MODE	Surface	162	"	MODE 0, Array 3
452	"	"	Intermed.	161	"	
453	"	"	Surface	158	"	
454	"	"	"	156	"	
455	"	"	"	160	"	
456	"	Muir Seamount	Intermed.	147	"	Tidal studies--Wunsch
457	"	"	"	-	Lost	
458	July	New Eng. Slope	"	147	Complete	Low-frequency variability array
459	"	"	Bottom	150	"	
460	"	Site D	"	150	"	
461	"	"	"	-	Lost	
462	"	New Eng. Slope	"	21	Complete	Internal wave experiment
463	Aug.	Site D	Surface	11	"	SCOR WG/21
464	"	"	Intermed.	11	"	
465	"	New Eng. Slope	"	103	"	Long-term slope array
466	"	"	"	101	"	
467	"	Site D	Surface	1	"	Routine measurements (aborted)
468	Sept.	"	Intermed.	99	"	Routine long-term measurements
469	Oct.	MODE	"	6	"	Mooring motions experiment
470	"	"	Bottom	7	"	
471	"	"	"	7	"	
472	"	"	"	7	"	

TABLE PO-I (continued)

MOORINGS SET IN 1972

No.	Month Set	Location	Type	Duration (Days)	Recovery	Notes
473	Oct.	MODE	Intermed.	-	-	Site maintenance moorings (still at sea)
474	Nov.	"	"	-	-	
475	Dec.	Site D	Bottom	5	Complete	Transponder test
476	"	"	Intermed.	1	"	Faking box test
477	"	"	"	-	-	Routine measurements (still at sea)
478	"	New Eng. Slope	"	-	-	Long-term slope array (still at sea)
479	"	"	"	-	-	

OCEAN AND ATMOSPHERE

Air-Sea Exchange (Peter M. Saunders)

In an attempt to explore the space and time variability of the upper 100 m of the ocean and the oceanic response to atmospheric inputs, an experiment (named JASIN) was performed in the Eastern Atlantic in collaboration with scientists from a number of Institutions in the United Kingdom. The experiment lasted a month and involved three ships and seven instrumented moorings.

Ocean currents were measured on the moorings, and time variability in the thermal structure was measured by N. L. Brown from repeated shallow dips with the new Conductivity-Temperature-Depth micro-profiler. Some observations were made of well-defined internal wave groups on the seasonal thermocline in calm, undisturbed conditions. Measurements of the spatial variability of the upper ocean were made by P. M. Saunders from a four-engined aircraft which flew nearly 150 hours during the experiment, employing radiation thermometers and air-dropped BT's. A weak thermal front, found aligned roughly north-south in the working area, persisted for the entire month.

Assuming accurate estimates of heating and cooling in the upper mixed layer are available on a daily basis, then corrected surface temperature can be treated in the short term as a conservative quantity and employed to map the flow. The ambiguity inherent in this technique can probably be removed by a few simultaneous current measurements, and thus synoptic maps of flow in the upper ocean can be generated. Interactions of the fields of flow in ocean and atmosphere can then be explored over a region rather than be confined to pointwise interactions.

Remote Spectroscopy of the Sea for Biological Production Studies (Gifford C. Ewing and George L. Clarke)

The primary thrust of these investigations has been to demonstrate the feasibility of remotely detecting differences in the color of the emergent light scattered upward through the sea surface at levels of discrimination pertinent to the study of biological productivity and physical oceanography. These results, documented in the literature, have been repeated and elaborated by several other investigators, and recognition of water color as a useful oceanographic parameter is well established.

Partly as a result of this research, the Earth Resources Technology satellites now orbiting or scheduled for use in the 1970's, as well as Skylab and other systems for studying the earth from synchronous and orbiting satellites, will carry color sensors suitable for acquiring repetitive global data on ocean color. ERTS A, orbited in July, is presently producing high quality imagery in four spectral bands.

With the advent of satellite ocean color information now made readily accessible, research emphasis naturally turns toward interpretation and analysis of the new material and its application to classical oceanographic problems. These data have been used to describe the distribution of biological productivity in the surface of the ocean as inferred from concentration of chlorophyll *a* and related biochromes. As a means of specifying ocean color numerically in a manner sufficiently concise to permit mapping, a color index was adopted equal to the ratio of green (540 nm) light to blue (460 nm). This index is characteristically .5 for blue, sterile oceanic water and progressively higher for water containing increased concentration of chlorophyll. As an objective test of this as an indicator of productivity, a map of the route of our 1970 flight over the Caribbean, Gulf of Mexico and Gulf of California was prepared (Fig. PO-6). Although data from many different altitudes was obtained, the figure has been drawn for those data obtained at 610 and 1524 m. Over most of the Caribbean and Gulf of Mexico the color ratios are uniform and of the type associated with low chlorophyll concentrations.

Spectra obtained over the Campeche Bank, shown in Fig. PO-7, indicate high turbidity and high chlorophyll concentration. This was confirmed in flight by bathyphotometers. The observed high color index is to be expected in view of the well-known productivity of this area which supports the major shrimp industry of the Caribbean.

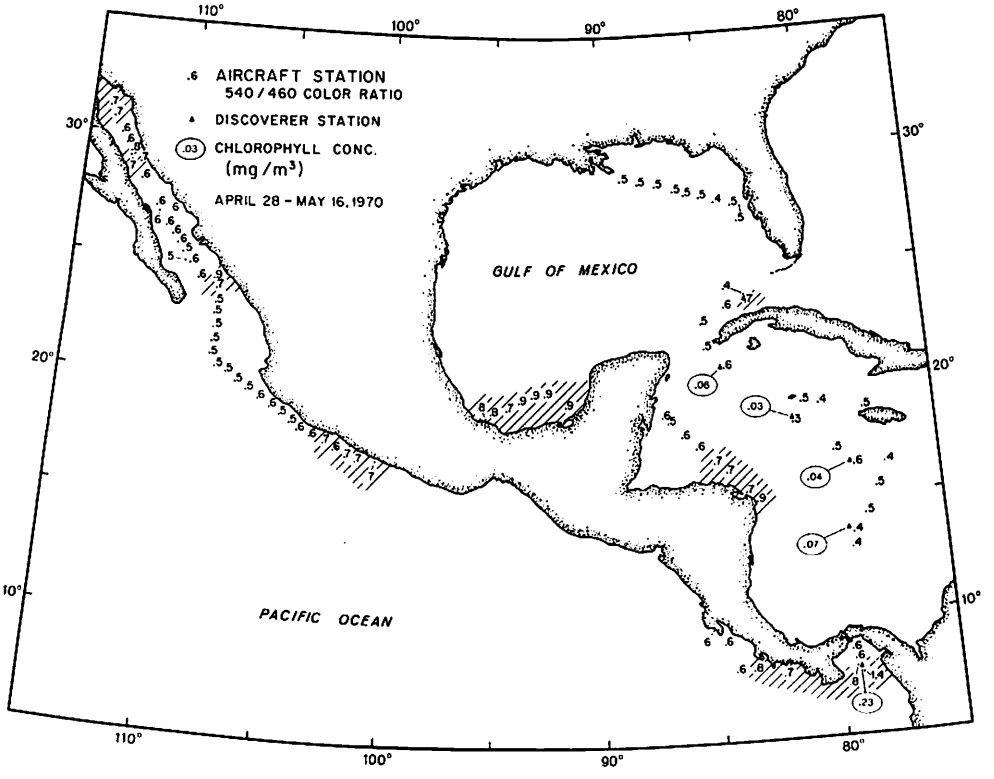


Fig.6 (Ewing and Clarke) Preliminary estimate of the distribution of discolored water along flight track. Shaded areas correspond to 540/460 nm reflectance ratios equal to 0.7 or more. Station locations for R/V *Discoverer* are shown together with notation of the measured chlorophyll concentration.

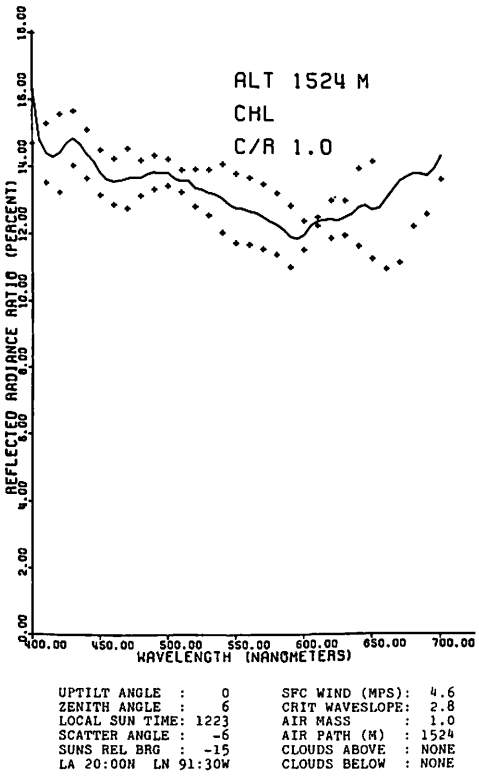


Fig.7 (Ewing and Clarke) Graph of data obtained over the shrimp beds of Campeche Bay.

Marine Geodesy and Satellite Altimetry (William S. von Arx and Jerome P. Dean)

The project aim is the realization of global ocean geoidal topography from an orbiting altimeter, from which time-varying oceanographic phenomena can be observed. The GEOS-C satellite will carry the first such altimeter and is now scheduled for launch in mid-1974. For calibration purposes, computations of geoidal topography from geophysical (gravity) and oceanographic data must be made for certain areas.

Technological advances in the gravity measurement system include installation and initial tests of a new gravimeter platform and improvements in the VSA gravimeter electronics to increase accuracy and improve reliability of the seagoing system.

Data reduction of an Atlantic equatorial gravity traverse has been completed, and studies are being conducted to develop new computational methods for the treatment of gravity data in the determination of geoidal heights; and new programs are being used to realize improvements in accuracy of gravity values by more accurate determination of the eötvös correction and removal of nonphysical discontinuities in the gravity results by renavigation techniques.

Analysis of Data from the Experimental Environmental Research Buoy (XERB) (Joseph Chase and Charles E. Parker)

Analysis of the data from the Experimental Environmental Research Buoy EBO-1 has been following two main lines. The influence of the sea on the air above the buoy has been studied, one object of which is to be able to extrapolate the heights of the 700 and 500 mb surfaces. Extrapolations from the EBO-1 data can be made with operational accuracy, and the system can be used on the data from environmental buoys in the Gulf of Mexico.

The position and speed of the Gulf Stream relative to EBO-1 has been examined since February 1970. We are attempting to link these variations with season and with wind.

Turbulence and Fluxes in the Trade Wind Boundary Layers (Andrew F. Bunker)

The central question is, "How and why do the turbulence and fluxes within the boundary layer of the undisturbed trade winds differ from the values observed when the trades are modified by large-scale disturbances?" A corollary question is, "How do the turbulence and momentum flux modify the wind distribution?" To answer these questions, aircraft data of turbulence, turbulent fluxes and clouds obtained during BOMEX (Barbados Oceanographic and Meteolorogical Expedition) are being analyzed and compared with wind profile data obtained from ships. The three sets of data compliment each other since the aircraft data give the details of the turbulence and transport of momentum and the distribution of convective clouds, while the upper air data give the wind profiles which represent the net influence of the turbulence and all other processes, which are numerous and poorly understood. These processes include: the thermal winds, variations of the semidiurnal pressure, variations of the frictional forces, instabilities of the Ekman boundary layer, and variations introduced by the presence of cumulonimbus clouds.

The range of turbulence, expressed as the standard deviation of the vertical velocities, was greater under disturbed conditions than under undisturbed conditions. Lower values were observed as well as the expected higher values. Analysis of the turbulence records in the neighborhood of cumulonimbus clouds showed that the turbulence drops to a minimum three shower-diameters from the shower which is lower than the general turbulence in undisturbed regions. A weak maximum is observed 10 diameters from the shower. These features are associated with the downward flow of the environmental air, compensating for the upward flow within the shower. The maximum appears to be associated with an outflow of air from the shower within the boundary layer.

The wind profiles have been studied in an attempt to understand the processes operating in the boundary layer which determine the wind vs. height distribution. It was found that at Station BRAVO, the northeastern corner of the BOMEX ship array, a fairly regular diurnal variation of the wind occurred in response to the semidiurnal pressure variation. Work is in progress to determine whether a diurnal variation of the frictional force in the boundary layer is a process capable of suppressing the accelerations associated with the daytime semidiurnal pressure waves so that only a diurnal wind variation is obtained.

The wind profile does not conform to the classical Ekman wind spiral. The thermal wind is one cause of the difference, but even when this is corrected, the agreement is poor. The corrected profiles have some similarities to profiles associated with instability flows in the boundary layer. A major difference is a pronounced maximum in the u-component of the wind at 150 m. This has a diurnal variation, being most pronounced at 0200 LST and under disturbed conditions. Analysis is being continued to determine how this maximum is related to the semidiurnal pressure variations, frictional force variations and accelerations of the air at several levels.

Genesis of Hurricane Agnes (Jerome Namias, *Rossby Fellow*)

A study of the birth and behavior of hurricane Agnes as it progressed over eastern United States in June 1972 was conducted in order to learn more about erratic flood-producing storms of this type. The research led to study of two primary genetic factors--a strong polar outbreak deep into the Gulf of Mexico and the occurrence of an "El Niño," or exceptionally warm sea surface, off Peru. Satellite cloud pictures were employed to show that a large convective cloud cluster moved northward from off Peru and apparently formed the "nucleus" of hurricane Agnes after colliding with a large mass of cloud at the cold front. The subsequent aberrant path of Agnes after landfall was blocked from pursuing the normal eastward course out over the Atlantic by an unusually strong and northward displaced Bermuda anticyclone. The study indicates that this large-scale steering pattern may have been rendered stable for several months by sea-surface temperatures in the North Atlantic which were closely coupled with the prevailing wind systems.

OCEAN CIRCULATION

Gulf Stream Studies (Frederick C. Fuglister)

A review of all the available hydrographic station data (including STD, XBT and BT observations) taken along or near the 50th meridian, south of the Grand Banks clearly shows the variable nature of the current structure at this longitude. To date there are 20 sections, made up of regularly-spaced observations and extending south from the Grand Banks to at least 38° north latitude. Except for September and December, all months are represented but no seasonal trend in the current structure is evident.

These sections show only the east-west components of flow, and the pattern of flow in the area at the time of each section can be interpreted in a number of different ways. In general, there is both easterly and, to a lesser extent, westerly flow in varying positions across the sections; disregarding the obviously colder, fresher water of the Labrador Current at the northern end of the sections, the remainder can be interpreted as showing:

1. One very broad ($\simeq$ 200 miles) current flowing to the east but generally containing within its structure streaks and swirls that produce, perhaps short-lived, counter currents and (or) eddies. This broad current could be called the Gulf Stream or the Atlantic Current.

2. One moderately wide (50-60 miles) current that meanders toward the north or south, crossing and recrossing the 50th meridian; this could also go by either name.

3. Two essentially different easterly currents generally separated by a relatively weak counter-current. McLellan (1957) called the current to the north the "Slope Water Current", changing the name to "Atlantic Current" at this meridian; for the current to the south, he retained the name "Gulf Stream".

4. A single "primary" current with an anticyclonic ring to the north of it or a cyclonic ring to the south of it.

The Gulf Stream System in the western North Atlantic cannot be described properly until the variable current pattern in this area south of the Banks is more fully understood. A preliminary look at the data recently obtained from the area to the east only confirms the variable nature of the system.

Reference

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Current System Southeast of Newfoundland (L. Valentine Worthington and Bruce A. Warren)

Our principal undertaking during 1972 was an investigation of the current system south and east of Newfoundland in collaboration with C. Mann and R. Reiniger of the Bedford Institute of Oceanography. The purpose was to resolve questions concerning the flow pattern in this region: whether the Gulf Stream splits into two branches, or whether the observed currents are parts of a two-gyre circulation system. The field work was done from 4 April to 11 June; ships involved were the *Chain* from Woods Hole, *Hudson* from Bedford, and *Cirolana* from Lowestoft (a latecomer to the project). The observations planned were nearly all carried out successfully despite adverse weather in mid-April.

At the beginning of the cruise the *Chain* set twelve moorings of sixteen current meters in a line along Long. 50°W, crossing the Gulf Stream and associated currents; the *Hudson* added two moorings to this line, and set a second line of eight current-meter moorings to the northeast, which ran westward into the Grand Banks; the *Cirolana*, limited to shallower moorings, set three current meters between Flemish Cap and the Grand Banks. Because of limited ship time, the *Cirolana* moorings had to be retrieved after only about ten days in the water; the other current meters ran for two months. All but one of the remaining moorings were recovered, and nearly all current meters appear to have operated successfully.

After the moorings had been set, the *Chain* and *Hudson* embarked on a large-scale but moderately detailed hydrographic survey southeast of Newfoundland. Properties measured were temperature, salinity, dissolved oxygen and silicate on the *Chain* stations, and these four plus dissolved phosphate and nitrate on the *Hudson* stations. In addition to these stations (65 for *Chain*, 63 for *Hudson*), the *Cirolana* occupied two zonal sections of 27 stations across the northern Newfoundland Basin, thus extending our coverage to the north. Various provisional maps of property distributions were drawn up while at sea, but it is too early at this time for us to have reached a uniform, jointly-agreed interpretation of them in terms of flow pattern (i.e., whether the current system consists of two separate gyres, or a single Gulf Stream which splits into two branches).

During the rest of the project, the *Hudson*, guided by the station observations, engaged in a very detailed survey with 750-m XBT's of the cold tongue which trends southeastward from the Grand Banks, generally overlying the Southeast Newfoundland Rise. (Depending on one's interpretation of the flow pattern, this feature appeared to be either a permanent meander of the Gulf Stream or a pressure trough separating two gyres.) Previous hydrographic surveys (including our own) had indicated this to be a long, narrow, curved, but essentially simple-looking feature. The great detail and rapid coverage allowed to the XBT survey (385 observations), however, revealed that the cold tongue was in fact broken up into several disconnected blobs, not defined at all by the coarser station spacing, and considerably complicating interpretations of the temperature field in terms of flow.

During this second phase, while *Hudson* was surveying the cold tongue, direct current measurements were made from *Chain* using the Autoprobe and Vertical Current Meters (VCM's). The performance of the Autoprobe was disappointing: it had been designed to remain on an isothermal surface for five days at a time and the purpose for this design was to see to what extent water moved up and down the slopes of the isotherms associated with the Gulf Stream. This it never accomplished; the longest dive lasted only 17 hours due to troubles with the control system, and the instrument never settled on an individual temperature surface. Nevertheless, by tracking the Autoprobe when it was drifting in the Gulf Stream and substituting VCM's when the Autoprobe was under repair, three current tracks were established. Of these, two drifted northward (favoring current splitting) and one eastward (favoring two gyres) but due to the complexity of the pressure field according to the XBT's taken both by *Hudson* and *Chain*, no unequivocal answer to the question of which scheme of circulation is more correct has been given. A careful look at the distribution of variables will unquestionably help in interpreting the current records.

World Water Mass Census (L. Valentine Worthington and C. Godfrey Day)

Considerable progress on the water mass census has been made. Data only from cruises in which salinity has been measured to three decimal places have been obtained from the National Oceanographic Data Center. To date, more than 2000 oceanographic stations, most of them from the Indian Ocean, have been scrutinized. About 500 of these have been rejected due to obvious errors of temperature or salinity or because a deeper, better station has been available at the same position. The remaining stations, many of which reach to within a few meters of the bottom, have been interpolated to obtain the depth of each intersection of temperature and salinity. Work charts of the salinity at the potential temperature surfaces 1.0^{o} to 2.0^{o} (by intervals of 0.1^{o}) and 2.2^{o} to 4.0^{o} (by intervals of 0.2^{o}) have been drawn for all the existing high quality data in the Indian Ocean, as have charts of the depths of these surfaces. These work charts have given a further opportunity to scan for data quality, and construction of the fine scale volumetric θ/S diagram in the northern Indian Ocean has begun.

