Woods Hole Oceanographic Institution

REFERENCE NO. 74-18

SUMMARY OF INVESTIGATIONS

CONDUCTED IN 1973

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

APPROVED FOR DISTRIBUTION

Paul M. Fye, Director

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Foreword

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

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a record of the scientific results obtained by our staff members, but publication delays make these at least a year out-of-date before they appear.

This report is the twelfth 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 1973, but also to let our friends and associates know what each individual staff member is currently studying.

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

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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

DEPARTMENT OF BIOLOGY

Richard H. Backus, Department Chairman

MESOPELAGIC FISHES AND CRUSTACEANS

Richard H. Backus, Richard L. Haedrich, James E. Craddock, David L. Shores,
Denise Franklin, David C. Judkins, Bruce H. Robison and Andrew Jahn

Our principal midwater fishing this year was done between Azores and the West Indies on *Atlantis II* Cruise 78 in September, October, and November when 120 collections were made. Another 20 collections were secured by Kenneth L. Smith, Frank G. Carey, and Dennis J. Sabo on *Atlantis II* Cruise 79 in December from the Caribbean Sea near the Cariaco Trench.

James E. Craddock and Bruce H. Robison participated in *Discovery* Cruise 52 in the "Ocean Acre" near Bermuda in March. Also participating were Ocean Acre scientists. The sampling done will allow a three-way comparison of conclusions about the mesopelagic fish fauna of the Northern Sargasso Sea - conclusions based on the *Discovery* mode of midwater sampling, those based on the Ocean Acre sampling program, and those based on our own samples in this region.

As a guest aboard the German R/V *Walther Herwig*, Richard L. Haedrich made 10 Isaac Kidd Midwater Trawl (IKMT) catches with the catches obtained with the much larger Engels midwater trawl. The Engels trawl has been used widely throughout the Atlantic by our colleague from Hamburg, Dr. Gerhard Krefft, in faunal investigations similar to ours.

A major laboratory activity was the processing of the 146 collections made on *Chain* Cruise 105 in June and July 1972. The myctophids (which comprise about half the volume of the fish fraction) had been done and other groups commenced by the year's end. Other collection processing is noted below.

We have continued to refine our computer operations, paying particular attention to the problem of graphics. We have modified our plotting programs, with extensive help from Roger A. Goldsmith, Information Processing Center (IPC), to combine and plot catch data within specified unit areas, thus resulting in a much clearer presentation over broad regions. We are prepared now to plot, by 5^{o} squares, the North Atlantic distributions of the 60 species of lanternfishes to be included in the next volume of "Fishes of the Western North Atlantic".

We have prepared a draft manuscript entitled "Mesopelagic Fishes from the Caribbean Sea and Gulf of Mexico", based on the almost 40,000 specimens in 219 species collected by us on *Chain* Cruise 60 (May-June 1966). The data suggest a relationship between proximity to land and abundance of mesopelagic fishes. Catch rates in those basins nearest to major land masses were more than double those of areas more remote, and were 30 times those of the poorest oceanic waters. Despite this difference, community structure and relative abundance of the component species in each area was quite similar. Though the difference may be one of degree only, this seems to stand in contrast to the inshore situation where increased productivity results in decreased diversity and changes in species composition.

As background for a study of the midwater fish fauna of Gulf Stream rings, it was deemed important to ascertain whether the Gulf Stream was simply a faunal boundary, or whether it was in fact a third and separate faunal region in the Slope Water-Gulf Stream-Northern Sargasso Sea area. Three

sets of collections were chosen from the area north of 32°N and west of 50°W as follows: Slope Water set, with 200 m temperatures at the collection site greater than 7°C and less than 15°C; Gulf Stream set, with 200 m temperatures greater than or equal to 15°C and less than 17.5°C; and Northern Sargasso Sea set, with 200 m temperatures greater than or equal to 17.5°C. These criteria yielded 27, 7, and 21 collections, respectively, for the three sets. A biomass (displacement volume) ratio of 8-3-1.5 for the Slope Water-Gulf Stream-Northern Sargasso Sea "transect" agrees will with a literature value of 8-3-2 for zooplankton for the same three regions. Percent similarity analysis of the three sets of collections shows that the faunal composition of the Slope Water is distinct from those of the Gulf Stream and Northern Sargasso Sea (S = 37 and 35, respectively) and that the Gulf Stream and Northern Sargasso Sea sets are faunistically rather similar (S = 57). In a cluster analysis using percent similarity as the coefficient of correspondence, four of the designated Gulf Stream collections clustered with one Slope Water station, adding weight to the suggestion that there is indeed a Gulf Stream fauna distinguishable from both the Slope Water and the Northern Sargasso Sea.

Midwater fishes of the family Myctophidae collected by two cruises of *Atlantis II* in the South Atlantic are being examined by Robison in a study of the distributional phenomenon "bipolarity". More than 75 species have been identified, eight of which appear to be indistinguishable from species inhabiting comparable latitudes north of the equator. Bipolarity is also expressed by similar but distinct species which have apparently evolved from two such separated populations.

The worldwide distributional patterns of these species are being correlated with ocean current patterns to suggest mechanisms for the creation of bipolar distribution patterns and the maintenance of gene flow between populations. It is hoped that the elucidation of this phenomenon will provide insights into the ecology of these fishes and their evolution.

Many species in the South Atlantic collections are familiar components of North Atlantic ones, being continuously distributed across the tropics. The recombination of these well-known species with South Atlantic forms into assemblages reveals much about the nature of niches and pelagic community structure. Similarly, Indian Ocean species which extend into the South Atlantic can be used to examine the basic composition of faunal assemblages. The South Atlantic studies also will complement long-term studies of the distribution of North Atlantic midwater fishes by providing information on the southern limits of their distributions.

Among the faunal assemblages of the South Atlantic, the one inhabiting the Guinean Region is of particular interest. The Gulf of Guinea contains a well-developed oxygen minimum layer and adjacent waters are upwelling sites. While most midwater fishes are widespread, inhabiting several assemblages, the Guinean Region interrupts the distribution of most myctophids while providing an environment for a few species which are essentially restricted to it. Thus the Guinean Region reminds us of the eastern tropical Pacific where similar hydrographic conditions occur and a somewhat similar distributional pattern is apparent.

Taxonomically, the South Atlantic material provides a number of interesting problems. At least two undescribed species are present as well as a number of species which exhibit morphological variations between geographic populations.

Judkins analyzed approximately 350 midwater trawl collections from the St. Lawrence estuary and Gulf of St. Lawrence, the Mediterranean and adjoining Atlantic, the Caribbean and Gulf of Mexico and the western and equatorial Atlantic. The decapod fauna in the St. Lawrence system was found to consist principally of boreal species usually associated with waters above the continental shelf. The Mediterranean fauna consists of a mixture of temperate-boreal and subtropical species, with temperate-boreal species dominant throughout most of the sea. The majority of subtropical species in the adjacent Atlantic do not penetrate into the Mediterranean. The decapod fauna in the Caribbean and Gulf of Mexico consists primarily of species found in the western equatorial Atlantic. The Sargasso Sea decapods, like the mesopelagic fishes from that region, appear to be divided into northern and southern assemblages by a persistent zone of east-west tending thermal fronts. The decapod fauna in the eastern equatorial Atlantic differs from the fauna in the western tropics in containing species identical or very closely related to those found below 40°S in the South Atlantic.

A study of mysid species in the St. Lawrence system showed two arctic-subarctic species to be abundant in midwater trawl collections from the Saguenay Fjord, but almost absent in collections from the St. Lawrence estuary and Gulf of St. Lawrence. Collections from the estuary and Gulf contained boreal mysids more typical of the latitude. The presence of apparently isolated, perhaps relict, populations of arctic-subarctic mysids in the fjord is further evidence that it is an arctic enclave within a boreal region.

PHYSIOLOGY OF PELAGIC FISH

Francis G. Carey

Swordfish, marlin and other billfish appear to have a structure in their skull for warming the brain. Dissection of a variety of species shows that this varies from what is clearly a specialized region of the rectus superior eye muscle in striped marlin, to a large discrete organ in the swordfish. We felt that one possible function of this organ would be to buffer the central nervous system against the rapid changes in temperature that a swordfish might encounter in passing through the thermocline. With John Kanwisher and Kenneth Lawson a telemetry experiment was designed to see if the swordfish did make frequent and rapid passes through the thermocline. We spent four weeks last summer fishing on Georges Bank, but were unable to obtain a live swordfish for this experiment and have put it off until next season.

POWER PLANT ENTRAINMENT STUDIES

Edward J. Carpenter, Susan J. Anderson, Junell Sayles,
Barbara Culliney, Bradford B. Peck, and Charles Price

Fish larvae and eggs are entrained through the cooling water system of a nuclear power plant on Long Island Sound. In 1973 we began a field study to determine the species, density and time of occurrence of fish larvae and eggs at the plant. Twenty-two species are entrained, the most numerous being *Pseudopleuronectes americanus* (winter flounder), *Tautoga onitis* (tautog), *Anchos mitchilli* (anchovy), and *Tautogolabrus adspersus* (cunner). There are no measurable day-night differences in numbers entrained; however, at the intake more fish are entrained from the near-surface stratum than midwater (3 m) or bottom (5 m). Preliminary studies show about 70% of the larvae that pass through the power plant are dead. We are now beginning laboratory studies in the thermal tolerances of fish eggs and larvae.

The 13°C temperature shock experienced during entrainment can significantly alter the activity of phytoplanktonic nitrate reductase. Entrained phytoplankton show about a 25% increase in specific activity of nitrate reductase with every 3°C temperature rise to about 24°C. Above this the activity decreases by about 25% with a 3°C increase. This research is valuable in understanding the functions of nitrate reductase in basic phytoplankton ecology.

A review of the effects of temperature on algal growth rates was completed with Dr. Joel C. Goodman of the Woods Hole Oceanographic Institution. A growth model was constructed using the Arrhenius equation for the temperature function and Monod model for nutrient relationship. A remarkably good relationship was developed between maximum growth rate (μ) and temperature, resulting in a Q_{10} value of 2.19.

NITROGEN FIXATION

Edward J. Carpenter, Charles Price and Barbara Culliney

Oscillatoria (Trichodesmium) in the open ocean

Nitrogen fixation by *Oscillatoria (Trichodesmium)* in the western Sargasso Sea was studied in the autumn of 1973. *Oscillatoria* standing crop and N_2 fixation rates, salinity, temperature, and nutrient concentrations were measured at eight stations. These data are the first precise measurements of N_2 fixation per m^2 of sea surface in the ocean. Light vs. N_2 fixation rates were measured together with diurnal cycles of N_2 fixation. Attempts to culture *Oscillatoria* were unsuccessful. Rates of uptake of N-15 labeled urea, nitrate, nitrite and ammonium by *Oscillatoria* were measured by Dr. James McCarthy of Johns Hopkins, thus giving us total N input measurements for the species.

Dichothrix - pelagic *Sargassum*

The productivity of *Dichothrix*, a blue-green epiphyte on drifting *Sargassum* from the Sargasso Sea was measured together with that of its host. Dr. James Cox of Southeastern Massachusetts University collaborated in the study. Carbon turnover rate of *Dichothrix* exceeded that of its host, *Sargassum*, by an average of fourfold. *Dichothrix* production on the continental shelf averaged as much

as 15% of the pelagic macroalgal production. In the Sargasso Sea north of 30°N *Sargassum* production averaged twice that to the south and this may be related to winter mixing. No major seasonal variations in production were observed. Gross production for all measurements averaged 0.71 mg C/g dry wt/hr and this corresponds to a C turnover time of no more than 41 days. *Sargassum* contributes no more than 0.5% of the total primary productivity of the Sargasso Sea.

Salt Marsh

Photosynthetic bacteria and benthic blue-green algae fix atmospheric nitrogen in Sippewissett Salt Marsh (off Buzzards Bay). We are measuring nitrogen fixation rates through the year to determine N-input to the marsh by N_2 fixation. Field and laboratory experiments show the following: 1) natural concentrations of combined N compounds in seawater are never great enough to inhibit N_2 fixation, 2) nutrient addition bioassays show that no nutrients are present in concentrations low enough to inhibit N_2 fixation, 3) sunlight in summer when reduced by even a small amount (ca·30%) will result in decreased N_2 fixation, 4) in the summer, typical diurnal temperature range in the algal mat is from 18°C to 36°C. Laboratory studies have shown that temperature inhibition of N_2 fixation occurs below 15°C and above 50°C, 5) N_2 fixation is inhibited in most afternoons in summer by high oxygen concentrations resulting from photosynthesis and this inhibition can be reversed by purging the oxygen from mat samples, 6) diurnal cycles showed nitrogen fixation in the mat to cease at night, then increase until noon where O_2 inhibition occurred. Photosynthetic bacteria fixed N_2 through the night, 7) the salt marsh exports relatively large amounts of combined-N compounds to Buzzards Bay, some of which result from N_2 fixation by marsh microorganisms. To aid in assessing the importance of nitrogen fixation in the marsh, studies are now underway in the import and export of dissolved and particulate nitrogen and carbon compounds.

Codium-Azotobacter relationship.

An *Azotobacter* capable of fixing N_2 has been shown to live on the green macroalga *Codium*. *Codium fragile* is a recently-introduced species that has spread through New England marine waters. Of all the macroalgae surveyed in the Woods Hole area, *Codium* was the only species with associated nitrogen fixing ability, and its relationship with *Azotobacter* may account in part for its rapid spread. We have shown that the *Azotobacter* receives the energy to convert molecular nitrogen to ammonia from the *Codium*. *Codium* in turn may receive combined nitrogen, a limiting nutrient in coastal seawater, from the *Azotobacter*. We have measured standing crop, productivity and nitrogen fixation by the *Codium-Azotobacter* at Nobska Beach. Also, we have shown by sampling the coastline of Massachusetts, Connecticut and Rhode Island that nitrogen fixation in this species is inhibited at ammonia concentrations greater than μM. Samples from the west coast (La Jolla) were also shown to fix nitrogen. This research has been done together with Mr. William Head, a Woods Hole Oceanographic Institution summer student fellow.

Shipworms.

During the R/V *Knorr* Cruise 33 to the Sargasso Sea a 10 m long pine tree was found, the boring shipworms were excised and were shown to have associated nitrogen fixing ability. Wood is a major part of the shipworm diet, and the C/N ratio of wood is very low, 300-500 to 1. Thus shipworms

require an additional source of combined nitrogen. Some nitrogen is provided by the filter-feeding of phytoplankton; however, it appears that a bacterium living in association with the shipworms may provide additional combined nitrogen. To date, four shipworm species have been assayed and all have associated N_2 fixing ability. Nitrogen fixation does not occur in the larvae, it occurs in moderate amount in adults and in relatively high amount in the rapidly-growing juveniles. N_2 fixation in juveniles is rapid enough to double body nitrogen in about three weeks. This work is being carried out jointly with Dr. John Culliney of the Marine Biological Laboratory.

BENTHIC INVERTEBRATE COMMUNITIES IN ANOXIC BASINS

Jean N. Driscoll

The amount of dissolved oxygen dissolved in the bottom water is an important physical factor controlling the structure of benthic invertebrate communities. During the past year I have studied the low-oxygen and anoxic regions of Golfo Dulce, off the west coast of Costa Rica, and the Fosa de Cariaco, north of Venezuela. In areas where hydrographic conditions cause the oxygen concentration to vary, species diversity is low; communities are dominated by a small-bodied polychaete *Paraonis lyra*. When oxygen concentration is constant, even though low, benthic communities have greater diversity.

CULTIVATION AND NUTRITION OF MACROPHYTIC ALGAE

Cameron E. Gifford

In the early part of 1973 experiments were conducted in the laboratory to determine the rates of nutrient (PO_4, NH_4, NO_2 and NO_3) uptake and growth (increase in biomass) of macrophytic algae as influenced by the rate of renewal of seawater and by temperature. Four 400-liter tanks, three containing *Ulva lactuca* and one of *Chondrus crispus*, were monitored weekly for nutrient levels and biomass increment. Also, during this period experiments were conducted concerning design and method of moving and circulating these dense seaweed cultures so as to provide maximum light to maximum surface area of the plants. In spring the experimental operation was moved outdoors to the Woods Hole Oceanographic Institution dock area. Four 400-liter tanks (two in series containing *Ulva lactuca* and two others in series containing *Chondrus crispus*) served as the final nutrient removal stage in a waste-recycling aquaculture system. The primary purpose of the investigation was to determine how effectively the two species removed low levels of nitrogen and phosphorus and the effect of such removal on algal biomass. The last stage of this investigation is now in progress at the Environmental Systems Laboratory.

Several indoor experiments are being conducted in 400-liter tanks, illuminated by artificial lighting. The red alga *Rhodymenia palmata* and a special clone (sterile gametophyte) of *Chondrus crispus* (T-4) which has a rapid growing rate of nutrient uptake and growth characteristics when

cultured in a sewage effluent sea-water medium. Experiments are being conducted outdoors in the large 4' x 5' x 40' cement raceways, using two species of seaweed in the final nutrient removal stage. One involves *Chondrus crispus* at the end of a phytoplankton-oyster chain; the other involves the red alga *Rhodymenia palmata* following a phytoplankton-quahog (*Mercenaria*) chain. These experiments involve several hundred pounds of each seaweed and employ aeration as a new method to achieve water circulation and uniform suspension of the algae.

A final experiment in a third raceway is investigating the growth rate and nutrient uptake of *Laminaria agardhii* and *L. digitata*, two cold-water species that are possible candidates for use in the waste recycling system during winter months.

NITROGEN ASSIMILATION AND SPECIES COMPETITION DURING MARINE ALGAE GROWTH IN WASTEWATER-SEAWATER MIXTURES

Joel C. Goldman, Helen I. Stanley, Nathaniel Corwin, John P. Clarner, Mirelle S. Vanpee, Mark Shelley and Judith White

Because the removal of inorganic nitrogen in wastewater is one of the prime objectives of our waste recycling-aquaculture project, we have investigated the nitrogen assimilation and growth characteristics of a wide variety of algal species in laboratory-scale continuous monocultures, using mixtures of wastewater and seawater as the nutrient source. Several of our more important findings to date include: 1) regardless of the wastewater source (i.e., location of waste, degree of treatment) the production of algal biomass, measured as particulate carbon, is generally a function of the amount of inorganic nitrogen in the wastewater; 2) many species rarely found in our outdoor cultures (e.g., *Skeletonema costatum, Monochrysis lutheri, Tetraselmis* sp.), when grown in monoculture under laboratory conditions, will grow as well as species such as *Phaeodactylum tricornutum*, a species frequently dominating our outdoor systems; 3) when the inorganic nitrogen pool in the growth medium is drained through algal growth, lower particulate C/N ratios will occur when NH_4^+-N rather than NO_3^--N is the predominant N form.

On the basis of our laboratory work we hope to devote special attention next year to developing the ability to control algal species in outdoor cultures through manipulation of operating parameters. In addition, by using wastewater from the Wareham, Massachusetts, treatment plant, which contains 1½ times as much inorganic nitrogen as does wastewater from Otis Air Force Base (our principal source of wastewater in the past), we hope to increase algal yields significantly beyond the 6 gr of particulate carbon/m^2/day achieved to date.

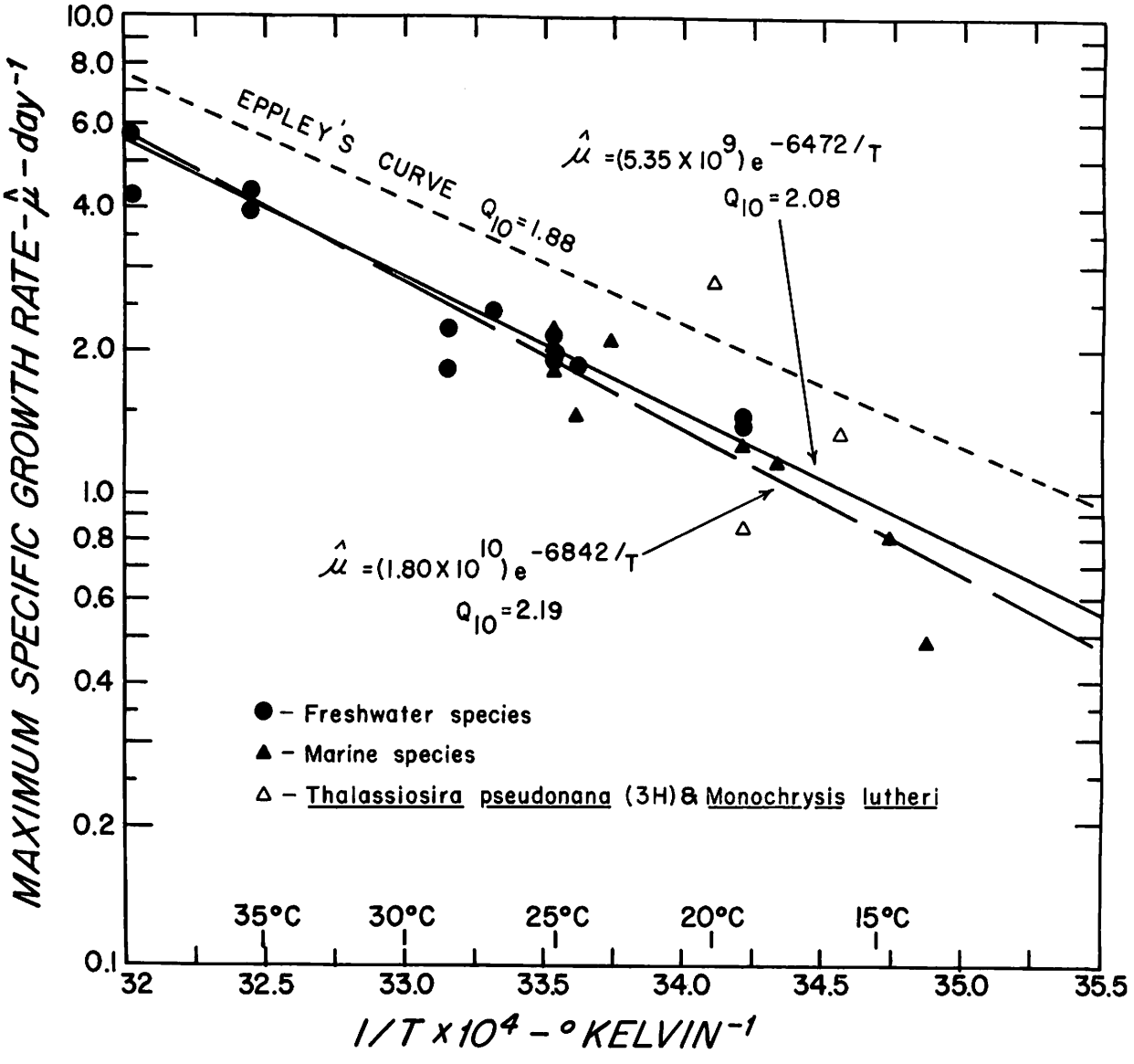

Fig.1 (Goldman and Carpenter) Effects of temperature on the maximum specific growth rate of marine and freshwater algae grown in continuous cultures.

A KINETIC APPROACH TO THE EFFECTS OF TEMPERATURE ON ALGAL GROWTH

Joel C. Goldman and Edward J. Carpenter

We have developed a simple model, incorporating the combined effects of temperature and nutrient limitation on the growth rate of algae. The temperature function is described by the Arrhenius equation and the nutrient relationship with the Monod model. The Arrhenius equation was inserted into the Monod model for $\hat{\mu}$ with the result that the growth rate was described by the product of temperature and nutrient expressions.

Although there are insufficient data available to test the validity of the complete model, it was possible to test the utility of the Arrhenius equation in describing the effect of temperature on $\hat{\mu}$ for phytoplankton. We compiled data from the literature on continuous culture experiments with freshwater and marine algae and found that the Arrhenius model described the relationship between $\hat{\mu}$ and temperature extremely well even though the data represented many diverse experiments with a number of species (Fig.1). Several restrictions to widespread use of the model are apparent, thus most likely limiting its application to laboratory studies. However, general concepts of the model may apply to natural water situations and may aid us in understanding the role of temperature in controlling algal growth and species diversity. Similarly, the combined effects of temperature and limiting nutrient concentration are described for a variety of situations showing how the interaction of environmental effects influence algal growth and species competition.

ZOOPLANKTON STUDIES

George D. Grice, Victoria Gibson, and Thomas J. Lawson

1. Life History Studies

A typical characteristic of temperate-boreal neritic copepod species for which there is no generally accepted explanation, is the seasonal appearance and disappearance of the species. One species which is represented in summer and fall but not in winter plankton between Cape Hatteras and Cape Cod is the calanoid copepod *Labidocera aestiva* Wheeler, a large predatory species. We have been making laboratory and field observations on those aspects of the biology of the species which could contribute to an understanding of its temporal and spatial distribution. From laboratory observations on eggs laid by ovigerous females which were collected from Vineyard Sound in late fall (1972), it was found that these eggs did not hatch at ambient temperatures. However, the eggs did hatch after a period of diapause lasting for five months. Scanning electron microscope examinations of the eggs showed that they were similar in size and ornamentation to eggs that are laid in summer, but the shells are thicker than summer egg shells. The prolonged period of viable dormancy of the fall eggs and their thick shells suggested that the eggs represented overwintering or resting eggs.

After their winter absence, adult specimens were first detected in Vineyard Sound waters in mid-June. These specimens probably represented individuals hatched in May from previously observed

over-wintering eggs. Eggs from summer females readily hatched and were successfully reared to adults in culture using two species of dinoflagellates and *Artemia* as food for the nauplius and copepodid stages. The development time, based on laboratory cultures, is approximately 20 days at a temperature of 18°C.

Periodic collections of zooplankton were made in Vineyard Sound throughout the summer and fall. Adult families were removed from each collection, placed in individual dishes and daily observations made on egg production and hatching. Eggs from the first clutch generally hatched within 72 hours at field temperatures in June, July and August. Beginning in mid-September eggs failed to hatch. These eggs are identical to those previously observed to undergo diapause and represent the onset of resting egg formation by fall females.

Based on a development time of about three weeks and a reproduction period of two and a half months, it is estimated that there are three or four generations per year from the time over-wintering eggs hatch in May until adults disappear in December.

2. Zoogeography of Family Candaciidae.

Five thousand candacid specimens have been removed from zooplankton collected from 200 m to the surface at 339 stations located throughout the Indian Ocean during the International Indian Ocean Expedition (1961-65). Associated with these collections is a suite of hydrographic data for the upper 200 m. All 5000 specimens have been individually identified and most of them measured and sexed. Analyses of species distribution and the relationship between the occurrence of the species and hydrographic data are underway. The mean number of adults at all stations is 1900/1000 m^3 ± 178 standard error and a significant correlation ($r = .76$, $p = .00001$) is present between the numbers of adult and juvenile candacids. Eighteen species occur in the collections. The mean number of species per collection is 3.8 and the maximum is 10. Considering the family as a whole, there was no significant difference in abundance between day and night stations.

Species maps have been computer constructed for all species and distributional patterns are discernible for most species. As examples, the distribution of two species (*Paracandacia simplex* and *P. truncata*) are shown here (Fig.1). *P. simplex* is more prevalent in the latitude of 30°S and in the east Central Indian Ocean in the region of the South Equatorial Current. *P. truncata* is ubiquitous throughout the tropical Indian Ocean north of 15°S.

3. Taxonomy.

As a result of detailed morphological analysis of specimens with both scanning electron and light microscope, it has been concluded that the Red Sea population of *Candacia bradyi* Scott is distinct from the population which extends from the Arabian Sea through Indonesia to Japan. The latter population is actually *C. tuberculata* Wolfenden, the name originally given to it in 1905 but unused subsequent to 1909 when it was synonymized with *C. bradyi*. It appears that *C. bradyi* differentiated from its ancestral stock during a period when the Red Sea was isolated from the Indian Ocean.

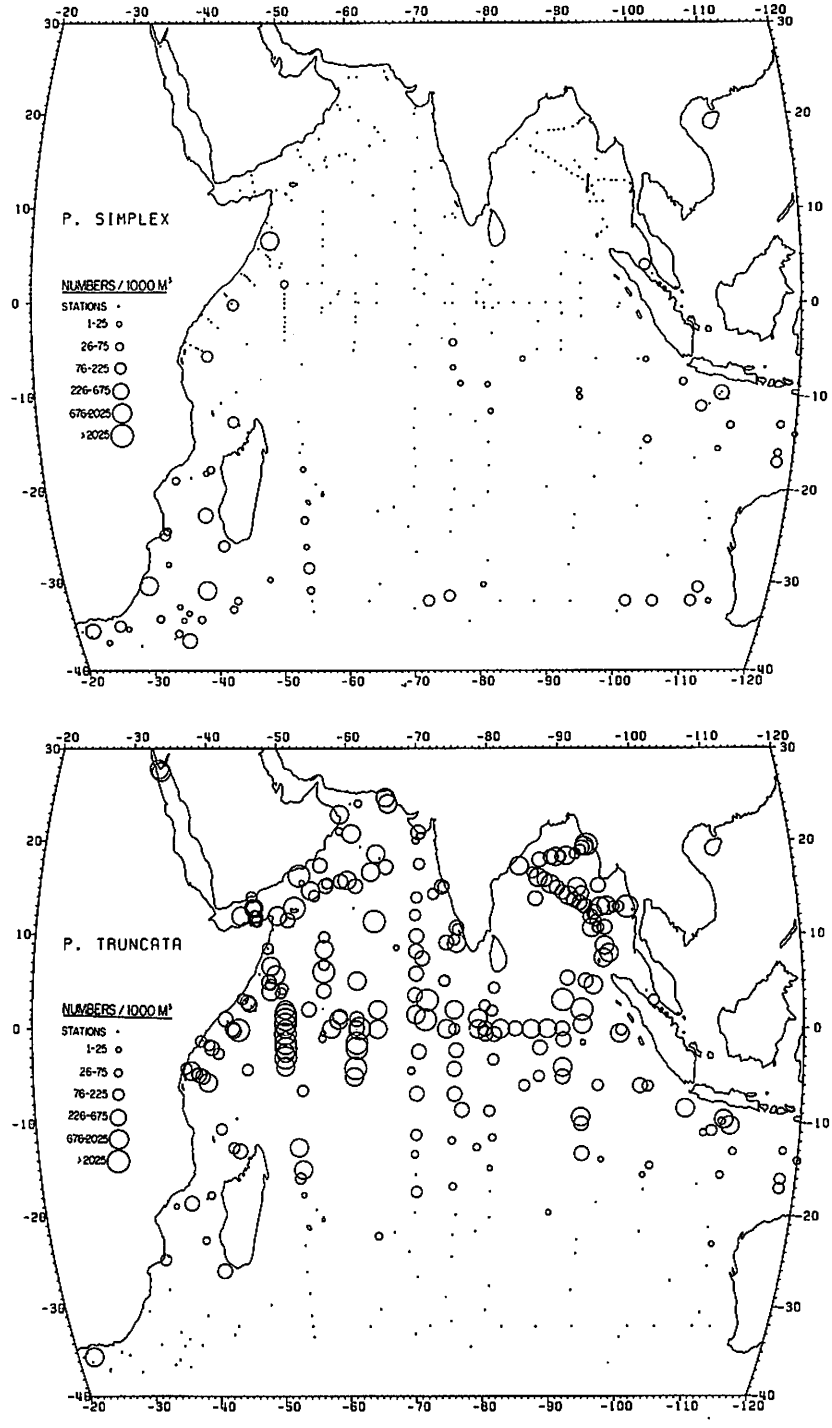

Fig.1 (Grice, Gibson and Lawson) Distribution of *Paracandacia simplex* and *P. truncata* in the Indian Ocean (International Indian Ocean Expedition, 1961-1965).

POPULATION GENETICS OF *Capitella capitata*

J. Frederick Grassle and Judith Grassle*

We have studied nine genetic loci by gel electrophoresis of the following enzymes: phosphohexoseisomerase, phosphoglucomutase, xanthine dehydrogenase, and isocitrate dehydrogenase. Temporal changes in genotypic frequencies have been followed in populations at four localities (Falmouth Harbor, Greater Sippewissett Marsh, Bourne's Pond and Wild Harbor Marsh). Azoic sediment has been placed at the two marsh localities at regular intervals to study changes in genotype following settlement from the plankton. Some of the trays of sediment have been caged to exclude predators. The very large increases in *Capitella capitata* found in similar experiments for two years after the Wild Harbor oil spill in 1969 did not occur.

Laboratory breeding experiments used to study the genetic systems are continuing. There is a high degree of linkage between some of the loci. A genetic component of our field populations are hermaphrodites, males becoming females with a possibility of selfing during the transision period. This is not a separate species as described in the literature since both hermaphroditic, genetic male and genetic female offspring have been produced by a single female in the laboratory.

*Marine Biological Laboratory.

PHYTOPLANKTON PHYSIOLOGY AND ECOLOGY

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

Phytoplankton nutrient kinetics (with Dag Klaveness)

An obligate silicate requirement for growth has been found for the first time for an organism other than a diatom. The growth rate of the freshwater flagellate *Synura petersoni* (Chrysophyceae) is reduced to half (V_{max} = 1.11 div/day) by 0.23 µM silicate. Germanium dioxide inhibited but did not stop growth. The silica scales of *Synura* resemble those of the one Sargasso Sea diatom that has been studied. A paper "The requirement for silicate in *Synura petersenii* Korschikoff" has been submitted to the Journal of Phycology.

Phytoplankton growth and petroleum hydrocarbons (with Max Blumer, Jeremy Sass, Denise R. Stoll, and Elizabeth L. Taylor)

Seawater has been exposed aseptically and without agitation to #2 fuel oil or crude oil. Dissolved substances, chiefly aromatics, enter the water, but emulsions are not formed (at least in detectable amounts). The effect of the dissolved substances on growth rates of 17 clones of phytoplankton belonging to 15 species, in 8 algal classes, has been studied. Species variability is much like that seen in algae exposed to PCB's or chlorinated hydrocarbon pesticides. Some species have proved intractable under the experimental conditions necessary for work with the volatile substances involved. For most species, a sufficiently high concentration of dissolved substances stops growth entirely; a lower concentration range inhibits but does not stop growth; a still lower range of con-

centrations stimulates growth rate and final yield slightly. A study is underway of the influence of one substance, naphthaline, on the growth rate of an oceanic diatom when that diatom is grown under nutrient-limiting conditions. One experiment has shown that phosphorus-deficient cells are more susceptible than phosphorus-rich cells to naphthaline levels that barely influence phosphorus-rich cells.

Analytical methods for the dissolved substances involve extraction with pentane, concentration in a rotary evaporator at low temperature, and gas chromatography. The presence of xylenes, naphthaline, and alkyl naphthalines (boiling range 140-270) is indicated by cochromatography with authentic samples.

Copper, phytoplankton, and chelators (Thesis research of William G. Sunda).

Functional relationships between copper activity in the external growth medium, cellular uptake of copper, and growth inhibition, have been investigated in batch cultures of the diatom *Thalassiosira pseudonana* (clone 3H). A Tris-Cu metal buffer system is employed to control Cu activity, which is also measured directly with a Cu-specific electrode. Growth inhibition depends on copper activity, not total concentration. Activity of copper in the medium is partially under control by the algae through the production of extracellular complexing agests. Copper potentiometric titrations have been used to investigate quantitatively the presence of natural organic complexing agests of copper in open ocean and near-shore waters.

Morphology and systematics of marine phytoplankton.

Long-term studies of characteristic assemblages of green algae from estuarine regions and of micro-diatoms from a number of habitats have been made.

Methyl iodide production by phytoplankton (with George R. Harvey).

Lovelock's find of methyl iodide in surface seawater together with the known distribution of iodide and iodate in the water column suggested that phytoplankton are responsible for iodide production via methyl iodide. *Skeletonema costatum* and *Thalassiosira pseudonana* (clone 3H) produced methyl iodide in culture experiments. Recovery techniques must be improved before quantitative production rates can be estimated and before negative findings can be substantiated. This is planned for the near future.

Barium uptake by marine diatoms (with Geoffrey Thompson, Vaughan T. Bowen, Donald C. Bankston, and Lolita Suprenant).

It has been argued that certain diatoms, notable *Rhizosolenia calcar-avis* and *Chaetoceros curvisetus* accumulate barium and contribute to the transport of this element to the sediments. These species are not in our culture collection at present. However, we have examined three other species of *Chaetoceros*, also *Skeletonema costatum*, and two clones of *Thalassiosira pseudonana*. All these had Ba contents in the range 25-50 ppm (as ash), two to three orders of magnitude lower than reported for *Rh. calcar-avis* and *Ch. curvisetus*, and about the same as reported for two other diatoms. We intend to examine other species, especially of *Rhizosolenia*, and to study the influence of growth conditions on Ba uptake.

Plankton harvesting by continuous density gradient centrifugation (Together with C. A. Price and collaborators of the Department of Biochemistry and Microbiology, Rutgers University).

The technique of continuous zonal centrifugation has been applied to the collection of marine phytoplankters from cultures. The ultimate application is the harvest of collection of living phytoplankton from large-volume natural samples processed in the zonal rotor.

Trichodesmium culture.

Edward J. Carpenter and Robert R. L. Guillard again attempted to culture *Trichodesmium*, using the facilities of the St. Croix laboratory of the Lamont-Doherty Geological Observatory, to which we were invited by Dr. Oswald Roels and Kenneth C. Haines. *Trichodesmium* is easily collected from deep water close to shore at nearby Cane Bay. We explored the suggestion that raising the osmotic pressure in *Trichodesmium* cultures would be of benefit; we found none. From a few colonies of *Trichodesmium* carried to Woods Hole we established persistent cultures in polycarbonate tubes or flasks kept in an incubator at low light intensity. Colonies had to be transferred by hand every 24-48 hrs to fresh medium. The population was kept for ten weeks, somewhat longer than has been done before, and attained sufficient size so that Edward J. Carpenter was able to carry out two preliminary nitrogen fixation experiments.

MARINE FISHES

Richard L. Haedrich

Live specimens of the allotriognath *Trachipterus arcticus* examined on board the German research vessel "*Walther Herwig*" could rotate their eyes through 90° so that the elongate pupil was either parallel with or at right angles to the body axis. This mechanism may allow efficient use of the eye with the fish in horizontal or upright postures. Allotriognaths are known to swim upright; examination of preserved specimens of other known "upright-swimmers" suggests convergent evolution of the rotating ability. A manuscript reporting this finding will be published in Copeia.

The high diversity and seasonal stability characteristic of oceanic fish communities stands in contrast to the situation found in temperate inshore environments. A seasonal survey of the fish community in the Mystic River, a polluted estuary in downtown Boston, Massachusetts, provided comparative data, and further suggested the possible usefulness of certain community parameters in the assessment of environmental quality. A paper on this work has been submitted for publication; the abstract states:

"Twenty-three species of marine fishes were taken in the Mystic River during surveys conducted with trawls and gillnets four times in a year. Winter flounder was the dominant species, with alewives and smelt abundant on a seasonal basis. These three species were present in all seasons. Others occurred less frequently with 17 species occurring only once. The fewest number of species, six, was taken in August, and the highest number, 11, in November. Diversity H (on numbers) ranged from a low of 0.33 in August to 1.03 in June; H (on weight) ranged from 0.12 in August to 0.75 in March. Standing crop (biomass) was 0.5 gm/m^2 in June and averaged about 2 gm/m^2 in August, November,

and March. During the warmest period, fishes tended to be found in the lower portions of the estuary but in winter they were concentrated upriver. Percent overlap in species composition between seasons if high through the summer, a period dominated by winter flounder, and is much lower from winter into spring, reflecting the increases in abundance due to spawning activities of smelt and alewives. Pooled annual diversity H is 1.19 (on numbers) and 0.71 (on weight). These values are at the low end of the scale assumed by this index when applied to fish communities."

The results of a summer project of long-standing (with Jonathan Wittenberg, Marine Biological Laboratory and Yeshiva University) on the *rete mirabile* of the fish eye were accepted for publication in Biological Bulletin. This study, which began as an attempt to correlate occurrence of the *rete* with habitat, developed into an examination of the function of both the *rete* and the pseudobranch. The abstract reads:

"The choroid *rete mirabile* is a vascular countercurrent organ located behind the retina of the eye and responsible in part for the maintenance of a high partial pressure of oxygen there. It is absent in cyclostomes, elasmobranchs, and all living non-teleost bony fishes with the exception of the holostean, *Amia calva*. The choroid *rete* is found widely distributed among teleosts and is nearly always present in the Acanthopterygii, which comprise the great majority of living forms. The ability to do without a choroid rete typifies families or orders, but is a character of limited phyletic usefulness. There seems little correlation between habitat and presence or absence of the choroid *rete*. The choroid *rete* and the *rete mirabile* of the swimbladder occur independently. This does not seem to be true for the choroid *rete* and the pseudobranch, since almost all fishes which have a choroid *rete* also have a pseudobranch. Arterial blood comes to the choroid *rete mirabile* by way of the pseudobranch, and those instances in which the latter is lost offer an occasion for deductions about its function. We argue that the pseudobranch acts to modify the incoming arterial blood in such a way that the choroid *rete* may concentrate oxygen without simultaneously concentrating carbon dioxide, which when hydrated becomes strong acid."

Large specimens of the nomeids *Psenes sio* and *Ps. pellucidus* taken off the Pacific coast of North America confirm the elongation with growth predicted from examination of smaller specimens, and suggest that these two closely related species replace one another north to south in the eastern Pacific. *Ps. sio* is a restricted tropical-subtropical species and *Ps. pellucidus* is a widespread temperate form.

SUBMARINE CANYON ECOLOGY

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

In 1973 we made our first major cruises devoted to study of the Hudson Canyon system. Emphasis was on trawling between 200 and 2800 m on both *Chain* Cruise 111 (February 20-March 3) and *Knorr* Cruise 35 (November 12-20), with complementary sampling conducted with grabs and cameras. Thirty-one deep trawls were made on *Chain* and 25 on *Knorr*. The familiarity with the fauna gained through laboratory identification of material taken on the *Chain* allowed us to identify large fractions of

the *Knorr* collections at sea. Using programs written on the cruise by Christopher Polloni, Information Processing Center (IPC), we analyzed this data on the sea-going Hewlett-Packard computer system, thus returning to the dock with preliminary conclusions already in hand.

The fauna of the canyon is quite similar to that found on the nearby continental slope. Although certain species seem to predominate more in one than in the other area, we have not identified a specific canyon fauna. Biomass in the canyon, however, is four or five times that of the slope at similar depths. With respect to depth, an abrupt change occurs in the faunal composition between 200 and 350 meters. A markedly lesser change occurs near 650 meters, and thereafter rather gradual changes in individual abundances grade to the condition seen at the deepest areas we have been able to sample well. On the slope, each species seems to have its preferred depth range, and, for fishes, larger individuals tend to be found always near the deeper portions of that range. With respect to season, there appears to be little change in the relative abundance of species. Our tentative conclusion is that these deep-living assemblages are quite stable ones. During September, Haedrich participated in deep bottom trawling conducted from the German research vessel *Walther Herwig* west of Iceland; data from that region shows substantially the same general picture of zonation and abundance there as observed south of New England.

In addition to processing samples from *Chain* and *Knorr*, laboratory work has involved continued analysis of over 3000 bottom photographs in an attempt to quantify absolute abundance of the dominant bottom animals, and identification to species of the infauna taken with grabs in Hudson Canyon axis from *Alvin*.

Although we are unable to characterize as such a distinctive fauna in Hudson Canyon, we are impressed by the number of uncommon and poorly-known species, most never before recorded from our area, that do occur in Hudson Canyon. The more important of these are reported in a soon-to-be-published paper (Journal of the Fisheries Research Board of Canada). The abstract reads:

"The alepocephalid *Rouleina mollis* (Koehler 1896), the ophidiid *Xyelacyba myersi* Cohen 1961, and the two macrourids *Nezumia longebarbatus* (Roule and Angel 1933) and *Sphagemacrurus grenadae* (Parr 1946) were trawled in Hudson Submarine Canyon (ca. 39°18'N, 72°00'W) between 1500 and 1960 m on the bottom. These records constitute considerable range extension. The eretmophorid *Halargyreus johnsoni* Gunther 1862, previously recorded from Hudson Canyon but unknown elsewhere in the area, was also taken. The trawl haul which captured these noteworthy species, took, in addition, 284 specimens in 18 species of deep benthic fishes. Abundant species included *Antimora rostrata, Synaphobranchus kaupi, Alepocephalus agassizi, Nezumia bairdi, Dicrolene intronigra,* and *Aldrovandia phalacra.* These species also dominated thecatch made in a similar trawl at the same place four years previously, suggesting that the species composition in such deep-living canyon assemblages is quite stable."

Feeding habits and trophic relationships among the members of the deep benthic communities are of major interest to us. We have completed a study of the feeding of one of the more abundant rattail fishes, and have submitted a paper for publication. The abstract reads:

"Stomach contents from 80 specimens of the macrourid *Nematonurus armatus* trawled at depths below 2600 m in Hudson Canyon fell into three major categories: benthic animals, pelagic animals, and items

of terrestrial or neritic origin. Pelagic cephalopods and fishes, expecially *Chauliodus* and *Serrivomer*, were important components of the diet, particularly of larger fish, and it is suggested that *Nematonurus* must make considerable migrations off the bottom into the midwater to feed. The finding of vegetables, insect and bird remains, and strips of rubber and plastic in the stomachs indicates that *Nematonurus* is extremely generalized in its feeding habits. Its activities are important in transferring food energy from the midwater to the deep-ocean floor, where originally rather large food items must be dispersed as finer particles."

Enzyme polymorphism, as revealed by electrophoretic studies of echinoderms obtained on the March *Chain* cruise, is marked in some species but not in others. There is no clear correlation of degree of polymorphism with depth. If canyons are providing a link between the shelf and the deep ocean, submarine canyons may be more subject to cataclysmic events than the slope in general and greater polymorphism might be expected. The lowest rate found, however, was in *Ophiura sarsi*, found at the head of the canyon where the environments would be expected to be most variable. There is some indication that populations of *Ophiomusium lymani*, in and out of the canyon, show different gene frequencies. This, and a significant deficiency of heterozygotes (from the expected Hardy-Weinberg frequency) may indicate a partial reproductive isolation of canyon populations. On the *Knorr* cruise, we turned to consideration of polymorphism in fishes by combining forces with investigators from The Johns Hopkins University. Preliminary results show no clear picture, although there is some suggestion that polymorphism within a species may decrease with depth. As the electrophoretic analyses can be done successfully at sea, we plan to continue this collaboration and to pursue these interesting studies further. We have also undertaken collaborative work with investigators from Southeastern Massachusetts University on the ecology of fish parasites in the deep ocean. This work, too, we look forward to continuing and expanding.

THE BIOLOGY OF SALPS AND OTHER GELATINOUS ZOOPLANKTON

G. Richard Harbison

Since salps are extremely delicate organisms, they cannot be collected with nets for most physiological experiments. Therefore it has been necessary to collect them with hand-held jars while SCUBA diving. This method of collection has been used successfully on a cruise aboard R/V *Westward*, on *Knorr* 33, and on several cruises on R/V *Gosnold*. In addition to enabling us to collect animals in an undamaged condition, SCUBA diving in the open ocean has allowed us to observe associations and interactions between a large number of planktonic animals. We have found, for example, that amphipods are often parasitic on salps, siphonophores, medusae, and ctenophores, and that their parasitism is highly specific. Furthermore, SCUBA diving has enabled us to observe the behavior of many planktonic animals, so that we may better simulate field conditions in the laboratory. (We are greatly indebted to L. Madin of the University of California, Davis, for helping us set up and use the special apparatus required for SCUBA diving in the open ocean. Frank G. Carey, John M. Teal and Robert Campenot have helped with observations in the field.)

Experimental studies on salps are being presently conducted. It appears that salps are continuous feeders, filtering large volumes of water. Food moves rapidly through the gut, so that substantial amounts of fecal material are produced. Experiments are underway to determine both efficiency of digestion and the possibility that salp fecal pellets are a significant source of food for other animals. In addition, rates of feeding and food selection are being studied. Kenneth Smith has studied *in situ* respiration of salps and other zooplankton in conjunction with us.

Douglas Biggs, a graduate student in the Joint Program, has conducted feeding experiments with siphonophores in the laboratory, made *in situ* measurements of their respiration, and has made field observations on their feeding and their swimming patterns.

PLANKTON FLORA

Edward M. Hulburt

Phytoplankton observations were made during a cruise on the western coast of Africa (Monrovia to Dakar). Similar observations were made on two cruises to the Gulf Stream system, south of Newfoundland and to the south of Nova Scotia. Species counts from the African cruise showed large increases south of Dakar in the upwelling region there. Species count south of Newfoundland in September-October showed no floristic difference, though coastal water, slope water, and Sargasso Sea water were crossed during the survey.

Five cruises to western Long Island Sound were accomplished, three in summer and two in fall. The summer cruises had higher counts and a preponderance of flagellate species. The fall cruises had lower counts and a preponderance of diatoms. Ammonia, nitrate, and phosphate were lower in summer than in fall. But nitrogen was never completely depleted at all stations on any summer cruise. Nitrogen was abundant in the fall.

PHYSIOLOGY AND ECOLOGY OF MARINE BACTERIA

Holger W. Jannasch, James D. Flanagan, Craig D. Taylor,

Hydrostatic pressure and temperature relationships in bacterial growth.

Studies on the transformation of ^{14}C-labeled organic materials by psychrophilic marine bacteria as affected by pressure, temperature and substrate concentration were continued. The data suggest a decrease in microbial activity with increasing depth. Contrary to a working hypothesis, the minimum growth temperature of psychrophilic bacteria does not shift upward at elevated hydrostatic pressure. While retaining their psychrophilic characteristics, their metabolic activities are strongly affected by the combination of high hydrostatic pressure and low temperature. Mesophilic bacteria from nearshore surface waters are essentially inactive under these conditions.

Microbial activity in the guts of deep-sea fish and invertebrates.

The intestinal tracts of fish and invertebrates collected from the deep sea are being examined

as possible niches of considerable microbial activity. The gut-isolates so far tested appear as sensitive to increased pressure and low temperature as bacterial isolates from deep waters or sediments.

Microbial activity as affected by particulate matter.

We are attempting to determine whether a significant portion of the viable and active microbial biomass in the ocean occurs in association with suspended particulate matter of both inorganic and organic nature. Chemostats are used in laboratory experiments in which sterile suspensions of the particulate matter are metered at a constant rate and density into the reaction vessel. In general, data reveal a stimulatory effect on growth and the metabolic transformation of ^{14}C-labeled organic substrates by marine bacterial isolates in suspensions of kaolin, bentonite, and Chitin. In the particular isolates studied the stimulation does not appear to be related to specific modes and rates of attachment.

Bacteriological deep-sea sampling.

The newly developed pressure-retaining bacteriological sampler is being used for retrieving and culturing microorganisms without decompression and change of temperature. The instrument, originally designed for operation from the research submarine *Alvin*, has been complemented with the necessary devices to be used on a hydro-wire during our December cruise (*Atlantis II* Cruise 70, 78, leg 9). A second chamber capable of sampling at depths up to 6000 m is under construction.

Microbial transformations of sulfur compounds in marine environments.

Two characteristic features of the marine microbial sulfur cycle have been newly described:

(1) Sulfide may not only occur as a result of bacterial sulfate reduction (or decomposition of organic matter), but also as a product of the reduction of oxidized inorganic sulfur compounds other than sulfate. Three strains of newly isolated, facultatively anaerobic marine bacteria performed the following conversions: (i) sulfite and thiosultate reduction to sulfide; (ii) tetrathionate and trithionate to thiosulfate; or (iii) thiosulfate reduction to sulfide only in the presence of specific organic substrates. Comparison of anaerobic growth in the presence or absence of inorganic sulfur compounds indicated true dissimilatory reductions.

(2) As new metabolic types, marine pseudomonads were isolated exhibiting growth stimulation by thiosulfate. The stoichiometric transformation of thiosulfate occurred simultaneously with the oxidation of organic substrates. A ten-fold growth stimulation was observed in chemostat experiments. The effect is dependent on population density, pH, and concentration of organic substrate. In the absence of truly autotrophic thiobacilli, the survival of heterotrophic pseudomonads in certain parts of the oceans (Black Sea, Cariaco Trench, and Pacific Ocean off the coast of Central America, for instance) may well be enhanced by the presence of thiosulfate.

Physiological studies on *Thiovulum* sp.

Enrichment cultures of the colorless sulfur bacterium *Thiovulum* sp. have been purified to a degree allowing preliminary studies on the autotrophic or heterotrophic nature of this genus. The uptake of ^{14}C-labeled carbon dioxide strongly depended on the concentration of sulfide and was in-

dependent of the presence of organic substrates at low concentrations. A low level uptake of labeled acetate was found while that of glutamate and casamino acids was negligible. Cell morphology was studied by scanning and transmission electron microscopy.

Cruise to study microbiological and biochemical processes in an anaerobic marine basin.

As an outgrowth of earlier microbiological studies on the Black Sea, a cruise was made in December 1973 (*Atlantis II* Cruise No. 79) to continue work on the marine microbial sulfur cycle in another anaerobic basin, the Cariaco Trench. Emphasis was on the re-isolation of the newly-discovered metabolic types of bacteria in relation to the occurrence of particular intermediate sulfur compounds. A buoy experiment provided an eight-day incubation of water samples for the measurement of *in situ* reduction rate of ^{35}S-labeled sulfate in various depths. Photosynthetic and heterotrophic fixation of carbon dioxide was measured in order to assess the intricate relationships between the marine carbon and sulfur cycles. Other microbiological work on this cruise included isolations of new psychrophilic bacterial strains and deep-water sampling using the newly-developed device mentioned above.

BIOLOGICAL INSTRUMENTATION

John W. Kanwisher and Kenneth D. Lawson, Jr.

The year 1973 has seen results from several of our earlier instrument development efforts. We have tried to only develop instruments which were tied to research actually in progress. This has assured us of field tests where the motivation of the user was sufficient to see early models of instruments through their teething troubles. In total we see the end in sight, particularly in our development of methods for monitoring free ranging animals under natural field conditions. In other work that we outlined at the beginning of our three-year project we have changed the original emphasis. When we, for instance, reviewed the sparse results from work attempted in habitats we decided against working on a poor man's version. Instead we have concentrated on instrumentation for monitoring scuba divers, and for making their time in the water more efficient researchwise. Some of these devices are now in routine use in both some civilian diving research and also in some human factors test of United States Navy diving gear.

Several people have urged the development of an improved *in situ* particle counter in order to monitor spatial and temporal variations of animals in a more detailed manner than nets allow. We have undertaken this as a major new task, which we think will occupy us through the first half of 1974. We aim towards a field test of our instrument in the late spring on the large bag experiments on Vancouver Island. This is an attractive place because of the large amount of corollary data which will be gathered. The counter will allow frequent vertical profiles of zooplankton because it is nondestructive of the animals.

In an earlier counter we suffered the continual uncertainty that the counter aperture might have plugged, and so was no longer giving valid data. Thus our first order of business has been the construction of a flow sensor to use in tandem with the counting cell. It is electromagnetic in principle and therefore has no moving parts, an important criterion for reliability. It is now working well

enough to also show promise as a current meter in its own right. We plan to supply it to Peter Wiebe so that he can study the flow pattern inside his experimental nets. In addition, John Teal will attempt to use it for volume flow monitoring of salt marsh creeks.

At present it looks as if we can measure flows of less than .01 knots in a time of five seconds. The device then shuts off until the next measurement is desired. It is thus linear in response, has a wide dynamic range, and uses little average power. We propose it as a solution to the depressing failures that have characterized the flow meter efforts of physical oceanography for fifteen years. The only parameter in doubt is its long term stability and this will be tested by monitoring the Eel Pond channel beneath our window. We are, of course, unable to mount a full-scale current meter project of our own, but would welcome a limited cooperative enterprise in which we would supply sensors and electronics for a test such as the determination of very weak bottom currents.

In summary there are three papers in press as well as several in preparation. It is found that the development of a good instrument does not assure that it will be used, even when recognized as such. The limited size of the biological instrument market does not make it economically attractive. As a last resort the biologist must frequently resort to in-house capabilities. To aid this we would like to assemble a standard instrument methods manual, comparable to that for chemical analyses by Timothy R. Parsons and John D. H. Strickland. This would feature a number of the more broadly useful devices for work such as acoustic net monitoring and control, animal physiological and behavioral monitoring, etc. An integral part will be printed circuit board layouts and parts lists, together with the pertinent design philosophy and circuit explanation. It would be hoped that this will encourage particularly the younger biologists to dive in and make their own, or to get their own technicians. We feel that once they are immersed in such work they will plagiarize and synthesize in their own right, as we have done. The usefulness of such a manual can only be found by trying it out. Our aim would be to print it cheaply and distribute it gratis. Because of the burgeoning solid state technology such a manual is certain to be out-of-date in a few years. But it seems important to attempt to get at least some of the biologists in step with the advancing instrument possibilities before they are even further behind.

COASTAL WATER RECYCLING AND MANAGEMENT ON CAPE COD

William B. Kerfoot, Paul C. Bowker, Peter E. Kallio, and John E. Huguenin

The Otis Recharge Project began in September and will evaluate alternative means of safely recharging renovated water to the groundwater table. The pilot project will determine the quality of water recharged by the existing sand filter bed disposal method, test the feasibility of denitrification prior to recharge and compare the performance with broad land application and crop treatment. The pilot project includes a denitrification cell, ¼ acre lagoon, force main, and two experimental agricultural plots including fixed and rotary rigs.

Preliminary soil and geological surveys of the agricultural area indicate a topsoil of fine sandy loam (Enfield sandy loam) extending to depths of one to two meters, interspersed at times

with silty deposits. X-ray diffractometry of the soil shows a clay content of 20% near the surface six centimeters to 9% in the Enfield deposits. A deep geological core to near bedrock (78.8 meters below surface) revealed a continuous column of medium to coarse sand, occasionally interrupted by cobblestone layers. No evidence of a clay layer or aquiclude was found under the agricultural site.

PERMISSIBLE LEVELS OF HEAVY METALS IN SECONDARY EFFLUENT FOR USE IN A COMBINED SEWAGE TREATMENT-MARINE AQUACULTURE SYSTEM

William B. Kerfoot, S. Andrew Jacobs, and Gregg A. Redmann

Domestic wastewater frequently contains a higher load of dissolved metals than the original source water due to the treatment of water for algae control, leeching from pipes, and solutes added during household use. While nutrient-rich secondarily-treated wastewater can serve as a substitute fertilizer for aquaculture of commercially valuable algae and shellfish, excessive levels of metals in solution may be toxic to the cultured organisms, accumulate in the meat of food products to an extent to pose a danger to public health if consumed, or impair the visual appeal and taste of the meat.

To determine what levels of heavy metals in the effluent are acceptable for domestic usage, a wastewater treatment-aquaculture system was monitored and original levels of metal in the effluent supplemented with simultaneous progressive increases in the concentration of copper (Cu^{+2}), zinc (Zn^{+2}), nickel (Ni^{+2}), chromium (Cr^{+6}), lead (Pb^{+2}) and cadmium (Cd^{+2}). The aquaculture system used a 1:4 initial dilution of effluent with seawater for algae culture (*Phaeodactylum tricornutum)* and a 1:20 dilution of culture solution with seawater for oyster culture. Levels of metal in the effluent, dilution seawater, algae, and oysters were monitored.

An elevation of metal concentration from background levels by steps of .03, .3, 3.0, to 10.0 ppm (mg/liter) caused an increase in the metal content of cells, but little difference in the average cell density between controls and experimentals. Laboratory tests indicated that toxicity was related to the concentration of algae in the culture. Elevation of metal concentration affected low density cultures more noticeably than the high density cultures. In the high density cultures present during operation of the aquaculture system, a downwards fluctuation in cell growth tended to be irreversible in the cultures with higher concentrations of metal, making them more unstable than controls.

A progressive increase in cadmium, nickel, chronium, and lead content of tissue occurred in oysters exposed to elevated concentrations of the respective metals in the effluent. Cadmium, nickel, and chromium showed similar rates of uptake when compared to concentration, although cadmium accumulated at roughly ten times the rate of nickel and forty-five times the rate of chromium. Uptake of lead in oyster tissue increased more rapidly than nickel at 10 ppm in effluent, decreased rapidly at lowered levels. No difference was noted between the accumulation of copper in control oysters and experimentals. On the other hand, the level of zinc in oyster tissue decreased with increasing

concentration in the effluent. Guidelines for permissible levels of the heavy metals in the effluent were computed from the rate of increase expected during three years of culture, if a toxic level could be defined for consumption of the meat, or on the level observed to be toxic to the cultured algae or shellfish.

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

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

The Cooperative Game Fish Tagging Program has joined forces with the National Marine Fisheries Service in the formation of a joint Woods Hole Oceanographic Institution - National Marine Fisheries Service Cooperative Game Fish Project. In working with the Southeast Fisheries Center, Miami, and Southwest Fisheries Center, La Jolla, we have continued analysis of the data gathered on certain pelagic species especially that of the bluefin tuna, *Thunnus thynnus thynnus* and presented results of some of this work at various scientific meetings and for publication. We have continued the tagging program, supplying nearly 8,000 tags to cooperating sport-fishermen, and have monitored closely the local bluefin tuna fishery in the northwestern Atlantic.

Results received for 1973, as of December, for the Cooperative Game Fish Tagging Program total 2026 releases and 158 returns of several species of fish. These results bring the cumulative totals for the tagging work since 1954 to 45,131 releases and 3.206 returns. In 1973 releases (denominators) and returns (numerators) for the respective species with the cumulative totals shown in parentheses were as follows: bluefin tuna 105/394 (2389/11,714); skipjack tuna, *Katsuwonus pelamis*, 0/61 (85/2371); white marlin, *Tetrapturus albidus*, 11/275 (157/9320); blue marlin, *Makaira nigricans*, 0/95 (6/879); sailfish, *Istiophorus platypterus*, 6/722 (106/13,657); greater amberjack, *Seriola dumerili*, 31/289 (409/3501); and other species 5/190 (54/3689). The great majority of this tagging continues to be carried out by cooperating sport fishermen using equipment furnished by Woods Hole Oceanographic Institution.

The majority of our work has been concentrated on the bluefin tuna in the past year. We are in the midst of a concerted effort to make widely known the difficulties faced by the population of this species in the Atlantic. The data gathered by this program continues to indicate the heavy fishing pressure being exerted on the body of small bluefin which appears off the eastern United States in the summer. Examples of the results to date show 44.2% and 40.0% returns for releases in 1968 and 1970 respectively and 30.1% returns for 1972 releases. In addition the average size of giant tuna caught in the northwestern Atlantic has been increasing while the number of fish caught decreases, and no significant numbers of medium size bluefin (75-275 lbs.) appear in any catches. Obviously, an extremely dangerous situation can be foreseen when the giants die off, as they must with time, for bluefin do not spawn significantly until they reach age five (100 lbs). Wide concern has, therefore, been expressed for the welfare of this species especially to National Marine Fisheries Service (N.M.F.S.), and N.M.F.S. is using the data gathered by this program in order to determine what measures must be taken to preserve this valuable species.

At the international level, Frank Mather presented the recently completed paper "Distribution, fisheries and life history data relevant to identification of Atlantic bluefin tuna stocks" (Mather, Mason and Jones) to the International Commission for the Conservation of Atlantic Tunas meeting in Paris, November 19 - December 4, 1973. This paper, in attempting to describe the stock structure of bluefin, points out events happening to the fisheries in the Atlantic and Mediterranean such as 99% declines in catches in the eastern Atlantic, lack of medium sized fish in any of the fisheries and an increase in the average size of giants everywhere. We feel a serious problem has arisen and must be dealt with immediately by all those involved in bluefin fisheries.

The tagging results for bluefin this year have been most successful. Two long distance migrations of giants tagged in the Bahamas have been recorded. One, the first recovery in Norwegian waters since 1967, was released in 1972 and the other, released in 1969, shows the farthest southward movement demonstrated, being recovered at 40°S off the coast of Argentina. We also had the first major opportunity to tag age 0 (2-5 lb) bluefin this year and released 38 of the size we have wanted for so long to release in significant numbers. In addition 264 school bluefin were released, double tagged, from local commercial tuna boats in the continuing study initiated in 1971 to compare efficiency and shedding of our two basic types of tags.

Effort concerning the white marlin is also of great importance to the Program. A paper entitled "Synopsis of the biology of the white marlin, *Tetrapturus albidus*, Poey 1860" has been completed and submitted for publication. Releases and returns for this species seem to be low this year but this may be due partially to the poor year in the area from Cape Hatteras, North Carloina, to Cape May, New Jersey, where most of the white marlin are tagged. All of the new returns support the cyclical migratory pattern for those fish which summer off the eastern coast of the United States. Of the ten returns from fish released in this area, seven were recaptured in the same waters from Cape Hatteras, North Carolina to Ocean City after periods of up to 36 months at large. The remaining three of these northern releases were recaptured off Venezuela in April after 57 months at liberty, off Cuba in April and northeast of the Bahama chain in May after uncertain lengths of time. The final recovery was from a fish released and recaptured in the Gulf of Mexico off Destin, Florida, after 26.6 months at liberty.

Blue marlin is of extreme concern as so little is actually known about its overall behavior and indications exist that show there may not be much of a chance to learn a great deal before it becomes endangered. Cooperators are being encouraged to take concern for this species so that we may learn as much as possible.

It promises to be a good year for sailfish results. All of the six returns were recaptured in the same release area off southeastern Florida and three were from the 722 releases of this year. The longest time at liberty was from a fish released in November 1970.

Greater amberjacks continue to be of interest to many cooperators fishing the waters off the southeastern United States. Of the 31 returns 27 continue to show the local migrations of this species up and down the Atlantic coast of Florida. The two longest of which were from off Key

West to Daytona in 25 months and from off Mayport to Miami Beach in 7. One fish was released and recaptured off southern Georgia after 24.7 months, and the remaining three showed inter-area migrations. One of these traveled from Palm Beach to Cumberland Island, Georgia in 17.6 months, another released off Palm Beach was reported from Jamaica, West Indies after 11 months at liberty and the third released off Charleston, South Carolina in August 1971 was the first to go into the Gulf of Mexico being recaptured off Freeport, Texas in August. These last recoveries give further evidence that the greater amberjack are not the sedentary animals they were once believed to be and that there may be much to be learned from continued studies of the species.

Frank Mather presented a paper "The bluefin tuna situation" at the sixteenth annual International Game Fish Research Conference, October 29-30, 1973, in New Orleans, Louisiana and John Mason presented this same material to the Committee for Salt Water International Fishing Treaties (S.W.I.F.T.) Action, November 20, 1973, in New York City. In addition to these presentations, several meetings have been held with the leaders of N.M.F.S. and others concerned with the bluefin fishery in Washington, D.C., in an attempt to make widely known the problem of overfishing of bluefin which we are facing.

FUNCTIONAL AND STRUCTURAL ASYMMETRY IN MEMBRANES OF MARINE PHOTOSYNTHETIC BACTERIA

Charles C. Remsen, Edward R. Gonye and Brian W. Schroeder

Membrane sturcture and function have been examined using the photosynthetic membrane systems (chromatophores) of marine photosynthetic bacteria. The objective is to examine in detail the concept of functional and structural asymmetry so that we might test the validity of current membrane methods.

Ultrastructural studies indicate that in the purple sulphur bacteria (*Thiorhodaceae*), the membrane surrounding sulfur granules is derived from the chromatophore membrane which in turn has as its origin, the plasma membrane. The intriguing aspect of this system is the differentiation that must occur when the chromatophore membrane evolves into the membrane surrounding the sulfur granule.

In order to examine this differentiation more closely, we have developed techniques which yield pure chromatophore and sulfur granule preparations. Using gel electrophoresis we have begun to compare the protein components of these two membrane systems with those proteins present in the plasma membranes. It is hoped to show that the protein(s) associated with the sulfur granule membrane are also present in the membranes of chromatophores, and specifically, are similar to those on the inner half of the chromatophore membrane.

Finally, we have begun cytochemical techniques in order to localize enzyme activities on these different membranes. These studies should reveal functional asymmetry in the chromatophore membrane.

RESPONSES BY OPEN-OCEAN MICROORGANISMS TO ENVIRONMENTAL POLLUTANTS

Charles C. Remsen, Edward R. Gonye, Brian W. Schroeder,
Nicholas Fisher, Anne C. Collins, and Kevin Ulmer

In the continuing study on the effects of environmental pollutants on the open-ocean microorganisms we have focused on three groups of organisms: bacteria, micro-algae and planktonic protozoa.

On three month-long legs of R/V *Atlantis II* Cruise 78, we have collected a variety of marine organisms including bacteria, yeasts, fungi, and protozoans. Utilizing a number of these organisms, experimental studies were conducted on board where natural conditions could be more easily maintained. In addition, the concentrations of pollutants (notably PCB) were measured in samples collected from surface slicks and subsurface seawater. Much of this experimental work was designed to provide data on the numbers of PCB-sensitive vs. resistant strains of marine bacteria present in the open ocean, and the correlation of these numbers with the exposure levels encountered. Studies were also conducted to examine the ability of non-sensitive marine bacteria to concentrate PCB. Preliminary data suggest a selective uptake of some PCB isomers over others.

We have continued our investigations on the effect of PCB on marine algae, and have recently shown that the toxicity of PCB to the diatom *Thalassiosira pseudonana*, grown in pure and mixed culture, was greatest when *T. pseudonana* was in competition with other species. Concentration of PCB as low as 0.1 ppb in the medium was toxic to *T. pseudonana* when interspecific competition occurred. This is one of the lowest chlorinated hydrocarbon levels reported to be toxic to algae, and it approaches or equals the PCB concentration found in rivers, coastal waters and the open ocean. Our results seem to indicate that steady-state (e.g., summer) phytoplankton communities may well be affected by persistent pollutants because of the constant competition factor.

In addition, it has been shown that concentrations of PCB as low as 0.1 ppb affect the growth and morphology of coccolithophorid cultures. These studies have been especially satisfying since they illustrate the value of using the electron microscope in studies of this sort. At concentrations of 0.1 ppb, the coccoliths produced by PCB-exposed cultures of *Emeliana huxleyi* showed evidence of deformities. At 25 ppb, the effects were quite drastic with extremely deformed coccoliths being produced together with a much reduced growth rate. These studies are being continued in an attempt to see if the effects are due to a stress situation rather than a specific effect of the organic pollutant.

SEDIMENT-FAUNA RELATIONSHIPS ON THE DEEP-SEA FLOOR

Gilbert T. Rowe and Charles H. Clifford

Deep-sea bottom animals may control the erodibility and mass physical properties of sediments, but the extent of their effect is unknown. Based on previous work, we have proposed that sediment erosion on steep bottoms is catalyzed by various animal activities, called bioturbation. This year work at sea, in collatoration with geologists Charles Hollister and John Southard, concentrated on the Mona Canyon northwest of Puerto Rico. Benthic fauna appeared less abundant than in the canyons

off the northeast United States, but the animals were no less important in catalyzing erosion. While currents in the continental canyons go both up and down the canyons, in Mona Canyon the evidence up to a depth of 3400 meters was of a swift, predominantly down-canyon current. Large fragments of shallow-water grass (*Thalassia*) and clumps of littoral algae were observed being swept like tumbleweed from shallow water down into great depths.

CONCEPTUAL MODELS AND COMPUTER SIMULATION OF BENTHIC NUTRIENT REGENERATION

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

The energy utilized by bottom communities is predominately organic detritus originating in the primary productivity of surface waters. A conceptual model has been constructed which uses this energy, as an outside forcing function, to drive biological processes which consume energy, and through metabolic processes, remineralize the organic matter. This provides a feedback of nutrients for the primary production of surface waters. An initial simple conceptual model was numerically simulated by simultaneous solution of the differential equations representing the fluxes of sediment nitrogen from one form to another. Experiments in Buzzards Bay to validate the model indicated that the simulation predicts far too great an accumulation of ammonia in pore water. The next form of the conceptual model included processes of nitrification and removal of ammonia from the pore water of the sediment due to interactions with the sediment clay particles. This version has not yet been simulated.

OCEAN REFUSE DISPOSAL

Gilbert T. Rowe and Charles H. Clifford

A small experimental reef constructed of ten tons of baled, shredded urban refuse continues to generate gas in Great Harbor in Woods Hole, Massachusetts. The gas generation, a result of microbial activity, reached a maximum of about 150 ml hr^{-1} per square meter of bale surface area at 2.5 atmospheres pressure. In winter, however, there was negligible generation. The activity of the microorganisms producing the gas is evidently temperature dependent. The microbial decomposition, although great, has had no noticeable effect on the physical character (size, weight or density) of the bales. The bales wrapped snugly with 6-mil polyethylene envelopes appear just about as they did when first deployed. Epifaunal growth continues to be variable. New sets of barnacles appear every month or so, grow a little and then fall prey to the starfish *Asterias forbesi*. The growth of the fauna on the bale covered with asphalt, used as an alternative to polyethylene covering, lagged a month or so behind the other bales. Moreover, the asphalt has now begun to slough off, taking refuse with it. We have concluded that asphalt is not a good way to encase baled refuse. The bale without any covering remains intact and supports an infauna characterized by *Capitella capitata*, a polychaete worm, in a silt-clay layer blanketing the bale's upper surface.

The first criterion for a reef of bales is that it remain intact and in place after emplacement. Solid refuse is about 50% paper and, therefore, reaching the density of seawater, even with compaction, is difficult We found, however, that bale density increases by about 15% after deployment. The resultant stability of the reef has inspired us, together with the University of New Hampshire and the Natioanl Marine Fisheries Service, to plan the construction of a refuse reef to ameliorate offshore lobster fisheries on the outer continental shelf.

WASTE RECYCLING AND AQUACULTURE

John H. Ryther, Nathaniel Corwin, Kenneth R. Tenore, Joel C. Goldman,
John E. Huguenin, Cameron E. Gifford, and James M. Vaughn

During the first four months of 1973, experimental laboratory studies, initiated the previous fall, were continued in temporary space rented from the Marine Biological Laboratories. Growth and nutrient-uptake kinetics of several species of marine phytoplankton were studied by means of chemostat culture techniques in an attempt to determine the optimal combination of sewage effluent and seawater in the medium, algal yield, and nutrient utilization consistent with the concept of a combined tertiary-treatment aquaculture system.

Output from the continuous algal cultures was fed to juvenile oysters in an attempt to determine growth of the molluscs as a function of algal food species. Other, separate experiments were conducted to determine the effect of concentration of a single diatom species, *Phaeodactylum tricornutum*, on the rate and efficiency of food assimilation, deposition (as feces and pseudofeces) and growth of juvenile oysters.

In an attempt to find suitable organisms for the aquaculture system capable of using the organic biodeposits of the oysters and their associated meiofauna as food, experiments were also carried out on the feeding, growth, and reproduction of the small polychaete worm, *Capitella capitata*, and the large nereid bait worm, *Nereis virens* cultured on oyster deposits and on various control diets.

Juvenile specimens of three species of abalone, *Haliotis rufescens*, *H. fulgens*, and *H. discus* were obtained from California and from Japan and preliminary work was initiated on their rate of feeding and growth using several species of macroscopic algae (*Ulva lactata*, *Chondrus crispus*, *Rhodymenia palmata*, and *Laminaria* spp.) as food.

Finally, the laboratory research also included studies of the nutrient-uptake and growth rate of the above-mentioned species of seaweeds and the effects of temperature, light, and other factors on their growth and reproduction, as background information preparatory to using these plants as a final step in the tertiary treatment process.

