Woods Hole Oceanographic Institution

WOODS HOLE OCEANOGRAPHIC INSTITUTION
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SUMMARY OF INVESTIGATIONS

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

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a record of the scientific results obtained by our staff members, but publication delays made these at least a year out-of-date before they appear.

This report is the thirteenth in the series of Summaries of Investigation. It is 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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BIOLOGY

DEPARTMENT OF BIOLOGY

George D. Grice, Department Chairman

MESOPELAGIC FISH DISTRIBUTION AND FAUNAL REGIONS IN THE ATLANTIC OCEAN

Richard H. Backus

The object of this research, which has continued for some years, is to determine the distribution patterns of mesopelagic fishes in the Atlantic Ocean and to determine, if possible, what it is that controls the ranges of such fishes. (Mesopelagic fishes are mostly small fishes inhabiting the upper 800 or so meters of the deep ocean; most species make diurnal vertical migrations.) A sampling program covering much of the North Atlantic and some of the South Atlantic was concluded in 1974. At the year's end about 320,000 specimens from about 1000 midwater trawl collections had been identified as well as about 30,000 specimens from neuston nets.

More particularly all lanternfish specimens (family Myctophidae) had been identified and put on a corrected master list in computer storage. The list comprises about 240,000 specimens in about 11,000 species lots. These data provide distribution information for 74 of the 81 myctophid species recorded from the North Atlantic. Using them we made computer-drawn distribution maps of three kinds for the 74 species: (1) maps with a dot for each lot captured in the upper 200 meters by night, the dot diameter proportional to catch rate and x's representing negative collections, (2) maps with one dot per five-degree square for captures in the upper 200 meters by night, the dot diameter proportional to the average catch rate for the square and x's marking squares with reliable negative data, and (3) maps with a dot for each lot, using both nighttime and daytime data, but with no attempt to show relative abundance and with x's representing negative collections. Together, these maps show that five patterns (northern, eastern, central, tropical, and broadly tropical) describe the distribution of all species in a general way.

These data suggest that the North Atlantic can be divided into 15 or 20 regions, each having a more or less homogeneous fish fauna. These regions are separated from one another by more or less conspicuous physical boundaries. The regions do not differ in degree uniformly - a hierarchy of regions can be constructed. The regions differ not only in the relative abundance of species but also in biomass, diversity and other ways. A paper describing North Atlantic distribution patterns, faunal regions and individual ranges of myctophid species is in preparation as well as a distribuional account of myctophids for "Fishes of the Western North Atlantic".

WARM-BODIED FISH

Francis G. Carey

The heads of swordfish and billfish contain an organ which warms the brain. There is a lower size limit for the appearance of this organ which is not present in fish smaller than 15-30 cm. Since the organ is present in fish which are still too small to maintain any significant temperature differential, it is possible that this tissue may have another function in a developing fish besides generating heat.

A tracer method, using a fluorescent powder, was developed for measuring feeding rate of menhaden in schools swimming free in Woods Hole Harbor.

Three months this past spring were spent on a commercial swordfishing boat in the Gulf of Mexico while on accumulated vacation and leave of absence. One trip was made on a fishing boat this fall to collect a variety of fish bloods for studies on the kinetics of hemoglobin reactions, in cooperation with Professor Q. H. Gibson of Cornell University.

NITROGEN FIXATION IN THE SEA

Edward J. Carpenter

The objectives of this program are to understand the sources, significance of, and factors affecting nitrogen fixation in the marine environment. Our work has centered on N_2 fixation by the following: (1) marine *Oscillatoria (Trichodesmium)* spp. in the open ocean, (2) endosymbionts in marine shipworms, (3) blue-green algae and photosynthetic bacteria in Sippewissett salt marsh, (4) sediments of Buzzards Bay. In addition as part of this program, we are carrying out a study on the tidewater flux of dissolved and particulate N in and out of Sippewissett marsh.

1) Uptake kinetic studies indicate that *Oscillatoria* has relatively poor enzyme systems for the utilization of NH_4^+ NO_3^- and urea. In the sea it must rely on N_2 fixation for its major source of N. In the Caribbean *Oscillatoria* is a major component of the phytoplankton averaging 56% of

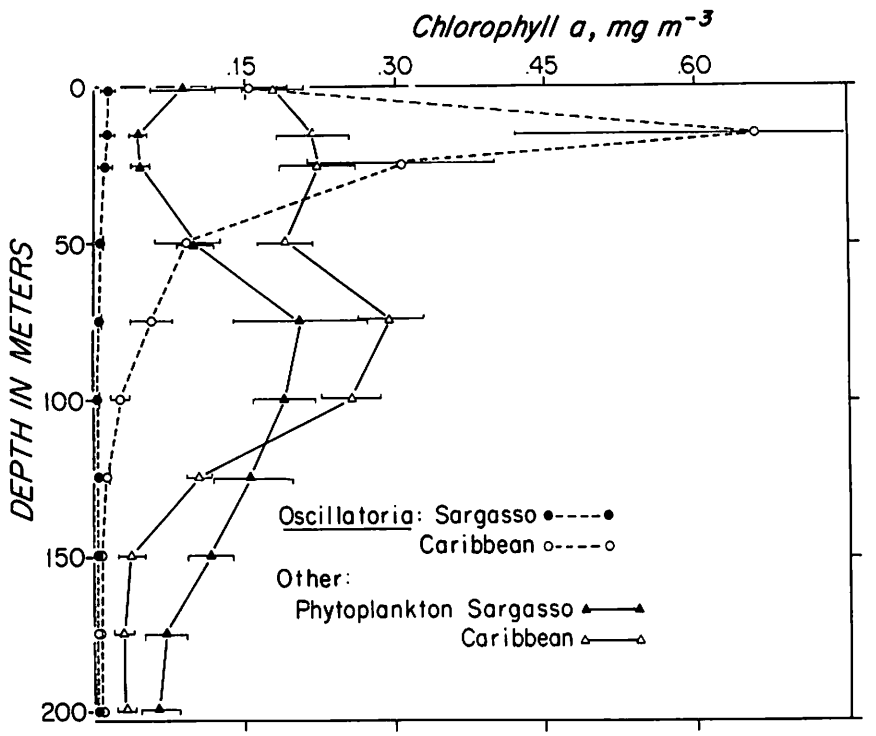


Fig.1. Standing crop of *Oscillatoria* spp. compared with that of other phytoplankton in the Caribbean and Sargasso Seas. Data were collected at 46 stations on three cruises.

the total phytoplankton biomass (as chlorophyll a) in the upper 200 m. In contrast, in the Sargasso Sea it only averages 12% of the total biomass (Fig.1). N_2 fixation supplies an average of 108 µg N_2 $m^{-2}hr^{-1}$ ($s_{\bar{x}}$= 47.) to the euphotic zone of the Caribbean, and only 4.6 µg N_2 $m^{-2}hr^{-1}$ ($s_{\bar{x}}$= 2.7) to the Sargasso Sea. Photosynthetically, *Oscillatoria* is more active in the Caribbean as compared with the Sargasso Sea. In the former area it supplies about 22 mg C $m^{-2}day^{-1}$, about a quarter of the total phytoplankton production in the open Caribbean. These data suggest that *Oscillatoria* could be of major importance in the Caribbean food web.

Physiological studies on *Oscillatoria* indicate that the area of N_2 fixation is a group of differentiated cells in the central area of the colony.

2) The diet of marine shipworms consists largely of wood (cellulose), and as such has a low content of nitrogen. Shipworms exhibit rapid growth (from 0.2 mm to 6 cm length in one month) and it has been a paradox as to how they obtain sufficient nitrogen for growth. We have discovered that N_2 fixation is associated with four marine shipworm species. A bacterium capable of fixing N_2 under anerobic conditions and of liquifying cellulose in culture has been isolated from the gut of one species. High N_2 fixation, up to 1.5 µg N/mg dry wt/hr which allowed a doubling of cellular N at rates up to 1.4 days, was associated with one species from the Sargasso Sea. N_2 fixation appeared to be inversely related to the ability of shipworms to obtain combined-N compounds in their diet. N_2 fixation can be a significant source of N for shipworms and possibly other oceanic organisms that ingest plant material of terrestrial origin.

3) Nitrogen fixation and the parameters affecting it have been measured over a two-year period in Sippewissett salt marsh. Organisms responsible for N_2 fixation are *Calothrix contarenii* in an exposed blue-green algal mat, *Stigonema* sp. and other blue-greens on the surface of sediments among *Spartina*, and photosynthetic bacteria on exposed sand along creek banks. The major source of N_2 fixation in the marsh is *Stigonema* and other blue-greens among *Spartina*, and these contribute an average of 1.84 mg N/m^2/day to the marsh.

The major factors affecting N_2 fixation in the marsh are the concentrations of combined nitrogenous compounds in ambient seawater and solar insolation. Rate of N_2 fixation is light-dependent as shown by long-term field shading experiments. In the summer the shading from the *Spartina* canopy is a major factor in regulating N_2 fixation. N_2 fixation occurs over a wide range of temperatures and in summer is only limited below 12° and above 48°C. However measurements made in early winter showed that significant N_2 fixation occurs as low as 0°C. Laboratory and field experiments showed no stimulatory or inhibitory effects on N_2 fixation resulting from the additions of PO_4, EDTA and iron and trace metals. However, the addition of either NH_4^- concentrations of 25 µg - at NH_4^- - N/liter and it ceased above 150 µg - at NH_4^- - N/liter. Subsequent laboratory experiments using controlled NH_4^- concentrations confirmed what was observed in the field. The addition of domestic sewage to test plots in the marsh also resulted in a dramatic decrease in N_2 fixation.

This study shows the importance of N_2 fixation in the ecology of salt marshes. Additionally, it illustrates the effects of additions of combined nitrogenous nutrients (as resulting from additions of domestic sewage) on the nitrogen cycle of marshes.

4) Our program on N_2 fixation in Buzzards Bay sediments began in October 1974. To date we have determined that depth of maximum N_2 fixation is between about 5 and 10 cm. Approximate rate of N_2 fixation in this stratum is 2 ng N_2 fixed/g (wet wt) sediment/hr. We plan to continue this program for one year, isolate the organism responsible and determine the factors affecting N_2 fixation.

PASSAGE OF ORGANISMS THROUGH AN ELECTRIC POWER PLANT

Edward J. Carpenter

The overall goal of this research program is to determine whether organisms are affected by heat shock, mechanical damage or chlorination in passage through the cooling water system of a nuclear power plant. Secondarily, together with biologists from the University of Rhode Island and Battelle Memorial Institute, we are attempting to understand the effect of the power plant on resident plankton and fish populations.

Laboratory studies were carried out to determine whether larval fish would be able to withstand the instantaneous 13°C temperature shock experienced when passing through the cooling water system of a power plant. At the Millstone Point plant (Long Island Sound) three fish species were studied: winter flounder, silversides and killifish. Over 1000 individual measurements were made on each species with temperature increases ranging from 8 to 13°C and from 10 min to 9 hr duration. Fish were observed for two weeks after temperature shock. The silversides and killifish exhibited no significant mortality as result of temperature increases ranging up to 13°C and 9 hrs. The same was true for post-metamorphosis winter flounder. However, pre-metamorphosis flounder of less that 5 mm in length exhibited a high mortality averaging up to 60% of these tested. Thus the stage of development of this fish species is of critical importance in determining its survival. This spring we plan further research on other species.

We have continued our field program of monitoring species and densities of fish larvae entrained through the power plant. We are assessing numbers of fish larvae entrained so that we can model the effect of the power plant on resident Niantic Bay fish. Over twenty fish species are entrained with maximum densities entering in the late spring and early summer. Most numerous fish species are winter flounder, tautog, anchovy and cunner. Fish survival is low after passage through the power plant.

At present we are adapting a ^{14}C-autoradiographic procedure for determining the effect of entrainment on phytoplankton. This technique will allow us to note the effects of entrainment on individual phytoplankton species under various combinations of temperature and chlorination *in situ*.

Additionally, we have studied the effects of entrainment on nitrate reductase activity of phytoplankton. Samples have been taken through the year, and data are now being analyzed. The research provides basic data on effects of light, temperature, NH^+ concentration, and species composition on the activity of this enzyme.

RESEARCH AT MATAMEK, QUEBEC, CANADA, 1974

R. John Gibson

Salmon

1. The main work has been completed on a fish-counting ladder at the first falls by the Quebec Government, and it will be operational next year. The holding pool has to be completed, a lifting floor has to be put in the corner pool to facilitate handling the fish, a cabin or trailer must be made available for a technician, and the area has to be cleaned up and planted.

2. In June, 280 smolt were tagged with Carlin tags. An estimate was made of about 8,000 for the total run.

3. Population estimates of salmon parr, brook trout, eels and suckers, were made in an area of fast water flow adjacent to the second falls, and in a slow deep section 300 m downstream. The number of two-year-old salmon parr close to the falls was about 470 per hectare, and downstream in deep water, there were about 110 per ha. There was no movement of salmon parr between the two areas. Trout and suckers on the other hand moved freely between the two areas.

4. Salmon were recovered from previous plantings in fishless waters. Much of the watershed is above the Labrador escarpment, and due to its glacial history, has no fish. The most numerous recoveries were in a shallow mud-bottomed lake called LO2 or Crosskey Lake, where growth was also excellent. Two-year-old fish here had a mean length of 30.7 cm. Planted fish remained in the lakes, and did not migrate as smolts. In the Tchinicaman River fry were recovered in September at 5.3 cm long weighing 1.7 g. At the same time fry in the main river were on the average 4.3 cm long weighing 0.8 g.

5. Physiological and behavioral work on salmon fry was carried on at Tadoussac hatchery and in the field. This was done as part of the study of stocking salmon into fishless waters, where in some lakes survival was apparently nil, in one it was fair (L. Gallienne), and in LO2 it was good. The work was related mainly to the effects of temperature, oxygen, acidity, feeding, and shock from transport.

6. In the stream tanks at the second falls observations were made on the reactions of salmon parr to changes in water velocity and temperature. In slow water velocities, the aggression decreases, and in very slow flows parr tend to hide amongst rubble, and are attracted to shade. In fast flows aggression increases, and parr are attracted below a turbulent water surface. Around $9^{o}C$ parr move into slow-flowing water, and hide amongst rubble. This explains why in cold water parr are very difficult to find, and then in somewhat warmer water of about $10^{o}C$, as in the spring and late fall, are in pools, roaming around, and then in the warmer water of summertime are found holding territories in faster water velocities.

7. Some scales of juvenile and adult salmon were compared microchemically by electron microscope. The greatest difference was in the sodium content, more than four times as much occurring in the scales of adult salmon.

8. Detailed changes in the skeleton of adult salmon in fresh water through the summer were described.

Trout

A population estimate was made of the trout below the second falls. Also, the trout below the fifth falls were compared with those below the second. The fourth falls from the sea is a barrier to upstream salmon migration, so salmon parr do not occur below the fifth falls. The trout below the fifth falls are fatter for their length than those below the second, with a condition factor of 1.3, compared with 1.1 for those below the second. Also, a higher proportion of trout are mature below the fifth falls, and fecundity is greater than below the second falls. Next year salmon are to be introduced below the fifth falls. The increased production of salmon will be measured, and interactions with the trout followed.

Limnology at Matamek Lake

Studies included: zooplankton; phytoplankton and primary production; physical and chemical characteristics of the waters and sediments of Matamek Lake; and measurements of the bottom profile.

Physical aspect of the Matamek River and watershed.

Physical measurements of the Matamek watershed, and a careful survey from the third falls downstream, were made. This included a depth profile, types of substrate, and water velocities. A preliminary forestry and geological survey of the watershed was also included.

Inverbetrate Studies

A taxonomic survey was made of the caddis flies (*Trichoptera*) of the watershed. These are the principal food of trout and salmon parr. The taxonomy and ecology of the phantom midge larva (*Chaoborus*) was studied in lakes with and without fish.

An ecological study was made of tide pool invertebrates.

ECOLOGICAL GENETICS OF OPPORTUNISTIC AND DEEP-SEA POLYCHAETES

J. Frederick Grassle and Judith P. Grassle*

Our electrophoretic studies have shown that the opportunistic species, *Capitella capitata*, often described as a cosmopolitan pollution indicator species, is a group of sibling species with a remarkable number of life histories and completely distinct groups of enzyme activities at eight genetic loci. In single intertidal and subtidal samples we have found three and four distinct *Capitella* species which differ from one another at some or all of the eight loci examined in each individual. The electrophoretic evidence indicates no hybridization between these sympatric populations. At least some of the species differ in morphology, weight at maturity, mode of reproduction, amount of brood protection and length of planktonic life. The proportions of the several species vary seasonally and from locality to locality.

The past six months have been devoted to a field experiment with Dave Schneider of State University of New York at Stony Brook to determine how genetic variation varies with population size in one of the species.

*Marine Biological Laboratory.

CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT (CEPEX)

George D. Grice

The objective of the CEPEX program is to determine the effect of pollutants on marine ecosystems. As part of this program, we are currently analyzing the results of three experiments conducted from April to October 1974 at the CEPEX site at Sannich Inlet, British Columbia: a replication study; and two copper experiments in which Cu (as $CuSO_4$) was introduced to produce concentrations of 10 and 50 ppb, and 5 and 10 ppb, respectively. The studies were performed in polyethylene cylinders, (CEE's, Controlled Experimental Ecosystems) each containing approximately 66 m^3 of seawater.

The replication experiment was designed to assess the precision and accuracy with which zooplankton population abundance could be estimated within a CEE. Two sampling devices were tested: a 20 cm modified Bongo net (202 μm) for collecting integrated samples from 14 m to the surface, and a Schindler trap for obtaining discrete samples from 14 m, 7 m, and just below the surface. Samples from these two devices were compared with samples collected by pumping all of the water from the CEE through a 202 μm net. Statistical analysis of the samples showed that both Bongo and Schindler samplers provide an acceptable level of precision and accuracy for the determination of population size and fluctuations. It was concluded that Bongo collections are the best means of estimating zooplankton densities in a CEE, while the Schindler trap can be used to investigate vertical distribution and other aspects of plankton patchiness.

Analysis of samples from the first copper experiment has recently been completed. Total counts show that the zooplankton in control CEE's declined during the month-long experiment, probably as a result of grazing by ctenophores and medusae. Zooplankton decrease in the two experimental (10, 50 ppb copper) CEE's was, however, significantly more rapid than in the control CEE's. The effect was more pronounced in the CEE with the addition of 50 ppb Cu than in the one with an addition of 10 ppb.

Diversity indices were computed for all samples, but no significant trends were evident, despite both a marked decline in total numbers and changes in species dominance. Samples were also compared by similarity index. A dendrogram constructed by cluster analysis of similarity coefficients for unweighted paired samples showed that the samples are divided into two groups, polluted and unpolluted. Samples from the two control CEE's, and samples from the experimental enclosures prior to the addition of copper are more closely related to one another than to samples obtained from the experimental CEE's after the addition of copper.

Samples from the second (5 and 10 ppb) copper experiments are currently being analyzed.

Thomas Lawson participated in the field collections and analyses of the results of the replication experiment and Victoria Gibson enumerated the samples and analyzed the results of the copper experiments.

ZOOPLANKTON STUDIES

George D. Grice

Considerable progress has been made toward completing the zoogeographic and taxonomic study of the copepod family Candaciidae in the Indian Ocean. Based on centers of abundance, four patterns of species distribution were recognized: 1) neritic waters north of 10°S latitude, 2) neritic and oceanic waters north of 10°S latitude, 3) neritic and oceanic waters south of the Arabian Sea and Bay of Bengal but north of 35°S latitude, 4) parts of the subtropical gyre enclosing the southern Indian Ocean. Two recurrent groups of species have been identified. One group of three species is generally restricted to north of 10°S latitude. The second group of two species has an overlap of range with the first group in a broad band along the equator. However, the second group is rare in the Arabian Sea and Bay of Bengal and its range extends south to at least 35°S latitude.

Certain of the distributional patterns correlate with environmental parameters such as zooplankton biomass, temperature, oxygen minimum and with certain hydrographic features. For example, some species are most abundant in the upwelling regions while other species appear to have the southern extent of their ranges limited by the 10°S hydrographic front. Still other species may be excluded from certain parts of the northern Indian Ocean because oxygen levels in these areas are too low at depths where the species would normally be found during part of the day. We are presently working on a multivariate analysis of species distributional patterns.

Measurements of 130 morphological characters, including feeding, swimming and secondary sexual appendages, have been completed and species have been taxonomically clustered for each functional set of characters. The recurrence of certain clusters throughout the analysis suggests a degree of phylogenetic kinship among member species beyond simply parallel functional adaptation.

Using morphological correlation as an index of functional similarity and Fager's Affinity Index as a measure of geographical association, we are also investigating the extent to which species may have become morphologically modified or divergent in their environmental adaptations so as to minimize interspecific competition.

We have had good success in our continuing studies on the ecology of *Labidocera aestiva* and the significance of resting eggs of this temperate calanoid copepod. Through laboratory and field studies on the viability and occurrence of these eggs, we have demonstrated that (1) eggs laid by fall females and maintained for six months in the laboratory at temperatures corresponding to the lowest winter water temperature (2° - 3°C) in the Woods Hole area remain viable and readily hatch on being warmed to 19°C, (2) similarly laid eggs kept in small bottles that were suspended beneath the Institution pier through the winter at a depth of 15 m also remained viable and hatched in May when water temperatures were between 11° and 14°C and (3) bottom sediment samples collected in March, the month of minimum water temperatures, contained viable eggs which hatched on being warmed to 19°C. We conclude from these studies that resting eggs are a part of the life history of *L. aestiva* and provide the means whereby this species occurs year around in temperate waters. Thomas Lawson and Victoria Gibson were essential participants in the research described above.

COMPARATIVE ENVIRONMENTAL PHYSIOLOGY OF MARINE PHYTOPLANKTON

Robert R. L. Guillard

Studies of the effects of dissolved hydrocarbons on marine algae have been terminated. A paper was given at the ASLO meetings and will be submitted for publication: Stoll, D. R. and R. R. L. Guillard. Synergistic effect of naphthalene toxicity and phosphate deficiency in a marine diatom.

A second project completed is the determination of the systematic position of an alga that is often abundant in polluted environments; our clone is called "GSC Sticho" from its superficial resemblance to a species of the chlorophyte genus *Stichococcus*. An electron microscope study in collaboration with C. C. Remsen has revealed that the alga has the internal structure of the class Eustigmatophyceae. This plant is the first non-motile and the first marine member of the class to be discovered. A name and description can now be written.

The major new program initiated this year is the study of genetic relatedness among clones of the same species of marine algae isolated from different environments. This work is in collaboration with L. S. Murphy. This promises to be very rewarding and the first results are submitted for publication in a paper of which the abstract follows:

Diatom systematics depends almost entirely upon structure of the silica shell. It is not known to what extent the taxonomic species, as defined by shell structure, corresponds to the genetic species - the reproductively isolated population. As an approach to this problem, we report here a comparison of enzymes by electrophoresis. We have examined the genetic constitution of a number of clones of (presumably) the same species for each of two closely related centric diatom species: *Thalassiosira pseudonana* and *T. fluviatilis*. The four clones of *T. fluviatilis* form a distinct group, clearly separated from all the *T. pseudonana* clones. Within *T. pseudonana*, the four estuarine clones and the one reef clone form a group that is distinctly different from the four oceanic clones. The shelf clone of *T. pseudonana* is intermediate between these two groups and shares genes with both groups, indicating that the two *T. pseudonana* groups are not genetically isolated. We conclude that 1) within groups, isolates are closely related even though they originate from different continents, and that 2) *T. pseudonana* is subdivided into ecological races.

THE ECOLOGY OF SUBMARINE CANYONS

Richard L. Haedrich and Gilbert T. Rowe

We are trying to understand the interrelationships and dynamics in and among the animals living on the deep ocean floor. We have focused first on the faunas of submarine canyons, for, in addition to their inherent interest as major features of the sea bottom, canyons appear to be important conduits for channeling organic material from the continental shelf into the deep ocean. Since virtually nothing is known concerning canyon faunas, we have had to do much of the basic groundwork ourselves and have paid particular attention to quantitative description of the canyon fauna (both invertebrates and fishes), analysis of species associations, charting species distributions, comparing patterns

of biomass, density, and diversity as functions of depth and topography (both in and out of a canyon), and determining life strategies of dominant species.

In 1974 we made two cruises, both in late winter, on the *Knorr* and the *Atlantis II*. These were for sampling in the Georges Bank canyons and in the deep water off Hudson Canyon. Major wire losses on the initial sets of both cruises resulted in no samples being obtained.

Work in the laboratory has been more successful. We have finished identifying the fishes from our late 1973 cruises and all the infauna from grabs made in Hudson Canyon and the Woods Hole deep ocean station. We will soon complete the identification of trawled invertebrates. We have in manuscript a report on the epibenthic macrofauna of the continental slope adjacent to Hudson Canyon. This fauna is zoned with depth, with important breaks at depths of 400 and 1000 m. There is little difference between this fauna and that in the canyon. The fish fauna in the canyon is similarly zoned, and appears seasonally stable. Animal abundance is greater in the canyon, but a parallel decline in numbers is noted with depth both in and out of the canyon. Diversity in the various faunal components follows no set pattern, but appears to be a function of the group examined. Preliminary analyses of the infaunal data indicate that these animals are more abundant within the canyon and are zoned with depth, with possible breaks at 250, 550, 1000, and 1500 m.

When the opportunity became available, we did some limited sampling of selected benthic communities for comparison with the canyon situation. The benthic fauna of deep basins in the Gulf of Maine, which we discuss in a completed manuscript, is low in abundance and biomass, despite the fact that the basins are contained within the extent of the continental shelf. Due to the relatively young geologic age of the basins, the fauna may not yet have achieved equilibrium; the faunal composition resembles that in the canyon but from almost 1000 m greater depth. Two manuscripts report the abundance and biomass of infauna and epifauna in the upwelling area off West Africa. This area of high productivity supports an infauna that is five-to-ten times as abundant as that on the continental slope south of New England, but the epibenthic biomass is rather low.

The rattail *Coryphaenoides carapinus*, which lives on the lower continental slope and rise, is a benthic feeder, taking primarily errant polychaetes and crustaceans, particularly amphipods. With growth, it may augment its diet with ophiuroids. This situation contrasts with that in its two congeners, *C. armatus* (which feeds on larger fish and cephalopods and opportunistically on material from the surface), and *C. rupestris* (which feeds on pelagic crustaceans). The parasite fauna from deep-living benthic fishes turns out to be very abundant and highly diversified; many new taxa have been discovered, and these are being described in a series of manuscripts by Dr. Ron Campbell of Southeastern Massachusetts University. A natural consequence of the presumed environmental stability of the deep ocean is that populations there should be genetically highly monomorphic. Electrophoretic studies of many enzymes, however, reveal considerable polymorphism, comparable to that in terrestrial animals, in both echinoderms and fishes. The work on echinoderms is reported in a completed manuscript, while the work on fishes, a cooperative effort with Dr. Dennis Powers of Johns Hopkins, is continuing.

STUDIES ON SALPS AND OTHER GELATINOUS ZOOPLANKTON

G. Richard Harbison

Feeding and Assimilation in Salps - - *Pegea confererata* has been the salp most extensively studied. Its feeding is disturbed less by confinement than other commonly encountered species. Filtration rates have been measured, using unialgal cultures, by following the decrease in particulate matter with a Coulter Counter. The carbon, nitrogen, hydrogen, protein, lipid, and carbohydrate composition are presently being measured on the algal stocks fed salps and on the feces produced by the salps. Results from experiments using *Thalassiosira pseudonana* indicate that this diatom is not a particularly good food material for *P. confederata*, so we have undertaken experiments using coccolithophores and microflagellates.

Metabolic Studies on Salps - - Respiration and ammonia excretion measurements indicate that most salps have low metabolic rates, with the exception of *Salpa cylindrica*. Enzymological studies indicate that *P. confederata*, like other filter feeders, has a high titer of amylase activity. Other digestive enzymes are currently being studied.

Associations of Hyperiid Amphipods with Gelatinous Zooplankton - - Our work on amphipods associated with salps has shown the need for a thorough taxonomic study of the genus *Lycaea*, before conclusions can be drawn as to host preferences. Four species that have been synonymized with *L. pulex* by earlier workers seem, from our material, to be valid. This and other work has led to a new understanding as to the nature of variability within the genus. Certain members of this genus seem highly selective in their choice of hosts, while others are much less so. All together, we have found four genera of hyperiid amphipods on salps, comprising 13 species. After salps, associations of hyperiid amphipods with siphonophores and medusae seem most varied and rich. We have found six genera and seven species on siphonophores and three genera and six species on medusae. We have also found amphipods associated with ctenophores (three genera, three species), pteropods (one species), radiolarian colonies (one species), and two genera and species free-swimming. The interactions of these amphipods with gelatinous zooplankton range from highly specific parasitism to a rather loose type of predation. Often the coloration of the amphipods mimics that of their hosts, but sometimes it contrasts strongly. Some have appendages that appear to be specialized for life on specific hosts.

The Biology of Siphonophores - - Douglas Biggs continued *in situ* measurements of oxygen consumption by physonect and cystonect siphonophores. This year ammonia excretion by freshly collected animals was also measured, but attempts to hold siphonophores in the laboratory to measure oxygen consumption and ammonia excretion under starvation conditions met with limited success. Since siphonophores do not egest compact and easily collectable feces, laboratory feeding experiments were designed using a C^{14} tracer incorporated in prey organisms. These experiments suggest that assimilation efficiency in these carnivores may be 70% or higher.

PHYSIOLOGY AND ECOLOGY OF MARINE MICROORGANISMS

Holger W. Jannasch

I. Microbial Transformations in Seawater.

(1) Population dynamics of psychrophilic and mesophilic marine bacteria.

Competition experiments have been conducted with bacterial isolates characterized by different physiological responses (growth and metabolic activity) to temperature. Combining varied temperatures with varied concentrations of the energy source, the outcome of successful or unsuccessful competition was studied in series of chemostats. The results bring us closer to explanations and predictions of microbial population dynamics in the sea, i.e., the occurrence, distribution, abundance, and succession of various metabolic types of microorganisms in certain characteristic parts of the ocean. It was found that high substrate affinities (expressed by low K_s values) of mesophilic bacteria (relative slow growth at low temperatures) may overcome the advantage of psychrophilic bacteria (relative fast growth at low temperatures) if the substrate affinities of the latter are low. Work at sea concentrated on the distribution of psychrophilic bacteria in ocean profiles and on some isolations.

(2) The effect of suspended particulate matter on microbial growth.

Marine bacterial isolates have been studied in batch and continuous culture to examine the effects of suspended organic and inorganic particulate matter on growth and metabolic activities. Steady state populations that received a direct injection of clay particles responded with a marked increase in cell density and in the incorporation of ^{14}C-labeled substrate. Populations returned to the original steady state level as the particles were washed out. Growth of non-chitin-degrading bacteria was increased by an addition of homogenized and washed chitin particles in glutamate limited cultures. Short term perturbations in chemostat cultures, shifted to media containing ashed offshore sediment, resulted in a rapid decline in cell density followed by the establishment of the original steady state level. Laboratory studies are being continued in this area examining the variables of particle size, type and concentration in relation to the culture conditions of temperature, dilution rate, oxygen concentration, and substrate type and concentration. Field studies are planned using *Alvin* for determining the *in situ* activities of microorganisms associated with areas of high particulate content in the water column.

(3) Microbial activity in the deep sea.

To obtain additional data on the earlier observed phenomenon of relatively slow microbial activity in the deep sea, the newly developed sampler-incubation chamber was used which retains the *in situ* hydrostatic pressure in laboratory studies. Samples were taken at 1900 m. A second sampler-incubation chamber was built and successfully pressure tested which is capable of being used to depths up to 6000 m. A new strategy for a more efficient acquisition of data was adopted by developing a multiple sampling system consisting of a filtration sampler and a number of transfer units. This will enable us to take up to eight samples per cruise and to free the high-pressure vessels just for the purpose of incubation. Plans are also made to study microorganisms from deep-sea trenches at 1000 atm to obtain pure culture isolates in the absence of decompression.

Co-workers on this project were: Craig D. Taylor, Carl O. Wirsen and Stephen J. Molyneaux.

II. Microbial Reduction and Oxidation of Sulfur Compounds in the Marine Environment

(1) Shipboard Experiments.

Our efforts in 1974 were aimed at perfecting our ability to measure *in situ* rates of sulfate reduction, sulfide oxidation, and dark fixation of CO_2. Results obtained on a cruise to the Cariaco Trench in December 1973 demonstrated the feasibility of *in situ* inoculation and incubation of samples spiked with radioactivity-labeled substrates and suspended on a mooring array. New, automated sampling and incubation chambers are being designed and constructed to allow time-course determination in early 1975. Backup measurements to be done on the ship will permit an evaluation of the results of the *in situ* incubations, particularly the effect of hydrostatic pressure.

(2) Incomplete thiosulfate oxidation by heterotrophic marine bacteria.

The basis for growth stimulation by the oxidation of thiosulfate to tetrathionate in two representative strains of marine pseudomonads was investigated by studying the incorporation and respiration of ^{14}C-labeled organic compounds in the presence or absence of thiosulfate. The oxidation of thiosulfate was accompanied by an increase in the amount of glucose or acetate incorporated, but a decrease in the amount respired. The total amount of the organic compounds metabolized remained constant. In agreement with the previously observed thiosulfate-stimulated growth, the increase in the ratio incorporation: metabolism (metabolic ratio) was greatest near the pH optimum for thiosulfate oxidation.