North Atlantic Circulation (L. Valentine Worthington)

The treatise on the general circulation of the North Atlantic is being prepared for publication. As originally planned, it was to have consisted, principally, of circulation diagrams in which the main current systems, such as the Gulf Stream system, were budgeted to the nearest five million m^3/sec. However, it became apparent in 1972 that the lesser circulation--involving formation of the North Atlantic water masses and their interrelationships--was better known than had been expected.

Box models of five layers were constructed: deep water, lower thermocline, mid-thermocline, upper thermocline, and warm water. In each layer the formation and mixing processes are budgeted to the nearest one million m^3/sec. Since the exact quantities of water in each of these layers are known from earlier descriptive work, the average residence time for a given particle of water can be calculated.

For example, the production of North Atlantic Deep Water can be estimated, on the basis of direct current measurements off Labrador, to be 10 million m^3/sec; the volume of the water mass is 62 million km^3, so the average residence time is 196 years. However, the box models show that the supply of deep water for the eastern side of the North Atlantic is as low as one million m^3/sec, and residence times there can be more than 600 years.

Large-Scale Circulation (Bruce A. Warren)

Work has continued, though not as rapidly as had been hoped, on the interpretation of hydrographic data taken east of Madagascar on *Chain* Cruise 99. The purpose of these stations was to determine whether a deep boundary current exists in the southwestern Indian Ocean; unambiguous evidence for such a current was found, but it is clearly much weaker than its counterparts in the South Atlantic and South Pacific Oceans, and the detailed interpretation of the property distributions is less straightforward.

Robert J. Stanley and George P. Knapp III have participated in all these projects, including the investigation of the current systems southeast of Newfoundland which is reported elsewhere.

Some time was also devoted to reduction of data from *Knorr* Cruise 22, which was a project designed to detect effects of seamounts on the path and structure of the Gulf Stream. The major part of this analysis is being undertaken by A. D. Vastano at Texas A & M University.

Primarily to assist in planning future investigations, preparation has begun of constant-level maps, on Mercator projection, of temperature and salinity for the whole world ocean at depths greater than 2000 m. These maps are intended to exploit the great number of modern station data now available, and to indicate deep-water areas or features not satisfactorily resolved.

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

Techniques of geological and physical oceanography were combined in an investigation into the abyssal circulation in the vicinity of the Greater Antilles Outer Ridge north of Puerto Rico. The investigation, which was begun in 1971, was completed in 1972 with two short cruises on R/V *Knorr* and a second setting of current meters on the northwest portion of the ridge. A paper has been prepared for publication.

The hydrography, geostrophic calculations, bottom photography and current meter records all indicate a bottom circulation pattern of Antarctic Bottom Water with a small admixture of North Atlantic Deep Water. The flow is southeastward along the continental margin, then along bathymetric contours counterclockwise around the Silver Abyssal Plain and clockwise around the northwest tip of the Greater Antilles Outer Ridge, and finally southeastward along the northwest flank of the ridge (Fig. PO-8). The source of the Antarctic Bottom Water is a flow to the west through Vema Gap and counterclockwise around the Hatteras Abyssal Plain.

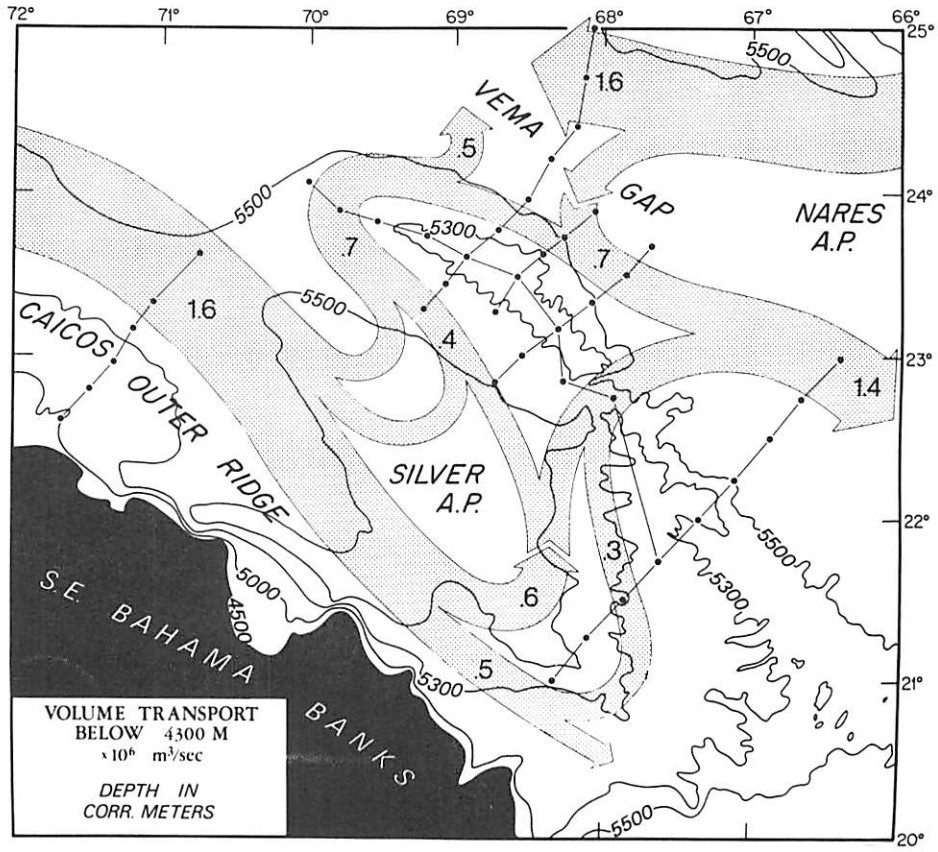

Fig.8 (Wright)

Caribbean Inflow Studies (William G. Metcalf and Marvel C. Stalcup)

Hydrographic stations and current observations from a cruise in February-April 1972 to the northeast passages connecting the Atlantic Ocean and the Caribbean Sea, combined with similar stations and observations made during a 1970 cruise to the southeastern passages, give a long line of closely spaced observations both inside and outside the Lesser Antillean Arc all the way from Puerto Rico to the South American Continental Shelf.

The deepest passage among the islands is the Anegada-Jungfern passage with a controlling sill depth of 1815 m a few kilometers southwest of St. Croix Island (Fig. PO-9). Although direct current observations at the sill showed a small intermittent flow of water of 4°C or slightly colder into the Caribbean at the very bottom of the passage, a comparison of the temperature-silicate relationship of the waters inside and outside the Caribbean indicates that the low silicate Atlantic water of this temperature is never discernible inside the Caribbean more than a very few kilometers from the point of entrance.

A similar type of comparison of the temperature-salinity relationships shows there is virtually no exchange of water between the Atlantic and Caribbean in a layer 600 to 800 m thick above the topographic barrier--a layer with a temperature range between about 4.2 and 5.2°C.

Only water with a temperature of above 6.9° escapes from the Caribbean Sea through the Straits of Florida in any appreciable volume; in the salinity minimum layer which falls between 5.2 and 6.9°, there is a gradient of steadily increasing salinity in the salinity minimum core across the whole basin from east to west. This indicates a steady movement of water at this level across the Caribbean from east to west with the salinity minimum core being gradually eroded by vertical mixing. The speed and volume of this flow is not clear.

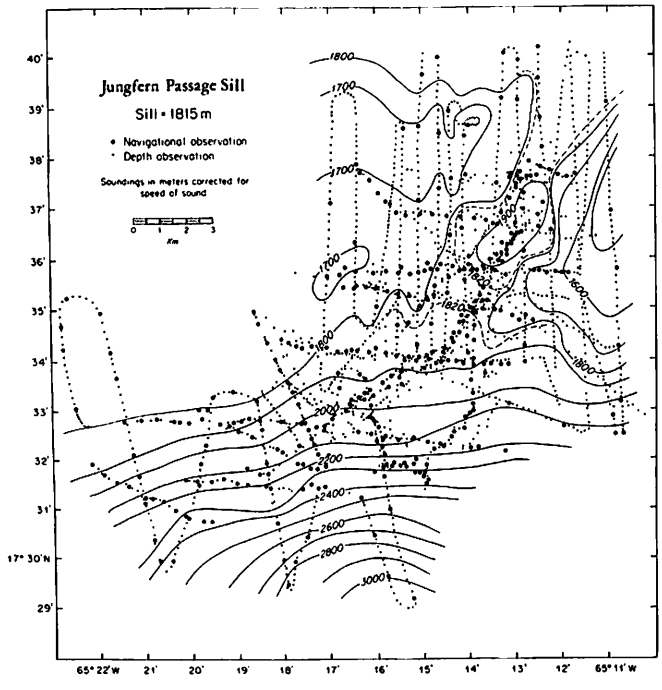

Fig.9 (Metcalf and Stalcup) Chart of the bathymetry in the vicinity of the Jungfern Passage sill. Depth contours are in meters corrected for the speed of sound in sea water. The small dots show the location of the depth measurements, and the large dots are the positions of the vessel (±200 m) as determined by radar ranges and bearings to two navigation buoys anchored near St. Croix. The geographical coordinates of the buoys were determined by the average of satellite fixes and are probably accurate to ±200 meters.

Mediterranean Sea Investigations (Arthur R. Miller)

Continuing investigations into the physical oceanographic problems of the Mediterranean Sea have been carried out using available data. A paper was published on the subject of semi-enclosed seas and their ecological balance. Inner seas like the Adriatic Sea, far removed from a major ocean, may be particularly sensitive to climatic change. The premise for this hypothesis is based upon separation from the ocean by a chain of sills and upon an incoming supply of ocean surface water. The deep water of the inner sea may consequently be a product of both the climatic happenings of the recent past and the local environmental conditions of the present.

Bottom currents in the Mediterranean were examined using sedimentary tracers as indicators of movement. In the north, alluvial deposits and suspensions contained in river run-off supply the sedimentary tracers. In the south, there is little run-off source material. However, North Africa provides an aeolian sedimentary source with winds carrying "red dust" from the desert regions. Sedimentary sources are variable with the season, and an annual deposition may be observable in the sedimentary layers.

In the Western Ionian Sea, a frontal zone is the result of inflow of relatively fresh water through the Strait of Sicily. The front is marked by rapid changes in salinity.

Participating in a colloquium on "Processes of formation of oceanic deep water," a paper on deep convection in the Aegean Sea was given in Paris. A dome-like density structure, symptomatic of deep convection may exist in the southern Aegean Sea. Here the deep water has the highest oxygen content in the Mediterranean and may indicate deep convective activity.

When the Suez Canal was opened, the salinity from the dissolution of salt beds in the intervening lakes became an effective biological fence, impeding the east-west migration of species. The salt beds are now completely dissolved; nevertheless, a barrier of sorts continues to exist in the Bitter Lakes. The heat budget is more than sufficient to account for the increased salt content.

Indian Ocean Studies (John G. Bruce)

Hydrographic measurements were made in the Alula-Fartak Trench (Fig. PO-10) from the trench sill at a depth of approximately 2280 m depth down to the bottom (deepest water sampled was 5328 m). The intrusion of dense water over the sill and its sinking to various levels appears to be the most important mechanism for determining the structure of water within the trench.

In the Somali current between the equator and 12°N during the southwest monsoon, the general pattern of circulation may change considerably within a season. Differing from the structure found during the same period in 1964, two regions of cold upwelled water were encountered along the Somali coast during August: at approximately 6°N and at 10°N, each being associated with a branch of the current that turned eastward offshore. During the peak of the southwest monsoon, currents associated with the large anticyclonic cells formed off the Somali coast might modify the equatorial undercurrent in this region.

Observations of weather are available from the heavy tanker traffic between the Persian Gulf and South Africa paralleling the Somali coast about 200 miles offshore. The monthly increase in magnitude of wind stress during the southwest monsoon has been estimated along the track. The track also crosses the area in which the Somali current has been observed to turn eastward offshore in the region where the greatest changes in wind stress occur.

Circulation on the Continental Shelf (Dean F. Bumpus)

A comprehensive description of our understanding of the circulation over the continental shelf of the east coast of the United States, including monthly charts of the surface and bottom drift generated from over 16,000 drift bottles and over 14,000 sea-bed drifter returns during the period 1960-1970, was prepared and accepted for publication.

In order to observe processes on the shelf in greater detail, we are developing a free-drifting buoy-location system (talking drift bottles). The intent is to be able to monitor the tidal and residual motions of a field of drogued buoys from several shore stations for a period of a month or so while a research vessel can simultaneously measure the hydrographic and atmospheric variables which influence these movements.

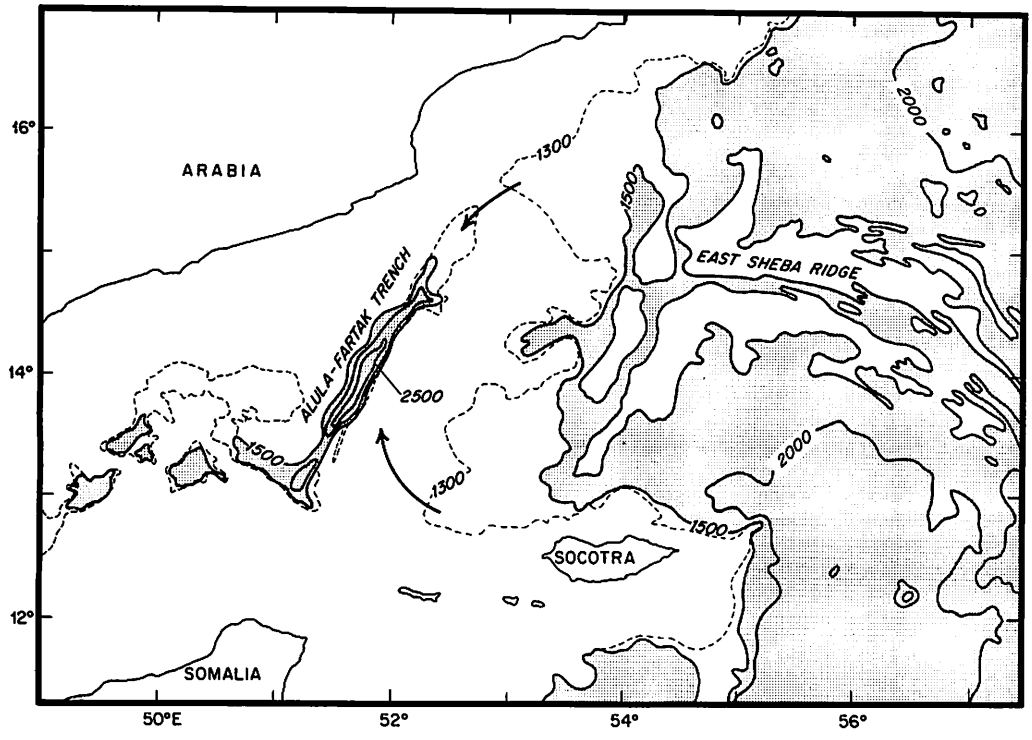

Fig.10 (Bruce) Alula-Fartak Trench and paths of water over sill.

Circulation on the Great Lakes (G. T. Csanady)

The project consists of evaluation and assessment of observations taken on Lake Ontario during the International Field Year on the Great Lakes (IFYGL), currently in progress. The international planning committee suggested a "core" program for this cooperative research effort, important parts of which were current measurements at a number of moored buoys, and also along several chains of flag stations in the coastal zone, to provide the necessary spatial resolution for the complex water movements near shore. One focus of the Woods Hole work is an evaluation of the near-shore observations, arising from the principal investigator's earlier involvement in research on the dispersal of pollutants in shallow bodies of water. Another point of interest is long internal wave motions, which also occur in the ocean, and the degree to which conclusions reached in the Great Lakes may be transferred to the oceanic environment. Advantages of the Great Lakes as "model oceans" are that field operations can be carried out with less effort, and certain complicating influences (notably tides) are absent, so that several scientific problems can be studied in them in a "purer" form.

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

Twelve oceanographers from Africa, Asia and South America were given four weeks of instruction during May and June 1972 as part of the Intergovernmental Oceanographic Commission--National Oceanographic Data Center Training Course in the Acquisition, Processing and Utilization of Ocean Data. Two previous sessions were held in 1971.

Woods Hole provided the first formal instruction for the trainees after a one-week orientation program in Washington, D.C. Later they received two months of training in computerized data handling at NODC in Washington and visited other laboratories and data centers in the U.S. and Europe. The whole program lasted six months.

The principal objectives were to provide: (1) a broad view of marine science in general; (2) experience at sea, handling gear and keeping records; (3) experience in evaluation and processing of raw data; and (4) some opportunity for individual work in areas of special interest.

The sea-going was accomplished for most of the trainees in two two-day cruises on R/V *Gosnold* across the edge of the Continental Shelf to provide experience in station making, BT's, oxygen and

salinity analysis. On shore there was a series of lectures in all oceanographic disciplines, with emphasis on the kinds of data scientists need, why they need it and how they use it. A similar series was provided at the Woods Hole laboratory of National Marine Fisheries Service.

OCEAN ENGINEERING

Department of Ocean Engineering

Earl E. Hays, Department Chairman

SOFAR FLOAT PROGRAM

Douglas C. Webb

Twenty long-range neutrally buoyant floats are required for the MODE I experiment, March to July, 1973. During 1972 the design, field trials, and a fraction of the construction have been accomplished.

The design is relatively new, a substantial lightening of the whole instrument being made possible by the development of a new sound transducer. The instrument underwent a first field trial by being moored for six weeks near Bermuda during the spring of 1972. Further refinements were carried out and tested in two neutrally buoyant instruments launched in the MODE area in September.

Ten of the 20 MODE floats will carry environmental sensors and a data recorder. The first three recording instruments were deployed as complete floats during trials in November, 1972.

Shipboard equipment for handling, tracking, and checking the instruments has been designed and tested at sea. Most of the problems uncovered during the field trials have been corrected and the fabrication of the remaining 15 floats is proceeding on schedule.

This investigation is also described by A. D. Voorhis, a co-investigator in the Department of Physical Oceanography. Substantial design constructions have been made by D. L. Dorson and K. D. Fairhurst.

AUTOPROBE

Kenneth H. Burt

Autoprobe is a general-purpose autonomous observational platform with the capability of making various programmed changes in depth much like an unmanned submarine. Autoprobe, a mid-water, free-floating instrument is ideal for making Lagrangian current measurements for any physical property that has a varying function of depth.

Autoprobe can change its displacement in response to internal commands as desired. Fluid is pneumatically forced into a bladder or pumped out of the bladder upon command from the electronic control system. The electronic control system generates the commands from the temperature and pressure measurements utilizing proportional control with rate feedback. The control system can be programmed to operate in the following modes of operation:

1. to stabilize at a constant pressure
2. to follow a constant temperature
3. to make vertical excursions
4. to operate as desired by remote control.

Acoustic telemetry is utilized in the instrument resulting in navigational information as well as temperature and pressure data. Hydrophones are used with a shipboard recorder for tracking the Autoprobe, and this system enables the operator to monitor Autoprobe's performance.

Autoprobe has an Acoustic Command System that can be used for various desired functions such as jettisoning weight, surface remote control operation, or changing program functions. Autoprobe's security is enhanced by its multilevel safety system allowing it to blow ballast on a time signal, or jettison weight if it goes too deep, or if a desired time is reached, or if an acoustic command is received from the surface.

Additional instruments and measurement equipment can be attached to the Autoprobe, increasing the versatility and ease of obtaining pertinent oceanic data.

Autoprobe was utilized during 1972 as an operational instrument in field observations of North Atlantic Circulation Studies conducted by L. V. Worthington, and Microstructure and Salt Finger Studies conducted by Albert J. Williams 3rd. Autoprobe was operated in the isothermal mode in North Atlantic Circulation Studies of the Continuity of the Gulf Stream System from the R/V *Chain* #104 off St. John's, Newfoundland, in May, 1972. Autoprobe made a series of eight dives, its longest was 18 hours. Although mechanical and pneumatic difficulties interfered with its performance as an isotherm follower, Autoprobe tracked a water mass on several dives, recording water temperature and pressure. Careful investigation after this cruise revealed the pneumatic and mechanical problems, and these were immediately remedied.