Beginning in March, 1973, a new pilot-scale system was designed and constructed on the Woods Hole Oceanographic Institution dock, where it was operated until October (Fig.1). Secondary sewage effluent from Otis Air Force Base, in amounts up to 1600 liters per day, was trucked daily to this system. The treated effluent and filtered seawater were pumped into head boxes, and mixtures of

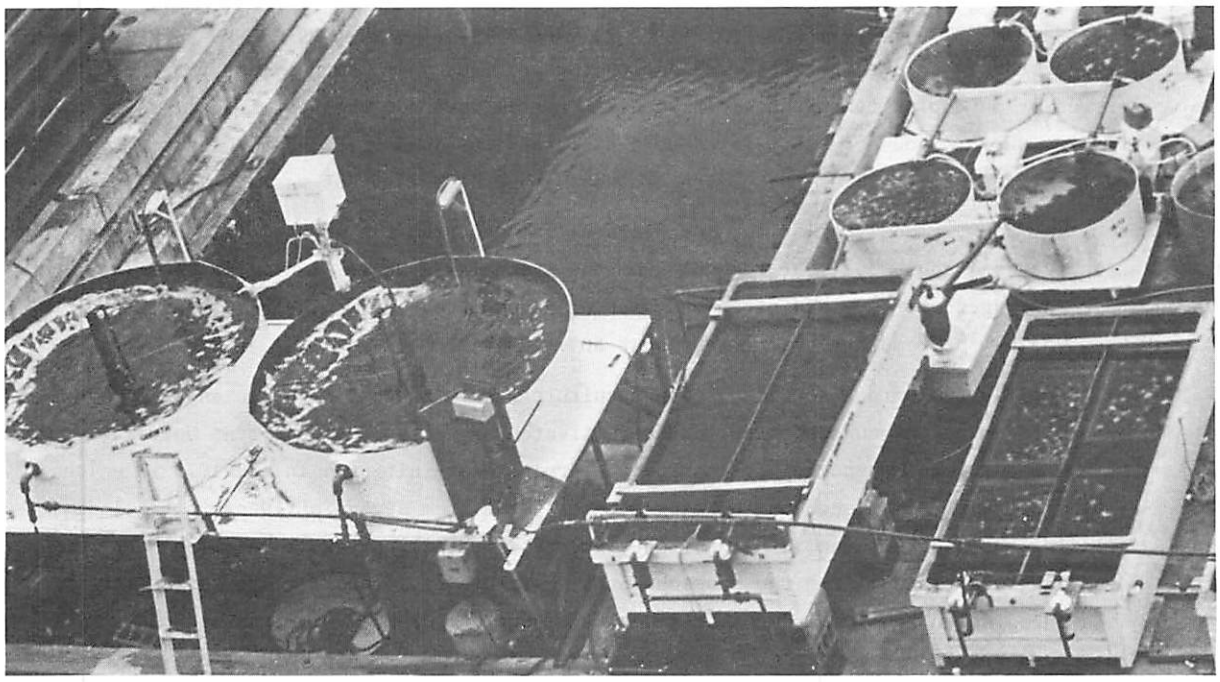

Fig.1 (Ryther *et al.*) Pilot-scale system on Woods Hole Oceanographic Institution dock.

the two were then added at different ratios and rates to two 400-liter phytoplankton growth tanks. For the first time, a complete, continuous flow, gravity-feed system was operated. Overflow (yield) from the continuous phytoplankton cultures was fed into rectangular tanks each containing vexar-lined trays of juvenile oysters totaling 2000 animals per tank. Overflow from the oyster growth tanks was in turn fed into 400-liter circular seaweed culture tanks containing either *Ulva* or *Chondrus*. The *Ulva* produced in the system was fed systematically to the juvenile abalone, which were maintained in separate tanks. The polychaete worms *Capitella capitata* and *Nereis virens* were stocked in the bottoms of the respective oyster culture tanks.

The above system was operated continuously from April through September, 1973. Through a combination of vigorous circulation and aeration, the same phytoplankton cultures were maintained in a healthy condition of active growth throughout this period. Various combinations of turnover rates, up to 100% of the phytoplankton pond volume per day, and sewage concentration, up to 66% of the sewage:seawater mixture, were used. Algal production rates up to 6 grams carbon/m^2/day were obtained under optimal conditions (75% turnover rate/day and 50% sewage effluent). A mixed diatom flora persisted throughout the period, at times dominated by *Phaeodactylum tricornutum* and at times by unidentified naviculoid species. A tendency for the diatoms to aggregate into clumps too large to be assimilated by the oysters was corrected by passing the culture through a commercial homogenizer before its flow into the oyster tanks.

The oysters removed on an average 83% of the phytoplankton from the continuous flow culture. Growth of the oysters was less than observed during the previous year, suggesting that the particular species of phytoplankton produced in the 1973 system were not the best food organisms for the shellfish. However food not assimilated by the oysters was deposited on the bottom, providing food for vigorous growth of the polychaete worms, and hence was not wasted.

Nitrogen (as urea, ammonia, nitrite, and nitrate) removed from the sewage effluent by the phytoplankton averaged about 40%, but removal from the system as a whole, including the final seaweed stage, averaged over 90% and often was virtually complete. Under the best conditions, phosphate removed by the complete system was about 50%.

One of the major risks in a sewage-based aquaculture system is that of human enteric pathogens that may be picked up by and concentrated in the cultivated organisms. A new joint University of New Hampshire - Woods Hole Oceanographic Institution project was initiated in mid-1973 in which enteric virus are monitored throughout the aquaculture system from sewage effluent to final discharge, including the shellfish and other cultured species. Preliminary work has also been initiated, jointly with personnel from the Massachusetts Institute of Technology, to assess the effects of high-energy electron bombardment of sewage effluent on survival of virus and other microorganisms of human origin.

In October, the dock experiment was discontinued and the project was moved into the newly-completed Environmental Systems Laboratory (Fig.2), where the balance of the year was taken in setting up and breaking in the new facility.

Fig.2 (Ryther *et al.*) Environmental system laboratory.

BENTHIC STUDIES

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

The decline in benthic marine fauna following an oil spill in West Falmouth, Massachusetts, permitted us to follow the responses of a number of polychaete and other invertebrate species to an environmental disturbance. Species with the most opportunistic life histories increased and declined at the two stations that were most heavily oiled. The stations that were intermediately affected showed increases and declines of somewhat less opportunistic species. Electrophoretic studies of the malate dehydrogenase loci of the most opportunistic species, *Capitella capitata*, indicated short-term selection for a single genotype in the large populations present in Wild Harbor following the oil spill. The work on *Capitella capitata* is being done in conjunction with Dr. Judith Grassle at the Marine Biological Laboratory.

Features of the opportunistic mode of life are the initial response to disturbed conditions, ability to increase rapidly, large population size, early maturation, and high mortality. Using these criteria, the species can be ranked in order of decreasing degree of opportunism as:
1. *Capitella capitata*, 2. *Polydora ligni*, 3. *Syllides verrilli*, 4. *Microphthalmus aberrans*, 5. *Streblospio benedicti*, 6. *Mediomastus ambiseta*.

Mortality is probably the best single measure of degree of opportunism. A definition based on mortality emphasizes the portion of the life cycle involved in adaptation through short-term selection. Two types of marine benthic opportunists are evident: 1. a mixed strategy variety with obligate planktonic dispersal where selection within local subpopulations occurs in a single generation; 2. a response-to-selection type with direct development or settlement shortly after release from brood structures allowing selection within local populations through more than one generation.

New analytical techniques have been successfully applied to both oil pollution and deep sea studies. Utilizing these methods, we have analyzed the distribution patterns of protobranch bivalves from a number of deep-sea transects throughout the Atlantic Ocean. Species with high levels of co-occurrence were arranged into faunal assemblages and described on the basis of regional and depth criteria. This effort is by far the most detailed and elaborate analysis for any major group of deep-sea benthic animals so far undertaken.

INVERTEBRATE ZOOLOGY

Rudolf S. Scheltema, Isabelle P. Williams, Alison S. Ament,
Gordon L. Hendler, David Leibowitz, and Jan A. Pechenik

The past year in our laboratory has included a diversity of interests with three students and one post-doctoral fellow contributing to this wide variety of activity. Our own studies have included further work on dispersal of invertebrate larvae, in particular those of polychaetes belonging to the family Chaetopteridae. Polychaete larvae have been found in surface waters of the major warm-temperate and tropical currents of the North Atlantic Ocean throughout the year. The occurrence

of pelagic stages over such large areas of the sea shows that long-distance dispersal and exchange of larvae between the eastern and western Atlantic is possible by way of the North Atlantic Drift and equatorial currents. The observed dispersal of *Chaetopterus* and *Spiochaetopterus* larvae can explain not only the very wide geographic range of the adults, but also the possibility for restricted but regular gene flow between populations separated by ocean basins. The present taxonomic uncertainties within the family Chaetopteridae reflect our ignorance of the relative importance of ecophenotypic and genetically determined geographic variation.

The question of geographic variation probably can be better considered over a smaller region than was heretofore studied by us. In a paper entitled "Relationship of larval dispersal, gene flow and natural selection to geographic variation of benthic invertebrates in estuaries and along coastal regions" read at the Second International Estuarine Research Conference in October, we summarized and reviewed some aspects of the problem of geographic variation in marine species. Our conclusion is that much more data are necessary to understand the relationship between larval dispersal, natural selection, and genetic variation between populations. Two students in our laboratory have started investigations related to larval dispersal and geographic variation; one is studying mortality and dispersal of benthic larvae in and out of a small estuary; the other, genetic differences between geographically separated populations of marine gastropods.

During October we contributed to the Conference on Marine Invertebrate Larvae held at Rovinj, Yugoslavia. Our contribution, "Biological interactions determining larval settlement of attached and benthic marine animals" resulting in a fifty-page manuscript attempts to cover the literature from the early work of Douglas P. Wilson in 1932 to the present. Settlement responses fall into six general categories, namely, responses to (1) filmed surfaces, (2) bottom sediments, (3) algal substrates, (4) wood and also (5) intra-specific (gregarious) and (6) inter-specific (predatory and symbiotic) responses. The inter-specific settlement responses are related in some instances to trophic relationships, and indeed most settlement is related to some biologically adaptive interaction. Often the settlement response is quite exact and occurs with a seemingly unerring precision. A student in our laboratory is studying problems related to the settling of certain pyramidellid gastropod species and is investigating the morphological transformations occurring at the time the veliger larvae changes from a phytoplankton-herbivore to a highly specialized extoparasite feeding on the body fluid of mulluscan and polychaete hosts.

Other morphological and ecological investigations during the year concern (1) the description of various telephanic larvae; (2) a study of the "Heart, pericardium, coelomoduct openings, and juvenile gonad in *Chaetoderma nitidulum* and *Falcidens caudatus* (Mollusca, Aplacophora)" by a visiting biologist, and (3) a study of the ecology and reproductive biology of certain echinoderms by a post-doctoral fellow.

In situ BENTHIC METABOLISM STUDIES IN THE SAN DIEGO TROUGH

Kenneth L. Smith, Jr.

The Remote Underwater Manipulator (RUM) from Scripps Institution of Oceanography was used to study the *in situ* respiration of benthopelagic fishes and sediments in the San Diego Trough at a depth of 1230 m (October-November, 1973). Two species of benthopelagic fishes, the rattail, *Coryphaenoides acrolepis* and the hagfish, *Eptatretus deani*, were individually baited into a respiration chamber attached to RUM. Their respiration was subsequently measured on the bottom while their movements were monitored by a television camera. The respiration of *C. acrolepis* was two orders of magnitude less than that of a phylogenetically related shallow water cod (*Gadus morhua*) at a comparable temperature. Respiration of *E. deani* was significantly less ($P < 0.05$) than that of a shallow water congener, *E. stouti*. These respiration measurements represent the first successful *in situ* attempts to determine the metabolic activity of deep-sea animals. This study was done in cooperation with Robert R. Hessler from Scripps Institution of Oceanography.

Bell jar respirometers were placed on sediments in the San Diego Trough by RUM. Total oxygen uptake by the sediments ranged from 1.46 to 2.92 ml O_2 $m^{-2}hr^{-1}$. These values are an order of magnitude greater than *in situ* measurements made at a comparable temperature and depth on the slope off Cape Cod. Formalin treatment was used to divide total oxygen uptake into chemical and biological oxygen demand. Chemical and biological demand constituted 39% and 61% of the total oxygen uptake.

Biological oxygen demand (community respiration) was compartmentalized into a bacteria component through antibiotic treatment. Bacterial respiration was 12% of the biological demand. Two attempts were also made to put the bell jars over large epifauna such as the ophiuroid, *Ophiomusium lymani*. The respiration of *O. lymani* was significantly lower ($P < 0.05$) than rates obtained for shallow water ophiuroids.

PHYSIOLOGICAL ECOLOGY OF THE MIDWATER FISH, *Bregmaceros nectabanus* IN THE CARIACO TRENCH

Kenneth L. Smith, Jr., Frank G. Carey, Dennis J. Sabo,
G. Richard Harbison and Bruce H. Robison

Bregmaceros is a midwater codlet, which diurnally migrates into the hydrogen sulfide waters of the Cariaco Trench. We began a physiological and biochemical study of this fish to find the mechanisms used to cope with anoxia for long periods of time. On *Atlantis II* Cruise 79 (December, 1973) we made preliminary measurements of respiration and lactic acid concentration of fish collected with a midwater trawl (IKMT) during various times of the day. Respiration rate decreased with decrease in dissolved oxygen concentration indicating a conforming pattern. There was increased lactic acid concentration in *Bregmaceros* with time spent in the anoxic H_2S water, but decreased levels in fish which had spent the night in oxic surface waters. These studies will be continued next summer in greater depth.

POPULATION AND COMMUNITY ENERGETICS IN AN UPWELLING ECOSYSTEM: BAJA CALIFORNIA

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

The red crab, *Pleuroncodes planipes*, which leads both a benthic and pelagic existence, is the primary herbivore in the California Current upwelling off Baja California. We measured the respiration and chemical composition of this crab to determine its energetic importance in the ecosystem. Respiration of *Pleuroncodes* ranged from 132 to 408 ul O_2 hr^{-1}. Biochemical analyses of the crabs showed that protein, lipid and chitin constituted 39.2, 7.2 and 31.4% of the ash-free dry weight. We concluded that *Pleuroncodes* is a dominant functional component of the upwelling ecosystem off Baja California, being the primary herbivore and in turn being a major food source of carnivores. The red crab is comparable in importance to the anchovy *Engraulis ringens* in the Peru upwelling system.

In situ measurements of total oxygen demand on naturally enriched sediments under the California Current off Baja California were made with diver-set *in situ* respirometers. The total oxygen demand was significantly higher than control areas. Both the biological and chemical oxygen demands, the constituents of the total uptake, were significantly enhanced by organic enrichment. We compared the effects of natural enrichment (upwelling) with sewage enrichment in the New York Bight (outwelling). No significant difference existed between the total oxygen uptake of the upwelling or outwelling sediments at a comparable temperature. Chemical demand was lower in upwelling sediments.

FREE VEHICULAR TRIPOD FOR *in situ* MEASUREMENTS OF SEDIMENT OXYGEN UPTAKE

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

Over the past year we have designed, constructed and successfully tested a free vehicular tripod for deploying and recovering transparent (plexiglass) bell jar respirometers from any depth in the ocean with a minimum of ship time. The tripod, constructed of aluminum tubing, supports an acoustic, three-command transponder. When deployed from a surface ship there is no connection. Control is maintained acoustically using a shipboard coder-receiver and transducer unit. Once on the bottom, a period of one to two hours is required before the command from the surface is given to release the bell jar respirometers which are suspended from the acoustic release at the bottom of the transponder. This waiting period is necessary to prevent anomalous measurements from initial sediment disturbance by the tripod landing. After release, the 4-bell jar unit slowly sinks to the sediment surface on four guide rods. The bell jar consists of four respiration chambers, polarographic oxygen electrodes, stirring motors, amplifier and recorder. A solenoid injection system was developed for timed release injection of chemicals into each chamber. Rustrak recorders continuously record dissolved oxygen concentrations for periods up to ten days.

The camera and strobe are used to photographically record the contact of the bell jars with the sediment and what, if any, large epifauna, might be enclosed in the chambers.

We have successfully tested and observed this device with divers *in situ* in shallow water to a depth of 30 m. A final test in deep water will be made at a site off the Bahamas (3000 m) and will be observed *in situ* from DSRV *Alvin*.

EVOLUTION OF SPECIFIC GENES IN FISH

John J. Stegeman

Lamprey, *Petromyzon marinus*, and hagfish, *Myxine glutinosa*, have been examined for the presence of multiple molecular forms of the pentose shunt enzyme glucose-6-phosphate dehydrogenase (G6PD). In higher vertebrates one of these genetically distinct forms catalysed oxidation of several hexose phosphates as well as unsubstituted glucose, while the other reacts mainly with glucose-6-phosphate. Data obtained thus far indicate the gene for the enzyme with the broader substrate specificity is not present in the hagfish. Lamprey do possess enzymic activity which oxidizes glucose, although further analysis of biological and chemical properties is necessary to determine homology between this enzyme and the broad substrate specificity form of G6PD. Several lines of evidence suggest an evolutionary relationship between the two forms of G6PD. Further examination of the lower vertebrates should provide information concerning the evolutionary origin of the gene for the broad substrate specificity G6PD, which is not found in invertebrates, and perhaps give insight to the physiological role of the enzyme.

METABOLISM AND EFFECTS OF PETROLEUM HYDROCARBONS IN MARINE FISH

John J. Stegeman and Dennis J. Saho

We have initiated a study of the metabolism and the pathological and biochemical effects of low level petroleum hydrocarbon contamination in marine fish. Experimental organisms (*Stenotomus versicolor*, scup or porgy) were collected in local waters and are being maintained at both the Woods Hole Oceanographic Institution and the National Marine Fisheries Service aquarium. To date our investigations have been mainly to characterize the normal condition of parameters related to the hepatic microsomial monooxygenase or mixed function oxidase system which is involved in hydroxylation of a variety of compounds, including hydrocarbons.

An electron microscopic study in collaboration with the Mallory Institute of Pathology, Boston, has shown very little smooth endoplasmic reticulum, where the majority of mixed function oxidase activity resides, in scup liver cells. Any proliferation of SER (Smooth Endoplasmic Reticulum), which usually accompanies induction of cytochrome P-450 by certain hydrocarbons, should be readily observable. The above results indicate that scup is well suited for use in continuing these studies.

ACCUMULATION OF PETROLEUM HYDROCARBONS BY OYSTERS

John J. Stegeman and John M. Teal

Two populations of *Crassostrea virginica*, differing in pentane-extractable lipid content, were exposed to petroleum hydrocarbons in a flow-through system. The rate of uptake of petroleum hydrocarbons by these oysters slowed dramatically as exposure time increased. After 50 days exposure the hydrocarbon uptake rate appeared to be approaching equilibrium. At this point the concentration of hydrocarbons in animals from one population differed significantly from concentrations in the other population when calculated on a wet weight basis, but no difference was observed when concentrations were calculated on a lipid basis. The apparent lipid effect was not evident when concentrations of hydrocarbons in the organisms were low. Neutral lipid can, at least under certain conditions, effectively determine the level at which petroleum hydrocarbons are accumulated.

The initial rate of uptake was directly related to the hydrocarbon concentration in the water up to at least 450 µg/l. At much higher concentrations the oysters remained closed and the uptake rate fell. The production of feces and pseudofeces was zero at these higher concentrations, a further result of the oysters being closed. At concentrations up to 450 µg/l there was a continuing decline in biodeposition.

Oysters exposed to 100 µg/l for 50 days and then transferred to clean water lost 90% of the accumulated hydrocarbons in a period of two weeks. The 10% remaining, 34 ppm wet weight, was persistent for a much longer period.

The aromatic hydrocarbons appeared to be accumulated more readily than aliphatic hydrocarbons, and the relative proportions of the various compounds accumulated exhibited changes with increasing length of exposure. Straight and branched chain alkanes progressively decreased in amount to a point of virtual disappearance, and in the aromatic fractions there was a gradual loss of the low molecular weight compounds with a subsequent enrichment of the higher molecular weight compounds. In addition to tissue level changes related to hydrocarbon concentration in the water, these alterations in relative amounts of individual compounds of petroleum hydrocarbons contained in oysters suggest that the total toxicological potential, for the oysters or their consumers, is slowly yet continually changing.

SALT MARSH EXPERIMENTAL STUDIES

John M. Teal, Kathy A. Burns and Norma Y. Persson

This is the fourth year of the marsh enrichment studies conducted as a joint project with the Boston University Marine Program. The grass in the treated plots continues to change becoming more and more like the most productive parts of the unmodified marsh, that growing along the creek banks. The grass is taller and thicker but there are fewer of these larger plants so that production per unit area is about the same.

The addition of another experiment, the exclusion of fish from one of each set of duplicate plots was begun this year. A simple hardware cloth fence across the mouth of the creek keeps the fish out of the plot. The effects of this modification have not yet been analyzed.

Budgets for lead, cadmium and zinc added to the plots in the sewage sludge fertilizer were worked out. Lead is almost entirely retained in the marsh. There was no measurable increase in the lead levels of marsh animals or detritus though the lead in marsh grass about doubled from control levels. Cadmium on the other hand, was exported in significant amounts, only about half of the added metal remaining on the marsh. Cadmium was also measurably increased in mussels on the treated marsh in contrast to the situation with the less mobile metals.

Studies of the recovery of Wild Harbor marsh from the oil spill are continuing. We have further analyses of the changes in the amount and composition of oil in the sediments. Kathy Burns has shown the presence of mixed function oxidases in the marsh fiddler crabs. Enzyme was present in highest concentration in the microsomial fraction of the subcellular components. Activity was highest in green gland, intermediate in gill, gut and muscle tissue and lowest in hepatopancreas.

HIGH PRESSURE PHYSIOLOGY

John M. Teal and Robert Campenot

A few further studies of the effects of high pressure and rate of change of pressure on animal activity were done to complete work done previously. Experiments with a recovery vessel were successful in returning animals and water at ambient pressure and temperature to the surface aboard the RRV *Challenger*. Attempts to transfer the specimens to the experimental vessel failed. This had led to consideration of construction of a recovery vessel-experimental vessel as one unit making such transfer unnecessary. Some preliminary design work has been done.

Studies have begun by Robert Campenot on the effects of pressure on the neuro-muscular junction of crustacea. Apparatus for making these measurements at high pressures was built and has been successfully tested at sea.

Experiments with lobsters show a diminution of excitatory junction potential at pressures above 50 atmospheres, while *Geryon*, a moderately deep-living crab shows little diminution up to 200 atmospheres. The results suggest that the mechanism of adaptation in *Geryon* is presynaptic. Apparently the nerve endings secrete more transmitter substance at high pressures which compensates for the reduced muscle membrane sensitivity.

FOOD CHAIN DYNAMICS IN AQUACULTURE SYSTEM

Kenneth R. Tenore, Mason G. Browne and Edward J. Chesney, Jr.

The study of the food chain dynamics of the various species comprising the polyculture system was continued in 1973. Most of the dynamics of the suspension feeders (oysters, mussels and clams) were completed and the results indicated the possible energy value of the biodeposits of the bivalves and led to a more detailed study of the food chain dynamics of the deposit-feeders. The ecological and assimilation efficiencies of the polychaete *Nereis virens* cultured on the biodeposits of oysters was lower than worms grown on animal tissue but a higher consumption rate of biodeposits resulted in growth rates comparable to those reported for this species in nature. In the summer dock experiments, *Nereis* feeding on the oyster biodeposits showed a 2.8-fold increase in average weight of worm in 40 days. In a similar tank, the biodeposits of oysters supported a mixed community of the polychaete *Capitella capitata* and the amphipod *Corophium* sp. This benthic community (>90% *Capitella*) reached a standing biomass of 24.4 gC/m^2 and would provide a suitable food source for a carnivore such as winter flounder. In the laboratory we are investigating the bioenergetics of *Capitella* cultured on carbon-14 labeled eel grass and the energetics of a *Capitella*-winter flounder food chain. Similar work is continuing for the culture of different species of abalone on different seaweeds.

CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT (CEPEX) AND RECENT INTEGRATED FIELD STUDIES

Ralph F. Vaccaro and Pamela E. Bowman

During 1973 we helped launch yet another major study on the effects of chemical pollutants on marine communities. This project termed CEPEX (Controlled Ecosystem Pollution Experiment) is being sponsored by the National Science Foundation as one of its International Decade Ocean Exploration (I.D.O.E.) projects. Objectives include an understanding together with predictions as to how marine organisms are affected by chronic long-term, low-level exposure to prominent pollutants. Emphasis is being placed on such ecological parameters as vital biochemical reactions, organs of selected species, community structure and food chain relations.

CEPEX promises to generate useful information on marine pollution via an unusual experimental approach. Large plastic cylinders are being launched to enclose the top segment of the water column together with its resident marine communities. These isolated columns of water will be manipulated experimentally by the addition of realistic concentrations of known or suspected pollutants. As experience is gained, the volume of water enclosed in each container will be increased up to a maximum of about 2000 tons of seawater (10 x 30 meters).

The site chosen for initial studies relating to CEPEX is Saanich Inlet, near Victoria, British Columbia. The reasoning behind the selection of this site was based on the following considerations:

1. Maximum protection from storms;
2. Sufficient water column to exceed the depth of the photic layer;

3. High standing crops and relatively simple food webs;
4. Preexisting information on the local hydrology, chemistry and biology.

Observations completed during the past summer at the Saanich Inlet site can be summarized as follows:

1. The engineering requirements leading to the launching of a full-scale installation are not insurmountable.
2. The cycling of organic carbon inside and outside the ¼-scale enclosures was reasonably comparable.
3. Phytoplankton populations which developed inside the enclosures were typical of those of Saanich Inlet and the Straits of Georgia.
4. Organisms typical of this local environment also characterized the microzooplankton population although some ciliates failed to survive the experimental period.
5. Quantitative zooplankton sampling was not satisfactory due to the restricted volume of the ¼-scale containers. Organisms which normally migrated tended to remain concentrated in the cod-end sediment jars because the limited depth interfered with their migratory habits. Increase in nauplii suggest that copepod populations effectively reproduced but because of experimental time constraints it is uncertain whether they retained the potential to evolve into adults.

At present we are looking forward to a continuation and expansion of our field studies in a full-scale facility during the summer season of 1974. Meanwhile we are continuing to evaluate the data obtained last summer and at the same time carrying on complementary laboratory studies pertinent to this work.

MARINE BIOACOUSTICS

William A. Watkins and William E. Schevill

New information about the underwater sounds of marine animals continues to emerge as intensive analysis of two species progresses: *Stenella* cf. *longirostris*, one of the Pacific spinner porpoises, and *Physeter catodon*, sperm whales from the Atlantic. Both were recorded with arrangements of a three-dimensional four-hydrophone array. The animals that were producing sounds were tracked as they swam within acoustic range of the array.

These cetaceans have voluntary control of the level of their sounds, just as terrestrial animals do. This was demonstrated by analysis of the array recordings of both species. We have assumed that this was likely, but sufficiently accurate measurements to confirm it previously have been lacking. This is of particular interest since the bioacoustic literature generally has treated underwater sounds as if they were from constant-level sources. Level variations of as much as 16 db were noted in the lower frequency sounds of individual porpoises (not including the effects of directionality on high frequencies). Up to 26-db variation has been found in the level of sounds from individual sperm whales.

As many as 19 clicking sperm whales could be heard at one time. The animals were scattered over a relatively large volume of water as indicated by the spread in both horizontal and vertical acoustic bearings. Measurements on the sounds of nearby sperm whales were unexpectedly complicated by their reactions to the sounds from our calibration pingers. The whales interrupted their own clicking for one to three minutes whenever they heard the pingers, and made it possible to plot only intermittent tracks for these whales.

Experimentation with various sizes of non-rigid hydrophone arrays and analysis of animal sounds recorded by these arrays have confirmed the useful lower limit in size. Array hydrophones with separations of less than 30 m do not provide usable sound-arrival-time differences, with analysis resolution at 0.1 msec. The practical size of the array for handling is determined by the length of the ship.

Efforts to simplify the laborious analysis of the three-dimensional acoustic data have produced successful short cuts in the laboratory procedures, but attempts to automate this analysis by computer continue to be limited by the difficulties inherent in recognition of random non-repetitive cetacean sounds.

Another study scrutinized the effect of limited bandwidth on the reception and analysis of broadband sounds. Comparison was made of earlier limited bandwidth recordings with those made more recently on broad bandwidth systems. Transient sounds were of particular interest. It was noted that even though a transient may be too short for proper response by a crystal hydrophone, nonetheless the hydrophone will respond by resonant ringing if the transient is at too high a level, or by a broadband low-level output for a transient of normal level.

In addition, we have listened to, analyzed, and compared sounds recorded both by ourselves and by others from a variety of other Cetacea including *Stenella styx*, *Lagenorhynchus albirostris*, *Balaenoptera physalus* and *Eubalaena glacialis*. Aerial observation of the animals in Cape Cod waters continues to provide a good assessment of local populations and their movements. Good aerial photographs were obtained showing individual size and color variation, feeding and swimming patterns.

MOLECULAR ECOLOGY

Stanley W. Watson, James D. Sullivan, Frederica Valois,
Helen Quinby and Marjorie Chase

Biomedical Utilization of Resources of the Sea: A program was established to explore the utilization of the biomedical resources of the sea. The initial phase of this program was concerned with a biologically-active substance derived from amebocytes found in the blood of the horseshoe crab (*Limulus polyphemus*). When this active material (lysate) is reacted with gram-negative bacterial endotoxins, a clot is formed. The lysate can detect as little as 10^{-12} grams of endotoxin.

This year, improved methods were developed to extract the active constituents of lysate, the biochemical events involving clot formation were examined, and the potential application of the

lysate test in medicine and ecology was explored. The *Limulus* test was introduced to the Children's Hospitals of Los Angeles and Washington, D.C. as a diagnostic aid with which clinicians could rapidly determine the etiological agent of spinal meningitis. The test proved successful with over 300 patients. Collaborative studies will be continued and expanded with investigators for these and other hospitals during the coming year.

On two cruises the *Limulus* lysate test proved a successful tool to measure the horizontal and vertical distribution of bacteria in the ocean. These studies indicated over 99% of the bacteria in off-shore waters were confined to the upper 200 meters of the water column where they comprised 10% of the total biomass.

Structure-Function Relationships of Membranes: For this study the intracytoplasmic membranes of nitrifying bacteria were used. Methods were developed for the isolation and purification of intra-cytoplasmic membranes from other cellular components. Various membrane-bound enzymes were studied to determine their association with specific structural units of the membrane.

The intra-cytoplasmic membranes are formed by infolding of the plasma membranes accompanied by intrusion of certain proteins normally confined to the periplasmic space. These membranes act as intra-cytoplasmic canals and serve to expedite the cellular exchange of substrates and endproducts.

Ecology of Nitrifying Bacteria: Studies were continued on the isolation, identification, and factors affecting growth of nitrifying bacteria. Many attempts were made to measure the *in situ* rates of nitrification in oceanic environments. These studies have yielded much information on nitrifying bacteria but have not solved the problem of how and where nitrate is produced in the ocean. Present evidence indicates that far too few nitrifying bacteria exist in the ocean to account for the nitrate which is formed in that environment.

Nitrogen-fixing Bacteria in the Ocean: On two cruises this past year attempts were made to isolate nitrogen-fixing bacteria. These bacteria could be found in waters and sediments from local and shelf sites but were never found in offshore waters except when associated with the pelagic alga *Sargassum*. Over 200 samples of *Sargassum* were found to have nitrogen-fixing bacteria living on their surfaces. Evidently these bacteria derived their nutrients from algal excretions but they fixed less than 1% of the nitrogen required for growth of the *Sargassum*. Algae from local waters were examined for the presence of bacteria with nitrogen-fixing activity. Only *Codium* was found to have nitrogen-fixing bacteria associated with it.

EXPERIMENTAL INTERBREEDING BETWEEN ATLANTIC AND PACIFIC POPULATIONS OF THE MARINE CALANOID COPEPOD *Acartia clausi*

Peter H. Wiebe

Experimental interbreeding of Atlantic and Pacific populations of *Acartia clausi* was used to evaluate the relevance of the morphological and biological species concepts for species assignment in this group of marine organisms. Individuals from these populations are morphologically similar,

but differ somewhat in size. Cultures from both sources produced many successive generations in the laboratory, but interbreeding with production of viable offspring did not occur. This is evidence that the Atlantic and Pacific populations have diverged in isolation to the level required to be assigned specific rank. However, we believe the assignment of new specific names should only follow a larger (possibly world-wide) study of *Acartia clausi* populations. This work was done in collaboration with Dr. Charles B. Miller and Mr. Enrique Carrillo B. G. of Oregon State University, Corvallis, Oregon.

TRANSPORT OF ORGANIC MATTER TO DEEP-SEA FLOOR

Peter H. Wiebe and Steven Boyd

Our effort to document the role that sinking of small particulate organic matter plays as a pathway for transport of organic matter to the deep-sea floor was continued in 1973. Construction of a proto-type sediment trap for use just above the sea floor was completed. *In situ* testing of the trap was performed in Buzzards Bay and in the Millstone Quarry outflow pond. Fluorescent dyed particles were used to study possible error sources which would result in bias of estimates of biogenous particle sedimentation rates. The trap will be used in a free-fall array in the Tongue of the Ocean, Bahamas, in early January 1974.

DENITRIFICATION IN BAHIA DARWIN (GALAPAGOS ISLANDS)

Peter H. Wiebe and James L. Cox

Anoxic conditions arise in a water body when oxidative consumption of organic material exceeds oxygen production or renewal. This most frequently occurs in semi-enclosed basins having a shallow sill depth and a strong pycnocline. The pycnocline in anoxic basins is usually the result of a strong halocline acting as a physical restraint to vertical circulatory processes which replenish the oxygen below the photosynthetic compensation depth. Basins in which the pycnocline is maintained by a strong thermocline are less well-known although the physical mechanisms responsible for the development and maintenance of anoxic conditions are assumed to be the same. Bahia Darwin of the Galapagos Islands is one of very few intermittent anoxic basins of the tropical type, wherein the pycnocline which isolates the deeper waters from lateral exchange is due largely to thermal stratification. Since processes which occur in the bay are likely to be more applicable to tropical oceans than results gained from halocline-type basins in temperate regions, the bay has been the subject of rather frequent study over the past six years.

This year we completed work on observations of surface hydrography and water column chemical properties made in July 1968 from R/V *Te Vega*. Comparison of our observations with Richards and Broenkows' (1971) March 1969 data provides additional evidence on the rate of denitrification and other chemical changes during the interval.

Changes in oxygen and nitrate in Bahia Darwin between July 1968 and March 1969 indicate that denitrification occurred in the deeper waters of this basin. During the period, both ammonia and phosphate declined, probably as a result of assimilation by bacteria with subsequent sedimentation. Assuming a uniform rate of oxidation of organic matter in equally spaced depth intervals below the thermocline, it was estimated that denitrification occurred at the rate of about 62 µg-atom NO_3-N/liter/year. This rate is attributable to water column denitrification, since there is a decrease in the estimated rate of denitrification closer to the sediment-water interface. Our yearly estimate falls within Richards and Broenkows' (1971) estimates of 50 to 70 µg-atom/liter/year for nitrate reduction in the 40 to 120 m depth interval of Bahia Darwin.

Reference

Richards, F. A. and W. W. Broenkow, 1971. Chemical changes, including nitrate reduction in Darwin Bay Galapagos Archipelago over a two-month period, 1969. Limnol. Oceanogr. 16(5): 758-765.

THE BIOLOGY OF GULF STREAM COLD CORE RINGS

Peter H. Wiebe, Edward Carpenter, James L. Cox, Edward M. Hulburt, Andrew Jahn, Peter Ortner, George Knapp and Steven Boyd

Gulf Stream rings form when meanders of the Gulf Stream become so accentuated that they break away from the stream forming a ring of swiftly-moving Gulf Stream water around a core of seawater of different origin. Rings forming to the south or east of the Gulf Stream entrap cold water of slope origin. This has been estimated to occur about five to eight times a year. These cyclonic or cold core rings range in size from 100-180 km in diameter when newly formed, and they have been known to persist as physically identifiable structures for periods of at least one year and possibly longer.

In cold core ring formation, organisms of Slope Water or Subarctic Water mass origin are also isolated within the ring structure. Many of the slope species are distinct from species living in the Northern Sargasso Sea although they occupy similar ecological niches. Thus the formation of a ring constitutes the beginning of a large-scale invasion of one biological oceanic community by another with the concomitant inter-community interaction. In essence, the time-dependent events associated with the formation and decay of a cyclonic ring constitute a large-scale natural ecological experiment which offers the possibility of separating major effects of the physical-chemical environment on the structure and function of an oceanic community from biological interactions between species. This is a major problem in biological oceanography today.

Over the past one and a half years we have jointly made physical, chemical, and biological observations in three cold core rings approximately 10 months, 3½ months, and 3 months of age. In these preliminary studies our basic objective has been to assess the standing crop (biomass) and species composition of phytoplankton, zooplankton, and fish inside and outside the ring while also obtaining pertinent physical-chemical data, i.e., T, S, O_2, NO_2, NO_3, NH_4, PO_4, POC. The same kind of observations were also made in slope water north of the Gulf Stream to provide a standard with which to compare the ring results.

Our preliminary results suggest that while the physical-chemical manifestation of the approximately 10-month-old ring is readily apparent, biological differences of the cold core from the adjacent Sargasso Sea are less distinct. No significant differences were observed in phytoplankton species or plant standing crop (as indicated by chlorophyll *a*) over the ring area although oxygen profiles suggested a somewhat higher production rate inside the ring. Zooplankton biomass was significantly higher inside the ring especially in the depth interval 300-800 m. However, euphausiid species composition in 0-300 m tows was quite uniform in and out of the ring with the exception of the single station at the ring center. Somewhat more pronounced differences in species distribution were observed in 0-800 m hauls. Fish and invertebrate biomass in 0-100 m midwater trawl collections showed no clear difference between the ring and the surrounding water. However, the composition of midwater fish catches was more uniform inside the ring than outside, and several dominant fish species showed significant differences in abundance across the area. Preliminary examination of data from the approximately 3½ month old ring sampled on *Chain* 111 in February 1973 indicates that biological distinctions are much sharper from the ring core to surrounding Sargasso Sea waters. A very tentative conclusion would be that the decay rate of the slope water assemblage was more rapid than the decay rate of physical-chemical properties associated with the ring structure. We speculate that this possibly occurs as a result of biological interaction between Sargasso Sea and Slope Water assemblages precipitated by the rapid modification of physical and chemical properties of ring surface water.

DEPARTMENT OF CHEMISTRY

John M. Hunt, Chairman

GEOCHEMISTRY

GEOCHEMICAL STUDIES OF SUBMARINE IGNEOUS ROCKS

Geoffrey Thompson and Donald C. Bankston

1. Basalts Recovered by the Deep Sea Drilling Program

a) Legs 2 and 3 - North and South Atlantic Ocean Basins

In association with Dr. Fred Frey of Massachusetts Institute of Technology and Dr. Wilfred Bryan of the Geology and Geophysics Department of Woods Hole Oceanographic Institution, we have studied basalts from seven Deep Sea Drilling Project (DSDP) sites in the North and South Atlantic. The age of the oldest sediment (and also the sea floor spreading age) range from 18 x 10^6 to 67 x 10^6 years. Because these samples were obtained at significant distances from the present ridge axis and are not from oceanic islands or seamounts, they provide a unique opportunity to determine the characteristics of old Atlantic sea floor. Of these sites, only one - Leg 2 Site 10, does not have basalt similar to that at the present ridge axis. The 2-10 basalts are characterized by the presence of titan-augite, and are more alkaline and enriched in large-ion lithophile elements such as La, Sr, Ba and Zr compared to mid-ocean ridge basalts. Since this basalt was not extruded at the Mid-Atlantic Ridge axis (it is a sill) our results are consistent with the hypothesis that vulcanism away from ridge axes produces basalts more alkalic than those erupted at spreading centers.

Basalts at the other six sites (Leg 2 Site 11A, Leg 3 Sites 14, 15, 18, 19 and 20) have the distinctive features of modern ridge basalts such as $K_2O < 0.2\%$, Ba < 25 ppm, Zr < 150 ppm and light rare earth elements (LREE) depleted relative to chondritic LREE abundances. At Sites 3-14 and 3-18, the petrography, mineralogy, major element and trace element abundance of the basalts all indicate a magma which had undergone very little fractional crystallization. To our knowledge, basalt glasses from 3-14 and 3-18 represent the most mafic liquids recovered from the Atlantic sea floor. If the sea floor spreading ages are applicable for Leg 2 and 3 basalts (except Site 10), the Atlantic Ocean floor is made up of large-ion lithophile element depleted basalt for at least the last 70 x 10^6 years.

b) Leg 22, Ninety-East Ridge Indian Ocean

Also in the past year we studied the igneous rocks recovered from Sites 214 and 216 on the Ninety-East Ridge. The basalts at both sites are similar in composition but the upper section of Site 214 is characterized by lavas unique in composition amongst submarine igneous rocks; these we called oceanic andesites. The petrography and chemistry of the Ninety-East Ridge lavas support the hypothesis that they represent fractionated magmas which have cooled and crystallized in shallow magma chambers before extrusion. The oceanic andesites are differentiated products (by fractional crystallization) of the lower basalts.

These basalts and andesites from the Ninety-East Ridge differ in texture, mineralogy and chemistry from rocks extruded at spreading centers along mid-ocean ridges. They are lower in Ca, Mg, Cr and Ni, and higher in Fe, Ti, K, Ba, Cu, Sr, V and Zr concentration than typical mid-ocean ridge basalts, and they have trachytic textures with plagioclase, magnetite and pyroxene as phenocryst

(liquidus) phases. They also differ in composition from lavas extruded in island arcs or those associated with subduction zones at continental margins. Thus the Ninety-East Ridge probably does not represent an old, previously active mid-ocean ridge and site of sea floor spreading, nor does it appear to be an island arc-type of structure. Rather, because of the similarity in mineralogy and chemical composition to basalts and andesites of the Iceland plateau, we favor a similar derivation for the Ninety-East Ridge. The Iceland plateau is presumed to represent the surface expression of a 'hot spot' or plume of molten material derived from deep in the mantle. We thus suggest that the fractionated lavas of the Ninety-East Ridge represent the surface expression of a mantle plume with consequent uplift of the lithosphere as it moved over the hot spot.

c) Leg 11, North Atlantic Continental Margin

We have recently begun work on basalts recoved from Sites 100 and 105 on Leg 11. These samples represent some of the oldest sea floor igneous rocks recovered - they are of mid-Jurassic age. The basalt at Site 105 is of special interest as it lies beneath sediment of Oxfordian age and we have recognized a pillow lava sequence with at least 12 cooling units. The work to date indicates that they have textural, mineralogical and some chemical features of typical modern mid-ocean ridge extrusions. This basalt may well represent one of the earliest eruptives associated with the initial rifting and opening of the North Atlantic.

2. Submarine Alteration of Basalts

The interaction of sea water and basalts at low ($< 25^{o}C$) temperatures (halmyrolysis) has been studied on rocks dredged from the Mid-Atlantic Ridge as well as on basalts recovered by drilling. The chemical changes resulting from the interaction, as well as the products of remineralization, have been examined. Of particular concern have been the effects of halmyrolysis on the budgets and fluxes of elements in the oceans. Our approach has been to look at those altered samples where sufficient of the original material remains so that we may directly compare fresh and altered portions and thus effect mass balances. In the accompanying Table, we show the changes produced by weathering, in terms of mass of oxide in grms/100 cm^3, for some altered basalts for which we have analyses of the fresh glass as well as the weathered interiors of the flows.

The data in Table 1 indicate that Si, Mg and Ca are the principal elements leached from the basalt and that K and H_2O are taken up from sea water. This suggests that Al, total Fe and Mn are also leached from, and P added to, the basalt. The effects on Na and Ti are much less certain although the more altered rocks indicate that Na may be leached by extensive weathering. Our data also indicate that of the trace elements B, Li, Rb, Cs, Pb, Cu, Ba and Sr are taken up from sea water and that some Cr, Ni, Co, V may be leached from the rock. Elements such as Y, Zr, Nb, Hf, Sc and the heavy rare earth elements show very little change and thus can be used to 'characterize' original magma compositions.

These calculations show the direction of alteration but the rates and the magnitude of the effect are much less certain. In the next table, (Table 2), we show the rate of chemical exchange calculated for a 16 million and an 80 million year old basalt. The magnitude and the direction for

TABLE 1

Change in Mass of Oxide in Grams per 100 cm^3 in Some Weathered Basalts Compared to the Fresh Precursor * (Total iron as FeO)

	1	2	3	4
SiO_2	-6.5	-10.7	-22.0	-18.4
Al_2O_3	+3.8	- 1.8	- 3.1	- 8.7
FeO*	+4.4	- 0.3	- 3.1	- 5.9
MgO	-7.8	- 8.0	- 8.4	- 1.4
CaO	-3.6	- 1.1	-24.8	- 4.3
Na_2O	+1.4	+ 0.5	- 1.7	- 0.7
K_2O	+0.3	+ 0.4	+ 4.3	+ 1.9
H_2O	+2.2	+ 7.6	+24.0	+ 9.7
TiO_2	-0.77	+ 0.77	+ 0.20	- 0.33
MnO	+0.02	- 0.02	- 0.11	-0.08
P_2O_5	+0.15	+ 0.08	+ 0.08	n.d.

individual elements are not in disagreement with other reported rates based on different samples and very different methods of calculation.

TABLE 2

Rates of Chemical Exchange During Basalt Weathering ($10^{-9}g/cm^3$/year)

	1	2	Other Reported Results	
SiO_2	-11.5	-2.7	-2.2	-7.4
Al_2O_3	- 5.4	-0.4	0.0	0.0
FeO	- 3.7	-0.4	-0.6	+4.2
MgO	- 0.9	-1.1	-1.5	-3.8
CaO	- 2.7	-3.1	-2.0	-2.9
Na_2O	- 0.4	-0.2	-0.3	+0.3
K_2O	+ 1.2	+0.5	0.5	1.1
H_2O	+ 6.1	+3.0	+2.0	+3.7
TiO_2	- 0.2	+0.2	0.0	+1.6
MnO	- 0.05	-0.01	-0.01	-0.08

Even if these rates are of the correct order, we still require to know the magnitude of the effect - that is the total mass of basalt that has undergone alteration and for how long. If we assume that the low seismic velocities measured in the upper part of the oceanic igneous crust are due to weathering (as well as the decay in magnetic intensity dur to alteration of titanmagnetite to titanmaghemite), and that the observed thickening of this low velocity layer out to 85 million years is also a measure of the time that alteration continues, then we have the area of oceanic crust undergoing weathering. Using the rates shown in Table 2 we can calculate that the thickness of besalt required to undergo weathering in order to balance the stream input of K into the oceans (0.74×10^{14} gms/year) is between 0.3 and 0.9 kms. This is a thickness not inconsistent with that

calculated for the low velocity cap on the oceanic basement. These results suggest that submarine weathering may well be an important process in geochemical budgets. We continue to work on this exciting aspect of oceanic element fluxes and in particular will be considering the role of hydrothermal alteration of basalts as a source or sink for elements, as well as its role in the mobilization and localization of metals.

3. Mid-Atlantic Ridge Transect

In October of this year we had a cruise on the R/V *Atlantis II* to study the Mid-Atlantic Ridge at 23°N latitude. Along a transect from the median rift valley out onto the western flank for over 1,000 kilometers, by dredging at intervals, an extensive collection of igneous and sedimentary rocks was recovered. These dredge hauls represent one of the best systematic collections of basalt showing progressive alteration with distance from the ridge crest. In terms of sea floor spreading age they span the range from 0 to 50 million years. Increasing alteration is accompanied by increasing thickness of ferromanganese crust. This collection is an exciting and interesting addition to our previous collections from on and near the ridge crest ranging from 45°N to 22°S latitude in the Atlantic. Our spatial and temporal coverage of the Atlantic igneous rocks will allow us to better define the genesis, composition and history of the oceanic lithosphere.

4. Ferromanganese Precipitates on Igneous Rocks

Many of the igneous rocks we have dredged from different parts of the Atlantic Ocean are characteristically encrusted (from mms to tens of centimeters thick) by ferromanganese precipitates. These crusts are not dissimilar to the so-called 'manganese-nodules' typically found at the sediment-water interface in many parts of the world's ocean basins. The crusts we have recovered, which are essentially precipitates of iron and manganese oxides with substantial amounts of minor metals such as Co, Ni and Cu present, represent an interesting collection of authigenic mineral deposits whose composition may reflect overlying water mass composition, volcanic input of metals into the ocean, the effects of metal leaching from the oceanic basement, differential rate of growth and other variables. We hope to begin a systematic study of these crusts in the near future. Some preliminary work begun this year indicates that their composition, in terms of Fe/Mn ratios and contents of the minor metals Co, Ni, Cu, Pb and Zn, is not a direct function of their proximity to a volcanic center (the median rift valley) nor their immediate substrate (the rock on which they are precipitated). We are thus encouraged to continue this work to try and relate compositional variations to such parameters as water mass compositions, mineralogy, rates of growth, geography and topography.

FLUXES OF IONS ACROSS THE SEA WATER-SEDIMENT INTERFACE AND SEA WATER-SEDIMENT INTERACTION

Fred L. Sayles, Paul C. Mangelsdorf, Jr. and Charles A. Olson

The concentration of several major elements in the oceans may be strongly influenced or even controlled by fluxes of ions across the sea water-sediment interface. These fluxes occur in response to chemical gradients set up in the pore waters of the uppermost sediments of the sea floor by diagenetic reactions. To provide accurate data on the nature of the interstitial chemical gradients that exist in the upper two meters of sediment on the ocean bottom an *in situ* sampler was developed. The instrument presently in use withdraws six filtered pore water samples from the upper two meters of sediment, three being collected in the interval 5-30 cm where the gradients are steepest. A bottom water sample is also taken to serve as a reference point for flux calculations.

Samples have been obtained from over 35 stations in the North Atlantic and Caribbean. Analyses of these samples indicate that uptake of K^+, Mg^{2+}, SO_4^{2-} and, to a lesser extent, Na^+ by the sediments is widespread. Ca^{2+}, HCO_3^- and Si, on the other hand, are being released from virtually all of the sediments samples. The concentration gradients of K^+ and Mg^{2+} are such that if they are typical of the sea floor in general, diffusion of these components into the sediments must account for a large proportion of the K^+ and Mg^{2+} supplied to the oceans by the rivers of the world. The Na^+ gradients are somewhat variable but indicate that Na^+ fluxes in response to these gradients in the upper 30 cm of sediment may be an important factor in the geochemical balance of Na^+. Similarly, the sediments appear to be an important sink for SO_4^{2-}. Ca^{2+}, HCO_3^- and Si are enriched in the interstitial solutions studied. The fluxes of these elements back into the oceans serve to balance, in part, their incorporation and burial primarily as biogenic particulate matter.

The nature of the reactions between sea water and the various components of the sediments are known only in a general sense in most cases. Both Na^+ and K^+ uptake must involve silicate authigenesis, but the phases involved have not, as yet, been identified. The mechanisms of Mg^{2+} removal are largely unknown and may involve either carbonate or silicate phases. Alkalinity balances and analyses from deeply buried sediments suggest that both types of reactions occur, but these approaches have not yielded more specific information. Ca^{2+} and Si are primarily released through dissolution while HCO_3^- is released by dissolution and oxidation of organic carbon. Where the latter process of oxidation occurs under anoxic conditions, SO_4^{2-} in the pore waters is utilized by bacteria as an oxidant. This bacterial reduction of SO_4^{2-} to sulfide accounts for depletions of SO_4^{2-} commonly observed in oceanic pore waters.

ORGANIC AND BIOCHEMISTRY

OXIDATION OF ORGANIC MATTER IN THE ATLANTIC

Werner G. Deuser and Edith H. Ross

We have continued our investigation of the place and extent of oxidation of organic carbon in the water column by measuring δC^{13} and ΣCO_2 in detailed profiles and determining δC^{13} of organic phases in the system. We have completed a sample suite from the western North Atlantic and are now working on a suite from the eastern side. An outstanding feature of the results is the relationship between δC^{13} and ΣCO_2 in the upper 1,000 m of the water column. The slope of the δC^{13} versus ΣCO_2 plot deviates significantly from the slope given by the formation and remineralization of bulk organic carbon as represented by living plankton. Whereas the plankton has a δC^{13} of -21 °/oo, the best fit of the data points corresponds to *in situ* production of CO_2 of a δC^{13} of -12 °/oo in the upper 1,000 m. This large and consistent difference implies a substantial isotopic fractionation between the organic carbon formed in the euphotic zone and that remineralized in the upper kilometer of the water column. It has been known qualitatively for some time that the carbon respired by organisms is enriched in C^{13} relative to their bulk carbon and also that the organic compounds which are relatively stable in the marine environment have lower C^{13}/C^{12} ratios than the labile compounds. Our data provide an independent means of assessing this difference in the resistance of organic compounds in the ocean and can be used, together with determinations of dissolved oxygen and dissolved and particulate organic matter, in the determination of relative oxidation rates as a function of depth in the water column. This mode of investigating the fate of organic matter in the ocean has the advantage of providing a view of the integrated result of decomposition at any depth. Next year we plan to complement this line of research with a more direct look at the organic matter itself.

STABLE-ISOTOPE STUDIES OF FOSSILS IN DEEP-SEA DRILLING CORES FROM THE RED SEA

Werner G. Deuser, Edith H. Ross and Blenda Antonellis

A study has been started of the parallel environmental histories of the Red Sea and the Gulf of Aden by determining O^{18}/O^{16} and C^{13}/C^{12} ratios in fossils, especially planktonic foraminifera, from Deep Sea Drilling cores. Thus far, we have analyzed about 250 single-species samples of *Globerinoides ruber*, *Globigerinoides sacculifer* and *Globigerinella siphonifera* from drilling Site 228 in the Red Sea. Although both δO^{18} and δC^{13} of all species vary considerably with depth in the strata, consistent differences between species are maintained in most cases. Thus, by analyzing several species of overlapping ranges, it is hoped to derive a generalized trend of stable-isotope variations throughout the cored strata, beyond the stratigraphic ranges of individual species. So far five intervals of abnormal δO^{18} values for all species between the Recent deposits and the Middle Pleistocene have been observed. Some of these variations indicate density variations in the water, in which the foraminifera lived, of up to six σ_t units. By comparing our results with those of micropaleontological and ecological investigations on foraminifera we can distinguish whether these

density variations were predominantly due to temperature or salinity changes. By further analyses of material drilled in the Gulf of Aden it is planned to assess the relationships between pluvial periods in the low latitudes and glacial periods in the high latitudes. This can be done because The Gulf of Aden was principally subject to glacial influence via the changing chemistry of the open ocean while the Red Sea, a partly or totally isolated basin, was more strongly influenced by changes in the precipitation-evaporation ratio.

ORIGIN AND FATE OF ORGANIC COMPOUNDS IN THE SEA

Max Blumer

As in the past, my research is aimed at the following questions:

(1) What are the sources of organic compounds in the sea and what are their concentrations?

(2) How great is the variability of the organic compounds which enter the sea from different sources and what are the reasons for such variability?

(3) How do organic compounds interact with other components of the marine environment?

(4) What is the long-term fate of organic compounds in the sea?

(5) How can this knowledge be applied to the study of marine processes?

Because of background and experience, my work concentrates on the study of marine hydrocarbons and other lipids. Progress has been made in these areas.

THE HYDROCARBON DISTRIBUTION IN BENTHIC MARINE ALGAE

Max Blumer and William W. Youngblood

Saturated and olefinic hydrocarbons were determined in additional species of benthic marine algae from the Cape Cod (Massachusetts, U.S.A.) area. The distribution of homologous and isomeric olefins was studied in plants of different age and in morphologically different parts of the same specimen. With two minor exceptions, only normal alkanes and alkenes are present. The Methylene-interrupted C_{19}- and C_{21}-polyolefins are particularly abundant; Δ^1-heneicosahexaene and the corresponding pentaene are common to all brown algae, while the corresponding Δ^3-isomers occur in green algae. The hydrocarbon concentration, the alkene-to-alkane ratio and the polyolefin content are highest in young plants or in rapidly growing tissues of older plants. This suggests a deeper involvement in cell biochemistry of straight chain hydrocarbons than previously considered. The biosynthesis of the plant polyolefins remains to be explored; no immediately obvious precursors of the Δ^1-polyolefins were found among the algal fatty acids. The hydrocarbon composition of these benthic algae differs greatly from that of fossil fuels in its simplicity and predominately unsaturated nature.

HYDROCARBONS AND LIPIDS IN SEDIMENTS OF THE WESTERN NORTH ATLANTIC

John W. Farrington and Max Blumer

We have analyzed sediments from 15 stations between Bermuda and Woods Hole. Hydrocarbon concentrations increase dramatically from the abyssal plain to the New York Bight. An odd carbon number predominance in the higher boiling n-alkanes at all stations, except three in the New York Bight, is thought to suggest a contribution of land or marsh plants, even in the abyssal plain.

The high hydrocarbon content and the details of the gas chromatograms from the New York Bight area suggest extensive pollution with fossil fuels.

Several olefinic hydrocarbons, not previously encountered in marine organisms, occur in the sediments of the continental shelf and slope. Their structure elucidation is in progress and should aid in finding the sources of these surprisingly abundant alkenes.

Analyses of a core (SE of Bermuda) show variations in hydrocarbon composition which may correlate with glacial stages. Additional work is planned.

Apparent contamination from sampling or shipboard processing was noted in the samples with the lowest indigenous hydrocarbon content. Additional sampling has been scheduled, with apparatus and handling techniques that have been tested and yielded samples without detectable hydrocarbon contamination. Thorough interpretation of the hydrocarbon composition, especially of the deep marine samples, in terms of possible sources, has to await the collection of these cleaner sediments.

HYDROCARBONS IN ATLANTIC OCEAN ORGANISMS

John W. Farrington and Max Blumer

Our earlier work had demonstrated the transfer and preservation of hydrocarbons in the food web, at least in selected organisms and in restricted areas. This concept is important for studies of the marine food web, for the tracing of fish populations and for the understanding of the fate of recent and fossil hydrocarbons in the food web.

John Farrington has now initiated a larger survey of hydrocarbons in zooplankton, shrimp, fish muscle and fish liver, in specimens primarily from the George's Bank area and from Icelandic waters. Results to date indicate again, that the hydrocarbon concentration and composition in fish is controlled by the lower food web. Thus, the abundance of pristane in the fish livers correlates with the population density of *Calanus*; the planktonic copepods of that genus are especially rich in pristane.

Further analyses of selected specimens from these earlier and some more recent collections are planned.

HYDROCARBONS IN SEA WATER AND BACTERIA

John W. Farrington and Max Blumer

Several studies of the hydrocarbon chemistry of the open ocean have been initiated by Dr. Farrington. At this time, they have not reached the reporting stage. They will be continued by Dr. Farrington, under different funding, with the principal aim of extending the knowledge of hydrocarbon baselines to a larger segment of the North Atlantic.

AROMATIC HYDROCARBONS IN THE SEA

Max Blumer

One of the least explored areas of marine hydrocarbon chemistry deals with the aromatic hydrocarbons. Little is known about their sources, though almost certainly there must be a multiplicity; neither do we have a clear picture of their compositional spectrum or of their eventual fate.

Yet, this class of hydrocarbons comprises compounds of demonstrated great biological activity, and the discovery of other potent biochemicals within it is virtually assured.

We have initiated a sizeable effort in this area and intend to continue it for at least another year. As in our past investigations on saturated and olefinic hydrocarbons, the eventual aim is the understanding of their sources, their compositional variability, their turnover and eventual fate. We suspect that the aspects of biological activity, even at extremely low concentration levels will become more prominent here than in our earlier work.

a) Analytical

Methods for the determination of individual aromatic hydrocarbons in relatively simple mixtures (e.g. airborne particulates) exist. More complex samples, such as crude oil or its environmental residues, can still be handled to some extent by chromatography and low voltage mass spectrometry. However, in such complex aromatic hydrocarbon mixtures, individual compounds can rarely be determined; as a rule the analyses yield only a breakdown into compound classes.

The isolation of aromatic hydrocarbons from complex extracts obtained from sea water, marine sediments or biological materials, is difficult because of the chromatographic overlap of the aromatics with other lipid classes. This had restricted our work in this area to samples that were sufficiently rich in aromatics, e.g. soils and, surprisingly, manganese nodules, but measurements in lipid-rich organisms seemed impossible.

In cooperation with Dr. Walter Giger, who is working with us under Swiss funding, we have now developed a method for the selective recovery of aromatics from such mixtures. A number of sequential steps involve chromatography, specific retention and clathration of the aromatics. Each step is simple and rapid and the cleanup is adequate for later gas chromatography, UV- and mass spectrometry. The recoveries are excellent, even in the nanogram range (10^{-6} - 10^{-9} g).

b) Composition

So far, we have analyzed a water sample, several soils, marsh and offshore sediments and a considerable number of benthic marine algae (with W.W.Youngblood and D.Baillargeon). In those instances where the polynuclear aromatic hydrocarbons exceed the background levels, we find a complexity of composition that is far greater than previously known. The compositional differences between fossil fuels and sediments from relatively unpolluted regions are striking.

Previous investigators have tended to think in terms of a simple composition and a single source (e.g. fallout from polluted air). Our data no longer support this; clearly, the simplicity of the compositional picture must have resulted from analytical bias: e.g. UV spectroscopy "sees" only the aromatic nucleus, but neither substituents nor partly hydrogenated rings.

TRENDS IN ORGANIC GEOCHEMISTRY

Max Blumer

We have reviewed for two journals the evolution of marine organic chemistry and of the broader field of organic geochemistry. In these interdisciplinary areas a great research opportunity has arisen through the rapid growth of basic science and instrumentation.

It appears to us that the transfer of basic knowledge and of research techniques to our area is slow, perhaps too slow. Thus, the polymeric organic material, which dominates organic geochemistry, is not understood in composition nor in its transformation. Knowledge of reaction rates and mechanisms for organic compounds in the sea and sediments is virtually nonexistent. Yet, the understanding of these chemical structures and processes lies at the core of all geochemical knowledge.

Some suggestions about research tools, techniques and relevant basic information have been made.

METHODS

Max Blumer

Progress in organic geochemistry hinges on the best utilization of existing analytical capabilities and on the development of new tools and techniques, where this is necessary. We have concentrated in these areas:

a) The Rapid Preparation of Capillary Gas Chromatographic Columns

Gas chromatography alone, or in conjunction with mass spectrometry is one of the most efficient tools for the resolution of natural organic products. Capillary columns are preferred for the analysis of complex mixtures, but they have been difficult to prepare in the laboratory. Commercial columns, often not reproducible, are expensive and somewhat restricted in availability because of the patent and licensing restrictions.

Thus, to advance the state of the chromatographic art, development of an easy method for the reproducible preparation of capillary columns seemed important. Our method involves the use of

various coating liquids with a commercially available hydrophobic silica of colloidal dispersion. The column performance is predictable, coating is simple and inexpensive and the rapidity of condidioning is unequalled by any other chromatographic columns. With Apiezon L as a substrate, columns can be fully operational within as little as 70-9- minutes after the beginning of the coating step.

b) Mass Spectrometry in Marine Organic Chemistry

The mass spectrometer is an eminently powerful tool for the analysis of natural organic products. In our earliest work, we made use of outside facilities, but some seven years ago, it became apparent that further progress depended on direct access to a mass spectrometer that could be maintained at the sensitivity level required for our work. We requested and obtained funding for a CEC (now DuPont) 21-104. After its installation, the basic instrument required numerous modifications and I devoted a sizeable fraction of one year to this task. Since then, the instrument has performed well, without major breakdowns, at sensitivities in the low nanogram range, and it has been depended on heavily for most of out work.

Some modifications of the CEC 21-104 spectrometer have been undertaken during this year. A persistent problem at the relatively high source pressures encountered during gas chromatographic and probe operation has been traced to discharges from the high voltage leads in the Isatron. This has been corrected through proper lead dress and installation of a glass duct through which the probe rod is inserted.

A scanning unit that will provide linear mass display during magnetic scan is under construction, also a scan control that will initiate the magnetic sweep, the scan of a storage scope and its erasure, the paper drive and the recycling of the magnet, automatically and according to a flexible program.

A refrigerated direct insertion probe has been received and is undergoing tests.

The increasing complexity of the samples which we are now studying led us to seek funding for a newer instrument, interfaced with a dedicated data processing system, that would also lend itself to the powerful technique of mass chromatography. A Finnigan 1015 Gas Chromatograph-Mass Spectrometer-Data System was purchased and has been operational for about a year. Again, it is apparent, that the basic instrument will need considerable attention and modification to operate successfully in the range required by this and other projects at this Institution.

I have been in touch with nineteen users of the Finnigan System, especially those who have similarly severe requirements. The survey was directed principally at instrument performance, samples handled, sample treatment, modifications of the instrument and operation of the facility. The responses, compiled in a Woods Hole Technical Report indicate general satisfaction with the performance of the instrument at sample levels in the nano- to pico-gram range. It appears that differences in instrument performance are largely due to differences in the management of the facility; especially for successful quantitative use, extreme restriction of the number of users appears mandatory.

GASOLINE RANGE HYDROCARBONS (C_4 - C_7) IN DEEP OCEAN SEDIMENTS

John M. Hunt

Microbiologically produced methane is the only light alkane formed in appreciable quantities in the first hundred meters of the sediment beneath the sea. Gasoline range hydrocarbons are mostly formed from the thermal and catalytic cracking of organic matter over a subsurface temperature range from about 75°C to 150°C. This is equivalent to depths of 2,000 to 5,000 meters in a typical sedimentary basin.

During the past year about 50 samples of relatively young, shallow sediments from the Deep Sea Drilling Project (DSDP) cores were analyzed for C_4 to C_7 hydrocarbons. These hydrocarbons were found more widely distributed than had been believed previously, although the concentrations were low. Quantities varied from 0.5 to over 6,000 ppb (parts per billion) in the 50 samples analyzed. In the Bengal Basin the number of detectable indivisual hydrocarbons increased from 4 to 10, with the total hydrocarbon yield increasing from 0.47 to 6.1 ppb over the depth range from 416 to 770 meters (Table 1). In the Red Sea, 24 individual hydrocarbons were identified in this range with a total concentration being 49 ppb (Table 1). The number of hydrocarbons and the total concentration was found to increase with depth in at least four of the DSDP holes. The concentration of hydrocarbons in the deeper and older sections of those holes studied in detail had toluene/benzene ratios of 2.3 and 3.2, which is close to the 2.5 value for the average crude oil. The order of isomeric hexanes and heptanes for several of the samples was also comparable to petroleum in the oldest and deepest cores.

The highest yields of C_4 to C_7 hydrocarbons were on the continental margins (shelf, slope and rise) with the lowest concentrations in the abyssal plains (Fig.1). The numbers by each station location in Fig.1 are analyses of individual samples in order of their depth, the deepest being last. The quantity of C_4 to C_7 hydrocarbons when compared with the total organic carbon indicates that three of the samples analyzed may be seeps, the rest being indigenous hydrocarbons (Fig.2). The C_4 to C_7 yields for the presumed seeps were so high that they could not be plotted on Fig.2.

The indigenous hydrocarbons may be forming in place through low temperature cracking of larger molecules, or they may be diffusing from nearby sediments. A combination of these factors may cause some of the scatter observed in Fig.2.

Much of the data is still being studied, but it appears that the C_4 to C_7 hydrocarbons in DSDP cores can be used to evaluate the capability of a marine sedimentary section to generate petroleum hydrocarbons. Furthermore, it may be possible to determine relative rates of formation of the different hydrocarbons if more complete sections can be analyzed to greater depths. Plans are underway to analyze additional samples from the Antarctic, the Greenland Sea, the Black Sea and possibly the Argentine Basin and Norwegian Sea. The studies will concentrate on a large number of samples from a few holes, rather than scattered samples from several holes. Also, the older and deeper samples will be emphasized when available.

TABLE I

C_4 TO C_7 HYDROCARBONS IN DSDP CORES

Hydrocarbon	N. Calif. Coast 34-4-4	34-5-4	Parts per Billion by Weight Bengal Basin 217-16-4	217-24-0	217-33-2	218-27-2	Red Sea 229A-13-5
Isobutane	0.064	0.236	0.149	0.281	0.234	0.241	2.08
n-Butane	0.72	1.12	0.210	0.130	0.276	0.295	1.75
Isopentane	0.548	1.75	0.026	0.109	0.115	0.315	2.17
n-Pentane	2.79	8.49	0.082	0.085	0.056	0.0247	3.33
2,2-Dimethylbutane	0.122	0.89					0.59
Cyclopentane	0.065	0.485		0.012		0.239	0.81
2,3-Dimethylbutane	0.017	0.266					0.75
2-Methylpentane	0.39	3.00				1.86	2.06
3-Methylpentane	0.261	1.53				1.87	1.56
n-Hexane	0.221	1.30				0.288	2.50
Methylcyclopentane	0.089	0.825					2.99
Cyclohexane	0.046	0.40					2.16
3,3-Dimethylpentane		0.235					0.92
1,1-Dimethylcyclopentane		0.156					0.78
2-Methylhexane	0.047	1.13					3.23
2,3 Dimethylpentane		1.12					1.75
1-c-3-Dimethylcyclopentane							3.12
3-Methylhexane	0.032	0.536					3.86
1-t-3-Dimethylcyclopentane	0.022	0.437					0.24
1-t-2-Dimethylcyclopentane		0.186					0.73
3-Ethylpentane							0.25
n-Heptane	0.018	1.56			0.029	0.496	3.55
1-c-2-Dimethylcyclopentane		0.435					0.94
Methylcyclohexane	0.011	1.81			0.028	0.208	6.97
Benzene	0.189	12.20	---*	---	---	---	---
Toluene	0.107	8.20	---	---	---	---	---
TOTAL	5.75	48.3	0.467	0.617	0.738	6.06	49.1

*Benzene and toluene not analyzed.

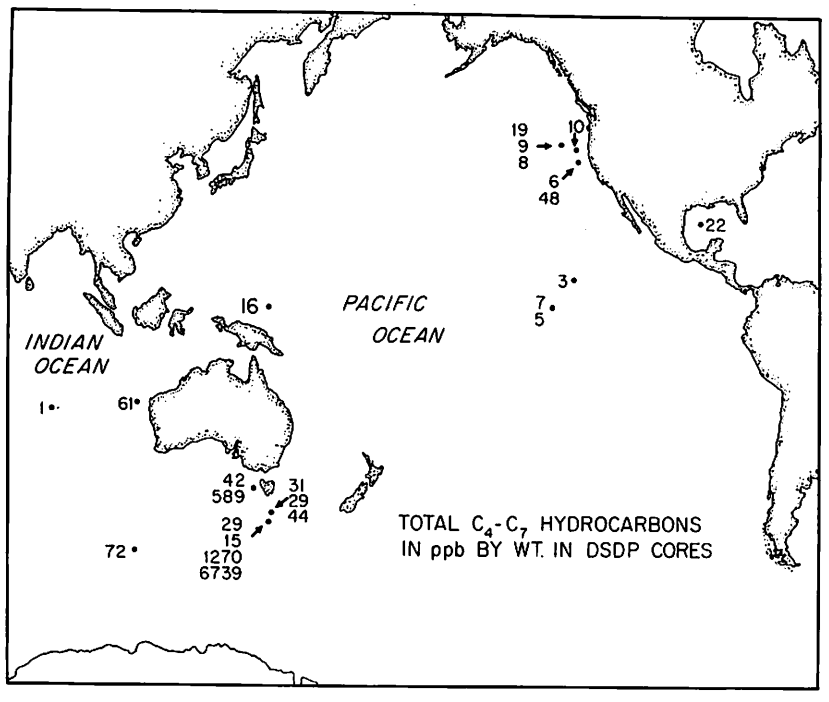

Fig.1 (Hunt)

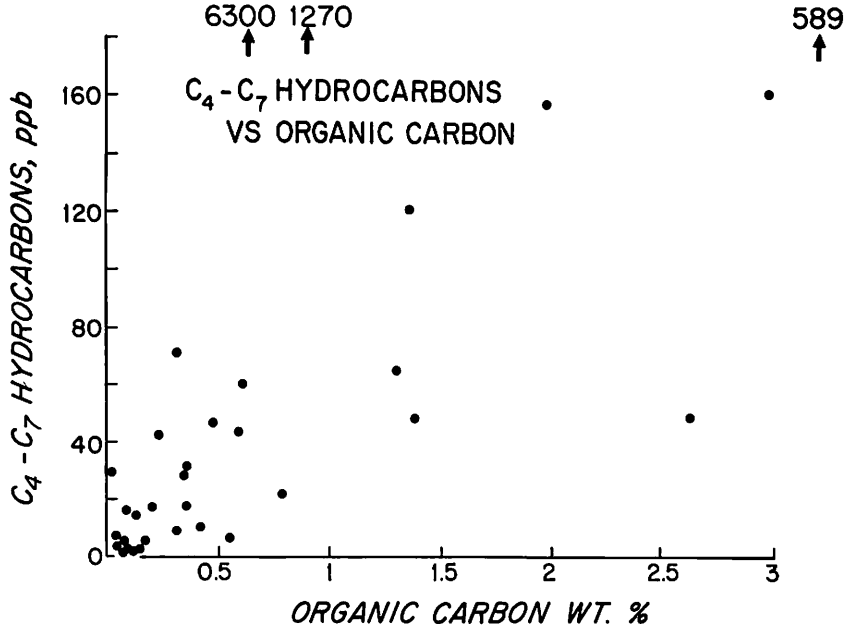

Fig.2 (Hunt)

PETROLEUM CONTAMINATION: QUANTIFICATION AND PASSIVE TAGGING IN ORGANISMS AND SEDIMENTS

John W. Farrington

A two-year research program has begun with the principal objectives of developing relatively simple, reliable, analytical methods for routine use in the average analytical laboratory to: (a) quantify petroleum contamination at the 1 ppm (wet weight) level in marine organisms and aquatic sediments; (b) correlate petroleum contamination of marine organisms and aquatic sediments with sources of contamination - "passive tagging". The state of the art will be evaluated to provide a realistic assessment of the limitations of the various analytical methods vis-à-vis various petroleum contamination problems. The selectivity and sensitivity of analytical chemical methods such as column chromatography, gas chromatography and UV-fluorescence analysis will be evaluated.

ORGANIC MATTER IN RECENT SEDIMENTS

John W. Farrington and Jean King

We have begun a long term research effort to study organic matter in Recent sediments, particularly surface sediments. Our efforts to date have concentrated on the biogeochemistry of fatty acids, polypeptides and amino acids. Analytical chemical capabilities have been developed to study the diagenesis of these compounds in sediment cores which we collected in the North Atlantic Basin.

INPUT AND LOSS OF PETROLEUM AND CHLORINATED HYDROCARBONS TO THE DEEP NORTH ATLANTIC

George R. Harvey, William G. Steinhauer, Helen P. Miklas and John W. Farrington

The objectives of this work are to determine the routes, quantities and mechanisms of hydrocarbon input to the North Atlantic, and to measure the rate at which they are penetrating the water column toward burial. To achieve these objectives, we have measured the polychlorobiphenyl (PCB) concentrations in the vapor and particulate phases at four sites over the western North Atlantic. Also, we have determined the PCB concentration in the water column at twenty stations in the eastern, western and equatorial North Atlantic and in selected large diameter gravity cores taken from different depths.