We attempted to uncouple the metabolic ratio increase from thiosulfate oxidation in intact cells with 2, 4-dinitrophenol or carbonyl cyanide m-chlorophenyl hydrazone. The results of these experiments demonstrate that the incomplete oxidation of thiosulfate by certain marine bacteria can allow more efficient use of available organic carbon, thereby enhancing the survival potential of these microorganisms in parts of the oceans where reduced sulfur compounds are present.

(3) Dissimilatory reduction of inorganic sulfur intermediates.

Our studies on the dissimilatory reduction of inorganic sulfur compounds other than sulfate by newly described facultatively anaerobic marine bacteria have been continued. A detailed study of the kinetics of formation of inorganic sulfur intermediates during anaerobic growth with a variety of inorganic sulfur compounds supplied as electron acceptors revealed the following conversions: (i) tetrathionate reduction quantitatively to tetrathionate; (ii) trithionate reduction to equimolar sulfite and thiosulfate; (iii) sulfite reduction to thiosulfate through trithionate; and (iv) thiosulfate reduction to sulfide and trace sulfite. These reactions are similar to the transformations carried out by the obligately anaerobic sulfate-reducing bacteria of the genera *Desulfovibrio* and *Desulfotomaculum*. Comparisons of growth rates and cell yields indicated that tetrathionate and thiosulfate were the electron acceptors of choice. The pathways of inorganic sulfur metabolism were unaffected by the organic electron donor used. The widespread occurrence of these facultatively anaerobic bacteria at the oxygen-sulfide interfaces in anoxic marine basins may imply a cycling of inorganic sulfur compounds without the formation of sulfate.

(4) Tetrathionate reductase (TTR) and thiosulfate oxidizing enzyme (TSO).

TTR catalyzes the reduction of tetrathionate to thiosulfate under anaerobic conditions; TSO mediates the oxidation of thiosulfate to tetrathionate under aerobic conditions. Until our recent discovery of both enzyme activities in certain marine pseudomonads, TTR had been primarily associated with species of the *Enterobacteriaceae*, commonly part of the intestinal microflora of man, while TSO activity had been found in the thiobacilli and in several terrestrial pseudomonads. It is not presently known whether these activities represent opposing functions of the same enzyme, or two distinct enzymes. Several of our marine isolates provide excellent models to study these reactions since they can carry out both thiosulfate oxidation and tetrathionate reduction. Control of these activities by environmental conditions may also be important to biological sulfur turnover at oxygen-sulfide interfaces in the oceans. Preliminary to cell-free studies, we investigated the formation of TSO and TTR activity in intact cells as a function of growth conditions. The results of temperature optima, pH optima, cyanide inhibition, and thiosulfate inhibition experiments on one of our isolates suggest that it has one constitutive TSO enzyme, but two distinct TTR activities, one of which is inducible and not associated with the TSO enzyme.

Co-workers on this project were: Jon H. Tuttle, Craig D. Taylor and James D. Flanagan

ELECTRORECEPTION IN ELASMOBRANCH AND HIGHER BONY FISHES

Adrianus J. Kalmijn

Sharks and rays are extremely sensitive to weak electric fields, responding to voltage gradients as low as 0.01 μv/cm. The sense organs mediating the electrical responses are the ampullae of Lorenzini, which are characteristic of elasmobranch fishes. Marine animals produce local bioelectric fields in seawater. Sharks and rays take advantage of these fields and use them in locating and cueing in on their prey. Electric fields induced by water flowing through the earth's magnetic field may inform sharks and rays of upstream and downstream directions of open-ocean currents. Sharks and rays may also sense the actual compass directions from the electric fields they induce by actively swimming through the earth's magnetic field. The main topics of investigation are:

1. the electric fields in the animals' natural habitat,
2. the possible biological significance of the various fields, and
3. the physics and physiology of electroreceptor systems.

Parallel to the shark work, comparative studies are performed on the electric sense in catfish, weakly electric fish, and other bony fishes.

Since our move from Scripps Institution of Oceanography to Woods Hole Oceanographic Institution, we have worked on selecting a location for, and on the design of new Shark Research Facilities at Quissett Campus. The location is dictated by the requirements of (1) minimal electromagnetic interference, and (2) a virtually undisturbed earth's magnetic field. The Shark Research Facilities will offer unique opportunities for well-controlled experiments on the electric sense of elasmobranch fishes. Eventually, the biological validity of the outcome will be tested in the animals' natural habitat, the ocean.

Duane D. Banashak is Assistant to this project. An extensive report on the Principal Investigator's work and its relations to other studies in the field of electroreception is given in: Kalmihn,Ad.J. The detection of electric fields from inanimate and animate sources other than electric organs. In: Handbook of Sensory Physiology, III/3, A.Fessard,Ed.,pp.148-200. Springer Verlag: Berlin-Heidelber-New York 1974.

BIOLOGICAL INSTRUMENTATION

John W. Kanwisher

This year has allowed us to complete most of the instrument development we have had underway. It has also been a time for writing and publishing. Among the specific projects are the following:

We have brought electromagnetic flow sensors to a stage where they are routine in application. One of them has shown the variable flow in a plankton net and allowed its redesign. Others have been tested for stream flow monitoring and as a speed element on a submarine. We still think their use in current meters will be rewarding. For that purpose we have redesigned the circuits to the necessary low power level.

As an adjunct to the sensor we have developed a magnetometer compass at an equally low power level. This will find use wherever remote indication of direction is important. An example is the monitoring of a coring tube as it penetrates.

Our attempt at an updated particle counter for *in situ* plankton studies was unsuccessful. We had not predicted the large sensitivity of the instrument to temperature gradients. We hope such false counts can be eliminated by a new cell design.

Most of our electronic work has involved circuit development around the new solid state devices which allow power levels to be reduced 10 to 100 times. This permits these circuits to be used in all manner of battery-operated field instruments. We are collecting this in a manual form for others to apply.

My past physiology, mostly on fish, has been digested and four papers published or in press. We have completed a study of human diver monitoring. As an extension of this I am working with a U.S. Navy medical research group to make the method routine in diving.

This fall I have been updating telemetry methods which I will use in behavioral physiology work at the new seawater facility.

CAPE COD WASTE WATER RENOVATION AND RETRIEVAL SYSTEM

William B. Kerfoot and Bostwick H. Ketchum

The past year marked the first year of operation of a pilot facility at Otis Air Force Base designed to provide scientific answers and guidelines to current and future problems of water quality management of insular water basins in the coastal Northeast. The three-year plan involves investigation of the *in situ* performance of (1) the existing sand filter bed method of wastewater disposal at Otis Air Force Base, (2) a rapid infiltration system designed to enhance biological denitrification, and (3) spray irrigation-cropping programs. For convenience, the summary is divided into two sections, construction and operation of facilities and site investigations.

Construction and Operation of Facilities

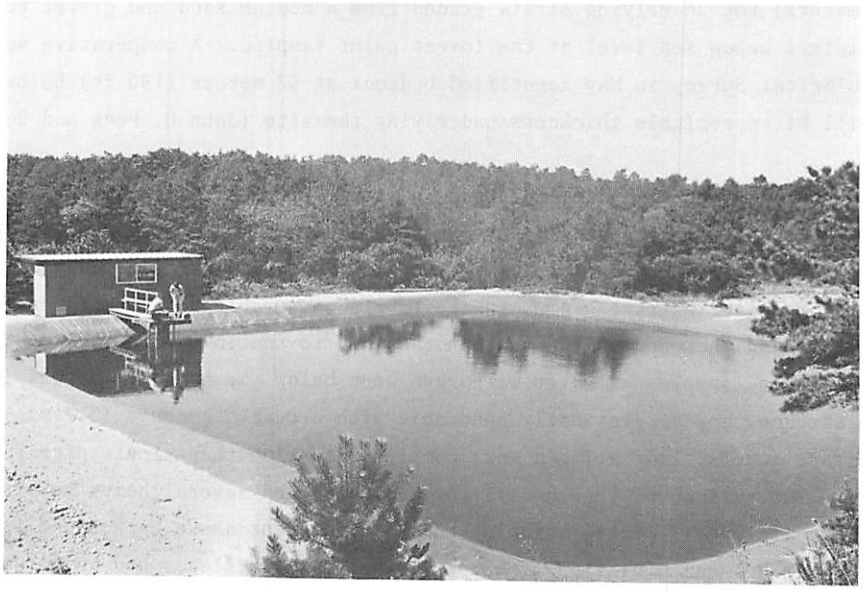
During December of the previous year and into 1974, experimental fields were cleared, prepared and set to winter rye for erosion control. Nine polyvinyl chloride (pvc) monitoring wells penetrating the upper two meters of the groundwater surface were installed. From March to May, an abandoned sand filter bed near the treatment plant was modified for a 100 x 100 ft lagoon, a pumping control system designed, and 2400 feet of force main and associated manholes installed on both agricultural plots, stationary sets of high pressure (50 psi) impact sprinklers on site A and a rotary center pivot low pressure irrigator (8 psi) on site B (see P. Kallio, Ocean Engineering). The hydraulic experimental area (site A) was seeded with reed canary grass, fertilized to establish the seed, then irrigated with hydrant water placed in the lagoon. The vegetative study area (site B) was seeded to four crops (reed canary grass, timothy grass, timothy and alfalfa, and smooth brome grass). A large trailer housed the field laboratory near the site.

Irrigation with lagooned secondary effluent began on July 17 on both experimental plots after extensive experience with irrigation of hydrant water. By September, the agricultural fields required harvesting. Irrigation of the fields ceased September 5 to allow adequate drying. From September 16 to 19, the fields were cut, raked, and baled. Following inspection of the operating data, sale of the hay was approved by the Department of Public Health as mulch or feed for horses. Thirty-two bales were sold at $.50 each for use as mulch.

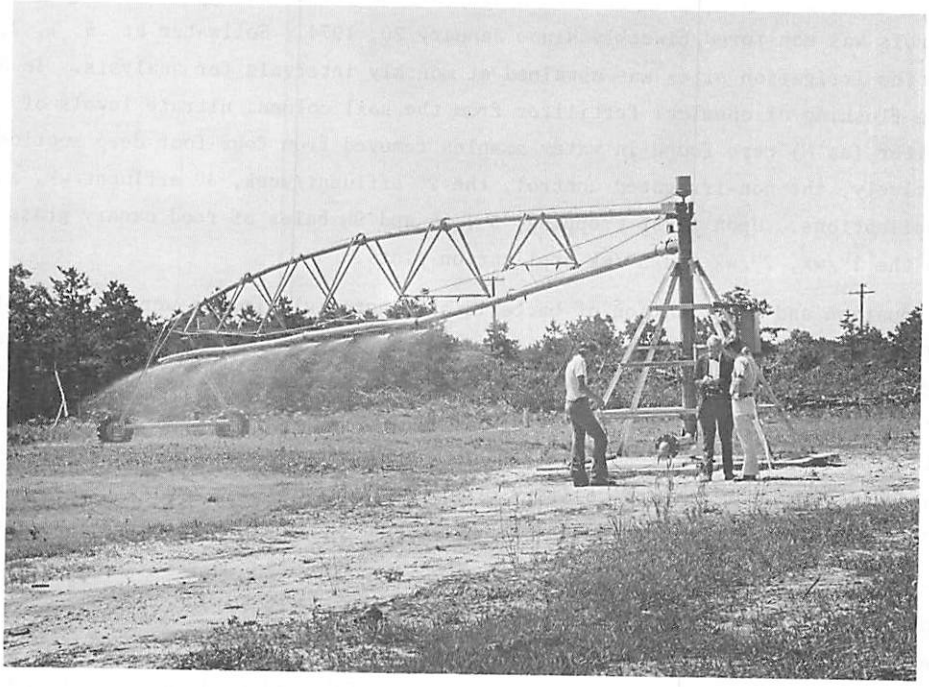
During October, work began on equipping the field laboratory with water and sanitary facilities. A retrieval well was completed behind a sand filter bed as part of the feasibility study of underground effluent storage prior to irrigation. Five additional monitoring wells were also established further downwater of the present sand filter bed discharge region.

Site Investigations

An intensive study of the geological, groundwater, and hydrological characteristics of the site continued through 1974. Soil cores to a meter depth were taken over the project area. Subsequent analysis of the cores of Enfield sandy loam for iron and aluminum oxides and associated phosphate fractions indicated a fixation potential for a two-inch (5 cm) soil layer equivalent to 185 weeks of application of two inches of effluent applied weekly with a mean content of 8 mg P per liter. Sections of a deep geological core to the vicinity of bedrock were analyzed and presented in the Technical Report WHOI-74-13 (Kerfoot and Ketchum, 1974). Beyond a surface deposit of sandy loam soil



The lagoon and pumping control station.



A rotary center-pivot irrigator on the agricultural experimental plot.

(two and three meters) the underlying strata graded from a medium sand and gravel to a fine and medium sand 45 meters below sea level at the lowest point sampled. A cooperative seismic study with the U.S.Geological Survey in May identified bedrock at 57 meters (190 ft) below sea level with no impervious till of appreciable thickness underlying the site (John H. Peck and Curtis R. Tuttle, 1974).

Two wells installed in the sand filter beds in January revealed high initial levels of nitrate, 54 and 42 mg/liter (as N). An exponential drop occurred with time to levels of, respectively, 3.4 and 10 mg/liter in early July until the beds were again inundated with secondary effluent, causing a rise to above 15 mg/liter nitrate and phosphate levels comparable to the effluent (6 mg/liter). The elevated nitrate and phosphorus levels are not unique to the immediate region of the beds but extend beyond. However, samples of water withdrawn deep below the beds, 12 meters (40 ft) beneath the groundwater surface, appear distinctly anaerobic with elevated ammonia (3.7 mg/liter) and phosphate (4.4 mg/liter) levels, indicating a more complex situation than simple nitrification of recharged effluent. The surface of the sand filter bed contained several heavy metals in excess of normal background soil levels. Integration of the total content above background in the upper 56 cm (22 in) indicated an accumulation of copper, zinc, cadmium, lead, and chromium to, respectively, 5.04, 1.63, .042, .050, and .044 gm.

The quality of the effluent, lagooned effluent prior to and after chlorination, groundwater underlying the irrigation sites, water from nearby Ashumet Pond and tap water from Otis and Woods Hole as controls was monitored biweekly since January 20, 1974. Soilwater at .5, 1, 2, 3, and 4-ft intervals on the irrigation sites was obtained at monthly intervals for analysis. In November, following the flushing of chemical fertilizer from the soil column, nitrate levels of .2, 1.5, 3.5, and 8.5 mg/liter (as N) were found in water samples removed from four-foot deep suction lysimeters from, respectively, the non-irrigated control, the 2" effluent/week, 3" effluent/wk, and 1" effluent/wk applications. Upon first cropping, 5½, 6¼ and 9½ bales of reed canary grass hay were removed from the 1"/wk, 2"/wk and 3"/wk application plots.

The attenuation and inactivation of bacteria and bacterial viruses were studied at various steps during operation of the existing plant, during recharge using the sand filter beds, during lagoon storage, during chlorination, and at the irrigation site. Addition of high concentrations of MS_2, a 200 Å bacteriophage, to the effluent showed a thousand-fold decrease (3 log) during recharge of the sand filter beds. The rate of attenuation of phage during winter storage of effluent in the lagoon proceeded slower than that of coliform organisms (as total and fecal). Gas chlorination of the lagooned effluent at 5 ppm chlorine dosage reduced the phage level over a million-fold (6 log).

A hydrological simulation model was prepared for the area of the sand filter beds and directly south of the discharge. The model employs a modification of a model developed by Pinder and Bredehoeft, as performed by Peter C. Trescott, and was successfully adapted to the Institution computer system. The initial grid consisted of ten nodes on a side, including the nearby Ashumet Pond. Values of head, hydraulic conductivity, thickness of the saturated zone, annual rainfall, and

evapotranspiration are being gathered for each grid point. The basic model will eventually serve as the functional coordinate system for predicting long-term groundwater chemical equilibria for different renovation alternatives.

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

Frank J. Mather

The objectives of our program are to continue obtaining data on the basic life history and fisheries of the Atlantic tunas, billfishes and greater amberjack, *Seriola dumerili*, and to analyze and to publish on the extensive data collected.

In response to the concern which arose subsequent to our presentations on the bluefin tuna, *Thunnus thynnus thynnus*, situation in the Atlantic in 1973, the National Marine Fisheries Service (NMFS) has initiated an intensive investigation of this species. We are associated in this effort on a contractual basis.

The Cooperative Game Fish Tagging Program is now being conducted jointly with the Southeast Fisheries Center of NMFS at Miami. The results of this program in 1974 have been good. As of early December, we had recorded over 3,175 releases and 157 recaptures of various species of fishes. These figures bring the cumulative totals to nearly 48,600 releases and 3,379 returns, giving an overall return rate of seven percent. The 1974 releases (denominators) and returns (numerators) for the respective species of interest, with the cumulative totals shown in parentheses were as follows: bluefin tuna, 104/1746 (2502/13477); skipjack tuna, *Katsuwonus pelamis*, 0/15 (85/2386; white marlin, *Tetrapturus albidus*, 7/268 (166/9600); blue marlin, *Makaira nigricans*, 1/88 (7/972); sailfish, *Istiophorus platypterus*, 12/658 (120/14530); greater amberjack *Seriola dumerili*, 25/131 (437/3653; and other species 8/269 (62/3981). Cooperating sport fishermen using equipment furnished by WHOI and NMFS continue to carry out the majority of these taggings.