Autoprobe was planned to be used next in a study of coastal upwelling dynamics with some vertical current meters (VCMs) off the coast of Oregon in cooperation with Robert L. Smith, Oregon State University, and a co-principal investigator of Coastal Upwelling Experiments (CUE-I). Unfortunately, shipping problems from Newfoundland to the Woods Hole Oceanographic Institution prevented its use for these studies.

Autoprobe is an ideal platform for microstructure observations since it is uncoupled from any surface motion and can be programmed for controlled vertical excursions. In September, 1972, Autoprobe was used to study microstructure south of Puerto Rico from the R/V *Crawford* with Albert J. Williams 3rd as Chief Scientist. An Optical Salt Finger Detector (OSFD) designed by Albert J. Williams 3rd and a Conductivity, Temperature, and Depth (CTD) Microprofiler designed by Neil L. Brown were attached to the Autoprobe for these studies. Autoprobe performed extremely well during these experiments as evidenced by the CTD data. Seven dives were accomplished off Puerto Rico resulting in excellent microstructure information. Salt fingers were observed with the OSFD in regions of strong temperature and salinity gradients, which confirms the theory that they do exist in the ocean.

Microstructure and salt fingers were studied next using the Autoprobe/OSFD/CTD on the R/V *Chain* #109, a buoy cruise in the region of the Continental Slope Front and Site D. Autoprobe operated as desired, sinking at a uniform rate of 7 cm/sec, providing an excellent platform for the measurements of microstructure with the CTD, and salt fingers with the OSFD. Autoprobe has operated successfully for a total of 51 dives.

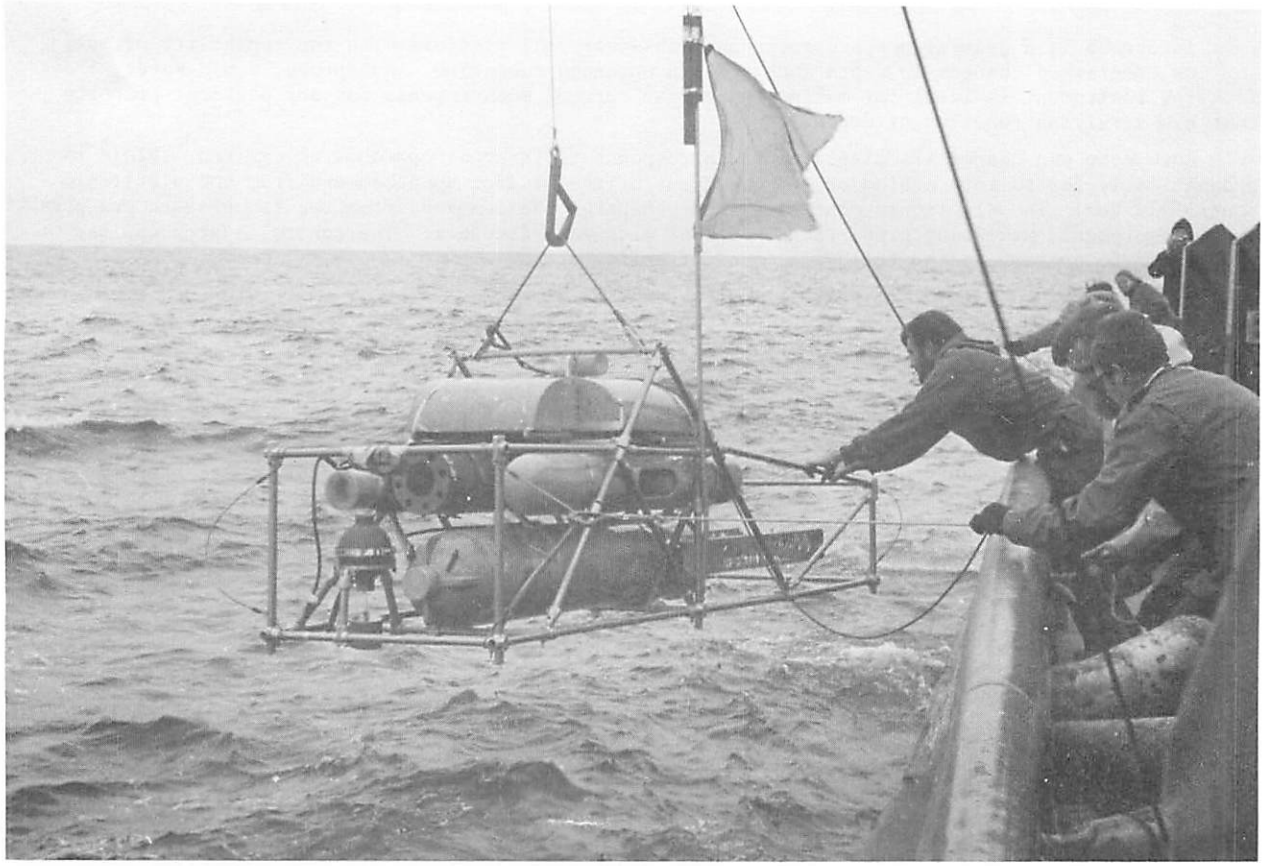

Fig.1 (Burt) Recovery of the Autoprobe, Optical Salt Finger Detector, and CTD package from the R/V *Chain* #109.

MICROSTRUCTURE STD (SALINITY, TEMPERATURE, DEPTH) SYSTEM

Neil L. Brown

The Microstructure STD System consists of an underwater unit which measures conductivity (C), temperature (T), and pressure (P), and a deck unit to process signals from the underwater unit. C, T, and P are sensed, digitized and transmitted from the underwater unit in the form of 16-bit words, 30 times per second. This information is transmitted serially via a cable to the deck unit which provides the following output:

(1) serial or parallel output to a computer

(2) digital display of C, T, and P in engineering units

(3) digital display of computed parameters - e.g. salinity, density

(4) analog outputs of C, T, P and computed parameters.

The deck unit is thus an inexpensive but powerful interface unit between the underwater unit and a computer, graphic plotter, etc.

The original system was first tested at sea during February 1971 and since then has undergone eight additional sea trials.

The equipment performed well during these trials and considerable interest in the system was aroused. Consequently, the main effort of the 1972 program has been design simplification in an effort to simplify assembly, check out, calibration, shipboard operation and adaptation to a variety of applications and configurations. At the same time the design was refined particularly in the area of noise and speed of temperature measurement. At present there are eight systems in existence and there will be more in the future. Consequently, the work involved in "streamlining" the design will prove to be very worthwhile.

The eight systems are as follows:

No.1 - The original unit first tested in February 1971.

No.2 - A second unit presently in use by the Buoy Group at Woods Hole Oceanographic Institution.

Nos.3, 4, 5, 6, and 7 - These five units are being used by the Operations Group of the GEOSECS (Geological Ocean Sections Study) program.

No.8 - This unit was used by Albert J. Williams 3rd at Woods Hole Oceanographic Institution for salt finger investigations and was mounted on Autoprobe along with special optical equipment.

Systems 1 and 2 were constructed as part of the principal investigator's contract with the Office of Naval Research. However, considerable advice and guidance was provided during fabrication of the other six systems.

Specifically the following items of work were completed during 1972:

Underwater Unit (UWU)

(1) The sensor and digitizer circuits were redesigned with these results:

(a) total of circuit cards reduced from 23 to 16

(b) power comsumption reduced from 1 watt to 0.4 watt

(c) noise in temperature circuits reduced by a factor of 8

(d) noise in pressure circuit reduced by a factor of 4.

(2) A new technique for very accurate, very high-speed temperature measurement was evolved. This technique utilizes a high-speed thermistor (25 milliseconds) and a precision platinum thermometer (300 milliseconds) and special circuitry such that the output has the excellent stability of the platinum thermometer and the fast response of the thermistor and is not affected by slow changes in the calibration of the thermistor.

(3) A general-purpose version of the underwater unit was designed and fabricated. This design has 1/3 less circuit cards than the microstructure version and samples at 1/3 of the speed but has the same accuracy and resolution.

Deck Unit

The deck unit containing the demodulator, decoder and display (analog and digital) modules was completely redesigned with the following results:

(a) excellent tolerance to noise

(b) parallel as well as serial outputs to permit direct interfacing with computers such as the IBM 1800

(c) ability to display and plot computer-generated data, as well as raw data

(d) repackaging reduced weight by a factor of 4

(e) the redesign reduced the number of power supplies from four to one and increased display capability from three to twelve parameters (five decimal digits each).

SALT FINGERS AND MICROSTRUCTURE

Albert J. Williams 3rd

Diffusion of heat is greater than diffusion of salt. This difference of diffusivity at the molecular level may be responsible in some cases for modification of water masses at vastly larger scales. It is quite likely that double diffusion is an important process in the generation, maintenance, and decay of finestructure, (vertical structure with a scale of meters). At this scale, it is hypothesized that the release of gravitational energy at a doubly-diffusing interface mixes the layers on either side, a process which tends to concentrate the vertical gradients on the interface and reduce the gradients in the adjacent layers. On the interface itself, double diffusion produces microstructure, structure with a scale at which molecular diffusion is the dominant process. Salt fingers, with a scale of centimeters, are a feature of the interface between a warm, salty layer and a lower cooler, fresher layer. This form of microstructure consists of downward-moving fingers of salty water, which lose heat faster than salt, interpenetrated by upward-moving fingers of fresher water, which gain heat faster than salt. In the laboratory, fingering interfaces can be produced artificially. Each interface exhibits tall columns densely packed in a square array. The packing is well-ordered over domains many finger widths on a side.

A search for such fingering interfaces in the ocean was rewarded in September 1972 by photographs of columnar microstructure in Caribbean water. The photographs were associated with high gradients in temperature and salinity. This discovery implies that salt fingering occurs in the ocean under conditions approximating those set up artificially in the laboratory. Transport of salt and heat across such an interface can be assumed to be high, the way it is in the laboratory when salt fingers are active. Competing mixing processes such as billow turbulence (overturning caused by shear) can be assumed inactive, at least at the time of the salt finger observation.

The salt finger observations were made from R/V *Crawford* just south of Puerto Rico in the thermocline from 150 meters to 400 meters. Being near the slope and near the surface, this region is quite active and complicated. So the consequences of salt fingering for finestructure are vague in this case. Shear measurements combined with the observation of fingering would help pin down the contribution of the salt fingers to the finestructure here. A shearmeter will be added to the instrument package when such regions are next studied. But for the next year, deep regions where salt fingering may be the principal actor will be studied.

The instruments used in this search for salt fingers were developed or adapted to this task in 1972. An optical instrument sensitive to inhomogeneities in the index of refraction of sea water was constructed to take horizontal photographs of adjacent five-centimeter sections of the water column. A number of cases can be distinguished with this instrument. Uniformly exposed photographs indicate homogeneous water. Vertically banded photographs indicate salt fingers. Photographs with randomly-oriented wavy lines indicate active mixing of water which is not homogeneous. Extreme inhomogeneities produce a pattern of small cells of high contrast.

A second instrument records conductivity, temperature, and depth from which temperature and salinity profiles are later computed. This instrument is Neil Brown's Microprofiler interfaced to a digital recorder. Coding on the salt finger photographs allows precise correlations to be made with the profiles recorded on tape. Thus each type of optical pattern can be associated with a characteristic profile of salinity and temperature.

These two instruments are deployed on Autoprobe, a free platform, which is programmed to sink at 7 cm/sec. The slow sinking, unaffected by surface waves or shear, allows measurements to be made with minimum disturbance to the water. This not only allows salt fingers to be observed but produces excellent salinity and temperature profiles.

During September, 1972, sea trials of the instruments were performed in deep water near La Parguera, Puerto Rico. All systems performed well. A great deal of optical structure was observed in addition to salt fingers. This structure is being associated with the profiles of salinity and temperature now.

A second cruise to Lat 39°N, Long 70°W (Site D) in December, 1972, permitted instrument deployment in a Gulf Stream eddy and in the Continental Slope Front. The Slope Front photographs suggest salt fingers may be present at a region where the temperature drops 0.5°C in a meter. Most of this information is unanalyzed as yet.

OCEAN STRUCTURES, MOORINGS AND MATERIALS SECTION

Robert G. Walden

In addition to engineering support to the Moored Array Program, section members were involved in other engineering, scientific and educational activities during the year.

Deep Sea Moorings

Twenty-four intermediate-depth, twenty-two bottom and eight surface moorings were set during the year by the Operations Group. One bottom mooring and two intermediate moorings failed. Acoustic release failures are suspected in all cases. Eight out of the 53 moorings were set to obtain engineering data. Four of these were instrumented to provide data relating to mooring motion. One bottom mooring was set and retrieved after one year on station.

Faking Box Mooring Deployment (Paul B. Stimson)

Six moorings were set by a new method to investigate the feasibility of a "hands-off" automatic deployment scheme. The complete mooring is boxed up, the wire rope specially faked into compartments, each holding 300 meters and allowed to pay out freely when the anchor is kicked over the side. Five of the six deployments were successful, but problem areas were indicated which are being corrected.

Tri-Moor Design (Robert G. Walden, Narayama N. Panicker, Henri O. Berteaux)

A large stable mooring consisting of three legs and a heavily instrumented apex 600 meters below the surface was designed and modeled. The mooring will be set in the MODE area in 5500 meters water depth. A special computer program was used to aid in the selection of a design which would meet the scientific requirements of tolerable instrument motion.

Analysis of Taut Buoy-Mooring Technology (Robert G. Walden, Narayama N. Panicker)

An analysis of the Woods Hole mooring statistics and performance for the years 1970 and 1971 was conducted. The reliabilities of three types of moorings regularly used at Woods Hole were computed and compared. The objective of the study was to provide information which can be used as a guide to define future engineering research and development efforts required to improve the reliability of the mooring types analyzed. One hundred and two moorings were set during these years; 35 were surface moorings, 19 intermediate and 48 bottom moorings. Of these 102 moorings, 85 were recovered completely, 12 were partially retrieved and five were lost.

Fishbite Research (Paul B. Stimson, Bryce Prindle)

Plastic armor for the protection of synthetic-fiber mooring lines against fishbite is still under study. The necessary mechanical properties are now well-understood, and a specific formulation is being sought. To this end, a subcontract has been let to Battelle Memorial Institute, which should lead to a recommendation in the spring of 1973.

The availability of new ultra-high-strength synthetic fibers from the du Pont Company adds new impetus to this program, by introducing attractive new possibilities. A mooring line of fiber "B" should be of about the same diameter as an equivalent wire rope, but the density of the material is about the same as that of Dacron. A great improvement in mooring performance is thus promised. Also, the very low stretch of the material greatly eases the problems of applying the armor.

ACODAC (Acoustic Data Capsule) (Henri O. Berteaux)

Methods of analysis of system mechanical performance during deployment, when on station, and during recovery design parameters and selection of components used in the 1971 ACODAC Systems were presented as part of a report on the 1971 ACODAC program. (Berteaux, 1972). In addition the design of 11 new systems for 1972 deployment was performed.

Microfouling Research (Stephen C. Dexter)

A number of methods are being investigated for protecting the Savonius current meter rotor from fouling by microorganisms and slime during prolonged exposures in pelagic conditions. Among these are thin films of copper-nickel alloys applied by either vacuum evaporation or electroplating, commercial antifouling paints and experimental antifouling coatings. Evaporated thin films of 90-10 and 70-30 copper-nickel and a phenolic-based coating utilizing 90-10 copper-nickel flake as the antifoulant, appear to be the most promising of the methods tested so far.

Test panels of high-impact polystyrene have been coated in the laboratory with the various antifoulants listed in the Table. The short-term shallow-water samples were evaluated by optical microscopy and by scanning electron microscopy to determine their relative effectiveness against various fouling types of both micro- and macroorganisms. The five-month open-ocean samples are currently undergoing evaluation, and the three most promising materials (mentioned above) are now undergoing longer term exposures at various depths at the MODE site. These are scheduled for recovery and evaluation sometime during 1973.

In parallel to the antifouling research, the general relation between corrosion and microfouling is being studied by scanning electron microscopy. The metallic system of copper-nickel alloys possesses a gradient in properties from rapid uniform corrosion with no fouling at the copper and to only pitting corrosion with heavy fouling at the nickel end. Commercial alloys selected to represent various points along this gradient have been subjected to the same types of exposures listed in Table 1.

Table 1.

Antifouling Materials Tested in 1972

Material	Exposure Conditions		
	Location	Duration	Depths
1. Bulk 90-10, 80-20 and 70-30 copper-nickel alloys	a) W.H.O.I. dock b) MODE Sta 453	1 day to 30 days 5 mo	5 meters Surface, 2500 & 4925 meters
2. Commercial Antifouling Paints: Amercoat 1780 Gloucester 540(CuO in Phenolic) Gloucester 550(CuO in Epoxy)	a) W.H.O.I. dock b) Sta 429 Site "D" c) MODE Sta 424 d) Sta 436 (Continental Slope)	1 day to 30 days 2 mo 2 mo 2 mo	5 meters 2 meters 1000 & 2000 meters 2 meters 800 meters
3. Experimental Antifouling Paints: 90-10 Cu-Ni Flake @ 6.5 lb/gal in Phenolic & Epoxy Vehicles	a) W.H.O.I. dock b) Sta 429 Site "D" c) MODE Sta 424 d) Sta 436(C.Sl.)	1 day to 30 days 2 mo 5 mo 2 mo 2 mo	5 meters 2 meters 1000 & 2000 meters 2 meters 800 meters
4. Evaporated Thin Films of 90-10 and 70-30 Cu-Ni & 90-10 Cu-Ni Flake in Phenolic	MODE Sta 473		500,1000,3000 & 5000 meters

Evaluation of Engineering Materials (Stephen C. Dexter)

The evaluation of materials for future use in the Buoy Program was continued with the five-month exposure of samples of beryllium-copper, 90-10 and 70-30 copper-nickel, 316 stainless steel, and Armco Steel's new stainless, 22-13-5. These were set at depths of 1000, 3500 and 5000 meters

on moored station No. 424 at the MODE site. Armco's 22-13-5 has roughly twice the yield strength and twice the corrosion resistance of conventional 316 stainless steel at only about 1½ times the cost. It thus looks very attractive for long-term (greater than six months) or repeated short-term applications requiring a nonmagnetic stainless steel.

Instrumentation (Clayton W. Collins, Jr.)

A total of about 50 instruments of various types - depth recorders, tensiometers, inclinometers, and acceleration recorders, are currently in stock, for use in measuring engineering parameters as buoy and mooring requirements occur. Work is continuing, as funds allow, toward a buoy telemetry system. A standard technique of installation and measurement of buoy radio antenna systems was developed during this period.

Grand Turk Hydrophone Installation (Robert G. Walden, Henri O. Berteaux, Foster L. Striffler)

To provide an increased tracking capability for the long-range SOFAR floats used in the MODE program a fourth listening station (and spare) was designed and installed at Grand Turk Island, B.W.I. The system as installed consisted of a buoyed-up array of four hydrophones connected by electromechanical cable to a shore station 3.5 miles away. Computer programs and mathematical models were devised to evaluate the loads in the cables and the path of the anchor during anchor lowering, the cable pay-out rate as a function of ship speed and bottom topography, and when implanted the loads and geometry of the subsurface mooring as a function of current speed.

In spite of adverse environmental and difficult logistic conditions the array was successfully installed in November. Signals from a SOFAR float 400 miles north in the MODE area were heard with a signal-to-noise ratio of 10:1.

Shallow Water Array (Henri O. Berteaux)

The systematic evaluation of specimens of mooring wire candidate materials was pursued and completed by the end of 1972. A considerable amount of valuable empirical information on the long-term performance of bare and jacketed steel and alloy wire ropes and glass fiber rods was acquired. Different types of wire rope terminations (swaged, booted, epoxy-filled) were also investigated. Some of the results obtained have been presented (Berteaux and Morey, 1972). A report reviewing the shallow test array entire program will be written.

Electromechanical cables and their terminations have been traditionally critical components of buoy systems. Two prototypes of torque balanced E/M cable and of quick disconnect E/M cable terminations tions (see Fig.2) have been designed and set at the Buoy Farm for a one-year endurance test.

Education (Henri O. Berteaux)

Course 13.994, "Buoy Engineering" of the Joint Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Ocean Engineering Graduate Education Program was taught in the spring term.