A. Atmosphere

Before the marine atmosphere could be analyzed for hydrocarbons, a new collection system had to be devised which could collect both vapor and particulate phases in high volume. For these requirements, we used a high volume air pump fitted with a filter holder containing a glass fiber filter. Between the filter holder and the pump was a chamber filled with ceramic chips coated with OV-17 silicone oil. The system was 70% efficient for vapor phase PCBs.

In Table 1, the results of our analyses are presented in chronological order. Only the samples collected on the 12th and 13th of February, 1973,on Bermuda had detectable DDT. In the other samples, the DDT concentration was less than 0.01 ng/m^3. In all cases the particulate matter collected on the filter contained 1% or less of the total PCB. In Chart 1 the average concentration at each site is plotted against the distance of that site from the northeast United States industrial complex. The exponential decay with distance from the source is characteristic of tropospheric fallout rather than like the longer trajectory stratospheric fallout seen after atmospheric nuclear tests.

B. Water

In the summer of 1972, 51 surface and 200 m water samples were analyzed for PCBs in the North Atlantic. The average concentration at that time was 35 ng/l at the surface and 10 ng/l at 200 m. It was estimated that the mixed layer of the North Atlantic contained about 20,000 tons of PCB. By the summer of 1973, the average surface water concentrations in the Sargasso Sea had dropped to 0.6 ng/l (±0.4) and in the eastern and equatorial North Atlantic to 3.6 ng/l (±0.3). In general, the PCB profiles followed the main features of the water column and showed a slight maximum at 200-300 m, the base of the thermocline. Also, subsurface high salinity layers showed minimum PCB concentrations. In contrast with true gaseous or particulate pollutants the PCB concentrations in plankton, surface or subsurface water showed no trend with changing latitude.

TABLE 1

Station	Date (1973)	Sample Volume m^3	Wind Direction	PCB ng m^{-3} (calc. as Aroclor 1254)
Bermuda	2-12	560	WNW	0.5
(32°20'N;64°40'W)	2-13	480	W	0.4
" "	2-14	820	Var.	0.16
" "	2-15	500	S	0.15
Georges Bank	4-10	105	NW	1.4
(41°40'N;67°30'W)	4-13	675	NW	0.82
" "	4-15	660	NE	0.58
" "	4-17	655	NW	0.61
" "	4-19	640	SW	0.80
" "	4-21	650	SW	1.60
Vineyard Sound	4-13	105	SW	3.9
(41°20'N;70°50'W)	4-30	224	SW	5.3
Grand Banks	6-25	780	SSW	0.05
(45°16'N;52°08'W)	6-26	960	SW	0.07
" "	6-27	840	WSW	0.10
" "	6-28	940	WSW	0.16
" "	6-29	540	W	0.05

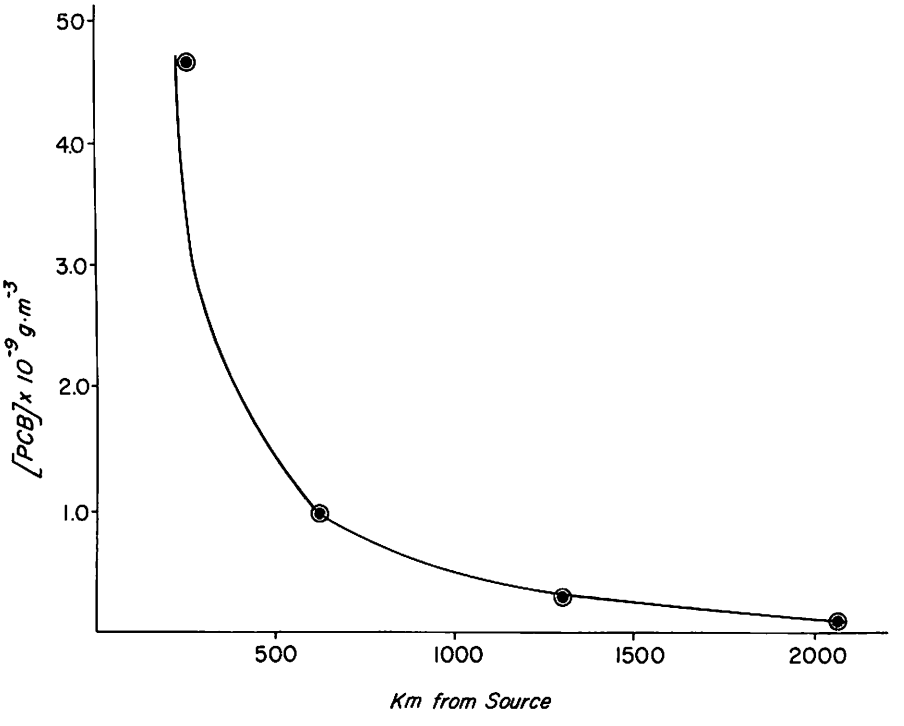

Fig.1 (Harvey *et al.*) Chart 1.

C. Sediments

Four sediment cores have been analyzed for PCBs. Shallow coastal sediments (top two cm) from Buzzards Bay, Massachusetts had PCB concentrations of 0.5 (clayey) and 0.2 ppm (sandy). Sediment obtained from the bottom of the Hudson Canyon under a 2626 m water column had 0.7 ppb of PCB. Finally, a core from the Hatteras Abyssal Plain, under 5200 m of water, had 0.2 ppb of PCB in the top two cm.

A suite of surface sediments collected between Bermuda-New York have been analyzed for total hydrocarbons (petroleum and biogenic). Similar to the PCB analyses, the total hydrocarbons decrease by 10^3 between New York (2912 ppm) to 1.07 in the Hatteras Plain. We have previously observed that the ratio of total hydrocarbons to chlorinated hydrocarbons in any sample of organism or water was about 10^3.

Conclusions

The delivery of chlorinated hydrocarbons to the ocean is greatest in the coastal zones. The decrease in aerial PCB concentrations is exponential seaward. This input is buffered by the higher particulate load and sedimentation rate in the near-shore ocean, causing the PCB concentrations in the water and organisms not to show a meridianal gradient. The delivery does appear to be reflected in the surface sediments of the ocean.

At this time we must conclude that the chlorinated hydrocarbons, which exist about 90% in the dissolved phase in the ocean, have penetrated the deep Atlantic. The mechanism of this transport must await further research.

MARINE GEOSHEMISTRY OF STEROIDS

Robert B. Gagosian, Richard A. Bourbonniere and Roxanne Beebe-Center

Steroids are one of the most important groups of biochemicals regulating growth, respiration and reproduction in marine organisms. Although they are widely distributed in both terrestrial and marine life, we know very little about their origin, distribution, concentration, and fate in sea water and the sediments. During the past year we have initiated a program of studying this cycling of steroids by analyzing sea water and sediments in as many marine sedimentary and oceanic environments as possible, including coastal, continental shelf and slope, and in the deep water of the North Atlantic. The development of a relatively simple method for isolating and elucidating the structures of sterols from sea water was accomplished.

Our results of coastal water analyses of Vineyard Sound, Massachusetts, from July-August, 1973 indicate a total sterol concentration range of 2.6-7.4 µg/liter with cholesterol, campesterol, and β-sitosterol being the major constituents. Deep sea water and sediment samples were collected from the Gulf Stream and Sargasso Sea and extracted on the R/V *Knorr* - Cruise 33 between Woods Hole and Bermuda in September of 1973. Preliminary results show that in the surface waters of the Gulf Stream cholesterol and β-sitosterol are the major sterols in approximately equal concentration, with stigmasterol, campesterol, and brassicasterol being significantly lower. The total sterol concentration is approximately 1-2 µg/l. In the surface water samples of the Sargasso Sea, cholesterol is the major sterol with much lower concentrations of β-sitosterol, stigmasterol, campesterol and brassicasterol. The sterol concentration in our Sargasso Sea samples is approximately 0.5-1 µg/l. The β-sitosterol concentration decreases in going from Gulf Stream water to the Sargasso Sea. This is consistent with our hypothesis that a source of β-sitosterol in sea water samples is terrestrial runoff of land plant detritus. After further analyses, we may indeed find that β-sitosterol can be used as a tracer of terrestrial input to water masses of the open ocean.

In conjunction with these studies, we have analyzed several lobsters (*Homarus americanus*) and shrimp (*Pandalus borealis*) for sterol concentrations and distribution. The sterol content found was 0.075%, based on wet weights, for the lobster and 0.13% for the shrimp. No differences in sterol content were found in lobsters when comparisons of female and male non-molted and molted animal extracts were examined. Sterol distributions for both lobsters and shrimp are approximately the same, with cholesterol being the major sterol (95%) and desmosterol, campesterol, and β-sitosterol making up the remaining 5%.

These results are consistent with previous results of other workers that cholesterol is the most abundant sterol in the advanced invertebrates. The more primative invertebrates have much more diversified sterol compositions. We find that the sterol content in crustacea is not only influenced by the sterol composition of the organisms' diet, but also by the sterols present in the organisms' water environment. Caution must therefore be exercised when comparing sterol variability among members of the same species from different regions.

LOBSTER MOLTING HORMONE

Robert B. Gagosian and Richard A. Bourbonniere

It is well-known how important molting is in the life cycle of arthropods. Although large efforts have gone into the isolation and structure determination of molting hormones (ecdysones) from insects, very little work has been accomplished on crustacea. In general, crustacea have distinct molting glands (Y organs) comparable to those of insects. However, in the lobster, *Homarus americanus*, no structure comparable to the Y organ or any molting gland has been demonstrated to be present. We felt that this physiological difference between lobsters and the other members of their class might also be reflected in the chemistry of the lobster molting hormone, both in its structure and biosynthesis.

Organic analytical chemical techniques have been developed for the isolation and structure elucidation of the lobster molting hormone. The quantities of molting hormone isolated were 6μg/kilogram wet weight of lobster. This compound, ecdysterone, has the same structure as the molting found in insects.

The biosynthetic precursors of ecdysterone in insects are cholesterol and α-ecdysone. In collaboration with Ernest Couch and William Smith of Texas Christian University, we have studied the biosynthetic pathway of ecdysterone formation in lobsters. To the best of our knowledge, this work is the first definitive study of the uptake and biosynthetic conversion of cholesterol to ecdysterone in crustacea.

CHEMOTAXIS INVESTIGATIONS

Jelle Atema

It has become clear in recent years that chemical signals provide a network that is essential in the maintenance of ecosystems. In the fourth year of research on chemical communication in aquatic animals we have continued to work at three levels of biological organization, chemical-molecular, neuro-sensory, and behavioral in an attempt to cut a path through this vast unexplored area between chemistry and biology. We have continued work on lobsters and catfish, and we started promising work on snails. A short exploratory study was done on the not-so-aquatic gypsy moth.

LOBSTER BEHAVIOR

Jelle Atema, Lauren S. Stein and Gwen Grabowski

We have used the 200,000 gallon giant ocean tank in the New England Aquarium in Boston, Massachusetts, to study in detail the behavior of a group of ten lobsters (*Homarus americanus*). Some interesting results were obtained from this one-month study, in which three observers kept several continuous around-the-clock watches, and aquarium divers assisted in keeping daily animal inventories. We observed that under the conditions of low population density there exists no true territoriality, very little aggression to cospecifics, and a little more aggression and defense behavior against fish

and turtles. The lobsters derived their protection from shelter. Diurnal activity rhythms and residencies were established. Our results closely resembled existing field observations. An interesting side observation of importance to lobster culture was that all lobsters exhibited normal behavior in unusually warm water (24°C), which will help. A follow-up study now underway uses a smaller, but more natural environment (by aquascapist Stewart Jacobson) in our own laboratory, and will explore the possibilities for raising lobsters in polyculture. The study also lends itself for measuring effects of pollutants on a Northeast Coast inshore community.

LOBSTER LEARNING AND INDIVIDUAL RECOGNITION

Jelle Atema and Lauren Stein

To find out if lobsters can recognize other lobsters as individuals using chemical information we have started experiments in which lobsters are trained to pull different targets. Correct responses are food rewarded. The advantage of such a study is that one discovers the discrimination potential of the animals much faster than by chance observation in a natural situation. At present we have shown that different food odors can be discriminated. In a next step we will replace food odors with the water from tanks holding other lobsters, etc. An interesting fact in itself is the discovery that lobsters can be trained this way, exhibiting a level of invertebrate intelligence, so far just below that of the octopus. The study lends itself well for use in a bioassay on effects of pollutants on the learning and memory of chemical signals.

SPINY LOBSTER ATTRACTION TO CONSPECIFICS

Donna Sandberg and Jelle Atema

A short study with the California spiny lobster, *Panulirus interruptus*, showed that in a Y-maze they exhibit significant preference to enter the upstream arm in which another spiny lobster is kept behind a screen. Under the paranoiagenic circumstances of running a maze they seem to be more interested in finding a conspecific than in finding food. The ecological significance is of interest: spiny lobsters derive their protection from group defense and they are a naturally aggregating species. The tests were run at night to avoid daytime inactivity. At present it cannot be determined whether chemical or other (possibly acoustical) signals were utilized in the attraction.

FUNCTION OF LATERAL VS. MEDIAL OLFACTORY TRACT IN CATFISH

Jelle Atema, Gail Burd and Thomas Finger

This work is part of our long-range study to define the functional significance of the chemical senses, specifically smell and taste, as they developed in the course of evolution. Neuroanatomical studies on catfish brains and lesion studies in mammals seemed to indicate that two functionally distinct olfactory tracts exist in vertebrates. To test this theory we lesioned the

lateral and medical olfactory tracts of catfishes (*Ictalurus natalis* and *I. nebulosus*) and observed their behavior before and after operation. Both social behavior, activity and feeding behavior were measured. The observers never knew which of three operations, including a sham operation, were performed to avoid bias. The results, which are still being analyzed, seem to indicate a slight difference in lesion effects, but by no means as dramatic as reported for mammals. Neuroanatomical differences are also much less pronounced. Feeding behavior was not affected as expected. The role of olfaction in social behavior remains an intriguing question of rather fundamental importance.

Preliminary studies on the ultra-structure of olfactory receptor cells have begun (see Fig.1) which will be used to determine peripheral effects of tract lesions.

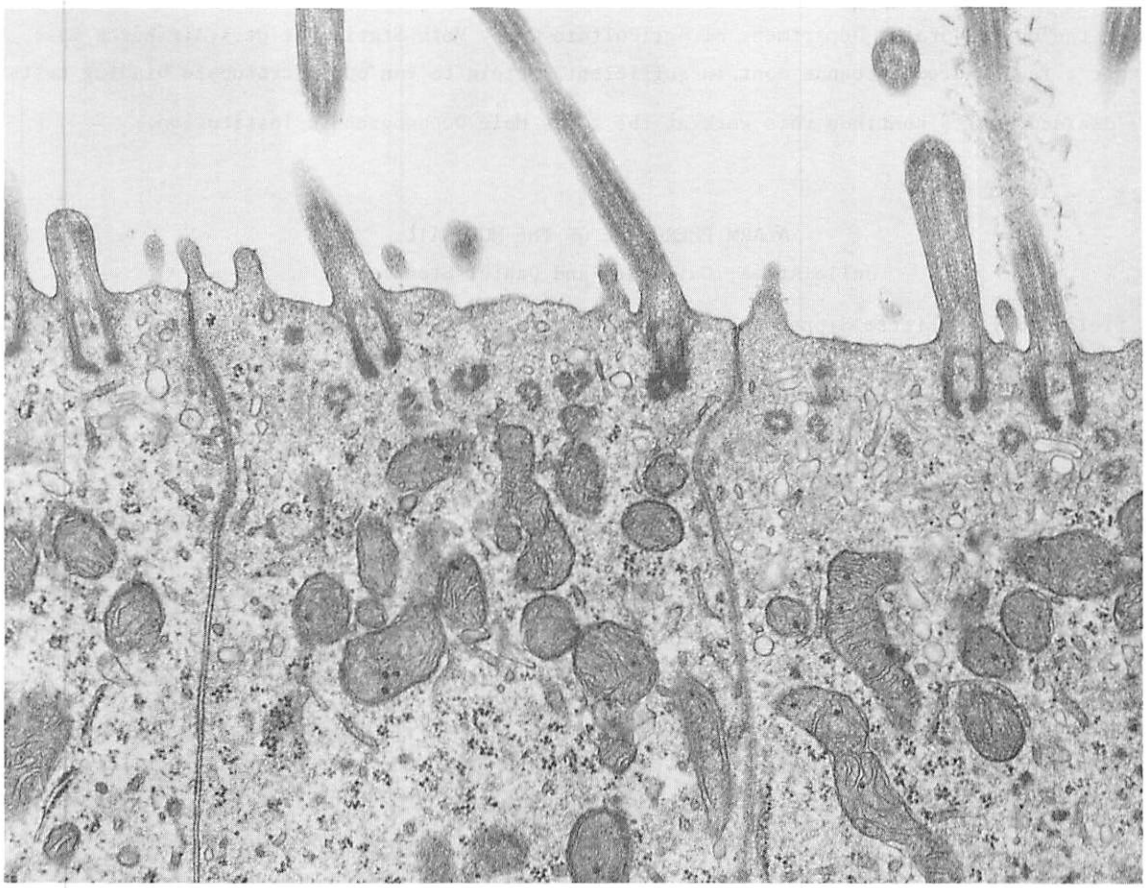

Fig.1 (Atema, Burd and Finger) Electron microscopy of the olfactory receptor cells of the catfish (*Ictalurus natalis*) shows several cilia, anchored inside the cell with dark stained basal bodies, and protruding into the mucus layer (light area) which covers the nasal epithelium. The general appearance is very similar in terrestrial and aquatic animals. Microtubules inside the cilia may play a key role in processes of sensory transduction and the initial coding of information coming from the environment. (Magnification 25,000 x).

MICROTUBULES IN (CHEMO-) SENSORY PROCESSES

Jelle Atema and Mark Winston

Two years ago we proposed the theory that microtubules may be involved in the reception and transduction of (chemo-) sensory information within the receptor cells. If proven true, this concept would have fundamental implications for medicine and biology since it deals with the basis of all sensory processes in animals. One experimental design to test this hypothesis is to show that structural disassembly of microtubules is followed by functional block of receptors. Two pilot studies turned out inconclusive. Another design is to isolate microtubule protein from receptor cells and test if it binds to radioactive pheromone, an odor molecule of great biological significance, which is known to be received via the animal's nose. In preparation for the latter we have succeeded in isolating rather large quantities of protein from male gypsy moth antennae, the biological receivers of disparlure, one of the few commercially available female sex pheromones. To obtain 10,000 male gypsy moth pupae we sent a 10-man task force to the badly infested woods near Sharon, Massachusetts, under supervision and in collaboration with the United States Department of Agriculture Gypsy Moth Station at Otis Air Force Base. We found that a few hundred antennae contain sufficient protein to run our microtubule binding tests.

We decided not to continue this work at the Woods Hole Oceanographic Institution.

ALARM PHEROMONE OF THE MUDSNAIL

Jelle Atema, Gail Burd and Daniel Stenzler

A field study in Little Sippewisset Marsh has shown conclusively that the mudsnail, *Nassarius obsoletus*, exhibits an alarm reaction which consists of burrowing in the mud and/or walking away from the area of pheromone release. The pheromone is released when a snail is crushed or otherwise damaged. Other molluscs, on the other hand, provide a food attractive stimulus when crushed and left on the marsh bottom.

Subsequent laboratory studies showed that any damage of the snail's body will release the pheromone. We were not able to define a specific body region for release. The substance is released passively, not under the animal's control. Cross specific examination showed that out of several different species, genera and families only *Nassarius vibex* releases an alarm response in *N. obsoletus*, albeit one delayed by five minutes.

An interesting discovery was that *N. obsoletus* must be well fed with access to fresh marsh mud to keep its normal level of responsiveness. When starved or fed on mussels for a week the level of response dropped considerably. The alarm pheromone can be diluted 1000 times for 50% response; it can be extracted in distilled water; it is heat resistant (boiling) and it can be stored frozen for a week. It cannot be extracted with ether. Further chemical isolation and chemical identification will be done in collaboration with Professor Meinwald at Cornell University.

BEHAVIORAL OBSERVATIONS ON THREE DIFFERENT DENSITIES OF JUVENILE LOBSTERS

Joan Mitchell

Studies on the behavioral development of young lobsters showed increased aggressive behavior during their development from Stage 4 to Stage 8, with the peak occurring at Stage 7. Animals observed in community situations (four individuals per 55 gallon tank), also showed increased behavioral activity during development. However, the observed behavior, including aggression, was significantly less in the community tanks than in the paired encounters. One major difference between the two studies was that the animals in the community tanks showed differential growth, with at least one individual in each tank molting more frequently, and growing larger than its tank mates. Therefore, interactions usually were not between individuals of the same stage or size, and it is probable that the smaller individuals avoided interactions with the larger animals whenever possible.

Following these descriptive studies on behavioral development of larval and juvenile lobsters, we completed an investigation of the relationship between population density, behavior, growth and survival in lobster communities. Communities of two, six and ten Stage 4 individuals were established in six 55 gallon aquaria (twelve communities; four replicates of each density). The communities were observed on a daily basis over a period of three months, to determine the behavior of animals held at different densities, as they developed from Stage 4 to Stage 10. In this study the animals were color coded to identify each individual in a community. Daily monitoring provided information on individual molting frequencies, growth rates, claw loss and mortality, as well as shelters occupied by each individual. It was found that behavioral activity was even lower than in the first community study. Again, diffential growth in the tanks at all three densities was observed. Excess food and shelter may have reduced the amount of cannibalism in these communities.

Information on density related behavior of young lobsters in closed systems will be beneficial in efforts to mass culture lobsters beyond the larval stages. At present, cannibalism and aggression are two major problems preventing mass culture of lobsters from larvae to marketable size.

CULTURE OF CHIRONOMID LARVAE (MIDGES)

William O. McLarney and Marcus M. Sherman

Experimental culture of larvae of the midge *Chironomus tentans* in fertilized ponds, begun in 1972 was continued. The goal is to develop a culture system more conducive to use of the larvae as fish food than present sytems in which the larvae are grown in or on a sand or gravel substrate. The method adopted to achieve this end is to provide hanging sheets of cloth or plastic as a substrate for larval attachment. This technique was modified in 1973 by hanging the sheets straight, like clothes on a line, rather than pleated, like curtains. The result was greater production per unit area.

The effects on larval production of several environmental variables were tested, with the following results (pending statistical analysis):

(1) Of four substrate materials tested, the most highly textured (burlap) was clearly the most productive.

(2) Soaking the substrate material in a fertilizer solution before use, so that particulate matter adhered to the cloth, increased production.

(3) Milorganite was a more effective fertilizer than animal manures.

(4) Results of adding an iron solution to the ponds were inconclusive, but this may have been due to problems of technique.

(5) The optimum spacing of substrate sheets appeared to be about 0.1 m.

(6) Circulation of the water appeared to be beneficial, but the optimum rate was not determined.

(7) Shading the ponds was detrimental.

(8) Raising the temperature in the autumn by means of a plastic greenhouse appeared to increase production.

(9) Aeration had a negative effect, apparently as a result of increased growth of filamentous algae.

The results of the 1972 and 1973 studies will be incorporated in a production level culture scheme, with fish feeding trials in 1974. Results of the current study are being prepared for publication.

RADIOCHEMISTRY

RADIOACTIVE FALLOUT IN THE ENVIRONMENT

FALLOUT RADIONUCLIDES

Vaughan T. Bowen, Hugh D. Livingston, John C. Burke,
John G. Farmer and Laurent Labeyrie

Open Ocean Seawater

It has often been suggested that ^{137}Cesium from fallout is an unreliable tracer of water movement because of its association with sedimenting particles; indeed we have shown that a few percent of the ^{137}Cesium delivered in fallout is transferred to the sediments by this means. Careful re-evaluation of several hundred ocean water samples, from all depths and from most parts of the Atlantic Ocean, analyzed for both ^{137}Cs and ^{90}Strontium by ourselves or by various commercial laboratories, has shown that sedimentation produces an undetectable effect on the ratios of these nuclides in the water column. In a large series of samples of over-ocean precipitation, from the North Atlantic, the mean ratio ^{137}Cs to ^{90}Sr was 1.47 ± 0.2; in open-ocean surface water the mean ratio found was 1.43 ± 0.4 and in subsurface samples having at least 5 dpm ^{137}Cs per 100 liters was 1.44 ± 0.4. These latter samples represented depths as deep as 2000 m. In samples from deep water, having ^{137}Cs less than 5 dpm per 100 liters, the mean ratio ob erved was 1.64 ± 0.7. No clear trend of the ratios correlated with time (over seven years of sampling represented), with depth, or with ocean area.

In contrast to this simple situation, water samples from near shore ocean areas in many parts of the world agree in being significantly depleted in ^{137}Cs versus ^{90}Sr; the mean ratio observed in several series ranges about 1.05. Sediment analyses do not, however, in such areas reveal enough ^{137}Cs to account for that lost from the water column; it seems necessary for explanation to resort to the combined action of several observed processes: ^{137}Cs sedimentation, river and run-off supply of fresh water having low ^{137}Cs to ^{90}Sr ratios, and ground water supply of salt wa er of very high ^{90}Sr content. The question remains why this diversity of processes should yield very similar ^{137}Cs to ^{90}Sr ratios in most near-shore areas so far examined; another question, at least as perplexing, is why the North Sea should be a clear-cut exception to the generalization.

Many of our earlier reports have emphasized that integration of the ^{90}Sr content over the whole water column, at most stations reported from the North Atlantic, indicates that more ^{90}Sr is present than would have been predicted by extrapolation of the various delivery measurements over land. Measurements on 14 stations, all taken in 1972 in the North Atlantic, partly on GEOSECS and partly on other Woods Hole Oceanographic Institution cruises, all confirm this excess over prediction. The amount of the excess, however, shows a surprisingly good correlation with latitude, passing from 500% about 75°N in the Greenland Sea, to only about 35% about 19°N in the Antilles Outer Basin. Interpretation of this set of observations is further confused by two other factors: first, that Danish measurements of ^{90}Sr fallout on the Faeroes Islands (at 62°N) agree excellently with the integrated contents of our two water columns in the same latitude band: 102 mc ^{90}Sr per km^2 on the Faeroes versus 104 at 63°30'N and 107.6 at 60°29'N, and second, that the same curves predicting ^{90}Sr delivery, unsuccessfully, seem to do an excellent job of predicting the delivery of ^{239}plutonium. Furthermore, a good deal of data, Danish as well as our own, agree in showing that the Polar Current, running southward along both coasts of Greenland, carries very large concentrations of both ^{90}Sr and ^{239}Pu, the sources of which are still wholly unidentified.

Our interest in the biogeochemistry of plutonium has been operating for some years; interest in such other transuranic elements as neptunium, curium, and americium has recently been stimulated by the prediction that new technologies in nuclear power production will soon begin to result in large amounts of these nuclides as radioactive waste. Last year we reported development of a method for separation of ^{241}americium in marine environmental samples. This has proved to be adaptable also to the measurement of curium, and we have recently, in a sample from the Irish Sea, reported the first instance of curium (^{242}Cm) in a marine sample. A good deal of data have been collected on ^{241}Am but most have not yet been evaluated. At one North Atlantic station (52°40.1'N; 36°49'W, occupied June 1972) the ratio ^{241}Am to ^{239}Pu increased smoothly from 0.16 at 200 m to 0.38 at 2900 m, both nuclides showing maximum concentration at 675 m. Because of the production of ^{241}Am by decay of ^{241}Pu (which has a much shorter half-life than that of ^{239}Pu) the ^{241}Am:^{239}Pu would be expected to increase with age of sample; the amount of increase observed at this station, however, greatly exceeds that to be expected because of decay of ^{241}Pu, and can be explained, we believe only by the existence of a geochemical process separating americium from plutonium, and moving americium downward with greater mean vertical velocity than we have observed for Pu. The small amount of data that we now have showing ^{241}Am to ^{239}Pu ratios in sediment cores do not show, unequivocally, that these nuclides separate in sediment geochemistry.

We have just begun an investigation of the marine geochemistry, especially in sediments, of ^{55}Fe. Preliminary data seem to confirm, in a core from Buzzards Bay, a very large excess of ^{55}Fe over the amount that would have been expected from direct fallout; the about-five-fold excess we observed compares well with the about-six-fold excess reported by Krishnaswani *et al.* (1973) in a core (somewhat deeper) from the Santa Barbara Basin. The mechanism for concentration of fallout ^{55}Fe in shallow water coastal sediments promises to be of considerable interest.

Development of sampling gear has continued to be an important activity. In the past we have been forced, by the manufacturer's discontinuing of production of Kel-F, the fluorocarbon coating we have always used on our large volume water samplers, to redesign this device using fiberglass pipe for the barrel. The first such unit is now at sea, on R/V *Knorr*, being tested, and several more are under construction. In addition to improved flushing characteristics, the new design promises to be about one-third less costly than the old one. For a variety of applications, we have also been working on a pressure-time actuated opening-closing device, of high accuracy, reliability and adaptability; our application will be immediately to opening-closing nets, and to water sampling, using a device lowered to depth filled with, for instance, distilled water. The new unit has been tested successfully, and now is being modified and improved by inclusion of a telemetering system for depth and operating information.

Reference

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TRANSURANIC ELEMENTS IN LAKE ONTARIO

John G. Farmer and Vaughan T. Bowen

Analysis of the 1972 water samples revealed trends similar to 1971, with higher mean Pu-239 concentrations in the deep water body, although vertical gradients were apparently less steep in 1972. Data for the western end of the lake suggested a significant input of Pu-239 via the Niagara River, a factor which the 1973 samples should clarify.

Remarkably high Pu-239 concentrations of up to 460 dpm per kg dry sediment were observed in the surface sediments at the southwestern end of the lake. Concentrations decreased rapidly with depth in the upper 5 cm but small quantities (0.5-7 dpm per kg) of plutonium persisted to at least 60 cm in the most westerly core. No evidence was found of strong subsurface maxima comparable to those seen at a depth of 20 cm in two 1971 cores from the eastern end of the lake where, quite paradoxically, significant amounts of plutonium were found to only 10 cm in the two 1973 cores analyzed. The complex nature of plutonium distribution in the lake sediments is further illustrated by the varying integrated sediment inventories of Pu-239 which range from 0-65% of the estimated fallout delivery of 2-2.1 mCi/km^2 to the lake.

The guts and liver portions of lake fish exhibit significantly higher plutonium concentrations than the meat, bones and roe, although levels are generally less than 1 dpm per kg wet weight, a figure comparable to the mean 1973 Pu-239 concentration in algae from the eastern end of the lake but 30 times greater than the mean 1973 plankton concentration. Noticeably higher Pu-239 levels have been detected in several bottom-feeding fish.

Initial analyses of the top few centimeters of 1972 cores for Am-241 have indicated the presence of the Pu-241 daughter at levels, varying with location, of 15-30% of the corresponding Pu-239 concentration. Further investigations will determine the significance of the interesting variations (0.06-0.20) of the Am-241/Pu-239 ratio observed in the few algae samples thus far analyzed.

CHEMICAL POLLUTANTS

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

We have continued to investigate the responses of open-ocean microorganisms to chemical pollutants. To date, large numbers of samples of bacteria have been collected from the North Atlantic (*Chain* 105), The Sargasso Sea (*Chain* 111) and Mid-Atlantic and Caribbean Sea (*Atlantis II* 78). These isolates are currently being tested in the laboratory for their sensitivity to PCB and DDT, and in some cases, their ability to concentrate these pollutants within the cell.

For approximately one year, Nicholas Fisher, a doctoral candidate at Stony Brook, was with us examining the growth responses of phytoplankton algae in pure and mixed culture, when exposed to environmental levels of PCB. One of his findings was that the toxicity of PCB to *Thalassiosira pseudonana* was greatest when this diatom was in competition with other species.

A good deal of time this year has been spent attempting to culture Acantharia. We feel that we are a good deal closer to accomplishing this; at present, some live culture has been maintained for over 1½ months. We have also been examining the ultrastructure of large numbers of Acantharia isolated from different areas of the Atlantic Ocean and comparing what we see with the *in situ* levels of pollutants to determine if any morphological effects are occurring.

LEAD-210 AND POLONIUM-210 IN SEAWATER

Michael Bacon, Derek W. Spencer and Peter G. Brewer

A program for measuring Pb-210 and Po-210, naturally occurring radioisotopes of the U-238 series, was begun. Both nuclides are known to be concentrated by marine particulate matter and study of their distribution promises to be a useful tool in understanding scavenging and transport by particles, processes believed to be important in controlling the concentration of a number of trace metals in seawater.

Particulate matter is sampled by pumping 50-100 liters of seawater through large-diameter, 0.4μ Nucleopore filters. Approximately 20 liters of filtered water is saved. After acidification and spiking with Po-208 and stable Pb tracers, the water samples are treated with ammonium pyrrolidine dithiocarbamate (APDC), and the insoluble metal complexes are removed by filtering through Millipore® filters. The filters are then destroyed by oxidation and the ash dissolved in 2N HCl from which Po is removed by spontaneous deposition on silver discs and counted in an alpha-spectrometer. After a period of several months, when measurable quantities of Po-210 have been regenerated from the decay of Pb-210, deposition and counting are repeated. Thus, both nuclides are

determined by alpha-counting of Po-210. Chemical yields are monitored by measuring the recovery of the added tracers. Particulate samples are spiked during the wet oxidation process and then treated in the same fashion.

During Cruise 32 of F/S *Meteor* in November and December, at the invitation of Dr. K. O. Munnich of Heidelberg, approximately 150 samples from nine stations in the tropical and northeastern Atlantic were collected. Extractions of the water samples were carried out on board and the filters returned to Woods Hole. In addition, about 55 samples were collected from the Cariaco Trench and the Venezuela Basin during Cruise A-II-79 of R/V *Atlantis II* in December, and further sampling is being conducted on the Pacific GEOSECS expedition.

Our laboratory is now equipped with four alpha-counting systems, and an additional two have been purchased.

SEA WATER CHEMISTRY

THE GEOCHEMICAL OCEAN SECTION STUDY

Derek W. Spencer

The Geochemical Ocean Section Study (GEOSECS) program has continued as planned. The Atlantic Cruise aboard the R/V *Knorr* was completed in April, 1973 and the Pacific Cruise aboard the R/V *Melville* started in August, 1973 and is due to be completed in April, 1974. The cruise tracks of the R/V *Knorr* and *Melville* are given in Fig.1.

One of the many objectives of GEOSECS is to produce a set of high quality hydrographic oxygen and nutrient data for each of the major oceans. The extent to which this has been accomplished for the Atlantic Ocean can now be assessed.

Throughout the cruises, we have attempted to determine the precision and accuracy of individual analysis using three approaches:

1) by replicate sampling at a single depth,

2) by assuming adiabatic deep water to be well-mixed for all salinity, oxygen and nutrients,

3) by repeat occupation of particular station locations.

During Legs 1, 2, and 6 of the Atlantic Cruise, duplicate samples were taken at the same depth. The analysts, unaware of this duplication, ran the samples as part of their normal routine. If one assumes that the error is independent of the concentration level of a constituent, then the mean difference of the duplicated samples should be zero and the standard deviation of the mean difference should be a measure of the overall sampling and analytical error.

Table 1 shows the standard deviation of the mean differences of the various constituents, expressed as a percentage of the medium range, in columns one and two. These are compared with the coefficients of variation of three replicates at a single depth at Station 4, six replicates at

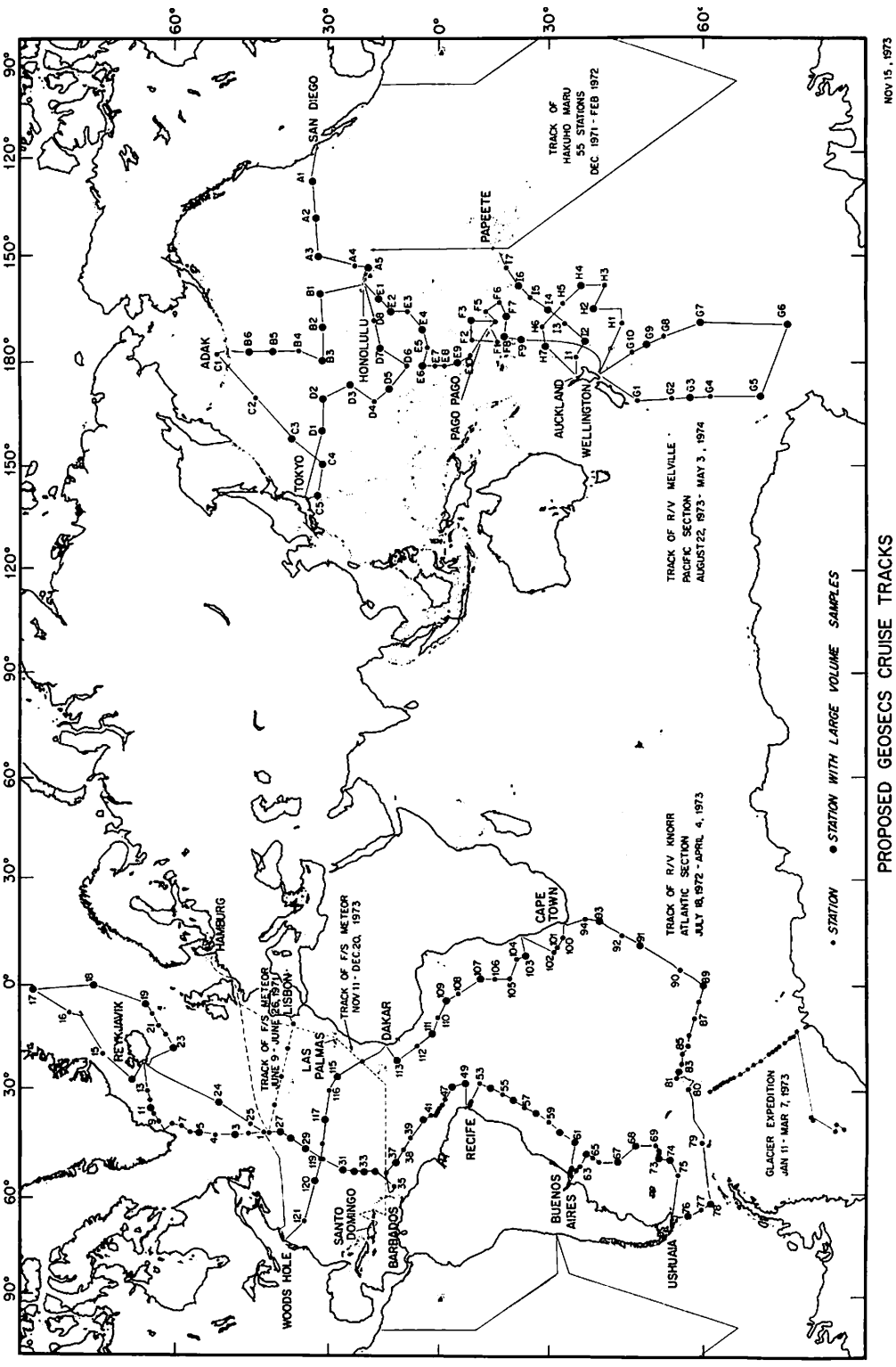

Fig.1 (Spencer)

Table 1.

COMPARISON OF PRECISION ESTIMATES

PROPERTY	MEAN DIFFERENCE LEGS 1&2 (18)	MEAN DIFFERENCE LEG 6 (21)	REPLICATE SAMPLES STA 4 (3)	REPLICATE SAMPLES STA 26 (5)	BOTTOM WATER STA 19 (17)	ROOT MEAN SQUARE
SALINITY*	0.0035	0.0014	0.0016	0.0017	0.0021	0.0023
OXYGEN**	0.2	0.4	0	0.15	0.14	0.25
SILICATE**	0.6	0.4	0	0.9	0.6	0.56
PHOSPHATE**	0.5	0.7	0.1	0.1	0.8	0.73
NITRATE**	0.6	0.3	0.7	0.7	0.8	0.60

*Data in $^{o}/_{oo}$

**Data in % STD.DEV./MED.RANGE for mean difference.
coeff.of variation for replicate samples and bottom water.

Station 26 and the coefficients of variation of 17 samples from the adiabatic deep water at Station 19 in the Norwegian Sea. The root mean square of these estimates is given in column 6 and it is evident that all of these properties have been determined with a precision equal to the best that can be supplied by modern techniques.

Reoccupation of three station locations throughout the Atlantic reveals variations that are in excess of those given in Table 1 by factors of 1.5 to 2 due to the effect of different operations and standards but such precision is still excellent and this result implies that calibration has been well-maintained throughout the whole nine-month cruise.

ANALYSIS OF OCEAN PARTICULATE MATTER

Derek W. Spencer and Peter G. Brewer

Recently, we have cooperated with Dr. Michael Bender of the University of Rhode Island to perform some neutron activation analyses of short-lived radioisotopes in ocean suspended matter. By irradiating samples that we had previously analyzed, it has been possible to extend the number of elements determined on each sample. We have found that a ten-minute cooling period and 800 second count gives us identifiable and useable gamma ray peaks on Ba^{139}, Ti^{51}, Sr^{87m}, Mn^{56}, Cu^{66}, Na^{24}, V^{52}, Cl^{38}, Al^{28}, and Ca^{47} and samples that we have previously measured the concentrations of Mn, Ra, Au, Mg, Cu, Sb, Sc, Fe, Ag and Co. The samples and standards are irradiated separately and the previously determined Mn used as a flux monitor. At this time, we have completed analysis of two stations in the South Atlantic, #1766 and #1768 from Cruise #60 of the R/V *Atlantis II*. The stations are located at 35°01'S; 44°55'W and 33°00'S; 34°33'W, respectively. The addition of Al and Ca to the list of elements is particularly important because they are major elements contained respectively in the detrital terrigenous clays and biogenic carbonate fraction of ocean suspended matter.

From a study of the intercorrelations of the elements, our data suggests that three phases are most important in controlling the distribution of the suspended elements:

a) Detrital clays which contain almost all the particulate Al and Sc and much of the particulate Ti, Mn, V, Ba, Fe and Co, and some of the particulate Cu, Mg, Cn, Zn, Sb, Sr, Ba and Ca.

b) Biogenic material containing most of the particulate Ca and Sr and some of the particulate Cu, Mg, Cn, Zn, Sb, Ba and Mg.

c) A possible hydroxide phase containing some of the particulate Fe, Co, Mn, V, Ti and La.

DEEP WATER WARMING IN THE CARIACO TRENCH

Peter G. Brewer

Examination of available potential temperature measurements in the bottom water of the Cariaco Trench, from 1954 to 1973, show that a temperature increase of 0.087°C, from 16.683 to 16.770°C, has occurred with no corresponding change in salinity.

The source of the heat is unknown, though there are three possibilities: (1) advection of warmer water, (2) diffusion of solar heat, and (3) geochemical heating. None of these explanations is immediately attractive. It is unlikely that the deep water is being replaced by warmer, more saline water from outside the trench, since water of this required salinity is not observed below 500 meters depth. The downward diffusion of solar heat from the surface is also improbable, since any "salt fingering" mechanism which might be operating would allow a net downward transport of salt, but not heat. Finally, an estimate of the required geothermal heat flow from the underlying sediments (15.4μcal $cm^{-2}sec^{-1}$) is very much higher than existing heat flow data for the Caribbean (1-2μcal $cm^{-2}sec^{-1}$).

The warming of the deep water has resulted in a density decrease of $0.0209\sigma_\theta$ units in 19.7 years (Fig.1). If this trend were to continue linearly, the deep water density would approach that of the water at the oxygen-sulfide interface in ~50 years and equal that at sill depth in ~150 years. The resulting instability could cause overturn of the anoxic waters. The residence time of the deep water is estimated to be about 100 years (Deuser, 1973). The similarity between the calculated residence times and the time scale of the deduced density instability suggests that deep water warming may be an important factor causing flushing of the basin.

(Fig.1 on Page C-34)

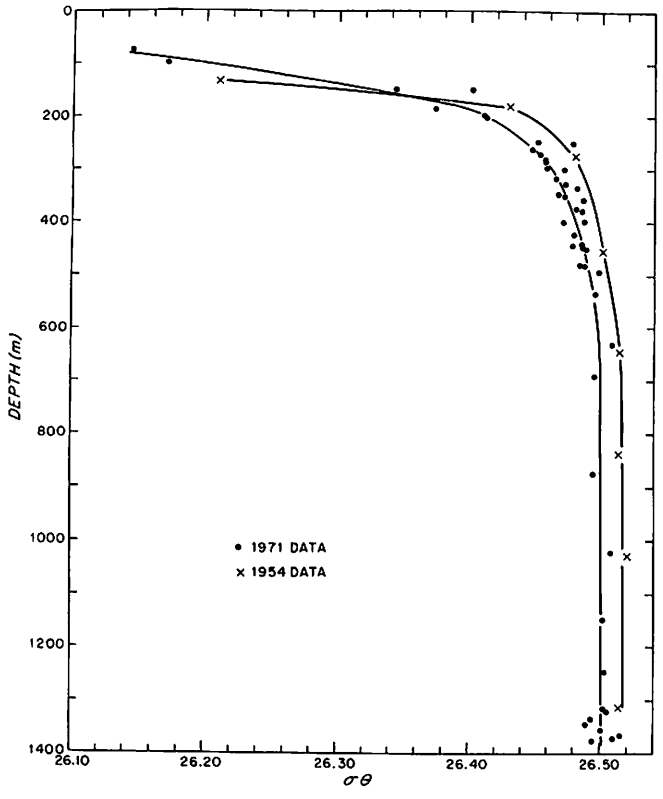

Fig.1 (Brewer) Potential density (σ_θ) of the deep water of the Cariaco Trench showing change in density between 1954 and 1971.

SULFUR CHEMISTRY IN THE CARIACO TRENCH

Nelson M. Frew

The oxidation of sulfide in anoxic basins by chemical and biological processes upon mixing with oxygenated waters is apparently rapid relative to mixing times. Coesistence of oxygen and sulfide in marine waters is difficult to demonstrate with present analytical methods, and depth profiles of these species characteristically show sharp opposing gradients approaching zero within a few tens of meters of the interface.

The chemical oxidation of sulfide is known to proceed via a number of reduced intermediates, including elemental sulfur, polysulfides, thiosulfate, polythionates and sulfite. Since many of these intermediates are metastable, it is suggested that they may be useful as tracers of mixing processes at the oxic-anoxic boundary of anoxic basins.

During a recent cruise to the Cariaco Trench (R/V *Atlantis II* - 79), observations of the depth distributions of HS^-, $S_2O_3^=$ (including polythionates), and $SO_3^=$ were made at stations in both the eastern and western basins of the trench. The data indicate that the total transport of reduced sulfur species other than sulfide to the interface is but a small fraction (< 5%) of the sulfide flux itself.

Hydrogen sulfide concentrations (Fig.1) were similar to levels found on previous cruises, increasing smoothly from the oxygen-zero boundary at about 300 meters to a maximum of 35μM in

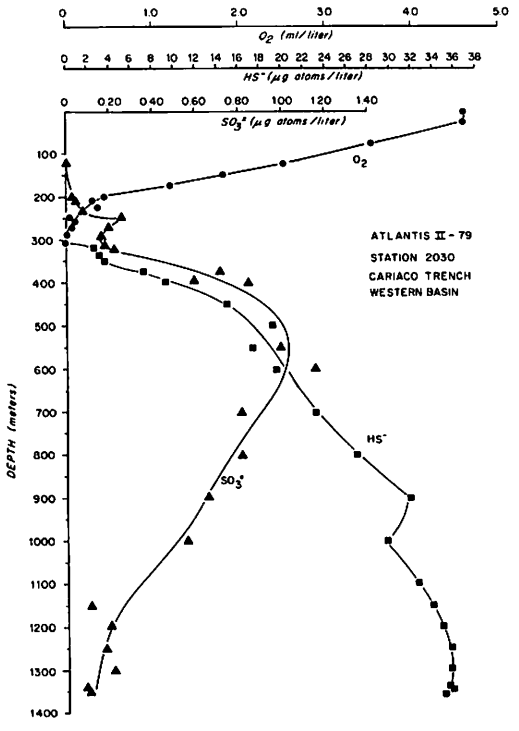

Fig.1 (Frew) Vertical profiles of oxygen, sulfide and sulfite in the western basin of the Cariaco Trench.

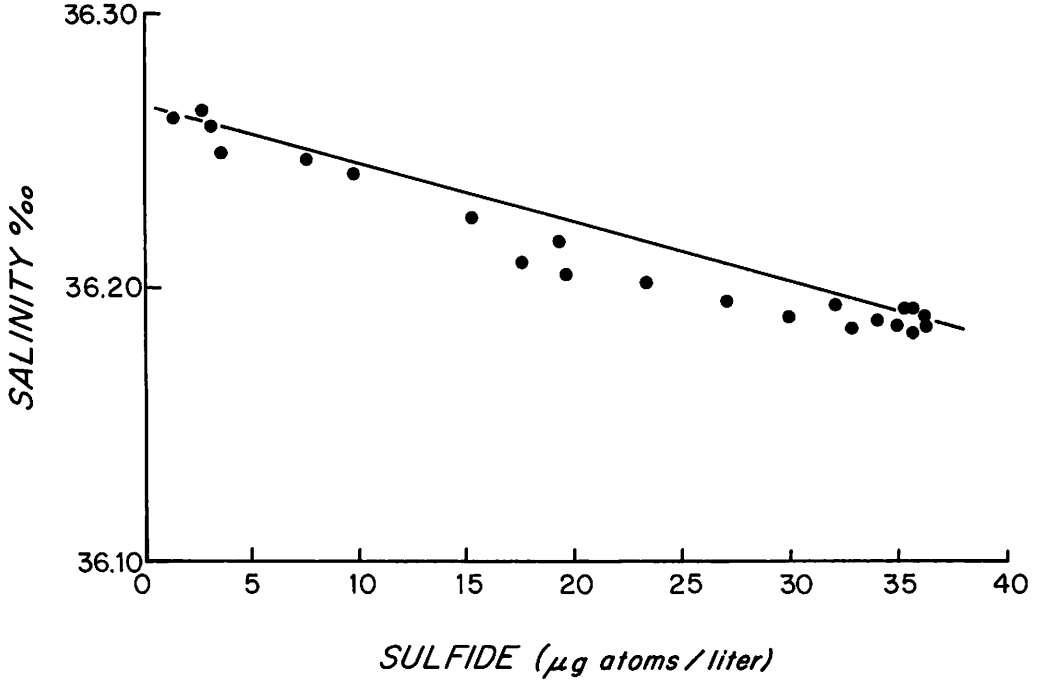

Fig.2 (Frew) Sulfide concentration versus salinity for Station 2030 in the Cariaco Trench.

the bottom waters of the trench. A plot of sulfide versus salinity (Fig.2), however, indicates an apparent consumption of sulfide in the deeper water. Thiosulfate and polythionates, known to be important microbiological intermediates, were not detected at any of the stations at concentrations above 2μM (analytical sensitivity). Significant concentrations of sulfite (0.2 - 1.2μg-atoms lit^{-1}) were found at all depths below the oxygen-zero boundary. A broad sulfite maximum at 550 meters is apparent in Fig.1. This feature is repeated at other stations in the trench and corresponds roughly to the depth interval over which sulfide is found to be non-conservative.

The production of sulfite in the water column well below the interface may be related to downward mixing of oxygenated water or to microbiological activity; either possibility is difficult to accept, however. The former case requires that warmer, more saline water (>36.2%) replaces the deep water, a mechanism which is not supported by the hydrographic data, and the latter would require that sulfide oxidation take place anaerobically and in the absence of light in the deeper waters of the trench.

LIGHT IN THE SEA

Oliver C. Zafiriou

As reported last year, we are exploring the natural photochemistry of the oceans. Progress this year falls into three categories:

(1) Light Absorbers

Calculational techniques for modeling the rate at which a given substance absorbs photons in seawater have been developed for two special cases: (a) the absorber is affected only in a thin layer at the sea surface, and (b) the absorber competes with all other absorbers in the water column for light. Case (a) is also applicable to the marine atmosphere, as presented below (Halogen Photochemistry in Marine Atmospheres").

(2) Identification of Significant Photochemical Reactions

Using the methods in (1), the information in the literature about seawater composition, and the relevant photochemical literature, we have shown that the solar photolysis of nitrate and nitrite occurs at a significant rate in surface waters in the tropics. For nitrate, the process is limited to the upper few meters, but nitrite may be photolyzed at significant rates down to at least 25 meters.

(3) Effects of Photochemistry in Seawater

Both the nitrate and nitrite photolysis produce the extraordinarily reactive radical O^-. We have been using the technique of flash photolysis-kinetic spectroscopy to assess the effects of this product in seawater. The work is in progress, but we have observed the formation of a light-absorbing transient in seawater on a microsecond time scale, and its subsequent decay on a millisecond scale. Significantly, the decay is faster in real seawater than in simple salt solutions or even relatively complete "artificial seawater" mixtures. We are currently designing tests of the hypothesis that this transient is a free radical which disappears by reacting with the dissolved organic matter in seawater.

HALOGEN PHOTOCHEMISTRY IN MARINE ATMOSPHERES

Oliver C. Zafiriou

The halogen gases Br_2 and I_2 appear to be lost from salt spray particles into the marine atmosphere, (Moyers and Duce, 1972); iodine in the marine atmosphere is unexpectedly abundant. We have not shown that the halogen gases are rapidly dissociated to free atoms by sunlight. For iodine, this process will be faster than any other in daytime, and the resulting I atoms will react with ozone to yield IO. The ultimate fate of IO is unclear, but it reacts rapidly with CO to yield CO_2 and I again. The net result of these processes is that I catalyzes the reaction

$$CO + O_3 = CO_2 + O_2 \ .$$

References

Moyers, J.L. and R.A.Duce 1972 Gaseous bromine in the Hawaiian marine atmosphere, *J.Geophys.Res.* 77: 5330-5338.

Moyers, J.L. and R.A.Duce 1972 Gaseous and particulate iodine in the marine atmosphere, *J.Geophys. Res.* 77: 5229-5238.

CHEMISTRY AND PHOTOCHEMISTRY OF THIAMINE IN SEAWATER

Oliver C. Zafiriou and Mary L. Bannister

Many marine algae cannot synthesize their own thiamine and must obtain it from seawater. Nevertheless, thiamine is chemically (Gold, Roels and Bank, 1966; Gold, 1968) and photochemically (Carlucci, *et al.*, 1969) unstable in seawater. In this study, we show that the chemical decomposition of thiamine in seawater appears to occur in two stages:

(1) Thiamine + OH^- $\leftrightarrows$ Adduct (Slow)

(2) Adduct + Trace metal $\rightarrow$ Decomposition Product (Fast)

The slowness of the first step may explain why thiamine decomposes at similar rates in waters from different areas and why added copper (known to catalyze thiamine decomposition) does not accelerate the reaction.

Preliminary results suggest that the reaction described above is faster than photochemical decomposition of thiamine by sunlight.

References

Gold, Roels and Bank 1966 Temperature dependent destruction of thiamine in seawater. *Limnol. & Oceanog.* 11: 410-412.

Gold, K. 1968 Some factors affecting the stability of thiamine. *Limnol. 7 Oceanog.* 13: 185-188.

Carlucci, A.F., S.B.Silbernagel, and P.M.McNally 1969 Influence of temperature and solar radiation on the persistence of Vitamin B_{12}, thiamine, and biotin in seawater. *J.Phycol.* 5: 302-305.

GEOCHEMISTRY OF METHYL IODIDE

Oliver C. Zafiriou and Charles L. Angevine

Using an ultrasensitive technique, Lovelock *et al.*,(1973) reports that CH_3I is detectable in both seawater and marine air. About 4 x 10^{10} g/yr of methyl iodide seems to be produced by marine organisms and evaporated into the atmosphere.

In this investigation, we determined that methyl iodide reacts with seawater about as fast as it can escape to the atmosphere, the reaction: $CH_3I + Cl^- = CH_3Cl + I^-$ having a half-life of about a month at 19°C. This is one of the few known chemical reactions of chloride ion in seawater. Some CH_3Cl is expected to escape to the atmosphere, and some is hydrolyzed to methanol: $CH_3Cl + H_2O = CH_3OH + Cl^-$; half-life at 20°$\sim$ 2.5 yr.

Reference

Lovelock, J.E. and R.J.Maggs 1973 Halogenated hydrocarbons in and over the Atlantic, *Nature* 241: 194-196.

DIFFERENCE CHROMATOGRAPHY OF SEA WATER

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

During the past year, our studies of major ion composition variations in sea water have been especially directed toward the effects on sea water of sediment interactions both *in situ* and in the laboratory. The successful development of the "Harpoon" *in situ* sampler for collecting interstitial water from marine sediments has provided us with a new source of samples having conspicuous and significant composition differences from ordinary pelagic sea water. Initial results of analyses of North Atlantic pore water samples, collected on *Chain* Cruise 106 in 1972, were reported in *Science* in July (Sayles, Wilson, Hume and Mangelsdorf, 1973).

New kinds of samples have also meant new analytical problems: pore waters from sediments frequently contain detectable NH_4^+ ion. With the cation-exchange columns we have been using, NH_4^+ produces a peak indistinguishable from the chromatographic difference peak which is most sensitive for variations in the Mg^{++}/Na^+ ratio. Also found in reducing sediments are exceptional variations in anion composition -- SO_4^+ depletion, HCO_3^- enrichment -- such that cation activity coefficients are significantly altered. Since the initial response of the cation Difference Chromatograph is to change in cation activity, such anion effects have had to be eliminated before absolute composition variations could be measured. (For diffusion processes in sediments, it is activity gradients that matter, not concentration gradients, but absolute concentrations are still useful to know.)

We have found that the NH_4^+ interference can be eliminated by using a chelating resin loaded with cupric ion. A small volume of this resin ahead of the regular cation resin delays the NH_4^+ peak enough to put it in a part of the chromatogram where it no longer interferes. Alternatively, a larger column consisting entirely of this Cu-Chelex will also permit analysis of the major cations giving better Mg/Na sensitivity than previously possible, but with such a column, the NH_4^+ signal

is so long delayed that it becomes undetectable. Ideally, we would prefer to retain the NH_4^+ response, even though, at ±0.02 meq/liter, it is about an order of magnitude less sensitive than standard colorimetric analysis.

To get around the anion effects on cation activities, we have devised a dual column chromatograph in which the effluent emerging in the first peak from a long anion exchange column is automatically collected and injected as sample into a cation exchange column for cation analysis. According to the theory of Difference Chromatography, the first peak out of a column includes all the solution composition variations which do not affect the composition of the column. This means, to a good approximation, that the first peak out of the anion column contains all the cation variations from our standard sea water stream and none of the anion variations (except, of course, total anion normality), so that the subsequent cation analysis is practically independent of the original anion mixture. Although this procedure is more complicated and more time-consuming than our earlier straightforward cation analysis, it is also more rewarding. The residual peaks from the anion column appear to provide enough information to give a complete major anion analysis of the same original sample, thus doubling the information output of the method.

In initial tests of this dual-column sample-splitting method, we were able to produce cation analyses of pore waters from Buzzards Bay sediments that agreed well with analyses obtained by Atomic Absorption, even in cases where SO_4^+ was almost completely replaced by HCO_3^-. Further work with such samples is in progress.

During the summer, samples of sediments and sediment pore waters from the North River estuary system were collected and analyzed. The sediment samples were tested for exchangeable ions and for total exchange capacity, making use of our new capability for measuring NH_4^+. These results are now being worked up by Mr. Randall Barba for a term thesis in geology at Princeton University.

Studies are also underway on a variety of fluvial sediments to find how the exchange capacity and the exchangeable ion complement of a sediment determine its reactions with sea water when it reaches the ocean.

Until now, Difference Chromatography has been used only to find changes in the ratios of major ions to one another, since for ordinary sea water, the changes in total salinity are so readily determined by conventional methods. With pore water samples having anion compositions grossly different from that of sea water, it has become necessary to determine total cation content in some other way. When an anion exchange column and cation exchange column are connected in series, the first sample peak to emerge measures, in principle, only the normality difference between the sample and our standard sea water stream. Preliminary experiments have confirmed this prediction for a variety of electrolyte sample solutions quite unlike sea water (NH_4NO_3, for example). However, we find, not surprisingly, that weak acids have an apparent normality somewhat less than stoichiometric, and we have not yet worked out to our own satisfaction whether, or to what extent, this apparent normality reduction might also result from other forms of association, such as "ion-pairing", or

simply from some general reduction of ionic activity coefficients. Meanwhile, we have a tentative sensitivity for normality difference from our standard amounting to about 1% of the difference at large differences, cutting off at about one part in 10^5 as a lower limit.

LEAD IN SEA WATER

Nelson M. Frew

During the past year we have continued efforts to develop accurate, workable methods for measurements of lead in sea water. Natural lead levels are extremely low (< 50 ng/kg) and a major effort has been directed toward eliminating laboratory sources of contamination during processing of samples. In cooperation with C. C. Patterson at the California Institute of Technology, we have analyzed samples of high purity water and coastal sea water, whose lead contents were standardized by the CIT laboratory using isotope dilution mass spectrometry; results of these intercalibrations have led to a number of refinements in our clean laboratory techniques.

Concurrent with the intercalibration study, we have made lead measurements of samples from the GEOSECS Program, because of convenient access and wide geographical coverage. Partial profiles from two stations in the North Atlantic (Fig.1) indicate strong depth gradients, decreasing from 150 ng Pb/kg near the surface to about 35 ng Pb/kg at 2,000 meters. These deep water lead concentrations are comparable to earlier measurements by Chow and Patterson (1966) near Bermuda, but

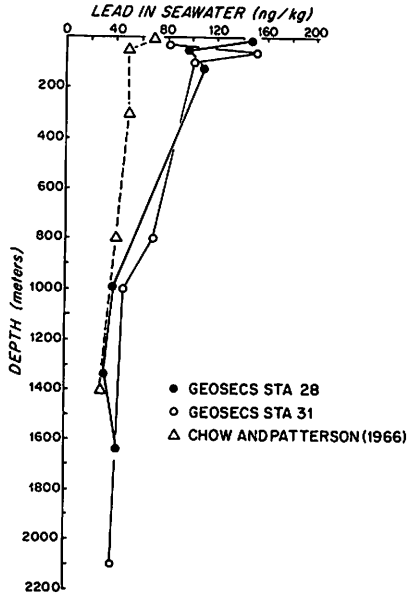

Fig.1 (Frew) Lead concentrations at GEOSECS Stations 28 and 31 in the North Atlantic.

surface concentrations are about twice as high, which may indicate that the atmospheric input of lead has increased the burden of open ocean surface waters considerably since 1966. A simple box model calculation based on an atmospheric dry deposition rate of 10^{-14} g Pb/cm/sec shows that such an increase would require only about

Reference

Chow, T.J. and C.C.Patterson 1966 Concentration profiles of barium and lead in Atlantic waters off Bermuda. *Earth Planet Sci.Lett.*, 1: 397-400.

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

James R. Heirtzler, Department Chairman

EASTERN ATLANTIC CONTINENTAL MARGIN

Kenneth O. Emery and Elazar Uchupi

During 1973 the second 5.5-month cruise of R/V *Atlantis II* completed the shipboard work between western Africa and the Mid-Atlantic Ridge for the Eastern Atlantic Continental Margin program of the International Decade of Ocean Exploration (Fig.1). The total 11 months (for both 1972 and 1973) permitted the completion of about 95,000 line km of 3.5-kHz bathymetry, gravity, and magnetic profiles, 68,000 line km of continuous seismic reflection profiles, 276 radiosonobuoys for seismic refractions and low-angle reflections, and 1534 samples of suspended matter with surface temperatures, and salinities, and less frequent associated measurements of water color, XBTs, winds, swells, phytoplankton, zooplankton, birds, and bottom samples.

Many results became evident aboard ship during the construction of maps that show regional variations in gravity anomalies, magnetic anomalies, depths to structural discontinuities, and thicknesses of sediment between the major acoustic reflection horizons. Some modifications and improvements to these maps occur through the later addition of data from radiosonobuoys, records from traverses of

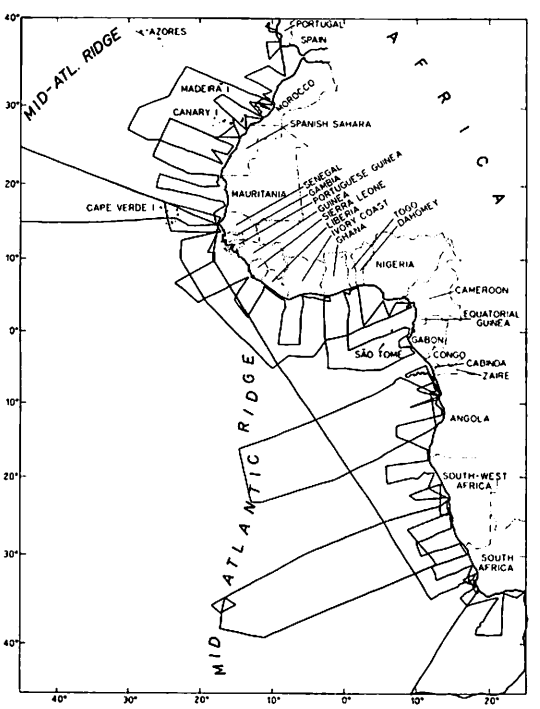

Fig.1 (Emery and Uchupi) Geophysical traverses completed during 1972 and 1973 as part of the International Decade of Ocean Exploration.

other ships, and further considerations of regional geology. Because the mass of data is so large we decided to concentrate in turn upon four sections of the Eastern Atlantic Continental Margin and to prepare each in turn for publication. The first section to be completed and submitted for publication is that off southeastern Africa, where the main structural features are the Agulhas Fracture Zone, the ancient Orange River delta, and the Walvis Ridge. In this latitude the date of separation between Africa and South America was found to be about 165 m.y. ago on the basis of dated magnetic anomalies, dated magnetic smooth zones, and general land geology. Most of the sediment atop the continental margin was deposited during the Mesozoic Era; the lesser amount deposited during the Cenozoic is attributed to possible change of climate of the region.

In addition to the results related to the origin and history of the continental margin, much new information was obtained about potential economic resources of this sea-floor region. For example, Fig.2 shows the presence of large basins containing more than 4 km thickness of sediments in the St. Francis Basin (south of South Africa), off the mouth of the Orange River (west of South Africa),

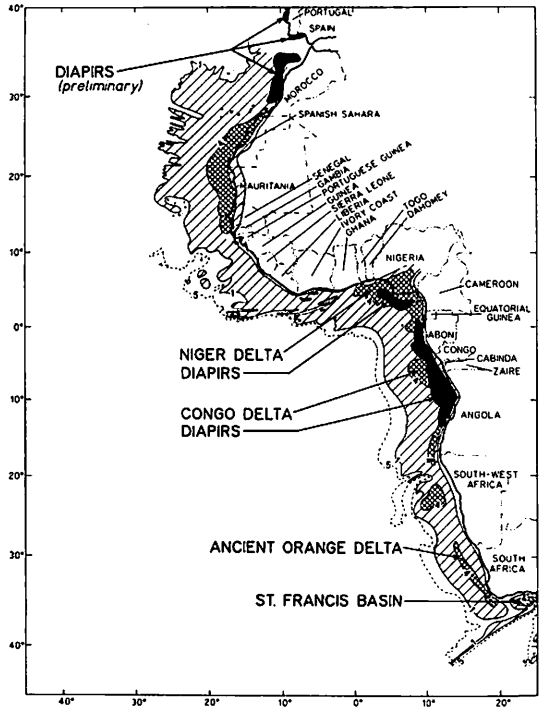

Fig.2 (Emery and Uchupi) Thickness of total sediments (in km) and distribution of salt diapirs off Western Africa (black) mapped during 1972 and 1973.

adjoining Walvis Ridge (west of South-West Africa), in a belt associated with the Congo and Niger Rivers (off Angola, Zaire, Cabinda, Congo, Gabon, Equatorial Africa, Cameroon, Nigeria, Dahomey, Togo, and Ghana), and in a belt along northwestern Africa (off Senegal, Gambia, Mauritania, and Spanish Sahara). Sediments not only are thick, but they contain many structural features suitable for oil and gas traps, and their positions off major rivers suggest a high content of organic matter, the starting substance for petroleum. In addition, the work outlined three belts of diapiric structures similar to those in and near the Gulf of Mexico. One belt is off Angola, Zaire, Cabinda, Congo, and Gabon and parts of it extend onshore where they are the sites of all the oil that is produced from these countries. Another is off Nigeria, and the third is off Morocco (with possible extensions off Spain and Portugal), from none of which is oil presently being produced. All of the diapir belts and all of the sediment-filled basins occur partly beneath the continental shelf (and thus are capable of early production after the completion of more detailed geophysical surveys), but most of their areas lie in deeper waters and probably are incapable of production for a decade or two.

One of the objectives of the International Decade Ocean Exploration (I.D.O.E.) is the transfer of technology and knowledge to developing nations, and so every effort was made during six to eighteen months prior to the cruises to interest and invite participants from black African governments of the west coast. Only two countries were not contacted (Togo and Gambia), but only because of their very small size, probable lack of interest, and our lack of contacts within them. The final list of actual shipboard representatives is as follows:

AFRICA (19 people)

Congo: 1
Ghana: 6
Senegal: 1
South Africa and South-West Africa: 11

EUROPE (13 people)

England: 3
France: 3
Germany: 2
Israel: 1
Portugal: 2
Spain: 2

SOUTH AMERICA, CENTRAL AMERICA, CARIBBEAN (9 people)

Argentina: 1
Brazil: 6
Guatemala: 1
Jamaica: 1

ASIA (1 person)

Taiwan: 1

NORTH AMERICA (13 people)

United States (other than Woods Hole Oceanographic Institution): 13

It is unfortunate that scientists from more African countries did not participate. In at least three instances this is attributed to various administrative difficulties within the governments. In spite of incomplete shipboard participation from west African countries, permission to work in territorial seas was received from all except two countries to which requests were directed: Dahomey and Guinea. Dahomey has only a small coastal frontage, but Guinea claims a territorial sea 130 miles wide that had to be bypassed. The Africans who participated in the cruises were interested in learning something about the geology of the west African continental margin and about the modern technology of shipboard research. They learned during the cruise the results that have potential economic benefit to their countries. On the other hand, the countries that refused permission for us to enter territorial waters learned nothing about the economic potential of their continental margins, and they do not have the technological ability to learn these potential benefits themselves. Representatives from the other, mostly industrialized, countries were aboard to compare and supplement results from their own previous cruises with the results from ours, or they wished to see the functioning of our geophysical equipment and general shipboard procedures.

MARINE GEOLOGY OF THE BRAZILIAN CONTINENTAL MARGIN

John D. Milliman, Colin P. Summerhayes, Jeffrey P. Ellis and Donald F. Koelsch

Until recently, the Brazilian continental margin has been one of the most poorly studied areas in the Atlantic Ocean. In 1972, however, a project to investigate the marine geology and oceanography of this area was initiated by the Woods Hole Oceanographic Institution and a number of Brazilian governmental organizations, companies and universities. The program was divided into two distinct phases. A nearshore phase included geological and geophysical studies on the continental shelf and upper slope, while an offshore phase would investigate primarily the outer continental margin and deep sea off Brazil.

The nearshore phase was carried out from November 15, 1972 to April 8, 1973, during which more than 35,000 km of ship track were covered on the continental shelf and upper slope aboard the R/V *Professor W. Besnard* (from the Instituto Oceanografico da Universidade de Sao Paulo) (Fig.1). Scientific operations included 3.5 kHz echo-sounding, continuous seismic profiling (CSP) with a 8-10 kilojoule sparker, towed magnetometry, collecting underway samples of the shelf and slope sediments, recording surface temperatures and salinities, and collecting surface-water suspended material. A total of 976 sediment samples, 700 suspended matter samples and 3000 temperature-salinity observations were collected during the cruise. The data samples are being analyzed at Woods Hole and in Brazil. In 1973 a total of 14 Brazilians spent nearly five man-years in Woods Hole helping to analyze and interpret the data.

For ease of data reduction and interpretation, the Brazilian continental margin has been subdivided into four distinct areas: southern Brazil (from Uruguay to Cabo Frio), southeastern Brazil (Cabo Frio to Salvador), northeastern Brazil (Salvador to Fortaleza) and northern Brazil (Fortaleza to French Guiana). For each area papers on the morphology and shallow structure, surface sediment distribution, and suspended matter and oceanography will be published, as well as papers on subjects of more local interest.

At present the northern and southeastern sections of Brazil have been studied in detail; by the end of 1974, all data collected on the nearshore cruise will have been analyzed and interpreted. An example of the type of data collected and its interpretation can be gained from a discussion of northern Brazil:

1) The magnetic character of the continental margin off northern Brazil was derived chiefly from tectonic activities prior to and during continental rifting in the Cretaceous (Fig.2). The bulk of the post-Cretaceous sedimentation has occurred within a seaward extension of the pre-Triassic Amazon Basin, although the exact mode of downwarping is not known. Apparently pre-Miocene sediment accumulation was confined to what is presently the inner and middle shelf, while post-Miocene sediments spilled over the shelf to form the Amazon Cone. Pleistocene uplift in this area has resulted in the outcropping of late Quaternary strata on the outer shelf and upper slope.

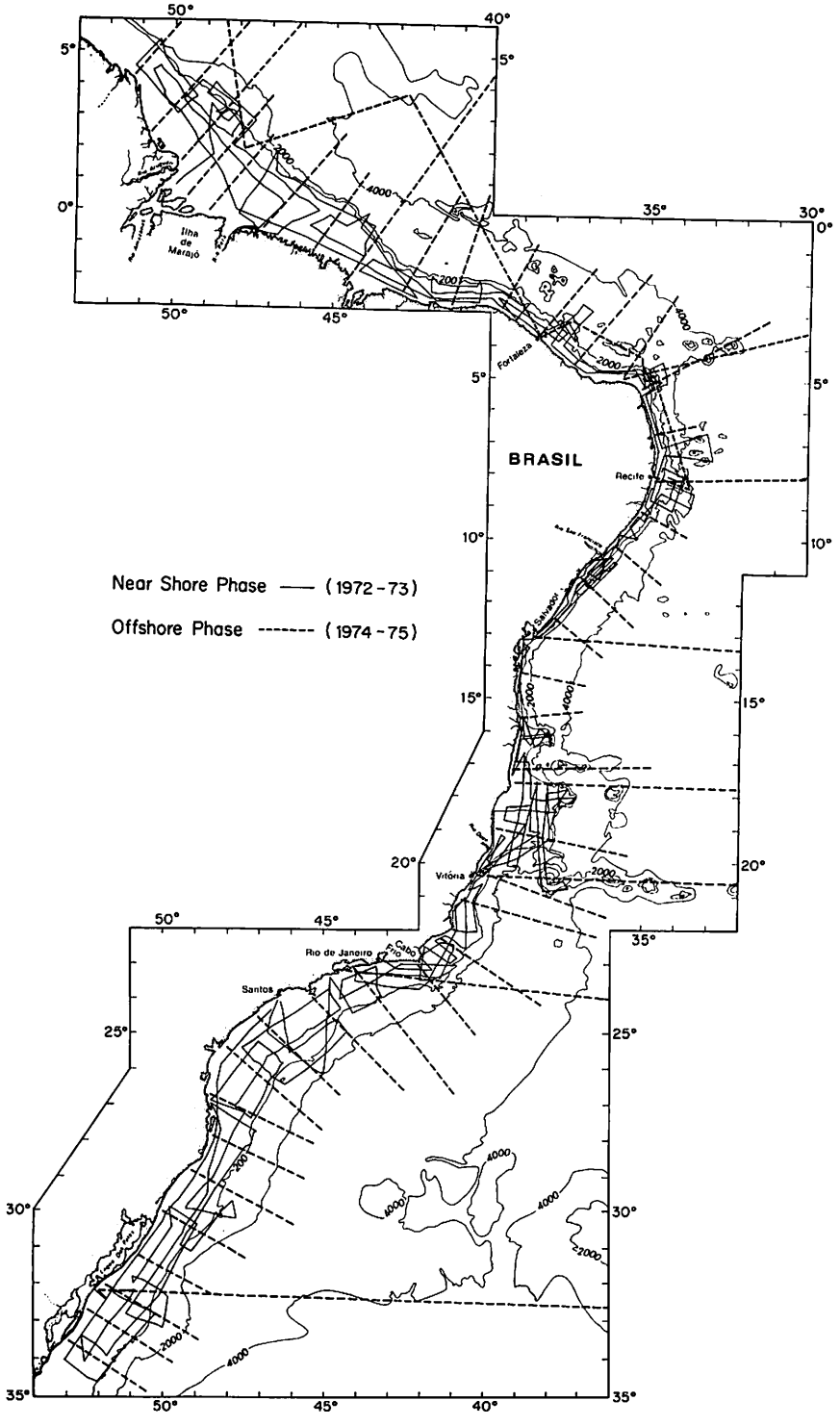

Fig.1 (Milliman *et al.*) Past and future studies on the Brazilian continental margin, showing the 1972-1973 nearshore cruise track together with the proposed cruise track for 1974-75.