Bluefin tuna tagged in 1974 include 1,705 small individuals and 41 giants. The results have provided further information on migratory tendencies and the structure of the stocks. To date we have six definite and one probable recaptures of giant tuna and 98 recaptures of school tuna. All but two of the school tuna were recaptured in the general release area off the northeastern United States, with the longest time at large being 1,466 days for a fish released as a one-year-old in August 1970. The two distant recoveries gave the first indication of winter habitats of these smaller bluefin. Both fish were recaptured over 200 miles east of Nantucket Island in January,

1974. The first had been released in July, 1972 off Virginia and the other in August, 1973, off New Jersey. In addition, we have recorded the first Western Atlantic recovery of a fish tagged at age 0. Released in October, 1973 at 44 cm, it was recaptured in the same general area off New Jersey in August, 1974, measuring 58 cm. Four of the six giant recoveries traced long distance migrations while the other two were local returns in Massachusetts Bay. Two of these returns were from fish released in the Bahamas in June 1973. One was recaptured off Gloucester, Massachusetts in July giving the first concrete evidence of Bahama fish entering the coastal fisheries for giant bluefin off New England and Canada. The other was recaptured off Norway in September, the second such return in as many years. The two others were from fish released off Newfoundland in August, 1970. These were both recaptured in July - one off Nova Scotia and the other off New England.

Length frequency data was collected from over 6,300 small bluefin taken in the purse seine fishery from Cape May, New Jersey to Cape Cod, Massachusetts. Information on the sizes of the larger bluefin taken by various methods between Cape Cod and Newfoundland was obtained from various sources. The average size of the giants taken in this area continues to increase and there are still no significant numbers of medium-sized fish (75-275 lbs) appearing in catches.

Frank Mather presented reports on "Trends in bluefin tuna catches in the Atlantic Ocean and the Mediterranean Sea" (Mather) and "U.S.Atlantic bulefin tuna tagging - October 1971 through October 1974" (Mason) at the Joint Meeting of the Bluefin Tuna Working Groups of ICES[1] and ICCAT[2] in Copenhagen in September and at the meeting of the ICCAT Council in Madrid in November. The ICES-ICCAT Working Group recommended a short-term reduction of fishing intensity on giant bluefin and long-term reduction in purse seine fishing of young fish. The ICCAT Council passed, for a mail vote by the nations comprising the Commission, a United States proposal for a minimum size limit of 6.4 kg for the Atlantic bluefin tuna fisheries, and a one-year moratorium on increasing fishing mortality of larger bluefin.

White marlin taggings were disappointingly few with only 268 releases and 7 recaptures reported to date. This is a cause for concern as overall catch rates for this species by the Japanese longliners continue to decline. A concerted effort to encourage sport fishermen to tag and release more of their catches seems necessary.

Blue marlin releases total 88 and one recapture has been reported. This fish was released off the Virgin Islands in November, 1969 and the tag was recovered in a Japanese fish-processing plant. The fish was taken in 1974 but no other data were available. Atlantic longline catch rates for this species have declined even more than those for white marlin. Increased tagging of small blue marlin is urgently needed.

Sailfish returns in 1974 have reached 12 and 658 releases have been reported. Eleven of the twelve recaptures occurred in the same general release area off southeastern Florida and the Florida Keys. The other was recaptured in August off the coast of Cuba 540 days after being released in the Florida Keys.

[1]International Council for the Exploration of the Sea.

[2]International Commission for the Conservation of Atlantic Tunas.

One hundred and thirty-one releases and 25 recaptures of greater amberjack have been reported this year. The two longest migrations recorded this year were from releases off Miami, Florida, in May, 1971, and Mayport, Florida, in June, 1971, and recaptures off Jacksonville, Florida, in May, 1974, and Topsail Island, North Carolina in October, 1974, respectively.

FUNCTIONAL AND STRUCTURAL ASYMMETRY IN MEMBRANES OF MARINE PHOTOSYNTHETIC BACTERIA

Charles C. Remsen

During the past year, with continued technical support by Brian Schroeder and Lyn Miller, and by Dr. Edward Gonye, a Postdoctoral Investigator, we have been examining the structure and protein composition of sulfur granule membranes and photosynthetic membranes of the marine photosynthetic bacterium, *Chromatium buderi*.

The results of our gel electrophoresis work, together with the many electron microscopic studies that we have made, suggest quite strongly that the sulfur granule membrane of *C. buderi* consists of a single protein. However, this protein is not unique to the sulfur granule but can be traced to the chromatophore and perhaps to the cell envelope. The question of a "unit" or a "non-unit" membrane is even less clear. The sulfur granule of some *Chromatium* species appear to have a unit membrane in thin sections. However, we have not been able to demonstrate a unit membrane in *C. buderi* or in the non-photosynthetic sulfur bacterium *Thiovulum majus* Hinze (unpublished data). In this respect the sulfur granule boundary is analogous to gas vacuoles and polybetahydroxbutyrate granules. It is difficult to imagine how a single protein species could be structured into a unit membrane. A simple boundary layer for cell processes which are primarily concerned with storage rather than complex metabolism is more easily visualized. A basic protein framework would still allow for a small number of enzymatic attachment sites to convert the sulfur into the soluble sulfate, which then can move freely throughout the cytoplasm and out of the cell.

Our findings are in agreement with those of other investigators that the sulfur granule is a storage depot or staging area for subsequent sulfur metabolism. Additionally we have found that the sulfur granule membrane develops as a resistant protein from the chromatophore and probably the cell envelope (cytoplasmic membrane). The sulfur granule membrane is not synthesized *de novo* but is present in the initial membrane fraction and could develop in response to latent degradative enzymes triggered by a critical level of sulfur intermediates from the conversion of sulfide to sulfur. It is our hypothesis that in those genera of *Chromatiaceae (Thiorhodaceae)* that accumulate sulfur inside the cell, sulfide is trapped inside the chromatophore as it is formed, thus providing a source of reducing power for photosynthesis. As the sulfide is oxidized to sulfur, the chromatophore becomes less efficient as a photosynthesizing unit until the point is reached where it is no longer functional and becomes, instead, a small sulfur storage granule. This is accompanied by a conversion from a unit membrane structure (chromatophore) to a non-unit membrane structure (sulfur granule). This, in effect, places a definite life-time on the chromatophore vesicle,

a fact which would account for the continual formation of chromatophores during its growth phase under light conditions. Once the chromatophore has lost its photosynthetic capabilities due to the utilization of sulfide and the accumulation of sulfur, it then has a tendency to coalesce with other similar chromatophores and form the large sulfur granules that become quite apparent in these cells.

There is still a great deal of confusion as to whether the chromatophore vesicles in the *Chromatiaceae* remain connected to the cytoplasmic membrane as has been shown for the *Rhodospirillaceae*, or whether they are discrete vesicles, no longer attached to the cytoplasmic membrane. According to our hypothesis, there is a correlation between the formation of discrete chromatophore vesicles, intracellular sulfur deposition, and sulfur granule genesis.

A manuscript entitled "Sulfur granule genesis in *Chromatium buderi*" and describing these results is currently being prepared for publication. In addition, an invitation has been accepted to write a chapter entitled "Comparative subcellular architecture of photosynthetic bacteria" to be included in a treatise entitled "The Photosynthetic Bacteria", edited by R. K. Clayton and W. R. Sistron and to be published by Plenum Press.

RESPONSES BY OPEN-OCEAN MICROORGANISMS TO ENVIRONMENTAL POLLUTANTS

Charles C. Remsen

In our continuing study on the effects of environmental pollutants on open-ocean microorganisms, we have collaborated quite closely with members of the Chemistry Department, specifically Drs. Vaughan T. Bowen and George Harvey, and ably supported by Linda B. Graham, Lolita D. Suprenant, Anne C. Collins and others.

Our primary concerns this year have focussed on two major efforts. Firstly to describe, in some detail, the effects of bacteriostatic and sublethal concentrations of polychlorinated biphinols (PCB) reported for oceanic waters (Harvey *et al.*, 1973, Science 180). It is also apparent that sensitivity to PCB follows an inshore-offshore gradient similar to that shown by Fisher *et al.*, 1973, Nature 241).

The lack of growth of some organisms exposed to 1 ppb of the various Aroclor mixtures is significant in that this is within the range of concentrations found in open ocean waters, and 100 ppb is within the range of concentrations found in surface slicks in open-ocean waters. There also seems to be some correlation with lack of sensitivity to PCB with organisms isolated from surface slicks. Only 13.5% of the surface slick organisms tested showed sensitivity to PCB in replicate plating experiments, while nearly three times that number, or 33% of the organisms isolated at various depths from 1 m below the surface down to 250 meters showed sensitivity to PCB in the same exposure experiments. Surface slick organisms may thus have become acclimated to the higher concentrations of PCB and other chlorinated hydrocarbons which seem to accumulate in the surface slicks on open-ocean water.

For the most part, bacteria exposed to PCB in liquid culture showed effects at concentrations several orders of magnitude lower than that shown in the replicate plating experiments. This

increased sensitivity to PCB in liquid culture was to be expected since one is observing more subtle effects on growth rather than the bacteriostatic effect one would pick up with growth on solid media.

A number of reports have indicated that sublethal effects of PCB have a direct correlation with chlorine content, while the lethal effects appear to be conversely correlated. Our data would appear to corroborate this in that the bacteriostatic effect noted in the replicate plating experiments were most often attributed to Aroclor 1242 while sublethal effects on growth rate and pigmentation were more often associated with lower exposure doses of Aroclor 1254 and 1260. Why this is the case is not absolutely clear; however, it has been shown previously that lower chlorine PCB's are more easily degraded or metabolized. This means that the PCB residue tends to be more similar to high-chlorinated types of PCB (regardless of the percent chlorine of the original PCB input) because the small amounts of the high chlorinated homologies also present are more slowly broken down, and thus will eventually dominate.

Our ultrastructural studies on Acantharia and Foraminifera continue and we are now beginning to have a better idea on the cellular organization of these organisms. We have completed studies on two organisms, *Globeriginoides* c.f. *trilobus* and *Amphistaurus complanatus* and are now in the process of preparing manuscripts for publication.

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THE ROLE OF SUSPENDED PARTICLES AND MICROORGANISMS IN THE TRANSFER AND CONCENTRATION OF ENVIRONMENTAL POLLUTANTS

Charles C. Remsen

In collaboration with Dr. George Harvey of the Chemistry Department we have continued our studies on how organic pollutants move through the complex marine environment. Questions of particular importance to this research are the following: a) How are PCB and DDT transported within the sea, and what is the role and effect of microorganisms on transport? b) Is PCB degraded by microorganisms; if so, to what extent? and c) Do PCB and DDT establish an equilibrium concentration between the dissolved and adsorbed states, or, is adsorption an irreversible process?

We have found that when PCB is allowed to distribute between water and suspended matter the PCB prefers the latter by about 500,000 to 1 on an equal weight-to-weight basis. Furthermore, the capacity of the suspended matter is 5-10 parts per million of PCB. These experiments thereby demonstrated that microorganisms can become exposed to enormous localized concentrations of PCB while attached to suspended particles in the ocean.

The first evidence of any degradation of PCB in a marine system has been discovered by isolating an acidic metabolite of a PCB from aerobic seawater-sediment-microbial culture in the laboratory. Since previous attempts to find PCB metabolites in marine fish were unsuccessful, micro-

organisms may be the only marine organisms capable of degrading this class of pollutant. By using a radioactive PCB as a tracer we discovered that a mixed population of marine microorganisms incubated in an aerobic culture system will metabolize about 5% of the PCB to an unknown acid. No metabolism occurred under anaerobic conditions and no radioactive carbon dioxide was generated in either system. We now have enough of this metabolite in hand to determine its molecular structure. Once the structure is determined we can measure its concentration in the sea to determine where PCB is being degraded by microorganisms, and to what extent.

SEDIMENT-FAUNA RELATIONSHIPS ON THE DEEP-SEA FLOOR

Gilbert T. Rowe

The abundance and biomass of organisms on the deep-sea bottom are extremely low and growth and metabolic rates are very slow, compared to shallow water. This is believed to result from the paucity and poor quality of detrital organic matter that reaches the bottom. The effects that the sparse biota has on the physical and chemical characteristics of sediments, however, appear to be accentuated in the deep-sea because of slow sedimentation rates. We are investigating how this intensified reworking affects the sediment physical and chemical properties at the sediment-water interface.

The most useful new method we have initiated this year has been conceptual modelling and computer simulation of biological processes in surface sediments. We can picture any particular non-conservative element, such as nitrogen, as compartmentalized in its various forms within and between different organic and inorganic states. These "state variables" change in time and with depth in the sediment, according to the physical conditions we impose and our assumptions about the rates of conversion from one variable to another. The deep-sea, relative to shallow water, has an environment that is physically static and seasonless, except for, we presumed, the influx of organic matter from above. We therefore have used the sedimentation rate of organic nitrogen as an external "forcing function". The change of each state variable (living and detrital organic nitrogen, nitrite, nitrate and ammonium ion) with time is the sum of all the fluxes into each particular form minus the conversions from that state into others. Simultaneous solution of all the differential equations representing each variable provides estimates of the concentration of each form of nitrogen with time after initiation.

In environments without macroinvertebrates, movements between the artificially defined layers of the model are dependent on diffusion alone. With invertebrates, rates of movement are much more dynamic. The models have allowed us to estimate, roughly, the rate at which organic matter is remineralized into forms useful as plant nutrients.

In our deep-ocean investigations, we now have evidence that large quantities of shallow water grasses and benthic macroalgae are moving with bottom currents and sediments down several submarine canyons off Puerto Rico and in the Bahamas. Knowledge of the rates at which this enters the deep ecosystem would allow our model to estimate the effects of such overloads of the "forcing function" on gas and dissolved nutrient production and surficial sediment mixing.

ECOLOGICAL EFFECTS OF THE DISPOSAL OF BALED SOLID REFUSE IN THE SEA

Gilbert T. Rowe and Charles H. Clifford

A small reef of bales of shredded, compacted, urban refuse was constructed three years ago in Great Harbor, at Woods Hole, Massachusetts, to determine its effects on the surrounding environment. During summer months the reef generated gases, visible on calm days as bubbles on the surface. The microbial activity generating the gases also utilized oxygen at high rates, but no depletion in the water could be detected, due to the rapid mixing around the reef. The bales remain in place and intact, with the exception of the split end of one bale, presumably ripped off by an anchor. The surface of the bales serves as a substrate for many epibenthic organisms which then fall prey to vagrant foragers and predators coming in and out of the reef's environs. We found no evidence of coliform bacteria in the reef material and no evidence that heavy metals were being released.

A single bale, weighing almost two tons, was deployed offshore, at a depth of 1800 m two years ago. The bale, relocated this year, remains intact and apparently physically unchanged by its two-year stay in deep water. Biological activity in and on the bale appears to have been slight compared to that associated with the bales in shallow water.

CARBON, NITROGEN AND PHOSPHORUS CYCLES ON THE SEA FLOOR OF AN UPWELLING REGION

Gilbert T. Rowe and Kenneth L. Smith, Jr.

The purpose of this research is to determine the degree of coupling between biological and chemical processes in sediments and the intensity and variability of productivity in the water column in areas of intense upwelling. We have approached the problem with traditional sampling to describe benthic community structure, *in situ* measurements of sediment oxygen demand and nutrient release, and a numerical simulation of the sediment nitrogen cycle.

During March, April and May of this year a major expedition (JOINT I) was undertaken by the entire Coastal Upwelling Ecosystem Analysis (C.U.E.A.) group. The work utilized three major U.S. research vessels, including our own *Atlantis II*, an aircraft and a satellite, to collect information on the upwelling system off Spanish Sahara and Mauritania, of northwest Africa. During the expedition, the Woods Hole Oceanographic Institution component, responsible for the sediments and benthos, worked out of the Mauritanian port of Nouadhibou, on their fisheries research trawler *Almoravide*, as well as on the *Atlantis II*.

A free-falling, instrumented tripod and several diver-placed bell jar enclosures allowed us to measure sediment oxygen demand and nutrient release close to shore, just off Cap Blanc. A double-spade box corer, designed and built by Ted Young for this project, was used by Charles H. Clifford to collect pore-water samples over a grid encompassing the major upwelling. The nutrient concentrations in the sediment pore water was one to two orders of magnitude higher than in the overlying water, suggesting that considerable remineralization occurs in the sediments and they

may act as a feedback mechanism for recycling some fraction of the nutrients within the system.

Other W.H.O.I. investigators involved in JOINT I with us on the *Atlantis II* were Richard L. Haedrich (fishes), who was Chief Scientist during leg 4, Pamela A. Polloni and Jean Nichols-Driscoll (invertebrates), Stanley W. Watson and associates (microbiology) and John D. Milliman (sediments).