THE DEEP SUBMERGENCE ENGINEERING AND OPERATIONS SECTION (DSE & OS)

William O. Rainnie, Jr., Section Head

Introduction

The Deep Submergence Program at Woods Hole Oceanographic Institution entered its second decade in 1972 with DSRV *Alvin* in the Iselin building high-bay area for the first time, undergoing an annual inspection and maintenance period after an eight-month operating season. It had just returned in December from southern waters on R/V *Lulu*. The latter was preparing to depart for Florida in early January to be the principal support ship for Project FLARE (Florida Aquanauts Research Expedition), a saturation diving program for scientists studying the reefs south of Miami. This program will be described later. The engineering staff was fully occupied by a variety of development tasks, as well as in the direct engineering support of the *Alvin* refit and *Lulu's* preparation for deployment.

The year 1972 saw the achievement of a truly broadened support base. The principal sponsors were the Office of Naval Research (O.N.R.), National Oceanic and Atmospheric Administration (N.O.A.A.), National Science Foundation (N.S.F.), and the Advanced Research Project Agency (A.R.P.A.).

Operations commenced in mid-May and were ended in late October covering a diverse scientific diving program using Woods Hole as a base of operations. Funding limitations and the original

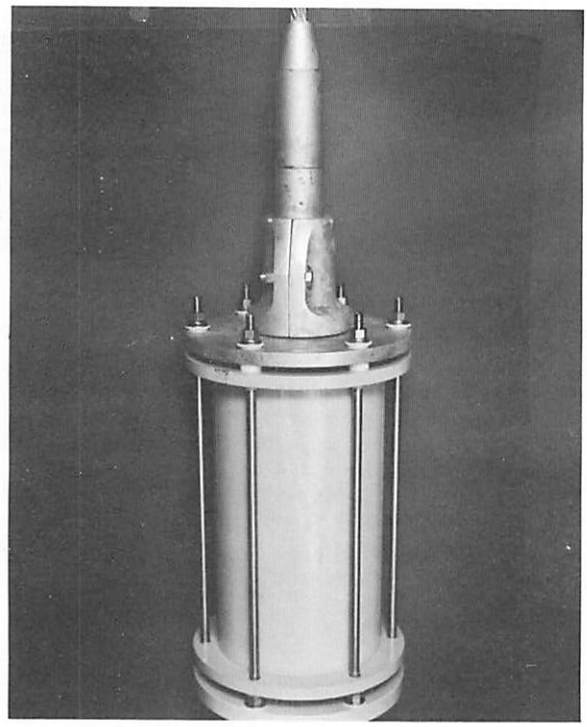

Fig.2 (Berteaux) Quick disconnect E/M cable terminations.

schedule of the new titanium hull, prevented a deployment to southern waters this fall and winter. At the end of this report period *Alvin* was back in the high-bay area awaiting the new hull, and *Lulu* was at the Woods Hole Oceanographic Institution's dock undergoing routine maintenance by a minimum-sized crew.

Summary of 1972 Operations

The operational period began with shallow-water trials in the harbor mid-May ending with the deep certification dive by the end of the month.

Eleven more cruises were conducted during the period to carry out various scientific and engineering experiments. Dive locations extended from the northern Gulf of Maine to the deeper end of Hudson Canyon.

Cruises are summarized in Table 1.

Sources of additional detailed information about the cruises are contained in the Operations Summary (Table 2) and the Dive Summary (Table 3) and in the files of the Deep Submergence Engineering and Operating Section.

Progress on Going Deeper

The titanium hull (Project TITANES) which has a design depth of 3650 meters (12,000 feet) and increases payload, was scheduled to be installed last winter. The completion date was extended to this winter and receipt is now expected in Woods Hole by mid-March 1973. One of the major systems required to go to the deeper depth was delivered on time and was installed in *Alvin* last spring and worked successfully throughout the operating season. This was the variable ballast system designed, built and tested by the Naval Ships Research and Development Center, Annapolis, Maryland. They assisted with the installation in the vehicle and rendered engineering assistance for the trial period.

No other major changes were made in *Alvin* then, but several more have been done or will be accomplished this winter. In summary they are as follows:

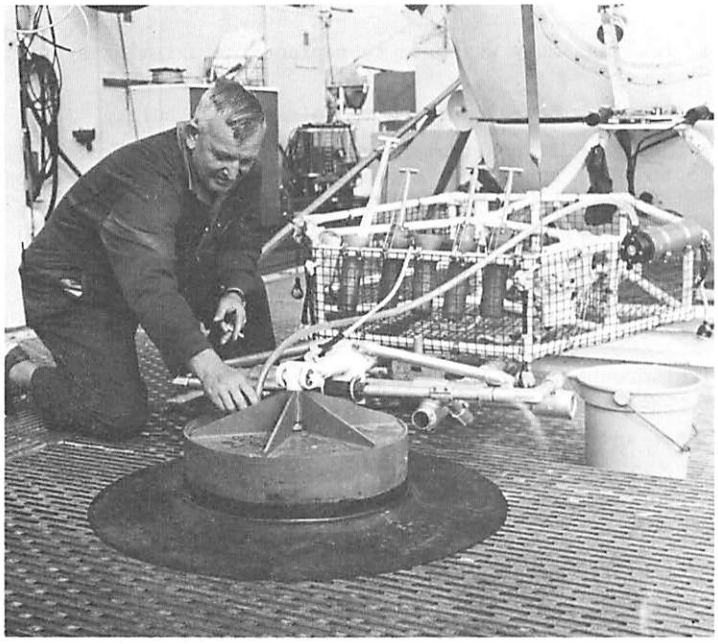

Fig.3 (Rainnie) A prototype bottom holding suction pod being readied for test on DSRV *Alvin*.

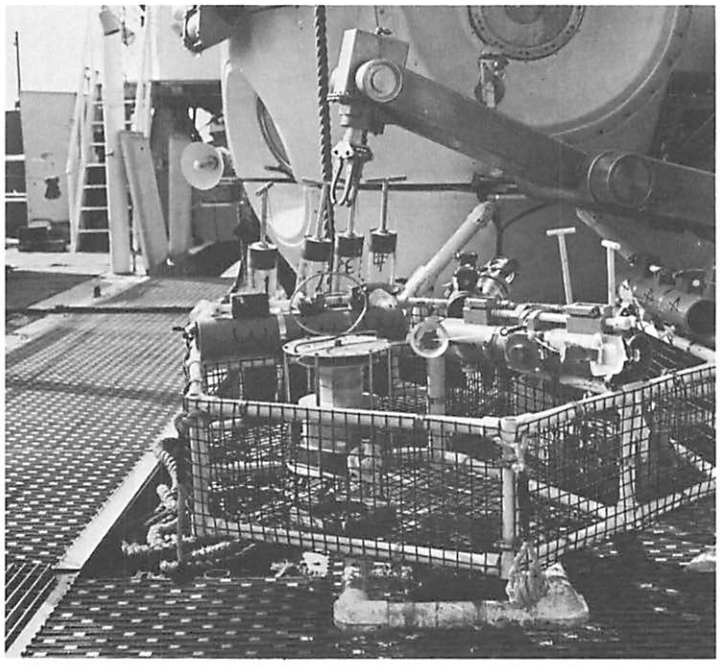

Fig.4 (Rainnie) A new concept in sampling baskets for DSRV *Alvin* built around the "lazy Susan" principle. This feature provides more space for storage of tools that can be brought within reach of the mechanical arm shown in the right center of the photograph. The arm can rotate the basket to pick up tools or deposit samples that it could not otherwise reach. This significantly improves the amount of sampling that can be done on any one dive.

1. A new syntactic foam assembly was made to replace the existing syntactic/titanium buoyancy package.
2. The forebody assembly is being modified to suit the new hull.
3. The electrical through-hull penetrators have been increased from 12 (216 leads) to 16 (384 leads) and almost double the number of forebody-to-afterbody electrical leads are being provided.
4. Deeper depth gauges, instrument housings, etc. are being provided and tested.
5. A new life-support system to extend the endurance in an emergency is being installed.
6. The internal arrangement of camera and lights controls, sensors and indicators is being improved for observer use.
7. Additional weight droppers are being provided to increase ascent/descent rates with minimum use of battery power.
8. An improved normal and emergency tracking pinger is being provided.

Several desirable features not necessarily associated with going deeper are being studied that would significantly improve the efficiency of the operation of *Alvin* for scientific use. These will be implemented where technically feasible and if funding permits:

1. A new TV viewing and recording system.
2. Low light level viewing capability.
3. More efficient and less noisy lift propellers.
4. Submersible data recording unit.
5. Additional battery capacity.
6. A less sea-state limited launch and recovery system for *Lulu*.
7. A reliable light-weight gyro system (to replace the existing MK22).
8. Bottom-holding suction pod(s) for sampling and drilling more efficiently.

Additional Deep Submergence Engineering Effort and Support

In addition to the considerable engineering effort required to support going deeper above, two other major categories of effort exist.

Three major projects, FLARE, Underwater Acoustic Navigation and SCAMP (Self Contained Auxiliary Modular Platform), are primarily carried out within the section and will be reported in more detail later by the principal investigators.

The other major category of effort has to do with smaller projects that are primarily support engineering for principal investigators in other departments or activities, and may or may not be directly related to the submersible or use therewith.

Several typical projects, but not all, are listed below to illustrate the Section's range of interest and activity:

1. A deep pressure retaining microbiological sampling and culturing chamber was designed, constructed and tested for the Biology Department (Jannasch and Wirsen). This device provides the investigator with the capability of sampling deep ocean mocroorganisms, retaining them in a sterile chamber under the conditions of pressure and temperature associated with their normal environment, for study on the surface ship or in the laboratory. This device is to be deployed and recovered by *Alvin*, (C.L. Winget).

2. A wide-mouth specimen sampler was designed, constructed and tested for the Biology Department (Teal). It will be used to capture and retain deep ocean living benthic organisms at *in situ* environmental conditions for later study. Like 1. above, it is presently designed to be deployed and recovered by *Alvin*. It allows entry of creatures up to 5.7 cm diameter in size. (C. L. Winget and P. E. Kallio).

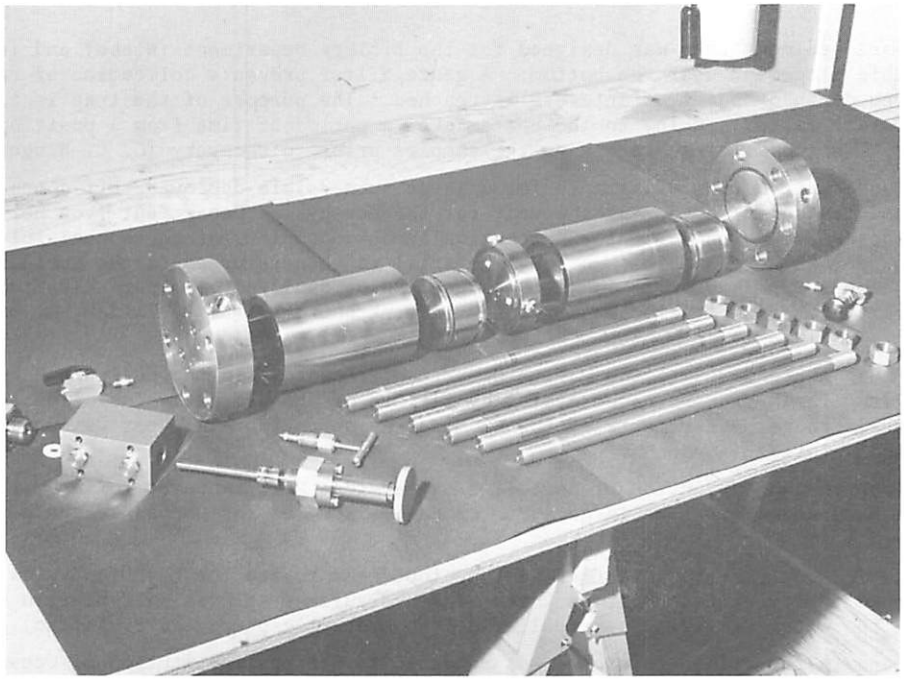

Fig.5 (Winget) Exploded view of microbiological sampling and culturing chamber, illustrating the various components fabricated by the W.H.O.I. Instrument Shop.

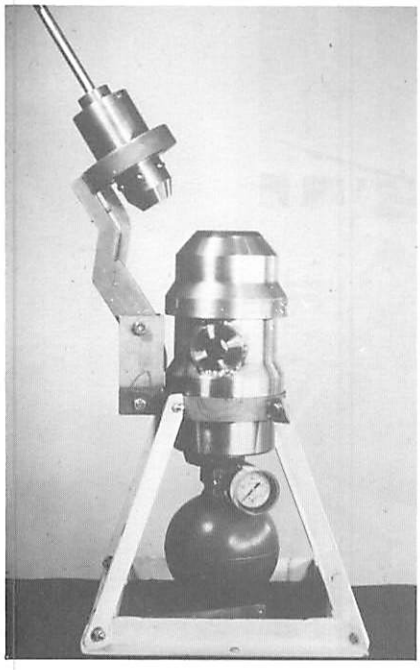

Fig.6 (Winget and Kallio) Wide-mouth deep-sea specimen retrieval chamber for the recovery and observation of small benthic animals.

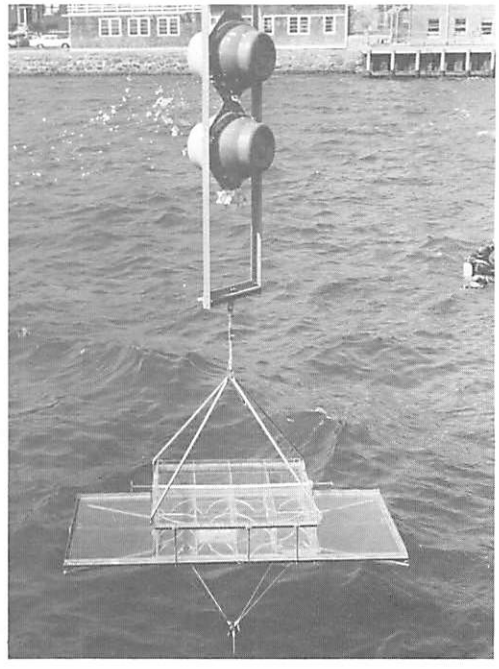

Fig.7 (Winget) Deep-sea sediment trap and the floatation device used to suspend it off the ocean bottom.

3. A deep-sea sediment trap was designed for the Biology Department (Wiebe) and features a free-fall or submersible placement near the bottom. A gauze filter prevents collection of unwanted samples until the sampling depth or point of interest is reached. The purpose of the trap is to measure the amount of particulate matter sinking to the bottom over a period of time from a position about 30 meters above the bottom. Two doors close retaining the samples prior to recovery (C. L. Winget).

4. Design and construction assistance for a large submersible deployed self-contained rock drill was undertaken and tested at sea during the year for the Geophysics Department (Von Herzen and Williams). The purpose of the drill, which activates automatically on decoupling of the submersible, is to take a one-meter long hard rock core sample *in situ*. The drill is then returned to the surface by the submarine and the sample recovered. This drill is also designed to be deployed alternatively from a surface ship and in the future to obtain heat flow measurements in rock bottoms. (B. B. Walden, A. Barrs and A. G. Sharp).

5. Assistance was rendered to the Marine Department (Edwards) in the design and construction of a new trawl winch drum for R/V *Knorr* necessitated by failure of the old one. Installed testing included the taking of strain gauge measurements of the drum during operation. A paper was presented on this design problem and solution (A. G. Sharp).

6. Design review and correction of deficiencies services were rendered to the Marine Department on the cranes on *Lulu* and *Knorr*. The large *Knorr* crane was studied for use as a launch system for *Alvin*. (P. E. Kallio).

7. A hydraulic supply/servo amplifier was developed and tested for the Geophysics Department to control the depth of a towed instrument package. The hydraulic system is self-powered by movement of the fish through the water utilizing a propeller-driven hydraulic pump. (P. E. Kallio).

8. Design and installation assistance was rendered to Scripps Institution of Oceanography in conjunction with the Marine Department to modify the forward shaft in the R/V *Melville* (sister ship of *Knorr*) to eliminate a serious vibration problem. (P. E. Kallio).

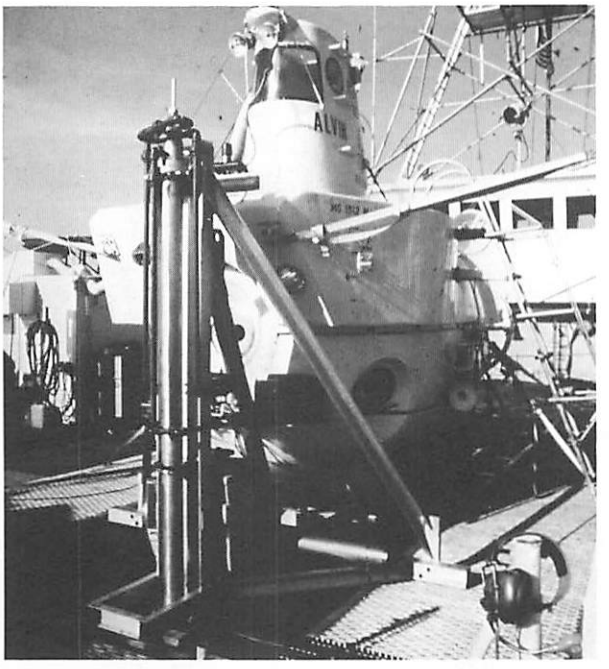

Fig.8 (Walden, Barrs and Sharp) A hard rock drill shown mounted on DSRV *Alvin*. This massive device is self-powered and can take a 1-meter long by 1.9 cm diameter core from a site selected by the scientist *in situ*. The submarine can detach itself submerged for doing other chores, and reattach itself for returning the drill to the surface.

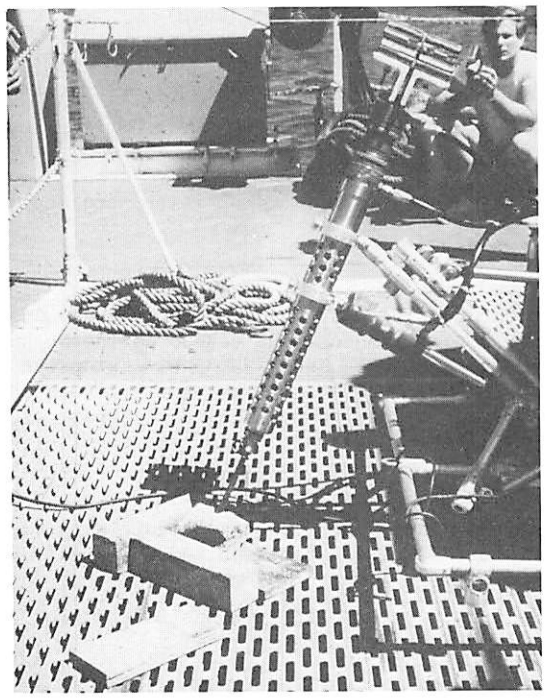

Fig.9 (McCamis, Walden and Winget) A prototype hard rock chipper that is hydraulically cocked and spring actuated, was designed for more rapid sampling of rock outcrops by the submersible in order to improve the amount of samples that can be obtained on a given dive for the geologist.

9. An hydraulically operated, self-contained hard rock chipper was designed, built and tested for the Geology Department (Uchupi and Ballard) to be operated by *Alvin* The purpose of this device is to break off by impact, selected and representative samples *in situ* quickly, thus improving the ability to take many more samples per unit of time on the bottom (M. J. McCamis, B. B. Walden and C. L. Winget).

10. Consulting and design assistance was rendered to the Geology Department (Hollister) and the Office of Naval Research (Cacchione and Carlmark) in preparing to take geological and other samples from the NR-1. (M. J. McCamis).

11. An hydraulic systems servicing device of W.H.O.I. design was built and delivered to the Submarine Development Group One, San Diego, for use with DRV *Sea Cliff*. (M. J. McCamis and D. H. Foster).

12. The DSRV acoustic navigation system was installed and operated on the R/V *Atlantis II* in support of Project FAMOUS (French-American-Mid-Ocean Study) for the Geophysics Department (Phillips and Bryan). This system was deployed and used successfully in the Mid-Atlantic Ridge recently. By interfacing it with the shipboard computer, real-time tracking of a camera sled and dredge was achieved in the rift valley. (W. M. Marquet, D. S. Hosom and A. Eliason).