Fig.2 (Milliman *et al.*) Magnetic anomaly pattern off northern Brazil. Values are gammas.

2) Suspended matter in the surface waters of the northern Brazilian continental margin is strongly controlled by the influence of the Amazon River. Terrigenous matter carried by the Amazon is deposited relatively close to shore, but large concentrations of dissolved silica within the Amazon effluent have facilitated a prolific production of diatoms which dominate the suspended matter over much of the middle shelf. Outer shelf waters are influenced by equatorial oceanic waters and as a result, contain relatively little suspended matter.

3) Surface sediments on the north Brazilian continental shelf have four major sources. The Amazon-province is characterized by sands and muds which are compositionally immature, reflecting their derivation from the Andes, via the Amazon River. In contrast, sediments on the shelf south of the Amazon are extremely mature and were derived from nearby coastal plain strata. Outer shelf sediments reflect a third source - benthonic carbonates, largely reef-forming communities; locally, carbonate components can contribute more than 95% of the outer shelf sediment. A fourth source of sediment is found on the outer Amazon shelf, where localized outcrops of uplifted Pleistocene strata have contributed both terrigenous and carbonate components to the nearby sediments.

4) Sedimentation patterns on the northern Brazilian shelf changed greatly during the late Quaternary. Sands which cover much of the shelf apparently were deposited during the last transgression of sea level five to fifteen thousand years ago. The primary site of modern sedimentation is the comparatively thick wedge of mud which extends seawards and northwest from the mouth of the Amazon River (Fig.3).

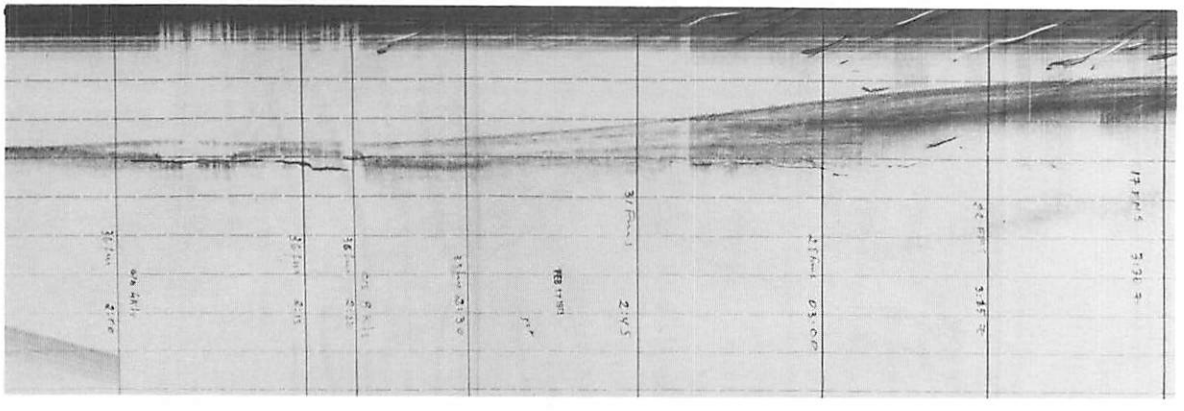

Fig.3 (Milliman *et al.*) A 3.5 kHz echo-sounding profile across the reflective relict sands on the outer Amazon shelf (left) to the transparent modern Amazon muds (right). Horizontal scale lines are 10 fathoms, time lines generally represent 15-minute intervals.

PROJECT FAMOUS

James R. Heirtzler and Susan H. Anderson

In 1971, the French American Mid-Ocean Undersea Study (FAMOUS) was initiated to make a detailed investigation of part of the Mid-Atlantic Ridge. Focusing on a section of the ridge about 300 kilometers southwest of the Azores, FAMOUS is directed at studying the unique geological processes at the ridge axis and the unique landforms that they produce. The overall plan of investigation calls for broad regional surveys to be followed by increasingly detailed surveys - the most detailed to be undertaken in research submersibles of France and the United States in the summer of 1974.

In late 1971 and early 1972 an aeromagnetic survey and initial ship surveys by the R/V *Knorr*, USNS *Hayes* and ships of NAVOCEANO (Naval Oceanographic Office) were made. The bathymetry from these surveys was combined to develop a 100-fathom contour map of the FAMOUS area. In the fall of 1972 comprehensive sampling, mapping, and bottom photography were undertaken by the *Jean Charcot* near 37°N, and similar techniques were employed by *Atlantis II* using bottom transponder navigation.

In the spring of 1973 NAVOCEANO completed a very detailed bathymetric survey over the central rift valley from about 36° to 37°N, from which a set of detailed bathymetric charts, some with a five-fathom contour interval, have been prepared. Several ships operated in the area during the summer, including the *Knorr* utilizing the Scripps Deep Tow package, the *Shackleton* using ocean bottom seismographs, the *D'Entrecasteau* doing detailed bathymetric surveying with 200-300 meter line spacing, the *Discovery* using mainly the 20-ton *Gloria* side scan system to make a side scan mosaic of the area, the *Atlantis II* studying microearthquakes with sonobuoys and bottom heat flow. In the fall, the *Hayes* was used to deploy other bottom seismographs. Later *Mizar* undertook large scale bottom photography with the new LIBEC camera system, and, on a subsequent cruise, recalled the bottom seismograph and planted ocean bottom current meters which were recalled by LYNCH early in December.

The results of these cruises are currently being analyzed and will provide a basis for details of the diving program in 1974. Catalogs of all man-made debris in the area have been prepared. The intercomparison of the various mapping, sampling, and photographic techniques will be one of the important spinoffs of this program. Preliminary results have already revealed regions of anomalous seismic activity, heat flow, rock types, and morphological characteristics.

The French submersible *Archimede* completed seven dives in the FAMOUS area in the summer of 1973, providing visual data indicating the extensive ruggedness of the topography and steepness of the rift valley walls.

Plans are being formulated for some 40 dives by the American and French in 1974. In addition to photographic coverage of the terrain from the submersibles and data logging of features seen, several bottom instruments may be deployed by the submersibles. Laboratories for processing and analyzing recovered samples, libraries of all data, and facilities for follow-up studies will be available on surface ships in the area.

DEEP TOW OPERATIONS ON THE MID-ATLANTIC RIDGE

Bruce P. Luyendyk

Between 18 May 1973 and 22 June 1973 about 22 working days were spent investigating the geophysical structure of the crest of the Mid-Atlantic Ridge in the FAMOUS area near 36°30'N. Instrumentation employed was the deeply towed fish instrument of the Marine Physical Laboratory (MPL) of the Scripps Institution of Oceanography (SIO). Besides near-bottom geophysical measurements from the fish, seismic reflection and surface magnetometer data were taken, and in addition, monitoring of microearthquake activity was made using arrays of SSQ-38A sonobuoys.

The field program was divided into two legs: Leg 1 leaving May 7 from Woods Hole Oceanographic Institution (WHOI) and arriving in Ponta Delgada (PDA) June 1; Leg 2 departing PDA June 8 and returning June 24. Leg 1 was under the direction of Bruce Luyendyk and Frederick Spiess of MPL and Leg 2 was directed by Bruce Luyendyk and John Mudie of MPL. Earthquake monitoring was conducted by Ian Reid (SIO) and Kenneth Macdonald (WHOI). The Leg 1 program concentrated on work in the rift valley and rift mountains, while Leg 2 divided work between Fracture Zone A (FZA; near 36°55'N) (Fig.1), long profiles over the northern and southern rift mountains, and extensive camera work in the rift valley (arrows in Fig.2).

Some of the results of the program are:

1. Virtually the entire relief of the rift valley and mountains is controlled by block faulting. This faulting is more striking in the western mountains where a few steeply-dipping faults have

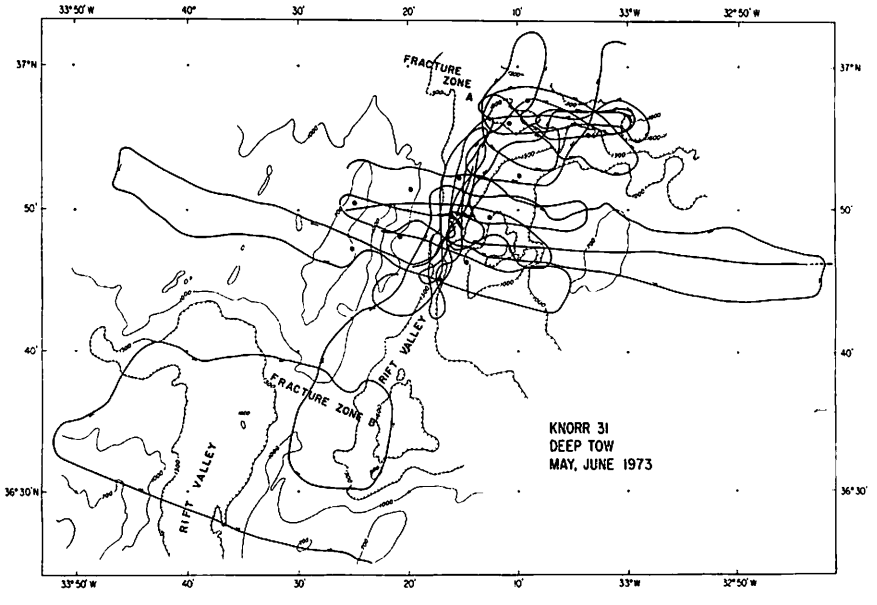

Fig.1 (Luyendyk) Tracks of the Deep Tow Fish in the FAMOUS study area.

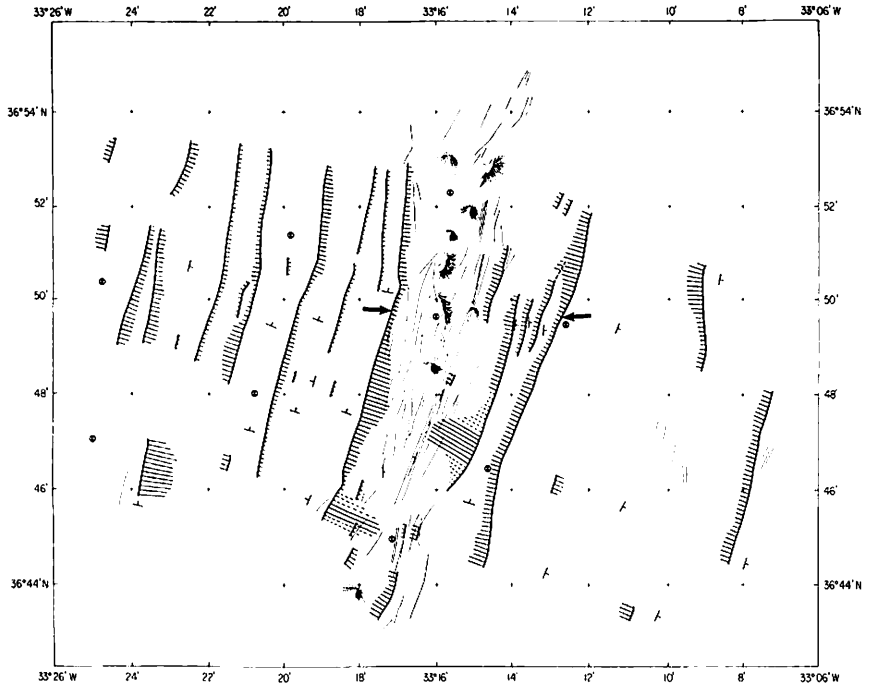

Fig.2 (Luyendyk) Physiography of the rift area, showing block faults hatchured on the down side, lineations in rift valley floor and location of rift valley photo traverse (arrows).

large throws. The apparent gentle slope of the eastern rift mountains down into the rift valley is actually a series of small-throw vertical faults. Besides upfaulting, down faulting was also observed which results in the formation of grabens away from the rift valley. The blocks of the west mountains are tilted away from the rift valley and also north towards Fracture Zone A - see Fig.2.

2. Within the rift valley it is not yet possible to define a clear intrusion zone. The floor of the valley is generally flat except for small throw step faults and volcanic cones and ridges. In the northern rift valley an apparent volcanic ridge is aligned along the valley for about five miles. A small volcanic cone just south of this ridge shows a distinct flat top. Side looking sonar coverage in the valley shows a highly reflective terrain with irregular small-scale relief together with strong lineations trending NNE parallel to the valley strike. These lineations are most apparent at the edges of the valley floor (Fig.2). In photo traverses made across the rift valley (Fig.2), sediment is virtually always seen but is thinnest at the central volcanic ridges. Flat areas appear to be terrains of pillow lavas, while the slopes of cones and ridges often appear to be composed of small angular pillow lava fragments. Photo data also show occasional step faults and open fissures - about one meter wide, trending parallel to the valley strike.

3. Studies of Fracture Zone A and Fracture Zone B indicate that the transform segments of these features are defined by steeply-dipping normal faults while the actual plate boundary is narrow

and median to the transform. Patterns of east-west and north-south normal faults in the transforms suggest a history of elevation and subsidence of the crust.

4. Near-bottom magnetometer data reveal high amplitude short wavelength anomalies over the crestal zone. Generally, these anomalies are not as lineated as the surface magnetic data appear. In addition, the transition from the normally magnetized crust of the central anomaly to the reversely magnetized crust outside of this region, is not obvious in the near-bottom data and is extremely difficult to locate. Magnetic model studies are underway now to study this. An obvious magnetic feature of the rift zone are anomalies of five to seven thousand gammas associated with the centrally located volcanic ridges and cones. Contrasting with the vague magnetic transitions in the vicinity of the rift valley, farther out on the crest mountains positively and negatively magnetized regions of Crust appear to be better defined by the near-bottom magnetometer data. We believe that we crossed anomalies 2' on the west side and out to 3' on the east side.

5. Earthquake monitoring by sonobuoys indicates about 10 shocks per day in the crestal region. Most events appear to be located near the intersections of the rift and transform faults.

6. Ancillary investigations include a long tow across the transition from the eastern crest mountains down to the high fractured plateau. These data showed the transition is a series of step faults down to the flanks, in contrast with faulting down to the rift valley in the crestal mountains.

The processing and analysis of these data are now underway with the aim of presentations at the spring 1974 American Geophysical Union meetings plus timely access of the data to the FAMOUS project. Between Legs 1 and 2 topographic data on the rift mountains and rift valley were delivered to French investigators in Ponta Delgada, Azores, in order to facilitate planning for diving operations of the *Archimede* in the FAMOUS area.

Future analysis is divided under the following responsibilities: investigation of rift mountain and rift valley data by Kenneth Macdonald (WHOI) and Bruce Luyendyk; Fracture Zone A investigations by Robert Detrick (SIO); and earthquake studies by Ian Reid (SIO) and Kenneth Macdonald. This program represents part of Ph.D. thesis work for Macdonald and Detrick.

Atlantis II Cruises 73/77

GEOPHYSICAL AND GEOLOGICAL STUDIES (FAMOUS AREA)

Joseph D. Phillips, Wilfred B. Bryan, Robert C. Spindel, Albert J. Erickson,
David L. Williams, Kenneth R. Peal, Alan H. Driscoll, Kenneth Poehls

A geophysical and geological study over the Mid-Atlantic Ridge crest near 36°30'N (FAMOUS area) was made during November 1972 and August 1973 aboard R/V *Atlantis II* (Cruises 73 and 77, respectively). The principal objectives of these cruises were to obtain (1) detailed bathymetric, magnetic and gravity information over the rift valley and the offsetting Fracture Zone B at 36°30'N; (2) four long reconnaissance gravity, magnetic and bathymetric profiles extending across the ridge crests between 31°W and 36°W; (3) detailed, acoustically navigated photographic and near-bottom topo-

graphic profiles in the rift valley floor/walls and fracture zone trough; (4) detailed, acoustically navigated heat flow and bottom water temperature profiles in sediment-covered areas and the rift axis region respectively; (5) rock sampling using acoustically navigated dredges in the rift valleys and fracture zones; (6) precise microearthquake location information in the rift valley and fracture zone region using surface sonobuoys; and (7) reconnaissance seismic refraction profiles along the rift valley axis.

Each of the above objectives have been accomplished and the following results can be reported:

(1) Detailed bathymetric, magnetic and gravity contour charts have been constructed for the region bounded by 36°46'N and 36°15'N. Radar transponder navigation, providing a one kilometer east-west line spacing has allowed 50 fathom, 100 gamma, and 10 milligal contour intervals, respectively. This information combined with the (2) four long reconnaissance profiles show the ridge crest here to be typical of other spreading segments of the Mid-Atlantic Ridge crest. The average spreading rate is about 1.2 cm/yr over the last 10 my.

A new acoustically navigated geophysical underseas survey system (ANGUS) using seafloor acoustic transponders has been developed to implement our objectives for detailed (3) photographic and near-bottom bathymetric profiling; (4) heat flow probing, and (5) rock dredging. The results of these detailed near-bottom observations show the rift valley floor to be marked by fresh, tubular "toothpaste" lava with virtually no sediment. Away from the rift axis increasingly thicker sediments and steep fault scarps are encountered. The fracture zones showed slab-like rock surfaces suggestive of severe tectonic movement. In all 18 photographic/bathymetric runs of about four hours duration each were made. A total of about 80 heat flow measurements were made in the vicinity of the intersection of Fracture Zone B with southern rift valley. These measurements showed the heat flux to increase by nearly a factor of 10 over a distance of 5-10 km on approaching the rift axis. A maximum value of the order of 12 H.F.U. was observed at the intersection. The rock dredging operations were very successful with 24 dredge hauls recovering rock, a total of nearly one ton of rocks was obtained. The results of the dredging in general confirmed the observation of the photographic profiles in that fresh pillow basalts - typical of mid-ocean ridge crests are found to floor the rift of the valley, while older manganese-encrusted basalts are found on the rift valley flanks. In Fracture Zone B typical lithologies are serpentinite, greenstone, and periodite which in some cases appear to here be brecciated as a result of local tectonism.

For the microearthquake monitoring work two approaches were developed. Aboard *Atlantis II* Cruise 73 a simple system using expendable Navy SSQ-38 somobuoys and SUS explosive charges for echo-locating the buoys was employed. For the *Atlantis II* Cruise 77 work a more precise and sensitive system which used the ANGUS seafloor acoustic transponders was employed to locate expendable Navy SSQ57 sonobuoy. These latter units are sufficiently broad-band to receive both the transponder signals and naturally occurring earthquakes. During about 150 hours of monitoring over 100 earthquakes were recorded. The precision locating scheme employed showed most earthquake activity to be concentrated on the east sides of the rift valley walls and in the troughs of Fracture Zones A and B.

For the seismic refraction work our radar navigation system allowed accurate positioning of the ship and sonobuoys over the rift valley. This was due to minimize topographic correction to the refracted arrivals. Four profiles about 15 km long were run using SUS charges and expendable Navy SSQ41 and 38 sonobuoys. The most significant result of this work was the observation of a mantle-type velocity on the order of 8.1 km/sec. 6 hr. beneath the rift valley floor between Fracture Zones A and B. Other workers have subsequently confirmed this observation.

GEOLOGY AND PETROLOGY OF FAMOUS AREA AT 36°N

Wilfred B. Bryan

The FAMOUS study area on the Mid-Atlantic Ridge (36°20'N-37°00'N) was investigated during November-December 1972 (*Atlantis II*-73) and August 1973 (*Atlantis II*-77). Detailed bathymetric, gravity, and magnetic surveys were run. A large proportion of the time was devoted to acoustically navigated station work, which included sea-floor photography, dredging, microearthquake monitoring, and on *Atlantis II*-77, heat flow.

During these cruises considerable improvements were made in the effectiveness of the dredging equipment and techniques. During the 1972 cruises there were nine successful dredge stations, although recoveries in all of these were small (under 100 lbs). During August, 1973, there were fifteen successful dredge stations, many of which recovered several hundred pounds of rock. This may be attributed to improved dredge design as well as more effective acoustic positioning.

Dredge samples, photography, and magnetic anomaly contours show that Fracture Zone B in the center of the study area has an effective width of about 20 km. Within this zone, typical lithologies are serpentinite, greenstone, and peridotite, with minor basalt. Active volcanic zones in the rift valleys both north and south of the fracture zone extend into it and connect with either end of the presently active transform fault near the north side of the fracture zone. It appears that the active transform periodically shifts north and south within the limits of the fracture zone, followed by the active zones of rift valley volcanism.

Major element analyses of pillow glasses and minerals by microprobe, and minor element analyses by Michael Rhodes and Jean-Guy Schilling on a limited selection of samples, shows that the median valley basalts are in most respects typical of other ocean ridge samples. However, they show slight enrichment in light rare earth elements and in certain other minor elements. In a separate study, Schilling has shown this effect increases toward the Azores, which may mark a "mantle plume" analogous to Iceland.

Older basalts within Fracture Zone B differ from those in the active median valley segments in that they do not show "hot spot" geochemistry, being more depleted in alkalies and related trace elements. It is tentatively concluded that they represent slices of older median valley basalts transported into the rift zones during shifts in the position of the active transform. If this interpretation is correct, the Azores mantle plume must be expanding and its influence has reached the FAMOUS area only within the last million years.

FAMOUS-LIBEC CRUISE OF U.S.N.S. *Mizar*

Joseph D. Phillips

The Light-Behind-Camera (LIBEC) photography system of the U.S.Naval Research Laboratory has been used to obtain photographs up to 200' in diameter in the FAMOUS region of the Mid-Atlantic Ridge near 36°45'N. Although the primary purpose of LIBEC is for use in search and recovery operations in support of U.S.Navy Fleet requirements, it is equally suited to scientific studies in that acoustically navigated, high resolution as well as large area photographs are afforded. Examination of a series of test photographic runs made over the scuttled *Le Baron Briggs* "gas ship" suggested that use of the LIBEC system in the FAMOUS program could make a unique contribution to scientific objectives by providing continuous mosaic-like coverage over the 1974 primary submersible diving sites. The National Science Foundation (International Decade Ocean Exploration) and the Office of Naval Research provided support for a joint Woods Hole Oceanographic Institution/National Research Laboratory cruise of the U.S.N.S. *Mizar* to the FAMOUS area to accomplish this goal. Selection of the primary dive site was made at a meeting of divers with Woods Hole and Naval Research Laboratory scientists in Woods Hole 11-13 September 1973. The site selected was located at 36°48.6'N, 33°16.0'W over a small hill and trough complex on the rift valley floor.

A total of 14 photographic lowerings (runs) were made during the period 4-15 October from U.S.N.S. *Mizar*. Each lowering was of about seven to eight hours duration, consisting of 650-680 photographs taken at a 20-30 second repetition rate. About 6,000 photographs were taken. Greater than 50% overlap was obtained for about 75% of the lowerings. Of the 14 lowerings 11 were successful. Ten of these lowerings (numbers 4-6, 8-14) were in the Primary Dive Site area (see Fig.1). The other successful lowering (#1) was in a test area three miles south of transponder "C" and is not shown in Fig.1. The unsuccessful lowerings (numbers 2, 7, and 3) failed because of two camera malfunctions and camera loss, respectively.

Chain CRUISE 115 (SOUTHLANT) LEG 1, WOODS HOLE TO DAKAR, SENEGAL: NOVEMBER - DECEMBER 1973 (Fig.1)

Elizabeth T. Bunce, John G. Sclater*, Dan P. McKenzie**

This is a coordinated geophysical, geological and geochemical attack on problems in the Equatorial and South Atlantic Oceans. The first leg was originally planned to make maximum use of time in the proposed work area - the Sierra Leone Rise. Although the impact of the energy crisis cum fuel shortage necessitated some changes in emphasis, and our oil-economical steaming meant less station time, the results of both transit and survey provided new information, some particularly relevant to the history of the Gambian Basin.

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* Massachusetts Institute of Technology

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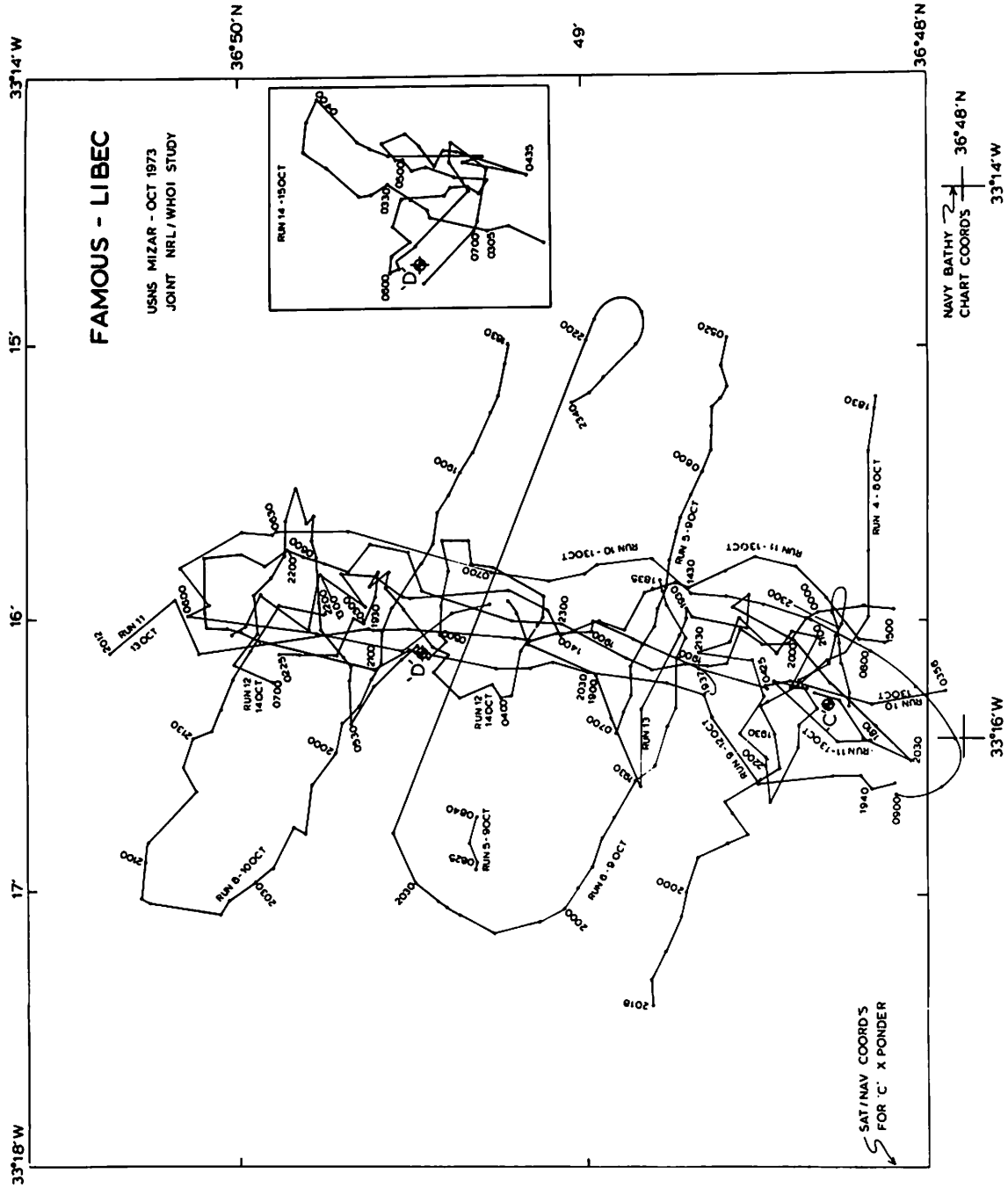

Fig.1 (Phillips)

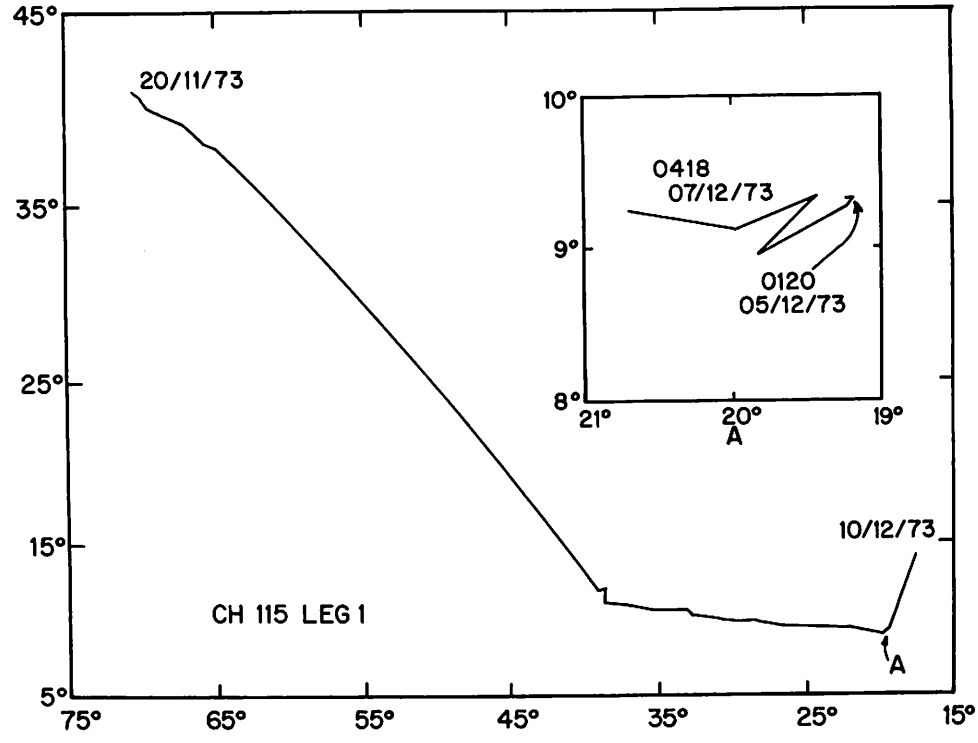

Fig.1 (Bunce, Sclater and McKenzie) Track of Leg 1, *Chain* Cruise 115 (SOUTHLANT), Woods Hole to Dakar, Senegal. Inset A - survey area, Sierra Leone Rise.

En route to the Mid-Atlantic Ridge we made a series of piston-core stations on Mytilus seamount.

The track southeast from Mytilus was planned as the shortest route to reach the point at 11°N, 39°W where we would turn east-southeast (093°), north of Vema Fracture Zone, toward the Sierra Leone Rise. Underway geophysical observations to this point had comprised 3.5 kHz bathymetry, magnetic and gravity fields measurements. This next section of track was designed to avoid the fracture zone, to obtain the optimum west-east magnetic profile and concurrently significant seismic reflection profile information for sediment distribution and basement character.

Briefly summarized: on our east-west line at 10°N we observed the Mesozoic anomalies of Roger Larson and Walter Pitman to the east of 29°W, together with, we believe, Anomaly J; closer to the ridge axis we detected, by magnetics and topography, and then traced (unwillingly until its trend was determined, a pronounced fracture zone trending N 097°E.

The productive investigation in the gap of the Sierra Leone Rise, using heat flow, piston core, and hydrographic techniques, will be described and its results presented in a paper in prèparation by Michael Hobart, John Sclater and Elizabeth Bunce.

CURRENT-CONTROLLED ABYSSAL SEDIMENTATION: SAMOAN PASSAGE EQUATORIAL WEST PACIFIC

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

A geological and geophysical study of the Samoan Passage in the west equatorial Pacific (168°-170°W; 7°-10°S) was carried out in 1971, utilizing underway seismic reflection profiles (3.5 kHz and sparker), bottom photographs, bottom current measurements, bottom water temperature profiles, and sediment cores. These data and those of previous expeditions were synthesized in this study of dynamic sedimentation processes.

Specific sedimentation processes were found to be associated with surface (12 kHz) and subsurface (3.5 kHz) morphology and composition of the sea floor: 1) parabolic echo returns, rugged topography, some local conformable subbottom penetration ($\lesssim$10 m); Process: pelagic draping of sediment, infrequent slumping (Passage walls); 2) highly reflective, smooth topography, no subbottom penetration, manganese nodules on semi-indurated sediment; Process: continued fast (20-50 cm/sec) bottom current flow causing erosion or non-deposition (Passage axis); 3) moderately reflective bottom with up to 20 meters of subbottom penetration lying over #2 above, compact unfossiliferous zeolitic and ash-rich clay containing some manganese nodules; Process: slow deposition of compact sediment from bottom currents (5-10 cm/sec), the "wind slab effect" (lee portions of Passage and in certain areas north of the Passage); 4) very weakly reflective bottom with up to 80 meters of subbottom penetration, watery abyssal brown clays interbedded with reworked and crossbedded biogenic ooze; Process: rapid accumulation of sediment from waning sediment-laden bottom currents (north of Passage).

The sedimentary record in and around the Passage indicates that relatively intense current flow through the passage was initiated at some time between the early Eocene and early Oligocene, and continued through most of the Tertiary. Lithologic data suggest significant periodic fluctuations in corrosive effects of bottom currents during the Quaternary.

NEAR-BOTTOM THERMOCLINE IN THE SAMOAN PASSAGE, WEST EQUATORIAL PACIFIC

Kenneth C. Macdonald, Charles D. Hollister

Antarctic bottom water (ABW) flows into the Pacific basin from the region between Macquarie Island and Antarctica. Dynamic considerations suggest that the bottom water flows northwards as an intense current along the western boundary of the Pacific basin. Oceanographers have noted that the Pacific is divided into at least four principal basins which are separated by relatively shallow sills that constrain the flow of water below 4,000 m. The narrow Samoan Passage, first recognized by Joseph Reid, is perhaps the most important channel with depth sufficient to allow a significant flow of bottom water from the southern basin into the central basin. Bottom current velocities in the passage of 5 to 15 cm s^{-1} towards the north have been measured and Nansen casts in the passage revealed a sharp decrease in temperature of 0.27°C in 150 m at a depth of about 4,400 m. This benthic thermocline marks the abrupt boundary between the deep water and the ABW and supports the observation of cold bottom water flow through the passage.

In the autumn of 1971, thirteen temperature profiles were taken with a thermal gradient recorder mounted on a sediment corer in and near the Samoan Passage in order to define the flow of bottom water through the area. The resistance of a precisely calibrated thermistor attached to the top of the instrument was recorded every 30 sec as the corer was lowered to and raised from the bottom. A pinger was mounted 78 m above the core weight so that a time record of the depth of the instrument could be recorded aboard ship. The temperature time data recorded on film in the heat flow instrument were then merged with the depth/time data to yield *in situ* water temperature profiles. The relative precision of the thermistor was 0.002°C and the absolute accuracy about 0.01°C. The error in depth determination was about 20 m near the bottom but could be as much as 150 m at a distance of 1.5 km above the bottom because of rapid changes in bathymetry and variations in the rate of film speed in the thermal gradient recorder. This estimate of the error in depth determination is in agreement with the magnitude of discrepancies in the temperature profiles obtained from the lowering and subsequent raising of the instrument at the same station.

A pronounced benthic thermocline was present at all eight of the new temperature profiles taken in the axis of the passage. A temperature decrease of 0.31°C (1.37°C to 1.06°C) occurs over a depth interval of about 250 m at a depth of 4200 to 4400 m. Below 4400 m there is a slight increase in temperature because of adiabatic compression. The thickness of the ABW using the 1.10°C isotherm (*in situ*) is 800-950 m in the axis of the passage. The thickness of the layer decreases near the walls of the passage in such a way that the boundary between the deep water and the bottom water (about 1.10°C) remains at a depth of about 4200-4400 m. At the northern end of the passage, the depth of the benthic thermocline increases while the thickness of the bottom water layer decreases. The benthic thermocline is not clearly present in four of the five temperature profiles taken north of the passage. The profiles do show a slight decrease in temperature and a warmer isothermal layer. The sharp boundary between the bottom and deep water may be obscured by turbulence as the water flows over the sill to the north (Peter Lonsdale, personal communication).

The temperature data suggest that the wedge of bottom water flowing northwards is narrowest and thickest in the axis of the passage. During *Chain* Cruise 100, two current meters were placed in the axis of the passage (8°15'S; 168°43'W, and 8°16'S; 168°40'W) for 139 h and 25 h, respectively, at a distance of three meters from the bottom. A mean velocity of 9.3 cm s^{-1} in a northerly direction was recorded, with a maximum velocity of 16 cm s^{-1}. Using a topographic cross section at 8°30'S, and an average velocity of 9.3 cm s^{-1}, we derive a transport of about three Sverdrup ($10^5 m^3 s^{-1}$) of cold bottom water flowing from the southern basin into the central basin of the Pacific.

North of the passage, a topographic high creates two channels, one striking northeast, the other northwest. Temperature data show a 320 m thick layer of bottom water in the axis of the northeasterly passage. A current meter placed near the east side of the channel for three days recorded a mean velocity of 2 cm s^{-1} sith a maximum of 4.9 cm s^{-1}. But the direction of flow was northeast for 1.5 days and southwest for 1.5 days, so the net flow is near zero. A more constant northerly flow may exist in the axis of the northeast channel. The lack of a sharp benthic thermocline in the four temperature profiles near the topographic high north of the passage, and the low flow through the northeasterly

channel, suggest that most of the flow (about three Sverdrup) is directed towards the northwest. The greater depth of the northwest channel as well as westward deflexion due to Coriolis forces (although weak at this latitude) would favour a greater flow to the northwest.

SEDIMENT DYNAMICS ON THE BLAKE PLATEAU

Charles D. Hollister and David A. Cacchione

The extensive lens of fine-grained sediment lying beneath the surface axis of the Gulf Stream was found to owe its shape and distribution to the southerly-flowing Gulf Stream Countercurrent.

The coral mounds in the bottom axis of the Gulf Stream were observed to be growing upwards and up-current in response to the "snow-fence effect" of the living coral.

Acoustic records, side-scan and narrow-beam echo sounding, reveal a good correlation between reflectivity and the above dynamic processes.

SEDIMENT DYNAMICS IN THE HUDSON CANYON

Charles D. Hollister and Alexander Malahoff

The origins of the physiographic features of the Hudson Canyon and dynamic oceanographic processes within the canyon were investigated with the use of a Navy research submersible and surface support ship. The goal of these investigations is to solve the nature of physical processes that control sediment dynamics on the continental margin.

The aim of the present study was to determine the degree to which bottom currents within the canyon and sediment motions on the canyon floor and walls affect the stability and configuration of the present canyon physiography. The study was carried out with the aid of surface seismic reflection traverses together with visual, side scan and echo sounding traverses along the sea floor and walls of the canyon by submersible. The surface traverses were used to determine the location of changes in the sedimentary structure at the canyon and to pinpoint the location of benches and sea-floor acoustic structures. Bottom current meters and disposable bathythermograph measurements were also made with the surface vessel and compared with data collected on the sea floor with the submersible.

The outstanding problem posed by the existence of the submarine canyons is whether they are:

a. Sites of active erosional processes such as turbidity currents which are eroding the heads of the canyons landwards and threaten cable routes near the continental slope.

b. Sites of active sedimentary deposition, filling canyons that were formed during a former sea level low.

c. A combination of (a) and (b).

d. Structurally controlled and mark the sites of ancient fracture zones or faults in the earth's crust.

It appears that the south and west wall of Hudson Canyon is the site of present sediment accumulation. The northeast wall is presently being eroded by the activity of benthic organisms. There is no evidence of the presence of turbidity currents within the canyon. The canyon head may be cutting back into the shelf by breaking internal waves. During the Pleistocene sea level low the canyon was probably the site of turbidity flows, the sediment being provided by the Hudson River. After a rise in sea level, the canyon became quiescent and a site of sedimentary deposition and bioturbation.

Details of the present study may be divided in the following manner:

a. Physical Oceanography:

1. The canyon axis is affected by strong tidal currents, 0.3 to 0.5 knots.

2. Sediment, especially in the axis of the canyon, is continually in motion due to benthic activity and tidal currents, giving rise to poor visibility.

3. On the flanks of the canyon, currents appear to be less than 0.3 kts up and down slope.

4. Frequent eddies and other turbulence phenomena were observed within the water column of the canyon head, near the seasonal thermocline.

5. Probable breaking internal waves were observed within the head of the canyon and the presence of warm interlayers of water was also detected.

b. Geology-Geophysics:

1. Seismic reflection studies showed a prominently layered sedimentary sequence along the axis of the canyon and highly reflective, acoustically opaque sediments at the head on the flanks of the canyon.

2. The western flanks of the canyon are the sites of rapid sedimentary accumulation of soft unconsolidated silty clay which acts as an acoustic sponge.

3. The eastern flanks of the canyon show a thin cover of unconsolidated sediments covering consolidated stratified muds.

4. The non-depositional environment on the eastern canyon wall is due to the activity of benthic organisms.

5. No sand was found to be present within the canyon axis. Sand was found, however, at the canyon head.

6. On the lower reaches of the east wall large bare-rock cliffs were observed with frequent overhangs. These cliffs were observed to be in a stable environment and are probably relect features.

7. Although fossil beaches were observed on the continental shelf east of the canyon axis, no such beaches were evident on the western shelf.

TRACE FOSSILS ON THE DEEP SEA FLOOR

Charles D. Hollister, Bruce C. Heezen, Katharine E. Nafe

Searching through over 100,000 photographs taken at more than 2,000 locations on the deep sea floor, it has been possible to find only about one hundred animals caught in the act of producing tracks, trails and fecal deposits. It is now clear, from a preliminary study of the morphology and arrangement of the ventral surfaces of bottom-dwelling animals, that the makers of certain tracks can be ascertained with some degree of certainty without actually being caught "in the act". Many of the organisms are unidentifiable due to their small size; but the larger animals, responsible for the majority of these markings, are probably members of the phylum Echinodermata, with lesser contributions being made by the larger arthropods and an occasional fish. Innumerable organisms produce the mounds and holes seen in abyssal sediments and their specific identification will have to await the probings of deep-diving vehicles equipped with external sampling apparatus.

ANCIENT CONTOURITES

Arnold H. Bouma*, Charles D. Hollister

Since the concept has been developed that recent sediment is deposited parallel to bathymetric contours by clean ocean bottom currents, a few examples of possible fossil contourites have been reported. Although many recent examples are known, not enough specific data has been collected to apply the results conclusively to ancient rocks. Paleoglobal circulation patterns or local paleobottom currents are not known in such a way that deposits can be predicted much less interpreted from them. Consequently it is necessary to determine transport-deposition conditions and paleobottom currents from examining rock outcrops. It then becomes obvious that the reconstruction of pretectonic conditions is required to examine the existence of such currents.

An example of possible fossil contourites is found in the Swiss Niesenflysch, a complex located south of Spiez, Switzerland. The complex tectonics, stratigraphy and petrology have been studied by many geologists.

The lower 470 m of the Niesenflysch complex near Adelboden (24 km south of Spiez) consists of 80 m of black shales overlain by 60 m of pelitic sandstones, followed by sandy shales. Fossils in this lower series (Frutig Series or Serie Inferieure) are rare. The age is interpreted as Maastrichtian-Paleocene and the depositional environment as deep marine.

Of the many sections examined only the Stiegelback section west of Adelboden has been re-examined using the concept of contourites. This section contains the platy sandstone-slate member of the lower sandy shales. This heavily tectonized area contains a rather undisturbed section just below the waterfall in the Stiegelback. A distinctive rhythm is visible, consisting of shale, a sandstone layer, shale, a series of thin sandstone layers with shale on the layer contacts, and followed by alternations of sandstone and shale. A detailed graphic representation is given by Bouma (1962).

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The layer thickness varies between one and twelve centimeters with the average being four to five centimeters. Upper and lower bedding planes are distinct. Parallel lamination, some foreset bedding and indistinct graded bedding can be observed macroscopically. Calcium carbonate content varies between 5% and 50%, the higher value corresponds to the sand-sized portions. According to Pettijohn's (1957) classification, the term graywacke should be applied. Due to the strong tectonic influence a high degree of re-crystallization is visible which makes it difficult to establish the exact amount of original clay-sized material. The very fine sand layers show a well-sorted distribution.

X-ray radiographs made of thin slices reveal zones with and without primary sedimentary structures. Parallel lamination and foreset bedding are the only structures and no fixed vertical succession has been observed as is diagnostic of turbidites.

With regard to the present knowledge of deep marine deposits of continental detritus these Stiegelback section deposits do not fit the proximal or distal turbidite concept, nor levee channel accumulations. Based on this deduction the present conclusion that they are contourites is favored.

Reference

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SEDIMENTARY PROCESSES

David A. Ross

Research centered on two main problems: sedimentary effects of the bottom interaction between the Gulf Stream and the Western Boundary Undercurrent; and the origin and nature of the lower continental rise hills. Data were collected on *Atlantis II* Cruise 72 (October - November, 1972).

Bottom current data off Cape Hatteras show lateral variations in current velocity. These variations, which also probably occurred in the past, should be reflected in the mineral content of the sediments, since each current comes from a different and distinctive mineralogic province. To test this idea and see if past current directions could be ascertained we took a series of piston cores and bottom camera stations across the continental slope and rise off Cape Hatteras. Presently, these cores are being analyzed for shear strength, water content, and sand, silt, and clay mineralogy. Preliminary results show mineralogical variations that could be due to current changes.

We also made a closely-spaced seismic and 3.5 kHz survey to see of the lower continental rise hills are isolated features or linear wave forms related to bottom currents. The data indicate that the "hills" are really linear ridges that are the result of small-scale slumping and faulting. Seismic profiles showing what has been called an "antidune-like feature" are more likely the result of seismic distortions along fault zones.

GEOLOGICAL AND GEOPHYSICAL STUDIES OF THE RED SEA

David A. Ross

The result of a detailed geological and geophysical expedition made to the southern and central portions of the Red Sea from *Chain* (Cruise 100, Leg 3 - March, 1971) and Deep Sea Drilling Project (DSDP) Leg 23B are near completion. The following reports have been completed:

a. Shallow Structure and Geologic Development of the Southern Red Sea
David A. Ross and John Schlee (U.S. Geological Survey, Woods Hole)

A series of 34 shallow-penetration seismic-reflection profiles made across the Red Sea show that it developed in two main stages. Initially, an early or pre-Miocene uplift and lateral extension resulted in crustal thinning and eventual formation of the main Red Sea Basin. During Miocene time, the Red Sea was isolated from the Indian Ocean but possibly 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 termination of evaporite conditions.

In Pliocene times, connection with the Indian Ocean was re-established, the opening to the Mediterranean was closed, and normal marine conditions were resumed in the Red Sea. Sea floor spreading first started in Pliocene-Pleistocene time, and resulted in the formation of the axial zone of the Red Sea.

b. Volcanic and Sedimentary Processes in the Red Sea Axial Trough
Robert A. Young and David A. Ross

Volcanic features observed in the axial trough of the Red Sea are typical of those seen in other sites of mid-ocean ridge volcanism. Extrusive volcanic features photographed included flows, pillow lavas, and rock fragments. Many lavas appeared fresh and unweathered.

Sedimentary cover is thin in areas of recent volcanic activity. Bottom currents and bioturbation are responsible for reworking of the sediments in the axial trough. Sediments within the *Atlantis II* hot brine area appear smooth in most places and thick enough to cover the volcanic topography. Sediments underlying the hot brines (about 60°C) may be reworked into ripples and dunes by internal waves where interfaces between brines of differing density intercept the sea floor. A group of mound-building organisms (polychaete worms?) similar in appearance to organisms photographed in other parts of the axial trough, apparently inhabit the transitional region between the overlying normal Red Sea water and the hot brine waters, or the hot brine area proper.

c. Red Sea Sediments
Peter Stoffers (University of Heidelberg, Germany) and David A. Ross

Sedimentation studies on materials collected on DSDP Leg 23B in the Red Sea show that four distinct lithologic units can be identified:

Unit I. Gray micarb rich detrital silty clay nanno ooze and chalk.

Unit II. Gray micarb rich nanno detrital silty claystone.

Unit III. Dark gray dolomitic silty claystone.

Unit IV. Evaporites.

Unit IV is an evaporite sequence of Late Miocene or older age. The top of this unit is marked by an acoustic reflector (reflector S) which is correlative with a similar reflector in the Mediterranean that also represents the top of a Miocene evaporite sequence. A sabkha origin for these evaporites is suggested by their chemistry, mineralogy, isotopy, and lithology. A deep basin evaporite model is favored with occasional changes to a more normal environment indicated by nannofossils and benthonic foraminifera found in black shale interbedded between the evaporites.

Unit III, overlying the evaporites, was probably deposited in a relatively restricted basin as indicated by its high organic carbon content and up to 10% pyrite.

Units II and I were deposited within more normal marine conditions reflecting the opening of the Red Sea to the Indian Ocean. Occasional dark shale layers within Unit II are enriched in vanadium and molybdenum and are comparable to the Kupferschiefer deposits. The high organic carbon and pyrite content of these dark layers suggests deposition under stagnant conditions.

The deep-sea sediments drilled during Leg 23 can be tentatively correlated with land stratigraphy.

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

Bruce P. Luyendyk

Work has continued this past year on analysis of results from Leg 26 of the Deep Sea Drilling Project (see Summary for 1972). Investigations have continued along several different lines.

John Peirce, Charles Denham and Bruce Luyendyk have analyzed the magnetic properties and paleomagnetism of basalts from sites 250, 251, 253, 254, 256 and 257, Leg 26. They found that most of these samples are relatively unstable magnetically, and have a high viscous component. Paleolatitudes for the sites are in general agreement with polar wandering curves for the Gondwanaland continents, except for sites in the Wharton Basin which indicate a latitude too far south relative to Australia in the Mid to Early Cretaceous.

A tectonic synthesis of the implications of the DSDP results on the breakup of Gondwanaland has been prepared by Luyendyk. This analysis suggests that the Indian Ocean opened first north of Australia in the Jurassic, then in the Wharton Basin (simultaneously with the South Atlantic) in the Early Cretaceous. The western Indian Ocean basins were formed during the middle Cretaceous.

Analysis has also been made of prominent regional hiatuses in the Indian Ocean by Luyendyk and Thomas Davies (S10). Prominent hiatuses are seen to be centered on the Oligocene, Early Tertiary (Paleocene?) and Late Cretaceous. These hiatuses are best defined in the western boundaries of the Indian Ocean (Leg 25) and southwest Pacific (Leg 21), suggesting their origin is related to a western

boundary undercurrent. The Oligocene and Early Tertiary hiatuses are believed caused by climatic deterioration in Antarctica during the late Cretaceous and Early Oligocene, which resulted in increased flow of Antarctic bottom water.

DEEP SEA DRILLING OFF WESTERN AUSTRALIA: DSDP LEG 27

James R. Heirtzler

Drilling on Leg 27 northwest of Australia was accomplished in late 1972. Initial results have been described by numerous investigators and submitted as contributions to the Initial Report for Leg 27. Two reports have been published giving the highlights of the cruise (Veevers, *et al.*, 1973; Heirtzler, *et al.*, 1973). The age of the sea floor basement was found to be 155 million years - as old as any part of the sea floor. Sediments overlying this old sea floor provided the opportunity to study the paleomagnetic record of the Mesozoic era and a history of the initial breakup of Gondwanaland in the Indian Ocean (Veevers, John V., Heirtzler, James R., *et al.*, in press).

A unique aspect of this cruise was the implementation of an underway program. That resulted in three papers: Aeolian Transport off Western Australia, Suspended Sediments off Western Australia, and Oceanographic Observations. These will be included in the Initial Report for Leg 27.

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PETROGRAPHY OF ROCKS FROM DSDP SITES 214 AND 216, NINETY-EAST RIDGE

Wilfred B. Bryan

Rocks from the Ninety-East Ridge differ from most submarine basalts in having andesitic affinities. They differ from typical ocean ridge basalts especially in the presence of large magnetite phenocrysts and in the relatively high proportion of plagioclase. Unlike ocean ridge pillow basalts which often show almost crystal-free glass rims and internal quench textures, the Ninety-East Ridge lavas show a distinct trachytic texture indicative of flow of magma with abundant crystalline material in suspension. This indicates crystallization in high-level magma chambers prior to extrusion.

Chemical analyses by Roger Hekinian, Geoffrey Thompson, and Frederick Frey show that some of these rocks are sufficiently mafic to merit the name basalt, but still differ markedly from ocean ridge basalts in their unusually high total iron oxide and low CaO and MgO. The andesitic varieties are higher

in alkalies and lower in CaO than typical andesites from Tonga. Thus, the Ninety-East Ridge does not appear to represent either an old spreading center or an inactive island arc on the basis of petrographic and chemical data. However, very similar rocks are known in Iceland, which is presumed to represent the surface expression of a mantle plume or "hotspot". Thus, the linear Ninety-East Ridge may have formed by passage of the Indian plate over a mantle plume situated near the south end of the ridge.

PALEOMAGNETIC RESULTS OF BASALT SAMPLES FROM DSDP LEG 26, SOUTHERN INDIAN OCEAN

John W. Peirce, Charles R. Denham, and Bruce P. Luyendyk

Magnetic measurements were made on 67 basalt samples from sites 250, 251, 253, 254, 256, and 257 of Leg 26, Deep Sea Drilling Project (DSDP). Paleolatitudes estimated from the inclinations after alternating field demagnetization at 100 oersteds are compatible with apparent polar wandering curves (except site 256) and reconstructions of the Indian Ocean based on lineated magnetic anomalies (except sites 250 and 256). The samples displayed low coercivities (95 oe average median destructive field), except at site 254 (383 oe MDF). Intensities of natural remanent magnetization are lower than are typical of dredged basalts, and low field susceptibilities are higher. Viscous remanent magnetization was shown experimentally to be high in many specimens and could account for a large portion of their original intensity. Low coercivities, high viscous remanence, and the limited number of flows sampled all detract from the statistical confidence of the paleolatitude estimates. Site 257 revealed a polarity reversal, which can most likely be attributed to a thin dike or sill injected during a reversed episode subsequent to the emplacement and cooling of the rest of the cored section, which is normally polarized.

STUDIES OF PILLOW BASALT GLASSES AND MINERALOGY

Wilfred B. Bryan

Most of the existing data for deep-sea basalts consists of bulk rock chemical analyses. Such analyses include both the quenched liquid portion of the basalt and suspended crystalline material and rock fragments in various proportions. Because in general these analyses represent mixtures of liquid and solid phases, and because the composition and proportions of solid phases are generally unknown, it has been difficult to interpret those data in terms of quantitative geochemical models for genesis and evolution of sea-floor basalt.

Using the electron microprobe facilities at the Geophysical Laboratory, Washington, D.C., and in the Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, it has been possible to separately analyze basalt glass (liquid) from pillow rims, and the enclosed suspended mineral phases (solid). Dredged basalt samples in the Woods Hole Oceanographic Institution collection from cruises of *Chain* 21 and *Chain* 43 are being studied in this way for the first time,

and in addition bulk chemical analyses of these same samples are being obtained by X-ray fluorescence analysis in collaboration with J. M. Rhodes, NASA-Lockheed, Houston. In collaboration with Geoffrey Thompson (Woods Hole Oceanographic Institution) and Frederick Frey (Massachusetts Institute of Technology) similar studies have been made of sea-floor basalts from DSDP Leg 2 and Leg 3 in the Atlantic. Analyses have also begun on DSDP Leg 11 samples in the western Atlantic.

In general, all basalt glasses analyzed so far lie along an olivine-plagioclase cotectic boundary in the system olivine-plagioclase-pyroxene. Glass from Leg 3, sites 14 and 18, represents the most mafic liquid so far documented among deep-sea basalts. It lies at the most "primitive" end of the cotectic, close to the spinel field. Glasses from DSDP sites 2-11A and 2-10 are among the most alkaline or "fractionated" basalt liquids known, although similar compositions have been recorded, for example, on the Juan de Puca Ridge. The restriction of these glass compositions to the cotectic boundary is good evidence that the liquids are derived by partial melting and/or fractional crystallization of a gabbroic parent composition. Preliminary model calculations do suggest that fractional crystallization involving olivine, plagioclase, and spinel can account for most of the compositional variation observed.

Data for the dredged *Chain* samples fall between the extremes represented by the DSDP basalts. The bulk analyses by Rhodes indicate that the *Chain* 43 samples fall in several distinct groups within the olivine field, and that variation lies along olivine control lines. Microprobe analyses confirm that the glasses lie at the end of these control lines and on the cotectic boundary.

Trace element and rare earth element analyses by Thompson and Frey confirm that minor elements behave in a manner consistent with the major element analyses. In addition, the minor element data combined with major element data for minerals and glasses can be used to distinguish compositional changes due to submarine weathering from changes produced by magmatic processes.

The mineral plagioclase makes up 50-70% of all submarine basalt and thus its composition and crystallization behavior plays an important role in the evolution of these rocks. Microscopic study has shown that sector-zoning, previously unknown in plagioclase, is common in sea-floor pillow basalt. Its presence or absence in plagioclase in basalt of terrestrial ophiolite complexes may provide an important clue to its marine or non-marine origin. A detailed statistical study of thirty plagioclase microprobe analyses from DSDP and dredged basalts demonstrates that the considerable Fe and Mg content reported last year is present as a $Ca(Mg,Fe)Si_3O_8$ compositional end member which may constitute 5% or more of the plagioclase. The effect of this end member is expected to be:

1. It will reduce the crystallization temperature of the plagioclase for a given content of Ca;

2. It will tend to increase the amount of Na and reduce the amount of Mg and Fe in the remaining liquid, thus favoring production of more alkaline basalt by fractional crystallization.

Also, there is evidence that in many basalts, the Fe/Mg ratio of the plagioclase can be related to the Fe/Mg ratio of the co-existing liquid, a relation which may be useful for deducing the composition of basalt liquids in cases where no fresh glass is available for analysis.

PALEOMAGNETIC REVERSALS DURING THE LATE BRUNHES NORMAL EPOCH

Charles R. Denham

The Blake polarity event was confirmed as a full reversal of the geomagnetic field 125,000 years B.P. through the detailed examination of giant cores *Knorr* 25-3 and 25-4, standard core *Chain* 57-8, and narrow core *Chain* 36-1, all from the Greater Antilles Outer Ridge. The base of the event coincided with the onset of the last interglacial period (X zone) and lasted about 25,000 years. *Knorr* 25-3 and 25-4 recorded a major excursion within the Blake event, and the latter core also preserved very rare records of polarity transitions. During the reversed interval, positions of the virtual geomagnetic (negative) pole lay within 20° of the south geographic pole, with transitions taking place along paths in the eastern hemisphere. Also confirmed by *Knorr* 25-4 and *Chain* 57-8 was another reversed period in the upper part of the V zone, about 175,000 years old. In conjunction with oxygen-isotope stratigraphy, the several periods of reversed polarity in the Late Brunhes are suitable as foundations for the development of a Late Pleistocene absolute time scale.

LUNAR VOLCANOLOGY

Wilfred B. Bryan

The early geological history of the Earth has been largely obliterated, presumably by repeated episodes of sea-floor spreading, continental collisions, and subduction. In contrast, the Moon appears to have "run down" very early in its history; and except for minor modification by impact cratering, its surface looks much the same today as it did 3.5 billion years ago. Like the Earth, the Moon's surface is clearly divided into highland or "continental" areas composed of relatively light feldspathic rock, and mare or "oceanic" areas composed largely of basaltic rocks. It is possible that similar mare-type basins once existed on the Earth, and were precursors of the present-day ocean basins. Utilizing medium and high-resolution *Apollo* 15, 16 and 17 stereo-photography, studies are being made of the volcanic episodes associated with the mare basins. Some of the more important questions to be answered are as follows:

1. Was volcanism continuous throughout the Moon's history, or is it confined to a particular time interval?

2. What is the distribution of volcanic source areas? Are there distinct zones of volcanism analogous to ocean ridges and subduction zones on the Earth?

3. How is volcanism related to tectonic deformation or impact events?

4. To what extent do lunar volcanic land forms resemble, or differ from, volcanic land forms on Earth?

During the past year effort has been concentrated on wrinkle ridges and associated lava flows in the southern part of Mare Imbrium and Mare Serenitatis. Preliminary investigations were made on possible volcanic features associated with the near-side crater Goclenius and the far-side crater Aitken.

Wrinkle-ridges tend to show an en-echelon distribution around the margins of the circular lunar maria and have been widely supposed to represent piles of volcanic extrusive material related to marginal tension faults. However, detailed study of the *Apollo* photography shows that large lava flows originate south of the outer margins of Serenitatis and Imbrium, and flow northward into the maria. The flows are crumpled and deformed where they cross wrinkle ridges. The evidence indicates that the ridges postdate the lava flows and that they are compressional tectonic features. Calculations show that the necessary crustal shortening could be produced by one or two kilometers of isostatic subsidence of the maria along vertical normal faults.

Crater Goclenius encloses a fractured mare-like crater floor in which possible volcanic vents are located at the intersection of the fractures. Crater Aitken shows unusual dome clusters enclosed in craters on a mare-like filling on its floor. These domes may be viscous volcanic extrusions. Scarps in the western floor of Aitken which have been supposed to be lava flow margins can be shown to be tectonic scarps on high-resolution photos.

Although much remains to be done in detail, some general impressions of lunar volcanic activity can be given at this time. Most of the volcanic activity appears to have taken place at the time of filling of the maria, about 3.0 to 3.8 billion years ago. There is little evidence of very recent volcanism, or of much older volcanism in the highland regions. Features analogous to mid-ocean ridges or subduction zones appear absent; the Moon apparently "ran down" before any appreciable deformation of the maria took place. The volcanic history so far appears compatible with the model of a second internal melting shortly after the time of maria formation, which has been invoked to explain the destruction of most of the lunar magnetic field, after an earlier period when the Moon apparently had a small convecting core.

GEOLOGY OF HISPANIOLA

Carl Bowin

At present we have only a very imperfect picture of the evolution of an island arc. Linear chains of active volcanoes presently occur in many island arcs and are associated with active subduction of an oceanic lithospheric plate beneath the arc, as are deep-sea trenches, but the initial stages as well as the processes involved are much in doubt. What happens to an island arc when underthrusting ceases is also a matter of conjecture. Obviously, detailed geologic studies of island arcs can and will contribute to a better understanding of these problems. A recent review of present geologic knowledge of the island of Hispaniola in the Caribbean island arc has been completed as a step toward that undertaking.

Hispaniola is the second largest of the Greater Antilles, and four structural trends converge upon it: the main axis of the island arc, the southeastern part of the Bahamas, the swell (Nicaraguan Rise) extending from Central America to southwestern Hispaniola, and the Beata Ridge. Greenschist metamorphic rocks occur in a belt diagonally across the middle of the island and small exposures of marble, gneissic amphibolites, glaucophane schist, and eclogite occur near the north coast. In the

central belt, a 127 m.y. radiometric age for a hornblendite intrusion probably provides the best minimum age for the suite of metamorphosed mafic volcanic rocks which are considered to be metamorphosed oceanic crust. These rocks are separated by a fault zone (inferred to be a former Benioff zone) along which serpentinized peridotite has been emplaced from metamorphosed quartz keratophyres and keratophyres and other lavas considered to have been formed during the development of the island arc. The metamorphic rocks of the central belt are predominantly volcanic flows, as is the Lower Cretaceous section (the oldest paleontologically dated rocks). Upper Cretaceous rocks are also predominantly volcanic rocks, but they are in large part of pyroclastic origin consisting of coarse to fine tuff and lapilli-tuff. Limestones of Upper Cretaceous age are locally prominent, particularly in Haiti. The Southern Peninsula of Haiti may have been distant from the remainder of Hispaniola until Maestrichtian time when translation may have brought it adjacent. During Maestrichtian and earliest Tertiary, phyroclastic material was locally deposited, but clastic sedimentation was becoming more common, although deposition of limestone continued being prevalent in portions of Haiti. Late Tertiary time was virtually devoid of volcanic activity, being overwhelmingly a period of deposition of clastic sediments. This succession leads to the view that the island has become increasingly emergent with time. Strike-slip faulting along the northern margin of Hispaniola probably dates back only to about Pliocene time, and suggests that a change in the tectonic pattern in this region has occurred in the last few million years.

BEHAVIOR OF THE NORTH AMERICAN MARGIN DURING CONTINENTAL SEPARATION

Robert D. Ballard and Elazar Uchupi

In August and September of 1973 the R/V *Gosnold* conducted two cruises into the Gulf of Maine. This work marked the end of a three-year seagoing effort in the Gulf during which ten cruises were made, 7500 km of seismic reflection profiles collected, 100 refraction stations conducted, and 26 dives were made by the submersible *Alvin*. The purpose of the study was to investigate the behavior of the North American margin during the separation of North America and Africa 200 million years ago. Based upon this work a tectonic map of the Gulf and surrounding area was constructed. Figure 1 is a generalized version of that map. The region contains three principal fold belts (the Appalachian geosyncline, the Avalon platform, and the Meguma geosyncline) which underwent compressional deformation in the Ordovician (Taconic orogeny) and Devonian (Acadian orogeny), and Late Paleozoic and Late Triassic rift systems. The compressional features are associated with the closing of the North Atlantic at the end of the Paleozoic and tensional features with the separation of North America and Africa that culminated in earliest Jurassic. The nature of separation apparently involved a component of left lateral motion, the formation of a series of horsts and grabens into which sediment accumulated, and the injection of large quantities of mafic material which increased the average density of the crust in the Gulf of Maine. Thus the basement of the North Atlantic margin is a product of crustal thinning, crustal collapse and oceanization of acidic crustal material.

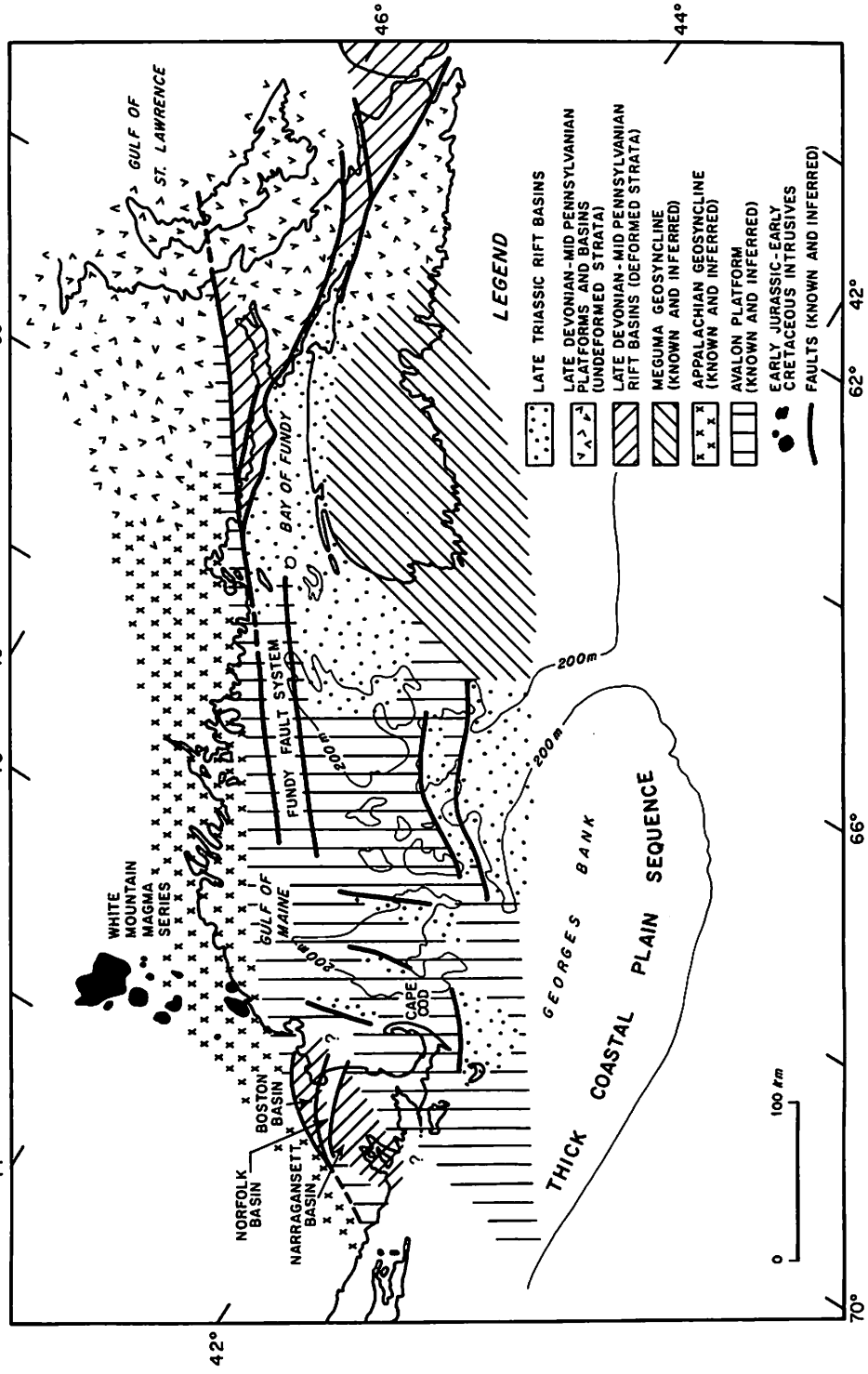

Fig.1 (Ballard and Uchupi)

MAGNETIC SMOOTH ZONES IN THE WORLD'S OCEANS

Kenneth A. Poehls, Bruce P. Luyendyk and James R. Heirtzler

Minor magnetic materials in the earth's crust cause anomalous variations in the intensity of the earth's magnetic field in most oceanic regions. In several places, however, the magnetic field is surprisingly free of anomalies. For example, on matching sides of the North Atlantic Ocean no anomalies exist and this fact has been attributed to the earth's magnetic field being of low value or not reversing to create sea-floor spreading anomalies.

An analysis was made of all the magnetic smooth zones of the oceans of the world (Poehls, *et al.*, 1973). Such zones around the continental margins could be due to slow initial rifting. This older basement would experience many reversals of the field. Such zones could be somehow related to the great depth of burial of the basement in those places. In addition marginal smooth zones and deep-sea smooth zones could be due to their being created when the geomagnetic field did not reverse.

Reference

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MIGRATION OF A PATTERN OF PLATE MOTION

Carl Bowin

A pattern of plate motion is documented to have migrated from the South Pacific into the Indian Ocean during the Cretaceous and Early Tertiary, and then across the Indian Ocean during the Tertiary. A diagram illustrating the migration is shown as Fig.1. Active spreading centers are identified by double lines, extinct spreading centers by double lines with cross-hatching, and inferred extinct spreading centers have dashed double lines with cross-hatching. The cross-hatched extinct spreading center without bordering lines shown in northern Indonesia represents diagrammatically the spreading center that was offset by the Ninety-East transform fault but has not lost through subduction beneath the Indonesian island arc. Areas with stippled pattern are oceanic crust that was formed by a former pattern of plate motion in the northern Indian Ocean. Major transform faults are indicated by heavy single lines, others are not shown but arrows indicate direction of spreading parallel to intraplate transform faults. Dotted lines show location of magnetic anomaly 32. Intermediate weight lines outline the approximate boundaries of oceanic crust formed during the westward migration of the proposed pattern of plate motion. The location of the boundary east of the Tonga Trench is uncertain. Numbers 1 through 5 refer to the order in which it is suggested that segments of these boundaries formed during the migration of the spreading center from the South Pacific to the Gulf of Aden. The (a) portions appear to have formed prior to the (b) portions. The dashed lines in the South Pacific outline approximate boundaries of crust formed following a younger adjustment in direction of plate motion. The opening of the Gulf of Aden may be a more recent extension of this migration. The migration takes place by the episodic formation of new segments of sea-floor spreading having the new direction of plate motion; or by development of the new direction of motion in

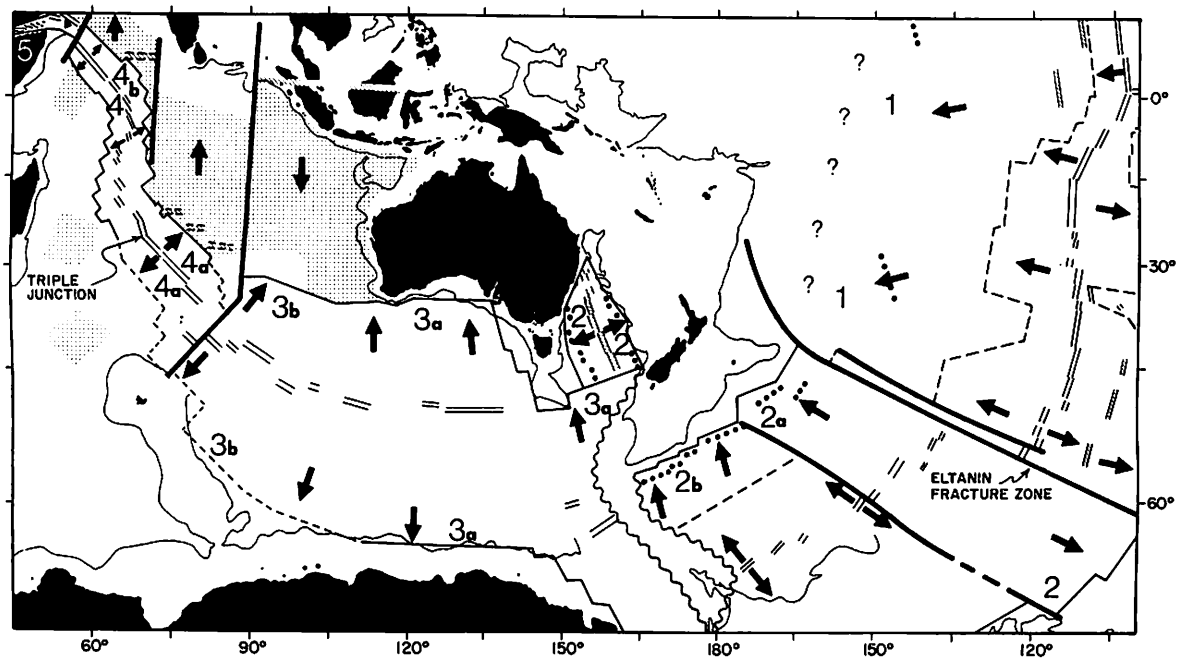

Fig.1 (Bowin) Diagram illustrating migration of a pattern of plate motion from South Pacific to western Indian Ocean. See text for explanation.

segments where sea-floor spreading had previously been active. The migration demonstrates that plate motions can extend beyond their previously limiting plate boundaries.