Biomass of the benthos, including the fishes and macrofaunal invertebrates, was relatively high compared to coastal zones without upwelling. A peculiarity was the relatively even distribution of biomass and organic matter in sediments, compared to typical, non-upwelling regions where biomass drops exponentially with increases in depth and distance from shore. We tentatively attribute this to the combination of horizontal advection and the persistence of the northwest African upwelling along the continental shelf margin, rather than nearshore.

WASTE RECYCLING AND AQUACULTURE

John H. Ryther

The Environmental Systems Laboratory was completed and commenced operation in the late fall of 1973. The facility, in addition to a modest laboratory building, consists of: six 50'x50'x3' (deep), 35,000 gallon algae ponds, five 40'x4'x5' (deep) cement raceways, and three 40'x8'x5' (deep) cement raceways. The seawater system is capable of delivering in excess of 650 gallons per minute to the laboratory, the algae ponds, and the raceways. The contents of two of the algae ponds and the seawater feeding the laboratory and all raceways may be heated to 20^{o} above ambient, 200 gallons per minute of the incoming seawater may be filtered through 20 μ sand filters, and all of the aquatic systems may be aerated. Three 8,000-gallon fiberglass tanks, buried behind the laboratory, serve as reservoirs for sewage effluent or other nutrients that may be pumped to headboxes in the laboratory and thence distributed to the ponds or raceways.

Starting in November, 1973, the two heated algae ponds, operating at about 15^{o}C, were fed filtered seawater initially enriched with chemical nutrients (ammonium chloride and sodium phosphate) and later mixed 50:50 with secondary sewage effluent from the Town of Wareham, Mass. These ponds developed dense cultures of the diatom *Phaeodactylum tricornutum* (10^{6}-10^{7} cells/ml, 15-20 mg organic carbon/liter) which have persisted throughout the year except for a brief period in August during maximum water temperatures, when the diatom was replaced by a small, green alga (*Stichococcus* sp.). These large, continuous-flow cultures were exchanged at the rate of 25% of their volume per day throughout the winter and increased to 50% of their volume per day in April, when artificial heating was discontinued. At that time, cultures enriched with chemical nutrients were started in the four unheated algae ponds and were operated in the same mode. All pond cultures consisted of *Phaeodactylum*, except as noted above. Repeated attempts to inoculate with or select for other species of algae (by varying nutrients, temperature, exchange rate, circulation, aeration, etc.) proved unsuccessful. Species control remains a major problem that will receive top priority in the coming year.

Three hundred thousand seed oysters (*Crassostrea virginica*) were stocked in trays in two of the raceways in November, 1973, and 150,000 seed hard clams (*Mercenaria mercenaria*) were stocked in another raceway in January, 1974. These have been fed the 9,000 - 18,000 gallon/day harvest from each of the algae ponds mixed with varying amounts of filtered and (in winter) heated seawater. Growth of the shellfish has been relatively slow (from 2.7 to 4.1 cm for the oysters and from 1.5 to 2.1 cm for the clams by October, 1974) and some mortality of the oysters was experienced, due it is believed to the exclusive diet of *Phaeodactylum*.

Other animals including the deposit-feeding polychaete worms, *Capitella capitata* and *Nereis virens* and various amphipods and isopods were added to the raceways to feed on the shellfish deposits, and 500 juvenile winter flounder (*Pseudopleuronectes americanus*) and 371 post-larval lobsters (*Homarus americanus*) were added separately to the raceways in June and September-October respectively, to feed upon the smaller invertebrates. The flounder grew from a mean total length of 7.0 cm carapace length when stocked in September and October and weighed an average of .37 grams. Six weeks later, they ranged in size from 8.0 to 24.5 mm carapace length and averaged 2.0 grams, a weight increase of fivefold. The larger individuals were of comparable or greater size than one-year-old lobsters in the wild.

The net flow from the animal raceways passes through adjacent raceways in which commercially valuable species of seaweeds are grown in suspended culture, by rotary circulation provided by aeration. The seaweeds provide a final polishing step in the polyculture system, removing nutrients not initially assimilated by the unicellular algae and the nutrients regenerated by the shellfish. Initially the red algae *Rhodymenia palmata* (Dulse) and *Chondrus crispus* (Irish moss) were stocked. As the temperature increased above 15°C in Spring, the cold-water species *Rhodymenia* was replaced with warmer-water species (*Gracilara foliifera*, *Hypnea musciformis*, and *Agardhiella tenera*). All of the seaweeds have done well in the system, but by far the most effective has been *Gracilaria*, which doubled its biomass every 5-7 days during the summer. All species of seaweeds have remained healthy and in good condition, with virtually no fouling from filimentous algae or from invertebrates.

The initial success with the seaweed culture and the fact that a world-wide shortage exists of all of these commercial species has led to some preliminary experiments, initiated in the spring of 1974, in which these algae are being grown directly in a sewage effluent-seawater medium.

In June, one of the 35,000 gallon algae ponds was inoculated with brine shrimp (*Artemi salina*) nauplii, which were fed the harvest (17,500 gallons/day) of *Phaeodactylum* from one of the other algae ponds. The brine shrimp matured and produced living nauplii (in contrast to resting eggs), quickly developing a dense culture of the crustacea that completely utilized the algal food. Harvest of the brine shrimp provided food for finfish and for larval and post-larval lobsters.

DEEP-SEA BENTHOS

Howard L. Sanders and J. Frederick Grassle

During the second year of support under Grant 36554, analyses of the distributional patterns of our deep-sea benthic transects in the Atlantic Ocean have been progressing well. Significantly higher levels of endemism have been found in the Argentine Basin than in any of the other regions of the deep Atlantic so far studied. These findings suggest that the bathyal and abyssal benthos of the Argentine Basin may have faunal affinities with the Antarctic deep-sea benthos. A number of samples from the Surinam transect and a transect in the Northeast Atlantic between Ireland and the Mid-Atlantic Ridge have been processed during the current year.

After a period of two years we have finally been able to recover a sediment box which was azoic when placed on the sea floor at our permanent bottom station at a depth of 1830 meters. The animals present in the box were extremely small, and almost entirely postlarva. The size structure was markedly different and dramatically smaller than for the benthic animals present in the control samples collected from the immediate surrounding areas. The specimens present in the deep-sea sediment box were also considerably smaller than the animals found in an exactly equivalent sediment box that was placed in 12 meters of water in Buzzards Bay despite the fact that the deep-sea sediment box was on the sea floor for 25 months while the Buzzards Bay sediment box was retrieved after a mere two months. These data support our postulation that growth rates of the deep-sea benthic fauna are considerably slower than those of the shallow-water benthos. Further support comes from isotope analysis done in collaboration with Dr. Karl Turekian who reveals that a specimen of a 6 mm long abyssal bivalve, *Tindaria callistiformis*, was at least 100 years old at time of capture.

LARVAL DISPERSAL AND ZOOGEOGRAPHY OF BENTHIC INVERTEBRATES

Rudolf S. Scheltema

Our principal effort this year has been directed to the culture of brachyuran decapod and stomatopod larvae, both on shipboard and in the laboratory, so that the crustacean species found in our hundreds of open-sea, north and tropical Atlantic plankton samples may be identified (Fig.1). The larvae of almost all species that have been encountered by us are heretofore unknown and undescribed. The ultimate objective in our plankton studies is an understanding of the long distance larval dispersal of decapod and stomatopod crustaceans and its relationship to the zoogeography of tropical and warm temperature species of the continental shelf. In connection with these studies we have during the past calendar year participated in five research cruises to the Gulf Stream, one on our own research vessel *Knorr* during early spring and four on the *Eastward* during our three months' summer visit to the Duke University Marine Laboratory. The collections made on these five cruises resulted in the culture of more than 1400 individual larvae. Some zoea and megalopa were reared as far as the 12th post-larval stage and these later instars we anticipate can now be identified and related back to their larval form. Other larvae could not be maintained through so many instars or did not molt at all. However, most reared megalopa are now identifiable at least to genus.

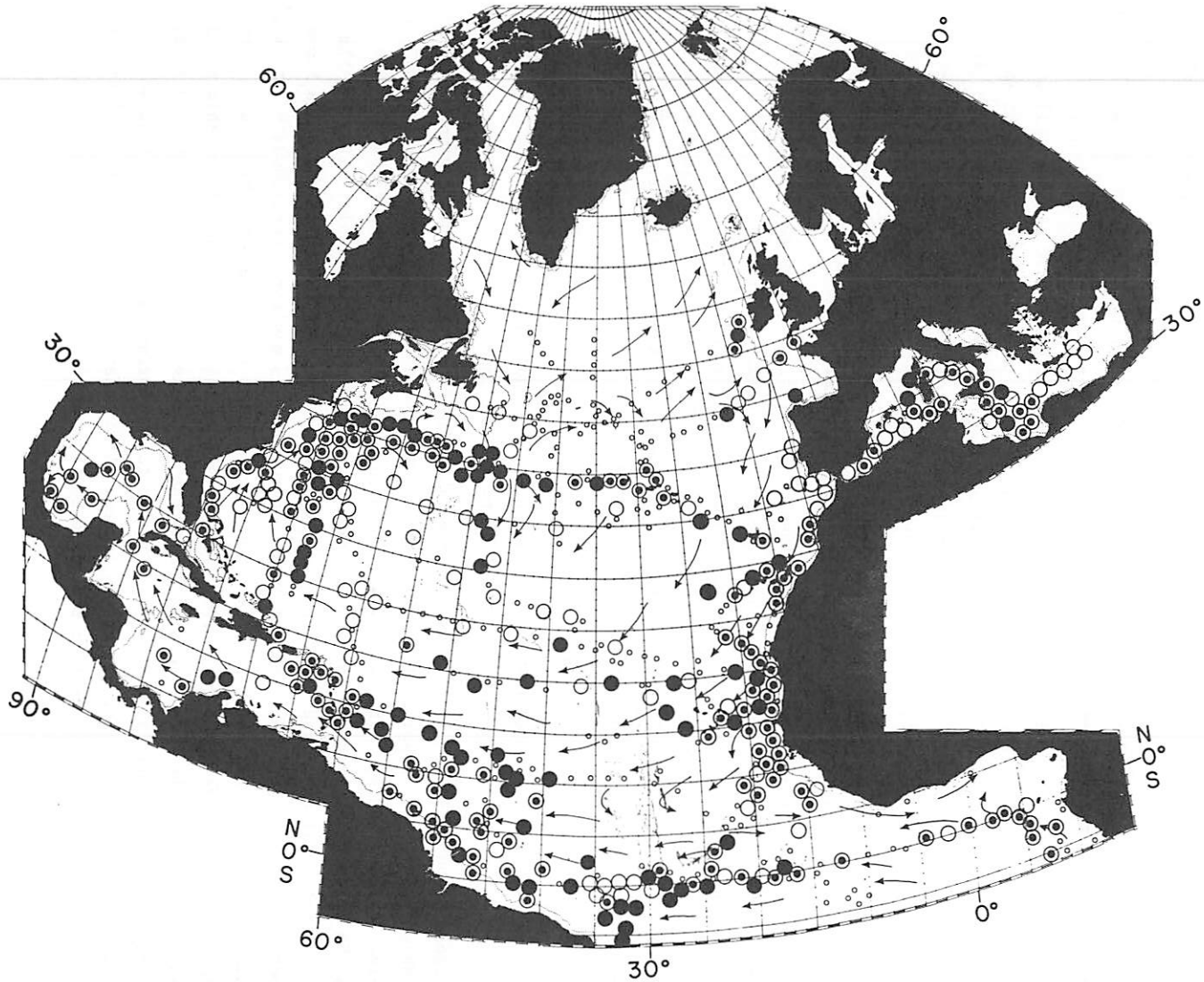

Fig.1. (Scheltema) Distribution of brachyuran decapod crustacean larvae in the North Atlantic Ocean. Large open circles = locations where zoes were found; large closed circles = locations where megalopa were found; large circles containing small closed circle = locations where zoes and megalopa were found; small open circle = locations where samples were taken but which lacked brachyuran larvae. Some locations include more than one sample. Arrows designate major circulation.

Included are about 15 to 20 different species belonging mostly to the Calappidae, Dromiidae, and other Oxystomatidae and also to the Grapsid and Portunid crabs.

The two *Sargassum* species of brachyuran crabs, *Portunus sayi* and the grapsid, *Planes minutus*, although of interest in themselves are not directly related to our present problem of long-distance larval dispersal as they are not properly continental shelf species. Their recognition in the plankton is necessary so that they may be eliminated from our present consideration and our efforts turned on the remaining portunid and grapsid larvae. *Portunus sayi* was successfully reared through its eight zoeal stages, the megalops and early crab instars. The earliest zoes and the megalops of *Planes minutus* can be recognized by us from rearing experiments and larvae captures at sea, but the complete development of this species is not yet known.

We have been particularly successful with the family Calappidae and have started studies to identify from this family the larvae from the Equatorial Atlantic between Africa and South America (on the basis of the material collected from the Gulf Stream and reared in the laboratory). At least five species of *Calappa* are recognizable from laboratory-reared megalops and one of these appears to be indigenous to both the Antilles and West Africa.

Some efforts have also been made to further our studies on the bivalve family Pinnidae by rearing veligers taken at sea and also by spawning adult individuals.

We have turned our attention to the implications of larval dispersal on the evolution of marine forms. Most contemporary species with a teleplanic (long-distance) larva not only have a very large geographical range but also a fossil record extending back into the early Pliocene or Miocene. This observation leads to the hypothesis that dispersal capability is related directly to geographical range and inversely to rate of phyletic change and species extinction. The hypothesis has been further developed in a manuscript just completed.

METABOLISM OF DEEP-SEA BENTHIC COMMUNITIES

Kenneth L. Smith and John M. Teal

The purpose of our research is to measure the metabolism of deep-sea benthic communities *in situ* using a free vehicle respirometer. This device, which consists of an aluminum tripod, acoustic release, respirometer unit, camera, and flotation, is deployed from a surface ship and descends to the bottom. Sediment disturbance is kept to a minimum by acoustically releasing the bell jar respirometers after tripod settlement on the bottom. The bell jar units enclose a known volume of bottom water and sediment, and the oxygen consumption is monitored continuously with a polarographic electrode and amplifier-recorder unit. After three to ten days the vehicle is acoustically recalled to the surface and recovered. We have successfully tested this free vehicle unit to 2000 m in the Tongue of the Ocean (TOTO). During the past year we have also been trying to develop this bell jar respirometer so that it will return to the surface with the intact sediment on which the measurements were made for biomass estimates. Also under development is a pH electrode to be incorporated in the bell jar unit to provide a continuous measurement of pH from which CO_2

evolution and subsequently respiratory quotients can be calculated. Professor Distèche of the University of Liège is helping in this development.

We have made several measurements of total benthic community respiration in shallow water along the Gay Head-Bermuda transect. The deep-sea stations along this transect will be monitored during February and March of 1975.

In shallow water we have also been conducting enrichment experiments with organic substrates and monitoring rate changes in oxygen consumption. This work is being done in conjunction with Stanley W. Watson, a microbiologist, who is measuring bacterial activity and biomass. Once our techniques are developed we will try enrichment experiments *in situ* on deep-sea sediments using the free vehicle.

Several unsuccessful attempts have been made with our fish trap respirometer attached to *Alvin* in the TOTO. Fishes and other movile epifauna are attracted to this trap by bait, and once inside, the door is closed by a manned manipulator and the oxygen consumption of the enclosed animal measured. We were successful in the San Diego Trough (Smith and Hessler, 1974), where fishes, such as macrourids, were very common but in the TOTO mobile epifauna were rarely seen.

We are also improving the sensitivity of our oxygen monitoring system to permit more accurate measurements of lower rates which we anticipate at abyssal depths. Additional experiments are underway to analyze the effects of antibiotics on benthic microflora.

Reference

Smith, K. L., Jr. and R. R. Hessler. 1974 Respiration of benthopelagic fishes: *in situ* study. Limnol.Oceanogr. 19 (in press).

EFFECTS OF PETROLEUM HYDROCARBONS ON METABOLISM IN MARINE FISHES

John J. Stegeman and Dennis J. Sabo

The objectives of this ongoing research are to determine the effects of petroleum hydrocarbons upon various metabolic processes and on cellular ultrastructure in tissues from marine fish. We have thus far established the normal patterns of hepatic and in some cases gill tissue, glucose metabolism, and lipogenesis from glucose-1-C^{14}, glucose-6-C^{14} and acetate-1-C^{14} for a number of fish species from coastal and open-ocean waters. We have also investigated these parameters in coastal fish species exposed to petroleum hydrocarbons in the laboratory or in the environment.

Exposure Studies

The fish used in the hydrocarbon exposure studies were *Stenotomus versicolor* (scup) and *Fundulus heteroclitus*. We found that in vitro exposure of scup liver slices to #2 fuel oil produced inhibition of hepatic lipogenesis from both glucose and acetate, with the effect on lipid synthesis from acetate being greater. ETOH, a carrier for the fuel oil, produced similar though less pronounced effects.