13. Periodic interface consulting by various members of the section was carried out within the Institution and outside for equipment to be used on *Alvin* Some instances were as follows:

a. Project TITANES (Mare Island Naval Shipyard)

b. Nuclear sediment density probe (Richards - Lehigh)

c. Acoustic Imaging System (Naval Underwater Research and Development Center) NURDC-San Diego)

d. Work Systems Package (Naval Underwater Research and Development Center) NURDC-San Diego)

e. Surface deployed time-lapse camera system (Rowe)

f. LHRP (Langdon Hardy Plankton Recorder) plankton sampling system (Wiebe)

g. Long term current meter (Keller-N.O.A.A.(National Oceanic and Atmospheric Administration)

h. Submersible Mounted Modular Acoustic System (Hess and McElroy)

i. Project FAMOUS Instrumentation (French opposites).

14. Participation in technical and scientific committees and meetings (Various members of Staff).

Project FAMOUS Progress

One of the more important future programs scheduled for the use of *Alvin* is Project FAMOUS (French-American Mid-Ocean Study), now planned to be conducted in the summer of 1974. The area of major interest is located between 35,5°N 33°W and 37°N 35°W. Extensive surveys by ships from France, England and the United States will have been or will be made prior to the submersible diving program. The French bathyscaphe *Archimede* and the new SP3000 will participate along with *Alvin*. The principal emphasis is to obtain direct visual observations, and to take precisely-located geological samples and geophysical measurements at the site where the Atlantic basin is believed to originate.

A major planning meeting was attended in Brest, France in early June. Engineering and science personnel were exchanged during the year. Two from France dove with *Alvin* in the Gulf of Maine and at Bottom Station No. 1. Two from the United States joined the *Archimede* with *Marcel le Bihan* off Corsica in October.

Another major planning meeting is to be held in Woods Hole during January 1973.

Future Plans

It is now planned to mount the titanium hull in *Alvin* in the spring of 1973 and take the vehicle on *Lulu* to Annapolis for a manned tank test to an operating depth of 12,000 feet. The hull itself will have been extensively instrumented and tested to 1.1 times operating depth at Naval Ship Research and Development Center prior to receipt in Woods Hole.

Upon completion of all testing and certification, *Alvin* should be ready about mid-June to commence an operating season as a deeper boat with more payload and more available wires through the hull. An attempt was made, without success, to provide increased battery energy within the physical space now used. Study of this problem will continue.

The operating season at this writing will be based on Woods Hole and will undertake cruises to the New England Sea Mount Chain; the Gulf of Maine, perhaps as far north as Nova Scotia; to Bottom Station No. 1, and establish a deeper Bottom Station between Woods Hole and Bermuda.

If sufficient support is received, a deployment south will be considered; however, at this point funding is such that the operating season will end in late September.

The Deep Submergence Engineering and Operations Section References in 1972

1. W.H.O.I. Technical Memorandum No. 5-72. DSRV *Alvin* Weight Report 1972. A.G.Sharp and A.E.Eliason. 15 pp. plus 1 Appendix. December 1972.

2. A.G.Sharp and R.S.Edwards. Flange Failure of a Winch Drum, Analysis and Cure. Presented at the Marine Technology Society Symposium, Washington, D.C., September 14, 1972.

3. Perlow, Michael Jr., and Adrian F. Richards. In-Place Geotechnical Measurements from Submersible *Alvin* in Gulf of Maine Sails. Paper No. OTC 1543, 8 pp. Presented at the Fourth Annual Offshore Technology Conference, Houston, Texas, May 1-3, 1972.

For other reports, see "Papers Published in 1972".

Table 1 1972 Cruise Summary

Lulu Cruise No.	Sponsor-Contract or Grant	Period From	To	General Location	Chief Scientist(s)	Operations Director	Purposes
50	ONR N00014-71-C-0107	5/16	5/30	Bottom Station No.1	W.O.Rainnie	W.O.Rainnie	Lobster Study and Navy Deep Certification Dive
51							
Leg I	ONR N00014-71-C-0284	5/26	5/30	Gulf of Maine	D.L.Williams	V.P.Wilson	Test of A.R.P.A. large rock drill.
Leg II	State of Mass	5/31	6/2	Gulf of Maine	G.T.Rowe	V.P.Wilson	Investigation of Pollution in Wilkinson Basin
52	NSF GD32558	6/7	6/15	Bottom Station No.1	J.F.Grassle	V.P.Wilson	Retrieve bottom biology experiments from 1971 and plant new ones.
53	N.O.A.A.2-37122	6/23	7/1	Hudson Canyon	G.H.Keller	W.O.Rainnie	Study of bottom geology and biology processes in a major canyon.
54	ONR N00014-71-C-0284 (A.R.P.A.)	7/6	7/15	Gulf of Maine	W.M.Marquet R.D.Ballard	V.P.Wilson	Test of submerged navigation,free fall elevator,rock chipper,magnetometer and sub-bottom profiler.
55	NSF GD32558	7/19	7/28	Gulf of Maine	R.D.Ballard	V.P.Wilson	Integrated geological investigation of the western Gulf of Maine.
56	ONR N00014-71-C-0107	8/9	8/18	Bottom Station No.1	G.T.Rowe	V.P.Wilson	Evaluation of a single acoustic navigation reference and deep ocean biology experiments.
57	ONR N00014-71-C-0284 (A.R.P.A.)	8/23	9/1	Gulf of Maine	W.B.Bryan W.M.Marquet	V.P.Wilson	Test of submerged navigation,conduct a detailed magnetic and bathymetric survey from a submersible and conduct a detailed geology study of a ledge.
58	N.O.A.A.2-37122	9/6	9/15	Hudson Canyon	G.H.Keller	V.P.Wilson	Continuation of *Lulu* Cruise No.53
59	NSF GD32258	9/29	9/29	Bottom Station No.1	H.L.Sanders	V.P.Wilson	Biological Studies of deep sea recolonization and growth deep wood borers,and observe fish and benthic invertebrates.
60	NSF GD32258 ONR N00014-71-C-0284 (A.R.P.A.)	10/4	10/13	Bottom Station No.1	J.F.Grassle W.M.Marquet	V.P.Wilson	Retrieval of biology samples planted earlier and planting of new ones; deep water test of submerged navigation
61							
Leg I	ONR N00014-71-C-0107	10/18	10/27	Mass. Bay	W.O.Rainnie D.L.Williams	V.P.Wilson	Submerged Recovery Measurements, low light level viewing, pilot training, large rock drill testing
Leg II	"	"	"	"	"	"	"

Table 2 1972 Operations Summary

Operating Season - 5 May to 26 October		
Days of Successful Diving	66	66
Days used for		
Transit	19.1	
Weather	26	
Alvin Casualties	5	
Lulu Casualties	2	
Maintenance and Replenishment	56.9	
	109.0	175
Overhaul Period		
1 January to 5 May	125	
26 October to 31 December	66	
	191	366
Dives by Major Category		
Biology	17	
Geology	30	
Ocean Engineering	16	
Test, Training, Certification	14	
	77	

Monthly Breakdown

	Dives	Time Submerged	
May	13	25h	09m
June	13	78	50
July	16	80	42
August	16	91	50
September	11	60	01
October	8	25	44
	77	362h	16m

Table 3 1972 Dive Summary

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
	5/5/72	391	Great Harbor Woods Hole	ONR Tethered Trim Dive	V. Wilson E. Bland	-	1501	1608	1^h07^m	10 ft.	-
	5/8/72	392	"	ONR Trim Dive	"	-	1505	1616	1^h11^m	57 ft.	-
	5/11/72	393	"	ONR Test large Rock Drill	"	-	1201	1241	40^m	57 ft.	Drill knocked off mounting
	5/12/72	394	"	ONR Test large Rock Drill	"	-	1059	1310	2^h11^m	60 ft.	Difficulty reattaching to drill
50	5/18/72	395	39°46'N 70°41'W	ONR Test Dive	"	-	1023	1126	1^h3^m	300^m	Leak indication
"	5/18/72	396	"	ONR Test Dive	"	-	1402	1407	05^m	40^m	Leak indication
"	5/19/72	397	"	ONR Deep Trial & Certification	"	-	0941	1443	5^h2^m	1833^m	Successful Certification Dive
51	5/24/72	398	Great Harbor Woods Hole	ARPA Test Large Rock Drill	"	-	1445	1727	2^h42^m	45 ft.	Successful Hook up
"	5/26/72	399	Woods Hole Harbor	ARPA Drill Test	"	-	1101	1210	1^h9^m	40 ft.	Test Sat.

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Time Surf	Time Sub.	Depth M/Ft.	Remarks
51	5/27/72	400	Wilkinson Basin 42°31'N 69°37'W	ARPA Drill Test	V. Wilson	A. Barrs	1318	1330	12^m	300 ft.	Abort due to grounds on 30V Battery
"	5/28/72	401	Cashes Ledge 42°51'N 68°52'W	ARPA Drill Test	E. Bland	D. Williams	1037	1642	6^h5^m	595 ft.	Unable to unhook from drill
"	5/29/72	402	"	ARPA Drill Test	V. Wilson	D. Williams	1010	1251	2^h41^m	320 ft.	Drill malfunctions. Very difficult recovery
"	5/31/72	403	Wilkinson Basin 42°38'N 69°38'W	ARPA Biology	E. Bland	G. Rowe R. Haedrich	1330	1431	1^h1^m	920 ft.	Dive shortened due to weather & suspected malfunction
"	6/1/72	404	"	ARPA Biology	V. Wilson	G. Rowe R. Haedrich	1103	1502	3^h59^m	925 ft.	Successful Dive
52	6/8/72	405	Bottom Station 39°46'N 70°40'W	NSF Biology Recovery	E. Bland	C. Wirsen T. McLellen	1027	1848	8^h21^m	1746^m	Unable to locate Bottom Station
"	6/11/72	406	"	NSF Plankton Tow	V. Wilson J. Donnelly	P. Wiebe	1434	1930	4^h56^m	1811^m	Passed very close to Bottom Station

Table 3 1972 Dive Summary (continued)

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
52	6/12/72	407	Bottom Station 39°46'N 70°40'W	NSF Biology	V. Wilson	K. Smith R. Turner	1006	1728	7^h22^m	1828^m	Relocated Towers No. 1, 2 & 3
"	6/14/72	408	"	"	E. Bland	F. Grassle T. McLellen	0900	1832	9^h32^m	1828^m	Located Towers No. 2 and 3
53	6/24/72	409	Hudson Canyon 39°34'N 72°25'W	NOAA Geological and Biological Reconnaissance	V. Wilson	G. Keller, A.O.M.L. G. T. Rowe	1332	2006	6^h34^m	530^m	Dropped AMF Transponder w/37 Khz Pinger at 4673/2537, Depth 258 FMS. To be recovered in Sept.
"	6/25/72	410	Hudson Canyon 39°31.5'N 72°21'W	NOAA Geological and Biological Reconnaissance	E. Bland	G. Keller, A.O.M.L. R. Ballard	0927	1652	7^h25^m	575^m	
"	6/26/72	411	Hudson Canyon 39°20'N 72°03'W	"	V. Wilson	"	0928	0948	0^h20^m	200^m	Aborted due to full ground on #1 battery. Vent check valve leaked.

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
53	6/26/72	412	Hudson Canyon 39°19.6'N 72°02.3'W	NOAA Geological and Biological Reconnaissance	V. Wilson	G. Keller, A.O.M.L. R. Ballard	1228	1943	7^h15^m	1827^m	
"	6/27/72	413	Hudson Canyon 39°34'N 72°25'W	"	E. Bland	"	0923	1634	7^h11^m	477^m	Planted current meter next to AMF transponder. Visibility 50 yds. on recovery.
"	6/28/72	414	Hudson Canyon 39°29.7'N 72°17.3'W	NOAA Geological measurements with Density Probe	V. Wilson	G. Keller, A.O.M.L. T. A. Terry, Lehigh Univ	0906	1326	4^h20^m	853^m	Motor on densiometer failed on 3rd penetration.
"	6/29/72	415	Hudson Canyon 39°25'N 72°09.5'W	NOAA Geological and Biological Reconnaissance	E. Bland	G. Keller, A.O.M.L. R. Ballard	0900	1729	8^h29^m	1438^m	
"	6/30/72	416	Hudson Canyon 39°39.5'N 72°28'W	"	V. Wilson	G. Keller, A.O.M.L. G. T. Rowe	0852	1158	3^h06^m	202^m	

Table 3 1972 Dive Summary (continued)

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
54	7/7/72	417	42°31.5'N 69°38.1'W	ARPA Geology	E. Bland	A. Malahoff, ONR R. Ballard	0901	1536	5^h35^m	232^m	
"	7/8/72	418	43°09.5'N 69°22.5'W	ARPA Geology & Navigation	V. Wilson	J. Carlmark, ONR W. Marquet	1348	1410	32^m	175^m	UQC failed
"	7/9/72	419	43°09.5'N 69°22.5'W	ARPA Geology & Navigation	V. Wilson	R. Ballard M. McCamis	0929	1605	5^h36^m	130^m	Rock chipper failed
"	7/10/72	420	43°10.5'N 69°21.5'W	ARPA Navigation	E. Bland J. Donnelly	W. Marquet	0957	1452	4^h55^m	255^m	
"	7/11/72	421	43°11'N 69°21'W	ARPA Geology	V. Wilson	R. Ballard D. Porter	1302	1830	5^h28^m	159^m	Rock chipper failed
"	7/12/72	422	43°10.5'N 69°21.5'W	ARPA Navigation	E. Bland J. Donnelly	D. Hosom	0835	1448	5^h13^m	182^m	
"	7/13/72	423	43°13'N 69°20'W	ARPA Geology	V. Wilson	R. Ballard D. Porter	1132	1557	4^h25^m	150^m	
"	7/14/72	424	42°43.5'N 69°47.8'W	ARPA Navigation	E. Bland J. Donnelly	J. Porteous	1029	1454	4^h25^m	375^m	

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
55	7/20/72	425	42°27'N 69°16'W	N.S.F. Geology	V. Wilson	W. Bryan L. King, Bedford Inst.	1431	1840	4^h09^m	264^m	
"	7/21/72	426	42°50'N 69°12'W	N.S.F. Geology	E. Bland	R. Ballard R. McMasters, U.R.I.	0945	1546	6^h01^m	410 ft	
"	7/22/72	427	43°23'N 69°10'W	N.S.F. Geology	V. Wilson	R. Ballard W. Bryan	1010	1617	6^h07^m	310 ft	
"	7/23/72	428	43°42.5'N 68°48'W	N.S.F. Geology	E. Bland J. Donnelly	L. King, Bedford Inst.	1218	1826	6^h08^m	318 ft	
"	7/24/72	429	43°02'N 68°54'W	N.S.F. Geology	V. Wilson	R. Ballard B. Walden	1001	1408	4^h07^m	411 ft	
"	7/25/72	430	43°01'N 68°59'W	N.S.F. Geology	E. Bland	R. Ballard R. McMasters, U.R.I.	0906	1513	6^h07^m	390 ft	
"	7/26/72	431	42°46'N 68°54'W	N.S.F. Geology	V. Wilson	R. Ballard W. Bryan	0946	1420	4^h34^m	288 ft	108 pounds of rocks
"	7/27/72	432	42°29'N 68°40'W	N.S.F. Geology	V. Wilson J. Donnelly	L. King, Bedford Inst.	0810	1230	4^h20^m	639 ft	
N.A.	8/8/72	433	Woods Hole Harbor	O.N.R. Post refit trial	E. Bland J. Donnelly		1119	1230	1^h20^m	50 ft.	
N.A.	8/8/72	434	Woods Hole Harbor	O.N.R. Post refit trial	J. Donnelly	W. Marquet D. Foster	1257	1316	0^h19^m	50 ft.	1st solo

Table 3 1972 Dive Summary (continued)

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
56	8/9/72	435	41°15'N 71°00'W	ONR Pilot Certification	J. Donnelly	W. Rainnie LCDR Whitaker, SUBDEVGROUP ONE	1450	1648	1^h58^m	31^m	
"	8/11/72	436	39°46'N 70°40'W	ONR Biology	E. Bland	G. Rowe D. Cohen, U.S. National Museum	1137	2100	9^h23^m	1827^m	Night Recovery
"	8/13/72	437	39°46'N 70°40'W	ONR Biology	V. Wilson	K. Smith J MacIlvaine	0836	1806	9^h30^m	1815^m	
"	8/14/72	438	39°46'N 70°40'W	ONR Biology	E. Bland	P. Wiebe D. Cohen	0810	1540	7^h30^m	1820^m	
"	8/15/72	439	39°46'N 70°40'W	ONR Biology	V. Wilson	G. Rowe C. Clifford	1026	1847	8^h21^m	1823^m	Rough Recovery
"	8/16/72	440	39°46'N 70°40'W	ONR Biology	E. Bland	G. Rowe K. Smith	1123	1807	6^h44^m	1822^m	
"	8/17/72	441	39°46'N 70°40'W	ONR Biology	V. Wilson J. Donnelly	P. Wiebe	0751	1427	6^h36^m	1800^m	
57	8/24/72	442	Cashes Ledge 42°50'N 68°55'W	A.R.P.A. Geology Navigation Recon.	V. Wilson	W. Bryan J. Heirtzler	1412	1839	4^h27^m	380'	

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
57	8/25/72	443	Cashes Ledge 42°50'N 68°55'W	A.R.P.A. Geology Navigation Recon.	E. Bland	R. Ballard G. Bellaiche, CNEXO, France	1129	1804	6^h35^m	414'	
"	8/26/72	444	"	"	V. Wilson	W. Bryan R. Ballard	1040	1637	5^h57^m	390'	
"	8/27/72	445	"	"	V. Wilson	R. Ballard G. Bellaiche	0946	1515	5^h29^m	400'	
"	8/29/72	446	"	A.R.P.A. Navigation	J. Donnelly	D. Foster A. Eliason	1028	1650	6^h22^m	300'	
"	8/30/72	447	"	A.R.P.A. Geology Navigation	J. Donnelly	W. Bryan G. Bellaiche	0958	1631	6^h33^m	453'	
"	8/31/72	448	Cashes Ledge 42°47.5'N 68°52'W	A.R.P.A. Navigation	E. Bland	D. Foster W. Page	0830	1315	4^h47^m	501'	
58	9/7/72	449	39°34.5'N 72°25'W	N.O.A.A. Geology	E. Bland	G. Keller, A.O.M.L. N. Staresinic	1012	1703	6^h51^m	537^m	
"	9/11/72	450	39°34'N 72°25'W	N.O.A.A. Current meter recovery	V. Wilson J. Donnelly	G. Keller, A.O.M.L.	0826	1026	2^h	460^m	Recovery successful

Table 3 1972 Dive Summary (continued)

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
58	9/11/72	451	39°38.5'N 72°26.4'W	N.O.A.A. Geology	J. Donnelly	G. Keller, A.O.M.L. W. VanSciver, Lehigh Univ	1236	1807	5^h31^m	368^m	
"	9/12/72	452	39°32'N 72°24.5'W	N.O.A.A. Geology	E. Bland	G. Keller, A.O.M.L. R. Swartz, Lehigh Univ	0844	1210	3^h26^m	582^m	
"	9/12/72	453	39°38.5'N 72°26.4'W	N.O.A.A. Geology	J. Donnelly	G. Keller, A.O.M.L. W. VanSciver Lehigh Univ	1507	1827	3^h27^m	368^m	
"	9/13/72	454	39°27.5'N 72°13.1'W	N.O.A.A. Geology	E. Bland	G. Keller, A.O.M.L. D. Lambert, A.O.M.L.	0838	1553	7^h15^m	1142^m	
"	9/14/72	455	39°32.4'N 72°24.5'W	N.O.A.A. Geology	J. Donnelly D. Foster	G. Keller, A.O.M.L.	0828	1231	4^h03^m	570^m	
59	9/24/72	456	Bottom Station No. 1 39°46'N 70°41'W	NSF Biology	E. Bland D. Foster	G. Hampson	846	922	36^m	300^m	Aborted due to suspected malfunction life support
"	9/24/72	457	"	NSF Biology	E. Bland D. Foster	G. Hampson	943	1746	8^h03^m	1790^m	Relocated Bottom Station Set Tower #5

LULU Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf	Sub.		
59	9/25/72	458	Bottom Station No. 1 39°46'N 70°41'W	NSF Biology	J. Donnelly D. Foster	P. Holmes	823	1715	8^h52^m	1830^m	
"	9/26/72	459	"	NSF Biology	J. Donnelly	H. Sanders T. McLellan	0820	1824	10^h04^m	1830^m	Longest dive this season
60	10/11/72	460	Bottom Station	ARPA Navigation NSF Biology	E. Bland	F. Grassle J. Drogou, CNEXO, France	0926	1815	8^h49^m	1830^m	
61	10/21/72	461	42°01'N 70°11'W	ONR Training	V. Wilson J. Donnelly	D. Foster	1339	1614	2^h35^m	140'	
"	10/23/72	462	42°02.5'N 70°10.5'W	ONR Training	J. Donnelly D. Foster	A. Barrs	1043	1130	47^m	65'	
"	10/23/72	463	42°00'N 70°11'W	ONR Training	J. Donnelly D. Foster	K. Wagner	1136	1533	3^h57^m	66'	
"	10/24/72	464	42°02.7'N 70°14.1'W	ONR Orientation	J. Donnelly	C. Darrell, ONR O. Zipf, ONR	1035	1313	2^h38^m	160'	
"	10/25/72	465	42°02.5'N 70°10.5'W	ONR Orientation	E. Bland D. Foster	K. MacDonald	1033	1224	1^h51^m	48'	
"	10/25/72	466	42°02.5'N 70°10.5'W	ONR Training	J. Donnelly D. Foster	A. Barrs	1233	1507	2^h34^m	63'	
"	10/26/72	467	42°09.8'N 70°32.3'W	ONR Rock drill test	V. Wilson	D. Williams	0940	1213	2^h33^m	126'	Rock core did not operate in normal mode - no core

SUBMERGED NAVIGATION

William M. Marquet

In 1971 a development program in submerged navigation was initiated at the Woods Hole Oceanographic Institution and has continued through 1972. The program is sponsored by the Advanced Research Projects Agency (ARPA) and is administered through the Office of Naval Research (ONR). A goal of the system being developed is to provide a real time readout of the positions of *Alvin* and her support ship *Lulu*. The positions are determined relative to two or more bottom-moored acoustic transponders. The major equipment and the system operator remain on the support ship to minimize the equipment installed in *Alvin*. A digitizing acoustic receiver has been interfaced with a digital calculating system. The display equipment provides an automatic, real time, plot and printout of the positions of both *Alvin* and *Lulu*. Table A is an equipment diagram of the surface system.