GRAVITY INVESTIGATIONS

Carl O. Bowin

Field programs include measurements aboard the R/V *Atlantis II* during Cruise 75 to the Atlantic continental margin of central and northern Africa; Cruise 76 to the region west of the Straits of Gibraltar; Cruise 77 to the Mid-Atlantic Ridge near 36°30'N latitude (FAMOUS area); aboard R/V *Chain* Cruise 115, legs 1 and 2, in the eastern Equatorial Atlantic Ocean; and aboard the R/V *Thomas Washington* of the Scripps Institution of Oceanography during Cruise TASADAY to the Bay of Bengal and western Pacific Ocean. The measurements aboard the *Atlantis II* and *Chain* were made with vibrating string accelerometer (VSA) gravity meters mounted on Sperry Mark 19 Mod 3c gyrocompasses enclosed in portable laboratories (described by Bowin *et al.*, 1972). These VSA gravity meter systems continued to perform very well, and have provided nearly continuous measurements during all the cruises. The measurements aboard the *Thomas Washington* were conducted using a newly developed gravity meter system consisting of a VSA sensor and readout system mounted on an Aeroflex ART-57 stabilized platform.

The gravity measurements over the continental margin of central and northern Africa are part of the Eastern Atlantic Continental Margin program organized by Kenneth O. Emery and Elazar Uchupi. Processing of the marine gravity data is complete and compilation of anomaly maps of the continental margin, including available data on Africa, is in progress. The measurements in the FAMOUS area have been combined with those from *Atlantis II* Cruise 73 for the preparation of a free-air anomaly chart of the crestal region of the Mid-Atlantic Ridge at the FAMOUS area. +80 mgal to +120 mgal anomalies were measured over the crestal mountains flanking the rift valley where anomalies of less than +10 to +20 mgals occur. Negative anomalies (to -20 mgal) occur over low topography associated with a prominent fracture zone. Slightly negative values occur in the rift valley near where it is terminated by fracture zones.

The gravity measurements aboard the *Thomas Washington* were conducted under a joint effort of the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology (John Sclater and John Grow). The original plan had been to operate a LaCoste and Romberg sea gravity meter on loan to Woods Hole Oceanographic Institution from the U. S. Army Topographic Command. This meter had been used the previous year by a Woods Hole Oceanographic Institution gravity program on the *Hakuho Maru* of the Ocean Research Institute, University of Tokyo, as part of a United States-Japan Cooperative Science Program. Unfortunately, the Army Topographic Command had to recall the LaCoste and Romberg meter prior to its planned use on the Scripps' *Tasaday* Cruise. After a thorough examination of the possibility of borrowing another meter, which proved extremely unlikely, Woods Hole Oceanographic Institution began construction of a new VSA gravity meter system. This system consists of a VSA oven and readout system (constructed under a previous Advanced Research Projects Agency (ARPA) contract) with the VSA and its oven mounted on an updated Aeroflex ART-57 stabilized platform mount. The original ART-57 mount was obtained Government Furnished Equipment (GFE) from the Air Force Cambridge Research Laboratory in May, 1973. The ARG-5 gyros that came with the mount were intended for only four to five hours of operation at a time, and hence would not perform under conditions of 24 hours of operation for months on end. A new stabilization system for the ART-57 platform was therefore required. Through the joint efforts of Aeroflex and Woods Hole Oceanographic Institution the new stabilization system was constructed in time for air-freighting of the VSA/ART-57 system to Singapore in early October to be installed aboard the *Thomas Washington*. The system performed satisfactorily on its first cruise and important measurements were obtained in the Bay of Bengal, Indian Ocean. Measurements are continuing on the remainder of the cruise to Hawaii. Linda Meinke and Keith Louden assisted in the conversion of W.H.O.I. gravity reduction programs for use with the IBM 1800 computer aboard the *Thomas Washington* and in preparing a new program for reading and filtering the one-second gravity values obtained from the new VSA system.

A compilation of free-air and simple Bouguer gravity anomaly maps of the Caribbean region has been completed and a manuscript has been prepared discussing the structure and tectonics of the region in relation to the gravity anomalies, topography, volcanoes, seismicity and terrestrial heat flow. A similar study of the western portion of the Sunda Arc of Indonesia is in progress in collaboration with Zvi Ben-Avraham of the Israel Oceanographic and Limnological Research Laboratories. The contouring of a detailed free-air anomaly map of the United States was completed during the year in collaboration

with James Hibbard of the University of Newfoundland. As part of our cooperative program with scientists at the Ocean Research Institute of the University of Tokyo, we have processed the gravity and magnetic data from several previous Japanese cruises to a common format and have processed (with the assistance of John Grow) the data obtained with LaCoste and Romberg meter S-32 during Cruises KH-72-1 and KH-72-2 of the *Hakuho Maru*. A report describing the gravity base stations occupied by Woods Hole Oceanographic Institution during the last ten years has been prepared for distribution.

Of particular interest this year has been a study of lithosphere underthrusting conducted in collaboration with John Grow of Massachusetts Institute of Technology. Gravity models over oceanic trenches computed before the advent of plate tectonic concepts were required to either (1) thin the oceanic crust beneath the seaward trench wall or (2) include high density mantle directly beneath the Moho near the trench axis. In light of plate tectonic concepts which predict low-temperature and high-density anomalies in the descending lithosphere, the thinning of the oceanic crust or incorporation of high density directly beneath the Moho can be eliminated by taking into account density anomalies in the down-going slab. A density structure for the descending lithosphere computed from thermal and petrologic data was compared with observed gravity data over the Chile Trench at 23°S from Hayes (1966) and other sources, and the density anomalies in the down-going slab appear to account for most of the high density required beneath the Chile Trench. The calculated density structure suggests that the oceanic crust may transform to high density eclogite at depths as shallow as 30 km. Furthermore, phase changes from plagioclase peridotite to garnet peridotite in the mantle part of the descending lithosphere also probably begin to occur at depths of only 30 kilometers.

We are also engaged in the study of the gravity field of the Moon. The gravity data are obtained by the Johnson Spacecraft Center, Houston, Texas, 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. We have been investigating the lunar MASCON (mass concentration) for Mare Serenitatis. Simple initial model configurations do not meet the magnitude nor shape constraints imposed by the observational data. Mare structure models with offsets in the subfloor of the mare fill also have not been successful in matching the observational data.

Important assistance in these programs has been provided by Robert Goldsborough, Leon Gove, Carolyn Dean and Edward Scheer.

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GEOTHERMAL INVESTIGATIONS IN OCEANIC REGIONS

Richard P. Von Herzen and David L. Williams

A field program of heat flow and bottom water temperature measurements was carried out on *Atlantis II*, Cruise 77 in summer 1973. About 60 measurements were successful in three small areas on the axis of the Mid-Atlantic Ridge near 36°30'N latitude (FAMOUS area). Many of these measurements were made with a new "Pogoprobe" designed to survive impact with a hard-rock bottom and continue operation with successive penetrations, and were precisely navigated with reference to bottom-mounted acoustic transponders. The measurements from one small region at the intersection of the ridge axial valley with a fracture zone show a concentration of high values ($\geq 7\mu$ cal $cm^{-2}sec^{-1}$, HFU) over a few square km, grading to lower values (≤ 1.5 HFU) several km away along the fracture zone trend.

We have nearly completed development and construction of a new digital heat-flow recorder. This should significantly ease the present task of data reduction from analog records and we hope to use it in next year's field programs.

Three manuscripts on geothermal data (heat flow and water temperature) from the Galapagos ridge field work in 1972 have been prepared. Evidence is presented for significant modification of the heat-flow pattern by hydrothermal circulation in the crustal rocks near the ridge axis (Fig.1). Laboratory experiments to model this mechanism with a Hele-Shaw cell show that the lateral size of the cellular circulation is controlled largely by its depth of penetration (aspect ratio), although the phase may be locked into topographic features.

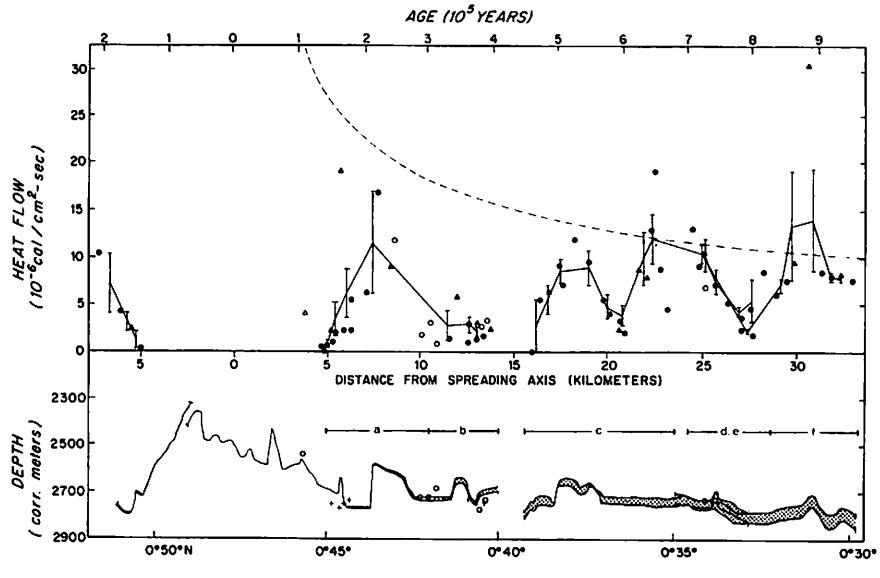

Fig.1 (von Herzen and Williams) Heat flow bathymetry on the Galapagos spreading center at 80°W longitude.

GEOMAGNETIC TIME VARIATIONS

Richard P. von Herzen, Kenneth Poehls, and Paul C. Murray

The sea-floor magnetometer developed in 1972 was successfully tested and obtained useful data during the MODE-I experiment southwest of Bermuda. From March to July 1973 the instrument was deployed and recovered three times at water depths near 5400 m, during which three components of the magnetic field were recorded for one period of eight days, and two successive periods of about 44 days. The recordings appear to have sufficient stability and low noise for a geomagnetic depth sounding or magnetotelluric sounding. Several periods of magnetic storm activity and/or "bay" disturbances were clearly recorded. The data are being processed and parts of the time series analyzed for frequent spectra. We hope to analyze the data in conjunction with simultaneous horizontal electric field recordings at the same site by other investigators.

GEOMAGNETISM

Joseph D. Phillips, Charles P. Denham

Our main research efforts during 1973 have involved an aeromagnetic study over the Greenland/Norwegian Sea, continued analysis of the aeromagnetic data collected south of the Azores over the Oceanographer Fracture Zone, and analysis of new bathymetric, magnetics, and seismic information collected aboard U. S. Navy and Woods Hole Oceanographic Institution ships over the Mid-Atlantic Ridge crest in the FAMOUS area near 36°45'N, aboard R/V *Chain* in the Sierra Leone Rise area and en route to Capetown, S.A. at the start of the SOUTHLANT cruise.

The aeromagnetic study completed over the Greenland and Norwegian Seas extends from 83°N latitude north of Greenland southward to 70°N near Jan Mayen Island and across the entire sea from the Greenland coast to the Svalbard and Norway coasts. The region north of 76°N was surveyed with a U. S. Navy P3C Orion aircraft equipped with a proton precession magnetometer. For the southern region the U. S. Naval Oceanographic Office P3D magnetic survey aircraft was used. The high accuracy inertial/satellite navigation systems of these aircraft allowed a six-mile spacing of track lines which were oriented along small circles about the present pole of opening for North America and Europe (68°N and 137°E). The anomaly trends over the deep ocean portion of the region are essentially parallel to those of the mid-ocean ridge axis. The ridge crest is usually marked by a large amplitude anomaly, generally over 1,000 gammas, which can be easily traced along the Mohns and southern Atka ridges. Sea-floor spreading interpretation of anomaly profiles suggests the crest is made up of numerous spreading axes arranged in an *en échelon* pattern with predominantly right lateral offsets over the Mohns ridge and left lateral over the Atka ridge. The northern Atka ridge is characterized by very low amplitude anomalies (less than 300 gammas), however the ridge crest can still be traced northward to join Nansen ridge, which is marked by larger amplitude anomalies of about 400 gammas. On the flanks of the Mohns ridge anomalies as old as 60 my (Anomaly 24) can be identified while north of the Greenland Fracture anomaly 21 is the oldest sequence observed. Along the Greenland coast a high amplitude long wavelength

anomaly trend is found over the shelf and has been used to infer the continental margin boundary beneath the permanent ice cover.

The analysis of the joint Woods Hole Oceanographic Institution/National Research Laboratory aeromagnetic study over the Oceanographer Fracture Zone south of the Azores is complete. During the last year computer-drawn total magnetic intensity and anomaly contour charts were constructed. These supplement our anomaly profile charts reported last year. These charts showed that the ridge crest central anomaly and anomalies 2' and 5 are easily traced across the entire region between 34° and 37°N. In the vicinity of 35°N specific identification of anomalies out to about 20 my years (Anomalies 1-6) has been possible. A new anomaly-trend-overlay matching technique was employed to estimate the finite rotation pole for the region for anomalies 2' and 5. A pole near 78°N;10°E was calculated with angular rotation rate of 4.5×10^{-7} dg/yr.

In conjunction with Hans Schouten (Vening Meinesz Laboratories, Utrecht), a computer program for calculating and manipulating magnetic anomalies by filtering with Fast Fourier transform methods was developed. Through phase-shifting in the wave-number domain, anomaly patterns can be easily generated which are appropriate to any combination of field direction and two-dimensional magnetization. Conversely, with proper band-pass filtering, magnetic anomalies can be inverted to yield the source magnetization, which can then be upward-or-downward continued to various datum levels.

In addition to our normal bathymetric investigations of the Mid-Atlantic Ridge in the FAMOUS area, a special study was made using ships of the U.S. Naval Oceanographic Office. These ships employed multi-narrow beam sonar systems which provide high resolution detailed topographic information heretofore unobtainable to marine scientists. The rift valley floor between 37°N (Fracture Zone A and 36°15'N (Fracture Zone B) has had virtually total insonification. A two-mile grid pattern of ship tracks with five-fathom contour interval charts has been constructed. These charts reveal that the valley floor is made up of alternating hills, 50-100 fathoms high, and depressions, about 50 fathoms deep, and spaced two to three miles apart along the valley axis. The transform faults, A and B, appear to be marked by well-defined narrow slots about ¼ mile wide and about 50 fathoms deep which connect the offset rift valleys. The rift valley walls are shown to be nearly vertical with several steps which may represent normal fault scarps.

During Leg 1 (Woods Hole to Dakar) of the SOUTHLANT Cruise an east-west profile along 10°N across the Gambia Basin has revealed north-south trending anomalies which have been tentatively identified as the Mesozoic sequence of Larson and Pitman. Anomaly "J" is particularly well-defined. Also on this profile evidence for a new major fracture zone at 11°N;35°W and trending N97°E was obtained.

MARINE SEISMOLOGY

Elizabeth T. Bunce and Sydney T. Knott

Marine seismic investigations other than those under International Decade Ocean Exploration (IDOE) funding, pursued by the Department of Geology and Geophysics concern continuous seismic profiling (CSP); refraction and oblique reflection studies with sonobuoys; bathymetry and studies of the surficial sediments with 3.5 and 12 kHz echo sounders; reflectivity and remote (acoustic or seismic) classification of sediments; correlations of the physical characteristics of cored sediments with the recorded seismic reflections including measurements of the compressional wave velocity in cores; devising instrumentation and its documentation for these tasks; signal processing development; data analyses and documentation; and participation in off-campus study groups. Support for our cruise preparations and field work is largely from the Office of Naval Research (ONR); the data analyses and documentation from ONR and National Science Foundation. Our participation in studies such as the Deep Sea Drilling Program (DSDP), the NSF-IDOE West African Continental Margin and the Gulf of Maine and FAMOUS is supported by their respective grants. Although instrument maintenance and development is largely provided by these ONR and NSF grants, during the past year we have obtained significant support from the Institution's Ocean Industry Program (OIP) for renewal of our seismic equipment and help in cataloging the reflection/refraction station data.

During the recent span of these studies we have, as a major objective, sought to classify the acoustic-mechanical character of the reflection horizons by measurement and analysis of the seismic 3.5 kHz and 12 kHz signals. The commonly used CSP and bathymetric graphic record is a travel time profile of the seismic reflections, only useful qualitatively for deducing the nature of the reflectors. We have been making quantitative measurements using calibrated analog tape recording or direct digital recordings. Reflectivity measurements made for this purpose have been discussed before (Bunce and Knott, 1973; Baggeroer *et al.*,1973); compressional wave propagation velocities in the sediments are being derived from the sonobuoy data. Within the framework of our budgets we must shift emphasis from one aspect of the problem to another, thus we have put more emphasis this past year on examination of the correlation between the seismic record and the actual cored sediments. These studies were pursued in two field programs.

DSDP, *Glomar Challenger*: E. T. Bunce was co-chief scientist with R. L. Fisher of Scripps Institution of Oceanography, during Leg 24 of the drilling program in the Gulf of Aden, Somali Basin, Mascarene Plateau and environs. Bunce, continuing similar studies by J. I. Ewing and others (eg. Ewing and Hollister, 1972), wished to see if it were possible to derive any clear relationship between the characteristics of the drilled and cored sedimentary sequence and the seismic reflection records. Seismic equipment limitations on *Glomar Challenger* (e.g.,long air-gun wavetrains, noisy receiving equipment, lack of a 3.5 kHz system) unfortunately reduced the effectiveness of such a study, but the data were sufficient to show promise for further more refined studies of a similar nature. A discussion of some of the results was presented by Bunce at an ONR-sponsored meeting at Austin, Texas in May: Symposium of Physics of Sound in Marine Sediments (Bunce, 1973).

R/V *Knorr* Cruise #31: Following Deep-Tow operations in the FAMOUS area, a program combining Giant Piston Core (6-inch diameter) operations (C.D.Hollister and A.H.Driscoll), soil mechanics (A. Silva of Worcester Polytechnical Institute (WPI)), CSP, and 3.5 kHz reflection studies (E.P. Laine and E.T.Bunce) and acoustic propagation velocity measurements in the cores (E.P.Laine) were carried out in the Sohm Abyssal Plain. These studies point up a number of problems similar to the theoretical (not instrumental) problems encountered during the DSDP work.

Although it is possible in some instances to correlate "reflections" with variations or discontinuities observed in the cored sediments (e.g., lithology, density, sound velocity and porosity) often a great number of seismic returns cannot be so correlated. For this reason there is a definite need to develop a firm practical understanding of the combined reflection/interference process (Widess, 1973). A firmer grasp must also be gained on the acoustic significance of each apparent change in the characteristics of the sedimentary sequence.

Previous attempts to obtain useful underway 3.5 kHz profiles on board the R/V *Knorr* had been hampered by the high level of ship-generated noise. Since support was not obtained for a 3.5 kHz installation in the bow chamber (See Bunce and Knott, 1973), a system was devised whereby the in-hull mounted array, located in a noisy, even though the deeper part of the ship's hull, was used only in the transmit mode while reception was via the 12 kHz UQN transducers in the bow chamber (the quietest part of the ship) and the towed seismic hydrophone array. Adequate results were obtained from the bow transducers at speeds of up to six knots as long as the forward cycloid was de-clutched and feathered; the array system (when towed at similar speed) was found to be almost as useful but was not required for general purposes.

Measurements were made (Knott and Laine) to calibrate this particular transceiver system. Such calibrations permit us to measure reflectivity on the basis of absolute levels, in addition to measurements relative to the level of the second bottom return (Baggeroer *et al.*, 1973, pp.4,5,Fig.3). Frequency doubling observed on the UQN-1 transducer at frequencies below its normal elector-mechanical resonance makes difficult such quantitative interpretation of the received signals. However, by monitoring the bottom reflection signals within the particular filter bandwidth at which the receiving sensitivity calibrations were made, reflection signals can be related to transmission levels with some reliability. Provision was made to measure the transmit voltage and current (Koelsch), and the transmit levels and receive sensitivities of the transducers were measured in the water beneath the hull. Transmit level of the through-the-hull 3.5 kHz system was also measured on station at sea (Laine) using a single Aquadyne AQ-1A transducer coupled to a seismic array preamplifier and cable system (Knott and Sutcliffe).

During *Knorr* 31, Legs 3, 4, and 5, high resolution reflection profiles were collected in order to correlate the observed reflectors with the funcamental textural and compositional properties of sediments recovered using the Giant Piston Corer. These same profiles were recorded on magnetic tape for later analysis of the effect of constructive and destructive interference of a pulse of finite length on the reflectors observed in the seismic profiles. The interpretation of these seismic data and the analyses of the sediments constitute a part of Laine's thesis and will continue for at least another year.

SOUTHLANT Cruise, R/V *Chain* #115: Similar calibration measurements were performed for the same purposes on the *Chain* prior to her departure (Knott and Laine). This ship is sufficiently quiet to permit reception on the 3.5 kHz array, an in-hull, (ping and receive through the hull) transducer installation (Knott *et al.*, 1970). This array was thus calibrated for both reception and transmission. Linear reception was obtained from the EDO (248B, C) sonar transceivers by tapping into the receive circuit ahead of the gain control and amplifier. Provisions were also made for magnetic tape recording of reflection signals for analysis.

IDOE, South and West African Continental Margin: Throughout this program there has been a continuing effort to reduce the problem of multiple reflection interference due to and while profiling in the relatively shallow waters of the continental shelves (Baggeroer, 1973). It is necessary to obtain, on a shot-by-shot basis, a signature of the downward radiated seismic source waveform in order to make use of the signal processing techniques for multiple reduction involving matched filtering and cross correlation, and for reflectivity measurements. At 3.5 and 12 kHz we can determine the outgoing signal with some reliability by observing the output voltage and current waveforms of the transmitter, assuming repeatable response of the transducer after calibration, but the downward radiated energy of a towed seismic source is less consistently predictable. A system for towing a reference hydrophone 20 to 60 meters below the source was devised and used by Hoskins for a significant period. The hydrophone and its depressor were towed from the bow of the ship (*Atlantis II*) from a towpoint installed near the foot of the stem on the forward observation chamber.

Measurements made at five knots in sea state 1 and wind force 2-3 show that the peak pressure of a 300 cu.in. airgun operated at 1.1×10^7 N/m^2 (1600 psi) was typically 222 db re 1μ Pascal at one meter (122 db re 1 dyne/cm^2 at 1 meter) towed 6.4 m deep. The cross-correlation between successive downward radiated outgoing waveforms ranges from .78 to .98 for 50 samples. It appears from comparison of the waveforms that most of the variability is due to fluctuations in the bubble pulse interval. We attribute this to two effects, one being that the reservoir pressure from the air compressor fluctuated on a two-to-three shot cycle. The compressor charged the shipboard high-pressure reservoir during one cycle and then shut off for one to two gun discharges before recharging it. The second effect is due to fluctuation in the depth of the airgun as it is towed through the water (even in sea state 1). Our present rigging for towing the airgun is with a tow line more nearly horizontal rather than vertical, which serves to better isolate the airgun depth from the pitching motion of the ship. In this configuration the average depth of the airgun is more sensitive to ship's speed, ranging from 5 m at 10 knots to 20 m at 2 knots. This depth could be readily determined with the source monitor by measuring the time difference between the onset of the direct arrival and the onset of the sharp phase-inverted surface reflection.

The sonobuoy analysis procedures and programs that had been established for use with the Sigma 7 computer were adapted (Hoskins) to run on the seismic processing system on board *Atlantis II*. This enabled reduction of data from 170 stations for preliminary examination during the cruise.

General Sonobuoy Data Analyses: We now have over 525 useful sonobuoy stations, of which analyses are completed for about one-third. (Fig.1). The analysis of the more recently collected data tends to be completed more rapidly than for the earlier data by virtue of application of better analysis techniques. A variety of quality standards and formats have been established so that the necessary information for a station can be cataloged and made readily available. The catalog will permit re-examination for interpretation of other such phenomena as shear-wave supported propagation in basement and lithified sediments (Knott, Hoskins and A. Woo).

Instrumentation: A grant from the Ocean Industry Program (OIP) allowed us to purchase new airguns and pulse shapers, two moderate-size electrically driven air compressors, and new tape recording equipment. A portion of a National Science Foundation (NSF) equipment outfitting grant, GD 32877, to the Institution permitted us to build three Z-axis modulated digital-logic controlled XYZ recorders for profiling and sonobuoy work and to purchase new 3.5 kHz transceivers. As a result the *Chain* was outfitted with a new suit of equipment with older equipment as backup. Mechanical design of the new airgun systems was executed by Warren E. Witzell and Earl M. Young, electronic design of the recorder electronics by Donald Koelsch; construction of this electronics, new receiver amplifiers, and testing was done by Carlton Grant, John Connell, Robert Handy and Donald Koelsch; tape recorder maintenance by Clayton Morehouse, Koelsch and Connell, and receiving array maintenance and construction by Thomas Sutcliffe and Sydney Knott. Our presently used ceramic cylinder array is now documented (Knott, 1973).

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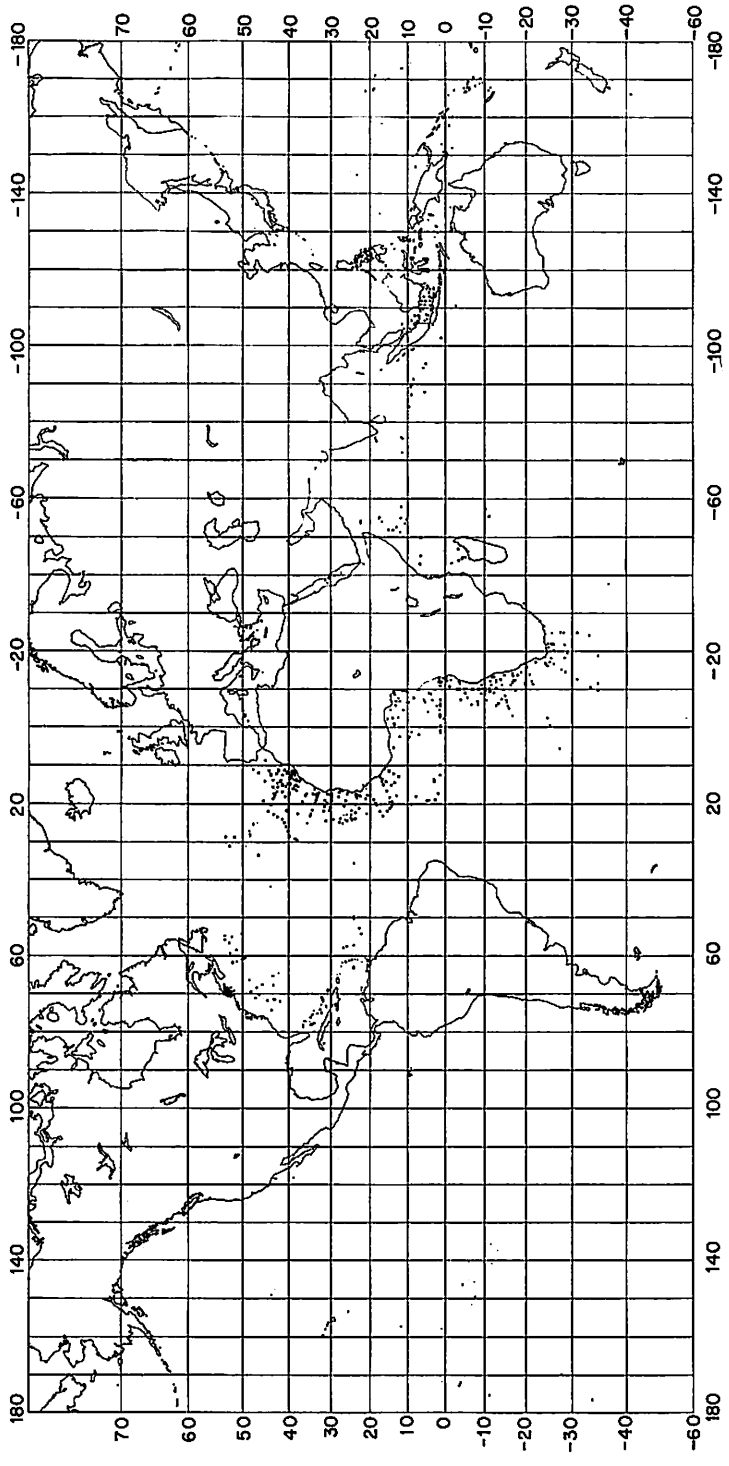

Fig.1 (Bunce and Knott) Oblique-Reflection and Refraction Stations made with Sonobuoys. 1967-1973.

RADIOLARIAN BIOSTRATIGRAPHY AND PALEOCLIMATOLOGY

David A. Johnson

Late Pleistocene radiolarian assemblages were examined in two cores (V24-58 and RC11-209) from the eastern equatorial Pacific Ocean, using recurrent group analysis. The radiolarian "climatic index" curves obtained by this analysis were in close agreement with fluctuations in carbonate levels established previously for the same cores. This correspondence suggests that equatorial radiolarian assemblages changed significantly in response to Pleistocene climatic oscillations. The radiolarian "climatic indices" of the two cores showed close agreement with each other. Our data indicate that equatorial radiolarian assemblages may prove useful for regional correlations between cores, and for paleoclimatic interpretations.

These same two cores (V24-58 and RC11-209) were examined in an attempt to establish an evolutionary lineage for the stratigraphically important collosphaerid *Buccinosphaera invaginata* Haeckel. This species apparently evolved from *Collosphaera irregularis* Haeckel via a series of morphologic changes ultimately leading to the test invaginations characteristic of the genus *Buccinosphaera*. The transition is dated at about 210,000 years B.P. Recognition of this speciation solves the stratigraphic problems caused by the scarcity and poor preservation of *B. invaginata*.

DINOFLAGELLATE STUDIES

David Wall, Barrie Dale

Studies have been continued on both living and fossil dinoglagellates to improve our understanding of their mutual interrelationship. This year's studies were devoted primarily to two subjects, namely, an examination of relationships that possibly exist between living species of the marine and freshwater genus *Ceratium* Schrank 1793 and certain extinct early Mesozoic marine fossil dinoflagellates and secondly, continuance of our studies on dinoflagellate cyst distribution in modern marine environments.

A manuscript is almost completed dealing with the problem of the phylogeny of *Ceratium* and this is being written in conjunction with Professor W. R. Evitt of Stanford University. In this paper we have reviewed previous literature on the tabulation of *Ceratium* and pointed out certain errors and inconsistencies that exist in it. We redescribe the plate pattern of the genus based on new studies of marine and freshwater species and compile a new plate-formula that indicates that this important living genus is gonyaulacid in affinity. We compare the thecae and cysts of living species with fossil cysts from Lower and Upper marine Cretaceous horizons and conclude that modern and these fossil "ceratia" probably are related in an iterative evolutionary pattern that is influenced by the selective fossilization of cysts as compared with thecae. We identify and discuss the particular fossil taxa that we consider to be related to living *Ceratium* and erect a set of morphological criteria by which we believe fossils of this affinity can be identified.

Our work on the distribution of dinoflagellate cysts in modern sediments is at the stage of analysis and synthesis prior to preparation of a manuscript. Groups of samples have been examined from widely separated geographic areas and contrasting marine environments and these are being used to determine patterns of distribution and make deductions about species autecology. Little is known about the distribution of cysts in marine sediments of Recent age and we hope that the results of our analyses will be of considerable value in the paleocology of fossil dinoflagellates and contribute to a better appreciation of their biostratigraphy by revealing how much lateral variation in assemblages can be found on a single time level.

In the course of investigating sediments samples we discovered that cysts in mud from Somes Sound in Maine include certain species in abundance that elsewhere are relatively difficult to capture. Thus we have taken special samples from this fjord-like environment and are attempting to culture cysts from them to further our studies on dinoflagellate life histories.

LATE NEOGENE BIOSTRATIGRAPHY, GEOCHRONOLOGY AND PALEOCLIMATOLOGY

William A. Berggren

Integrated studies of paleomagnetism, radiometric dating and biostratigraphy in marine and continental sediments and rocks provide a secular time scale for the past 10-15 million years (Late Neogene) to which various geologic and biologic events may be calibrated. Multiple planktonic criteria indicate that the Pliocene/Pleistocene boundary is associated with the Olduvai Normal Event (1.61-1.82 my) of the Matuyama Epoch, so that the duration of the Pleistocene Epoch is somewhat less than 2 my.

The Pliocene spans the interval between 5 and 1.8 my; its lower and upper limits can be determined by multiple micropaleontological criteria. Within the Pliocene twelve planktonic foraminiferal and seven calcareous nannoplankton datum levels can be calibrated to the paleomagnetic time scale.

A biochronologic framework of the late Miocene of the Mediterranean is of paramount importance to interpretations of the geologic and geographic evolution of this region and our studies have provided significant information in this area.

The Late Miocene (Tortonian and Messinian stages) spans the interval between approximately 11 to 5 my. The Serravallian/Tortonian boundary lies within the *Discoaster hamatus* Zone (NN15), within the *Globorotalis continuosa* Zone (N15) and at about the *Cannartus petterssoni/Ommatartus antipenultimus* radiolarian zonal boundary. This level is within Magnetic Epoch 10.

Recent data on diatom biostratigraphy suggests that the Tortonian/Messinian boundary is about 6.5-7 my old and lies within Magnetic Epoch 6. This boundary is equivalent to levels within planktonic foraminiferal zone N17 and calcareous nannofossil zone NN11 and also to the base of the radiolarian *Stichocorys peregrine* Zone.

A general correlation and calibration of the Mediterranean-European Pleistocene continental stratigraphic sequence can be made with coeval sequences in North America as well as with the marine stratigraphic record. The Villafranchian spans the interval between 3.4 and 1 my, approximately, and the Pliocene/Pleistocene boundary as defined in the type section at Santa Maria di Catanzaro, Calabria, Italy. The lower and middle Villafranchian (3.4-1.8 my) are equivalent to the Akchagylian (mammalian) Stage and the upper Villefranchian is equivalent to the Apsheronian Stage of the Ponto-Caspian region. The Biharian ($\simeq$ "Cromerian") corresponds to the Gunz-Mindel interglacial and to the later part of the Matuyama and early part of the Brunhes paleomagnetic epochs. The Menapian cold phase (northern Europe) appears to span the later part of the Matuyama (0.9-0.7 my) and overlaps the earliest Biharian. Thus the youngest Villafranchian faunas in Italy lived in a cold climate phase dated at about 1.1 my and are at least as young as the Jaramillo Event (0.9 my) at the base of the Menapian cold phase in the Netherlands. Faunal and paleomagnetic studies indicate that the Tiraspolian and the Ponto-Caspian region is approximately equivalent to the Biharian as well.

Although climatic changes characterize the Pleistocene history of the globe, they cannot be used in delineating the age of its lower boundary. Polar ice built up great thicknesses in Antarctica much earlier than in the Arctic region. Initial ice cap formation in Antarctica may be older than 40 my, and the presence of thick ice sheets is indicated throughout the Neogene, a great advance of grounded shelf ice is linked to Late Miocene Antarctic cooling and the recession of this ice may be correlated to initial Pliocene inundation of the desiccated Mediterranean Basin. Floating ice, calved from sea-level glaciers first appeared in the North Atlantic and the North Pacific about 3.0 my ago. The "long school" of glacial chronology which puts the continental glacial history of Europe and North America in a chronological framework in excess of 2 my is based on false assumptions linking evidence for initial cooling and montane glacial advances with the initiation of major temperature region continental ice sheets. The concensus of opinion is that Neogene cooling was progressive, with relatively rapid increments of lower temperature approximately 1.5 to 1.2 my ago and again from 0.9 to 0.5 my. There is no well-known calibrated evidence to link the base of the Calabrian (beginning of the Pleistocene) about 1.8 my ago with a marked cooling event, and all indications point to the first temperate glaciation at a significantly younger age with the next general lowering of the average temperature.

A general correlation between North American and European paleoclimatological sequences, based on radiometric and paleomagnetic calibration of mammalian biostratigraphy, appears to be corroborated by the deep-sea paleoclimatological record. A salient feature of this correlation is support for earlier research which suggests, contrary to conventional views, that the first two North America glaciations (Nebraskan and Kansan) are represented in Central European climatological history by cold intervals without major lowland glaciation (Donau, Gunz). Details of this correlation bring out the fact that far too many former correlations were naive in supposing that glaciation was independent of regional variations in topography, meteorology or latitude, or that the influence of changing climate on one set of evidence might show different apparent intensities than on another coeval set. In consequence of this it is emphasized that the first continental lowland glaciation

in Central Europe, the Mindel, is equivalent to the most intense glacial conditions of the Pleistocene and to the Illinoian glaciation of North America. This interval of maximum cold climate extended from *ca.* 0.6-0.45 my in deep sea cores and is in agreement with dates on the Mindel and Illinoian continental deposits.

The principle that Northern Hemisphere climate cycles were, in general, synchronous on both continental masses, is upheld, but the assumption that correlated climate cycles had comparable absolute temperature levels is shown to be insufficient.

Sediments of Pliocene and Pleistocene age were recovered at sites 111-113 in the Labrador Sea on DSDP Leg 12. The Early Pliocene planktonic foraminiferal fauna is quite diverse and contains forms typical of low-, mid- and high-latitudes. Biostratigraphically important calcareous nanoplankton are present but rare. The Late Pliocene and Pleistocene fauna is less diverse and tropical forms are rare, being essentially restricted to carbonate intercalations in Late Pliocene glacially-rafted detrital sediments. Semi-quantitative faunal analysis suggests that the Gulf Stream (or analogue) had a strong influence in the region of Orphan Knoll (site 111) during the Early Pliocene. In the earliest Late Pliocene the following sequence of events took place: 1) a reduction in the influence of the Gulf Stream over Orphan Knoll, 2) the initial appearance of ice-rafted debris ($\sim$3 my), and 3) the invasion of the entire Labrador Sea by polar waters. During the remainder of the Late Pliocene, the Gulf Stream had a sporadic and less pronounced influence on the Orphan Knoll area than in the Early Pliocene. This influence did not extend to site 112. No evidence of Gulf Stream influence is seen from Pleistocene levels in the Labrador Sea.

Using a Pliocene time framework provided by paleomagnetically-calibrated biostratigraphic datum levels, the Labrador Sea section has been correlated with the Pliocene of NE Pacific (DSDP site 36), the Mediterranenn (DSDP site 142) and New Zealand. The sequence of floral and faunal events in the Labrador Sea and the Mediterranean are in good agreement. Correlation with New Zealand, based on age estimates for paleomagnetic events, suggests that at least the upper portion of the Kapitean Stage of New Zealand is Early Pliocene rather than Late Miocene age.

STUDIES IN PALEOGENE BENTHONIC FORAMINIFERA

William A. Berggren

We are studying Paleogene benthonic foraminifera from various parts of the world with a view towards understanding their biostratigraphy, biogeography and bathymetry and utilizing them in local and regional geologic studies. Two specific studies were completed during the year and the general conclusions are outlined below.

The Paleocene of the Sirte Basin (Libya) is developed in a structurally controlled embayment of the Tethys Sea which extended southwards as far as the Chad border (Tibesti Mountains). The Paleocene of Mali is developed along the inner shelf margin of a broad, shallow seaway in which organogenic carbonates accumulated and which extended from Algeria to northern Nigeria. Comparison

of their respective benthonic foraminiferal faunas yields the following information: 1) the assemblages in Mali are dominated by shallow water cibicidids, rotaliids, rosalinids, nonionids, elphidiids, and various "larger" foraminifera; planktonic foraminifera are rare or absent; 2) the assemblages in Libya are developed in two lithotopes: one, similar to that in Mali and containing numerous faunal elements in common and a second, deeper and developed in a basinal shale environment and containing a typical "Midway" type fauna, together with planktonic foraminifera; precise biochronologic control of these different assemblages is afforded by the planktonic foraminifera; 3) vertical and horizontal relationships between the benthonic foraminiferal assemblages in the Sirte Basin are shown and paleoenvironment reconstructions are made at approximately two million-year intervals in the Paleocene; 4) the Paleocene of Mali was deposited in a broad shallow shelf sea at water depths probably less than 50 m. The Paleocene of the Sirte Basin (Libya) was deposited in a transgressive sequence characterized by basinal infilling. In the axial region of the central and southern part of the basin sediments of the early and middle Paleocene may have been deposited at depths somewhat in excess of 200 m; during the late Paleocene sediments in the axial part of the basin were probably deposited at depths between 100-200 m. One must probably look north of the present-day shoreline of the Sirte Embayment for deeper water sediments of late Paleocene age. Laterally the basinal shales may be traced into middle and inner shelf carbonates which were deposited at water depths between the shoreline and 50 m.

A variety of paleocologic and lithologic evidence indicates that Rockall Bank subsided from 0-$\sim$600 m over a five-million-year interval of Late Paleocene-Early Eocene time (t = 56-51 my). As such it is a natural laboratory in which to study the paleoecology of early Paleogene benthonic foraminifera.

About 70 taxa of benthonic foraminifera are recorded in the early 3-4 my of this subsidence history and in a stratigraphic sequence interpreted as representing a subsidence of from 0-200 m. Three depth-controlled faunal assemblages are recognized and the changing composition of the fauna is a direct reflection of the early subsidence of Rockall Bank. The lower (inner neritic: 0-10 m) and middle (middle neritic: 10-100 m) assemblages are late Paleocene in age, contain numerous elements of the Midway fauna of the Gulf Coast, and are dominated by nodosariids and polymorphinids. They are distinguished by the presence in the lower (shallower) assemblage of *Operculina* sp. and *Pararotalia tuberculifera* and their absence in the middle (deeper) assemblage. The upper assemblage (outer neritic: 100-200 m) is of early Eocene age and contains elements of the Lower Eocene three faunas of northwestern Europe. Comparisons are made with similar faunas recorded in age-equivalent deposits elsewhere in the circum-Atlantic-Mediterranean region.

PALEOGENE CALCAREOUS PLANKTON PALEOBIOGEOGRAPHY OF ATLANTIC OCEAN

Bilal Ul Haq, Isabella Premoli-Silva and William A. Berggren

During 1973 selected horizons of the Lower Tertiary deep-sea cores from Atlantic were studied in detail for their planktonic foraminifera and calcareous nannoplankton contents. After a preliminary investigation 12 time-slices were chosen for a detailed study of floral and faunal content and statistical analysis. These time-slices represented by following calcareous nannoplankton zones are about 3 to 4 my apart: *M. astroporus* Zone; *C. danicus* Zone; *F. tympaniformis* Zone; *D. multiradiatus* Zone; *M. tribrachiatus* Zone; *C. alatus* Zone; *R. umbilica* Zone; *I. recurves* Zone; *H. reticulata* Zone; *S. predistentus* Zone; *S. distentus* Zone and *S. ciperoensis* Zone, and have the widest possible geographic coverage in DSDP cores from the Atlantic, in the North Sea and Europe and in the Caribbean and Gulf of Mexico. The data thus gathered is being applied in the following lines of investigation:

1) Development of a boreal province after the opening of the North Atlantic and changes in biogeography as a reflection of changes in the paleocirculation patterns with time.

2) Fluctuations in the diversity of calcareous plankton as a function of changing environments and climates.

3) Test of proposed plankton diversity models to account for major highs and lows in the evolutionary rates of calcareous plankton (see Haq, 1973).

After the quantification of the diversity data and delineation of the paleobiogeographic provinces the data will be reduced and plotted on maps of paleo-Atlantic generated for each time-slice studied.

Reference

Haq, B. U., 1973 Transgressions, climatic change and the diversity of calcareous nannoplankton. *Marine Geology* 15: M25-M30.

TAXONOMICAL INVESTIGATIONS ON PALEOGENE PLANKTONIC FORAMINIFERA

Isabella Premoli-Silva

A significant contribution to our knowledge on the evolution of planktonic foraminifera was afforded by the recovery of lowermost Paleocene sediments during some Deep Sea Drilling Project (DSDP) cruises in the South Atlantic, northwest Pacific, Gulf of Mexico, and particularly, in the Caribbean Sea.

The exceptional state of preservation of the foraminifera occurring in the Caribbean cores allowed the first detailed description of an assemblage attributed to the *Globigerina eugubina* Zone, which was established by Luterbacher and Premoli-Silva in 1964 for the earliest Tertiary foraminifera assemblage from the Gubbio section (Perugia, central Italy).

It is apparent that the *Globigerina eugubina* Zone contains the most primitive paleocene planktonic foraminiferal assemblage known until now and that all Paleogene genera can be derived either directly or by inference from this fauna.

DISTRIBUTION OF COCCOLITHS THROUGH THE SURFACE AND DEEP-SEA WATER COLUMN IN THE MID-PACIFIC: THEIR CONTRIBUTION TO THE BOTTOM SEDIMENT

Susumu Honjo

The mode of distribution and community structure of coccolithophorid species along a mid-Pacific meridian (155°W) from 50°N to 15°S were studied. A variety of data for investigation of coccosphere/coccolith community was collected from samples of surface film water, photic and near photic water layers (from 10 m to 200 m in late summer) and the aphotic water column from approximately 200 m to near bottom (a maximum of 5,500 m). The diversity (H') of coccolith species in the aphotic layer decreases rapidly with depth and northward direction in the Transitional Zone and Central Gyre. Diversity remained almost unchanged between 10°N and 10°S throughout the aphotic water column. The technique for computation of percentage similarities was used extensively to observe the transition of community structure between productive and non-productive water layers. The provincialism of coccolithophorid species distribution in the photic water column was not replicated in the deep water column except in Equatorial areas.

The number of suspended coccoliths decreased rapidly at the water depth between 400 m and 1000 m in the Transitional, Central, and Equatorial Zones. Strong dissolution occurred between 3,500 and 4,000 at those three zones. In the Transitional Zone approximately 99.9% of coccolith production at the bottom of the photic layer disappeared at the 4,000 m level, 99% in the Central Zone, and 90% in the Equatorial Zone.

The electron microscopic study showed that dissolution and destruction of coccoliths varied from species to species in one deep-water sample. The relationship between the depth, latitude and the degree of dissolution/destruction of coccolith species has been classified, however, many excellently preserved, fragile species have been found at great depth. Besides, the rates of accumulation contributed by the free-fall coccoliths are too small to explain the coccolith ooze sedimentation. Such discrepancy between the sedimentation model of suspended coccoliths and reality suggests direct mass transportation of coccoliths from upper productive layers to the sea bottom. A vehicle for such rapid descent through the water column may be fecal pellets of predators.

GROWTH RATE AND COCCOLITH FORMATION OF TWO COCCOLITHOPHORID STRAINS AS DETERMINED BY TEMPERATURE AND SALINITY

Susumo Honjo and Dag Klaveness

The two coccolithophorid strains used in this study were collected from surface waters of the Oslo Fjord, Norway, and at a depth of 1000 meters in the Sargasso Sea, respectively, in order to provide a strong contrast in environment.

The study was conducted with three variables in mind. Temperature and salinity vs. growth rate were plotted simultaneously in order to determine each species' adaptability to a wide range of environmental conditions. Throughout the experiment all possible variables, such as light intensity,

were maintained constant. Coccolith formation was also observed at different growth rate levels.

The Norwegian strain realized optimal growth at 23°C, 20°/oo, the Sargasso Sea strain at 18°C, 20°/oo. Using the identical temperature/salinity combinations, it was further determined that perfect coccolith formation for each strain occurred only under their respective maximum growth conditions. Similarly, coccolith malformation became increasingly prevalent in each strain as the environmental conditions moved toward the extreme.

THE EFFECT OF PCB CONCENTRATIONS ON GROWTH RATE AND COCCOLITH FORMATION IN *Emiliania huxleyi*

Susumu Honjo, Dag Klaveness*, Nicholas K. Fisher**,
and Anne C. Collins

The purpose of this study was to determine the effect of various dilute polychlorinated biphenols concentrations on both growth rate (cell division) and coccolith formation in *Emiliania huxleyi*, which was collected in the Central Atlantic waters.

In the first phase of the experiment, *Emiliania huxleyi* was exposed to dilute PCB concentrations of 0.1 ppb (parts per billion), 10 ppb, and 25 ppb, respectively, for a period of 240 hours, in order to determine a growth curve. Using the rate of cell division per day as the growth indicator, the following was observed. *Emiliania huxleyi* demonstrated no apparent negative effects in its cell division process at the 0.1 ppb level. At the 10 ppb level, significant impairment to cell division was observed, and at the 25 ppb level, a lethal dose, no cell division occurred. It was further observed that after three days exposure at the 10 ppb level, *Emiliania huxleyi* appeared to have recovered, with a return to a normal cell division rate.

During the second phase of the experiment, concerned with coccolith formation, *Emiliania huxleyi* was exposed to the same dilute PCB concentrations described above. Prior to exposure, it was necessary to strip the coccolithophorids of their coccoliths through CO_2 bubbling. The culture was gently bubbled with a mixture of 5% CO_2 in air for approximately 20 minutes, thereby lowering the PH to a level sufficient to dissolve all the coccoliths, leaving only the naked cell. The culture was then rebubbled with air to restore the PH level to normal sea-water, and thereby instigate coccolith formation. The following was observed after several hours of exposure period. At the 0.1 ppb level, where previously no growth rate deviation had been observed, suggestive malformation of coccoliths was detected. (The effect of PCB at this concentration level requires further elective-microscopic and statistic study before any conclusion is drawn.) At the 10 ppb level, coccolith formation was more obvious. The ability to form normal profligations had apparently been lost. At the 25 ppb level, the great majority of coccolithophorids did not produce coccoliths or were apparently dead. It was further observed that after 22 hours at the 10 ppb level, *Emiliania huxleyi* had recovered to approximately the similar production quality level observed at the 0.1 ppb level.

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NON-COMBUSTIBLE SUSPENDED MATTER IN SURFACE WATERS OFF EASTERN ASIA

Susumu Honjo and Kenneth O. Emery

A total of about 1100 well-distributed samples of suspended matter in surface waters off the length of eastern Asia are available. From these, 180 samples were selected for detailed examination of the non-combustible fraction using optical and electron microscopy along with a package of computer methods for precise particle measurement and counting.

The following charts of various hydrographical, geological, sedimentological, and biological parameters were present from the East China Sea, South China Sea (Sunda Shelf), and the Java Sea: temperature, salinity, total suspended sediment, combustible fraction of suspended sediment, size fraction of mineral grains, ratio of mineral grains to the suspended sediments, sorting coefficiency of grains, distribution of diatoms, silico-flagellates and coccolithophorids.

The results showed that generally all major components are most abundant in the nearshore belt (combustible fraction, mineral grains of silt size, skeletal debris, and clay minerals), the result of mechanical transport of detrital sediment and chemical transport of nutrients from the land. Mineral grains of silt size averaged about 2%, skeletal debris plus clay minerals - 20%, and combustible organic matter - 75%, but the last two categories vary over a wide range depending upon geographical positions of the samples. Most evident is an oceanward decrease in percentage and concentration of the total non-combustible fraction.

The suspended matter in surface waters in those areas average about 2% mineral grains (chiefly quartz, feldspar, and mica) of silt size, with the remainder ranging from 90% skeletal debris plus clay minerals to 100% combustible organic matter. The mineral grains have median diameters mostly between 4 and 12 microns and are most concentrated off the mouths of large rivers, but the largest median diameters occur in offshore regions, perhaps because the smaller grains were floccucated and deposited with clay minerals or tended to be deposited as faecal pellets. The skeletal debris also is more concentrated in nearshore than offshore belts, but its weight relationship to clay minerals cannot be accurately established by optical or electron microscopy owing to irregular shapes and porous nature of the debris. Most numerous by far are frustules of marine diatoms followed in order by those of coccolithophorids, silicoflagellates, and radiolarians. The diatoms and coccolithorids were more concentrated in the South China Sea, whereas the silicoflagellates and radiolarians were more concentrated in the East China Sea.

THE TOKYO SURFACE SHIP GRAVITY METER: RECENT DEVELOPMENTS AND RESULTS OF COMPARISON MEASUREMENT

Jiro Segawa* and Carl Bowin

The Tokyo Surface Ship Gravity Meter (T.S.S.G.), which uses a single vibrating string accelerometer, formerly had a problem that resulted from non-linear rectification errors. This has been solved by using a newly designed processor which is based on a rapid sampling of the frequency of the accelerometer. A comparison of the T.S.S.G. equipped with the new processor and a gyro-stabilized LaCoste and Romberg (L&R) meter was carried out on board the R/V *Hakuho-Maru* of the Ocean Research Institute, University of Tokyo, between October and December of 1972. By means of this comparison we confirmed that the T.S.S.G. performance is comparable with that of the L&R meter. A comparison between results from the new processor and the processor previously used was also made on board the R/V *Shoyo* of the Hydrographic Office, Japan. This study has shown that the non-linear rectification errors suspected in the case of the conventional method, when properly corrected through digital data processing, resulted in unexpectedly small errors in gravity measurement as long as short-period environmental accelerations were not great. This result assures us that most of the data which were obtained for the past ten years from the T.S.S.G. are reasonably accurate (±10 mgals).

A NEW GIANT PISTON CORE

Charles D. Hollister, Armand J. Silva, Alan H. Driscoll

A new large piston coring device utilizing well-casing pipe 14 cm (O.D.), 11 cm (I.D.) has obtained cores over 20 meters in length in water depths of 100 to 5,000 meters. Recovery ratios range from 0.76 to 0.87. Penetration varies between 24 and 29 meters with a total core weight of 3,200-4,000 kg and 2 to 3 meters of free fall.

Pullout resistance was about half of the average shear resistance as measured with a vane device. Results of consolidation tests in the Gulf of Maine cores indicate that the sediment is normally consolidated thus ruling out the probability of compaction by grounded ice. Visual observations and consolidation studies indicate that structural disturbance of the sediments was minimal and clearly much less than that noted in the standard 6 cm diameter piston cores. Preliminary correlations with 3.5 kHz sub-bottom profiles taken at the coring site suggest that anomalous zones of high shear strength and high water content produce reflecting horizons.

The success of the first few trials indicates that it is feasible to obtain larger cores using a larger, modified version of the standard piston-corer. The only requirements are a large ship, at least two A-frames and strong wire. Until the development of more sophisticated driving mechanisms such as sonic vibration and hydraulic jetting, the intention of the Woods Hole Oceanographic Institution - Worcester Polytechnical Institute coring program is to upgrade and enlarge upon the original piston coring concept, developed over 20 years ago.

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The longest (3050 cm) deep-sea piston core yet taken was recovered from 5000 meters of water depth on the Bahama Outer Ridge with the W.H.O.I. Giant Piston Corer. Twelve cores averaging over 24 meters of nonflow-in sediment were recovered during the summer of 1973 from various sedimentological/acoustic provinces in the abyssal western Atlantic on the R/V *Knorr*. Preliminary at-sea observations suggest that there is a positive correlation between changes in physical properties and the presence of 3.5 kHz reflecting horizons.

A SELF CONTAINED DEEP SEA ROCK DRILL

David L. Williams, Raymond Davis, Richard P. von Herzen

This past year was spent optimizing the drilling parameters, improving reliability and completing the final phases of drill development. In order to facilitate this work, the remaining testing was done at the Woods Hole Oceanographic Institution dock, rather than with *Alvin*, and included preparation for deep sea trials from a surface ship.

After several modifications to increase reliability, the drill was employed as a test stand, primarily to gather engineering data towards determining a better bit configuration and secondarily as a continuous check of drill reliability. During June and July the drill was lowered eighteen times into 50 feet of water for fully automatic systems operations. Together with nine dry runs on the dock, 257 inches of core were produced by five different bit configurations. One bit type clearly out-performed the others in achieving drilling rates of over 2½ inches per minute and now enables the drill to recover cores in excess of one meter.

Following strengthening of the structural framework, the drill was lowered from the R/V *Gosnold* to depths up to 1200 feet for the purpose of recovering rock cores in the Gulf of Maine (Fig.1). Seven cores were recovered with six more attempts unproductive due to difficulty in locating rock outcrops. Cores were mainly granite, although the dock testing showed that drilling oceanic basalts is comparable.

The drill can now be effectively utilized from either a DSRV, such as *Alvin*, or a surface vessel to recover bottom samples from the oceanic crust. Future plans include bottom sampling during the joint FAMOUS venture in 1974, and for a similar study of the Galapagos Spreading Center in 1975.

GEOTHERMAL STUDIES IN DEEP SEA DRILL HOLES

Richard P. Von Herzen and Albert J. Erickson

Measurements of heat flow were made at several sites on Leg 31 (Western Pacific and Japan Sea) of the Deep Sea Drilling Project (DSDP), as part of a continuing program. Two improved downhole instruments were constructed, to replace one lost on Leg 26, and the on-deck readout equipment has been refurbished after several years of use. A digitized thermal conductivity system was constructed and has been in operation aboard the drilling vessel *Glomar Challenger* since Leg 31.

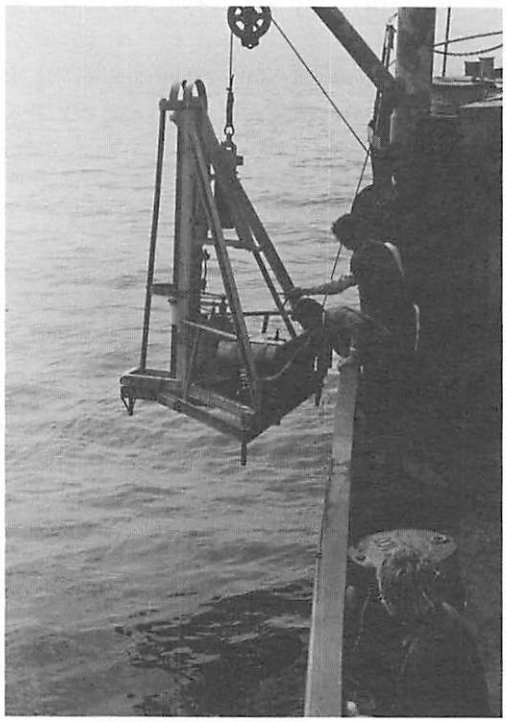

Fig.1 (Williams, Davis and von Herzen)

GEOLOGICAL SAMPLING

Alan H. Driscoll

a. Digitization of Sediment Core Collection

A relatively simple, but highly versatile system for computerizing the geological samples stored at the Data and Earth Sample Center (D.E.S.C.) building was begun in September of 1973.

When fully operational, this system will make it possible to obtain a listing of all geological samples in storage as well as an ability to sort out individual station by any one of the following: station, latitude, longitude, marsden square, water depth, physiographic provinces, rock type or sediment type, sampling device, or sample length or volume.

A manual has been written (Gregg Mountain, W.H.O.I. Ref.No. 73-54) which describes the procedure for handling data obtained from individual stations.

Work is currently in progress to complete the digitization of all the samples and to record this information on magnetic tape.

b. Replacement of Lost Sampling Equipment

A program was begun in April of 1973 to improve the status of the geological sampling equipment inventory. At present the program has been completed and rarer items of equipment are already in use on *Chain*.

Specifically the nonmagnetic core weights, fifteen pressure housing and associated smaller parts were purchased to replace items lost at sea over the past three years.

The equipment inventory is now at a stage where individual items are readily available for use at sea.

c. Coring Dynamics Studies

A short study has been undertaken to determine the effects of wire rope stretch on the standard picton core during *Chain* Cruise 115. Preliminary results of these tests have indicated that the larger portion of the wire rebound is absorbed by the pilot core and that only a small portion of this rebound works directly on the piston.

Analysis of all the samples and available data is still in progress at this time, and it is not possible, at present, to accurately determine the effects of the rope stretched on the core sample.

CSP DIGITAL ACQUISITION AND PROCESSING

Kenneth E. Prada and Arthur B. Baggeroer

The system for digital acquisition and processing of Continuous Seismic Profiling (CSP) data underwent extensive expansion and modification during late 1972 and early 1973. The changes resulted from experience gained during the 1972 Eastern Atlantic Continental Margin cruise, and were implemented in preparation for the 1973 field work.

a. Data Acquisition

The significant change to the acquisition portion of the system involved analog-to-digital conversion. The 10-bit converter used during 1972 lacked sufficient dynamic range for the seismic signals. A new converter with 15-bit resolution was installed. Modifications also were made to permit automatic input of the parameters associated with each sample cycle. These parameters included day, time, sample rate, delay from shot instant, course, and speed.

The acquisition software package incorporated extensive revisions reflecting the hardware changes. Data gathered during 1972 showed a need for constant quality control analysis. The new acquisition package provided this analysis in real time, and enabled the operator to exercise better judgment in the adjustment of system parameters. The recorded data format was changed to include the available acquisition parameters. The continuous recording of these parameters was valuable to the processing operations since changes could be accommodated without operator intervention.

b. Shipboard Processing

Hardware changes to the CSP processing computer system were extensive, based on a need for more data storage area and increased processing speed. The earlier processing computer was replaced by a model 2100 Hewlett-Packard computer with 32K words of core memory. A hardware floating-point arithmetic processor option was included to provide more than an order of magnitude increase in processing speed. Disc mass storage facilities were installed, with a 2.5 million word storage capacity. The

disc mass storage enabled versatility and speed in software development; and the large random access storage required for some of the complex processing operations. Graphic output facilities were improved by the addition of a multi-purpose plotting unit. The plotter, with associated interface, was designed in-house to provide X-Y graphics for waveform analysis and variable printing density for display of processed CSP data.

The processing software implemented both current technology in signal processing and some unique methods (Baggeroer, 1973) particularly related to the single channel nature of the system and data. Implementations of the current technology involved:

1) Stacking of successive time series with selective use of weighting and time offset between sample sets.
2) Digital filtering with variable limits on cutoff frequencies.
3) Time expansion for high resolution display of short term events within the sample window.

The unique aspects of the processing package principally involved the dereverberation of water column multiples which mask real reflections in shallow water depths. This was done using tapped delay line concepts developed in radar and sonar signal processing. A useful by-product of this deconvolution was a measure of bottom reflectivity, which could be encoded on the processed data displays. While the results of the multiple deconvolution were good in traverses along the continental slopes, the improvements realized in very shallow water (less than ¼ second) were not sufficiently useful because of the extremely large amounts of reverberation encountered. For this reason a six-channel CSP acquisition system has been proposed and accepted. Implementation of the six-channel system will occur during 1974 in preparation for field studies on the continental margin of Brazil during 1975.

Hartley Hoskins prepared a towed hydrophone arrangement for monitoring the output of the air gun source. The signature information thus derived was digitally recorded and processed. The work provided valuable results regarding source repeatibility and the use of signatures for envelope deconvolution and filtering. Programs for sonobuoy refraction data analysis were adapted for use on the shipboard CSP processing computer system by Hoskins. At-sea velocity determinations were made easily possible by these adaptations.

Reference

Baggeroer, A.B., 1973 Tapped delay line models for the dereverberation of deep water multiples, *Woods Hole Oceanographic Institution* Tech.Rep.73-66, Oct.1973 (in press, *IEEE Transactions on Geoscience Electronics*).

DATA HANDLING

Bruce P. Luyendyk, Charles Denham, Robert C. Groman

The data handling group is responsible for the management of marine geophysical data obtained by Department members aboard Institution and other vessels and aircraft. Data processing and computer programming continued to be our major effort. Processing of current Woods Hole Oceanographic Institution cruises included *Atlantis II* Cruises 68, 72, 73, and 75; and *Knorr* Cruise 31. In addition, we have continued to digitize older Institution data. As of this writing, we have virtually finalized both the navigation and bathymetry for 10 cruise legs of data.

The software packages for the shipboard and shore-based computers have been improved to facilitate their use and expanded to provide more options to the user. We have continued to maintain over 25 commonly-used programs as element files on DISC at the Sigma 7, as well as maintain our Sigma 7 library of over 80 subroutines and functions. New programming efforts included a geomagnetic analysis program which makes use of the Fast Fourier transform to synthesize and phase shift anomalies from magnetization values. This program permits easier identification and comparison of magnetic anomalies at different latitudes and strikes. In addition, we have developed a program package to process and display data acquired from a bottom-towed sled. This may include bottom magnetics, temperature and topography which are merged with acoustic navigation in Cartesian coordinates and is plotted on x-y charts or in profiles. This processing package has been used successfully on both the *Knorr* deep-tow cruise and the *Atlantis II* FAMOUS cruise.

As in the past, all finalized data are stored at the computer center with back-up copies stored at the DESC building. This includes over 500,000 line kilometers of navigation data. Quarterly lists of finalized data are distributed to Department personnel to keep them informed of available data. Data history forms are now routinely completed for each cruise leg to preserve the processing details and subsequent distribution. The graphical reference system, project MYLAR, is ready for publication. We have divided the world into eight areas at a scale of 0.36 inches per degree (standard H.O.World Chart). For each area, there are four MYLAR sheets on which are plotted ship's tracks, magnetics, gravity and bathymetry profiles. In addition to this geographical reference we have begun a new effort to produce library profiles of all underway data versus time. For each cruise leg, bathymetry, magnetics, and gravity (when available) are plotted beside each other to provide an accurate and convenient visual summary of the data. This project is about 60% complete.

The Digital Data Library System (DDLS) is now operational, although all user options have not yet been implemented. DDLS consists of a set of programs to build, maintain, and retrieve digital data from blocked magnetic tapes. It enables a scientist, without extensive knowledge of programming or computer operations, to retrieve data by area, cruise, and time, and produce lists, charts, and profiles. During this year we have completed the data transfer from individual tapes to multifile blocked tapes. All of our digital data is now stored on only five magnetic tapes.

We have continued to disseminate data in accordance with OCEANAV instructions. Older cruises which have been recently finalized as well as newer gravity and magnetics data have been distributed.

ANGUS CAMERA FISH DEVELOPED FOR PROJECT FAMOUS

Alan H. Driscoll and Joseph D. Phillips

An acoustically navigated camera fish capable of being towed within four meters of the bottom while height above the bottom and relative position within the transponder net are monitored from the surface ship, was developed for Project FAMOUS in late 1972.

The fish can be instrumented with an EG&G model 250 survey camera in either stereo pair of single camera mode, two strobe lights, 12 kHz pinger to determine the height of the fish off the bottom, thermistors and telemetering pinger for a record of bottom water temperature, and a water-sampling device such as a Nansen bottle which is triggered from the ship.

Since its first deployment in 1972 and later use in 1973 a series of modifications to the fish have been carried out which have substantially reinforced its basic structure as well as providing the fish with a self-steering capability in the direction of tow.

The incorporated survey camera system is capable of photographing the sea floor at eight-second intervals for up to six hours while direction and speed over the bottom are controlled from the surface ship. To date approximately 20,000 bottom photographs have been recovered as well as a series of bottom water temperature and bathymetric profiles.

The ANGUS fish has become a major tool in the initial surveys of the FAMOUS area and its continued usage on future cruises is planned.

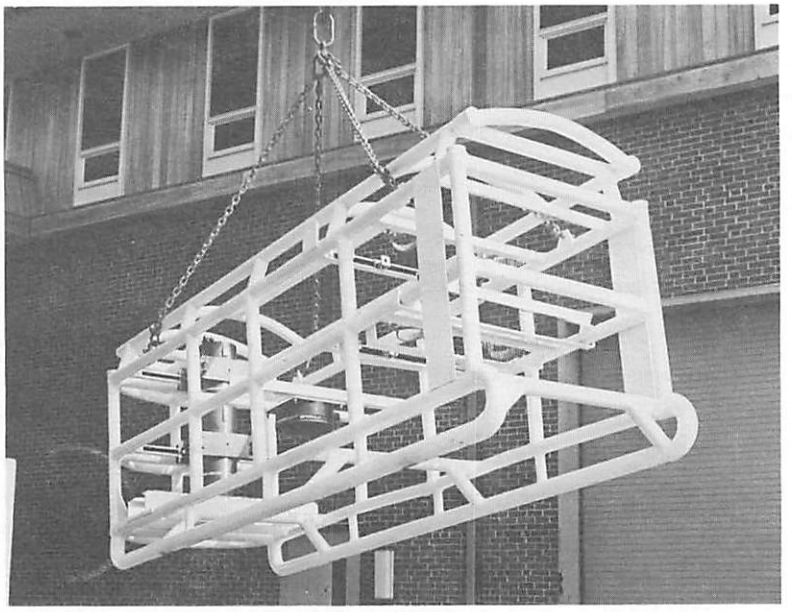

Fig.1 (Driscoll and Phillips) Structural framework of the ANGUS fish with single camera and transducer mounted.

A NEW NEAR-BOTTOM GEOLOGICAL SURVEY TECHNIQUE

Joseph D. Phillips, William M. Marquet, Andrew H. Eliason, Kenneth R. Peal,
Alan H. Driscoll, Carlton Grant, Jr., and Donald E. Koelsch

Detailed investigations of the Mid-Atlantic Ridge crest in the FAMOUS area near 36°N have required the development of new tools for resolving the fine scale features of the sea floor. Among these tools a new Acoustically Navigated Geologic Undersea Survey System (ANGUS). This system was used to position and accurately navigate tethered devices (FISH) such as cameras, dredges, cores, and heat flow probes as well as surface sonobuoys and ships during *Atlantis II* Cruises 73 and 77. The essential elements of the system include (1) two or more bottom-moored AMP acoustic transponders (Model 324), (2) an on-deck AMP signal processing unit, model 204, which is coupled directly to the standard Woods Hole Oceanographic Institution shipboard Hewlett Packard 2100 series computer system, (3) a relay transponder attached to the tethered devices, (4) an FM radio link for monitoring the surface sonobuoy position aboard the ship, (5) a hull-mounted transducer aboard the surface ship for interrogating the various transponders, (6) extensive real time, as well as analytical computer programs for acquiring, processing, and editing the acoustic signal information.

The system is designed for both real-time monitoring of the position of tethered fish and sonobuoys/ships as well as digital recording for post-cruise analyses. The former feature is a most important characteristic of the system in that real-time observations allow precise maneuvering of the ship and/or fish for positioning the sensor in any desired location. To accomplish such real-time monitoring, the location of the ship/fish in the horizontal plane is displayed on a techtronics oscilloscope unit (CRT). The water depth and altitude of the tethered fish off the bottom are displayed on a CALCOMP graphic plotter. The altitude information is obtained by use of a new, delayed "bottom bounce" mode of operation for the relay transponder aboard the fish. That is, the time difference between the direct signal arrival from the fish transponder and signal which is reflected from the sea floor is used to estimate fish altitude. This measurement when added to the fish depth information provides the total water depth. In this way a near-bottom topographic profile can be obtained. Further discussion of the various devices which have utilized the ANGUS system and scientific results are included in other sections of this report. (See A. Driscoll and J. Phillips, "ANGUS camera fish developed for project FAMOUS", S.I., 1973, pp.GG-63; W. Bryan "Geology and Petrology of the FAMOUS area at 36°N",S.I. 1973, pp.GG-17; R. Porter and R. Spindel, "Array Coherence, Experiment and Analysis", S.I. 1973, pp.OE-51; R.von Herzen and D. Williams, Geothermal Investigations in Oceanic Regions", S.I. 1973, pp.GG-40; J.Phillips *et al.*,"*Atlantis II* Cruise 73/77: Geophysical and Geological Studies", S.I. 1973, pp.GG-15.)

Department of Ocean Engineering

Earl E. Hays, Department Chairman

THE DEEP SUBMERGENCE ENGINEERING AND OPERATIONS SECTION

William O. Rainnie, Jr. and Lawrence A. Shumaker

Introduction

At the beginning of the year, the DSRV *Alvin* was in the high bay area of the Iselin building being prepared for receipt and installation of the new titanium hull. R/V *Lulu*, with a minimum crew assigned, was undergoing routine maintenance at the Institution dock.

Early in January, a Project FAMOUS (French-American-Mid-Ocean Study) planning meeting was held in Woods Hole attended by a large group of scientists and engineers from many countries. More detailed plans were developed including an additional field trip and further exchange of personnel between France and the United States. Several additional cruises to the FAMOUS area also were firmed up at this meeting.

The first titanium hull was scheduled to arrive in Woods Hole in late March after a test program at USNR&D Center, Carderock, Maryland, designed to establish the predicted collapse depth. An extensive study and collection of the quality assurance data for the hull was conducted during the spring in order to establish the safe operating depth as well as to acquaint the staff with the characteristics of the alloy used in this project. Of special interest were questions concerning useable yield strength, stress corrosion and creep.

A significant portion of the engineering staff was involved in direct support of the conversion of *Alvin*. In addition, several major projects were continuing in development: SCAMP (Self Contained Auxiliary Modular Platform), Submerged Navigation, and Instrumentation for Project FAMOUS being the principal ones in this category. All of these activities will be discussed later in this report.

One of the major problems facing the Section during this year was finding adequate support in the face of reduced Federal budgets for submersibles.

In April, Mr. Shumaker assumed the duties of Section Head from Mr. Rainnie, who was assigned other duties within the Institution

During April, May and June work continued on readying *Alvin* for deeper depths. From 20 June through 17 July *Alvin* underwent a series of pressure tank tests at the Naval Ship Research and Development Center at Annapolis. These tests are discussed later in this summary. One of the major discoveries during this period was the advanced state of deterioration of the main ballast tanks. Nearly all of August was used to manufacture and install new ballast tanks and re-do inclining and stability tests. During September and October several test dives were made off Provincetown and quite a bit of time was spent in remedying minor discrepancies uncovered by these dives.