Routes of glucose metabolism and hepatic lipogenesis were also studied in environmentally contaminated *Fundulus* from Wild Harbor and control fish from the Sippewissett Marsh. The role of hepatic lipogenesis from glucose-1-C^{14} was six times greater in the fish from Wild Harbor than in the control fish. The reverse was true for lipogenesis from glucose-6-C^{14}. In addition the level of G6PD activity was elevated in the contaminated fish. A further finding was that the increased lipogenesis was accompanied by an increased rate of lipolysis.

Fundulus were also examined from creeks in Sippewissett Marsh treated with varied amounts of fertilizer derived from sewage sludge. The fertilizer contains significant amounts of chlorinated and petroleum hydrocarbons. Fish from creeks receiving the greatest amount of fertilizer showed greater pentose phosphate pathway activity and a higher level of liver lipid than did fish from lower-fertilized creeks. *Fundulus* from a region of the Hackensack River (New Jersey) contaminated by a sewage outfall also exhibit elevated levels of liver lipid.

Baseline Studies

Studies with three bathypelagic fish species and one mesopelagic species have indicated that both the glycolytic and pentose pathways are actively involved in glucose metabolism in these fish. Experiments are being designed for the study of these metabolic processes under varied temperature and pressure regimes.

Other fish examined from either local or open-ocean waters include menhaden (*Brevoortia tyrannus*), yellow jack (*Caranx crysos*), bluefish (*Pomatomus saltatrix*), striped bass (*Roccus saxatilis*), dolphin (*Coryphaena hippurus*), big skate (*Raja ocellata*), spiny dogfish (*Squalus acanthias*), and blue shark (*Prionace glauca*). For all of these species the pentose phosphate pathway was more significant than glycolysis in the metabolism of glucose in the liver. For the bluefish and the three elasmobranch species the pentose shunt was by far the predominate pathway for glucose catabolism. These species also possessed the highest percentages of liver lipid, ranging from about 22% for the bluefish to more than 75% for the dogfish and blue shark.

SALT MARSH NITROGEN BUDGET

John M. Teal

The purpose of this work is to measure the nitrogen budget for an entire salt marsh. We are working on Great Sippewissett Marsh which has a single entrance where we can measure gains and losses in the water. Other parameters are measured throughout the marsh area.

We have set up a tide station deep in the marsh to give records of water height. A solid state current meter is set up in the mouth of the marsh. From these two data sets we will calculate the tidal volume flowing in and out of the marsh area. Measurements of various forms of nitrogen in the water have been made over twelve-hour cycles once a month in cooperation with Dr. Edward Carpenter.

Input of nitrogen in rain water is measured at gauging stations. We have found nitrogen equivalent to 25 μM NH_4NO_3 on the average in the rainfall which has a pH between 3 and 4. Groundwater

inputs will be calculated from changes in salinity between incoming and outgoing tide. Groundwater springs on the marsh contain nitrogen mostly as NO_3.

Nitrogen fixation has been measured on soil samples collected throughout the marsh in all types of areas. Aerial photographs were taken at the same time from which the marsh has been mapped for measuring the area of each type.

Measurements of denitrification have been made with bell jars at several sites within the marsh from summer up to winter.

EXPERIMENTAL STUDIES OF SALT MARSH ECOSYSTEMS

John M. Teal

The study seeks to better understand the function of salt marsh ecosystems by experimentally manipulating their productivity and species composition and following the consequent changes in function. This study has been underway for five years. Sewage sludge is used as the fertilizer to stimulate production and imitate the effects of pollution in coastal area. We continue to fertilize to maintain the productivity differences we have achieved.

This year a higher treatment level was begun of 75 $g/m^2/wk$ to try to determine the upper limit of additions at which the marsh can function. These plots increased their production immediately, without the delay found at lesser dosages, but otherwise the pattern of response was similar.

The two-to-threefold increases in productivity of marsh grasses continue but further changes have occurred. The *Spartina alterniflora* on the low marsh has become altered toward the tall form found naturally only on creek banks indicating the difference is due to nutrient limitation not genetic difference. *Salicornia* sp. and *Distichlis spicata* which responded to nutrient addition in the first years of fertilization have gradually disappeared as the *Spartina* spp. have increased their production. The nitrogen content of the Spartina's, which possess the C-4 photosynthetic pathway, has increased to the level characteristic of C-3 grasses, about 2.5% compared with the 1.5% characteristic of C-4 plants. We find the lower level in Spartina from our control plots.

Growth of underground parts of marsh plants was measured this year by coring the mud, replacing the core with sand, and subsequently coring the sand and counting roots and rhizomes contained therein. This will be compared with the biomass in the original mud cores.

We found a twofold increase in herbivorous insects, principally plant bugs, noctuid larvae, grasshoppers, and plant hoppers in the fertilized compared to the unfertilized areas. We believe this is more due to the increased nitrogen in the fertilized plants than to the increased plant biomass.

Fundulus exclusion experiments have shown a dramatic increase in amphipod populations in the high marsh where fish predation is prevented. In low marsh there was little effect of excluding *Fundulus*. Amphipod populations there may well be controlled by crab predation which we have not changed in our experiments. Larval tabanid populations in the fertilized plots have

decreased in contrast to most animals. They may be adversely affected by the pesticides in the sewage sludge.

We have begun experiments on the relation of nutrient level to degradation of oil in marsh muds with measurements in the Sippewissett marshes, at Wild Harbor in the oil spill area and in Hackensack Meadowlands where oil spills are fairly common. We have also begun a study of the hydrocarbon budget in the fertilized plots to try to measure the retention of oil by the marsh.

FOOD CHAIN DYNAMICS OF DEPOSIT-FEEDING BENTHOS

Kenneth R. Tenore

A combination of radioisotope tracer and long-term growth experiments has been used to investigate the dynamics of detrital food chains of deposit-feeding benthos comprising the mud bottom community in Buzzards Bay. Tracer feeding experiments, properly modified to account for isotope recycling, have been used to ascertain differences in the availability of eel grass detritus at different stages of decomposition to the polychaetes, *Capitella capitata* and *Nephthys incisa*. Incorporation of label increased with the aging of the detritus. Differential availability of detritus derived from different sources might be important in food resource partitioning in benthic food chains. The presence of meiofaunal species, typical of Buzzards Bay did not affect the incorporation rate of the detritus by *C. capitata* but did enhance feeding by *N. incisa*. Populations of *C. capitata* were also cultured for five months at different daily food rations of eel grass detritus and comparison of these data with the higher densities obtained by culturing on oyster biodeposits suggest the necessity of investigating the nutritive value of different detrital sources.

Studies have continued on the importance of the phenomenon of tidal resuspension of unconsolidated sediments as contributing to the food resources of the benthos. Resuspension of benthic microalgae results in a significant contribution to the daily primary productivity rate. Tracer feeding experiments have shown that *C. capitata* utilizes the small pennate benthic diatoms as a food source. In addition, heterotrophic activity during the resuspension of detrital particles could further increase the organic carbon available to the benthos.

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

Ralph F. Vaccaro

The ecological role of heterotrophic microbial populations which control the cycling of organic matter in the sea remains our principle target area. Of particular interest to us are the observed modifications in microbial behavior in artificially created stress situations involving controlled amounts of chemical pollutants. Such studies are an integral part of a much broader program on biological effects currently being sponsored by the National Science Foundation under the acronym CEPEX (Controlled Ecosystem Pollution Experiment).

CEPEX provides a multidisciplinary approach to problems in biological effects and incorporates diverse research specialists from the United States, Canada and the United Kingdom. Long-term objectives include improved predictive capabilities concerning the consequences of chronic exposure of entire marine ecosystems to low-level concentrations of such perturbants as heavy metals, petroleum hydrocarbons and pesticides. Emphasis is directed toward multitrophic community responses in terms of biomass, energy and food chain dynamics.

To experimentally assess heterotrophic microbial activity we characteristically employ readily available species of ^{14}C labelled organic substrates at trace concentrations. Such studies are conducted both in the laboratory and at our *in situ* installations at Patricia Bay, British Columbia, Canada. Kinetic uptake patterns obtained by this technique permit an assessment of appropriate parameters which uniquely and sensitively describe organic carbon assimilation in a variety of experimentally defined situations.

Studies completed during the past summer at Patricia Bay were aimed at discerning the effects of copper on the local marine community. Present indications are that copper concentrations within the range 10-50 parts per billion cause a dramatic increase in heterotrophic activity during the initial 3-4 days of a 20-day experiment. Plate counts indicative of total heterotrophic biomass also show a corresponding increase in bacterial numbers. Such stimulation appears to reflect the appearance of increased amounts of labile organic material due to the toxic effect of copper on the autotrophic component of the marine community. Actually the enhanced heterotrophic response is accomplished by the ascendency of selected bacterial species which show an increased tolerance for copper. Ancillary data on phytoplankton behavior indicate that either death or lysis of primary autotrophs is the important source of the necessary organic material and that the organic substrates involved are typical of those excreted in dissolved form by a stressed phytoplankton population. In this sequence heterotrophic bacteria provide a useful function by ensuring a rapid mineralization of stress-derived organic excretions, whose endproducts provide an abundant source of inorganic nutrients for the development of a secondary phytoplankton regime less susceptible to copper stress.

The valuable assistance of Miss Pamela Bowman in this research is gratefully acknowledged.

MARINE BIOACOUSTICS

William A. Watkins and William E. Schevill

The general objective of our marine bioacoustics program is to study the environmental biology of cetaceans and other aquatic animals. Recorded sounds have been correlated with observed behavior. Techniques of acoustic tracking have permitted glimpses into the animals' behavior even when they were out of sight.

Analysis of sounds heard from sperm whales (*Physeter catodon*) has been used in the study of their behavior. With records made on a 4-hydrophone array, we've been able to track some of these animals by their own sounds. All of the sperm whales within range of the array of hydrophones and

pingers temporarily interrupted their own sound production in reaction to pinger sounds. Nearby whales remained silent for at least two minutes, and some of the more distant ones quieted for shorter periods. These whales moved underwater at speeds of about 2 kts and downward at a slope of 10-15 degrees, usually in the direction of other clicking sperm whales.

Another interesting behavioral sequence that was analyzed is of two sperm whales interacting acoustically. One whale with a 9-pulse coda was answered by another whale producing a 7-pulse coda, answered in turn by the 9-pulse coda, and then by the 7-pulse coda again. This interchange of codas continued until overlapping codas were heard and both produced 9-pulse codas, then 14-pulse codas, and finally back to multiple exchanges of 9 and 7-pulse codas. The tracks of these sounds from the array indicate that the 9-pulse whale was stationary with the 7-pulse whale steadily approaching. They are together at the 14-pulse codas, and then move off together for the remainder of the sequence.

Computer processing of the three-dimensional array data has been a goal this year in our acoustic analysis program. Various commercial "correlators" were tried to see if short-cuts in processing could be found. Several new methods of analysis have been explored and data previously analyzed were scrutinized with the new techniques. The results agreed with our reported acoustic locations for sounds of the porpoise (*Stenella longirostris*) and the sperm whale (*Physeter catodon*) and reaffirmed that these animals apparently do have voluntary control of the level of their sounds.

A combination of analytic techniques is required for computer analysis of whale sounds on the 4-hydrophone array. These result in compromises that provide high accuracy calculation of selected field data but not an automated program for acoustic location. The latter appears to be beyond the current state-of-the-art. The problems center around the difficulty of obtaining computer recognition of random whale sounds. For analysis, selected portions of analogue field data are digitized, referenced for detailed scrutiny, filtered, signal thresholds located, Fourier spectra compared, time differences noted, and then locations of the sounds calculated. This still is a cumbersome method, but it has a number of advantages over previous hand analyses.

Observations of Cetacea, especially right whales (*Eubalaena glacialis*), from aircraft and ship have produced the best photographs to date. Individual whales were recognized from previous years and our knowledge of their movement has been extended by locating animals as far out as Cape Sable, Nova Scotia. Preparation has been made toward returning to a program of marking and tagging these animals, but the necessary permissions from the Marine Mammal Commission have not yet been received.

The sounds of right whale baleen rattling were heard both in air and underwater as whales swam at the surface feeding. The sounds apparently were caused by surface wavelets moving the partly exposed forward baleen plates against other plates in the sides of baleen. This was an adventitious sound, obviously not purposeful, but much like some of the sounds attributed by others to an echolocation function in other whales.

BIOMEDICAL UTILIZATION OF THE RESOURCES OF THE SEA

Stanley W. Watson and James D. Sullivan, Jr.

The aim of this program is to find practical uses for biological products from marine organisms in the fields of medicine and biology. During the past year we have continued to study and find new uses for *Limulus* lysate, an aqueous extract derived from the blood of the horseshoe crab *Limulus polyphemus*.

Limulus lysate forms a firm clot when mixed with lipopolysaccharides (LPS) derived from the outer cell walls of Gram-negative bacteria. This reaction is specific and can detect 10^{-11} gms/ml of LPS. LPS are known in the medical field as pyrogens or endotoxins which are harmless until they enter the bloodstream. These compounds are extremely biologically active and once in the bloodstream can cause high fevers, chills, headaches, platelet aggregation, intravascular clotting, and a myriad of other biological reactions. When a patient has endotoxin in the blood, the condition is referred to as endotoxemia, and in severe cases death can result.

Because of the biological activity of LPS and because LPS is not destroyed by autoclaving, special precautions must be taken to destroy these compounds in any drugs used for intravenous injection. The LPS test (or *Limulus* lysate test) provides a convenient means for determining the presence and concentration of endotoxins in products used for intravenous injection. We anticipate that in the near future the LPS test will be used by all drug houses to monitor their products.

The LPS test can be used as a convenient tool to aid in the diagnosis of spinal meningitis caused by Gram-negative bacteria. This disease may be fatal within 24-48 hours to children if not correctly diagnosed and proper chemotherapy given at the earliest opportunity. We have worked with clinicians at the Childrens' Hospitals in Washington, D.C., and Los Angeles and have utilized the LPS test for the diagnosis of spinal meningitis in over 1000 children.

We have just started another collaborative program with clinicians at three hospitals in Los Angeles to determine if Gram-negative bacteria are responsible for "crib deaths" in newly-born infants. The clinicians believe that this respiratory disease, at least in some cases, is caused by Gram-negative bacteria which cannot be detected using standard procedures. If the clinicians are correct in this hypothesis, the LPS test could provide experimental verification that Gram-negative bacteria are the etiological agents responsible for death in these infants.

We have also entered into another collaborative program with Dr. Favaro at the Center for Disease Control Laboratory in Phoenix, Arizona. This program deals with endotoxemia commonly observed in patients undergoing dialysis. At present there are 12,000 patients undergoing dialysis in the United States and next year, because the government is underwriting the program, there will be 40,000 patients on dialysis. Frequently outbreaks of endotoxemia occur in these patients and we are trying to determine the cause. In the dialysis machine the blood is dialyzed against a non-sterile salt solution. Dialysis usually takes six hours, but the same salt solution may be used to dialyze several patients. During this period extensive bacterial growth may occur in this salt solution.

Normally the LPS is prevented from entering the bloodstream because the dialysis membrane prevents molecules having a molecular weight larger than 20,000 from crossing the membrane. We believe that frequently cellulose decomposing bacteria grow on the dialysis membrane and perforate it, allowing the LPS to cross the membrane into the blood. If this hypothesis is correct, it could explain the presence of endotoxemia in patients undergoing dialysis. We are now in the process of testing this hypothesis.

To fully exploit the use of *Limilus* lysate, the biochemical events taking place when it is reacted with LPS must be understood. At least two proteins are involved in the gelation reaction triggered by the LPS. LPS activates a high molecular enzyme which in turn initiates polymerization of a low molecular weight clottable protein causing gel to be formed. An inhibitor in the lysate prevents a spontaneous gelation and this inhibitor can be removed by chloroform extraction. Once this inhibitor is removed, the sensitivity of the lysate is improved nearly 100 fold. We have continued to purify and characterize the active proteins in the lysate. Using column isoelectric focusing, the endotoxin-activated enzyme and clottable protein were found isoelectric at pH 5.5 and 9.0 respectively. Additional characterization studies will be done when these proteins have been purified to homogeneity as judged by polyacrylamide disc gel electrophoresis.

In another program we have collaborated with Dr. Stephen Dexter trying to determine the role of bacteria in marine fouling and the effect surface energies have on the degree of fouling that occurs. For details, the reader is referred to Dr. Stephen Dexter's Summary of Investigations.