Lulu and *Alvin* each carry precision clocks. These are synchronized before *Alvin* dives. The clocks act as controllers for the system. The *Alvin/Lulu* positions are determined every 30 seconds.

A new mooring for the AMF transponders was successfully used in 1972. This mooring is easier to launch and recover and provides flexibility not found in the 1971 mooring. During 1971-1972 thirty moorings have been set. One has been lost. The transponders being used are all interrogated at 8.1 KHz and answer at individual frequencies, typically 13.0 and 14.0 KHz.

At 15-second intervals *Lulu* and *Alvin* alternately transmit 8.1 KHz to call the reference transponders. *Alvin* also transmits at 12.5 and 13.5 KHz to send to *Lulu* a slant range signal and telemetry information. During 1972 pressure depth and acoustic depth information was sent by telemetry. A sound velocity sensor, purchased in 1972, will be added next year.

Sea trials were conducted in the Gulf of Maine and at the W.H.O.I. Bottom Station No. 1. During *Alvin* Dive #424, 14 July 1972, in the Gulf of Maine *Alvin* sat on the bottom ten times to permit obtaining successive fixes of a fixed target. The fixes per station varied from five to thirty. A total of 113 fixes was obtained. The after-the-fact data reduction showed that standard deviations of the N-S and E-W components of the various station fixes were always less than two meters. It should be noted that this is an indication of the repeatability of the system and not necessarily its accuracy.

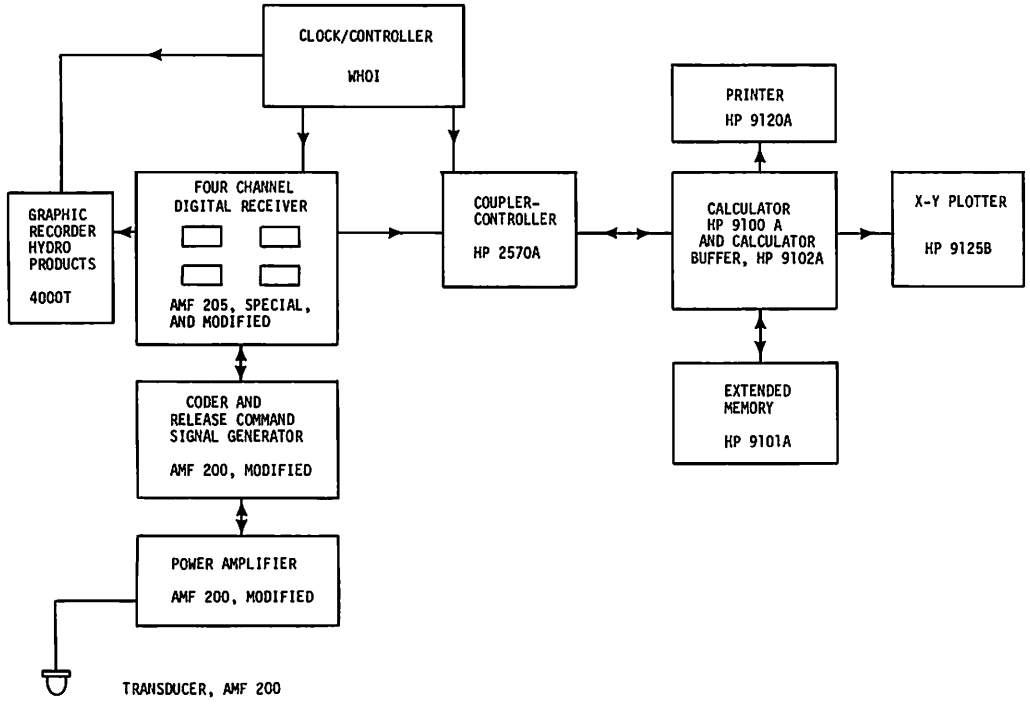

TABLE A

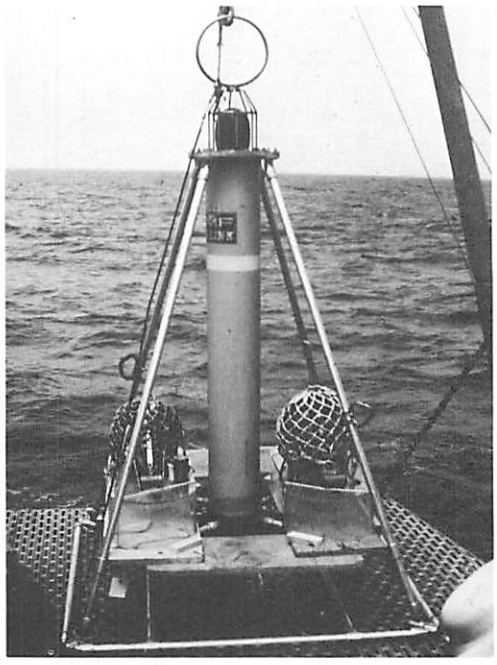

Fig.10 (Marquet) A surface or submersible deployed underwater "elevator" that can carry instruments to the bottom and retrieve them or samples attached by the submarine. The heart of the system is the AMF acoustic transponder and release device shown in the center of the tripod. This permits tracking from the surface, acquisition submerged by the submersible, and finally retrieval acoustically without reliance on the submersible (in bad weather for example).

A free-fall elevator system was also used in 1972. (Fig.5). The elevator is a framework built around a relay transponder that is interrogated at 7.0 KHz and retransmits 8.1 KHz which is the interrogation frequency of the bottom-moored reference transponders. To determine the position of *Lulu* and the elevator, *Lulu* at 15-second intervals alternately transmits 8.1 and 7.0 KHz. The free-fall elevator can be acoustically commanded to return to the surface.

During November of 1972 the *Lulu* navigation equipment was installed on the *Atlantis II* and was used at the Middle Atlantic Ridge to track a surface lowered bottom camera. The elevator relay transponder was clamped to the wire above the frame of the camera. The navigation system coupler controlled was interfaced to the HP2116 computer on the *Atlantis II* to provide computation and magnetic tape data logging not obtainable with the simpler 9100A calculator system. Real time tracks of the *Atlantis II* and dredge lowerings were also obtained.

PROJECT FLARE

Barrie Walden

The Florida Aquanaut Research Expedition (FLARE) was a four-month underwater habitat program involving ten saturated diving teams consisting of scientists from twelve organizations throughout the United States. Woods Hole Oceanographic Institution personnel formed the program coordination agency and directed the operations.

The program developed because of the success of the *Edalhab II* project off the Isles of Shoals early in 1971. This program demonstrated the feasibility of combining the University of New Hampshire's habitat *Edalhab* (Engineering Design and Analysis Laboratory Habitat) with Woods Hole's research vessel *Lulu* to form a mobile habitat system for use in shallow water. This combination proved to be unique in many ways. The habitat is a minimum-cost, student design with little of the sophistication and resulting complexities of the more costly undersea laboratories. Its small size and light weight make it ideally suited for an application requiring portability.

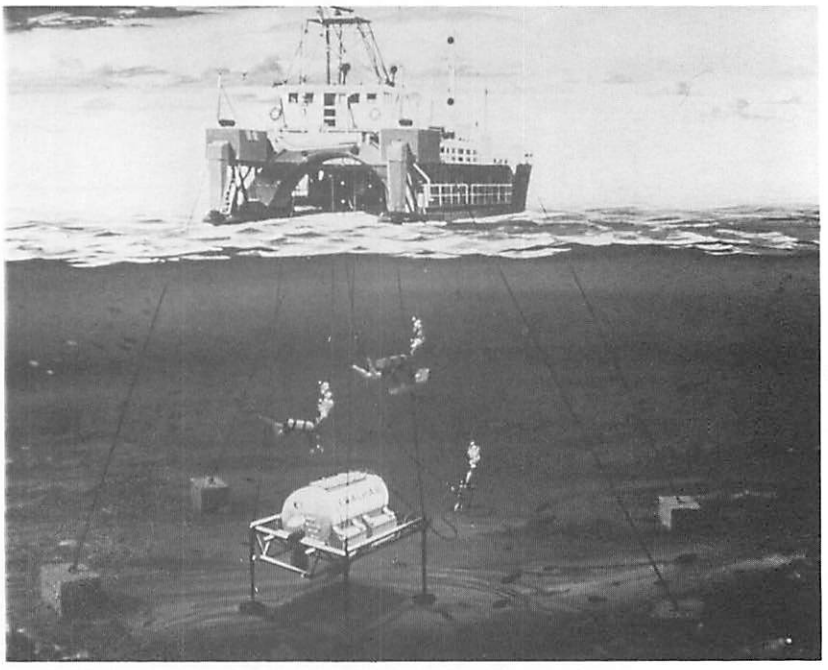

Fig.11 (Walden) Artist's conception of the R/V *Lulu* - *Edalhab* combination.

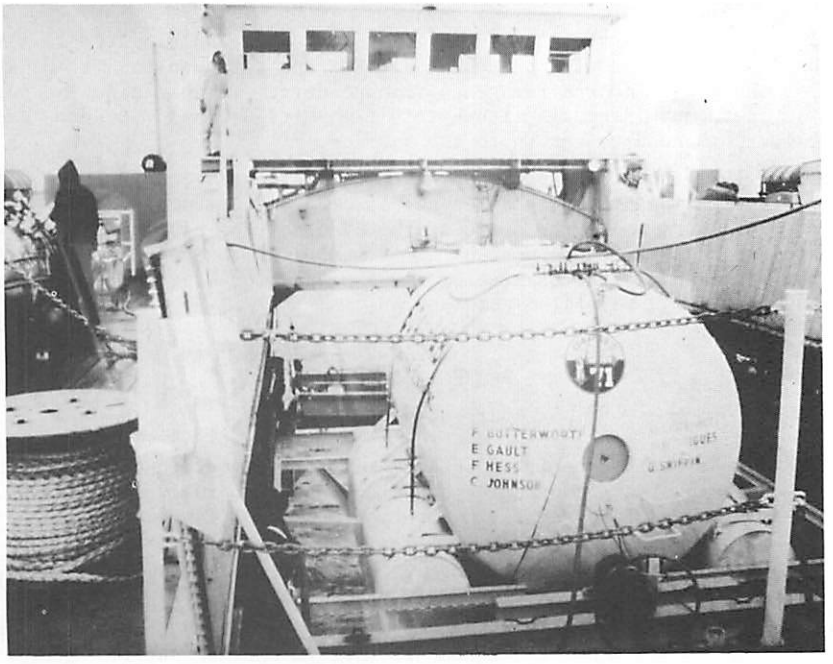

Fig.12 (Walden) *Edalhab* (Engineering Design and Analysis Laboratory Habitat) in stowed position aboard R/V *Lulu*.

The R/V *Lulu's* catamaran configuration and its large capacity hoist system made it an excellent choice for the role of transporting and supporting *Edalhab*. The vessel's size provided sufficient space for the equipment and personnel associated with the operational and safety aspects of the project as well as a platform for conducting surface-based experimentations.

In preparation for the January through May FLARE operations, Woods Hole personnel extensively modified both the habitat and *Lulu*. The interior of *Edalhab* was completely rebuilt along with much of the exterior. A four-point mooring system was added to *Lulu* as well as a habitat control station, deck decompression chamber, and diving station.

Lulu arrived at the first operations site off Miami in mid-January. This site, together with three others, had been previously chosen and surveyed by a site selection committee so as to satisfy both the scientists and the operational personnel. The first task upon arrival was to set the four-point mooring system which would hold the *Lulu* directly over the habitat during the mission. This anchoring system consisted of 500-pound anchors, 3/4" chain, 4-foot diameter surface buoys and cable or synthetic line to the ship. The correct deployment often required use of divers to insure that the chain did not foul and that the anchors were properly set.

After the mooring operation, the scientists joined the ship and loaded their equipment into the habitat. This loading operation was particularly easy since the habitat was brought to the surface between each mission. Once loaded with equipment and supplies, the habitat was lowered to the bottom on the hoist system chains. Support divers then entered the water and adjusted the habitat's anchors and legs to stabilize *Edalhab* on the bottom. The hoist system chains were disconnected and brought back aboard *Lulu*, leaving the umbilical as the habitat's only connection with the surface. The aquanauts were now able to begin their four-day mission while personnel aboard the *Lulu* provided support for their efforts.

During aquanaut excursions, one member of the ship's crew and two support divers formed a safety team which was prepared for all types of aquanaut emergencies. One diver remained on the main deck and kept watch for an aquanaut distress signal. If a signal was spotted, this diver would inform the control station personnel and then stand-by the decompression chamber in case its use whould be required. The control station personnel would dispatch the second diver and the crew member to aid

Fig.13 (Walden) Diver's view of an aquanaut and the habitat deployed over a reef off Miami.

the aquanaut. A small rubber diver-assistance boat was always ready and was equipped with a set of emergency equipment including air tanks, regulators and a bang-stick for possible shark problems.

At the completion of a mission, an oxygen breathing system was delivered to the habitat and the aquanauts received 40 minutes of O_2. After this time, two support divers assisted the scientists, one at a time, from the habitat to the surface. Once on the surface, the aquanauts were lead up to the main deck and into the decompression chamber. This operation was conducted so smoothly that the aquanauts consistently went from pressure to pressure in less than 1½ minutes. Decompression lasted 19 hours and consisted of alternating periods of air and oxygen breathing.

After each mission, the habitat was recovered and reconditioned. It was usually kept on the surface for one night and redeployed the following day if the same site was to be reused. Since four sites were occupied during the program, *Lulu* frequently had to travel and reset the mooring system between missions.

Ten scientific programs were planned using the habitat, and five more were to be conducted from the support ship. Of these, one aquanaut investigation and one surface investigation had to be deleted because of operational difficulties primarily caused by weather. The remaining projects were completed although many had to be shortened somewhat, again primarily due to weather.

Project FLARE was intended to accomplish a number of objectives: many valuable research projects were to be conducted from both the habitat and the support ship encompassing such disciplines as geology, chemistry, biology and physics; information was to be gained on the applicability of habitats and saturated diving to the types of investigations undertaken; a large number of personnel were to be trained in the techniques of saturated diving; and finally, the type of habitat system represented by the R'V *Lulu* - *Edalhab* combination was to be evaluated. The project was successful in that each of these goals was realized to a high degree.

A SELF CONTAINED ANCILLARY MODULAR PLATFORM (SCAMP)

Clifford L. Winget

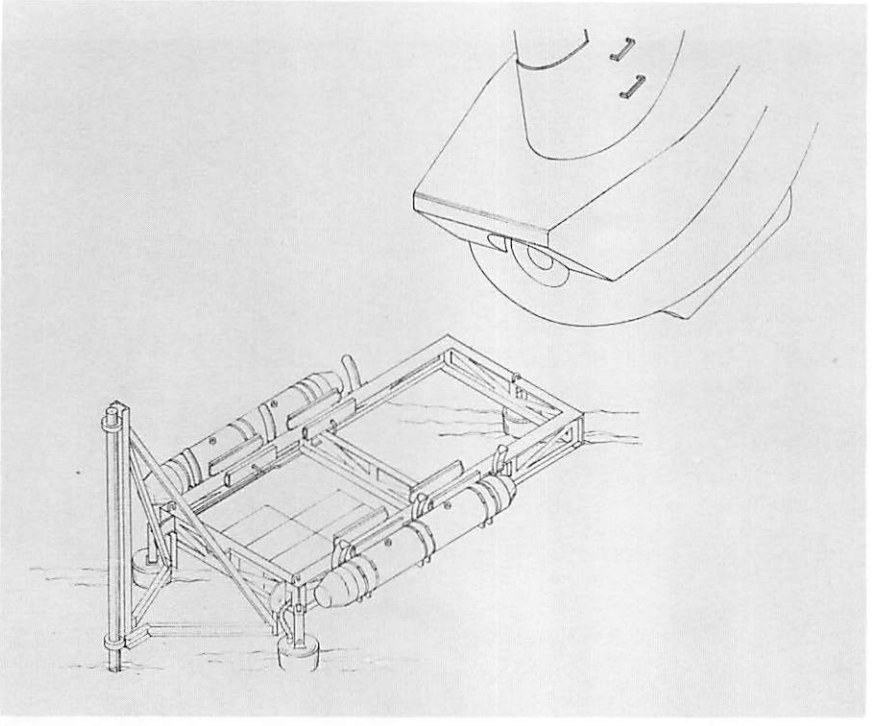

Fig.14 (Winget) Artist's sketch of *Alvin* submersible approaching for a bottom landing on the self-contained ancillary modular platform (SCAMP).

The principal objective of the device illustrated in the artist's sketch is to design, fabricate and test a self-contained platform that can be attached to the *Alvin* submersible, effectively increasing the payload capability of the vehicle.

Its proposed use will be to support a wide variety of science apparatus too large or heavy for the submersible to handle with its existing payload buoyancy and power capability.

The platform will have a fixed ballast system capable of supporting science gear having a water weight up to 400 pounds. The payload ballast will be provided through the use of blocks of syntactic foam, an epoxy resin/glass microsphere matrix, that can withstand the exposure and hydrostatic crush pressure of sea water to depths as great as 12,000 feet. The Platform will have the capability of providing 30 volt D.C. power for science apparatus, without becoming a parasite to the submersible power system. It will be capable of anchoring itself to the bottom through the use of electrically-powered pumps and three suction pod assemblies.

With proper ballasting and suction pod operation, the platform may be left on the bottom as a long-term bottom station. It can be moved, or recovered and returned to the surface by landing the submersible on the platform, remotely latching the submersible skids to the platform landing rails, and flying the device and its science apparatus to the surface. The platform operating depth will be 12,000 feet, making it compatible with the new depth capability of the titanium personnel sphere to be installed in the *Alvin* vehicle.