The first 10 days in November were spent with *Alvin* on board *Lulu* in transit to Fort Pierce, Florida, where the remainder of November was spent in test and training dives off the Florida coast. In December *Lulu/Alvin* proceeded to the Bahamas where the ARPA (Advanced Research Projects Agency) navigation system was thoroughly tested and *Alvin* made its deepest dive of the year to 3822 feet. The operations are summarized in Table 1. *Lulu/Alvin* returned to Linkport, Fort Pierce for the

Table 1. 1973 Cruise Summary

LULU Cruise No.	Sponsor	Period From-To	General Location	Chief Scientist	Ops Director	Purpose
62	ONR	6-20-73	Annapolis	None	V.P.Wilson	Test dives in Annapolis chamber manned and unmanned.
63	ONR	9-4-73	vicinity Provincetown, Massachusetts	None	V.P.Wilson	Test and training.
64	ONR	10-12-73	vicinity Provincetown, Massachusetts	None	V.P.Wilson	Test and training.
65 Leg 1	ONR	10-31-73 11-10-73	Transit to Fort Pierce, Florida	None	V.P.Wilson	Transit
65 Leg 2	ONR	11-15-73 11-17-73	Transit to Linkport, Florida	None	V.P.Wilson	Transit
65 Leg 3	ONR	11-20-73 11-23-73	Florida Straits	None	V.P.Wilson	Test and training
65 Leg 4	ONR	11-26-73 11-28-73	Transit to Nassau	None	V.P.Wilson	Transit
65 Leg 5	ARPA	11-29-73 11-30-73	Tongue of the Ocean	W.M.Marquet	V.P.Wilson	Test and navigation.
65 Leg 6	ARPA	11-30-73 12-1-73	Tongue of the Ocean	W.M.Marquet	V.P.Wilson	Test and navigation.
65 Leg 7	ARPA	12-2-73 12-4-73	Tongue of the Ocean	W.M.Marquet	V.P.Wilson	Test and navigation.
65 Leg 8	ARPA	12-5-73 12-6-73	Tongue of the Ocean	W.M.Marquet	V.P.Wilson	Test and navigation.
65 Leg 9	ONR	12-8-73 12-10-73	Transit to Port Everglades Florida	None	E.L.Bland,Jr.	Transit
65 Leg 10	ONR	12-10-73 12-11-73	Transit to Fort Pierce, Florida	None	E.L.Bland,Jr.	Transit
65 Leg 11	ONR	12-12-73 12-12-73	Transit to Linkport, Florida	None	E.L.Bland,Jr.	Transit

1973 Diving Log

Lulu Cruise No.	Date	Dive No.	Location	Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf.	Sub.		
62	7/5/73	468	USNRDC Annapolis Maryland Test Chamber	Unmanned Test Dive	None	None	1415	1245	22^h30^m	12000'	Power off
	7/6/73	469	"	"	"	"	1720	0447	11^h27	12000'	Power on
	7/10/73	470	"	Test Dive Manned Certification	V.P.Wilson E.L.Bland,Jr.	L.H.James NAVSHIPS	1040	2014	9^h34^m	12000'	Successful test
	8/24/73	471	W.H.O.I.	Tethered Trim Dive	E.L.Bland,Jr. J.D.Donnelly	None	1150	1235	45^m	10'	Successful test
	8/24/73	472	W.H.O.I.	Inclining Experiment	V.P.Wilson	None	1312	1417	1^h05^m	10'	Successful test
	8/30/73	473	W.H.O.I.	Inclining Experiment	V.P.Wilson J.D.Donnelly	D.B.Foster	1405	1528	1^h23^m	10'	Successful test
	9/4/73	474	W.H.O.I.	Trim Dive	V.P.Wilson J.D.Donnelly	L.A.Shumaker	1640	1716	36^m	10'	Successful test
63	9/6/73	475	Province-town harbor	Test and Training	V.P.Wilson	E.L.Bland,Jr. L.A.Shumaker	1123	1353	2^h30^m	65'	Successful
63	9/7/73	476	$42^o01.5'N$ $70^o13.5'W$	Test and Training	J.D.Donnelly	E.L.Bland,Jr. J.G.Moore	1432	1939	2^h07^m	132'	Successful
	10/9/73	477	Woods Hole	Tethered Trim Dive	V.P.Wilson J.D.Donnelly	D B.Foster	1054	1150	56^m	15'	Successful dive
	10/9/73	478	Woods Hole	Test	V.P.Wilson J.D.Donnelly	L.A.Shumaker	1424	1514	50^m	50'	Successful dive
	10/10/73	479	Woods Hole	Rock Hammer Test	J.D.Donnelly D.B.Foster	M.J.McCamis	1307	1425	1^h18^m	10'	Successful test
64	10/13/73	480	$42^o05'N$ $70^o10'W$	Test and Training	V.P.Wilson J.D.Donnelly	D.B.Foster	1011	1126	1^h15^m	143'	Successful dive

1973 Diving Log (continued)

Lulu Cruise No.	Date	Dive No.	Location	Purpose	PIC/CP	Obs.	Time			Depth M/Ft.	Remarks
							Dive	Surf.	Sub.		
64	10/13/73	481	Province-town harbor	Training and Test	J.D.Donnelly D.B.Foster	A.F.Barrs	1346	1457	1^h17^m	56'	Successful dive. Foster's first solo launch & recovery
65	11/15/73	482	27°29'N 79°54'W	Training and checkout	V.P.Wilson J.D.Donnelly	D.B.Foster	1340	1504	1^h24^m	136^m	Successful dive strong currents low visibility
65	11/16/73	483	27°29'N 79°48'W	Training and checkout	J.D.Donnelly L.A.Shumaker	A.F.Barrs	0900	1435	5^h35^m	1445'	Successful dive
65	11/22/73	484	26°27'N 79°30'W	Training and checkout	V.P.Wilson L.A.Shumaker	D.B.Foster	1000	1513	5^h13^m	2513'	Successful dive
65	11/23/73	485	26°27,5'N 79°35'W	Training and checkout	J.D.Donnelly L.A.Shumaker	D.B.Foster	0805	1315	5^h10^m	2133'	Successful dive
65	12/5/73	486	24°58'N 77°38.7'W	Training and checkout navigation	J.D.Donnelly L.A.Shumaker	A.F.Barrs	1110	1422	3^h12^m	3822'	Successful dive.

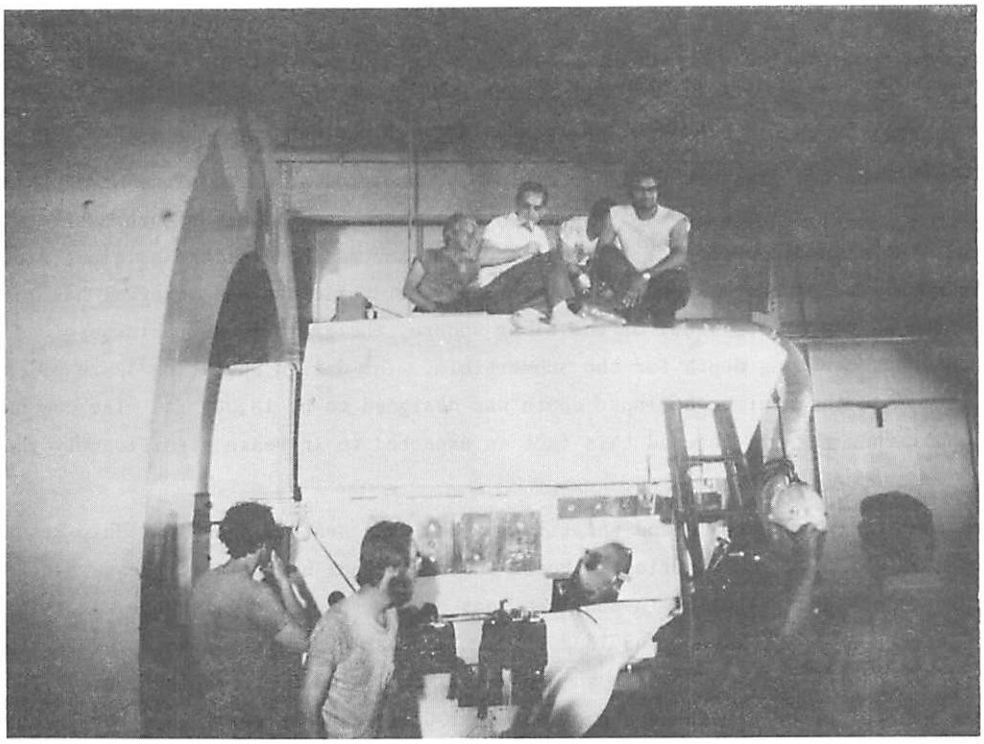

Fig.1 (Rainnie and Shumaker) *Alvin* submersible emerging from high pressure test tank.

Christmas holidays. During December, three members of the *Alvin* operations team spent a week in Brest, France, with the *Archimede* and *Cyana* teams, scientists of both countries planning for FAMOUS operations in the summer of 1974.

Future Plans

In addition to the FAMOUS operation which is scheduled for June, July and August, several other operations are planned for 1974. Work in Bahamian waters in January, February and March will support NAVOCEANO, the Naval Underwater Systems Center, the Naval Ordnance Laboratory and a scientific program funded by the Atlantic Foundation. FAMOUS training dives are also scheduled for this period as is some work under existing ARPA contracts.

It is during this period that *Alvin* will also continue a staged program of deeper dives to prepare her for the depths required during the FAMOUS program.

In May a dive series is scheduled in support of National Oceanic and Atmospheric Administration (NOAA). Although post-FAMOUS scheduling is somewhat less than clear at this time, it is probable that operations in support of Office of Naval Research (ONR) and ARPA contracts will be conducted in September.

New work will commence in 1974 on Experimental Underwater Lighting for ARPA and on an Investigation of Operator Performance and Force Feedback Variables in Undersea Manipulator Systems, and work on Navigation and Sonar Systems as reported herein will continue.

In October it is presently anticipated that *Alvin/Lulu* will return south to Florida for winter operations.

NEW TITANIUM PERSONNEL SPHERE FOR *Alvin*

Arnold G. Sharp and Barrie B. Walden

Early in 1973 the new pressure hull for *Alvin* was completed at Mare Island Naval Shipyard. The new sphere is made of titanium alloy 6Al-2Cb-1Ta-0.8Mo, which has a minimum compressive yield strength of 100,000 psi. Outside dimensions of the hull are the same as those of the original steel hull but the wall thickness was increased from 1.33 in. to 1.93 in. While the new material has approximately the same strength as the HY-100 steel of the older sphere, the greater wall thickness was selected to permit an increased operating depth for the submersible. The design operating depth of the new sphere is 12,000 ft., while the minimum collapse depth was designed to be 18,000 ft. The new hull is considerably lighter than the old one and this fact is expected to increase significantly the vehicle's payload.

Upon its completion at Mare Island the titanium hull was sent to the Naval Ship Research and Development Center (NSRDC), for a series of tests under external hydrostatic pressure. Electric resistance strain gages were installed in 258 locations on the sphere. Tests were run to pressures equivalent to depths of 9000, 12,000 and 13,200 ft. The last pressure was held for 24 hours for investigation of creep properties. Results showed a maximum measured stress level of 77,000 psi at 13,200 ft. and a total creep strain of approximately 100 microinches per inch after 24 hours at pressure.

Following installation of the new hull in *Alvin*, hydrostatic testing was conducted by the Deep Submergence Group in conjunction with the U.S.Navy at Annapolis, Maryland. The tests consisted of five simulated dives to 12,000 ft. (5,330 psi) the last of which was manned; and an eight-hour hold at 12,000 ft.

Fourteen strain gages were monitored during the tests. Four gages were located in a "dummy" penetrator as two biaxial pairs to measure the strain encountered in the predicted outward movement of the penetrator under hull loading. The remaining gages were located on the inboard side of the titanium hull in three biaxial pairs and one three-gage rosette. The positions of the gages were chosen to correspond to points where the greatest stresses were recorded during the Carderock test of the completed hull prior to delivery to Woods Hole. Biaxial stresses for each pair were calculated from the strain gage data. During the manned dive, dial indicators were positioned to record hatch, window and blanking plug deflections.

For all cycles the hull behaved elastically. Stress was a linear function of hydrostatic pressure. The maximum stress computed was 65,452 psi in compression. All stresses were within the design criteria. The eight-hour hold revealed no discernible changes in stress.

The data recorded on the "dummy" penetrator was inconclusive. Each dive resulted in an independent and unpredictable stress record, often involving stress reversals. Despite the erratic stress records, one important result was obtained. The maximum stress recorded in the penetrator neck area was 7,000 psi which is approximately 1/17 of the yield value of the 6-4 Ti penetrator material (120,000 psi). This would seem to indicate that at least with the present installation procedure, the penetrator neck stresses are maintained well within acceptable levels.

NEW AFT BUOYANCY PACKAGE

Clifford L. Winget

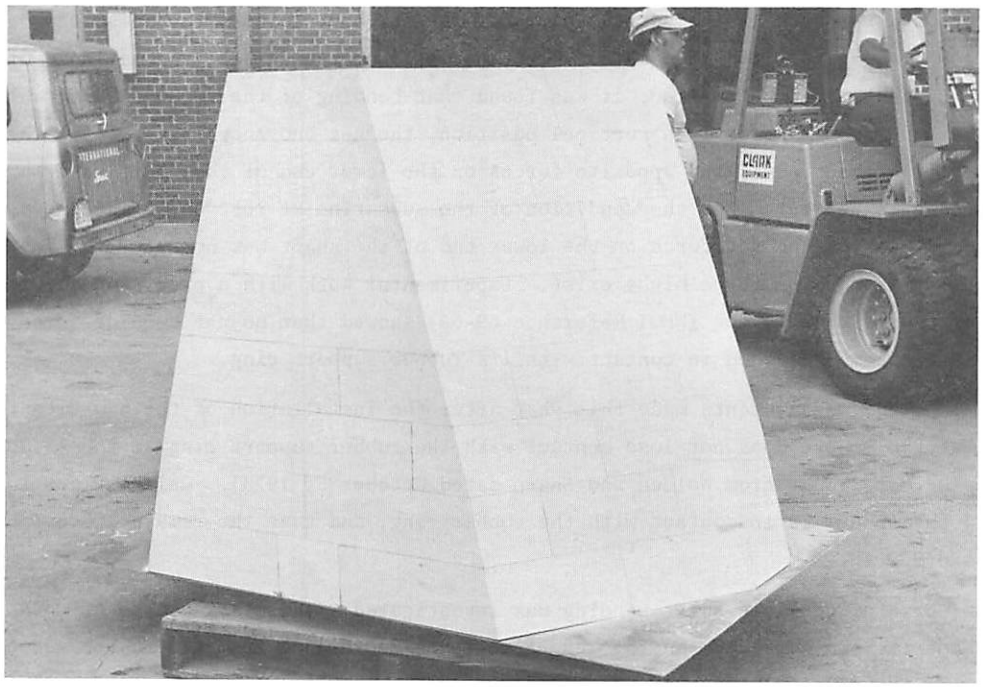

Fig.1 (Winget) The new floatation block.

Originally *Alvin* contained a large fixed buoyancy package (upper aft) made up of seven of the titanium buoyancy spheres encased in a capsule of syntactic foam. Advances in syntactic foam technology during the last few years have produced lighter and more pressure-resistant foams than were possible at the time *Alvin* was built. The result is that during the planning stages of converting *Alvin* to a 12,000 ft. vehicle it was found that a solid package of the newer syntactic foam would be lighter in weight and more pressure-resistant than the original sphere-syntactic composite.

Late in 1972 such a package was built and delivered to Woods Hole. Outside dimensions were approximately the same as those of the old package and construction was done by laminating a number of flat planks of the syntactic foam. The air weight of the new package is 2310 pounds and the computed displacement is 4083 pounds of seawater. The average density of the material used was calculated to be 36.1 pounds per cubic foot. The net buoyancy of the new package is 1783 pounds, some 140 pounds greater than that of the old sphere-syntactic combination.

EMERGENCY FOREBODY RELEASE

Arnold G. Sharp

The structural strength of the various parts of the forebody release mechanism has been carefully studied and found to be more than adequate for the normally operating level submarine. Of the various kinds of loading that might be applied, it was found that bending of the release shaft was the most critical. When the submarine is in a vertical position, the net buoyancy force of the forebody (because of symmetry) causes equal and opposite forces on the lower end of the shaft, and thus no tendency for bending is present. For the condition of the submarine at rest on an inclined surface (producing a list angle) the net force on the lower end of the shaft was not at first known, but it was suspected that a bending force might exist. Experimental work with a precision-machined full-scale model of the release device (WHOI Reference 69-68) showed that no net bending force was present if the personnel sphere remained in contact with its rubber support ring.

Observations and measurements made this year after the installation of the new titanium sphere, have shown that the sphere does not lose contact with the rubber support ring at the 12,000 ft. operating depth (Memorandum from Walden and Sharp dated October 5, 1973). Calculations indicate that at 12,000 ft. the sphere is in contact with the rubber ring, and that the remaining compression of the rubber is 0.029 in.

One other case of possible shaft bending was investigated. This is the case of rotation of the sphere about its own center (assuming zero frictional resistance from the rubber support ring). If the submarine takes on a list angle (say 30 degrees) the gravity and buoyancy forces of the forebody are displaced from each other laterally causing a rotational moment. This moment has an approximate value of 15000 x .02 = 300 ft.-lbs. The lateral force reaction at the release device necessary to resist this moment would be about 75 lbs., which is not considered of sufficient magnitude to cause a bending problem.

Alvin ELECTRICAL SYSTEMS

David S. Hosom

The major activity of the spring and summer season was fitting and testing the many changes made in association with the new titanium hull. The interior of the sphere has new electrical distribution and instrumentation panels as well as new wiring harnesses. The inside distribution system was redesigned, and new fuse holders, meters, and switches were installed. New electrical through-hull penetrators have increased the number of available wires through the hull from 216 to 384, providing a more versatile instrumentation wiring and greatly increased science wiring to various parts of the vehicle.

External wiring was completely replaced and several new oil-filled junction boxes installed to permit easier access to system wiring. New larger forebody - afterbody electrical disconnects were designed and obtained. Figure 1 shows the external frame wiring and disconnects being aligned. New depth gages, pressure sensors and associated electronic equipment were designed, built and

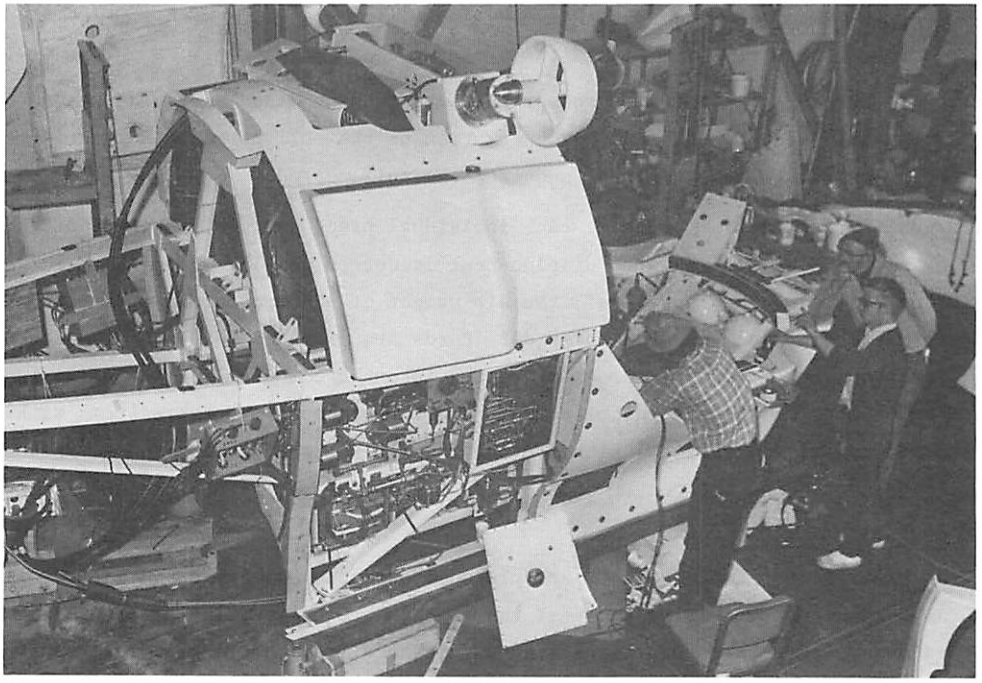

Fig.1 (Hosom) *Alvin* frame with external wiring and junction boxes.

tested. The external cameras and strobe were packaged in new 12,000-foot operational pressure cases.

Additional weight droppers were provided to increase the ascent and descent rates for the 12,000-foot operation. An improved normal and emergency tracking pinger was installed.

A new external television camera and companion thallium iodide light were installed. A small monitor is located in the sphere as well as a television tape recorder to permit replay of tape at some later time. An analog data recording system has been installed and a digital data logger is being planned for the coming season. A light-weight gyro was installed and interfaced with the analog data recorder.

Usable battery energy will be increased by new monitoring instrumentation and improved charging procedures.

WEIGHT AND STABILITY

Arnold G. Sharp

The vertical stability of the entire submarine, both submerged and surfaced, was determined by computation, by inclining experiment, and by observation of the roll period. For the forebody alone, stability was found by inclining experiment and from the roll period.

a. Computation As far as is possible, each individual piece part or component of the submarine is weighed in air and its seawater displacement is determined (by weighing it in water or by calculating its volume). In general, the air weight of a component is easier to obtain accurately than its displacement. Computer data cards are prepared for each of these parts, and these, together with a suitable program are fed into the computer. The program is set up to produce summations of weights, displacements and first moments of these items with reference to fixed horizontal and vertical planes. The final results are the x and y distances to the center of gravity G and the center of buoyancy B, for the entire vehicle and its major subassemblies.

b. Inclining Experiment Known weights are placed aboard the submarine and their total added to the total displacement. During the test the weights are shifted in increments from port to starboard and vice versa to positions a known distance from the longitudinal centerline. After each movement of weights, the vehicle's list angle is obtained using a sensitive inclinometer. Data thus obtained are used to construct a curve called the plot of tangents. This plot in turn leads to the determination of the vertical component of a.) the BG distance (submerged vehicle) and b.) the GM distance (vehicle on surface). These tests were performed for the entire submarine, both submerged and surfaced, and for the forebody alone, on the surface.

c. Induced Rolling The submarine is caused to roll at its natural frequency of oscillation, about its longitudinal axis. In *Alvin*'s case a line is attached to the top of the sail and several men haul on it, then release it, repeating this a number of times. The total elapsed time is recorded. This is divided by the number of rolls to give the average roll period. Using this value in the appropriate vibrations equation, one obtains the vertical BG or GM distance. This test was done also for the forebody alone, on the surface.

d. Summary of Results The following table presents the results of the computations, and the experiments, done in 1973 for *Alvin* with the titanium hull:

	Entire Vehicle (Submerged)	Entire Vehicle (Surfaced)	Forebody (Surfaced)
BG Vertical, ft. (computed)	.36		
BG Vertical, ft. (inclining)	.34		
BG Vertical, ft. (roll period)	.35		
GM Vertical, ft. (inclining)		.47	.66
GM Vertical, ft. (roll period)		.44	.62

e. Conclusions For the submerged submarine, the center of buoyancy B must lie above the center of gravity G, for vertical stability. This was found to be true for *Alvin* in all determinations made. The computed value of BG is about 12% greater than that for the 1972 steel hull *Alvin*.

For the submarine on the surface the metacenter M must lie above the center of gravity G even if the center of buoyancy B does not. This was found to be true in all the tests done, on the evidence that a righting moment was present in each case.

The computer output also yields a value for the horizontal component of BG, a measure of longitudinal trim. Ideally this value should be zero, but in practice it never is. The value obtained in the present computation, 0.10 ft., is considered small enough to be readily corrected by the mercury trim system.

For the released forebody the computed value of BG is so small that a nearly neutrally stable condition is indicated. This, taken together with the fact that the sail would be subject to hydrodynamic drag, indicates that the released forebody would almost certainly travel to the surface in the inverted condition. Further study is being conducted relative to the stability of the released forebody on the surface. There are indications that surface stability exists in both upright and inverted positions. If this proves to be true, measures will be taken to insure that the forebody can be righted; or that safe egress from the inverted hull can be accomplished.

Reference

"DSRV ALVIN Weight Report, 1973", by Arnold G. Sharp and Kenneth W. Doherty, Technical Memorandum W.H.O.I.-6-73, December, 1973.

VIEWPORT PROTECTION

Barrie B. Walden

Alvin's new depth capability will be utilized during the FAMOUS Program for a series of dives in the extremely variable terrain of the Mid-Atlantic Ridge. As a result of the complex bottom topography likely to be encountered during this dive series, the safety review committee recommended that an increased amount of protection be afforded the *Alvin* viewports. In response to this recommendation, a design has been completed and manufacture is in progress for viewport protection shields. These will be constructed from 3/4 inch thick lexan, mounted 3/8 of an inch away from the face of the viewport. The space between the two surfaces will be filled with distilled water and a resilient mounting will be used to allow pressure compensation and afford some degree of shock absorption.

Lexan was chosen for this application because it has greatly superior impact resistance and similar tensile and compressive strengths compared with other suitable materials. Its light transmittence is 89% and its refraction index is 1.586 (compared with 92% and 1.49 for plexiglass). As a result, both the viewing angle and maximum viewing distance will be decreased slightly but both effects should be minimal and easily tolerated. There should be no increase in viewing distortion.

INCLINOMETER FOR SMALL DEEP SUBMERSIBLES

Arnold G. Sharp and James R. Sullivan

A small pendulum type inclinometer, which utilizes viscous damping, was developed. The need for such an instrument arises from the fact that small deep-diving research submarines, such as *Alvin*, having relatively low stability and short roll periods, are quite sensitive to small disturbances in the surrounding water. In the case of *Alvin*, to perform the surface and submerged inclining experiments in a perfectly calm body of water would be time-consuming and costly. For practical reasons these tests have usually been performed in Woods Hole Harbor at the Institution dock. Although a calm day is selected for these tests there is inevitably enough harbor traffic to produce some wave action. The result is a slight but ever-present oscillation of the boat under test.

In previous years a bubble-type inclinometer of the kind used on large combat submarines has been used for the *Alvin* tests. In many cases it was found that the bubble excursion, due to the vehicle's oscillation, was great enough to cause it to go off scale completely, making an estimate of zero bubble position very difficult.

A long free-swinging pendulum such as used on large ships could not be used because of space limitations; furthermore, such a device would eventually go into oscillation at its own natural frequency.

A viable solution appeared to be one using a short pendulum, with a mechanism for multiplying its motion, and having a viscous fluid to damp unwanted motion. Such an instrument was designed and built, and was used in the 1973 inclining experiments. Figure 1 illustrates the completed inclinometer.

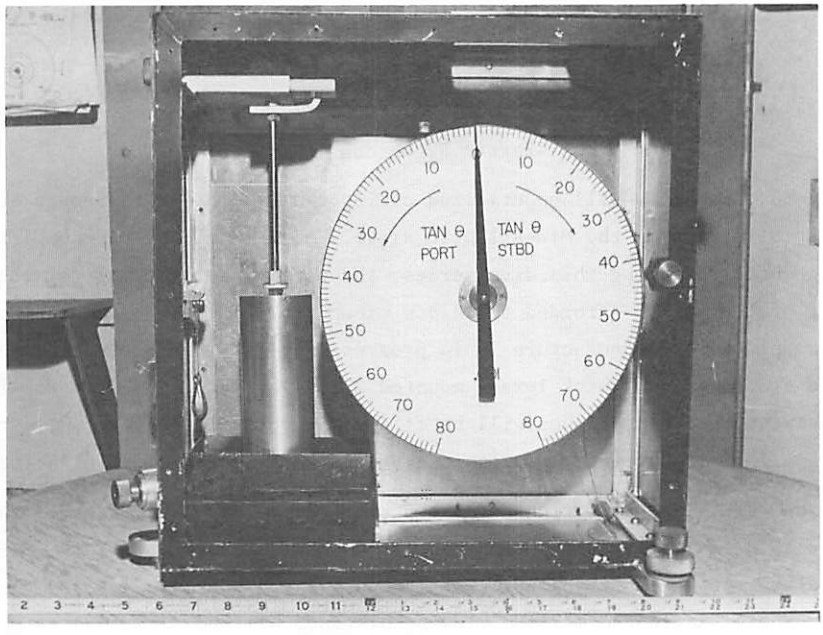

Fig.1 (Sharp and Sullivan) Completed Inclinometer.

HYDRAULIC IMPACT ROCK HAMMER

Marvin J. McCamis and Robert D. Ballard

The device illustrated in Fig.1 is a hydraulically operated rock chipper. The apparatus provides the submersible operator with a means of obtaining selected specimens of rock from deep water outcrops. Preliminary surface testing was satisfactory, with a power thrust of approximately 500 foot pounds. To improve the operation, and enhance the reliability of obtaining specimens from different rock formations, the hammer power was increased to 2,000 foot pounds in air. The increased thrust tends to offset the 10% to 15% power reduction resulting from the water cushion effect.

To accomplish this, the hammer size was increased in length to provide a longer stroke, and a stronger spring installed to increase the thrust. A recoil buffer plate was added to reduce the recoil generated by the hammer. A new positioning arm was also designed to simplify the operation of the device. It allows the operator to position the hammer at the most advantageous angle to the rock outcrop, enhancing the ability of the hammer blow to fracture selected sections of the rock.

The positioning arm is being modified to include a claw-type hand, which will increase the capability of the device. The positioner will hold the rock hammer for impacting, then lay it down and pick up the rock sample. The positioning arm is capable of picking up about 250 lbs. when extended six feet. Discussions concerning other uses for the rock chipper, have included the possibility of modifying it to fire a harpoon or spear type device for sampling large marine animals.

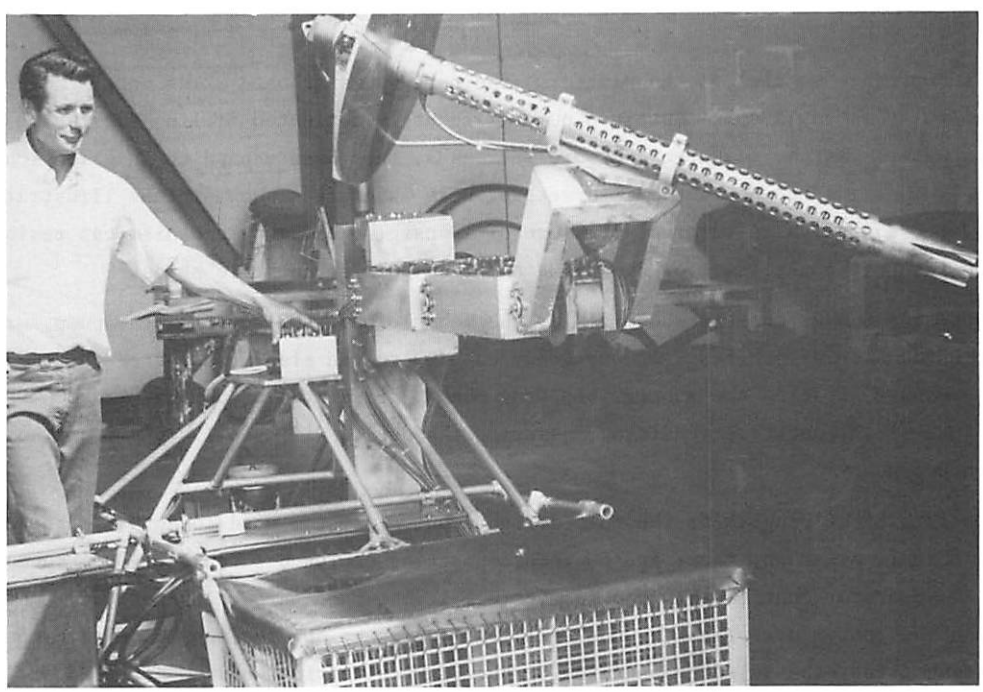

Fig.1 (McCamis and Ballard) Hydraulically-operated Rock Chipper.

A SELF-CONTAINED ANCILLARY MODULAR PLATFORM (SCAMP)

Clifford L. Winget

The Ancillary Platform (SCAMP) illustrated in Fig.1, was designed to attach to the skids of the *Alvin* submersible, providing the vehicle with a means of moving large items of science apparatus to the ocean floor. It will allow the submersible to increase it's normal payload capacity by providing the additional buoyancy necessary to offset the water weight of heavy scientific gear.

The two tubular sections mounted on the port and starboard sides contain lead acid batteries that supply power to the science apparatus attached to the device. The self-contained power source enables the *Alvin* submersible to handle large power drain devices without depleting the battery system of the submersible. The batteries within the tubular sections can be remotely moved fore and aft to change the trim of the SCAMP. The trim control feature provides the operator with a means of compensating for various payloads, allowing the submersible to remain in a level flight condition throughout the dive. Preliminary water tests have demonstrated the platform has a payload capacity in excess of 600 pounds, with excellent fore and aft trim compensation capabilities.

From a standpoint of vehicle and operator safety, the initial design criteria stressed a fail safe nonmechanical clamp mechanism between the *Alvin* submersible and the platform. Figure 2 illustrates the "soft" clamp design that was developed to perform the operation. In it's basic form, the system consists of several lengths of high-pressure hose clamped to flat back-up plates secured to the main longitudinal frame members of the SCAMP frame. Then the submersible and the SCAMP are mated, the bottom skids of *Alvin* are guided into position by several rubber bumpers, two of which are shown in the illustration.

As the submersible settles on the platform, the port and starboard skids enter their respective clamps. When fully mated, a self-contained pump is remotely activated filling the twelve hose assemblies with seawater. As the seawater pressure increases, the hoses expand to an elliptical shape clamping the *Alvin* skids between the paired sets of hose assemblies shown in the illustration. Tests have demonstrated that with an internal pressure of 18 psig, the clamp mechanism can resist a pull-out force of 1400 lbs. without release of the SCAMP and the *Alvin* submersible skids.

To release the SCAMP from the submersible, the vehicle operator reverses the pump, withdrawing the water from the hose assemblies. An emergency dump valve can also be actuated to release the internal hose pressure, freeing the submersible from SCAMP. By virtue of design, the SCAMP will always be operated in a slight negative condition, assuring the device will "fall away" from the submersible in case of an emergency.

Figure 3 is a block diagram of the pulsed light control system used to actuate the various functions of the SCAMP. As shown, there are no interconnecting cables between the *Alvin* submersible and the SCAMP. All operator control from the submersible is obtained through the use of light pulses directed through the bottom port light of the vehicle. A pick-up head on the SCAMP receives the coded light, actuating either the science apparatus or the SCAMP electrical system as the operator manipulates the various switches within the submersible. The pulsed light control system allows the *Alvin*

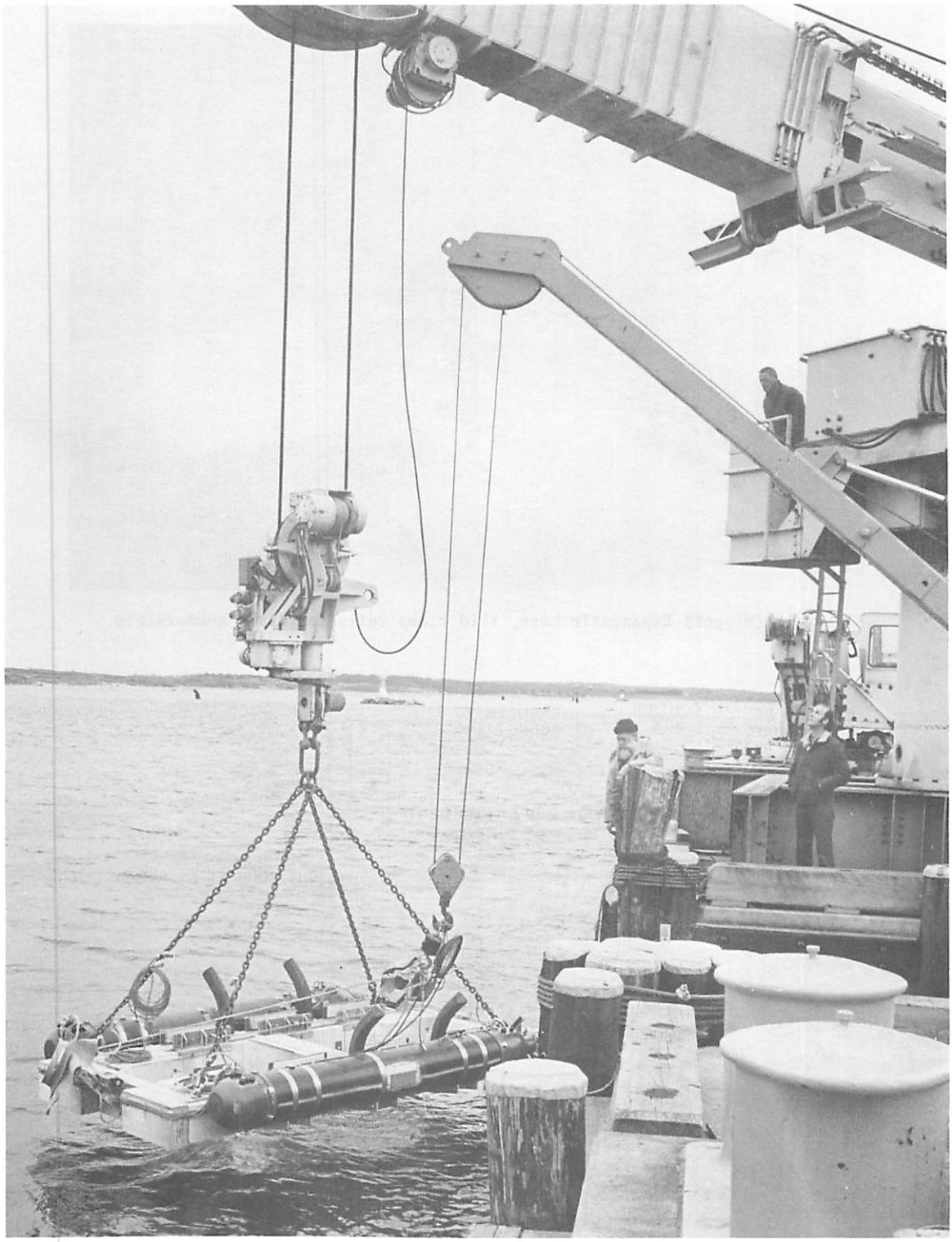

Fig.1 (Winget) Auxiliary platform.

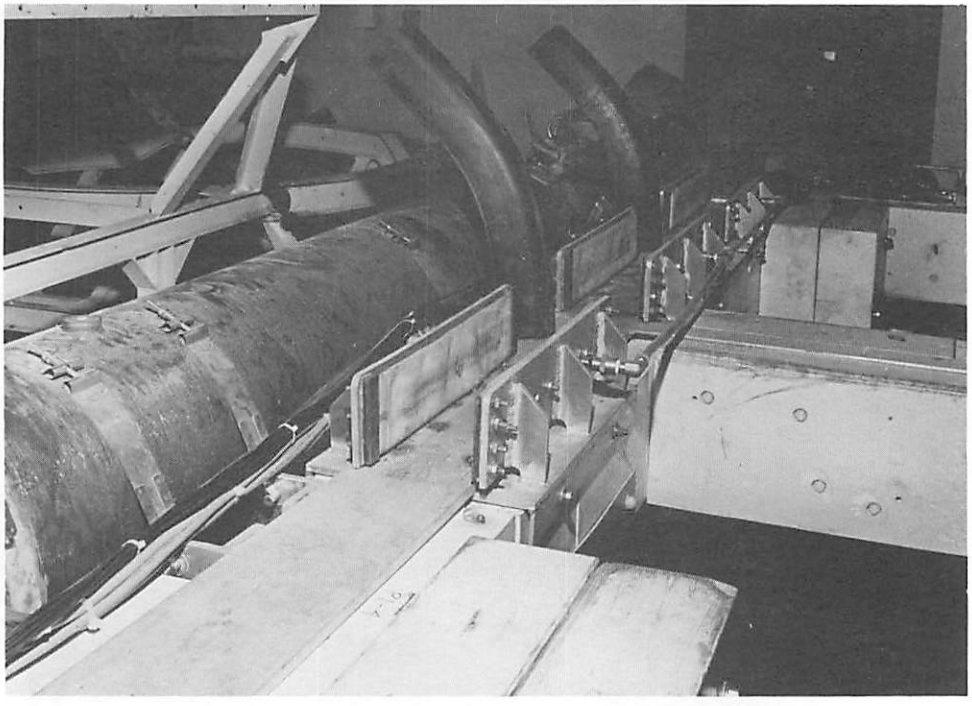

Fig.2 (Winget) Expandable hose, skid clamp rails for *Alvin* submersible.

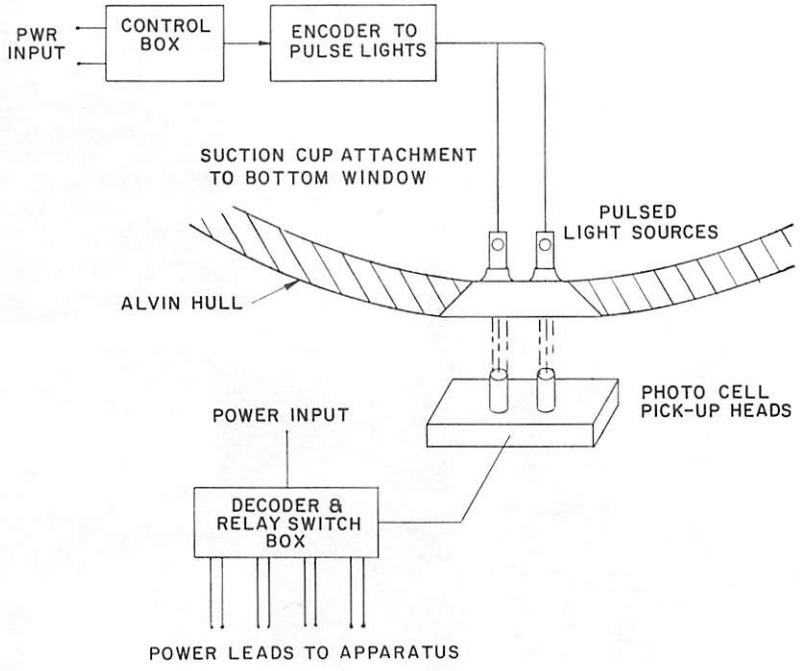

Fig.3 (Winget) Pulsed light control system schematic.

to fly the platform to the bottom, detach itself and perform other operations. On returning to the SCAMP, the submersible can land, remotely activate the clamps and return the SCAMP and it's science payload to the surface.

SUBMERGED NAVIGATION

William M. Marquet and Andrew H. Eliason

In 1971 a development program in submerged navigation was initiated at the Woods Hole Oceanographic Institution. The program was continued through 1972. The terminal phase of this activity has continued during 1973. The program is sponsored by the Advanced Research Projects Agency (ARPA) and is administered through the Office of Naval Research (ONR).

The goals of this development program have been to provide real-time readout and graphic display of the positions of a surface support ship and a free or tethered submerged vehicle or instrument. The primary test vehicles for this equipment have been DSRV *Alvin* and her support ship *R/V Lulu*. The positions are determined relative to a network of two or more bottom-moored acoustic transponders. The equipment within the submerged vehicle is minimized and the operator and major equipment remain on the support vessel. The positions are determined at intervals of 30 seconds typically.

The major task of the final phase of this program has been to complete the developments necessary to process, after the fact, the navigation data gathered during the real-time operations in order to reconstruct the original tracking positions with increased accuracy. The accuracy is improved by refining the calculated positions of the reference transponders, correcting the calculated slant ranges for the measured sound velocities and for refraction, correlating measured pressure depth with measured acoustic depth and applying least-square fits where applicable. These improvements increase repeatability of the system and are a major factor in the establishment of good actual accuracy for later conversion to geographical positions.

An informal Woods Hole Oceanographic Institution Committee of Investigators with Applications of Submerged Navigation was formed. This group has representatives from the Ocean Engineering, Geology and Geophysics, and Physical Oceanography Departments. This led to agreements to pool information and efforts to develop common systems and computer programs for submerged navigation. This pooling of efforts by investigators from three of the five Woods Hole Oceanographic Institution's scientific departments is considered to be a major milestone in the system metamorphosis.

The major hardware developments during 1973 were as follows:

A. The final design and construction of three timing control units (Fig.1), one for each of the three above-mentioned departments. This unit provides flexible and integrated control of the surface system.

B. The design specification and purchase of a dual digital tape cassette system for data logging applications of the *Alvin/Lulu* system. The system features simplified interfacing to a wide variety

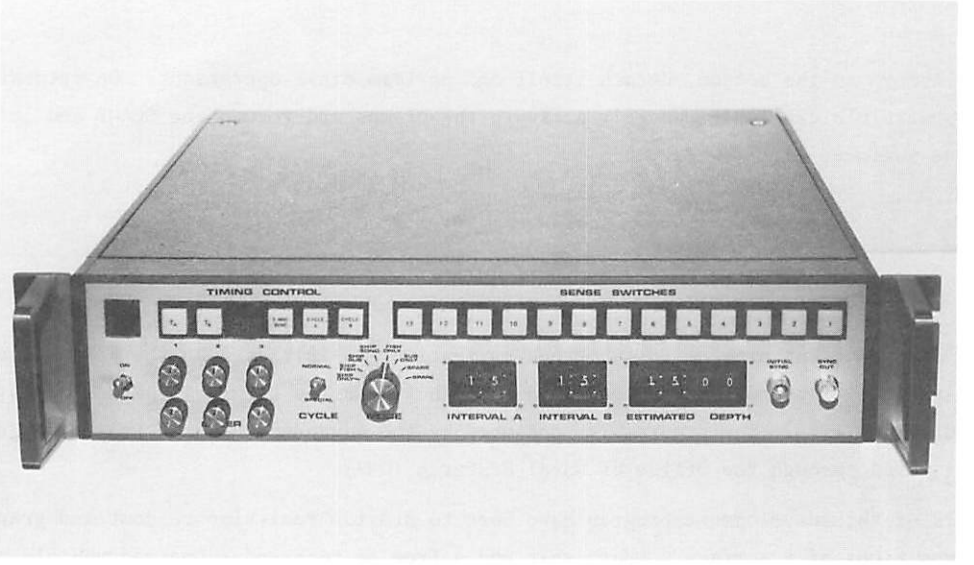

Fig.1 (Marquet and Eliason) Timing control console developed for navigation system.

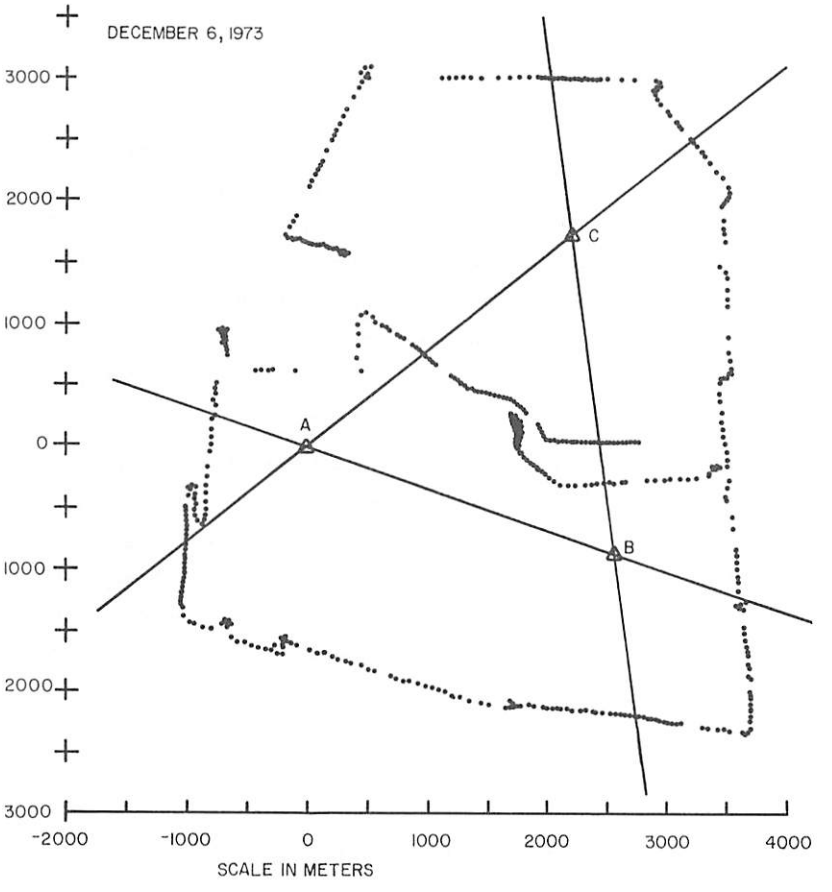

Fig.2 (Marquet and Eliason) Real time graphic output during a transponder survey exercise in December 1973.

of computer systems to allow ease in cross correlation of data between systems and users. Other features are high data transfer speed, simplified control instructions, and utilization of a new high reliability cassette.

Improved equations for transponder survey and vehicle navigation were developed. These equations improved the ability to determine accurately the transponder locations and reduced calculation errors in areas of poor system geometry. Among the joint users committee a series of HP2100 computer programs was developed. This software includes four primary categories:

a) SETUP - Given a sound velocity profile this program calculates the ray-bending correction coefficients.

b) SURVEY II - Given surface ship baseline crossing data this program calculates the depths and distance between two near-bottom transponders.

c) SURVEY III - Given surface ship track data this program calculates the depths and distances between three near-bottom transponders.

d) ACNAV - This is the real-time program that processes the information from the acoustic system, calculates the position of the ship and submerged device, and displays the calculated positions.

The HP9100 calculator programs were also rewritten to include many of the mathematical improvements.

The system was evaluated during the *Alvin/Lulu* operations in Tongue of the Ocean in December, 1973. The purpose of the expedition was to evaluate system performance and to study a variety of survey and tracking techniques. System performance was good and evaluation of the survey and tracking data is proceeding at the time of this writing. Further experiments to study reduction of ship's noise interference will be conducted in January and February of 1974.

Helgoland

Barrie B. Walden

An engineering evaluation of the German habitat *Helgoland* was conducted in the North Sea during July as preparation for an American-German joint saturated diving mission. The evaluation was made by engineers from the University of New Hampshire with Barrie Walden of Woods Hole Oceanographic Institution's deep submergence group acting as team leader.

The *Helgoland* is a 75 ton habitat with a depth capability of 100 meters. It consists of three chambers: a living room decompression chamber, a machinery space with kitchen and laboratory area, and a wet room with a large trunk leading to the water. The system receives power from a buoy moored above the habitat but emergency provisions are provided, capable of sustaining three men for 10 days should the energy buoy fail. Decompression is conducted in the habitat at the end of each mission.

During the evaluation, the engineering team spent two nights in the habitat, one with the system on the surface and one with it submerged in shallow water. No problems were encountered and on the basis of the team's recommendation, the American-German mission was conducted successfully in August. (See Fig.1, P.OE-22.)

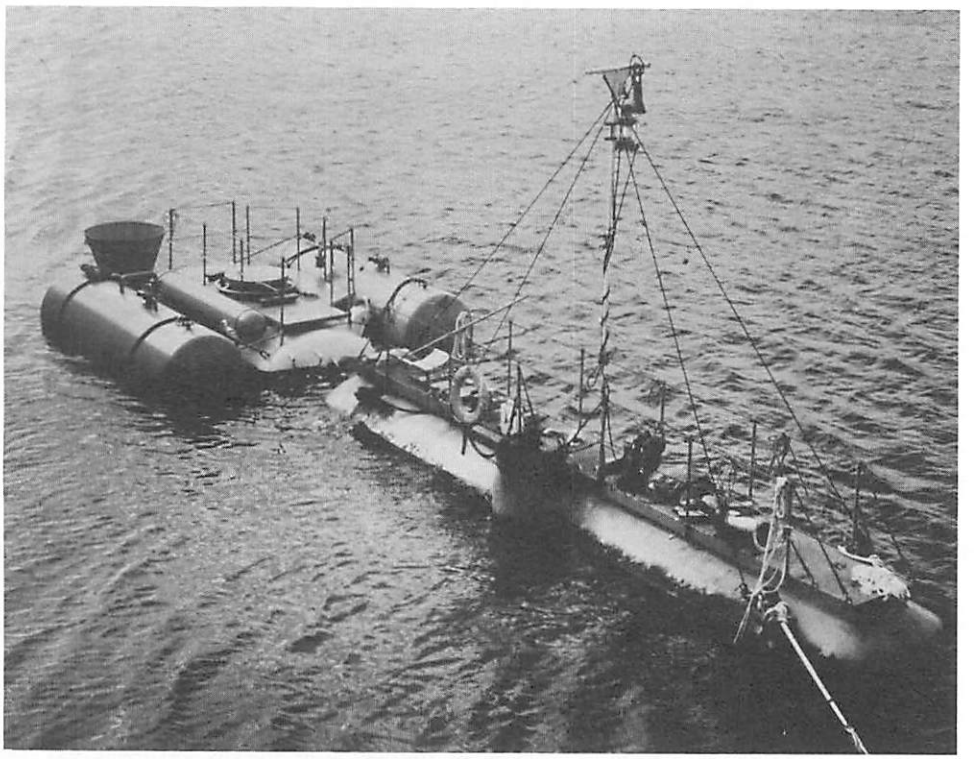

Fig.1 (Walden) *Helgoland* habitat prior to deployment in North Sea.

MECHANICAL ENGINEERING PROJECTS

Peter E. Kallio

High Pressure Biological Chamber

Specifications were prepared for Dr. John Teal for an advanced design of a high-pressure vessel for study of biological specimens at simulated pressure depths to 30,000 ft. Several companies recognized in the field were asked to submit proposals for construction, however no interest was generated for numerous reasons, including uncertain funding and technical complexity. The vessel was to have been constructed of nickel-iron alloy with titanium liner enclosing an isolated heat-exchange circuit. Optical windows were provided, illumination, two liquid penetrations, and six electrical penetrations. The design has been placed with the Harbor Branch Foundation for study and possible funding.

Deep Tow Winch

R/V *Knorr* Cruise 31 was scheduled to make extensive use of Scripps' Marine Physical Laboratory's deep-tow system. The requirement of keeping the deep-tow fish at a constant height above an irregular ocean floor while traversing at five knots meant that the trawl winch would have to be in nearly constant operation adjusting the amount of wire out. It was determined that the *Knorr* winch would not be capable of this type of duty cycle without serious overheating or burn out of motor and brake.

Consequently, an old Western Gear Model DSWH-150 electro-hydraulic traction winch was purchased at reasonable cost. This unit would be capable of unlimited start-stop operation at very low speeds. The fact that the machine had been in open storage for a number of years indicated complete overhaul and inspection.

In March and April the Woods Hole Oceanographic Institution's Mechanical Shop rebuilt the machine to the last o-ring. The hydraulic system was modified to improve the response of the storage drum. The flanges of the storage drum were redesigned to increase resistance to spreading. The storage frame was widened to accept the elongated drum. The control console was modified to permit remote speed and directional control from the main laboratory, with emergency manual override from the deck control station. Last minute difficulties delayed sailing four or five days, but once placed in operation, the machine performed as required without malfunction for the entire cruise.

Knorr Forward Shafting

Supervision and design assistance were provided for the reinstallation and alignment of *Knorr* forward propulsion shaft in Ponta Del Gada, Azores. The shaft had previously been removed for modification to permit relocating support bearings to improve loading of the main engine crankshaft. Accomplishing this with an all-Portuguese non-English-speaking work force was an experience, and left a high degree of respect for their workmanship and industry. The ship's Engineering Department was almost totally involved in the repair of the aft cycloid gear at that time. Sea trials and subsequent cruises have proven the installation properly accomplished.

Plant for Tertiary Sewage Treatment

Design has been proceeding on a plant to store and deliver secondary-treated effluent for a "living filter" evaluation system for Dr. William Kerfoot. The efficiency of the living filter in improving the quality of wastewater recharged to the ground water reservoir will be compared to the performance of existing sand filter beds. The plant consists of a 300,000 gallon storage lagoon with associated drains, a pumping and control station, and 2,000 feet of 4" PVC force main to deliver the effluent to the living filter installation. The pumping and control station will be equipped with necessary pumps as well as a recording flowmeter, gas chlorinator, flow controls and various monitoring devices. The force main is capable of being back-drained, and all intakes and drains may be back-flushed to eliminate clogging. Interlocks are provided to prevent starting or to shut down the system if any malfunction is indicated.

Construction started 19 December, 1973. Weather permitting, the plant should be fully operational by May, 1974.

OCEAN STRUCTURES, MOORINGS AND MATERIALS SECTION

Robert G. Walden

A cooperative experiment between the Draper Laboratory and the Woods Hole Oceanographic Institution to measure the motion of an intermediate mooring in a changing current field, was set and recovered. As a result of this test and observed instrument motions in the Mid-Ocean Dynamics Experiment (MODE), a high priority is being given to optimization of this mooring configuration. A new design of a surface buoy to provide greater buoyancy with minimum weight was set as the central marker in the MODE experiment. A new type of swaged fitting and hardware were used in the wire rope portion of the mooring to eliminate a problem of cocked shackles observed in many of our past surface moorings which led to hardware failure. Three other separate experiments were aboard the buoy. Three and one-half months after implantation the R/V *Chain*, working in the area, observed a large vessel close by the buoy position. As the *Chain* proceeded to the position the vessel immediately got underway to the East at full speed. A subsequent search by the *Chain* failed to find the buoy. It appears that we have another example of high seas pilferage.

In our attempt to provide longer duration moorings, a one-year intermediate mooring was set. Previously a one-year bottom mooring was set and successfully retrieved.

The section was deeply involved in the design and analysis of the IWEX Tri-moor which was successfully set in October. Figure No.1 shows the apex float of this mooring which is designed to separate

Fig.1 (Walden) Apex float for tri-mooring.

into three segments (each segment connected to a leg of the mooring) for retrieval. The buoy is constructed of 39 lb/ft^3 density syntactic foam which provided 4000 pounds buoyancy at a design depth of 600 meters. The buoy is separated by an acoustic command which fires explosive bolts allowing a belly-band around the center of the sphere to drop away. This mooring was recovered without incident in December.

INSTRUMENTATION

Clayton W. Collins, Jr.

A motion study experiment was performed at the Hydronautics Ship Model Test Basin in Laurel, Maryland, on a current meter, using accelerometers as sensors and a high-gain amplifier and recorder for collection of data. Methods of damping instrument oscillation in the presence of current were successful.

Efforts were begun to develop a radio field-strength measuring technique as a sequel to the present standard antenna system tuning method. This will lead to evaluation of antenna radiating efficiency and the experimentation with various types of antennas.

Instrumentation was furnished and installed on the IWEX Tri-moor experiment and associated moorings, to measure inclination and direction, and tension on various parts of the Tri-moor, and record the results. Radio telemetry was utilized to monitor tension at all times while deploying this mooring. Assistance was furnished in the operations phase of the acoustic navigation system used to accurately place the Tri-moor anchors.

CORROSION AND MICROFOULING RESEARCH

Stephen C. Dexter

A research program aimed at increasing our understanding of the complex relationship between the initial stages of marine corrosion and microbiological fouling was continued during 1973. The scanning electron microscope is being used to determine the influence of marine bacteria on the nucleation of micro-anodic areas on metallic surfaces such as stainless steels, 90-10 copper-nickel and aluminum alloys.

The effect of surface-free energy of various metals and nonmetals on the rate of microbiological attachment is being studied. During 1973 the effects of heterogenieties in surface energy caused by metallic grain boundaries and crystallographic orientation on the location of microbial attachment sites were investigated using the scanning electron microscope. This research may eventually allow us to control fouling by manipulating the surface energy of engineering materials.

A number of toxic antifouling materials including copper-nickel alloys, commercial cuprous oxide anti-fouling paints, commercial inorganic tin anti-fouling paint and two experimental 90-10 copper-nickel flake paints were deployed in the Sargasso Sea on a Woods Hole intermediate mooring during October, 1972. They were deployed in special modules at nominal depths of 500, 1000, 3000

and 5000 meters and will be recovered in December 1973 after 14 months on station. Their performance is being evaluated for use on long-term deep sea instrumentation. An important part of this program is the collection of data on the severity and time constant of fouling and the species of microfouling organisms encountered at various depths to 5000 meters in the Sargasso Sea.

TRI-MOOR SIMULATION AND DESIGN OPTIMIZATION

Narayana N. Panicker

Computer simulation studies of a tripod mooring for the Internal Wave Experiment continued. The sensitivity of mooring excursions to the variable system parameters like line buoyancy, apex buoyancy, line diameter and slope and environmental parameters like current speed and direction, were investigated. Based on the findings the interactive system parameters were optimized to arrive at a basic design that would meet the requirements of stability, safety, operational feasibility and economy. The system was then designed in detail and simulated on computer for predictions of mooring excursion, factor of safety and tolerable errors in deployment.

Further developmental effort resulted in a capability to simulate a general multilegged mooring system. Besides the facility to simulate mooring structures with more than three members and non-planar current field, this program uses a parabolic interpolation technique for better accuracy in predictions. Initial results for the IWEX tripod mooring using this program were obtained.

ANALYSIS SURFACE MOORING DYNAMICS

Narayana N. Panicker

Investigations were conducted on the dynamics of single point, taut, deep-sea surface moorings in a current and wave field. A numerical model of linearized equations in the frequency domain was used for computer simulation of the system. The study revealed several dynamic characteristics of compound moorings with sensor attachments. For given input wave spectrum the simulation results in response spectra for parameters like horizontal and vertical components of cable velocity, line tension and line slope as well as the surge, heave and pitch response of the surface buoy.

Comparison of the predictions with measurements was made for Mooring #290 set by the Woods Hole Oceanographic Institution on R/V *Chain* Cruise #90. Time series analysis was made on a vertical acceleration record. The acceleration spectra obtained from the record compared well with the acceleration spectra computed from the results of computer simulation. Preliminary investigations showed good agreement in the response spectra of tension and horizontal cable velocity also. Continued studies were made on the energy transfer through surface moorings.

FLOW-INDUCED OSCILLATIONS OF CURRENT METERS AND CABLES

Narayana N. Panicker

Experimental and numerical studies were made on flow-induced oscillations of current meters and cables. It was found by calculation that there is a real possibility of appreciable oscillations for a Vector Averaging Current Meter suspended vertically from an inclined leg of a tripod mooring for a likely current field. Detailed experimental investigations were conducted at the ship model towing tank at Hydronautics, Inc., at Laurel, Maryland and the calculation was verified. Several techniques to mitigate the oscillations were tried empirically. It was found that nylon rope wound aroung the current meter body in a herring-bone pattern would cut down the oscillations drastically. This solution was suggested and used for the current meters suspended from the IWEX tripod mooring.

The possibility of strumming of the cables in the IWEX tripod mooring was investigated. Calculations were made for the first few harmonics of vibration considering the longitudinal and transverse wave speeds in the legs and the distribution of lumped masses and discontinuities in them. Comparison with the respective Strouhal frequencies of vortex shedding at the various segments showed that the likelihood of strumming was small.

RESEARCH ON THE ENERGY TRANSFER FROM SURFACE WAVES THROUGH MOORING LINES

Narayana N. Panicker and Susan Schultz

Research on the transfer of energy from surface waves through mooring lines was initiated. Review of energy techniques and a preliminary attempt to apply them for mooring dynamics was made. Computer simulation of surface moorings excited by waves was made through linearized equations in the frequency domain. Records of accelerations and tension obtained during R/V *Chain* Cruise #90 on Mooring #290 were analyzed and compared with computer simulation results for program verification. The work is continuing.

INFORMATION PROCESSING CENTER (IPC)

Melvin A. Rosenfeld

During 1973 Information Processing Center computers and services continued to be important tools for both the scientific and administrative sectors of the Institution.

Both the capability and the efficiency of our Sigma 7 operation were increased this year. A dual spindle disk storage system now allows much more long term storage of user files. A change in the method of monitor job scheduling has cut the turnaround time for short jobs. The installation of a Versatec electrostatic matrix plotter has provided an alternate and faster means of plotting data.

Shipboard Computer Systems

The current year shipboard computer activities showed a marked increase in the use of the three shipboard computer systems. The additional funding received in 1973 made it possible to add peripherals previously lacking on some of the computer systems so that a balance was achieved in computing power between the three shipboard as well as the shore computer systems. This year was also marked with a definite increase in joint inter-institutional cooperation for scientific investigations. Projects such as International Decade of Ocean Exploration (IDOE), Mid-Ocean Dynamics Experiment (MODE), and Geological Ocean Sections Study(GEOSECS) consumed a large portion of the total ship time with a definite increase in the use of shipboard computing systems. Experience gained in MODE and IDOE in the use of multi-computer systems revealed definite weaknesses in the operational structure of the use of computer systems at sea. The increased use of computer time, coupled with the added diversity of scientific experimentation was not sufficient to realize the full potential of the computer systems placed aboard ship during these joint scientific ventures. Although the shipboard group did not participate in GEOSECS, it became particularly evident during project MODE that sufficient planning had not taken place prior to the cruise in the actual use of multi-computer systems. The problems encountered during this mission are being studied and should have a definite impact on future cruises with respect to multi-user adaptation, utilization, and flexibility.

Navigation played an important developmental role during this year with the addition of LORAN-C as an operational navigation tool for science. Heretofore, LORAN-C navigation was experimental, with respect to Woods Hole Oceanographic Institution navigation requirements, and limited to individual project use. LORAN-C, for the first time, was introduced as a navigational aid both for the ship in general as well as for the scientific community. Automatic fix processing was used during MODE and Acoustic Data Capsule (ACODAC) to fill the gaps between satellite fixes. It was shown that the use of LORAN-C coupled with satellite navigation presented an accurate ship's track suitable for most of the scientific requirements. Although there are only two LORAN-C receivers available at present, with one on loan from Massachusetts Institute of Technology, it is hoped that a third receiver will be added in the near future.

Also, for the first time, a beacon navigation system, developed and tested successfully, was used in the deployment of buoy systems to within a few meters of expected positioning. The real time computer program was used to position the ship for the actual deployment.

Computer Use Time

Chargeable use time of the off-line computers (PDP/5 and HP) associated with the Sigma 7 decreased from 1883 hours in 1972 to 1727 hours in 1973. This 8% decrease is probably due to the addition of the Versatec plotter which has begun to assume an important role in plotting. The shore-based HP associated with shipboard com-uting had 2537 chargeable hours in 1973, an increase of 39% over the 1824 hours in 1972.

The Sigma 7's chargeable use increased from 2081 hours in 1972 to 2466 hours in 1973, an increase of 18.5%. Total Sigma 7 usage in 1973 was 2849 hours; the non-chargeable portion of 383 hours was used for system/library development and testing and record keeping within the Information Processing Center. The Sigma 7 job statistics are:

	1972	1973
Number of jobs processed	46,521	58,847
Total hours used	2,320	2,849
Central processor hours	1,880	2,151
Cards read	8,139,984	9,139,707
Pages printed	1,083,728	1,343,202
Cards punched	611,687	754,210
Tape mounts	----	44,453
Average CPU time/job	2.42 mins.	2.19 mins
Average no. cards read/job	174.97	155.31
Average no. pages/job	23.30	22.83
Average no. cards punched/job	13.5	12.82
Average no. tape mounts/job	----	.76

The distribution of chargeable Sigma 7 use by source of support in 1973 was:

W.H.O.I. Department	Percentage of use
Physical Oceanography	62.9
Geology and Geophysics	18.9
Administration (business)	6.4
Ocean Engineering	6.0
Biology	2.6
Chemistry	1.8
Education	1.4
	100.0

As was the case last year, some 82% of the W.H.O.I. chargeable use was by two departments.

Programming and Analysis

By far the largest job undertaken by the programming staff at IPC during the past year has been the development of a software package for Acoustic Underwater Navigation. Acoustic navigation is a system whereby the position of a ship or underwater instrument package can be found from the travel times of sound pulses to known positions. The package consists of three programs; versions of each are available for the Sigma 7, the Hewlett-Packard shipboard systems, the Hewlett-Packard 9830. Six members of the IPC staff have been involved in the project which has been financed jointly by four different projects at W.H.O.I. from three departments.

As in previous years, about half the time of the programming staff was spent in operating computer functions. In addition to the usual system improvements, user consultation, and handbook

revision, the software supplied with the new Versatec was modified extensively to increase throughput. A deferred plotting plan was implemented which enables the user to direct graphic output either to the Calcomp plotter or to the Versatec plotter. Our statistical capability has been greatly improved by the inclusion in our system of the Statistical Package for the Social Sciences (SPSS).

With increasing capabilities for data acquisition at W.H.O.I., software for data management and display becomes a necessity. Several jobs in this category have been completed during the year. A program has been written for the Sigma 7 to process and display on the Calcomp plotter the relationships between properties of oceanographic data. Although primarily for analysis of current meter measurements, several program options allow input and processing of data from other sources. A program has been written for the Hewlett-Packard to display unprocessed current meter data on a Cathode Ray Tube. Routines for data storage and retrieval have also been written for the Hewlett-Packard.

Business applications have included revision of the payroll and retirement program.

Two FORTRAN courses have been given in 1973, with a total attendance of about 50 Woods Hole Oceanographic Institution employees and students.

Realizing that the best software in the world is only as good as its documentation, the programming staff spends considerable time in producing complete and accurate program reports. Every effort is made to ensure that documentation reflects the most recent program revisions.

INSTRUMENT SECTION

Douglas C. Webb

MICROSTRUCTURE CTD

Neil L. Brown

The microstructure CTD (conductivity, temperature and depth) development commenced in 1970 was continued throughout the year. The system measures conductivity, temperature and pressure 30 times per second with 16 bit resolution. It consists of an underwater unit containing the sensors, precision A/D converters and data formatting and modulating circuits. Data are transmitted to the shipboard unit using frequency shift-keying (FSK) where it is demodulated, displayed and interfaced to a computer.

During the year the following design improvements were made:

(1) A technique for high speed, high accuracy temperature measurement evolved last year and was very successfully reduced to practice. It utilizes a high speed thermistor (25 msec) and a platinum thermometer (300 msec) with special circuits such that the combined output has the excellent stability and linearity of the platinum thermometer and the high speed of the thermistor without being degraded by calibration drift in the thermistor.

(2) A technique of "adaptive sampling" was evolved which resulted in a four times increase in speed of the digitizer in the underwater unit. This means that if necessary the microstructure CTD could easily be made to run at 120 samples/second. Also the so-called "general-purpose" CTD can be run at least as fast as the original microstructure version at a very considerable saving in cost and complexity.

The technique takes advantage of the fact that a strong signal can be detected more rapidly than a weak signal. The process of digitizing a 10 KHz signal from a sensor involves making a comparison of the sensor and D/A converter signals. Previously a fixed time (2 msec) long enough to resolve a difference equal to one least significant bit (LSB) was allotted to the comparison at each bit time (Successive approximation method). The new method automatically adjusts the bit time sampling so that large differences result in short bit times and small differences in longer times up to two milliseconds.

(3) Various other improvements have simplified the design and reduced the total number of circuit cards from 23 to 13 while significantly improving speed, signal to noise, power consumption and reliability.

Presently there are 10 copies of the system in use by Woods Hole Oceanographic Institution and Scripps Institution of Oceanography and three more under construction at Woods Hole by personnel from Yale University, University of Miami and National Institute of Oceanography in England. In all cases considerable guidance and supervision were provided by the principal investigator. During the year these systems were extensively used in large programs such as GEOSECS and MODE. The users all reported obtaining data of excellent quality.

A full patent disclosure was written and submitted to the Woods Hole Oceanographic Institute Patent Committee. Work on the rest of the documentation is proceeding.

Calibration Unit

Since an instrument is no better than the equipment used to calibrate it, the need for means of rapidly and accurately calibrating CTD's was very evident. Consequently, a conductivity-temperature calibration unit consisting of a digital temperature-conductivity bridge and a precisely controlled seawater bath was designed. The bridge was breadboard and a prototype completed. An important part of this development was the A/D having an accuracy of ±1 ppm. The bridge has a temperature range of -100 to +100°C and conductivity range of 0 to 100 mmhos. The resolution is ±0.0001°C and ±.0001 mmhos respectively. There is every reason to believe that the absolute accuracy will be limited only by the ability to calibrate it in the first place.

TALKING DRIFT BOTTLE

Foster L. Striffler

One of the various ways to measure currents in the ocean is to launch a pattern of drogued free-drifting buoys and trace these buoys to obtain the current transport in this area. One of the problems has been the lack of buoys and buoy location schemes that can be gotten in reasonable numbers at a reasonable price. The goal of this program is to solve these problems.

The talking drift bottle locationing method uses precision oscillators on the buoys and in the shore stations and the relative phase shift of these oscillating pairs (as measured by a high-frequency radio communication link) gives the ranges from the shore stations to the buoys.

Two shore stations and three buoy electronics have been built and the initial tests using one shore station and one buoy package in a truck indicate that a resolution of 0.1 miles and an accuracy of one nautical mile might be obtained. Sea trials using two shore stations and three buoys will be done in the near future. The first buoys will weigh about 200 pounds and the estimated cost now is at $1500 for each buoy package.

AUTOPROBE

Kenneth H. Burt

Autoprobe was deployed as an observational platform for the studies of microstructure during 1973. Autoprobe is a free-floating instrument capable of making various programmed changes in depth in response to internal or external commands. Fluid is pneumatically forced into a bladder or pumped out of the bladder upon command from the electronic control system. The control system, utilizing proportional control, can be programmed to operate in the following modes: (1) to stabilize at a constant pressure, (2) to follow a constant temperature, (3) to make vertical excursions, and (4) to operate as desired by remote control. The instrument uses acoustic telemetry yielding navigational information as well as temperature and pressure data. Autoprobe is tracked using hydrophones and a shipboard recorder, TRACS (Telemetry Receiver Acoustic Command System) designed and built in 1973.

Autoprobe incorporates an acoustic command system that can be used for desired functions such as jettisoning weight, surface remote control operation or changing program functions. Autoprobe has a 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.

Autoprobe is an ideal platform for microstructure observations since it is uncoupled from any surface motion and can be programmed for controlled vertical excursions. An internally recording Conductivity, Temperature, and Depth (CTD) Microprofiler designed by Neil Brown (WHOI) and an Optical Salt Finger Detector (OSFD) designed by Albert Williams (WHOI), were attached to the Autoprobe for microstructure measurements. Williams used the Autoprobe, CTD, and OSFD during 1972 and 1973 to study microstructure, and photograph salt fingering in the ocean.

Autoprobe was deployed from the R/V *Maria Paolina G.*, a SACLANT ship in the Tyrrhenian Sea off the coast of Italy in April-May, 1973 with Mr. Robert Molcard as Chief Scientist. Autoprobe was programmed to fall at a constant rate, using its internal control system to make the necessary corrections. Shipboard acoustic commands were sent to the Autoprobe to reverse its direction when desired, resulting in a yo-yo mode of operation. The yo-yo mode with the CTD attached revealed the presence of the step structure of temperature and salinity. The interfaces were not very sharp,but a careful analysis of the photographs from the OSFD revealed the presence of salt fingers in the ocean.

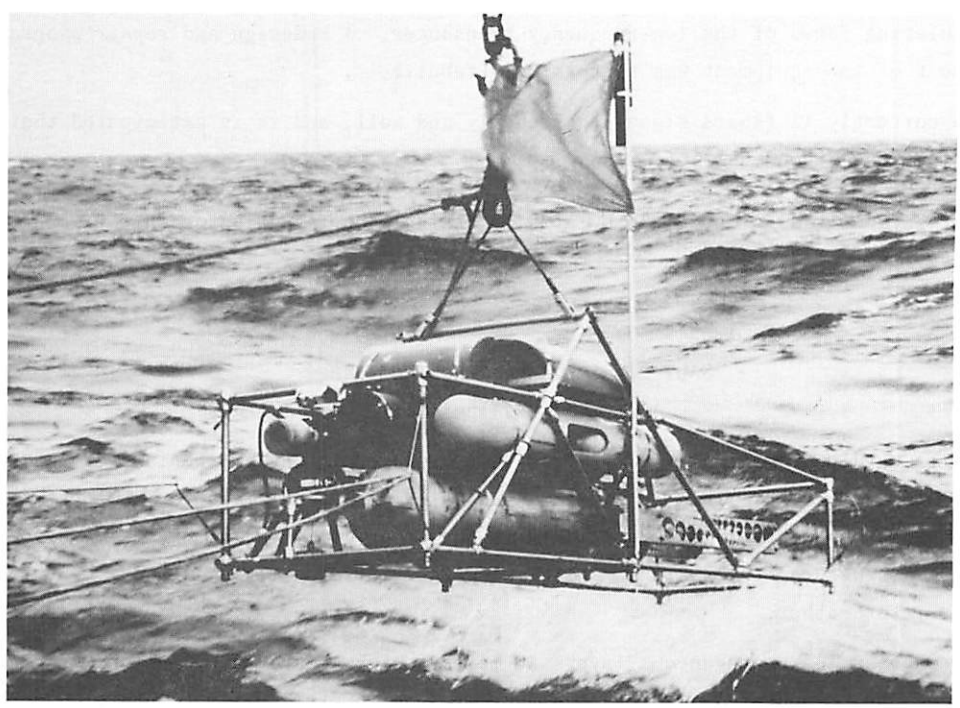

Fig.1 (Burt) Autoprobe, CTD and OSFD ready to launch from R/V *Atlantis II* in Mediterranean outflow experiment.

A joint study of microstructure in the Mediterranean Outflow region by several scientists on board the R/V *Atlantis II* was accomplished in July, 1973. Dr. Williams used the Autoprobe carrying the OSFD, and CTD to examine this region for microstructure. A typical launching of Autoprobe is shown in Fig.1. Salt fingering was observed at the sharp gradients of temperature and salinity as measured by the CTD and photographed by the OSFD in four out of six dives. Autoprobe operated as desired for these microstructure studies falling at a constant rate according to the internal program.

A new digital microstructure vehicle is presently being tested, which will perform similar functions for microstructure studies. Autoprobe was successfully used as an observational platform for a total of 44 dives.