MARINE MICROBIOLOGY

Stanley W. Watson

The concentration, distribution and metabolic role of bacteria in oceanic environments have not been clearly defined because of inadequate methods. In this investigation a new method, referred to as the lipopolysaccharide (LPS) assay, has been developed to measure the concentration of bacterial biomass within the water column and sediments of the ocean. In this test, *Limulus* lysate is used to determine the concentration of lipopolysaccharides which are outer cell wall components of all Gram-negative bacteria and which compose approximately 5-10 percent of the dry weight of the cell. Since most bacteria in the water are Gram-negative, one can estimate the bacterial biomass from the concentration of LPS present in samples. The LPS technique is used in conjunction with the adenosine triphosphate (ATP), chlorophyll a and C^{14} techniques to study microbial biomass concentrations and activities in the marine environment.

In laboratory studies we showed, using cultures of *Escherichia coli*, that each bacterial cell contains 3×10^{-14} gms LPS, 7×10^{-16} gms ATP and 3×10^{-13} gms carbon. Each cell oxidizes 4×10^{-14} gms glycine/hr. Factors derived from these values permit us to estimate the number of microorganisms present in seawater and sediment samples and their metabolic activity.

Water and sediment samples were collected from Buzzards Bay every three weeks from July to November. The bacterial biomass within the water column varied from 65 mg C/m^2-790 mg C/m^2.

Using LPS conversion factors we estimate that the bacterial population varied from 2 x 10^4/ml in August to 1 x 10^6/ml in November. During this same time period the phytoplankton biomass ranged from 614-2273 mg C/m^2. These data suggest that 15% of the biomass within the water column was composed of bacteria. Approximately 10% of the bacteria present in these waters was found to oxidize glycine.

In the sediments we found that 6% of the microbial biomass was composed of Gram-negative bacteria. Based on ATP measurements the average total microbial biomass in the sediments, down to a depth of 20 cm, was 13.3 gm C/m^2 while the microbial biomass within the water column was 2.2 gm C/m^2. The sediments contained 86% of the total microbial biomass suggesting that a large percent of the carbon fixed by plants must be mineralized in the sediments. Our studies suggest that approximately 133 gm of carbon are oxidized/yr/m^2 in these sediments and that approximately 90% of all mineralization in these waters takes place in the sediments.

Similar survey studies were carried out on the fourth leg of the Coastal Upwelling Ecosystems Analysis cruise off the coast of the Spanish Sahara in May of 1974. In shallow shelf waters the total microbial biomass averaged 6 gm C/m^2 while the bacterial biomass averaged 0.64 gm C/m^2. In shelf waters bacteria composed 10.6% of the total microbial biomass. In slope and offshore waters the average microbial biomass was 7.1 gms C/m^2 while the average bacterial biomass was 4.8 gm C/m^2 indicating that 67.6% of the microbial biomass in slope and offshore waters was comprised of bacteria. The average phytoplankton biomasses in the upper 20 meters of the water column in shelf, slope and offshore waters were 3, 1.5 and 0.46 gms C/m^2 while the average bacterial biomasses in these same areas were 0.6, 0.5 and 0.48 mg C/m^2. This indicated that the phytoplankton biomass was similar in shelf and slope waters but decreased markedly in offshore waters while the bacterial biomass in these three water masses remained relatively constant.

These studies showed that a large percentage of the organic carbon produced in this upwelling area moved a hundred miles seaward where it was mineralized. They also indicated that bacteria comprised 44% of the total biomass in the waters and sediments of an upwelling area. On the shelf 90% of the bacteria present were localized in the sediments, while in offshore stations nearly 90% of the bacteria were found in the water column rather than within the sediments. Similarly over 90% of the organics tested were oxidized within the sediments in shallow stations while over 95% were oxidized within the water column in an offshore station.

These data suggest that bacteria utilize nearly 50% of the energy captured by photosynthetic processes in an upwelling area. The study provides the first firm estimate on the distribution, concentration and role of bacteria in the marine environment.

STRUCTURE FUNCTION RELATIONSHIPS OF MEMBRANES AND CELL WALLS OF GRAM-NEGATIVE BACTERIA

Stanley W. Watson

Continuing studies on nitrifying and other Gram-negative bacteria have concentrated on the composition of the outer membrane, the association of lipopolysaccharides (LPS) with outer and inner membranes and the localization of enzymes on membranes.

One of the organisms studied was *Nitrosococcus oceanus*, a marine nitrifying bacterium. This organism has an unusual outer membrane referred to as the "L membrane". Thin sections of this "L membrane" revealed that it was composed of two electron dense regions separated by an electron opaque area and was similar in gross morphology to the "L membranes" of most other Gram-negative bacteria. However, upon closer examination, it was found that this outer membrane differed radically both in chemical composition and fine structure from other "L membranes". For instance, this membrane was not solubilized in guanidine HCL, SDS, trypsin, papain and pronase but hot dimenthysulfoxide (DMSO) solubilized 80% of it. Thin sections revealed that it had a double track nature but negatively-stained membranes were found to be composed of 40 A subunits arranged in a rectilinear manner. Hot DMSO solubilized these subunits but left a thin backing layer which was subsequently found to be composed of peptidoglycan.

LPS was not detected in this membrane fraction until it was solubilized in hot DMSO. After the membrane was solubilized it was found to consist of 40-50% LPS and 40-50% protein. This evidence suggests that the "L membrane" of *N. oceanus* is comprised of subunits consisting of LPS covalently bound to proteins. This is the first time LPS has been demonstrated to be organized in a molecular array and the first membrane found to be composed of repeating subunits.

The fate of LPS was followed during growth and cell fractionation with cultures of *Escherichia cole*, *Nitrosococcus oceanus*, and *Nitrobacter winogradskyi*. During growth these organisms excreted 50% of the LPS into the growth medium. To determine how tightly bound LPS were to various cellular fractions, the cells were ruptured by means of a French Press and the component parts of the cells subsequently separated by differential contrifugation. During the logarithmic phase of growth only a small percentage of LPS was detected associated with the "L membrane", but during the stationary phase of growth a large percentage of the LPS was found associated with the outer membrane fraction. This evidence suggests that the LPS is covalently bound to proteins in the outer cell wall of bacteria during logarithmic phase of growth. This molecular arrangement appears to decrease the biological activity of LPS. During the stationary phase of growth this covalent bond is broken and the LPS becomes biologically active.

Collaborative studies have been carried on with investigators from the Max-Planck Institute in Freiburg, Germany, to find the biologically active portion of the LPS molecule. Preliminary evidence suggests that the reaction of LPS with the *Limulus* lysate is largely controlled by the "Lipid A" moiety of the molecule. However, the core polysaccharide part of the molecule dictates the degree of biological activity. The biological activity of the molecule can also be decreased if it is bound to a protein molecule.

DEVELOPMENT OF A MULTIPLE OPENING/CLOSING NET AND ENVIRONMENTAL SENSING SYSTEM FOR COLLECTION OF OCEANIC ZOOPLANKTON AND MICRONEKTON

Peter H. Wiebe

A multiple opening/closing net and environmental sensing system (MOCNESS) has been designed, constructed, and ocean tested. The system is a redesigned and improved model of the net system recently developed and operated by D. B. W. Frost of the University of Washington.

The system carries nine nets which are sequentially opened and closed by commands transmitted via conducting cable from a surface deck unit. The deck unit also provides for real time display and computer processing of parameters monitored by the subsurface electronic unit while at the same time recording the data for later replay. In addition to the nets, the subsurface unit is composed of an electronics package, and a mechanical net release mechanism all mounted on a rigid frame. Pressure, temperature, conductivity (CTD circuitry from the microprofiler system developed by Neil Brown), flow through a net, angle of the net mouth from the vertical, and which of the nine nets is open are monitored. The mechanical release motor turns an escapement crankshaft sequentially releasing the nets to an open then closed position. The nets are 1 m x 1.4 m at the mouth.

The system was successfully used on R/V *Atlantis II* cruise 75, leg IV (October 1974) to examine vertical and horizontal distributions of zooplankton in the Northern Sargasso Sea, and slope waters to depths of 800 meters.

LONGHURST HARDY PLANKTON RECORDER BIAS STUDIES

Peter H. Wiebe

The Longhurst Hardy Plankton Recorder (LHPR) has been in use since 1966 to take discrete sequential samples of zooplankton on a scale of from five to 120 meters per sample. This work has been done by some 25 investigators using 14 different versions of the device. While there has always been an awareness of the possible sampling biases in the net-recorder system, there have been no systematic studies of any LHPR to ascertain the kinds of biases, their magnitudes and the means of eliminating or reducing them.

For the past year we have made an intensive study in both the field and under laboratory conditions of the factors governing LHPR biases. A special test frame allowed LHPR net length, net mesh size and recorder box design to be varied. Animate and inanimate test particles of different sizes and shapes were then injected into the LHPR in its various configurations and under various tow speeds. The injections were either as instantaneous pulses or as a continuous stream of particles. The biases were determined by analyzing the spatial distribution of the injected particles along the recorder gauze tape. In addition, flow rates through the nets and recorder boxes were measured to help understand the hydrodynamics of the filtering processes. This work used an electromagnetic flowmeter designed and built by John Kanwisher and Kenneth Lawson.

Field studies were done in Buzzards Bay and the northern Sargasso Sea. The Deep Water Basin of the U.S. Naval Ship Research and Development Center, Carderock, Maryland, was used to test the systems under conditions free from ship motions, speed variation, and clogging. The wide range of biological conditions, from the essentially sterile Deep Water Basin, to the highly eutrophic Buzzards Bay, allowed us to assess the effects of clogging.

While data analysis is still in progress, three important results have been obtained:

1) Recorder boxes must be designed using the same principles as plankton nets. That is, the ratio of open area of the filtering gauze to the throat area (R) should be about three or greater to insure acceptance of at least 85% of the water presented to the recorder by the net. All recorder boxes built prior to our tests accept only 60-70% of the water. Thus there is an unavoidable mixing of organisms in front of the net cod end. Clogging of the recorder gauze during the sample interval further increases the severity of the problem. We have built a new recorder box which is at least 95% efficient and should be able to filter effectively, even with some clogging.

2) Clogging of the net ahead of the recorder can cause rapid deterioration of the resolving ability of the LHPR. Comparative tests showed that both the new and old recorder boxes had greater biases in eutrophic Buzzards Bay, presumably because of net clogging. The severity of the clogging observed in the Buzzards Bay tests suggests that LHPR's using nets are not feasible in such rich waters. However, for many species, an efficient recorder design should give sufficiently large, unbiased samples without a net.

3) Old OHPR recorder box designs lose as many as 50% of the injected particles due to extrusion out the slot through which the gauze passes. Our new box design has reduced this loss to about 20% by using pressure pads to seal the slots against the gauze. Further improvement is necessary to completely solve this problem.

Our tentative conclusion is that the LHPR, with a correctly designed recorder box, can be used to sample small-scale zooplankton distributions to a scale at least as fine as 30 meters, and probably, to less than 15 meters. Clogging conditions are critical, however, and where performance is degraded by it, no net should be used.

Loren Haury was co-investigator in this research.

RELATIONSHIPS BETWEEN ZOOPLANKTON DISPLACEMENT VOLUME WET WEIGHT, DRY WEIGHT, AND CARBON

Peter H. Wiebe

Interconversion of various measures of zooplankton biomass have great utility in studies requiring non-destructive techniques, as for interpretation of past data. Since previously-published conversion factors were based on small numbers of observations and have been generally regarded as unreliable, we sought to establish predictive relationships between biomass measures using a larger data base. We found the appropriate regression to use is the geometric mean estimate which provides

a regression line in which the regressions of X on Y and Y on X are identical. We have employed this type of analysis to determinations on samples from diverse sea areas in different seasons and have determined that statistically significant relationships exist between carbon, wet weight, displacement volume, and dry weight. The slope of the regression line for log transformed values for carbon vs. dry weight and wet weight vs. displacement volume was sufficiently close to unity to assume a straight percentage conversion between these values. Carbon was 31-33% of dry weight and wet weight was 72-73% of displacement volume, according to our techniques. Comparability of different techniques for a biomass measurement may be poor, especially in the case of displacement volume and wet weight measurements due to variations in the interstitial water content. Moreover, interstitial water content varies inversely with total biomass density, which accounts for the absence of a simple percentage relationship between wet weight or displacement volume and other measures of zooplankton biomass.

TRANSPORT OF ORGANIC MATTER TO THE DEEP-SEA FLOOR

Peter H. Wiebe

The "rain of particles" to the deep-sea floor has long been suggested as one means of supplying nutritive material to organisms inhabiting the deep-sea floor. However, the major difficulty in attempting to sample these particles at great depths to assess their importance stems from their apparent rarity in the water column relative to most deep POC (particulate organic carbon) which is thought to be largely refractory and sinking at minimal rates. At the present, evidence is circumstantial that sinking of organic matter as small particles is a major pathway for food and associated elements into the deep-sea and direct measurements are required to substantiate it. To do this, a prototype sedimentation trap for use just above the deep-sea floor was free-fallen to a depth of 2150 meters on the axis of the Tongue of the Ocean canyon on January 3, 1974. On March 6, it was successfully recovered with the assistance of DSRV *Alvin*. As part of an on-going analysis,filters in the trap bottom were analyzed for carbon and nitrogen and PCB/s. Portions of filter material were examined with light and electron microscopy.

Total carbon (inorganic and organic) on the filters as determined by high temperature combustion of eight aliquots averaged 1560 mg C/m^2 or an average on a daily basis of 24.8 mg C/m^2. Four similar filter aliquots were fumed over cold phosphoric acid for one hour after which they were analyzed for carbon ($\overline{X}$ = 6.35 mg C/m^2/day). These values suggest that 26.5% of the total carbon reaching the sea floor at 2000 m in this area is organic in origin. Fecal material is one readily identifiable component of the material contributing to the organic fraction on the filters. Counts of fecal pellets on filter aliquots suggest an average of $\sim$650 pellets/m^2/day are reaching the trap. These counts are possibly an order of magnitude smaller than actually occurred on the filters because some of the material was lost during recovery of the trap, and also because some of the fecal pellets being extremely soft, lost their form and could no longer be positively identified.

These and other findings are presently being incorporated with a description of the trap into a manuscript to be submitted for publication.

THE BIOLOGY OF GULF STREAM COLD CORE RINGS

Peter H. Wiebe and Edward M. Hulburt

Classically, two strategies have been used for study of the causal factors responsible for the development and maintenence of biogeographic patterns of plankton organisms: Transect sampling of transition regions permitting the investigator to observe sharp changes in the abundances of species while simultaneously monitoring the physical-chemical environment; and repetitive sampling of a species and its environment within its home range to observe seasonal or yearly change. While both approaches have yielded valuable insight into factors which are strongly correlated with species occurrence and/or abundance, interpretation of causal mechanisms has not been possible.

Gulf Stream cold core rings would appear to provide a third alternative to study factors responsible for the maintenance of biogeographic boundaries. The formation of a ring constitutes the beginning of a large-scale invasion of slope water organisms into the Sargasso Sea community. The processes of change in the ring community composition and the ring physical-chemical environment are substantially different from those which occur in the slope water or Sargasso Sea, or across the slope water/Sargasso Sea boundary. Documentation of the processes of change should provide unique insight into the role various features of the environment play in regulating plankton populations.

This year on R/V *Knorr* 38 (March) we sampled a cold core ring estimated to be greater than nine months old and on R/V *Atlantis II* 85 IV (October) we sampled a large meander believed at the time to be in the process of forming a ring. As on past rings cruises, physical, chemical, and biological observations were made inside and outside the ring (meander) and in slope water north of the Gulf Stream.

We now have the data analyzed from four cruises to cold core rings of different ages which show that rings retain for months after formation, a biological composition recognizably distinct from that of the surrounding Sargasso Sea. The biological features and nutrient chemistry as well as physical structure of the young rings show strong affinity to the slope water. Biological distinctions between the older rings and the Sargasso Sea are less clearly defined, yet are measurable. The fact that physical features of older rings remain clearly distinct, especially at depths greater than 200 m has led to our tentative conclusion that the decay rates of the slope water assemblage is more rapid than the decay rate of the physical properties associated with ring structure. We have previously speculated that this possibly occurs as a result of biological interaction between Sargasso Sea and slope water assemblages precipitated by rapid modification of physical and chemical properties of ring surface water.

CHEMISTRY

DEPARTMENT OF CHEMISTRY

Derek W. Spencer, Chairman

Geochemistry

PETROLOGICAL AND GEOCHEMICAL INVESTIGATIONS OF SEAFLOOR BASALTS AND BASEMENT ROCKS OBTAINED IN THE (JOIDES) DEEP-SEA DRILLING PROGRAM

Geoffrey Thompson and Wilfred B. Bryan (Woods Hole)
Frederick A. Frey and John S. Dickey (MIT)

Basalt samples from the Deep-Sea Drilling Program (DSDP) present a unique opportunity to study stratigraphic relationships and variations at a single site, to study samples collected from regions inaccessible by conventional dredging techniques, and to study compositional variations in different tectonic, geographic and temporal provinces. The aim of these studies is to understand the genesis and composition of the oceanic crust.