Figure 15 is an overall view of the basic SCAMP frame, showing the starboard tubular battery compartment mounted on the platform. Each compartment has a removable fiberglass nose and tail cone mounted at its extremities. Each cone is an oil-filled pressure-compensated compartment, that will house the power control relays and circuits used to operate both the science equipment and the SCAMP electrical system. Snap latches are used to attach the cones to the tubular compartments, and will provide easy access to the battery compartments.

Fore and aft pitch control of the platform, necessary to compensate for the weight of science apparatus, will be provided by sliding the batteries longitudinally along tracks mounted within the tubular battery compartments. The battery position within the tubes, can be adjusted by the operator while submerged.

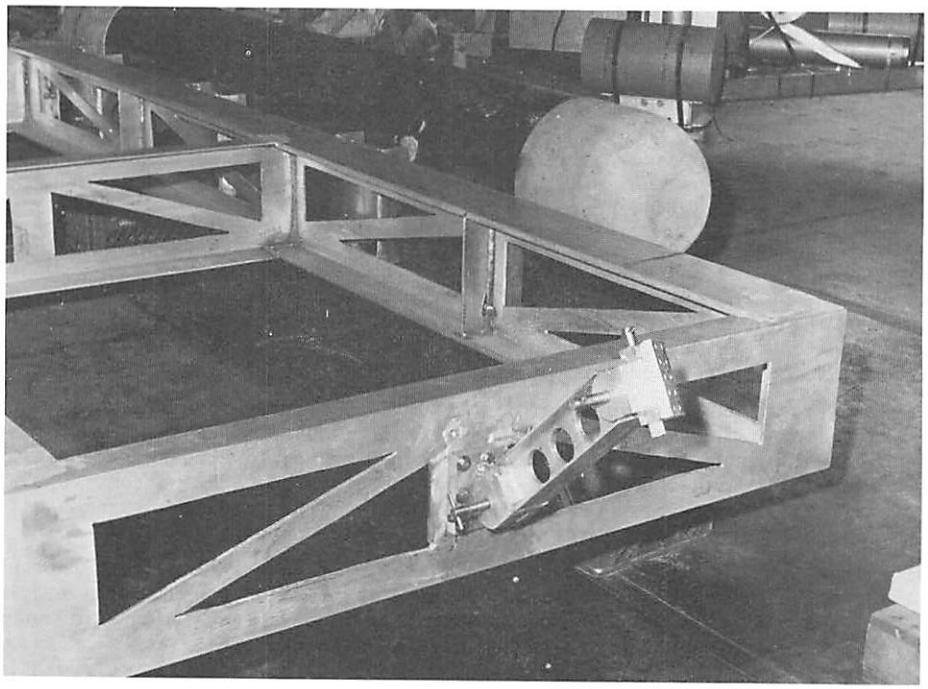

Fig.15 (Winget) SCAMP frame, illustrating the welded truss construction of the 12-inch 6061 aluminum I beams, with one of the tubular battery compartments in the background.

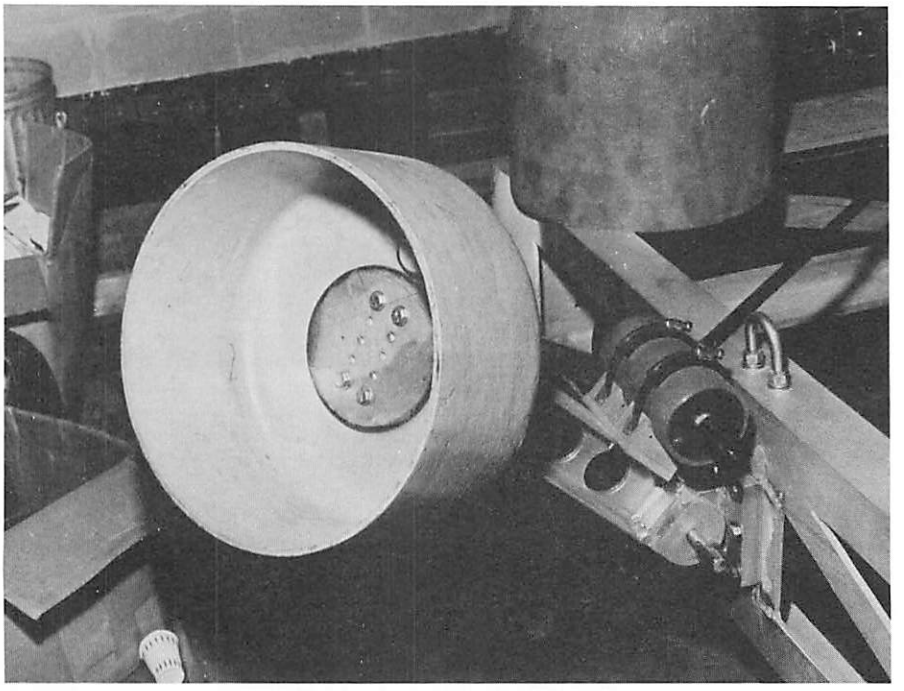

Fig.16 (Winget) Close-up view of the starboard pump and suction pod assembly used to hold the SCAMP to the ocean floor.

Figure 16 illustrates one of the three suction pod anchors that are attached to the base of the platform. They are positioned in a location that permits them to contact the ocean bottom before the hull or skids of the platform.

At this point the pilot applies power to the motor/pump assemblies mounted at the top of each suction pod. In the suction mode, the pump extracts water from the plenum chamber that forms the housing of the assembly. A low pressure area is created within the chamber, pulling the shell walls down into the bottom sediment. As the shell sinks into the bottom, water seepage under the chamber walls decreases to a minimum quantity, depending on the sediment density.

After the plenum chamber has ceased settling, the operator may turn the pump/motor assemblies to the "off" position. The design and construction of the rubber impeller suction pump, provides a check valve type action, preventing back flow into the plenum chamber. To extract the bottom anchor suction pods, the operator applies power to the pump, reversing the direction of water flow. The pump forces water into the plenum chamber, creating a large area low pressure hydraulic piston effect, pushing the assembly out of the bottom sediment, freeing the submersible and the work platform.

When operating in areas having a flat hard rock surface, or very soft silty sediment, the use of a thin flexible skirt around the base of the plenum chamber is used. The skirt conforms to the rock surface, allowing the motor/pump assembly to maintain the required low pressure condition within the chamber, effectively holding both the platform and the submersible on the bottom. Operation of the various pumps, lights, battery traverse mechanisms, as well as the science apparatus attached to the platform, will be controlled from within the submersible by the operator.

The control system will encompass a light-transmitter section mounted within the submersible pressure hull, the light pulse bits will be selected by the pilot through the use of a toggle switch panel, which in turn actuates a universal asynchronous transmitter/receiver subsystem. The subsystem codes the signal into pulsed light bits which are transmitted through the plexiglass windows of the submersible. The receiver section will be mounted on the SCAMP and has the capability of both light bit detection and error detection. The output control circuit of the receiver will be used to actuate the appropriate circuit power control relay. The pulsed light concept provides a total of 99 bits, or operations, with each operation taking place within 100 milliseconds.

The ability of the pilot to control the platform and science apparatus without the necessity of interconnecting cables, will provide a flexible science bottom station that can perform numerous science tasks with a minimum expenditure of submersible time. The pulsed light concept eliminates the necessity of mating waterproof connectors to the submersible when the vehicle returns to the platform, and could, with a minimum of design modifications, be provided with an acoustic receiver section that would permit surface control of the SCAMP bottom station.

OCEAN ENGINEERING ACADEMIC DEVELOPMENT

Albert J. Williams, III, James W. Mavor, Jr., Henri O. Berteaux,
Stephen C. Dexter, Earl E. Hays

Ten students were enrolled in the Joint Program in Ocean Engineering with the Massachusetts Institute of Technology during 1972. Of these, four graduated with the degree of Ocean Engineer. This degree, not widely known, requires three years of full-time graduate study including a thesis. The degree is more comprehensive than the Master of Science but less than the Doctor of Philosophy. In addition, three students passed the Part I qualifying examination for the Ph.D. Of the four graduates, two have accepted employment in oceanographic instrument development, one is in the United States Naval Submarine service and one is pursuing a Ph.D. at another University.

In the Joint Program, students while at Woods Hole Oceanographic Institution, work in ocean science and supporting technology. At the Massachusetts Institute of Technology they study basic engineering and the general subject of man-sea interaction.

Academic Subjects

Five subjects were given during 1972:

Oceanographic Systems I & II, by R. W. Miller

Oceanographic Instrumentation and Measurement, by A. J. Williams, III

Buoy Engineering, by H. O. Berteaux

Deep Submergence Oceanographic Engineering, by J. W. Mavor, Jr.

Texts are in preparation for the last two subjects.

The text in Deep Submergence Oceanographic Engineering, nearly complete, treats primarily the process of transporting the scientist and his instruments into the deep sea. It includes Working Environment, Mission Analysis, Hydromechanics, Structure, Machinery, Platforms, and Design Studies.

Research Projects

In faculty and student research sponsored by the academic program, beginning programs are emphasized. Interdisciplinary experience is important and we were pleased to have had students working in all of the major areas of ocean science during 1972. Research is carried on with other sponsored research programs and in the courses of study.

Exposure of Materials and Monitoring of Environment at Deep-Bottom Station of W.H.O.I. (S. C. Dexter)

The following galvanic corrosion couples were recovered by *Alvin* from the Deep-Bottom station during August, 1972, after a one-year exposure:

1. 316 stainless steel coupled to equal area anodes of 6061-T6 aluminum, 1020 hot rolled steel and zinc.
2. 6061-T6 aluminum and 7079-T6 aluminum coupled to equal area anodes of zinc.
3. Sintered 316 and Allegheny-Ludlam's 6X stainless each coupled to equal area anodes of 1020 hot rolled steel and zinc.

These samples are now being evaluated to determine if the mode of deployment of these couples was satisfactory and to see if the actual corrosion rate of the samples agrees with theoretical predictions. The couples involving sintered stainless steels were included as part of a program aimed at evaluating the possibility of fabricating marine hardware by powder metallurgy.

Nucleation of Localized Corrosion in the Presence of Microorganisms (S. C. Dexter)

Experimental technique was developed including freeze drying and electron microscopy.

Handbook of Oceanographic Engineering Materials (Stephen C. Dexter)

A handbook is being assembled to serve as an aid in materials selection to oceanographic engineers and designers. The first part of the handbook covering metallic materials has been completed. It is a collection of data on composition, mechanical and physical properties, seawater corrosion resistance, forms available, fabricability, and cost of the eighty-odd metals and alloys having the greatest utility in the marine environment. The second part of the handbook, covering nonmetallic materials, will be completed during 1973.

Motion Sensitivity of Flame Ionization Detectors (Albert W. Williams, III and Ronald C. Gularte)

The gas chromatograph developed in 1971 was packaged as a portable sea-going instrument. Laboratory work to decrease the detector's motion sensitivity continued. The instrument was taken to sea locally where performance was evaluated.

Other Research Projects

Other research projects with major contributions by students were as follows:

Development of Chesapeake Entrance Buoy Farm
Alvin Submerged Retrieval
Saltfinger Research
Fish Hydrodynamics
Oceanographic Spherical Platform
Impact Sound Source
Great Harbor Sediment Transport
Beach Wave Force Measurement
Self-Powered Towed Acoustical Platform
Deep Rescue Submarine for Helicopter Deployment
Aquaculture and Virology
Deep Towed Instrument Fish
Use of Long Range Side Scan Sonar
Deep Submersible Hydrodynamics

SAFETY PROGRAM

James W. Mavor, Jr.

With the increase in physical size of the Institution and its number of employees and resultant difficulty of communication, there has been moderate increased use of impersonal means such as signs and rules to promote safety. A safety inspector has been appointed by the Manager of Facilities to cover shops and buildings as required by the new OSHA (Occupational Safety and Health Act) regulations.

The safety program continues to depend primarily on individual responsibility and live supervision. The safety engineer reviews on a spot-check basis, investigates potential hazards, and accidents and advises on corrective action. Occasionally it has been necessary to suspend scientific operations because of obvious or suspected hazards. This is inevitable and in the long run probably has a salutary effect. Three such suspensions occurred in 1972. One involved the system for attachment of a large instrument to *Alvin* and another, the seaworthiness of a ship on which Woods Hole Oceanographic Institution employees were scheduled to work. The third was a chemical etching process performed under unsafe conditions. All other safety problems were resolved early enough to avoid altering cruise schedules or seriously modifying other schedules. Safety problems were treated in several areas as follows:

Manned Submersible Operations

Alvin postseason condition review, submerged retrieval plans, review of plans for *Alvin* 12,000 ft. operation, swordfish attack, interfacing *Alvin* with scientific gear, deep rock drill, frame cracks, freeboard, hatch seal.

Ships

North Seal stability review, stability review of entire Woods Hole Oceanographic Institution fleet, shipboard cranes review, post-cruise meetings participation, *Lulu* maintenance review, *Lulu* drydocking accident, ship transducer air lock safety, prepare structural history of *Lulu*.

Pressure Vessels

Prepare guidelines for undersea pressure vessle design for ASME (American Society of Mechanical Engineers), review of pressure vessel designs, plan installation of Dahlgren 10,000 psi test facility, high pressure air system problems with geophysics air gun systems, high pressure gas container inspection and test, disposal of illegal or retired pressure vessels.

Operations at Sea

Prepare booklet crane data, trawl winch problems, buoy deployment procedures, long wire breakage problem.

Shore Facilities

Building structure review, chemotaxis glass refit design review, fume and dust problems in carpenter shop, GRP (Glass Reinforced Plastic) shops, photographic laboratory, chemistry laboratory, disposal of dangerous chemicals.

Government Safety Regulations

Accumulate and review Federal and state safety codes.

INFORMATION PROCESSING CENTER

Melvin A. Rosenfeld

The responsibilities of the Information Processing Center continue to include the four general areas: 1) providing technical services to the Institution's computer users, 2) operating, maintaining and developing software for the general purpose Sigma 7 and associated equipment, 3) operating and maintaining the general purpose shipboard computer systems and satellite navigation systems and, 4) developing and operating computerized aspects of the Institution's business work. During 1972 a fifth area, education, was started with the acceptance of responsibility for teaching statistics and related subjects as part of the Joint Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Program.

The Sigma 7 has served the Institution for nearly five years and all aspects of its operation continue to improve. During 1972 two major changes were made to the Sigma 7. First, 16,000 words of core memory were added bringing the total core to 48,000 words. Second, the basic operating system was changed from a serial mode (one job at a time) to a mode which allows simultaneous computing and input-output operations. In late December 1972, a dual spindle disk pack system with an on-line capacity of 50 million bytes was delivered; it will be installed in early 1973.

A shore-based Hewlett-Packard 2100 computer was added to the shipboard complement of equipment. It has been installed in the DESC building.

Computer usage, both on shore and on board ship, showed a very large increase over that of 1971.

Shipboard Computer Systems

The major goals of the year were met with the installation of the Hewlett-Packard shore computer system in the DESC building, and the addition of peripherals to the three shipboard systems to bring each system to equal computing level as well as increasing the overall throughput rate of each system. The number of shipboard scientific users has increased significantly from last year.

New technicians were added during the year to support the increasing demand for computer time on the ships. Logistic support for the shipboard computers was improved by converting the inventory of parts, supplies, and equipment to a punched-card system. The new location of the Shipboard Computer Systems group at the DESC building has provided a center of operations for repair, maintenance, and program preparation for sea. The shore-based system has provided means for scientists to prepare programs and systems for scientific cruises. Use of new high-speed devices such as line printers, CRT displays, and card reader inputs has decreased the average turn-around time for the user. An hourly charge for use of shore-based Hewlett-Packards, started in May, has provided the means to make the shore system self-supporting.

Also, various project groups installed additional computer systems on W.H.O.I. ships to meet the increasing demands of computerized scientific investigations. The IDOE (International Decade of Ocean Exploration) cruise on the R/V *Atlantis II* had an installation of four computer systems for the

various scientific experiments. The basic IPC (Information Processing Center) shipboard computer system still remains the central computing facility to accommodate the various tasks of scientific processing, while the other project systems meet the need for specialized instrumentation systems. The tendency to supplement the central computer system with additional project-oriented computers is increasing. Two additional systems, one for acoustics, and the other for physical oceanography will become fully operational within the next few months.

The number of at-sea days for the R/V *Atlantis II*, R/V *Knorr*, and R/V *Chain* was approximately 673. This figure does not reflect *Knorr's* sea schedule after 8 May 1972 at which time the ship embarked on the GEOSECS cruise. GEOSECS was not supported by IPC technicians. IPC technicians spent 697 days at sea.

A computer system was installed on the R/V *Gosnold* for the first time. The *Knorr* system was used and a self-contained instrument hut was modified for the computer system operation. The free-fall electromagnetic current meter (EMCM) used the computer to process the data collected from the instrument. The use of the Tektronix Graphics Display unit to make fast output plots speeded data processing manyfold.

Computer Use Time

Chargeable use of both the Sigma 7 and the PDP-5 increased; chargeable use of shore-based Hewlett-Packards was initiated during 1972. The chargeable time on the PDP-5 went from 1515 hours in 1971 to 1883 hours in 1972, an increase of 24 percent. The chargeable use for shore-based Hewlett-Packards was 1824 hours.

The Sigma 7's chargeable use increased from 1450 hours in 1971 to 2081 hours in 1972, an increase of 44 percent. Total Sigma 7 usage in 1972 was 2320 hours; the non-chargeable portion of 239 hours having been used for system/library development and testing and record keeping within the Information Processing Center. Please note that these hours reported for the Sigma 7 in 1972 are defined differently than the hours reported in prior years. In June, 1972, the Sigma 7 operation changed from a serial mode (completion of one job before the start of another) to a "symbiont" mode (simultaneous computing and input/output operations). This change required a complete revision of the method of measuring computer use; an equivalent computer hour is calculated from a combination of central processor (CPU) time, number of cards read, and number of pages printed. The calculation results in equivalent computer time which closely approximates the amount of time required to accomplish the same amount of work prior to the introduction of the new system. The following Sigma 7 job statistics, then, are based on real hours for 1971 and for the first five months of 1972, and on equivalent hours (and minutes) for the last seven months of 1972:

	1971	1972
Number of jobs processed	36,125	46,521
Total hours used	1,657	2,320
Central processor hours	1,657	1,880
Cards read	7,174,922	8,139,984
Pages printed	762,509	1,083,728
Cards punched	620,336	611,687
Average CPU time/job	2.75 mins.	2.42 mins.
Average number cards read/job	198.61	174.97
Average number pages/job	21.11	23.30
Average number cards punched/job	17.17	13.15

The distribution of chargeable Sigma 7 use by source of support in 1972 was:

Source of support	Percentage of use
Office of Naval Research contracts	51.3
National Science Foundation grants	18.2
National Marine Fisheries	7.0
W.H.O.I. business	6.4
Outside commercial	5.5
Other government	2.8
Other universities and laboratories	2.7
Johns Hopkins Applied Physics Laboratory	2.1
U.S.G.S.	2.0
W.H.O.I. education	1.0
Miscellaneous	1.0
	100.0

There were no major changes in the relative proportions of support from those of 1971 except that the outside commercial work more than doubled in percentage of use. The Moored Array Project is still the biggest single user of Sigma 7 time with 32 percent of chargeable use, a slight decrease from the 34 percent of 1971.

A new analysis was tried this year - to determine chargeable Sigma 7 use by Institution department. An attempt was made to identify each user project with a department. This was relatively easy for regular W.H.O.I. personnel; arbitrary splits were made for interdepartmental projects. Some outside users were associated with a W.H.O.I. department. Some students were associated with a department if identifiable support was shown; other students were grouped under "education". The following distribution, then, does not account for all of the chargeable use hours; outside commercial and much of the outside university and laboratory use is not included. The result is a very close estimate of the actual use distribution:

W.H.O.I. Department	Percentage of use
Physical Oceanography	53.6
Geology and Geophysics	28.2
Administration (business)	7.4
Ocean Engineering	5.6
Education	2.8
Biology	1.3
Chemistry	1.1
	100.0

Programming and Analysis

During the past year about half the time of the programming staff of IPC has been spent in general upgrading of computer functions. For the Sigma 7, this includes system improvements, user consultation, and writing, modifying, and documenting general purpose routines. For the Hewlett-Packard computers, some software modifications were necessary following the acquisition of the permanent shore-based system and peripherals at the DESC building.