Reference: "Autoprobe",Exposure Vol.1(4), September, 1973.

SOFAR FLOAT PROGRAM

Douglas C. Webb

The deployment of 20 long-range and long-endurance neutrally buoyant floats was carried out successfully during the MODE I experiment. The fabrication and testing program was completed during the first quarter of 1973, and the field program took place during the following four months.

The principal aim, the development of an effective float of reasonable cost and weight, has been met. One severe design fault was uncovered during the field operations; that is, the unbonding of the insulating faces of the low-frequency transducer. A redesign and repair program was started, and most of the equipment was successfully rebuilt.

There are currently 11 floats signaling steadily and well, and it is anticipated that they will continue into the second half of 1974.

The investigation is also described by A. D. Voorhis, a co-investigator in the Department of Physical Oceanography.

SALT FINGERS AND MICROSTRUCTURE

Albert J. Williams, III

SCIMP (Self-Contained Imaging Micro-Profile) was deployed in the Tyrrhenian Sea and in the Mediterranean Outflow in 1973. This instrument sinks slowly, while it records temperature and salinity and photographs optical inhomogeneities in the water column. The optical inhomogeneities reveal microscale structure, the scale at which molecular diffusion mixes salt and heat from one parcel of water into another.

In the Tyrrhenian Sea, homogeneous layers 50 meters thick separated by regions of high gradient six meters thick were encountered. Theoretical work led me to expect tall counterflowing columns of water, called salt fingers, in the interface region between the layers. However, only the

faintest traces of structure appeared in this region. The structure that appeared might have been associated with a finer scale gradient variation within the six-meter interface. Large salt fingers were either not visible or absent.

Southwest of Gibraltar, in the Mediterranean Outflow, fingers were observed in interface regions below the salinity maximum at 1200 m. One such interface was particularly sharp and provided high contrast pictures of fingers. Other interfaces occurred in an alternation of layers of low gradient and interfaces of high gradient called a staircase. Many of these also exhibited fingers. The Mediterranean interfaces were only 30 cm thick, much less than the Tyrrhenian interfaces, which fact either favors salt fingering or brings the gradients up to the level of easy detection.

The photographs of fingers within an interface confirm the identification of fingers in the Caribbean by SCIMP in September, 1972. The confirmation brings to an end the original train of this project which was to detect fingers if they exist in the ocean. Along the way, new interests have appeared: turbulent mixing structures, velocity shear, and horizontal and temporal structures. Understanding of vertical ocean mixing depends on these features as well as salt fingers. Future observations will include measurements of shear and horizontal gradients.

OCEAN ENGINEERING ACADEMIC DEVELOPMENT

James W. Mavor, Jr.

Eleven students were enrolled in the Joint Program in Ocean Engineering with the Massachusetts Institute of Technology during 1973. Of these, three graduated with the degree of Ocean Engineer.

Jay Martin Cohen O.E. June 1973 "An Experimental Analysis of the Dynamics of a Submerged Tethered Cradle in a Seaway".

Paul Jeffrey Simonetti O.E. June 1973 "An Investigation of Various Forms for a Tuned Oceanographic Platform"

James Francis O'Sullivan O.E. September 1973 "The Design of a Surface Launch and Recovery Fender for DSRV *Alvin*".

Richard Jaffee and J. Kim Vandiver passed Part II of the qualifying examination for the Ph.D. and have commenced work on their theses. Of the three graduates, one is in the United States Naval Submarine Service, one has accepted employment with an oceanographic instrument firm and one is employed at Woods Hole Oceanographic Institution as Visiting Investigator.

1973 has seen increased joint MIT/WHOI activity in research, student support, faculty and student communication, and realized complementary objectives.

The record shows that the best oceanographic science is done by a combination of good science and good engineering, sometimes by an individual, sometimes by a group. The engineering academic program offers an opportunity to the student to develop graduate level engineering skills and use these in research in either man-made or natural systems.

Academic Subjects

Four subjects were given during 1973:

Oceanographic System I & II, R. W. Miller

Deterioration of Materials in the Ocean, S. C. Dexter

Buoy Engineering, H. O. Berteaux

Deep Submergence Oceanographic Engineering, J. W. Mavor, Jr.

The first two subjects were held at Woods Hole Oceanographic Institution and the last two held at Massachusetts Institute of Technology because of the student's residency schedules. The subjects given at Massachusetts Institute of Technology enjoyed larger enrollment than was the case when they were given at Woods Hole Oceanographic Institution.

Texts continue in preparation for the last two subjects.

Research Projects

Faculty and student joint research outside of formal courses is an important part of the academic program.

Deep Sea Oceanographic Systems Deployment

A. Deep Submersible Launch and Retrieval in Higher Sea States

(James W. Mavor, Jr. and James F. O'Sullivan)

Measurements of statics and dynamics of the *Alvin* cradle on *Lulu* were made with the cradle submerged to a depth of 80 feet for proposed submerged retrieval. The results were hopeful but complex decoupling means were indicated.

Improved surface launch and retrieval systems for deep manned submersible were studied with a promising scheme carried through preliminary design.

B. Design Specifications for a Semi-Submerged Oceanographic Research Vessel

(James W. Mavor, Jr. and Susan Schultz)

This project follows up on a proposal made in 1971 and dormant until recent prospect of actually building such a craft.

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. Part I covering the properties of some eight metals and alloys was completed in 1972. Part II covering non-metallic materials will be completed during 1973.

Other Research Projects

Research projects with major contributions by students, single copy reports available in some cases, were as follows:

Pneumatic breakwater study (Blue Cover Report in preparation)

Wave Impact Force Measurement (Blue Cover Report in preparation)

A Digital Recording System for Marine Experimentation

Salt Finger Research
Underwater Acoustics Research
Swordfish Attack Experiments
Deep Sea Capsule Design
Alvin Structural and Hydrodynamic Analysis
Tri-moor Wave Research
Ocean Wave-Structure Interaction of Fixed Towers
Alvin Dynamic Stability
Marine Science and International Law
Role of Oceanographic Engineer
Monitoring Deep Ocean Circulation by the Use of Long Term Floats
Engineering Analyses of the Giant Corer
Maximizing Ship Use
CURV and Other Unmanned Probes in Oceanography

SAFETY PROGRAM

James W. Mavor, Jr.

The Institution's safety program underwent extensive review during 1973. In addition to the work of the safety engineer in this connection, several committees and consultants were active as follows:

Ad hoc Alvin Review Committee convened in May 1973.

Capt. C. B. Momsen (USN,Ret.) General Motors Corporation
Capt. Frank Andrews (USN,Ret.) The Catholic University
Dr. Fred Spiess, Marine Physical Laboratory, Scripps Institution of Oceanography

Alvin FAMOUS Operations Committee convened July 1973

Dr. M. A. Rosenfeld
Mr. W. O. Rainnie, Jr.
Mr. L. A. Shumaker

WHOI *Alvin* Review Committee convened August 1973

Dr. A. E. Maxwell
Dr. T. F. Webster
Dr. R. W. Morse

Trustees Safety Committee convened September 1973

Mr. Noel McLean
Mr. Townsend Hornor
Mr. A. Bemis

Consultants: Capt. Harry Jackson (USN,Ret.) was retained from August 1973 to evaluate Safety and General Engineering programs.

Mr. Norman Reese and his firm of safety consultants were retained to conduct a safety inspection relative to OSHA requirements.

The first three committees dealt with the readiness of *Alvin* for proposed deep operations after refitting with a new titanium alloy personnel sphere.

The Trustees Committee dealt broadly with Institution safety and defined three areas of concern:

1. Deep Manned Submersible Operations
2. Surface Ship Operations
3. Laboratory Safety, covered for the most part by the Occupational Safety and Health Act (OSHA) regulations.

The Trustees Committee report states the following: "that the President and the Board of Directors have reaffirmed their desire that the work of the Institution be carried on in a manner that will ensure safe conditions for the personnel and afford the maximum protection of equipment. It is recognized that the work of the Institution must be carried on in an efficient manner and that an overriding consideration of safety might slow down or even stop many of the operations. To prevent this from happening, any safety program must be tempered with good judgment."

Two major accidents to deep manned submersibles during 1973 (not under WHOI cognizance) gave urgency and importance to the work of the committees, consultants and safety engineer. They were the *Sea Link* tragedy, in which the vehicle caught in the rigging of a sunken ship with two fatalities, and the sinking of the *Pisces III* during cable laying operations, with recovery just in time to save the crew from suffocation.

The safety engineer participated in the work of all of these committees and that of the consultants which led to a major restructuring of the safety program. James Mavor, who had served four and one-half years as safety engineer on a one-half time basis, having felt throughout 1973 that the position should be a rotating one and due for a change of occupant, resigned the position on October 30. A new position, Institution Staff Engineer, was established, and Henri O. Berteaux was appointed for a two-year term. The Staff Engineer, in addition to other staff duties, supervises the Institution's safety program with the assistance of a staff including a full-time safety coordinator. Whereas the safety engineer had authority, delegated by the Provost, to suspend operations for safety reasons, this authority was reserved by the Provost and Director in the reorganization. This removes some of the overlap of responsibility which previously caused conflicts between the safety engineer and line management. In addition, it was decided to establish a safety committee made up of middle management, which would act as arbiter in conflicts between the staff engineer and management and review accidents.

The problems receiving the most attention by the safety engineer and management during 1973 were those related to *Alvin* safety. In March 1973, the safety engineer submitted, to the Director, a status report of *Alvin* safety noting some items of concern. Subsequently operations at sea were

delayed some four months by a series of problems, some critical to safety, some not, effectively cancelling all scientific dives for the year. The more persistent of the safety problems were:

Hull electrical penetrator strength and leakage
Basic hull stress analysis
Hull release design
Quality assurance program
Buoyancy and stability
Released forebody condition
Freeboard in surfaced condition
Retrieval in rough seas
Titanium air storage and variable ballast sphere strength
Window protection from collision
Appendage release reliability
Rescue plan
Life support requirements
Dive hydrodynamics

Technical safety problems treated in areas other than Deep Submersible Operations were as follows:

Laboratory Safety

The safety consultants found weaknesses primarily in the areas of eye protection, electrical grounding of outlets and portable machinery, clear access through passageways and rooms, storage of inflammable and other hazardous materials, and dust removal. Action is underway to correct these deficiencies.

The Chemotaxis aquarium window design was reviewed and approved.

A fork truck accident was reviewed.

The periodic crane test program was enforced.

Pressure Vessels

Preparation of guidelines for undersea pressure vessel design for the American Society of Mechanical Engineers (ASME) continued. A policy for pressure vessel design within the Woods Hole Oceanographic Institution was defined and pressure vessel designs were reviewed.

Proposal for installation of the Dahlgren large pressure test facility was updated.

The Blake pressure test facility was derated to 5000 psi because of wear deterioration.

Deep Ocean Technology (DOT) compressed gas cylinder law was enforced.

Ships

Three serious injuries were sustained on board ships at sea related to handling instruments over the side.

The safety engineer participated in litigation over the *Lulu* dry dock accident of 1972.

The *Lulu* arch strength was reviewed.

HYDROSTATIC PRESSURE TEST FACILITY - 1973 UTILIZATION

William S. Shultz

Total Number of Tests: 181

Total Number of Cycles: 692

Total Hours at Pressure: 3975

Supervisor/Operator (Testing) Approximately 500 man hours

Including:

1. Syntactic Foam H_2O absorption tests (Project 16/372111.04)

   23 Tests

   81 Cycles

   3053 Hours

2. Certification Tests for implodable items: DSRV *Alvin*

   40 Tests 400 Cycles 100 Hours

   Plus 28 other tests, calibrations, etc. 32 Cycles 7 Hours

3. Internal Pressure Tests of biological samplers

   7 Tests 20 Cycles 62 Hours

4. Residue:

   83 Tests 159 Cycles 753 Hours

A pressure-versus-time recorder has been hooked up to the high pressure manifold for permanent recording of events. This has been especially useful for tests requiring certification.

ACOUSTIC SECTION

Earl E. Hays

Alvin MODULAR ACOUSTIC SYSTEM

Paul T. McElroy and Frederick R. Hess
(assisted by Roger S. Walen, Donald L. Dorson, Maxine M. Jones,
Foster Striffler, Walter D. Nichols)

Under sponsorship of the Advanced Research Projects Agency (ARPA), development began in December 1972 on a complete sonar suite for the research submersible *Alvin*. Its purpose is to provide the scientiat/user of *Alvin* with a set of acoustic tools with which to conduct many different investigations.

The completed system will contain the following components:

1) A precisely controllable signal-generator (synthesizer) with appropriate linear power amplifiers and electro-acoustic transducers capable of generating and receiving acoustic energy at frequencies in three separate bands covering the range of 2-45 kilohertz.

2) A display and recording system capable of various displays of the sonar information and of recording it for later analysis. Visual presentation is by oscilloscope, and permanent recording is by film camera and magnetic tape recorder.

3) A programmable training mechanism which permits pointing the sonar transducer in any direction and scanning any bearing interval. The training mechanism is coupled to the display for presentation of sonar data versus bearing angle.

4) A general-purpose digital computer capable of performing all control and data processing functions under program control as well as providing the capability of faster and more complex sonar modes than are possible in a purely manual system.

A major scientific investigation planned for the system is its use to determine the frequency spectra of oceanic volume scatterers. The computer's capability of rapidly shifting frequency (via the synthesizer) coupled with the wide operating frequency range of the transducers used enables determination of discrete frequency target strength at virtually any number of such discrete frequencies in a band. Additionally, the computer can be programmed to process the signal returns and present the data in real time to the scientist. The extent of on-board processing is dependent mainly on the memory capabilities, a capability which has been doubled recently.

The system is capable of operation in a simpler "manual" mode, independent of computer control. While the system is capable of all the conventional sonar operations, it is of necessity more limited in its ability to process received data. However, all conventional echo-sounding and echo-ranging functions can be accomplished.

Our efforts in 1973 were devoted to detailed engineering design and development of the basic system. Various components such as the synthesizer, computer, transducers, tape recorder and display device were purchased. These have been combined with numerous circuits designed here to create

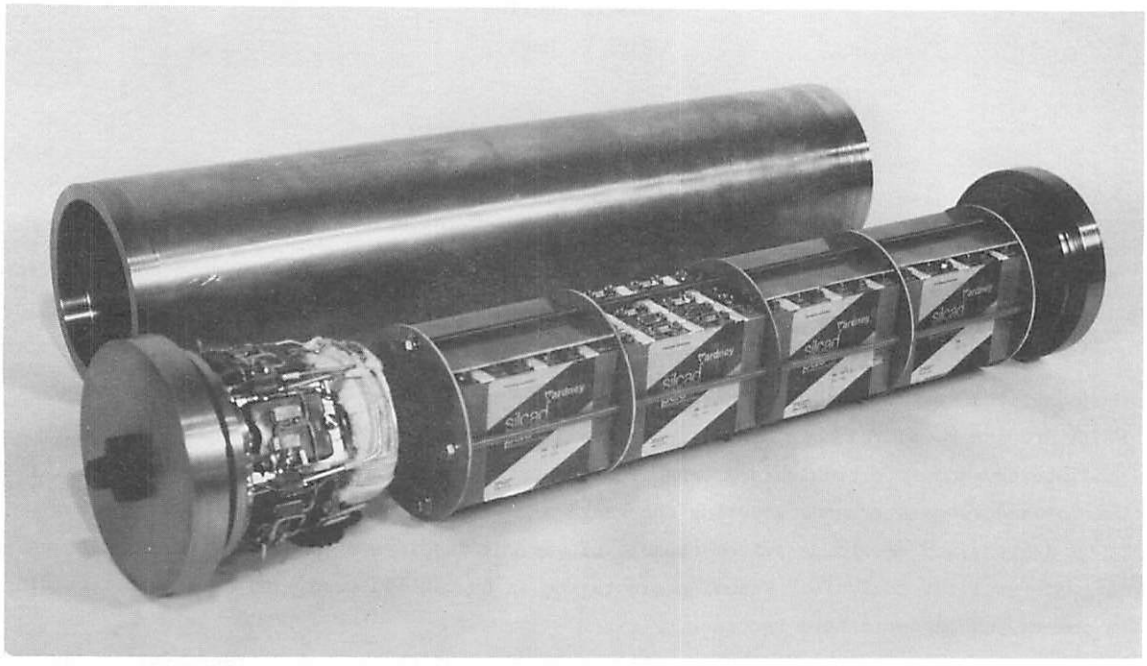

Fig.1 (McElroy and Hess) One of two outboard power amplifier/battery packs.

the various subsystems which make up the acoustic system. Of these, the control unit, transmitters (Fig.1), and receive circuitry are nearly complete. The control circuit includes a keyboard for selecting experimental parameters and a data logger for recording many experimental parameters. The transducer training mechanism lacks only installation of brakes (Fig.2). Prototype packaging of the display unit has been coupled with some circuitry; however, circuits controlling the different display modes and relating the display to transducer azimuth and elevation are still under development. We have acquired a two-computer system; the surface system is on line (Fig.3), while the submersible computer requires extensive modifications. However, considerable progress has been made in interfacing the computer to the devices it controls.

Overall, the subsystems are nearing completion. Their testing, first individually and then combined in the composite system will take place in early 1974. These tests will be confined to the simpler "manual" modes of operation, while further development of the computer capability will continue throughout 1974.

A more detailed description of the system can be found in the original contract proposal (McElroy, Hess 1972).

Reference

Paul McElroy and Frederick Hess, 1972. "A Deep Submersible Modular Acoustic System." Subtask E in "Advanced Marine Technology." A research proposal submitted to the Advanced Research Projects Agency of the Department of Defense by the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. Robert Morse, Principal Investigator. 30 September 1972. Unpublished manuscript.

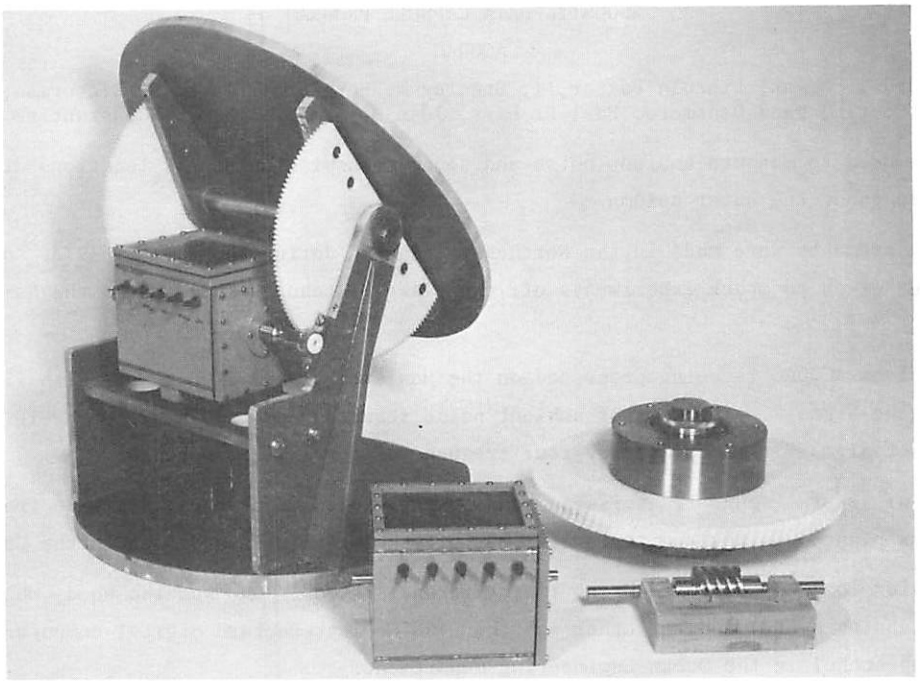

Fig.2 (McElroy and Hess) Transducer training mechanism. Elevation drive assembled. Step motors in oil-filled boxes.

Fig.3 (McElroy and Hess) Surface computer system. Repco high speed printer at left rack, Top to Bottom: Disc Storage Unit, Remex High Speed Tape Reader NOVA 1220 CPU, Scope Graphics Terminal, Keyboard, Disc Controller (under table). ASR-33 Teletype at Right.

ACOUSTIC DATA CAPSULE PROGRAM

ACODAC

Richard T. Nowak, Lincoln Baxter,II, Stanley W. Bergstrom, David S. Bitterman, Paul R. Boutin, Dana Densmore, Earl E. Hays, Jess H. Stanbrough,Jr., Constantine D. Tollios

ACODAC is used to measure ambient noise and sound transmission at six locations distributed vertically throughout the water column.

Field measurements were made in the Northeast Atlantic during the fall of 1973. Engineering cooperation was given to other experiments off the Blake Plateau in June and in the Caribbean in November.

The data from ACODAC is being processed on the Hewlett-Packard 2100 system with final displays being made on the Sigma-7. Ten days of ambient noise requires about 30 hours of Hewlett-Packard time and six hours of Sigma-7 time to display four frequencies for six hydrophones.

Analysis of several sound transmission runs, using explosive charges, was made from tape recordings of ACODAC buoys planted in the Mediterranean Sea, off the Madeira Islands and in the Caribbean Sea.

Transmission loss was computed using two different systems. One was the Woods Hole Oceanographic Institution's analog system and the other was the 2100 Hewlett-Packard digital computer using programs developed by personnel in the Ocean Engineering Department.

The results of each compared favorably.

SOUND TRANSMISSION AND AMBIENT NOISE

Lincoln Baxter, II and Cheng Y. Yang

A report was completed based on ambient moise measurements made in February 1972 in the North American Basin. Some further analysis of the September-October measurements has been completed, but development of computer programs for the Acoustic Data Capsule analysis and for the new Fourier System have preempted the time that would have been required for a report similar to the previous ones. Moreover it is felt that, if support for analysis of this suspended hydrophone and sonobuoy data should be available, it would be better to take advantage of our new Fourier analysis facility to study more detailed spectra of the noise and the effects of suspension strum at lower frequencies. In this investigation a Fortran computer program has been developed to permit high speed graphic terminal plotting of nearly all the possible functions that can be computed by our Fourier analyzer installation. Correctly labeled axes are automatically drawn on the plots with options for interactive control for plotting nonstandard data obtained with other digitizers.

A start has been made, with Cheng Y. Yang, to investigate sound transmission from the Swallow floats deployed in the "MODE" experiments. The acoustic transmissions have been used by Dr. Thomas Rossby's group at Yale University, but only for tracking the positions of the floats. We plan to study the short, medium and long period fluctuations in the amplitude and arrival time of the

transmissions, to find any correlations with internal waves and tides. For long period variations we shall also be interested in studying the stability of the float sound sources and if possible the transmission as a function of range. The latter investigations can determine whether the design of the float sources needs to be improved for more effective tracking or further transmission studies. Since the signals from the floats are received at several geographically separated stations we should be able to separate effects in the source or its locality from range effects.

MODIFIED RAY THEORY

James A. Davis

Theoretical work on a modified ray theory, designed to take certain diffraction effects into account within a ray representation, has continued. This modified ray theory and an extended modified ray theory, the latter extending the modified ray theory calculations through caustic regions, have been reported in detail in two articles which have been submitted to the Journal of the Acoustical Society of America for publication.

Also, the theoretical extensions of the theory to include general boundaries, reported previously (Summary of Investigations, 1971), have been further developed and the results adapted to computer programs written for the Sigma 7. The general situation which is treated is that of two adjacent semi-infinite inhomogeneous media, and therefore contains as special cases:

(1) An inhomogeneous media in contact with a homogeneous media, and therefore suitable for characterizing the ocean bottom.

(2) Sound velocity profiles for which there is a maxima somewhere within the water column.

(3) Representations of the sound velocity profile by linear segments.

While these programs are still in "debug" status, preliminary numerical results indicate, just as we expect from theoretical considerations, that the representation gives reasonable results except for those modified rays having angles either in the vicinity of a "critical angle" or an "angle of intromission".

LONG RANGE ECHO-RANGING DEEP-TOWED ARRAY

Willard Dow

A long range echo-ranging system similar in principle to a deep-towed side-looking sonar, was designed and assembled at Woods Hole Oceanographic Institution in 1970-71.

This system employed deep Signal Underwater Sound (S.U.S.) charges as sound sources and a deep-towed 100-foot hydrophone array as a receiver. The array was designed to be towed by single conductor 1/4 inch diameter logging cable at depths to 5000 feet.

The system was employed for mapping the ocean bottom off the Bahamas in August, 1971, and ranges out to 460 km were recorded.

While most echoes correlated well with known topographic relief, additional persistent returns indicated bottom features not recorded on bathymetric charts. Unfortunately the bearing of these reflectors with respect to the ship's track could not be accurately determined partly because of the wide beam of the array (25^{o} at 100 Hz).

This ambiguity provided considerable incentive to construct a new and longer array (250 feet) having a narrower beam width ($\prec 10^{o}$ at 100 cycles) for improved directionality and target definition.

This array has been completed recently. New preamplifier design and array construction techniques should result in a far quieter and more reliable instrument than the original experimental model, which consisted primarily of a surface type array reinforced for the high pressures of deep operation.

TEN CHANNEL LINE AMPLIFIER

Willard Dow

The four-channel solid state amplifiers employed in the ship's laboratory for amplifying on-line signals from the deep-towed array and ship-suspended hydrophones have proved very unsatisfactory for these applications with respect to dynamic range, noise, and recovery from high amplitude transients.

A new ten-channel solid-state amplifier designed particularly for such on-line operations is nearing completion. Each of the five wide-band low-noise channels has 80 db dynamic range and a 40 watt peak output power capability. The five additional channels have provision for low-level plug-in or external filtering, and the system is arranged to provide filtered and wide-band outputs, or dual-gain amplification simultaneously from each signal source. A versatile input switching system permits combining amplifiers in various ways without resorting to confusing networks of patch cords.

NEUTRALLY BUOYANT SUSPENSION SYSTEM

Willard Dow and Lincoln Baxter II

During 1972, Mod II of a neutrally buoyant suspension[1] was constructed and taken on *Chain* Cruise #107. An experiment was conducted at sea off Bermuda to determine the effectiveness of the system in quieting a deep hydrophone by isolating it from motion of the suspended cable.

For purposes of comparison, a second hydrophone was clamped directly to the cable, and thereby subjected to cable motion generated by rolling and pitching of the surface vessel.

Early in 1973 tape recordings of the flow noise generated by the two hydrophones were subjected to Fourier nalysis via the Hewlett-Packard computer[2]. It was found that the shape of

[1]See W.H.O.I. Ref.#73-12.

[2]See W.H.O.I. Ref.#73-26.

the curve from the isolated hydrophone essentially followed Wenz's* ambient noise curves for the existing conditions of wind and traffic. However, the cable-mounted unit averaged 6-8 db higher over the same frequency bands with flow noise bursts ranging from 13-15 db above ambient noise during periods of maximum ($\pm 5^{o}$) roll and pitch.

A complete description of the new system together with details of this analysis was then prepared and issued as a Technical Report in April 1973.

Reference

*Wenz, Gordon M. Dec. 1962. *J.Acous.Soc.Amer.* 34(12): 1936.

SURFACE LAYER IN THE SARGASSO SEA

Peter E. Raschig and Eli J. Katz

Sound velocimeters were towed simultaneously at 25 and 45 meters in April of 1972 (*Chain* #102) between 29^{o}N;55^{o}W and 34^{o}N;62^{o}W. Climatological averages indicate that the region should have had a well-mixed surface layer at this time of year and the objective was to measure the variability of the sound velocity in such a layer.

From temperature and salinity (T-S) measurements made at 25 meters, the track was found to have crossed four distinctive T-S waters: southern Sargasso, a discrete transition region, northern Sargasso and a cold ring Gulf Stream eddy embedded in the latter. The discontinuity between the transition region and the northern Sargasso water was a thermal front.

The surface water varied considerably in the degree of its homogeneity, with stratification and inversion being the general rule. Only two extensive areas of well-mixed waters were observed. The first of these was in the transition region before the front and may be related to the current that has been previously observed to flow along its warm side. The second instance of an isothermal surface layer occurred when the winds increased above force 4 (Beaufort), and can be attributed to wind mixing.

VOLUME REVERBERATION

Paul T. McElroy

During 1973 my efforts were concentrated upon the analysis of volume reverberation data which had been collected in prior years. There were two significant successes:

Geographic Patterns in Volume Reverberation Spectra in the North Atlantic between 33^{o}N and 63^{o}N (with Harold K. Lim)

A paper with this title has been submitted for publication. Its conclusion is that there are similarities in volume reverberation spectra and that stations with similar spectra group geographically.

In the summer of 1972 volume reverberation data were collected at 34 stations on Cruise #105 of R/V *Chain* during its passage from Newfoundland to the Azores, and thence to Portugal and Ireland. During 1972 the acoustic returns at each station were analyzed in 16 one-third octave bands extend-

ing from 1 kHz to 31.5 kHz. This year the data were fully reduced to give column strength spectra, and each pair of spectra were compared quantitatively using a new measure which I have called the cross-standard deviation (σ_{cross}). Low values indicated that the spectra were similar (Fig.1a); high values, that they were dissimilar (Fig.1b). By studying a matrix of σ_{cross} values comparing each pair of stations, it was noted that spectra for nearby stations were similar and thus could be classed in geographically-based groups called pelagic regions. This is reasonable since much volume reverberation is sound scattered from animals which in turn are distributed in pelagic faunal regions (Backus *et al.*, 1970). Many of these regions have been identified on the basis of physical-oceanographic features such as the polar front and subdivisions of the Gulf Stream system (Fig.2). These features are used in defining boundaries for the regions. This is the first quantitative demonstration that volume reverberation spectra can be grouped in a meaningful way.

The analysis of fish trawls for this cruise has not been completed so that a comparison of acoustic data with the faunal patterns is not possible at this time.

Other Analyses of Explosive Column Strength Spectra (with Harold K. Lim and Woollcott K. Smith).

Column strength spectra for the 26 stations of *Atlantis II*-59 were fully reduced in 1973 and compared in a σ_{cross} matrix. The spectra from *Atlantis II*-49 were also analyzed to give a σ_{cross} matrix. The assignment of these stations to regions based on their spectral similarities will take place in 1974.

In 1971 while looking for patterns in the *Atlantis II*-49 spectra, factor analysis was employed without success. This year a more sophisticated form of factor analysis was used - correspondence analysis - with the higher quality data from *Chain* #105. This time we saw meaningful clustering of stations, a clustering which correlated well with the grouping deduced from the σ_{cross} matrix. Thus correspondence analysis is a useful tool in grouping spectra and thereby seeking geographic patterns.

Correlations between the Results of Faunal Sampling of the Deep Scattering Layer and Single Frequency Measurements of Volume Scattering Strength (with Harold K. Lim, Richard H. Backus, Woollcott K. Smith, and Richard L. Haedrich).

The second success was in noting a significant correlation between acoustic and biological data.

During the portion of *Atlantis II*-59 between Cape Verde Islands and Woods Hole (November - December 1970), measurements were made of the volume scattering strength of a scattering layer while that same layer was being fished with the Isaacs-Kidd midwater trawl. Scattering strength was determined at 12 kHz using the integrator, a specialized analog computer (McElroy, Wing, 1971), and was an average value restricted to the depth range of the trawl.

With the recent completion of the analysis of the trawls, we were able to compare the biological and acoustic data for the 35 nighttime and six daytime trawls. Specimens per hour correlates highly ($r = .84$) with volume scattering strength, a far better correlation than had been expected. Regression analysis of the data shows that it is not inconsistent with the hypothesis that volume scattering strength and specimens per hour are linearly related to the 5% significance level. A

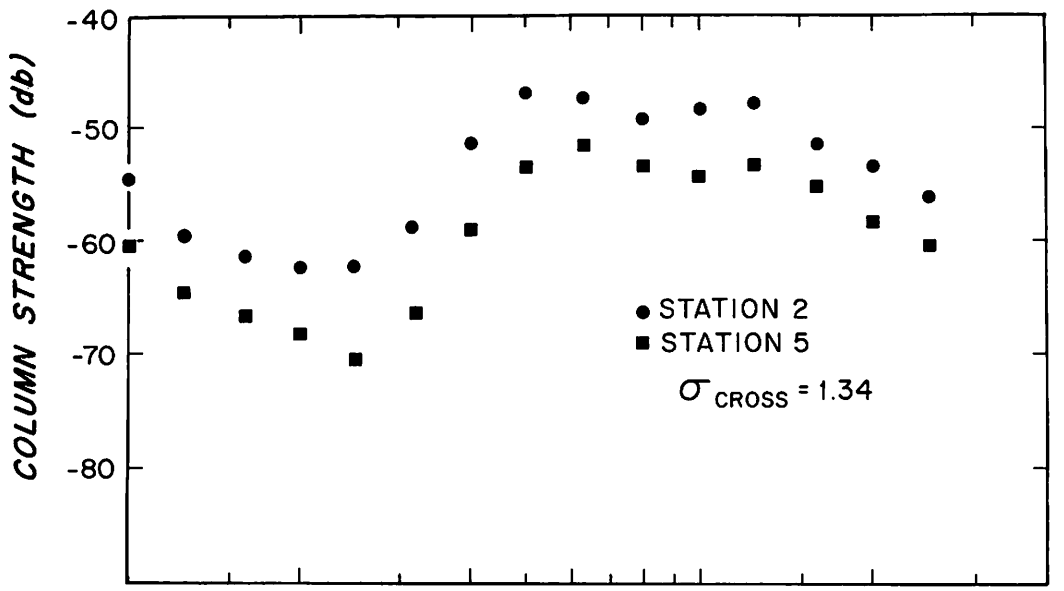

Fig.1a (McElroy) Comparison of two stations which have similar spectra and a low value of the cross-standard deviation. They lie in the same region.

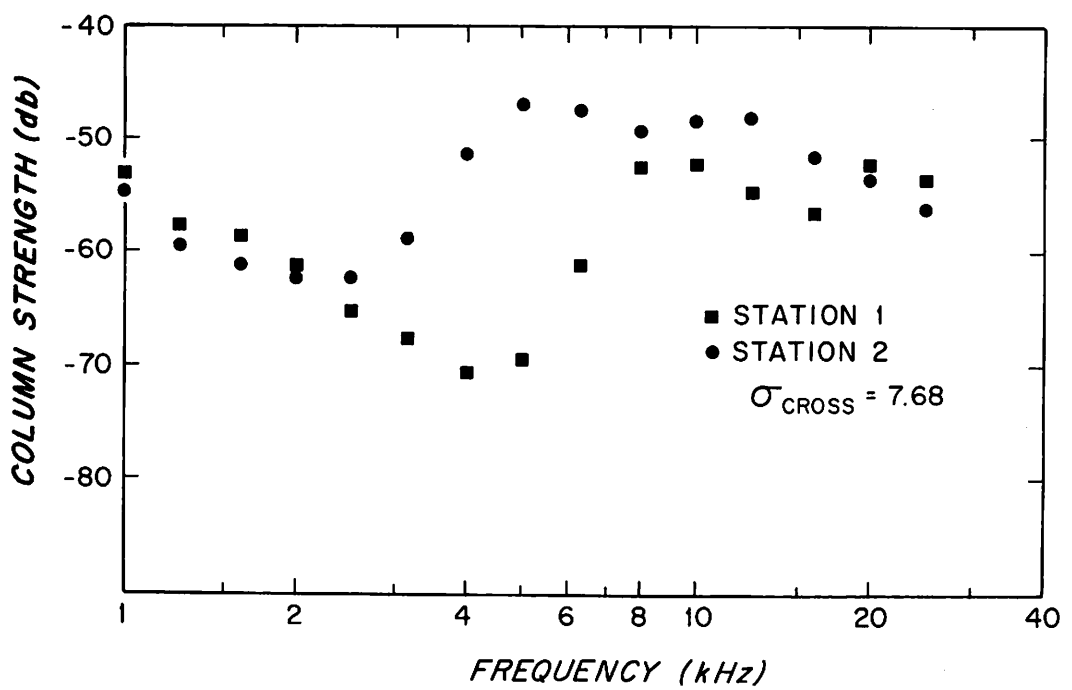

Fig.1b (McElroy) Comparison of two stations which have dissimilar spectra and a high value of the cross-standard deviation and, hence, are inferred to lie in different regions.

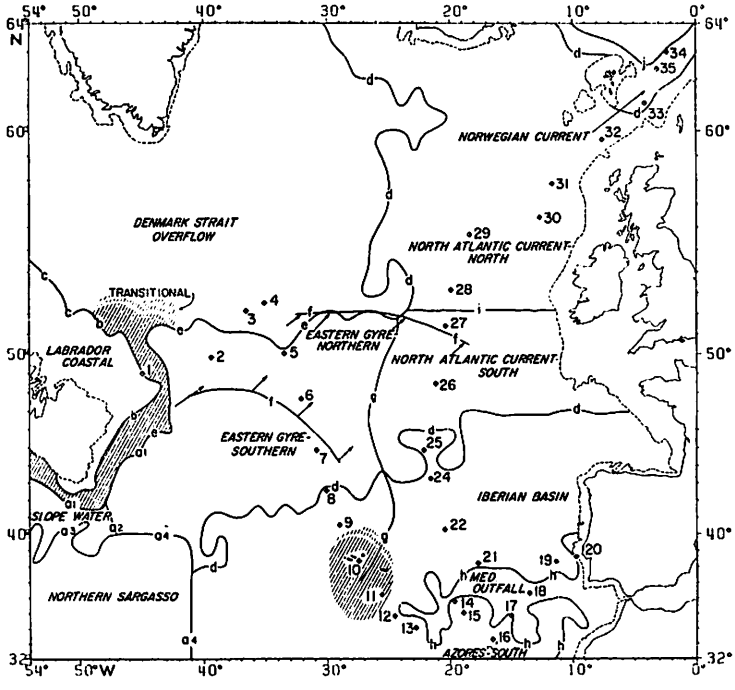

Fig.2 (McElroy) A geographic plot showing the regions inferred from the cross-standard deviation matrix of spectra. Station positions and numbers are given. The boundaries, marked with solid lines and identified with lower case letters, are discussed in the paper (McElroy, 1974). Dashed lines indicate the 200-meter depth contour. Striated regions are transitional in character.

lower correlation is shown between volume scattering strength and volume of fish per hour.

The analysis is continuing to see if we can describe any more of the variance in the data. Depth and temperature of the water at trawl depth are parameters showing significant correlation. Interestingly, geographic position, 200-meter temperature, and the measurement error in trawl depth determination have far less statistical significance.

If the high correlation is confirmed in *Chain* #105 data, it will suggest that single frequency measurements are a better predictor of scatterer density than had been thought likely.

Multiple Resonance (with Harold K. Lim).

The hypothesis that deep scattering layer fish with air bladders whould return acoustic energy strongly at more than one frequency is being examined. The usual model restricts itself to monopole radiation from an air-filled sphere. We are looking for dipole, quadrupole, and the higher-order radiations. A computer program has been written to test this hypothesis using the theoretical model (Anderson, 1950).

In addition we are looking for multiple-frequency returns from a single layer in our explosive records from *Chain* #105 and *Atlantis II*-59. Two computer programs were written in 1973. The first digitizes scattering returns after the receipt of a trigger pulse signaling the source explosion.

The second loads these digitized records into the 5451A Fourier Analyzer portion of our Hewlett-Packard 2100 computer where they can be analyzed. Fourier analysis of 5 and 10 msec portions of these shots has given some very preliminary indications of multifrequency returns. The evidence lies primarily in the occurrence of spectral patterns which repeat at two or more frequencies.

This work will continue, examining many shots in detail, before firm conclusions can be drawn.

SAVOR (Spectral Analysis of Volume Reverberation).

Efforts on the SAVOR system were restricted to improving the design of the filter to eliminate noise and to some small program improvements. A more detailed discussion of the system can be found in the 1972 Summary of Investigations.

References

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McElroy, P.T. and A.Wing (1971) Scattering Returns in the Mediterranean and Eastern Atlantic - Data and Instrumentation. In *Proc.Internat.Symposium on Biological Sound Scattering in the Ocean*, G.Brooke Farquhar,Ed. (U.S.Government Printing Office,Washington,D.C.).220-231.

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ARRAY COHERENCE: EXPERIMENT AND ANALYSIS

Robert P. Porter and Robert C. Spindel

The phase and amplitude of low frequency acoustic signals received at a range of 210 km have been analyzed. Data for this analysis, collected during the experiments reported in the 1972 Summary of Investigations, represents an initial foray into (a) the study of spatial and temporal variations of phase and amplitude of long-range transmissions, and (b) the relationship between observed variations and casual environmental factors. A fixed bottom mounted acoustic source was used in conjunction with free-drifting receiving hydrophones. The hydrophones were suspended at mid-water depths to eliminate bottom, and most surface reflection paths. Phase variations due to hydrophone drift were removed by a bottom-moored Doppler tracking system especially designed for these experiments.

The most remarkable aspect of the data is that maximum phase fluctuations over continuous four-hour intervals amount to as much as 15 cycles. Rates of phase change are relatively slow; the phase fluctuation spectrum falls off with a slope of -2 between 0.4 and 40 cycles/hour. On the other hand, amplitude fluctuations are extremely rapid. Comparison of phase fluctuations with hydrophones of varying depth reveals a striking depth dependence. It has been postulated that internal waves, which produce maximum sound velocity fluctuations in the main thermocline,

are responsible for the major portion of phase fluctuation in the data. Rays which spend a larger percentage of their total source-receiver travel time in the main thermocline are most affected by internal waves and exhibit maximum phase fluctuations. For the particular sound velocity profile encountered during these experiments deeper hydrophones (1500 m) interrupt rays spending a larger fraction of their travel time in this region than do shallow hydrophones (300 m). As a consequence, phase fluctuations are greater in the deeper phones.

A theoretical ray model has been developed, based on an internal wave spectrum postulated by Garrett and Munk, which shows that the spectrum of the acoustic phase for both fixed and drifting hydrophones is proportional to the spectrum of the internal wave field. It is also shown that the internal wave field produces high-frequency, random amplitude variations. Comparison of these predictions with the data supports the conclusion that internal waves do indeed account for a considerable fraction of the total phase variation observed. The model can, in addition, predict phase variations as a function of range, frequency and source and receiver location.

Additional work was performed this year in conjunction with the Department of Geology and Geophysics in their investigation of the Mid-Atlantic Ridge under project FAMOUS. Modifications were made to the pulsed acoustic navigation system originally developed for the tracking of DSRV *Alvin* so that free-drifting sonobuoys could be tracked with relative accuracies of about 10 meters. Sonobuoy arrays were deployed near the median valley of the ridge to detect and localize microearthquakes acoustically. A total of 112 seismic events were detected in 74 hours of listening; 29 with sufficient signal-to-noise to enable geographical location. Location accuracy is estimated to be about 400 meters. It appears that most seismic activity near 36°30'N occurs on the eastern wall of the median valley. Spectral analysis of close events ($\lesssim$ 5 km) shows a strong energy peak in the neighborhood of 20 - 25 Hz.

The transmission and reception of transient signals propagated in a SOFAR channel was investigated theoretically and compared with data obtained during *Chain* #82. The analysis can predict the received waveform when a wide-band pulse is transmitted through arbitrary oceanic sound channels. A computation scheme has been developed to calculate propagation loss as a function of depth, range and pulse shape.

INTERNAL WAVE EXPERIMENT (IWEX) TRIMOOR DESIGN

Henri O. Berteaux

Design, acquisition, and strict quality control of the mooring line components (wire rope, chain, instrumentation swivels, attachment hardware, syntactic line floats, special anchors) were performed for each of the three (plus one spare) 6000 meters leg of the IWEX trimoor. Mooring design and components selection proved to be satisfactory during deployment, implantation, and successful recovery of the large trimoor.

SPAR BUOY

Henri O. Berteaux

53 foot 3325 lb. SPAR buoy with a natural heave period of 27 seconds was designed and built (Fig.1). The buoy was launched during the October, 1973, cruise at the MODE site. It was tethered to a single point surface taut moor anchored in 5600 meters of water depth. Recording instrumentation was inserted in a free hanging 120 meter long mooring line attached to the lower end of the SPAR buoy. It is hoped that oceanographic measurements made in the upper part of the water column with this approach will have a reduced and/or predictable amount of noise due to sensor motion.

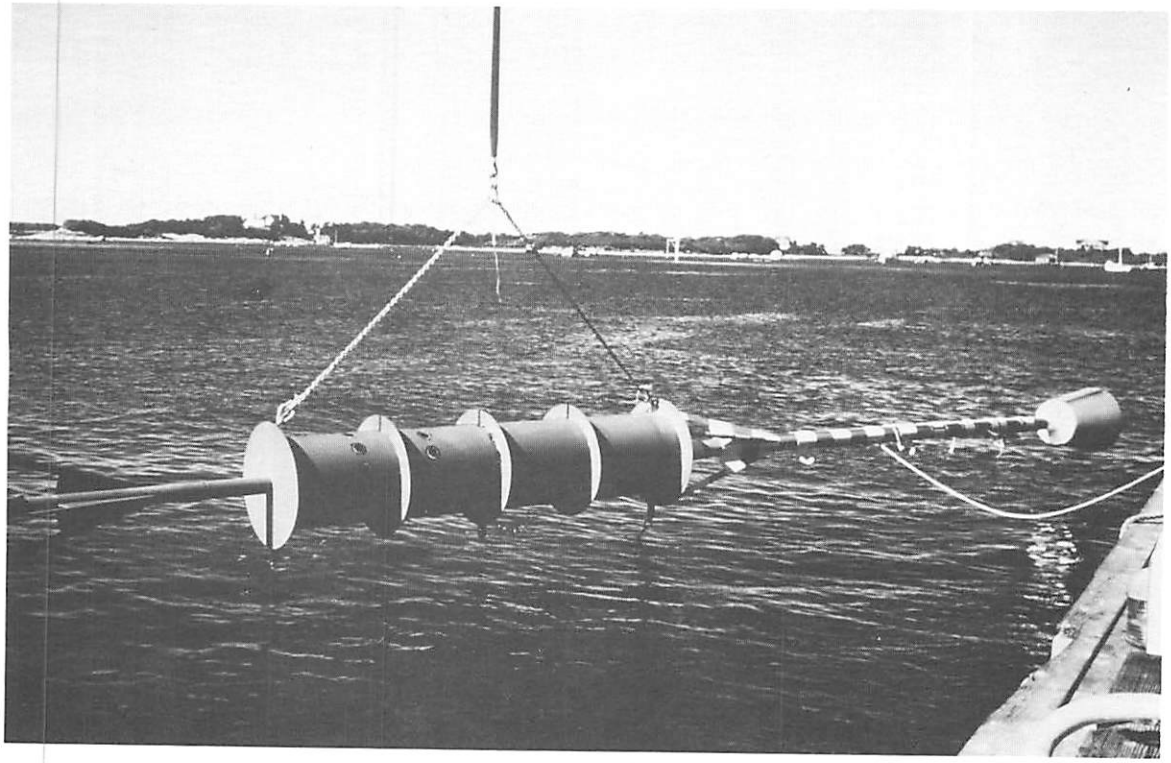

Fig.1 (Berteaux) Spar Buoy

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

Ferris Webster, Department Chairman

STUDIES OF OCEANIC PROCESSES:

LABORATORY MODELS OF OCEANIC PROCESSES

John A. Whitehead, Jr.

The hydrodynamics laboratory has been used to study a variety of physical processes which can either generate or affect currents in the ocean. Flows through narrow openings in a rotating frame have continued to be studied with the objective of a clearer understanding of oceanic flows through straits and over sills. The original studies, which were mainly concerned with stationary flows, have been extended to studies of non-stationary flows. The agreement between these results and observations in the Straits of Gibraltar and the Denmark Straits has been good.

A second class of studies has concerned the forms of motion that exist when a thin layer of fluid lying above (or below) a deep fluid with lower (or higher) density goes unstable and tries to fall down (or up) through the deep fluid. Nonlinear arguments were developed which predict a preferential "spouting" of one liquid into the other. In this case, the thin liquid was predicted to spout into the deep liquid. An experiment showing such spouts is shown in Fig.1. Such convective patterns are seen in a variety of circumstances in the oceans and atmospheres. They are common in the winter when very cold and still centers of high pressure move out over the ocean. The mixed layer of the ocean, cooled from above, is seen to have such convection. The air also is heated from below in such a case and is seen to have upward-moving thermals.

Some basic research is being conducted into the behavior of fluid heated from below. An understanding of the forces and energetics which generate the flow continues to contribute to our understanding of turbulence. An analogy between these convective structures and microstructure in the ocean is being explored.

TAYLOR COLUMNS AND ROSSBY WAKES

Michael S. McCartney

The goal of this study is to determine how the inclusion of the beta effect modifies the formation of inertial Taylor columns. All other Taylor column studies to date have been restricted to zero beta effect, and hence to the smaller horizontal lengths of interest to oceanographers. This study has been primarily theoretical, with some experimental work in the Hydrodynamics Laboratory facilities to confirm some of the predicted features.

The main features of Taylor columns on a beta-plane in a homogeneous fluid that were found are: (1) For a retrograde current, the streamlines are quite similar to those for $\beta = 0$ theories. The main effect of beta is to limit the radial extent of the disturbance to the approaching flow. The column sits over the north side of the bump. (2) For a prograde current, there is a radical change in the character of the flow. In addition to the Taylor column (now over the southwest side of the bump), there is a Rossby wake downstream of the obstacle - a large-scale steady meandering of the

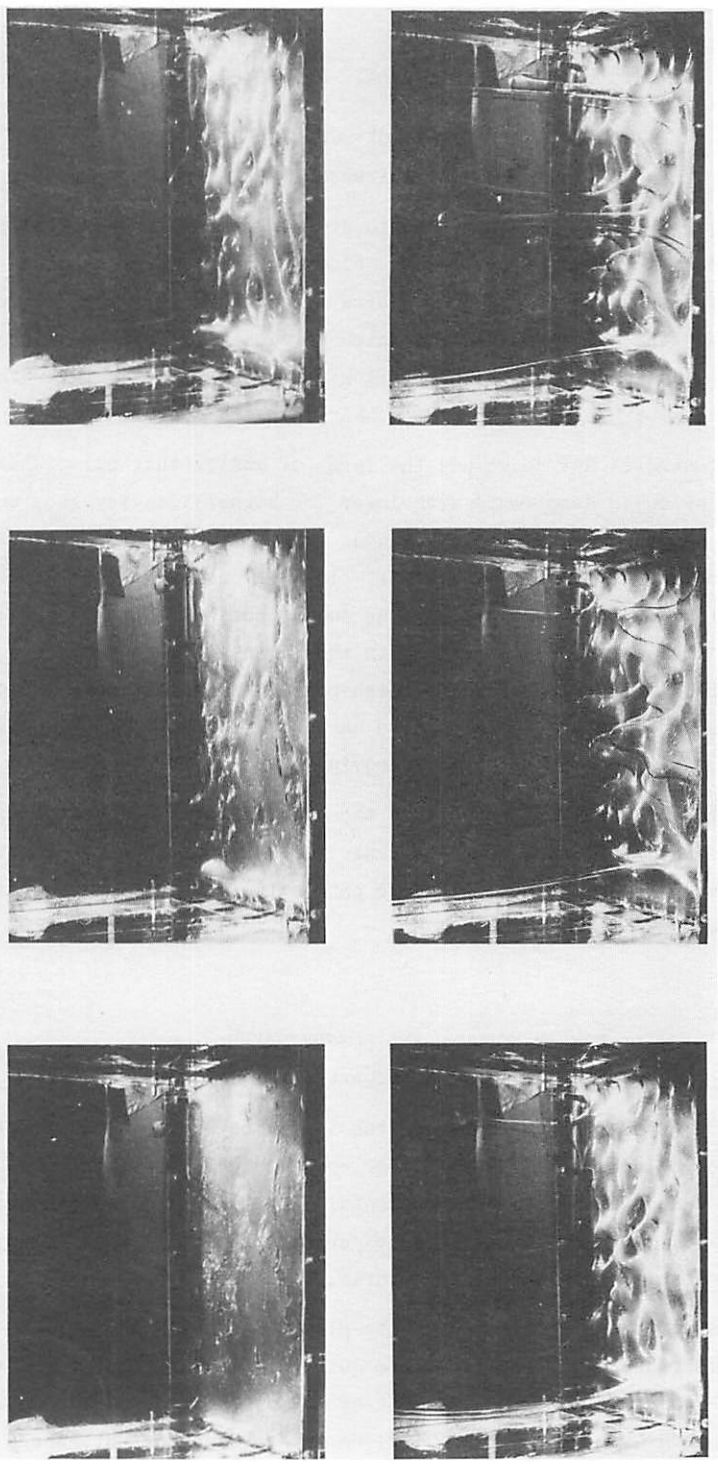

Fig.1 (Whitehead) Time sequence photographs of a thin layer of viscous fluid rising up through a denser clear fluid as a series of circular "spouts".

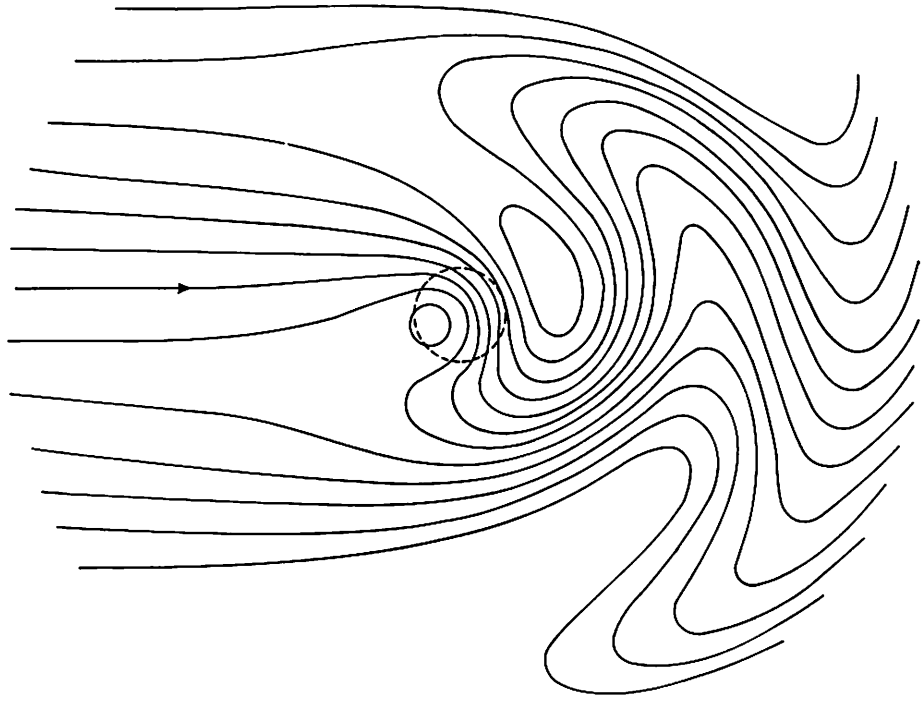

Fig.1 (McCartney) Flow streamlines for uniform prograde flow past a right circular cylindrical bump (dotted line) on a beta-plane. $\beta L^2/U = 1.0$, fractional obstacle height 6 x Rossby number.

current. (3) Associated with this meandering there can be additional closed streamlines (eddies), in particular, a cyclonic eddy to the northeast of the bump. Figure 1 shows the streamlines for $\beta L^2/U = 1.0$ (L = bump radius, U = approaching flow velocity) and fractional obstacle height = 6ε ($\varepsilon = U/fL$). (4) The wave drag associated with these wakes has been computed, and found to be much greater than the bottom Ekman drag for many oceanic situations, thus emphasizing the importance of bottom topography in the overall momentum balance of eastward current systems. Experiments that confirm the general character of the flows are underway.

A similar theory has been developed for a two-layer fluid system, with different current velocities in the two layers. The general character of the streamlines is the same as in the homogeneous fluid case. The effect of the density difference ($\Delta\rho/\rho = .001$) is to reduce the tendency towards Taylor column formation in the upper layer. The wake structure is, however, quite similar in both layers. An additional feature of interest: the cyclonic eddy to the northeast of the bump will sometimes have a cold core, i.e. the lower layer domes and surfaces, giving a cold core cyclonic current ring. The relation between this ring formation mechanism and the actual observed current rings in the northwest Atlantic is being investigated.

EQUATION OF STATE FOR SEAWATER

Nicholas P. Fofonoff

A study of several equations of state for seawater was started to evaluate their suitability for use in processing oceanographic data. The Knudsen-Ekman equation presently used at the Woods Hole Oceanographic Institution does not yield estimates of compressibility of acceptable precision, particularly at pressures below 2000 decibars and above 6000 decibars.

Four equations of state were selected for study, two based on sound velocity measurements and two on direct measurement. These equations were compared with estimates derived directly from sound velocity formulas of Wilson and Del Grosso and Mader. A preliminary comparison is given in Table 1.

Table 1

Comparison of Specific Volume Equations for Seawater

The mean difference and standard deviation are computed on a 0.5°C, 500 decibar grid over the range 0-10°C, 0-10000 db at 35 °/oo (441 points). Units are 10^{-6}cm^3/gm. Row - Column for sign of mean difference.

	Knudsen & Ekman	Fisher	Wang & Millero	Crease	Wilson (October)	Wilson (June)	Del Grosso & Mader
Knudsen & Ekman (1901, 1908)	0 0	73.9 13.4	-32.0 16.2	-57.9 18.3	-32.8 16.9	-35.5 18.4	-18.0 9.4
Fisher (1967)		0 0	-105.9 9.4	-131.8 10.0	-106.7 10.0	-109.4 10.2	-91.9 8.2
Wang & Millero (1973)			0 0	-25.9 2.9	-0.7 0.9	-3.5 2.8	14.0 8.5
Crease (1962)				0 0	25.1 2.5	22.4 2.0	39.9 10.4
Wilson (October) 1960					0 0	-2.8 2.2	14.8 9.3
Wilson (June) 1960						0 0	-- --
Del Grosso & Mader (1972)							0 0

Sound Velocity: Del Grosso & Mader -- Wilson (October)
mean: -68.4 cm/sec st. dev. 21.1 cm/sec

The goal for an internationally acceptable equation of state is to achieve a precision of 3 ppm at atmospheric pressure and 10 ppm at higher pressure to 10,000 decibars. Specific volumes based on Wilson's October formula for sound velocity (1960) and Del Grosso and Mader's formula (1972) differ by 32 ppm at 10,000 decibars (at 0°C, 35 °/oo). The goal will be difficult to achieve unless the average systematic difference of about .7 m/sec in the two sound velocity formulas can be resolved.

LONG-PERIOD STATION PROGRAM - BERMUDA

Elizabeth H. Schroeder

This continuing series of Nansen bottle stations which began in June of 1954 was designed to provide a complete description of the waters southeast of Bermuda. This is the only long-time deep station in the North Atlantic and has proved to be invaluable as a source of research data in diverse fields.

Since the inception of this program, a total of 388 Nansen bottle stations have been made; fourteen through the middle of November, 1973. Bad weather and extra use of the *Panulirus* have limited the number of stations made to one in most months instead of the usual two.

A study of the steric level at the station site in relation to sea level and pressure for the second eight-year period of the series, June 1962 through May 1970, has been completed. All illustrations have been drawn and the test is being worked on. The results of this study will be compared to those of the previous study published in 1969 (Schroeder and Stommel).

An extensive analysis of 18 years of *Panulirus* data, January 1955 through December 1972, stations #9 through #374, is nearing completion. This study will illustrate and hopefully explain the changes in temperature, salinity and oxygen which have taken place during the years of this program. The long-range changes have proved to be quite exciting with a dramatic cooling and freshening of the entire water column to 2500 meters, but the year-to-year changes are not as clearly defined.

Reference

Schroeder, Elizabeth and Henry Stommel 1969 How representative is the series of *Panulirus* stations of monthly mean conditions off Bermuda? *Progress in Oceanog.* 5: 31-40.

ACQUISITION AND USE OF TEMPERATURE-SALINITY DATA

Elizabeth H. Schroeder

This section of the Physical Oceanography Department was created to process and maintain temperature and salinity data collected by research vessels from Woods Hole Oceanographic Institution and other institutions in addition to those received from various Navy and Coast Guard ships. These data, which cover the Atlantic Ocean and adjacent seas, are maintained to provide convenient access to permanent records in several forms for easy use in research.

Through November 30, 1973, this section has processed 1,422 mechanical bathythermograph slides, 1,611 expendable BT records and 13,262 BT prints received from outside sources. A total of 17,270 BT and Nansen bottle station cards were averaged by month at standard depths and added to our data collection; 1,909 of these were stations copied from various sources. There is a backlog of data to be averaged.

In addition to reading and checking these reports to ensure proper quality control, 16 BT reading grids were made for instruments calibrated at Woods Hole Oceanographic Institution and 44 mounted grids were issued to various people for use on cruises.

INTERNAL WAVE INTERACTIONS

William F. Simmons

All experimental work was devoted to the development of a forced-flow conductivity sensor suitable for use in salt-stratified internal gravity waves experiments. The sensor has an actual response time of less than 0.1 seconds, and is only a few millimeters in diameter. Thus it is fast compared to internal wave periods, yet small enough to be an inefficient generator of spurious waves. Testing of the sensor over a wide variety of stratifications, amplitudes, and frequencies continues at year's end.

Theoretical calculations for inertio-internal gravity waves show that all waves in the frequency band between the inertial and Brunt-Vaisala frequencies can and must send energy to the inertial frequency in a single step, as well as by less efficient multiple-step processes. Energy residing at f cannot of itself leak back to higher frequencies by the same process. Thus, unless an equally efficient mechanism can be found to leak energy to frequencies lower than f, this nonlinear process stands as a plausible contender to explain the energy peak at f seen in mid-depth ocean-wave spectra.

As an attempt to find efficient mechanisms to leak energy to frequencies below f, Barry Ruddick has performed trial calculations on nonlinear transfers from f to Rossby wave scales. The analysis becomes prohibitive as the model approaches reality, so attention was focused on the very simplest models. These do not transfer energy efficiently enough, although they do provide a plausible partial energy source for low-frequency motions.

ELECTRIC AND MAGNETIC FIELDS IN THE SEA

Thomas B. Sanford

The program for 1973 emphasized extensive velocity profiling during the MODE-1 field program and the development of a moored electric field sensor.

During MODE-1 (Mid-Ocean Dynamics Experiment) over 70 velocity and density profiles were obtained at a variety of locations. A series of profiles revealed a striking difference between the velocity structure over a ridge and that seen even a short distance ($\sim$10 n.mi.) out onto the smooth

abyssal plain. The baroclinic structure over the rough topography was confined to the deep water (below 2500 m) while over the plain the shear was present most strongly above the thermocline.

A series of profiles for a five-day period at the central mooring of the MODE-I array showed that the low-frequency structure is largely of low mode. Velocity variations of small vertical scale are the result of inertial and tidal-period internal waves.

For the first time we were able to deploy two instruments at separate locations set to fall simultaneously. The purpose was to determine at a given time the horizontal scales associated with the velocity structure. A pair of examples are shown in Fig.1 where DROPS 215U and 216U at 100-m separation are compared together with a similar set (DROPS 235U and 236U) at 4.8 km relative separation. As expected the cross-correlation decreases with relative separation. Yet features are clearly traceable over 5 km scales.

A moored electric field sensor has been designed and built to measure three horizontal and one vertical electric potential differences. The purposes of this instrument are to measure the local velocity and the vertically averaged velocity in the deep sea. Field trials will be made in early 1974.

TOPOGRAPHIC EFFECTS ON CURRENTS AND SEDIMENTATION PROCESSES

Nelson G. Hogg

Ocean bottom relief (seamounts, ridges, islands, trenches, etc.) may have significant near- and far-field influences on currents and the complimentary geostrophic density field.

Previous investigations of the near-field effects have been extended to allow stationary, baroclinic-topographic waves to be generated in the lee of a steady, uniform flow past a seamount. Such waves are found either when the bottom slopes upwards to the left, looking downstream (topographic lee waves) or when there exists a level of no motion above the seamount (baroclinic lee waves). These waves may be significant for they permit a far-field seamount influence which is either trapped to the bottom for short waves or felt throughout the water column for very long waves (even though the near-field, trapped disturbance may be confined both laterally and vertically).

The manner in which this alteration of the current pattern affects the associated sediment deposition problem is also being studied theoretically. Assuming that the local rate of deposition is inversely proportional to the local fluid speed, the predicted streamline patterns give asymmetric sediment distributions similar to those observed.

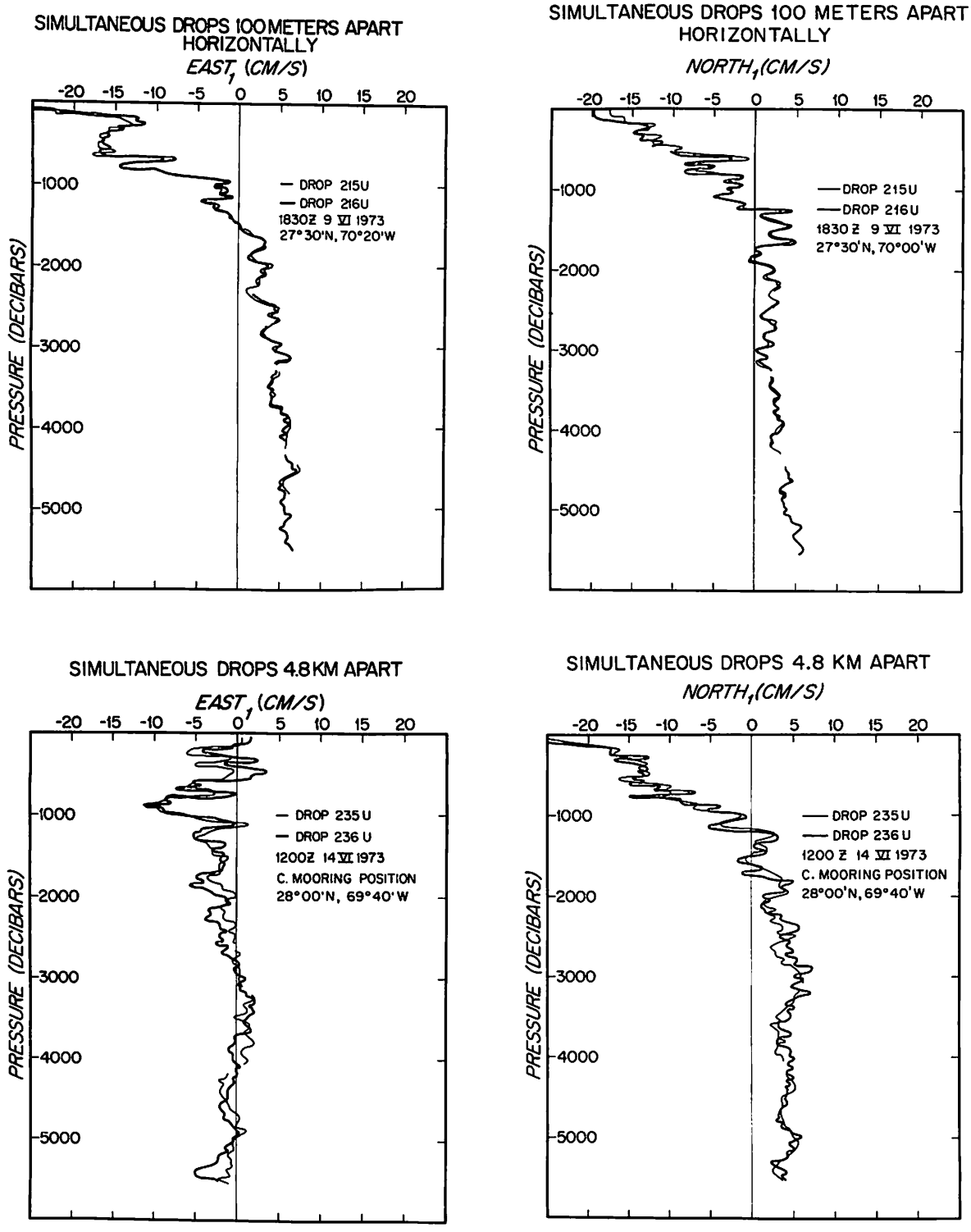

Fig.1 (Sanford)

INTERNAL WAVE EXPERIMENT (IWEX)

Melbourne G. Briscoe, Terrence M. Joyce, Claude Frankignoul, Walter Zenk,
Thomas C. Aldrich, Jerome P. Dean, and Donald Moller

Using a three-legged subsurface mooring in the Sargasso Sea, IWEX was an attempt to measure the vector wavenumber frequency spectrum of motions in the main thermocline over a range of space and time scales appropriate to internal gravity waves. The mooring was deployed in late October, 1973 (*Knorr* 34) and recovered about six weeks later in mid-December (*Knorr* 36).

Between 600 m and 1000 m depth, spaced logarithmically along the inclined legs of the moorings, there were 17 vector-averaging current meters (VACM) each modified to carry two thermistor pods for the measurement of temperature and vertical temperature gradient. Also on the mooring were four Geodyne 850-T current meters, nine Wunsch-Dahlen pressure-temperature recorders, three inclinometers, and four tensiometers; most of these instruments were for engineering assessment of the mooring motion. The mooring and all of the instrumentation except one 850-T were recovered successfully, and at the end of the year the data tapes were being read.

An additional experiment during the October deployment cruise involved a 16 m long spar buoy (designed by Henri Berteaux of the Ocean Engineering Department) supporting an instrument string to 125 m depth. Good data were recovered from VACMs at 100 m and 125 m depths, both below the seasonal thermocline. An Aanderaa thermistor chain, borrowed from the Institut für Meereskunde in Kiel, West Germany, obtained temperature data at ten depths between 45 and 90 m spanning the seasonal thermocline.

Scientific Investigations

Other than planning and preparation for the IWEX field work, scientific efforts during 1973 were primarily directed toward understanding and development of various techniques for the large data processing and interpretation task to come in 1974. A data workshop, tentatively scheduled for late summer, 1974, will also involve Klaus F. Hasselmann, Dirk Olbers, and Peter Müller, all from the Institute for Geophysics of the University of Hamburg, West Germany.

Melbourne G. Briscoe has been studying the coherence properties of several moored array experiments in the western Atlantic and the Mediterranean. Tentative results include coherence scales proportional to the maximum Brunt-Väisälä frequency, confirmation of WKBJ solutions for the vertical profiles of internal wave energy, and significant vertical coherence near the local Väisälä frequency. To aid in the interpretation of these results, a program has been developed for the calculation of the vertical modes of internal waves and is being tested for its sensitivity to the details of the Brunt-Väisälä frequency profile.

A numerical study by Terrence M. Joyce of the effect of temperature fine-structure upon the inference of vertical displacements using moored temperature sensors has been completed. Results indicate that for fine-structure intensities typical of the main thermocline (Mediterranean water) in the Sargasso Sea, fine structure should play a small (major) role in masking internal wave dynamics. The employment of temperature sensors which in addition to temperature, measure temperature gradient, should further reduce contamination from vertical fine-strucutre scales greater than ten meters.

Temperature measurements in the main thermocline could possibly be less noisy than those of horizontal velocity in the internal wave frequency band. The analysis including temperature gradient information and horizontal velocity contamination is in progress.

The variability and directionality of the internal wave field have been studied by Claude Frankignoul from moored current meter data using the technique of short-time spectral analysis of horizontal current. Two time scales associated with the internal wave energy have been detected: a short time scale associated with wave events and a long time scale associated with stationarity of internal wave spectra. Energy correspondences over vertical and horizontal distances are found by cross-correlating the energy time series. These are used in a preliminary attempt to sort out energy flux in the internal wave field. A strong dominance of internal wave dynamics is found in the whole inertial-internal wave frequency range. There is some variability of energy flux in the frequency, depth-space, and periods of well-defined energy propagation are detected. A study of the anisotropy of spectral characteristics of internal waves suggests that the wave field is modulated by low-frequency currents.

Several sets of internal wave data made with towed instruments are being intercompared in the wavenumber domain by Walter Zenk. The results will be related to the discrete wavenumber measurements made by the tri-moored instruments.

Technical Investigations

The principal technical work, aside from Ocean Engineering efforts (see Ocean Structures, Moorings, and Materials section), involved acoustic navigation (Thomas Aldrich), mooring deployment (Donald Moller), and differential temperature measurement (Jerome Dean).

Programs were developed or revised to provide highly accurate relative position determination by acoustic navigation. Graphical displays were provided of:

1. the ship and the anchor position relative to the ideal position during lowering of the three tri-moor anchors, and
2. deviations of anchor position from an optimum glide path. The acoustic network used transponding AMF releases and ship-mounted hydrophones.

The mooring required a sophisticated deployment technique to minimize potential fouling or parting of mooring lines. During the entire deployment (3½ days continuous) instruments and computer programs monitored the tensions of the system of tether buoys, mooring legs, and floats.

In addition to horizontal current and temperature measurements, specially stabilized and matched thermistors were used and a unique differential temperature bridge circuit was developed to measure the vertical temperature gradient at VACMs on the legs of the tri-mooring. Calibration procedures were refined for use prior to deployment and again following recovery to determine the stability of the instrumentation and the accuracy of the thermistor measurements.

SUMMARY OF INVESTIGATIONS, 1973

Walter Zenk (Visiting Investigator)

Mediterranean Outflow

The evaluation of hydrographic data and moored current meter records, both obtained in early 1971 during *Meteor* Cruise 23, led to balance computations of the Mediterranean undercurrent in the Gulf of Cadiz. Data indicate that the outflow takes place in three branches of which the main one carries two-thirds of the total mass. Further, a dependence of the often-observed double maxima structure in vertical salinity profiles is the eastern North Atlantic from tidal-controlled outflow modulation in the Strait of Gibraltar could be shown by repeated CTD (conductivity, temperature and depth) observations in the outflow channels. This work was done mainly in Kiel until September. Three publications were prepared: a) Siedler, G., and W.Zenk (1973) Variability of the thermohaline staircase, *Nature Phy.Sc.*, 244(131): 11-12; b) On the Mediterranean Outflow west of Gibraltar; c) Some current and temperature observations within the Mediterranean Outflow in the Gulf of Cadiz. Both b) and c) have been submitted to *Meteor Forsch.Ergbn.*

Small scale structure of the main thermocline

A study of the spatial wave number spectra (E. J. Katz) from the deep thermocline in the MODE area was continued. Special attention was given to constant observation levels. The obtained spectra cover the wave number range, k, of 5 - 500 cycles/km showing the well-known exponential decay independent of the direction with a break-off at approximately 200 cycles/km. This work was done between October and early December until it was interrupted by my participation in *Knorr* Cruise 36 to recover the tri-mooring.

LOW-FREQUENCY VARIABILITY IN THE WESTERN NORTH ATLANTIC

James R. Luyten and William J. Schmitz, Jr.

The goal of this study of the low-frequency variability is to understand, through a combination of observations and theoretical modelling, the energetic processes which appear to dominate the flow in the vicinity of the Gulf Stream. These processes, through the transports of mass, energy and momentum must affect, and perhaps control, the general circulation in the North Atlantic. The work carried out during this past year has focussed on two aspects of this general problem. Some theoretical aspects of the energetics and propagation of topographic Rossby waves have been examined. The available current observations in the vicinity of the Gulf Stream have been studied.

The long moored-current-meter records from Site D ($39^{o}10'N$, $70^{o}00'W$) and Site J ($36^{o}00'N$, $70^{o}00'W$) show characteristic variability with amplitudes of 5 - 10 cm/sec over scales of 5 - 10 days. At Site D, this variability shows a negative correlation, $\overline{u'v'} < 0$, whereas at Site J, the correlation is positive. It has been suggested by Rory Thompson that the correlation at Site D is evidence for a topographic Rossby wave field progressing up the slope past Site D. The corresponding interpretation for Site J implies a field of topographic waves progressive downslope; thus, this field of topographic waves would be radiating energy away from the Gulf Stream region in between Sites D and J.