There appears to be a growing emphasis on computer analysis involving several programs for both the Sigma 7 and Hewlett-Packard computers. Such a project is the analysis being done for the Acoustic Data Capsule project, which involves preliminary analysis on the Hewlett-Packard, and editing, digitizing, and narrow band and third octave analyses on the Sigma 7. Another dual computer operation is involved in the processing of data from the new vector-averaging current meters and other instruments using similar recording devices. A program has been written for the Hewlett-Packard to transfer the data from the original cassettes to magnetic tape. Routines have been written for the Sigma 7 to facilitate additional processing of the data.

The result of this increased use of dual systems and other shipboard work is that between 30 and 40 percent of the IPC programming and analysis time was devoted to Hewlett-Packard work. This is in sharp contrast to 1970 and earlier years when essentially all such work was for the Sigma 7.

Another area of increasing importance is storage and retrieval of data. Such a program has been written in collaboration with a member of the Geology and Geophysics Department. This involves creation, indexing, maintenance, and retrieval of a library of magnetic, navigation, and bathymetric data.

In addition to creating new programs, the programming staff spends much time in modification and improvement of existing programs.

One FORTRAN course was given to about 25 W.H.O.I. employees and students during 1972. A one-semester graduate course in statistics was offered to students of Joint Educational Program.

National Science Foundation Grant GJ-133

This grant of $250,000 was given on July 1, 1968 and terminated on June 30, 1972. During the four years of its existence this grant furnished the sole support for student computer use and served both W.H.O.I.-M.I.T. joint students, W.H.O.I. fellows and guest student investigators and students from the Marine Biological Laboratory. Since June, 1972, W.H.O.I. student support has been provided by the Education office. Grant GJ-133 also supported the IPC analysis and programming staff when it was engaged in Institution-wide activities such as library building, systems development or training. There were also some capital acquisitions including the general-use CALCOMP plotter, part of the cost of the Bendix DataGrid digitizer, a tape-cleaning machine, and a magnetic tape drive and controller for the Hewlett-Packard systems.

Over the four years the use of the Sigma 7 under grant GJ-133 was:

System program and development	107 hours
Education (student use)	189
Unsponsored research	22
	318 hours.

LONG RANGE ECHO RANGING - DEEP TOWED ARRAY

Willard Dow, Thomas O. Sutcliffe

The deep towed array was used successfully on cruises in 1970 and 1971 as part of a long-range echo-ranging system. However, some deterioration in array sensitivity has been noted following long periods of deep towing. This has been traced to a slow seepage of oil through the hydrophone seals.

A method was devised for extracting the oil with a hypodermic syringe without destroying the transducer. All of the elements were then encapsulated in a special compliant adhesive coating of polysulfide-rubber which is impervious to oil and water. Extended tank tests at high pressures (3000 lbs) followed by acoustic measurements revealed that the units had been effectively sealed without altering their sensitivity. It is believed this technique may well permit certain other shallow transducers to be used for deep work, providing, of course, that their operating characteristics are not compromised by the increase in static pressure.

NEUTRALLY BUOYANT SUSPENSION SYSTEM (MOD II)

Willard Dow, Thomas O. Sutcliffe

The neutrally buoyant deep hydrophone suspension originally described in the 1970 Summary of Investigations has been partially redesigned and streamlined for quieter operation and improved stability underway. Following extensive tank tests with a 1/3 scale model, sea trials of Mod. II were undertaken during *Chain* cruises #102 in February 1972, and #107 in July and August.

During these cruises the rig was deployed principally for ambient noise measurements. However, it also proved successful in tracking bottom-mounted beacons where a high degree of hydrophone stability was required for purposes of phase comparison of the acoustic signals. Comparison of flow noise recorded simultaneously from a hydrophone mounted on the suspension and from one clamped to the suspending cable showed the suspension unit to be quieter by 8-20 db depending on the amplitude of cable excursion resulting from the ship's pitch and roll.

Another experiment showed quieting to be equally effective when a vertical two-channel array was substituted for the single hydrophone. Some residual strum from the hydrophone supporting bridle was still evident, indicating the need for improved fairing.

A technical report on Mod II is in preparation.

MODIFIED RAY THEORY

James A. Davis, Stanley W. Bergstrom

A modified ray representation for some of the diffraction effects associated with two turning-point problems which arise in inhomogeneous media has been reported previously. This modified ray theory (MRT) predicts a frequency dependent distortion of the sound field obtained by ordinary ray theory. Some of the qualitative consequences of this distortion are illumination of shadow regions and leakage and trapping effects. During this last year it has been possible to expand the investigation to include quantitative results. This has been done, in part, through various programs written for the Sigma 7. Numerical results indicate that the accuracy of this approximate theory is strongly dependent on the treatment of the caustic which arises in the MRT field. In problems in which there is no caustic in the ordinary ray theory field, the simplest, and most practical, treatment of the MRT caustic,results in a field that follows the field obtained by normal mode theory to within a few decibels for at least two decades into the shadow region. The degree of illumination of the shadow region is found to be strongly dependent on frequency and type of problem. The results of this part of the investigation were presented at a meeting of the Acoustical Society of America in Buffalo, New York, in April.

In sound propagation problems where there is a shadow region, the ordinary ray theory field may or may not contain a caustic, whereas the MRT field always contains at least one caustic and either an inflection point or additional caustics. The behavior of the MRT field depends, in part, on whether or not the problem parameters are such that there is a caustic in the ordinary ray theory field. Based on an approximation technique valid for only one caustic, or well-separated caustics, it is possible to identify several MRT behavior patterns. For ranges much less than the shadow boundary range the MRT field approaches the ordinary ray theory field. For ranges much greater than the shadow range, the MRT field (suitably extended to take the caustic into account) approaches either (1) the ordinary ray theory field (also extended), or (2) the normal mode field depending on whether or not the problem parameters are such that a ray theory caustic is present. For ranges in the vicinity of the shadow range, the behavior can be very complicated. In problems of this type the fall-off of the field in the shadow region is a combination of diffraction associated with the surface and diffraction associated with the ray theory caustic. The ability of the MRT field to follow the proper mixture of these two effects in some cases and not in others is felt to be due to the caustic treatment, and that use of an approximation technique valid for two or more closely-spaced caustics will result in a field which will follow the fall-off of the exact answer in all cases. The results of this part of the investigation were presentdd at a meeting of the Acoustical Society of America in Miami, Florida, in November.

AMBIENT NOISE 1972

Lincoln Baxter, II, James A. Doutt, Frederick R. Hess and Willard Dow

R/V *Chain* was employed in making ambient noise measurements in the North American Basin. Three locations were occupied in February and three during September and October. As in the last few years, sonobuoys and a ship-suspended deep hydrophone were employed to obtain measurements at three or four depths simultaneously. Sites were occupied for 24 hours. The signal processing for analysis has been much more thoroughly automated this year. Hydrophone signals (or replays of analog recordings of them) filtered through one-third octave bandpass analog filters were processed and plotted by digitizer and shipboard computer system. The plotting program has also been adapted for use on the Sigma 7 computer for processing of ACODAC (Acoustic Data Capsule) data.

A report on the results of the February measurements and one on the development of the neutrally buoyant ship-suspended hydrophone are almost completed.

ARRAY COHERENCE: EXPERIMENT AND ANALYSIS

Robert P. Porter and Robert C. Spindel

This past year a major effort was made to initiate a unified program of experimental and theoretical research in the important area of long-range, low-frequency, acoustic propagation. The primary goal of this research is to form a better understanding of the spatial and temporal variations of phase and amplitude of long-range transmissions, and in audition to understand the appropriate causal oceanographic environmental factors. Emphasis is placed on transmission wholly through the water column without the complicating effects of bottom and surface reflection.

Two preliminary experiments were conducted. The first was performed 100 miles east of Eleuthera Island using a low-frequency source mounted on the continental shelf. A variety of ship-suspended hydrophones and sonobuoys were used as receivers. A CW (Continuous Wave) Doppler detection scheme was conceived and developed to continuously track the motion of suspended hydrophones with accuracies to 4 cm. In principle, it is a straightforward matter to continuously correct for phase shifts due to hydrophone drift. The hydrophones were allowed to drift under the influence of prevailing winds and currents (nearly normal to the direction of propagation), thus sweeping out an array approximately five miles in length. Data from this experiment will produce information on spatial coherence in a horizontal plane. Amplitude and phase time series were obtained and are now being analyzed. In addition, an analysis of suspended hydrophone motion has been made using the Doppler tracking system.

The second experiment, a multi-ship exercise (*Chain, North Seal, Dearborn)* conducted near Bermuda Island, employed two bottom-moored buoy systems (ACODAC) as receivers, together with a variety of towed sources. Time series data has been collected and is being analyzed. This data will produce spatial and temporal coherence data for a range of frequencies as well as some propagation loss data.

Environmental measurements were made during both experiments to allow correlation of acoustic variability with environmental variability. Both STD tows and lowerings were made.

These two experiments, and data processing to date, have revealed several factors to be considered in this continuing program. First, it is essential that the location of a towed acoustic source be known within a wavelength in order to isolate phase variations due to the effects of the medium only. Second, the source should be deep, at least in the main thermocline in order that most energy arrives along non-bottom bounce paths. Third, motions of moored and suspended hydrophones are complex and can be of large magnitude, hence it is imperative that such motion be tracked by a system such as that described above. Fourth, the tracking system works so well that rigidly-moored hydrophones are not required. Thus a simple data-collection buoy may be designed to obtain long time series data in mid-water depths.

Additional work was performed this year on the dispersion of axial SOFAR propagation in the western Mediterranean. The data used in this analytical study were obtained on *Chain* 82 during July 1968. Dispersed high-order modes have been observed at frequencies as high as 300 Hz and at ranges of 600 km for shots detonated and received in a SOFAR channel with an axis depth of 100 m. Spectrum analysis of the shot records has revealed as many as five identifiable group velocity profiles that correlate with modes as high as 70. It is typical of these records that high frequencies arrive later. Agreement between theoretical and experimental dispersion curves has been obtained with the WKB (Wenzel, Kramers and Brillouim) approximation to mode theory. The observed, large time spread of signal arrivals is characteristic of deep, sound-channel propagation of short pulses and is normally explained by ray acoustics; high-order mode theory predicts time spreading of the arrival and, in addition, predicts dispersion of the spectrum. It has been shown that only certain high-order modes are received due to the interference between the upward- and downward-travelling waves constituting each mode.

VOLUME REVERBERATION

Paul T. McElroy

In 1972 we continued our efforts both to understand the geographical factors affecting scattering column strength spectra and to formulate and test better-measurement techniques for determining important volume reverberation parameters. At-sea measurements were made during cruises *Chain* 102 and 105.

Geographical Distributions

Our studies of geographical distributions employed two techniques we have reported in earlier Summaries: The Integrator and Explosive Broad-Band Methods.

Integrator (Harold K. Lim, Carlton Grant, Jr.)

The final steps to make the Integrator a useful instrument for data-taking at sea were completed: a program was written to compute column strength and volume-scattering strength from the raw data, and chart plots of these data versus position along ship's track are now generated on a nearly daily basis on the shipboard computer system. Considerable updating of the analog portions of the instrumentation took place.

Some data were collected during *Chain* 102, while a large body of data was collected during *Chain* 105, much of it during trawls. Crude correlations were noted during *Chain* 105, with variations in fish catch and geographical position. Detailed comparisons await the completion of the analysis of fishing. Early in 1973, the anticipated completion of fish trawl analysis from *Atlantis II* 59 will permit comparison with analyzed Integrator data from that cruise.

Explosives (Samuel T. Simkins, Stanley W. Bergstrom and Harold K. Lim)

We noted in the 1971 Summary of Investigations the lack of any clear-cut geographical groupings of explosive spectra from *Atlantis II* 49. There was a strong expectation that such groupings might occur based on faunal groupings of samples taken during the same cruise. Before rejecting the hypothesis that there could be a correlation between variations in acoustic volume reverberation spectra and variations in faunal distributions, we decided to develop spectra for the much broader geographic area covered by *Atlantic II* 59 and *Chain* 105.

The first step in this process was using improved analysis instrumentation. A new version of the Oceanographic Computer, an analog computer, was first assembled in 1971, but proved to be unusable without a number of improvements. When those changes were made we found we had an increase in dynamic range from 20-24 db in the old Oceanographic Computers to 30-33 db in the new - and within that range, accuracy was improved.

Using the new computers we have processed 34 stations from *Chain* 105 and 26 from *Atlantis II* 59 to yield column strength spectra at a total of 16 one-third octave frequencies. At the end of the year, reading of the records was still underway. When those spectra have been computed, the entire body of data, including that from *Atlantis II* 49, will be examined to determine if any geographical correlations exist within the spectra itself. This will represent 85 stations with an average of three useful explosive shots per station.

Another study made during 1971 was the source level of explosive charges fired very near to the surface. In our report W.H.O.I. 72-31, we deduced the directivity pattern as a function of frequency, showing that it was not omnidirectional. During *Chain* 102, a relatively uncomplicated experiment was carried out to measure the directivity pattern directly. During 1972, a small effort was expended in writing programs to permit digitization of these returns on the Sigma 7 computer and their subsequent display so that we might employ the extensive capability of the fast Fourier Transform programs available for that computer to get the directivity patterns. The decision to acquire a Fourier-analysis system/computer system for use by the Acoustics Group suggested deferring that effort.

Volume Reverberation Parameters

The other important area of study in volume reverberation is an examination of various phenomena and their associated physical parameters, without regard to the geographical variation. Examples which we are presently pursuing are resonance effects and density. The SAVOR system is a spectral analysis system, designed to measure resonant frequency and Q (sharpness of resonance) of scattering layers. Zero-crossing experiments yield estimates of scatterer density.

SAVOR (Spectral Analysis of Volume Reverberation) (Maxine M. Jones, Richard T. Nowak, Robert C. Spindel)

Our efforts with the SAVOR system during 1972 were entirely developmental. A number of problems still remain, but they seem to be in detail and not in conception.

One of the standard Woods Hole acoustic fishes was modified slightly to carry the circuitry which flattens the frequency response of the 12 kHz transducer over the octave from 8 to 16 kHz. It was mounted on the end of a section of the dinosaur tail from the 85-foot hoist. Two methods of streaming the fish were tried, one on the fantail and one forward of the bridge on the main deck of the *Chain*. Neither was completely satisfactory, problems arising in launch and recovery and while streaming in sea states above three at speeds over 10 knots. An improved launch-recovery system would eliminate the problems occurring in rougher seas.

We are not completely satisfied with the amount of energy we are able to couple into the modified transducer from our 2-kilowatt source. However, we do get source levels of the order of 100 db.

A major development was the acoustic signal filtering system. Taking advantage of the highly coherent nature of the signal generated by the frequency synthesizer, we have devised phase-coherent detectors for the scattered returns. These detectors operate under computer control, changing their beat-frequency as the outgoing signal changes its frequency. Following these detectors with low-pass filters permits narrow-banded filtering of the acoustic returns. In phase and quadrature signals are developed, permitting a detailed examination of the phase-structure of the signals. By heating to frequencies other than zero frequency, we have the means of AC coupling our signals to other display devices such as the Precision Graphic recorder which operates only on AC signals. Three of these filters have been built. Incorporated in the design is an improvement in the circuitry used to initiate and time outgoing pulse trains.

To date, the filter has been beset with a number of problems, noise level being the most serious. These will be rectified.

The most significant effort in the SAVOR system was expended in the programming area. A great deal of progress has been made. The first program, FREAK, permitted only the generation of one or two pulses in a train. During 1972, FREAK has been extended to provide what is a nearly complete set of programs for spectral analysis.

1. TRAIN permits generation of up to six pulses in a train, and the control of the filters used to narrow-band filter the signal returns. One can step through a group of frequencies in going from one group of trains to another thereby scanning a spectrum.

2. DTRAN is a digitization routine added to TRAIN. The output of up to six filters (three frequencies with in-phase and quadrature components) are digitized and put on magnetic tape, suitably formatted. These three frequencies change from one end of the frequency range to the other as one sweeps through a spectrum.

3. PDIG plots selected portions of the digitized record on a Calcomp plotter. One has considerable choice of what will be plotted. For instance one trace at one frequency can be shown - or one trace of each of a number of frequencies. Alternatively, one can get a display similar to a seismograph by displaying a number of traces of one frequency.

4. SPECK gives the final spectrographic output of the experiment. The digitized signal is range-gated and the selected portion squared. After normalization for number of pulses at a given frequency, gate-time, and calibration factors, a spectrogram is plotted on a Calcomp, giving a plot of energy versus frequency. We hope that such a plot will display the resonance effect of scattering layers.

Still remaining is adaptation of the last two programs for Tektonic Graphic Terminal display and a more effective way of computing and entering calibration factors.

Our hoped-for use of the SAVOR system for measurements during *Chain* 105 proved infeasible because of a large number of residual engineering problems. Considerable testing and engineering change did take place, however. These problems are being solved, and we hope for measurements during 1973.

Zero and Level Crossing (Robert C. Spindel)

A continuation of last year's effort dealing with the statistics of the level crossing structure of volume reverberation signals has resulted in the development of a relatively simple technique for estimating scatterer density in oceanic scattering layers. A point scatterer model is applied to regions of quasi-Gaussian behavior. A theoretical expression is derived for scatterer density in terms of the expected number of zero crossings of a reverberation return, and the distribution of scatterer reflectivity coefficients. When some simple assumptions are made concerning this distribution a measurement of the expected number of zero crossings provides an estimate of scatterer density. An analysis of statistical error has been completed and indicates that the expectation may be computed with little error from ensembles of about 150 samples. An experiment using this technique east of Bermuda has yielded scatterer density as a function of depth through a scattering layer. Peak densities of 10^{-3} to 2×10^{-3} scatterers/m^3 were calculated.

An additional analysis relating scattering strength (rms level) derived from zero and level crossings measurements has been applied to experimental data. A satisfactory comparison of this data to that obtained with average power techniques using the Integrator has been made.

A DEEP SUBMERSIBLE MODULAR ACOUSTIC SYSTEM

Paul T. McElroy and Frederick R. Hess

The Deep Submersible Modular Acoustic System is a versatile acoustic measurement system which has been proposed for use in *Alvin* in a broad range of acoustic, biological, and geophysical experiments. Signal generation and transmission, processing of received signals, recording and display of returns, and manipulation of experimental data are each receiving detailed attention in an attempt to create a system of broad applicability.

During 1972, an engineering study was carried out to specify the operational characteristics, engineering features and scientific use of the system. The result of that study is summarized in the next two paragraphs:

The system will consist of transducers of various types having common mountings which will be interchangeable in a mechanically trainable mount. Transmitters and receiving equipment will be provided for an operating frequency range of one to fifty kilohertz. A scan-conversion system coupled with a television monitor gives an extremely flexible real time display. A magnetic tape system records both signal returns and all experimental parameters. A minicomputer will be used as a system controller in signal generation and return filtering, and in a computational mode in the manipulation of the returns. This will permit measurement of frequency-dependent effects.

The engineering development will be oriented toward the ultimate scientific use. Included in the applications are volume reverberation studies, bottom topography studies, and bottom reflectivity/scattering measurements.

During the one month of full-scale funding at the end of 1972, a start was made on detailed design and on the purchase of major system components. Over a longer period the minicomputer market was surveyed to permit the best choice in terms of power, space, and weight constraints.

ACOUSTIC DATA CAPSULE PROGRAM

Earl E. Hays

The Acoustic Data Capsule (ACODAC) 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 vertical array are recorded according to preset instructions which depend on the mission.

Instruments were deployed in June and October near Bermuda, near Madeira in August, in the Ionian Sea in August/September and in the Caribbean in December.

Ambient noise and sound transmission data was obtained which is now in the process of being analyzed using a system developed by the Information Processing Center.

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