The current meter observations from J show energetic variability at longer time scales. Several large-amplitude (> 30 cm/sec) events of a typical duration of 30 days have been observed in the deep water at Site J and as far north as 37°30'N, 70°00'W. The flow is characteristically to the north. These energetic events are infrequent, occurring perhaps, at 3 - 4 month intervals. Similar events have been seen in an array of two-month records from under the Gulf Stream at 50°W, the Tail of the Grand Banks.

Three sections of the Gulf Stream at 67°30'N, occupied by Joseph Barrett and William Schmitz, using the dropsonde technique, show similar variability to the south of the near-surface core of the Stream. These disturbances appear to have horizontal scales of the order of 50 km and vertical scales of 2000 m, suggesting a quasi-geostrophic eddy, coupled perhaps with the strong distortion of the thermocline in the Stream.

An experiment designed to investigate these phenomena and their possible relations to the flow between the Gulf Stream and Site D, has been planned for April-December 1974.

The behavior of topographic Rossby waves in a stratified region over smooth topography of otherwise arbitrary shape has been investigated. Since the waves are quasi-geostrophic, changes in the local depth which establish the dynamics (vortex stretching) are of the same small order as the effects of refraction. The paradox of the non-equality of different expressions for the flux of energy for these waves is resolved by a proper, uniformly valid, perturbation approximation. With this problem solved, we are investigating the effects of rough topography and scattering.

MID-OCEAN DYNAMICS EXPERIMENT:

MODE-I MOORING ARRAY

William J. Schmitz, Jr., Richard E. Payne and Nicholas P. Fofonoff

An array of 16 moorings with 83 current meters and 60 temperature-pressure recorders was set in March and recovered in July, 1973 as part of the joint Mid-Ocean Dynamics Experiment (MODE-I).

An objective of the current meter array was to map the currents as a function of time and space for comparison with the current field inferred from neutrally buoyant floats and the density field.

Data returns from the array fell below expectations. Electrochemical deposition in the vane bearings, apparently driven by protective zinc anodes, caused striction and consequent loss of directional data in many of the current meters. An additional problem with intermittent rotor signal reduced overall date recovery to about 50% for the velocity data. In contrast, temperature data from both current meters and temperature-pressure recorders was good (about 80%). Modifications to the current meters reduced the stiction problem in subsequent experiments. The rotor drop-out problem is still under investigation.

In spite of the problems encountered, usable data were obtained at nearly all of the levels sampled. An example is given in Fig.X and Fig.X+1 of the current field at 500 meters depth. The

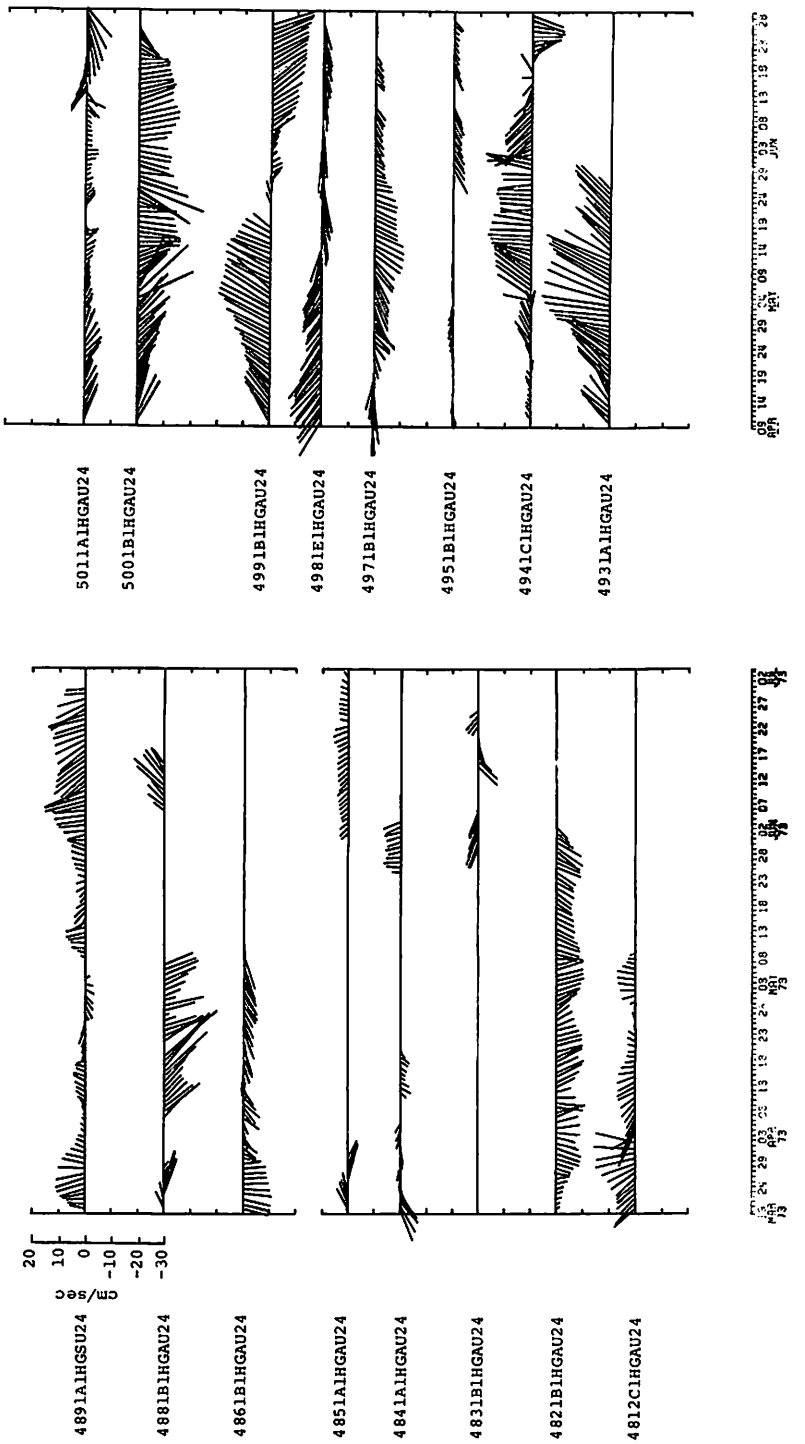

Fig.X (Schmitz, Payne and Fofonoff) Average velocity vectors at 500 m from the MODE-I array.

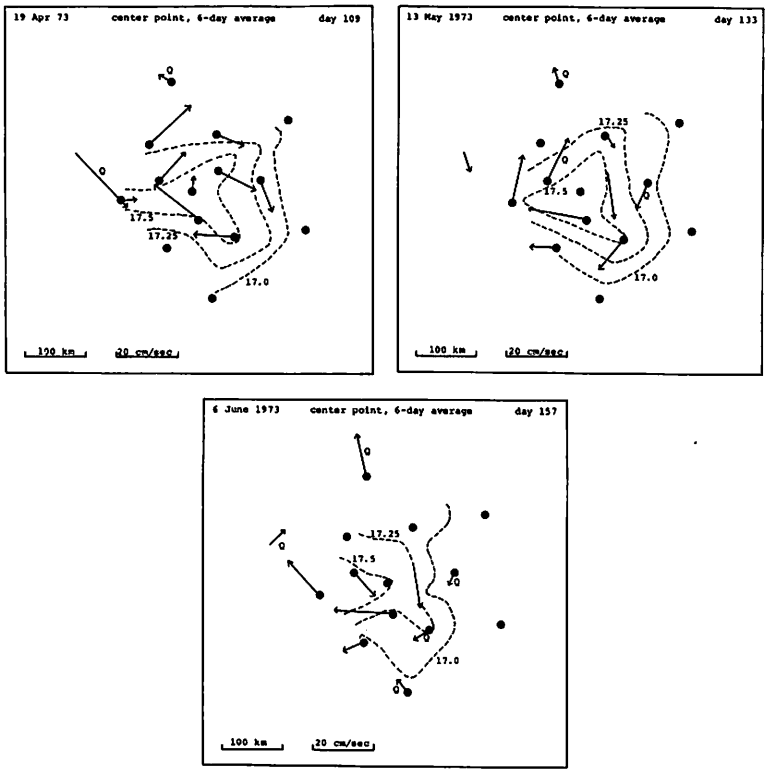

Fig.X+1 (Schmitz, Payne and Fofonoff) Maps of average velocity and temperature at 500 m for three periods during MODE-I. Temperatures were obtained at positions shown by solid dots. Vectors labelled "Q" have vane or rotor problems.

vectors in Fig.X are averaged to remove tidal and inertial components to show the low-frequency variations. In plan view (Fig.X+1) the currents and temperature fields show a clockwise eddy moving slowly westward.

The data is being prepared for distribution to participants and to National Oceanocgaphic Data Center (NODC).

OBSERVATIONS OF AN ISOPYCNAL SURFACE

Eli J. Katz and Richard T. Nowak

On several occasions during the Mid-Ocean Dynamics Experiment (MODE) field experiment, a density surface in the main thermocline was mapped by continuous towing. Horizontal scales of the vertical displacement of the surface from ten meters to one hundred kilometers were resolved.

The observations were made in April and June of 1973 (*Chain* Cruise 112) by towing sensors 5000 meters behind the ship in a depth range of 700 to 800 meters and at a speed of five knots. Five sensors were carried on and below the tow body. The sensors were kept at the depth of the isopycnal surface by applying a variable lift on its fixed winds under shipboard control. Frederick Hess,

Peter Kallio and Maxine Jones (Ocean Engineering) assisted in the design and programming of the system.

Preliminary analysis of the results include a confirmation of a pre-MODE wavenumber spectrum of the vertical displacement of the internal wave field: characteristically being non-directional and having a continuous and invariant energy distribution from 0.02 to several cycles/kilometer. The temperature fluctuation spectra at a constant depth are being examined by Walter Zenk (visiting investigator), and are confirming the increased power law spectral slope at wavenumbers above several cycles/kilometer.

Coherence between temperature sensors towed ten and twenty meters apart vertically is being studied by Edmund Sambuco (graduate student). Comparisons with predicted coherence are being made. This towed vertical coherence is determined by the energy distribution in the vertical internal wave modes and further observations at increased vertical separation and different Brunt-Väisälä frequencies are contemplated.

The large-scale slope (or mean trend) of the surface was variable, ranging from 10^{-4} to nearly 10^{-3} over adjacent one hundred kilometer triangular planes (see Fig.1). On another occasion, a repeated smaller tow pattern suggested a vertical movement of such a plane to be as much as ten meters in two days.

An objective in making these observations during the MODE experiment was the opportunity it affords to compare filtered contour plots of a surface in the thermocline with the vertical shear of

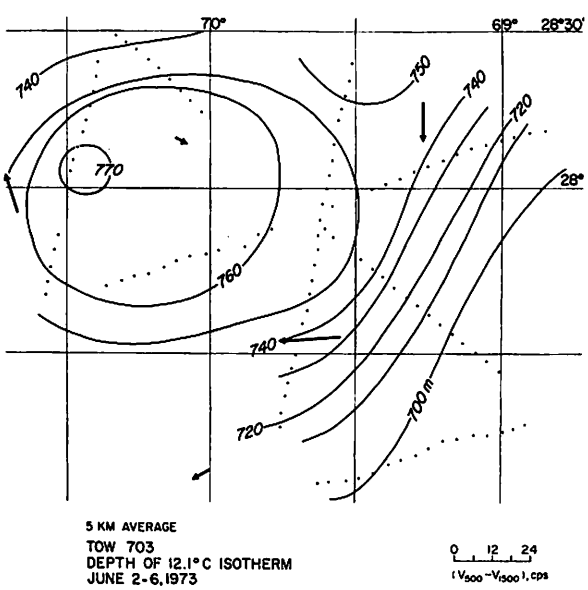

Fig.1 (Katz and Nowak) Preliminary comparison of isothermal contour surface in thermocline to current shear across thermocline from MODE moorings (compliments of W. J. Schmitz, Jr.).

the horizontal currents across the thermoclines as recorded by the moored current meters. A still-preliminary, but very encouraging, comparison is indicated by the shear vectors on the figure where, as predicted by assuming geostrophy, the vectors roughly parallel the contour lines and increase in magnitude with increasing gradient.

WAVES AND TURBULENCE IN THE OCEAN INTERIOR

Peter B. Rhines

The goal of this work is to understand the physics of ocean variability at length scales 20-5000 km, time scales greater than a day, with local theories of the behavior of geostrophic eddies and long waves, then proceeding to look at their generation, decay and interaction with mean circulations.

This year we have completed the 'flat-bottom' studies, in which theory and computer experiments (via grants from the National Center for Atmospheric Research) consider an idealized ocean without rough bottom topography or coastal boundaries. Closely packed eddies migrate about a space whose co-ordinates are time-scale, horizontal length scale, and vertical length scale, according to simple laws: they move toward a horizontal length scale lying between the 'Rossby radius' (wavelength/$2\pi \approx$ 40 km) and a wave-determined scale $\lesssim$ 70 km, from scales which initially were either large or small. This range thus gives the 'natural' scale expected of the dominant oceanic eddies. Fig. 1 shows an example of currents with this scale, which grew spontaneously from a broader flow in a few months.

Interactions also proceed toward large <u>vertical</u> scale, the currents at different depths becoming more and more alike as time goes on. There is a general tendency for potential energy to cascade into kinetic, and for east-west currents to exceed north-south currents. At the same time we are trying to use simple instability theory to estimate the rate at which energy shifts from one scale to another. It would be most useful if the fully turbulent flow could be inferred from these linear theories, and thence the role of eddies in the long-term ocean circulation be simply represented.

Detailed comparison with currents observed in the Mid-Ocean Dynamics Experiment suggests that the experiment was strongly affected by the nearby coast (currents running north-south more than east-west), and by the bottom topography (there being considerable vertical shear), but that otherwise the eddies observed agree in time-scale, intensity, and horizontal length-scale, with the models.

Working with Rossby's SOFAR float data, we have produced what may be the first moving picture of deep-ocean currents, spanning about a year, or several oscillations of the eddies. The restoring effect of the Earth's curvature is strikingly visible, and the notion that the fluid undergoes excursions typical of an eddy diameter (the 'wave steepness' $\approx$ 1) seems verified. The wavelike character of the motions prevents the floats from dispersing rapidly, suggesting rather gradual mixing of Mediterranean water at this level (1500 m).

We have also initiated theoretical work on the mean currents induced by waves (surface-, Rossby-...), and, with students, investigations into sill flows, flow over bottom ridges, laboratory eddies, baroclinic adjustment, and harbor pollution.

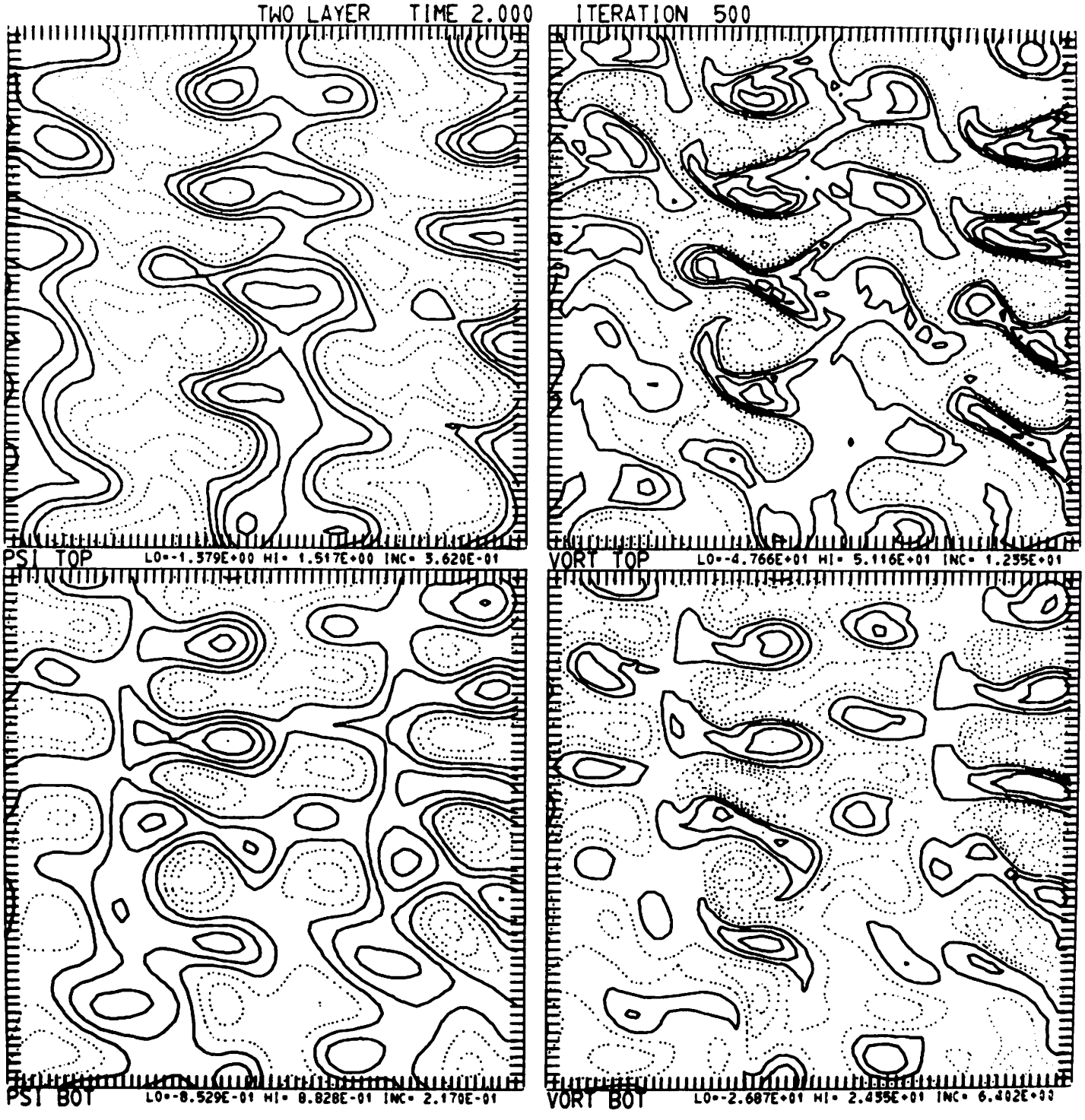

Fig.1 (Rhines) Eddies generated spontaneously from smooth, alternating north-south currents by baroclinic instability, in a two-layer computer 'ocean'. Upper panels show the upper layer (streamlines and vorticity, respectively), lower panels show the lower layer. The region represented is 2000 km wide.

SOUND FIXING AND RANGING (SOFAR) FLOAT EXPERIMENT

Arthur D. Voorhis

In general, the principal investigator is interested in exploring the variability of currents and material properties in the ocean using drifting instruments. This year one of the most extensive neutral buoyant float experiments ever attempted was carried out successfully in the spring as part of Mid-Ocean Dynamics Experiment (MODE). Eighteen large floats were launched in an area 600 km southwest of Bermuda near 28°N, 70°W and were tracked acoustically for four months as they drifted at a depth of 1500 m. The purpose of the experiment was to explore large-scale features of the mid-ocean circulation having dimensions of 100 to 300 km. At the end of the experiment all surviving floats were relaunched for an extended drift of at least a year. As of December, twelve floats are still being tracked.

The principal investigator and D. Webb of the Department of Ocean Engineering were in charge of the construction and deployment of the floats. T.Rossby at Yale University was in charge of tracking the floats.

During the experiment ten of the floats were instrumented to sense and record pressure, temperature, and vertical current. This data is now being analyzed to determine the variability of the vertical current and of the vertical temperature gradient in the MODE area over periods of time from four minutes to about one month. Preliminary results show maximum vertical currents as high as 1 cm/sec due to internal waves with periods near 90 min. Vertical currents with periods longer than one day are detected but have speeds less than 0.1 mm/sec.

STUDIES IN THE MODE AREA

John G. Bruce, Jr.

Approximately 300 expendable bathythermograph stations were arranged in a one-degree-square grid in the northeast sector of the MODE area. The slopes of the isothermal surfaces below 500 m (i.e.,the 12° surface slopes down from east to west approximately one meter per nautical mile) appear to be in agreement with measurements made west of this area by towed STD (salinity, temperature, depth) instruments.

THE MODE HOT-LINE COMMUNICATIONS NETWORK

Ferris Webster and Margaret Chaffee

For the unity and cohesiveness of the MODE-I Field Program, a MODE Communications Network, or "Hot Line" was established, with the elements including a ship-to-shore radio, a communications center, and a telephone link to several United States mainland laboratories. The Hot Line Center at the Bermuca Biological Station operated between 1 March and 15 July.

The system provided both voice and facsimile communications to serve two needs: (1) to transmit field data for ongoing stratigic decisions to guide the course of the field experiment and (2) to provide a flexible, full-time communications link between the members of the MODE Executive Committee, the participants in MODE, the Hot Line Center, and the six participating research vessels.

MODE HOT-LINE NEWS

Ferris Webster and Kathleen Daly

The MODE Hot-Line News, a biweekly newsletter, was begun in March, 1972, to disseminate information about the scientific progress of the Mid-Ocean Dynamics Experiment (MODE). It acted as a forum for timely discussions of MODE-0 results to plan for MODE-I. During 1972, most contributions were received from non-MODE scientists discussing MODE-related problems, i.e., mooring motion studies, temperature/salinity features, eddy structure interpretations, internal wave influences,and theoretical and experimental techniques for data interpretation. However, the major source of information for the Hot-Line News continues to be centered on the discussion and analysis of MODE data by participating MODE scientists.

The MODE Hot-Line News is issued to a steadily growing circulation list, now comprising over 100 oceanographic institutions and groups throughout the world.

During the four-month MODE-I field program this year, another newsletter, the MODE Hot-Line Bulletin, was published for those scientists directly involved in MODE. Issued weekly to MODE scientists, the Bulletin provided an on-going record of work carried out during the field program by reporting summaries of ships' activities and data collected in "raw" form.

MOORED ARRAY EXPERIMENTS

MOORED ARRAY PROGRAM

Nicholas P. Fofonoff and Ferris Webster

A total of 43 moorings were set in 1973 in several scientific and engineering experiments. Most of the effort during the year was devoted to two major experiments. An array of 17 moorings was set during March to July to map the current field over a 400 km area centered at 28°N, 69°40'W in the MODE-I field experiment. In addition, over 150 CTD (conductivity, temperature, depth) stations were taken in support of the MODE density mapping program.

An instrumented Tri-moor was set near the center of the MODE-I region to examine the frequency and wave number spectra of internal waves. The Tri-moor, set in water depths of 5400 m, represents a significant step in the development of mooring capability to examine a wide range of space and time scales in the ocean.

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

ARRAY EXPERIMENTS AROUND SITE D

Rory Thompson and James R. Luyten

The two-year array experiment around Site D (39°10'N;70°00'W) continued through the year at three moorings and two levels, plus two more levels on the central mooring. About two-thirds of the data attempted has been recovered, which is probably the best recovery date for any long-term, deep-ocean moorings. However, this rate is low enough so that one can expect that usually one out of the three records

at a given level will have failed at any given time; there is only a 30% chance all three will have worked. This makes intercomparison difficult, and suggests that all array experiments should have redundancy built in.

Despite the large gaps in the records, some cross-correlations and cross-spectra can be computed between the current-meter records: These (preliminary) results are in good agreement with theory, showing westward propagation, north-south wavelengths of the order of 150 km, east-west wavelengths of the order of 250 km, and reasonable match of these with the dispersive relations. There are also bottom-trapped modes evident, with principal axes turning from straight up-and-down the slope at periods of about six days, swinging through northwest-southeast to along the slope as the period gets long, in agreement with theory. A short temperature record also shows the vertical displacement out of phase with the up-slope velocity, as it should be.

The last replacement of the array includes three current meters at 200 m, with temperature sensors, to look at eddies, which seem to be frequent at Site D.

SCOR WG21 CURRENT METER INTERCOMPARISON EXPERIMENT

Stanley Hayes

Under the sponsorship of the Scientific Committee on Oceanic Research (SCOR) Working Group 21, the comparison of current meters was continued in 1973. The analysis of the experiment set at Site D in August of 1972 was completed. This experiment involved Alexaev (U.S.S.R.), Geodyne (U.S.A.), LSK (G.D.R.), and VACM (U.S.A.) current meters on surface and subsurface moorings.

The results showed generally good agreement among the instruments on the subsurface moorings. However, there were large differences in the records obtained on the surface mooring. Comparing the surface and the subsurface records showed that all meters read higher currents on the surface mooring. The differences are particularly pronounced at high frequencies.

A report on this experiment is being prepared in cooperation with the SCOR WG21 members.

CONDUCTIVITY, TEMPERATURE, DEPTH (CTD) HYDROGRAPHY

Terrence M. Joyce, Stanley Hayes and Robert C. Millard

Vertical profiles of temperature and salinity were taken using a Neil Brown CTD Microprofiler after setting and recovery of moorings by the Moored Arrays Project. The field work of two additional programs was supported using the CTD: The Density Program of the Mid-Ocean Dynamics Experiment and the Internal Wave Experiment. The CTD was used at sea for six months to collect over 200 stations. All of the CTD data has been calibrated and edited using the Buoy Laboratory Hewlett-Packard computer. The data processing to pressure sorted data files is 75% complete for the MODE data.

The CTD calibration, which involves the methods of temperature lag correction and salinity computation, yields salinities of Nansen bottle/thermostatic salinometer (±.002 ppt) accuracy except in locally sharp temperature gradients. Laboratory calibrations of the CTD temperature and pressure sensors are linear within ±.001 degrees Centigrade and four decibars. The calibration of the con-

ductivity cell against water bottles gives a correction to the conductivity which is predicted by the change in the cell geometry with temperature and pressure. CTD calibration and data handling techniques are being compiled into a report.

The MODE Density Work Group has been resolving intercalibration problems arising from the multiple ship MODE density program. We have participated in this group to help form a unified set of MODE density stations.

Because of the extensive field work in 1973 a large backlog of data exists, only a portion of which has been analyzed. A number of different statistics have been investigated for the temperature and salinity fluctuations with depth, horizontal position and time.

Vertical spectra of temperature fine structure show a marked similarity in spectral shape throughout the entire water column, temperature spectra having shapes between -2 and $-5/2$. Thus a single number, for example the variance of the fluctuations, together with the slope completely characterizes vertical spectral variability with depth. Histograms of the temperature gradient fluctuations indicate a probability distribution which is distinctly non-Gaussian for scales less than 10 meters. In addition, temperature and salinity fluctuations tend to have a large negative correlation so as to preserve static stability.

Time variability of fine structure about a given depth can be considerable. Temperature fluctuations have been parameterized by a nondimensional Cox number, which is the ratio of the rms variability of temperature gradient to the mean gradient. This quantity can be used to estimate the contamination of moored temperature measurements of internal waves. In the Sargasso Sea it reaches a maximum in the Mediterranean Water (1400-1800 m). A preliminary study of the temporal and spatial variability of Mediterranean Water in the MODE region shows that the fine structure observed is due to lateral mixing along isopycnal surfaces. There are large variations in the T-S characteristics in this area. No evidence for the local generation of these structures was found. The gravitational stability of the observed temperature inversions showed that these water layers had a stability which corresponded to the mean stability of the surrounding water. No dependence of the gravitational stability on the sign of the temperature gradient was found in the region of the inversions.

Horizontal variations in CTD profiles are being studied with a section of stations along 70°W between 28° and 39°N. From a cluster of stations in the MODE area, preliminary spatial mean temperature and salinity profiles have been produced. The horizontal temperature standard deviations and vertical temperature gradient of the mean profile have also been computed to aid in interpreting moored temperature measurements made during MODE.

MOORING MOTION PROBLEM

Edwin F. Ford

Richardson current meters on moorings with surface buoyancy tend to indicate higher velocities than corresponding meters on adjacent subsurface moorings. (See the articles by John Gould in MODE *Hot Line News* Nos. 10, 12, 14, 16, 21.) I have been trying to find out why this is so, and what can be done about it.

It appears that these velocity discrepancies are due to a nonlinear response of the current meter sensors to wave-induced high frequency motions of the surface moorings. The experimental evidence for this comes from several sources. A comparison of vector variance and 850 burst data with wind and tension recorder data for mooring 463 (the surface SCOR mooring) shows that the entire mooring was subjected to a disturbance, at or above wave frequencies, originating at the sea surface. 3-Axis accelerometer (TENSAC) data from surface moorings 290 and 428 show strong wave-induced motions. In the deep record (mooring 428, 2100 m), the motion is entirely along the instrument axis; lateral oscillations of the mooring are apparently removed close to the surface by drag damping. However, tests with two Geodyne 850s under the Woods Hole Oceanographic Institution dock confirmed the finding of Algis Kalvaitis *Hot-Line News* Nos. 28, 29) that axial motion alone can increase the velocity indicated by a current meter in a steady lateral flow.

General quantitative conclusions about current meter response to high frequency "noise" require an experimentally verified sensor response model. No such model exists for the Savonius rotor. Consider lateral motions only for a moment; a rotor will be called "quasi-steady" if the rotor angular velocity ω is related to $v(t) = [v_x^2(t) + v_x^2(t)]^{\frac{1}{2}}$ by an ordinary differential equation of the form $\frac{d\omega}{dt} = F(\omega,v)$. An initial series of tow tank tests, using a sinusoidally varying tow speed, showed that the Savonius rotor is not quasi-steady.

Preparations for more extensive tank tests of the Savonius rotor, and of a variety of alternative rotors, are in progress. A theory of the lateral response of a current meter using a quasi-steady rotor is being developed; this should prove useful in discriminating between the various rotor designs. Flume tests appear to show that axial motion affects the rotor primarily through vortex shedding from the rotor cage end plates; no serious efforts to model or mitigate this effect have been made as yet.

MOORED ARRAY DATA PROCESSING

John A. Maltais and Richard E. Payne

Data from 90 current meters were processed during the year, 78 of them from MODE. For the first time there were more VACM than 850 current meter records. Interest in temperatures recorded by current meters increased considerably this year. Twice as many meters (over 70%) recorded temperature this year as last. Because of this and the rigorous demands of IWEX on temperature accuracy, the quality control on thermistor calibrations has been improved. All thermistors are now recalibrated each

time they return from sea and a complete calibration history will be kept on each thermistor.

A new plotting program (DISPLO) was developed during the year and substantial changes were made to several standard programs to increase their applicability.

Fifty-one vector-averaged data series covering the period 1970-71 (stations 326 to 398) were transmitted to NODC archives.

MOORED ARRAY OPERATIONS

Robert H. Heinmiller

A total of 43 moorings was set during 1973. Most of these were set in the area of the MODE-I site (28°N, 69°40'W) either for the Mid-Ocean Dynamics Experiment (MODE) itself, or in connection with the Internal Wave Experiment (IWEX).

Moorings for the MODE-I array, a total of 16 intermediates and one surface, were set in March. Although two of the intermediates were aborted at launch, no gear was lost, and the moorings were subsequently set successfully. All 16 of the intermediates were recovered complete in June. However, the surface mooring marking the center of the array was apparently stolen by an unknown vessel in May while the *Chain* was some miles away. After the recovery of the main array, the MODE site was occupied by two site-maintenance moorings through the rest of the year.

A continuous three-mooring array was maintained at Site D (39°10'N, 70°W) through the year. The three moorings put in on the December 1972 cruise were replaced in March and again in October. Two of the moorings set at Site D in March were set by the faking-box technique. This experimental technique was later abandoned.

The August cruise was cancelled because preparations for the Tri-mooring had not been completed. The Tri-mooring was set in October and recovered successfully in December. Associated moorings included a net of three transponder bottom moorings used for acoustic navigation during the setting, a surface tether mooring, a spar buoy attached to the tether buoy and a surface navigation mooring. The navigation mooring was lost when the float sank just before the anchor bottomed due to a miscalculation in the anchor weight.

Other moorings set during the year included an intermediate mooring at Site D to test Vector-Averaging Current Meters (VACMs), two intermediates in the Windward Passage for Marvel Stalcup and William G. Metcalf, three intermediates at Muir Seamount for Carl Wunsch (Massachusetts Institute of Technology), and a one-year intermediate engineering test at Site D.

Table I

Moorings Set in 1973

No.	Month Set	Location	Type	Duration (days)	Recovery	Notes
480	March	MODE	Surface	74	Lost	MODE marker buoy -- stolen
481	"	"	Inter-mediate	116	Complete	MODE-I
482	"	"	"	106	"	"
483	"	"	"	113	"	"
484	"	"	"	112	"	"
485	"	"	"	111	"	"
486	"	"	"	110	"	"
487	"	"	"	1	"	" -- aborted at launch
488	"	"	"	108	"	"
489	"	"	"	106	"	"
490	"	Site D	"	203	"	Faking-box launch }
491	"	"	"	204	"	" " " } array
492	"	"	"	201	"	}
493	March	MODE	"	91	"	MODE-I
494	April	"	"	89	"	"
495	"	"	"	89	"	"
496	"	"	"	1	"	" -- aborted at launch
497	"	"	"	87	"	"
498	"	"	"	86	"	"
499	"	"	"	86	"	"
500	"	"	"	84	"	"
501	"	"	"	87	"	"
502	June	"	"	170	"	MODE Site mooring
503	"	"	"	169	"	" " "
504	Nov.	Windward Passage	"	at sea	--	For Stalcup and Metcalf
505	"	"	"	" "	--	" " " "
506	Oct.	Site D	"	" "	--	
507	"	"	"	" "	--	array
508	"	"	"	52	Complete	VACM Test Mooring
509	"	"	"	at sea	--	
510	"	MODE	Surface	51	Complete	IWEX Tether Mooring
511	"	"	"	0	Lost	IWEX Navigation Mooring -- Float sank at launch
512	"	"	Bottom	8	Complete	IWEX Transponder Mooring
513	"	"	"	8	"	" " "

Table 1 (continued)

Moorings Set in 1973

No.	Month Set	Location	Type	Duration (days)	Recovery	Notes
514	Oct	MODE	Bottom	8	Complete	IWEX Transponder Mooring
515A	Oct/Nov	"	Tri-mooring	43	"	IWEX Tri-mooring
515B	"	"	"	45	"	
515C	"	"	"	44	"	
516	Nov.	"	Spar	2	"	IWEX near-surface experiment
517	Dec.	Site D	Intermediate	at sea	--	1-year Test Mooring
518	"	Muir Seamount	"	" "	--	For Wunsch
519	"	"	"	" "	--	" "
520	"	"	"	" "	--	" "
521	"	MODE	"	" "	--	MODE Site Mooring
522	"	"	"	" "	--	" " "

INSTRUMENT DEVELOPMENT

James R. McCullough and Richard Koehler

During the past year, 17 modified Vector-Averaging Current Meters (VACMs) with temperature difference circuits and sensors capable of one milli-degree differential accuracy have been designed, constructed, calibrated and used at sea in the Internal Wave Experiment (IWEX). Calibrations before and after the experiment as well as recorded ocean data indicate that all temperature circuits and sensors performed as desired. The results indicate an order of magnitude improvement for thermister temperature measurements made at sea. The measured time series of temperature and local (1.8 meters) temperature gradient will be used to make multiple estimates of vertical ocean currents for the first time from a deep-sea mooring.

To compare estimates of vertical currents made by this technique with conventional vertical current measurements made with floats, three vertical current meter floats with modified VACM temperature circuits were constructed. Unfortunately, only one float could be set during IWEX and it failed to record data. Continued effort to complete this sensor intercomparison experiment is anticipated.

As reported in the MODE *Hot-Line News* performance of the first AMF VACMs in MODE was not good. Both vane and rotor readout showed intermittant periods of no change. The vane "straight line" data is believed to have resulted from bearing corrosion in nearly still sea water. Laboratory and sea test seem to confirm this.

Drift of the rotor magneto diode pick up is thought to be a major factor in the apparently erroneous rotor zero readings. An AC coupled circuit to avoid the drift problem was designed and success-

fully tested at sea. Greater emphasis on quality control of current meters has resulted from the MODE instrument problems.

Response of the VACM rotor, vane and vane follower sensors to controlled oscillatory and steady flow was started. A special cassette data logging system was built for these tests. An improved model of the dynamic response of the sensors (perhaps improved mechanical sensor response) is sought.

Construction of acoustic current sensors for laboratory testing was started. The initial instrument is a copy of that developed by Trygve Gytre in Norway (1970 to present).

Finally a new endless cartridge reader for 850 current meters was designed and put in operation together with a display program to replace the now retired PDP-5 computer read system.

OCEAN AND ATMOSPHERE

AIR-SEA EXCHANGE

Peter M. Saunders

In the past year we have been principally concerned with the analysis of data from the JASIN (Joint Air-Sea Interaction) experiment which took place at Ocean Weather Station J in September of 1972. The principal aim of JASIN was to measure fluxes of momentum and heat at the sea surface and observe the response of the upper layers of the ocean, thereby providing data for the development of improved models of the seasonal thermocline.

The experiment was coordinated by Dr. Raymond Pollard (University of Southampton, U.K.) and the principal support and facilities were provided by United Kingdom laboratories. Three ships participated and seven instrumented moorings were deployed. The principal investigator made twelve flights (nearly 150 hours) in a four-engined Hastings aircraft in an area 200 km by 200 km around the moorings and ships. Surface temperature measurements were made with a radiation thermometer and 250 AXBTs (air-expendable bathythermographs) were dropped. Because the majority of the data from the experiment was stored in the United Kingdom and because of the need to incorporate the data into his own analyses, the principal investigator spent eight months of the year in the Department of Oceanography in Southampton.

Maps of the distribution of the surface temperature of the ocean at two- and three-day intervals throughout the month of the experiment have been prepared and, from the continuity in the evolution in the temperature patterns, are seen to be of high quality. Two important elements in achieving this quality have been (i) the observation of sky conditions made with an upward-looking radiometer and (ii) the discrimination of 'contaminated' observations made with the downward-looking instrument arising from rain and clouds (under) by means of dry and wet bulb measurements made continuously from the aircraft.

Certain provisional conclusions have been reached; an energetic anticyclonic eddy (diameter $\sim$ 150 km with free circulation of 30 cm/sec) influenced the region of the experiment for the entire

month. Our maps show the slow (2-8 cm/sec) northwest progression of this eddy so that advective processes become dominant at all moorings during periods that can be identified. The AXBT data shows the eddy vertically coherent throughout the thermocline and ship CTD (conductivity, temperature, depth) observations reveal a penetration of the circulation to 1500 m.

Drogue observations and current meter data gathered during the experiment are being studied now. It is our aim to synthesize these direct flow measurements with flow estimates from isotherm displacements derived by the repeated mapping. Some encouraging correspondences are emerging.

TURBULENCE AND FLUXES IN THE BOUNDARY LAYERS OF UNDISTURBED AND DISTURBED TRADE WINDS

Andrew F. Bunker

The purpose of this research was to determine the processes operating in the tropical marine boundary layer utilizing BOMEX (Barbados Oceanographic and Meteorological Expedition) observations.

The winds observed from *Oceanographer* during Phase III of BOMEX were used, together with aircraft turbulence data, to evaluate the various effects of stability, secondary instability circulations, cumulus convection and periodic pressure changes. During undisturbed conditions the vertical wind profiles show maximum east winds at 150 m and 750 m. This profile does not agree well with the Ekman spiral predicted for the stability and roughness length conditions found in the trades. Recent studies of the dynamics of the boundary layer indicate that such jettiness may be produced by periodic variations in the pressure field. The profile does show some resemblance to the roll vortices due to Ekman instability, but the u-component deviations are greater than predicted. The winds show that a diurnal variation of the winds occurs at several levels with irregular variations at other levels. Placing values of the semi-diurnal pressure variations and the observed accelerations of the air into the equations of motion, it is found that the frictional force varies diurnally in such a way that the expected semi-diurnal variation of the wind is transformed into a predominately diurnal variation. Aircraft observations of turbulence and Floating Laboratory Instrumented Platform (FLIP) observations of the dissipation of energy also display a diurnal variation. It is shown that nighttime instability of the air combined with stronger nighttime winds produce the diurnal variation of the frictional force which suppresses the accelerations produced by the morning pressure wave.

A final report to the National Science Foundation has been written entitled "Observations and interpretation of turbulence, wind variations and showers in the tropical marine boundary layer".

THE ENERGY PROBLEM

William S. von Arx

Objectives

To study the energies involved in various geophysical, astronomical, biological and botanical processes; to outline the routes, rates and reservoirs of energy in each; to define the points in each natural system where it is technically feasible to divert energy continuously for social applications; to estimate the ecological consequences of large-scale intervention in these natural processes.

Progress in 1973

The energies involved in some fifteen natural processes have been examined and arranged in order of their total power. Solar energy heads the list with a power of some 10^{17} watts. The most energetic geophysical processes produce some 10^{11} watts which, strangely, is of the same order as that required to keep the present world population alive. Industrialized society is presently consuming some 10^{13} watts or some two orders of magnitude more than the energy required for human metabolism.

To sustain industrialized society at its present level of energy consumption, without depending on fossil or nuclear fuels, it will be necessary to utilize solar energy directly or employ solar-dependent alternatives. Bioconversion of vegetable and other organic residues of farming and the wastes produced in urban centers seems to offer one hopeful prospect that has the necessary level of power (10^{13} watts if fully developed) and is compatible with present farming and industrial practices. Only "solar sea power" which employs the thermal contrasts of the world ocean exceeds this (by half an order of magnitude) and may represent an "energy ceiling" unless some practical and economically feasible methods are found for using solar energy directly.

To date one paper on electric power generation from the Florida Current has been published, with Harris B. Stewart, Jr. and John Apel as co-authors, and notes assembled for the preparation of a paperback presenting the results of this study of the energy problem with primary emphasis on long-range "steady-state" solutions.

MARINE GEODESY AND SATELLITE ALTIMETRY

Jerome P. Dean

In the long-range program to provide global oceanic topography,work has been done to assist in providing ground truth calibration data for a satellite altimeter.

The Gyro Erected Optical Navigation (GEON) system was used on R/V *Chain* Cruise 112 to make an astrogeodetic section in the Atlantic between latitudes 32° and 35°N along longitude 70°W. GEON provided astronomic position, and Loran C and satellite navigation provided geodetic control. Gravity measurements were made simultaneously with D4e Vibrating String Accelerometer (VSA) gravimeter. The observations indicate that the deviations of the geoid from the best-fitting ellipsoid are large compared to geoids derived from satellite perturbations or gravity data.

Geoidal topography derived from these direct measurements result in quite large undulations which do not appear on computed geoids.

ANALYSIS OF DATA FROM THE ENVIRONMENTAL BUOY EB01

Joseph Chase, Charles E. Parker and Robert M. Alexander

The purpose of this research was to find scientific uses for the data being collected by the Environmental Buoy EB01 located at the northern edge of the Gulf Stream off Norfolk, Virginia.

Three main lines of study proved profitable:

1. The extrapolation of the height of the 700 mb and 500 mb surfaces was found to have an accuracy well within operational limits.
2. A study of rhythm of speed and position of the Gulf Stream was accomplished through identification of water masses at the buoy.
3. A preliminary study of positional shifts in the Gulf Stream in response to wind developed some apparent relationahips and indicated that further study with an array of buoys would be promising.

The techniques developed in these studies were analyzed for application to the Engineering Experimental Phase (EEP) buoy system in the Gulf of Mexico.

The contract terminated with a final report on 31 March 1973.

OCEAN CIRCULATION

LARGE-SCALE CIRCULATION

Bruce A. Warren

Analysis was completed this year of hydrographic sections occupied in 1970 along Latitudes $12^{o}S$ and $23^{o}S$ between Madagascar and the Central Indian Ridge. The purpose of these sections was to identify the deep western boundary current of the South Indian Ocean predicted by deep circulation theory. The existence of the current, lying just east of Madagascar at depths greater than 3000-3500 m, was clearly demonstrated in the distributions of temperature and dissolved-oxygen concentration, and geostrophic estimates (necessarily somewhat equivocal because of the absence of direct current measurements) give a volume transport for the current on both sections of $4\text{-}5 \times 10^{6}\ m^{3}\ s^{-1}$, with maximum speeds of 4-6 cm s^{-1}. Water properties indicate that the current flows northward from the Antarctic through the Crozet Basin into the Madagascar Basin, and that some portion of it continues northward into the Somali Basin: it is thus the source of deep water for the western Indian Ocean. This conclusion is at variance with earlier thoughts that the route of northward flow here would be through the Mozambique Basin (rather than the Crozet Basin). It seems likely that the ridge systems of the Indian Ocean block any continuation of this flow into the deep eastern Indian Ocean; it would therefore be useful at some time to extend these observations

across the southeastern Indian Ocean to discover whether there is any deep northward flow just east of the Ninety-East Ridge, which could supply the deep water of the eastern basins.

Property distributions at shallower levels in the western Indian Ocean (2-3 km, say) are ambiguous with regard to sense of flow, and it is difficult to judge whether the mean flow is northward from the Antarctic or southward from the Arabian Sea.

Reduction of Salinity, Temperature, Depth (STD) data from *Knorr* Cruise 22, an investigation of the Gulf Stream in the vicinity of the New England seamounts, has been completed at Texas A & M University, and a joint Texas A & M - Woods Hole Oceanographic Institution (TAM-WHOI) data report has been issued. It is hoped to write up the analysis of this material (and current measurements) with Andrew C. Vastano in 1974.

Robert J. Stanley and George P. Knapp, III have continued to assemble constant-level maps of property distributions at 500-m depth intervals from 2000 m to the bottom. Except for a large block of Pacific data awaited from Scripps Institution, they have completed preliminary plotting and contouring of the potential temperature and salinity maps, and they have begun plotting dissolved oxygen data. These maps are intended as summaries of existing deep-ocean observations, to help us plan field projects, and to provide reference material for thinking about deep-circulation problems. They have been helpful in the last year, for instance, in considering the route of deep northward flow in the western Indian Ocean.

GULF STREAM STUDIES

Frederick C. Fuglister

The variable nature and complexities of the Gulf Stream System in the area south of the Grand Banks of Newfoundland was demonstrated on a month-long cruise, September 20 to October 20, 1973. Nine expendable bathythermograph sections -- 750 m -- were run from the coastal water out to the Gulf Stream between 48° and 55° West longitude. The long, several-degrees-of-latitude, north-south meanders of the Gulf Stream together with the shifting slope-water current to the north and the complicated, rugged bottom topography just to the west of the Newfoundland Rise, all explain why it is so difficult, if not impossible, to interpret the results of a single line of stations across this region.

On this one cruise, two different results were obtained tracking drogued buoys in the slope current. This current shifted its position 40 miles to the westward in ten days and instead of heading to the east or northeast as it is generally pictured, its course was southeast and south. Current speeds of the upper 200 m layer were between 1.5 and 2 knots; however the first buoy, after traveling about 90 miles to the southeast, came virtually to a stop for several days and then moved to the east at about 0.5 knots. The second buoy, placed in the current after its shift to the west, started off much the same as the first but it showed no signs of stopping or of turning to the east, indeed after moving 120 miles in a curved path toward the south it had a slight westerly component.

It became apparent on this survey that the available bathymetric charts for the area are inaccurate. In view of the fact that recent direct current measurements show appreciable currents (>15 cm/sec) at depths of 5,000 meters, the circulation patterns in this area must be strongly influenced by the complicated topography, especially to the west of the Newfoundland Rise. Of particular interest is the ridge, or spur, that points west from the Newfoundland Rise, just north of the 40th parallel.

NORTH ATLANTIC CIRCULATION AND WORLD WATER MASS CENSUS

L. Valentine Worthington and C. Godfrey Day

In 1973 the principal investigator completed box models of the meridional circulation of the North Atlantic for five layers based on physical measurements and water mass analysis. These box models, in which the water entering and leaving each layer is given to the nearest 1 million m^3/sec, accompanying the circulation diagrams, already completed, in which the transports of the major current systems have been given to the nearest 5 million m^3/sec for the same layers. The net meridional circulation of the North Atlantic is 1 million m^3/sec to the south; this amount enters the North Polar Sea from the Pacific and an equal amount must cross the equator into the South Atlantic. However, there is a much stronger meridional circulation which consists of deep and bottom water formed in the north which flows toward the equator and warmer water which is drawn northward to replace it.

The combined box model for all five layers is shown here (Fig.1); space does not allow a full

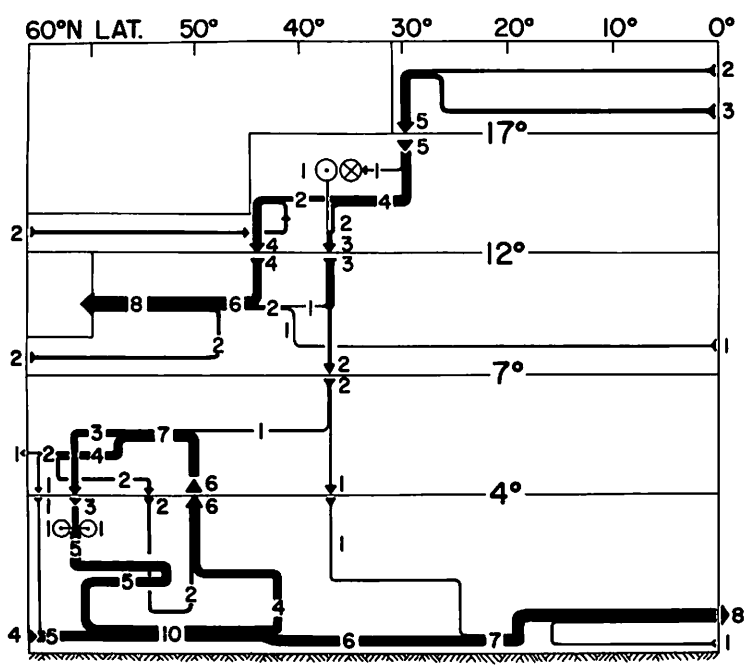

Fig.1 (Worthington and Day) Box model of the North Atlantic circulation.

description and justification of this model but the main features should be clear to those familiar with the North Atlantic. In the deep water layer ($< 4^{o}$) the flow is equatorward; it consists of Norwegian Sea Overflow water entering from the north, augmented by Atlantic water entrained from the lower thermocline layer (4^{o}-7^{o}). In all but the deep water layer the general flow is poleward; 8 million m^3/sec flow into the Norwegian Sea from the mid-thermocline layer (7^{o}-12^{o}). This flow is provided by a slow drift up the eastern side of the Atlantic -- the upper thermocline (12^{o}-17^{o}) water cools to below 12^{o} by latitude 45^{o}N. Similarly the warm water layer ($> 17^{o}$) supplies the upper thermocline flow at 30^{o}N where the temperature of the northward flowing water drops below the 17^{o} isotherm.

A principal feature of the model at mid-latitudes is the contribution of Mediterranean Water (36^{o}N) consisting of 1 million m^3/sec of pure Mediterranean Water plus 2 million of entrained Atlantic water; this is all contributed to the mid-thermocline layer and below. The result of this contribution would be to raise the salinity of the North Atlantic as a whole if it were not balanced by relatively fresh water from the South Atlantic and from the Labrador Current.

Since the volume of water in each of the layers can be obtained from the atlas of Wright and Worthington (1970), it has been a simple matter to calculate the mean residence time of a given particle of water in each layer and in each of the six major basins of the North Atlantic. The North Atlantic contains 137 million km^3 and the total amount entering and leaving the ocean is 18 million m^3/sec thus the mean residence time for the ocean as a whole is 240 years. The deep water residence times vary between 4.5 years in the European Basin and more than 900 years in the Guinea Basin off equatorial Africa. These box models are included in the principal investigator's completed paper on the general circulation of the North Atlantic.

Substantial progress has been made in the water mass census of the Indian Ocean. All suitable hydrographic data have been acquired and evaluated. Charts of salinity at 24 levels of potential temperature in the deep water ($4.0^{o}\theta$ and less) have been virtually finished. A companion group of charts showing the depth of these temperature surfaces has been prepared for presentation after the manner of Worthington and Wright (1970). The basic structure of the Indian Ocean in terms of temperature and salinity has emerged. The volumetric calculations have been determined by computer and remain to be summarized and plotted.

In 1973 the principal investigator also submitted a paper in which it is proposed that the distribution of dissolved silicon in the World Oceans is consistent with near-zero Antarctic Bottom Water formation in the present century. Previous circulation models ignored the fact that if silicon-rich Antarctic Bottom Water flows northward in large quantities, it must return to Antarctica as thermocline and surface water: these waters are devoid of silicon. The amount of silicon removal required by these models seems most unreasonable.

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REVIEW OF THE PHYSICAL OCEANOGRAPHY OF MASSACHUSETTS BAY

Dean F. Bumpus

The object of this contract is to review and bring into focus all available physical oceanographic information for Massachusetts Bay. This is an important area in the view of the National Marine Fisheries Service. An experiment, since discontinued, was being developed to determine the environmental effects of sand and gravel mining off Boston. This study was designed to provide the background information.

The temperature and salinity cycles for Massachusetts Bay have been described, as have the tidal, residual and high frequency oscillations. An annotated bibliography on the hydrography, chemistry and sea level of Massachusetts Bay has been prepared.

DEVELOPMENT OF DRIFT BUOY LOCATION SYSTEM (TALKING DRIFT BOTTLE)

Foster L. Striffler and Dean F. Bumpus

See summary entitled "Talking Drift Bottle" by Foster L. Striffler in section for Ocean Engineering, p.OE-32.

CURRENTS AT THE EDGE OF THE CONTINENTAL SHELF SOUTH OF CAPE COD

W. Redwood Wright, Joseph Chase and Charles E. Parker

Preliminary to a series of direct current measurements to be made in 1974, the past year has been spent examining existing hydrographic data in the Institution files from the continental shelf east of Cape Hatteras and the Slope Water region.

The area of greatest concentration is the shelf edge south of Cape Cod, where there is a sharp boundary between the relatively fresh Coastal Water and the saltier Slope Water offshore. Nearly 20,000 bathythermographs and hydrographic stations, dating back more than 30 years, have been examined for evidence of seasonal and long-term variation in the boundary and for indications of the production of detached parcels or bubbles of Coastal Water within the Slope Water.

There is a clear seasonality in the structure and character of the boundary, and in the production of bubbles, which reaches a peak in August. However, the position of the region of sharp gradients on the sea floor does not show much seasonal variation although it does reflect extraordinarily warm or cold years. In a similar survey, of some 1,200 hydrographic stations in the Slope Water region, fresh anomalies in the top 100 meters were taken as indicators of Coastal Water

bubbles. These also show a marked seasonal pattern with a peak in August. Warm, salty anomalies indicating Gulf Stream water occurred much less frequently but with roughly the same seasonal bias.

In order to obtain continuous temperature measurements at various depths from a moving ship, an inexpensive, shallow-water thermistor chain has been designed, and a simple prototype has been successfully tested in the laboratory.

A start was made at relating historical weather data to observed changes in the coastal water. For example, it is known that either low air temperatures or northerly winds can lead to low water temperatures in winter. Preliminary studies indicate that it might be possible to separate the two effects. In preparation two banks of information were assembled:

1. A tabulation of weather and air temperatures at Nantucket in the weeks preceding oceanographic cruises on the shelf south of New England in January.

2. A file of over 100 weather maps showing average surface pressure and therefore mean wind in the Middle Atlantic Bight and adjacent land areas for periods of from a few days to several weeks, prior to cruises.

CARIBBEAN SEA INFLOW INVESTIGATION

William C. Metcalf and Marvel C. Stalcup

The analysis of the STD (Salinity, Temperature, Depth), hydrographic station and current meter data from *Knorr* Cruise 25 (1972) has continued during 1973. The relationship between temperature and direction of the deep flow across the sill of the Jungfern Passage is very marked (Fig.1). Water moving into the Caribbean at speeds between 20 and 30 cm/sec was commonly of an observed temperature between 3.80 and 3.85°C. For a period of about a week in the middle of a five-week record, the water movement was very much slower with some outflow observed, and the temperature was about 4.0°C. This is taken to indicate that the inflowing cold Atlantic water sinks below sill depth, and when the current reverses, it is warmer Caribbean water which flows out. The amount of inflow (estimated to be about 80,000 m^3 sec^{-1}) is so small and the water mixes away so rapidly that evidence of it, using silicate, oxygen and T/S relationships as tracers, is lost within 10 km or less of the entrance point.

In November 1973, a short bathymetric survey of the Windward Passage was carried out aboard the *Atlantis II* on Cruise 78 to delineate the depth and configuration of the sill between Cuba and Haiti. Four current meters and six temperature/depth recorders were moored near the sill to monitor the water movements. Recovery of these instruments will be attempted in March 1974.

The buoys used in our radar-ranging navigation system were extensively remodeled during 1973 and the system was refurbished for use by the Geology and Geophysics Department during the FAMOUS (French American Mid-Ocean Undersea Study) project. A radar transponder was prepared for use during

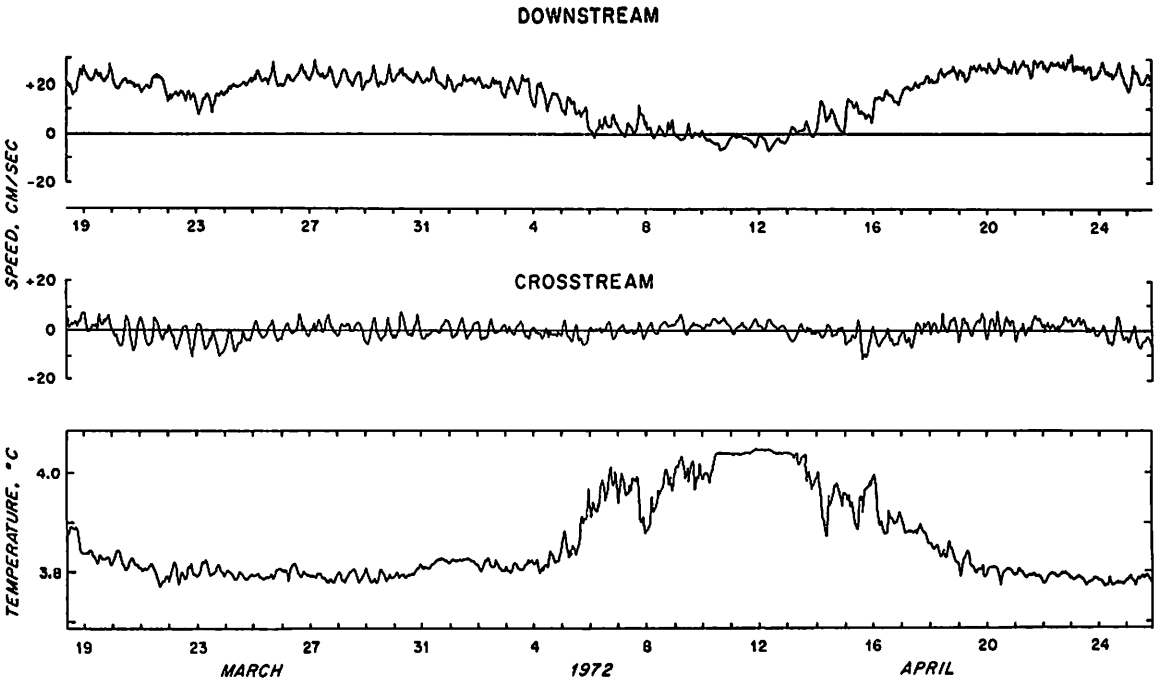

Fig.1 (Metcalf and Stalcup) Current and temperature records from within 10 m of the bottom on the Jungfern Passage Sill. "Downstream" (positive) speeds represent inflow into the Caribbean in the direction of 210°True. For the "crossstream" direction, positive speeds are to the right (300°T) and negative to the left (120°T) of the downstream flow.

the IWEX (Internal Wave Experiment) and a new navigation program was written for the Hewlett-Packard 9820 calculator.

With Lorraine Barbour, a new thermometer calibration edit program was designed which will permit calibration changes, deletions, etc. to be made to the master thermometer calibration record. The HYD-1 and HYD-2 hydrographic programs were extensively remodeled and progress was made towards initiating a standard system for the reduction of hydrographic station data.

MESO-SCALE CIRCULATION FEATURES OF THE GULF OF MEXICO

Worth D. Nowlin, Jr.

For a number of years the principal investigator has been studying the meso-scale circulation features of the Gulf of Mexico. More recently he has been trying to improve his regional oceanographic knowledge of the Caribbean Sea, South Atlantic and Southern Ocean. His goals while at the Woods Hole Oceanographic Institution as a visiting investigator were:

a) To continue studies of the energy sources responsible for meso-scale circulation and property distributions in the Gulf of Mexico;

b) To learn more about the Mid-Ocean Dynamics Experiment; and

c) To assist in the organization of a new physical oceanographic program in the Southern Ocean.

During the stay at Woods Hole Oceanographic Institution, the principal investigator:

a) Completed a paper on the "Effects of a cold-air outbreak on the shelf waters of the Gulf of Mexico", which was subsequently submitted to, and accepted by *Journal of Physical Oceanography*;

b) Completed preliminary draft of a paper entitled "Meso-scale circulation of the Gulf of Mexico, I. Effects of the Look Current and anticyclonic rings";

c) Spent two weeks in Bermuda at the MODE Hot-Line Centre; and

d) Helped prepare for and co-chaired the first organizational meeting of the International Southern Ocean Studies, a sequence of monitoring and dynamics experiments now receiving National Science Foundation sponsorship as an IDOE (International Decade Ocean Exploration) program.

DEEP VARIABILITY IN THE MEDITERRANEAN SEA

Arthur R. Miller

Most of the water in the Western Mediterranean Sea, other than the surface layers, is made up of mixtures of Eastern (Levantine) water and Western (winter) water. A line drawn between 13.20°C/38.500°/oo and 12.67°C/38.397°/oo will be sufficient to describe the potential temperature/salinity characteristics of deep Western Mediterranean water. The proportions of the two water types within the water column change with the season, the greatest amount of "winter" water appearing in late spring at 2500 meters. The level at which East and West water appear to be equally mixed fluctuates between 600 and 800 meters in the Western Mediterranean proper. This level rises to sill depth at Gibraltar (350 m).

INDIAN OCEAN STUDIES

John G. Bruce, Jr.

A study has been continued of the circulation of the Indian Ocean during the southwest monsoon. Our data suggest that the Somali Current system is comprised of somewhat unstable gyres which are continually changing position and size (Fig.1). The geostrophic volume transport of the coastal Somali Current may vary nearly an order of magnitude over the period of a month from approximately 4×10^6 to 40×10^6 m^3/sec (layer between 0 to 400 dbr relative to 1000 dbr). The region of maximum upwelling along the coast is associated with the turning offshore of the coastal current, and thus both the degree of upwelling and location appear to change also (Bruce, 1973a).

Data from meridional equatorial sections in the western Indian Ocean during the peak of the southwest monsoon indicate that the undercurrent was not present at the equator, but a rather large westward component was found that extended from the equator as far north as 5°N and had transports

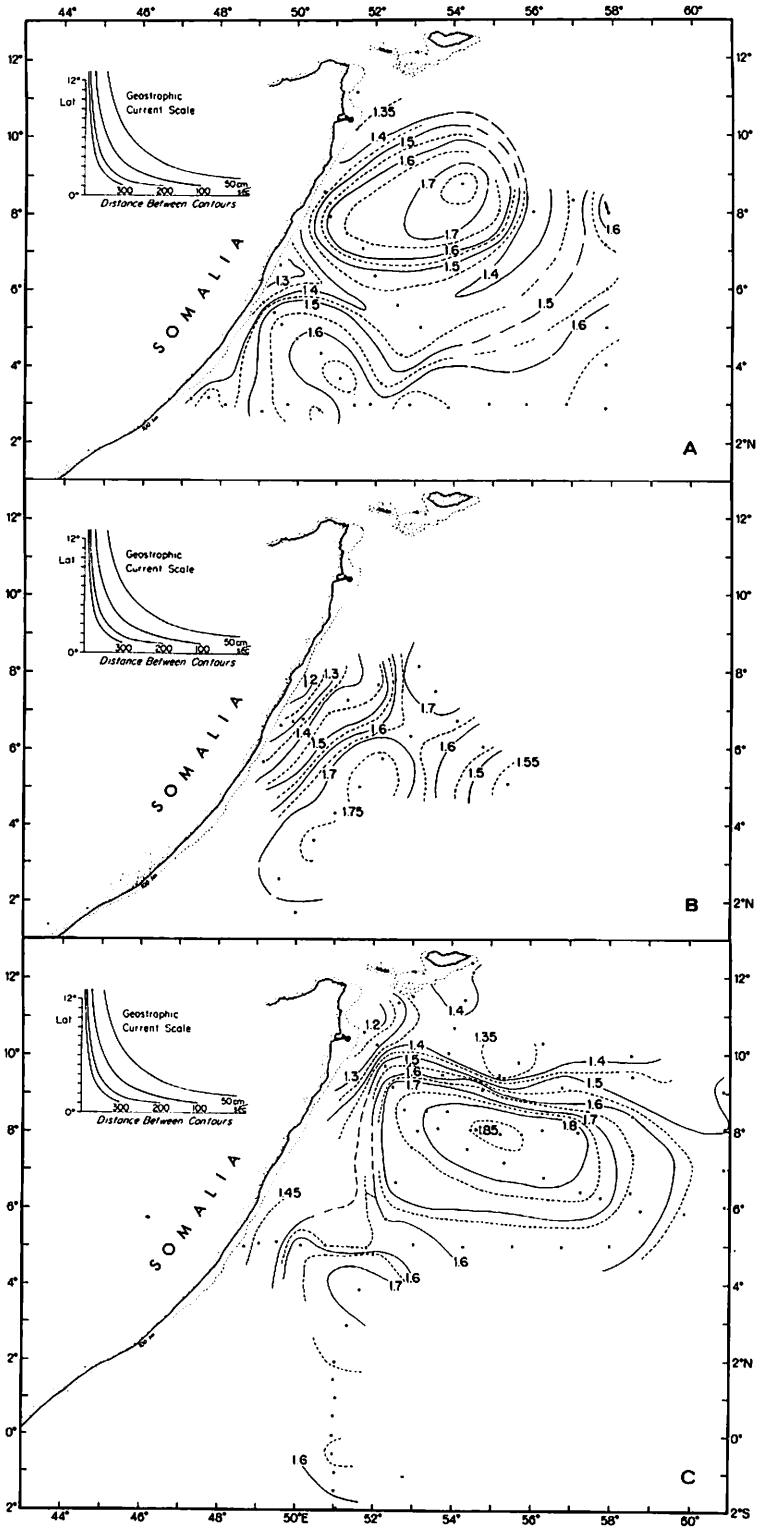

Fig.1 (Bruce) Dynamic topography of the sea surface in dynamic meters, relative to 1,000 decibars off the Somali coast during the southwest monsoon, 1970. A. August 4 - 20; B. August 20 - 27; C. September 5 - 25.

amounting to about 40 x 10^6 m^3 sec^{-1} to the west. A weak undercurrent was observed at 1°S to 2°S with transports as low as 5 x 10^6 $m^3 sec^{-1}$ to the east which suggests that in the western ocean during the southwest monsoon the strength of the current may be considerably reduced and the axis shifted to the south (Bruce, 1973b).

The heavy year-round tanker traffic off the Somali coast en route to the Persian Gulf offers an excellent means of monitoring changes in the current structure with XBT (Expendable Bathythermograph) stations and surface samples. We have corresponded with a number of corporations and found several willing (particularly Exxon) to allow observers aboard as frequently as every week between Cape Town and the Persian Gulf. It is hoped to commence a program of observations as a pilot study leading up to Indian Ocean work during the First GARP (Global Atmospheric Research Program) Experiment in 1977-78.

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ATLANTIC EQUATORIAL UNDERCURRENT

Eli J. Katz and John G. Bruce, Jr.

A field investigation of the Atlantic Equatorial Undercurrent has been planned for June and July of 1974 in coordination with the International Global Atmospheric Research Program's Atlantic equatorial experiment. By a combination of tow mapping and hydrographic sections it is hoped to develop a three-dimensional perspective of the undercurrent's zonal meandering and to test its theoretical response to shifts in the atmospheric winds. A doppler-scattering current meter is being adapted to a tow application by Warren Witzell, Jr., and Frederick R. Hess of the Ocean Engineering Department.

COASTAL CIRCULATION IN THE GREAT LAKES

Gabriel T. Csanady

Work is aimed at understanding water movements in the Great Lakes, especially near shore where pollution problems are most critical. A major field program was carried out during 1972 on Lake Ontario, the International Field Year on the Great Lakes (IFYGL). The results are being analyzed and evaluated. The purposes of this large cooperative experiment were mainly to understand large-scale, lakewide dynamical phenomena.

During the 1973 analysis year some notable insights have been achieved. The manner in which storms set up circulation gyres could be related to a simple dynamical theory, according to which the depth distribution in the lake is the key to the water transport pattern. During the summer, under stratified conditions, winds also set up intense nearshore currents called coastal jets. Some interesting and unexpected aspects of the beharior of these could also be elucidated, notably how

these jets may reverse and begin to flow upwind. The work has demonstrated beyond doubt that Lake Ontario is large enough for the earth's rotation to affect water movements in a very pronounced way. The results should therefore also be valuable for the understanding of nearshore oceanic phenomena. With certain limitations one may legitimately regard the Great Lakes as "model oceans".

COOPERATIVE INVESTIGATIONS IN SPANISH COASTAL WATERS

Joseph Chase (Arthur R. Miller, Principal Investigator)

The purpose of this effort is to study Spanish coastal waters in cooperation with personnel of the Instituto Espanol de Oceanografia. In response to the question, "Could weather help explain why the Ria de Arosa is more productive than the other estuaries of the Atlantic coast of Galicia?" a visit was made to Spain and Portugal in order to gather information.

Whereas wind and river run-off, both of which depend on terrain, could produce significant differences in the current systems of neighboring estuaries, a study of terrain by personal observation and by means of maps was made. From this study it appears that the valley of the Ulla River, which flows into the Ria de Arosa, is conducive to promoting katabatic air flow in cool seasons and that the flow of air down the valley in summer may be enhanced by damming of winds by mountains. This would result in a high frequency of northeast winds flowing out of the Ria de Arosa. The rivers leading to the other three rias are not so favorably situated for these types of flow. Meteorologists of both Spain and Portugal have agreed with this reasoning but the necessary precise knowledge of climatic variation in the area is lacking.

River run-off and effects from wind flow are important environmental factors affecting the water quality of the ria. The apparent decisive importance of terrain presents a challenging problem in marine meteorology.

MANAGEMENT AND PROCESSING OF MARINE DATA

Marvel C. Stalcup

During September a course in the acquisition, analysis and processing of physical oceanographic data was held for twelve UNESCO-sponsored trainees from twelve different countries. The course included an eight-day cruise aboard the University of Puerto Rico's research vessel *Crawford* in the Mona Passage during which the trainees were instructed in the technique employed during detailed bathymetric and hydrographic surveys. After the initial data processing in Puerto Rico, the trainees spent two weeks in Woods Hole attending lectures, touring the facilities and reducing and analyzing the data gathered during the cruise.

Six weeks during May and June were spent as a part-time instructor in the University of Michigan's Ocean Practicum course offered each spring at Woods Hole.

CALIBRATION FACILITIES

CALIBRATION OF OCEANOGRAPHIC SENSORS

Karl E. Schleicher and Alvin L. Bradshaw

The primary objective of this work is to establish a facility at the Institution to calibrate instruments in respect to temperature, electrical conductivity and pressure. This is a new program started in January 1973 and the first year was spent in the construction of some calibration apparatus and the calibration of temperature sensors, primarily thermistors used in the Mid-Ocean Dynamics Experiment (MODE-I).

The major item that was constructed for this program was a water bath large enough to accommodate most temperature, electrical conductivity and pressure sensing instruments at the Woods Hole Oceanographic Institution, in at least a partially submerged condition. Except for a removable copper cooling coil used as a cooling booster for more rapid slowing of the bath temperature, the bath is constructed of plastic or stainless steel material so sea water may be used with minimum contamination. Its polyethylene tank measures 28 inches inner diameter by 42 inches deep and has a capacity of approximately 100 gallons. A 70 gpm pump serves to mix the water in the tank as well as circulate it through an external cooler when a fixed temperature is being maintained in the tank. Quartz-sheathed heaters, thermostatically controlled, are used in the bottom of the tank. The entire system except for a 17,000 BTU/hr refrigerator compressor used with the booster cooling coils is mounted on a 32-inch by 5½-foot platform on casters for easy portability.

With this system the temperature of the fresh or sea water in the tank can be maintained constant to within three to five millidegrees Celsius depending on the amount of water in the tank and the configuration of the instrument to be calibrated. The average rate in cooling from 25° to 0°C is approximately 8°C per hour.

The tank has been used so far to calibrate the temperature and conductivity units of two of Thomas Sanford's electromagnetic current meters, three CTD-type instruments and a 50-meter Aandaraa thermistor string.

Most of our temperature calibration work has been concerned with the separated sensor component rather than with the whole instrument. We have made temperature runs on about 360 thermistors (including repeat measurements), most of which were for instruments used in MODE-I field programs. The usual calibration schedule for these thermistors was a temperature point every 5°C from 0° to 30°C. The measurements were done in a modification of the bath constructed earlier for our work on the properties of sea water. The temperature of the bath could be held constant to about ±0.001°C or better. These temperature fluctuations were smoothed out further by placing the thermistors and the platinum resistance reference thermometer in an oil-filled vessel. A Mueller bridge was used to measure the resistance of the thermometer. We estimate the overall precision of the thermistor calibrations to be ±0.002°C or better.

SUMMARY OF INVESTIGATIONS, 1973

Geoffrey G. Whitney, Jr.

My specialty is calibration of reversing thermometers for this Institution and other institutions, government agencies, etc. Other responsibilities include inventory control and issuance of Woods Hole Oceanographic Institution reversing, and other types of thermometers, psychrometers, etc., making minor repairs to such instruments, manipulation for correction of malfunctional behavior, recoloring thermometer scales and making periodic checks of thermometers for detection of ice point shifts. This is essentially a technical, service-type of operation involving little research.

Calibrations and ice point checks have been made during the year for Woods Hole Oceanographic Institution, U. S. National Marine Fisheries Service, Narragansett Marine Laboratory, U. S. Naval Underwater Systems Center, Atlantic Oceanographic Meteorological Laboratory, Lamont-Doherty Geological Observatory, and W. H. Kessler Company. Value of work for others billed was $2757.50; value of "in house" calibrations and ice points was $1722.50.

There were no technical reports or publications during the year.

NEW ENGLAND COOPERATIVE COASTAL RESEARCH VESSEL PROPOSAL

W. Redwood Wright

The Institution is one of 12 academic research organizations from New England which have collaborated in producing a $1.3 million proposal to the National Science Foundation for construction of a 125-foot coastal research vessel to be operated on behalf of all marine scientists interested in the region.

The ship would be capable of year-round research out to the edge of the continental shelf for periods up to two weeks, except in severe storms. She would fill an existing gap between the workboats of the smaller New England laboratories, all 65 feet or smaller, and the deep-sea research vessels of the larger laboratories, 180 feet and larger.

Operation would be by a member institution, not yet designated, under the direction of an advisory committee representing all research interests in the region. Provision would be made for "opportunistic" scheduling, to permit quick investigation of the effects of an environmental accident such as an oil spill or tropical hurricane.

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N00014-71-C-0057
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N00014-72-C-0206
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GD-27251
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GF-39056
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GI-32140
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GJ-133
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GP-4384
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GU-3927
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GX-28193
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GX-28334
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GX-30415
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2798
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