In 1974 we completed and published studies of the basalts obtained during Legs 2 and 3 of the DSDP in the Atlantic Ocean, and our studies of basalts and their derivatives from the Ninety East Ridge in the Indian Ocean. Our major effort in the laboratory was on studies of basalts obtained on Leg 11 in the North Atlantic, and Leg 34 on the Nazca plate in the Pacific Ocean:

Leg 11, Western Atlantic Ocean

Major element analyses of basalt glass and minerals, and minor element analyses of fresh and altered glass or rock, show that pre-Oxfordian basalts from Sites 100 and 105 in the Western Atlantic lie within the compositional range of modern ocean ridge basalts. At Site 100, the 14 m of basalt penetrated shows evidence of no more than two cooling units. In some samples plagioclase and pyroxene are on the liquidus and there is slight enrichment in elements such as the light rare earths, suggesting a moderately fractionated composition. At Site 105, abundant glassy selvedges throughout the 11 m cored, the textures of the crystalline rock, and minor chemical variations in the fresh rock and glass, indicate penetration of a pillow lava sequence of remarkably constant composition. This basalt is more mafic than at Site 100, with olivine and plagioclase on the liquidus. Rare earth elements appear unaffected by weathering but there is considerable mobility of Cu and Zn in the altered rocks, with concentration of these elements in the overlying sediment.

Leg 34, Nazca Plate

Geochemical studies of basalts from Holes 319 (16 million years), 320 (28 million years), and 321 (40 million years) of Leg 34 indicate that in all cases they are large-ion-lithophile (LIL) depleted tholeiites typical of ocean floors; that is, they are depleted in light rare earth elements (LREE) relative to chondrites and have low abundances of K, Sr, Ba and Zr relative to island and continental basalts. Samples from Hole 319 and the upper cooling units of 319A have K_2O (0.04%) and TiO_2 (1.17%) concentrations similar to those of tholeiitic basalts from the East Pacific Rise. Compared to the upper flow units, the lower units of 319A have higher concentrations of elements such as V, Y, Zr, Sr and REE and lower concentrations of Ni, Co and Cr. In Hole 320A the upper units are similar to the upper units of 319. One lower unit in 320A is texturally and petrographically different and shows higher concentrations of elements such as K, Ti, Fe, V, Y, Zr and lower concentrations of Mg, Cr and Ni. Hole 321 is similar in composition throughout. Compared to the other sites, these basalts have higher concentration of Fe, Ti, Ba, V, Y, Zr and heavy REE (30 x chondrite), and lower concentrations of Mg, Ni and Cr.

The geochemical and petrographic evidence is compatible with an origin of these flows at a spreading center. Differences in composition, particularly for the major elements, between flow units and sites probably represent differences in the degree of fractionation of the original magmas. Differences in trace element composition can be ascribed in part to these same processes and in part, particularly for the LIL elements, to differences in the original magma compositions reflecting differences in degrees of partial melting of the source materials or mantle inhomogeneities.

Future Work

At the latter end of 1974 we received samples from the deep basement drilling (500 m penetration) in the North Atlantic on Leg 37. We will be studying these and comparing them with basalts obtained from the nearby spreading center in the French American Mid-Ocean Undersea Study (FAMOUS) area of study. In addition, we have obtained and are beginning work on a selection of basalts from twelve different sites in the Eastern Indian Ocean. These will be studied with a view to making overall comparisons and synthesis of the crust of that part of the Indian Ocean.

GEOCHEMICAL STUDIES OF ROCKS FROM THE ATLANTIC OCEAN

Geoffrey Thompson

Studies of the structure, geology, petrology and geochemistry of selected regions of the Mid-Atlantic Ridge and adjacent seafloor have been undertaken over the last ten years. In all we have studied ten different regions, ranging from 43°N latitude to 22°S. The aim of these studies is to understand (1) the nature, composition and characteristics of rocks originating at, and away from, spreading centers; (2) the geochemical evolution of the oceanic crust and mantle; (3) the interaction of seawater with oceanic basement rocks.

In 1974 our studies were principally directed to four different regions and to two aspects of the rock-seawater interaction.

43°N

In cooperation with Akiho Miyashiro and Tsugio Shibata of the State University of New York at Albany (SUNYA) and Frederick Frey of Massachusetts Institute of Technology (MIT), we have begun studies of the basalts and peridotites obtained during cruise *Atlantis II*-32 from the ridge and fracture zone at 43°N. Our analyses to date indicate that the basalts from the median valley, although tholeiitic in character, have anomalously high concentrations of certain large-ion-lithophile elements such as K, Ba and rare earths. Basalts erupted in the fracture zone differ from the spreading center basalts and are alkaline in character.

King's Trough, North Atlantic

Studies of a collection of basalts we obtained from the King's Trough during *Chain* Cruise 105 were begun this year. Our preliminary data indicate that the basalts in the trough are very different in composition from those at the present day spreading center at this latitude, and probably represent a later volcanic extrusion through older oceanic crust.

$22^{o}S$

Studies of the basalts and gabbros from a large transverse fracture and adjacent ridge sections, collected on Cruise 60 of R/V *Atlantis II* were the major part of a Ph.D. thesis by Beverly Carroll of M.I.T. done in collaboration with us and Frederick Frey at M.I.T. Compositional differences between basalts erupted in the spreading centers appear due mainly to fractional crystallization processes. The gabbroic rocks in the fracture zone represent layered intrusions showing wide ranges in composition due to differentiation in the magma chambers. The original magma compositions were not greatly different from those found in spreading centers. Thus in this fracture zone, the long linear ridge features appear to represent uplifted 'normal' oceanic basement.

New England Seamounts

In August of 1974 we led a cruise (*Atlantis II*-85) along the New England seamount chain. We successfully dredged igneous rock from Bear, Pickett, Kelvin, Atlantis II, Gosnold, Allegheny, Michael, Susan, Brenda and Nashville seamounts. In addition, ferromanganese pavement and nodules, lithified sediments, unconsolidated sediments and glacial erratics were recovered. This collection will be studied to ascertain the geochemical and petrographic variations within and between seamounts. Dating of the rocks and sediments will be undertaken, in collaboration with other workers, to help resolve the problem of the origin of the seamount chain.

Basalt-Seawater Interactions

Studies of the high temperature seawater-basalt interaction were begun in 1974 by Susan Humphris as part of her Ph.D. thesis in collaboration with, and partly supported by, this grant. Studies of the metamorphosed basalts indicate this reaction results in leaching of Ca from the rock to seawater, and uptake of Mg by the rock from seawater. Other chemical changes are evident as well as mineralogical reconstitution. Recognition of the sources and sinks for individual metals, as well as mass balances, are an integral part of this study.

In the summer of 1974, in collaboration with Windsor Sung of M.I.T., a Summer Student Fellow, we looked at some of the ferromanganese encrustations on basalts from the ridge flank at $23^{o}N$ recovered on Cruise 78 of *Atlantis II*. Most of the encrustations and nodules show compositions similar to other such deposits at other localities in the North Atlantic, and appear to be independent of volcanic activity on the ridge. In one dredge haul, however, we recovered a very different deposit, todorokite in mineralogy and almost pure MnO_2 in composition. We are presently studying this deposit in conjunction with C. C. Woo of the U.S. Geological Survey and comparing it with hydrothermally deposited manganese oxides from other regions to ascertain if it is indeed the result of leaching of basement rock by heated seawater.

SEAWATER-SEDIMENT REACTION AND MASS BALANCES IN THE OCEAN

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

Interstitial Gradients and Fluxes across the Seawater-Sediment Interface

Studies of the nature of interstitial gradients of the major ions of seawater near the water-sediment interface have continued. Samples have been obtained by *in situ* methods developed in this laboratory. Studies carried out in the Atlantic indicate that the character of interstitial gradients varies considerably on a regional scale. In the North Atlantic, virtually all samples are characterized by depletions of K^+, Mg^{2+} and SO_4^{2-}, enrichment of Ca^{2+} and conservative behavior of Cl^- and possibly Na^+. In the Caribbean and South Atlantic ($\sim 32^oS$) depletions of K^+ and Mg^{2+} are less pronounced. SO_4^{2-} depletion is readily detectable only in continental margin areas. Ca^{2+} enrichment is accompanied by alkalinity increases in all samples.

The enrichment of Ca^{2+} amd alkalinity (HCO_3^-) may be attributed primarily to the dissolution of biogenic $CaCO_3$. However, in continental margin areas anaerobic oxidation of organic carbon by bacteria contributes significantly to interstitial alkalinity. In such areas, HCO_3^- enrichment generally exceeds that of Ca^{2+} and may even lead to the precipitation of $CaCO_3$ at depths in excess of 30-60 cm. In most samples, Ca^{2+} enrichment exceeds HCO_3 increases. This is particularly true of the open ocean profiles obtained. The discrepancy between Ca^{2+} and alkalinity enrichment indicates that reactions other than the simple dissolution of $CaCO_3$ are occurring. These reactions must involve the consumption of alkalinity, most probably through the release of H^+. This may occur either as a consequence of the aerobic oxidation of organic carbon or in the formation of authigenic silicates.

The interstitial gradients observed near the water-sediment interface are such that, if universal, fluxes across the water-sediment interface must be considered an important part of geochemical balances in the oceans. The fluxes of K^+, Mg^{2+} and SO_4^{2-} are into the sediment, balancing, in part, the addition of these elements to the oceans by rivers. Ca^{2+} is returned to the oceans from the sediments in large quantities by dissolution. Although the flux of HCO_3^- in solution is into the oceans, there appears to be a net loss of HCO_3^-. This occurs through the cycling of $CaCO_3$ through the oceans and sediments. HCO_3^- is removed from the surface waters as biogenic $CaCO_3$ and settles to the sediments where some dissolves. Concurrent with this dissolution are the reactions noted above which consume a part of the HCO_3^- released. Such a removal of alkalinity, conveyed to the sediments as particulate matter, may be an important mechanism in regulating the ocean buffer system.

Clay-Seawater Reactions

Experimental studies have been initiated to elucidate the nature and extent of the reaction that occurs on the introduction of clay minerals into seawater. Reevaluation of the composition of exchangeable cations on a series of standard clay minerals demonstrates that previous work has been seriously in error (see report of P. C. Mangelsdorf, this volume). Na^+ ions generally dominate on the exchange sites of most clays studied, (equivalent ionic fraction of Na^+ = .3 to .6), particularly montmorillonite and a mixed layer clay. Whereas previous work indicated a dominance of Mg^{2+} and Ca^{2+}, we have found equivalent ionic fractions for both to be relatively constant at about .3.

Small but significant quantities of K^+ were also found to be taken upon exchange sites.

As has been observed previously, exchange reactions are rapid, proceeding to completion in a few days, but reaction of the clays does not cease. Analysis of the effect of clay-seawater reaction upon the alkalinity of the seawater indicates the continued removal of significant quantities of alkalinity even after several months. Investigation of the nature and significance of these long-term reactions is in progress.

Organic and Biochemistry

CARBON IN THE OCEAN AND FOSSIL CARBON

Werner G. Deuser

One of our aims is assessing the fluxes of organic carbon in the ocean, beginning with the amount of organic carbon produced by photosynthesis in the surface water and ending with the fraction of that production which is buried in the sediment. Drawing on a variety of different types of information from biology, chemistry and geology, we have attempted to estimate long-term global averages of the orders of magnitude of primary carbon fixation, flux of organic carbon to the deep water, flux to the sediment, and burial rate. It turns out that each one of these fluxes is reduced by an order of magnitude with respect to the preceding one.

It is possible also to compare the total pool of fossilized carbon to the best current estimates of world resources of petroleum, shale oil and coal, and to compare current production rates of fossil fuels to long-term average formation rates of those resources. We calculated that the "formation rate" of recoverable crude oil reserves is equal to no more than about ten parts per billion of the photosynthetic production rate of organic carbon on the one hand (or 200 tons per year in the entire world), and to the current per capita consumption rate of less than 100 U.S. residents on the other. Expressed in other words: at our present consumption rate, twenty households utilize as much petroleum per year as has been forming per year throughout the world during the last hundred million years.

PALEOCLIMATOLOGICAL STUDIES ON CORES FROM THE DEEP-SEA DRILLING PROJECT

Werner G. Deuser

We have continued our studies of the stable-isotope ratios O^{18}/O^{16} and C^{13}/C^{12} in planktonic foraminifera separated from Deep-Sea Drilling cores from the Red Sea. Unfortunately, we discovered a considerable reduction of the information content of the cores which may not become apparent in other types of study. Even in cores which show no evidence of serious perturbation, vertical mixing of successive layers of unconsolidated Pleistocene sediments during the drilling process has obliterated much of the amplitude of stable-isotope variations caused by changing temperatures and salinities in the past. The disturbance is greatest near the top of each core

and decreases downward. In many of the 9-m cores only the bottom 1 to 3 m have preserved their original layering sufficiently to retain fully the records of short-term deviations from the climatic mean of several thousand years. Nevertheless, we now have a number of clearly defined records representing periods of abnormally high salinities and/or low temperatures in the Red Sea during the Pleistocene and we shall attempt to compare them to time-equivalent records in sediments from the Gulf of Aden which we plan to analyze next. A comparison of the simultaneous stable-isotope variations in the tests of identical species of foraminifera in those two neighboring but quite different oceanographic settings will allow separate appraisals of changes in the precipitation/evaporation ratio in the isolated Red Sea and of the worldwide changes in temperature and ice volume in the ocean and open gulfs such as the Gulf of Aden. We hope, thereby, to find out the relationship in time between high-latitude glacial and low-latitude pluvial periods.

We have analyzed separately samples of the three species *Globigerinoides ruber*, *Globigerinoides sacculifer* and *Globigerinella siphonifera* wherever they occurred in sufficient numbers. Consistent differences in either O^{18}/O^{16} or C^{13}/C^{12} or both between species are common and may yield information on the vertical hydrography of the Red Sea in the past. Particularly interesting in this regard is our observation that over the last 500,000 years the difference in the O^{18}/O^{16} ratio between *G. ruber* and *G. sacculifer* has changed by almost one part per thousand. Unless one of these species has undergone a change in its physiology or habitat preference this observation signifies a decrease in the vertical temperature and/or salinity differences in the near-surface water of the Red Sea during that period.

ORGANIC CHEMISTRY OF THE SEA

Max Blumer

Long Range Scientific Objectives

Organic compounds are abundant in the sea and occur in a compositional complexity that is not yet fully understood. My research has been concerned with and continues to ask the following questions:

(1) Which processes are responsible for the formation of marine organic compounds and where are the principal sources?

(2) How complex and how variable is the chemical composition of the marine environment; can the complexity and variability be explained in terms of physical, chemical and biological processes?

(3) How do organic compounds interact with the biota and the non-living components of the sea?

(4) What is the long-term fate of organics in the sea and which processes are involved in transformation and removal?

Because of my background and experience, my research has concentrated on the study of marine hydrocarbons, lipids and pigments. This work, extending over the past fifteen years, has contributed

to our knowledge of the sources, composition and persistence of organic compounds in the sea. As new analytical techniques have become available, the scope of questions has widened and the apparent complexity of nature has increased. This forces me to re-examine our approach to marine geochemistry and the role that further development of highly resolving analytical techniques will play in this field.

PROGRESS OVER THE PAST YEAR

The Complexity of Marine Organic Chemistry

Organic geochemistry and marine organic chemistry have interacted with and profited greatly from natural products organic chemistry. Initially, the natural products approach (isolation, structural elucidation, functional interpretation) could be applied to selected individual compounds; the approach was fruitful, it led to the recognition of new compound classes in the environment, and to a degree, to insights into their involvement in environmental processes. As the development of highly resolving analytical techniques progressed during the last decade, it became apparent that the marine environment is far more complex than natural products chemists and geochemists had anticipated. We now know that at least certain compound classes (fossil hydrocarbons, porphyrins, polycyclic aromatic hydrocarbons) defy complete analytical resolution by any combination of existing analytical techniques.

The proper evaluation of this structural and compositional complexity of the marine organic matter is crucial for our understanding of marine processes and for the future planning of the analytical approach to be used in studying the sea.

Polycyclic Aromatic Hydrocarbons in the Environment

a. Literature Survey

An extensive literature survey has revealed over 1,000 references on the occurrence, analysis and properties of polynuclear aromatic hydrocarbons (PAH). Surprisingly, modern analytical techniques (gas chromatography alone or in combination with mass spectrometry) so far have had little impact in this field.

Though specifically compiled for our needs, the literature survey has been computer-processed according to key words and is available from this Institution or through the National Technical Information Service.

b. Methods

b_1. Analysis of Aromatic Hydrocarbons in Marine Sediments

Environmental samples contain PAH from many sources, usually in trace amounts and in the presence of many other extractable materials. Specific and relatively simple techniques, such as adsorption chromatography with subsequent spectrophotometry or gas chromatography, determine reliably some aromatic hydrocarbons in simple environmental mixtures. However, no previously existing method separated and resolved adequately the entire PAH fraction on a milligram-to-microgram scale and on samples that contain a very large excess of non-hydrocarbons. We have developed a new

isolation technique which utilizes a sequence of gel filtration, adsorption chromatography, charge transfer complexation and distillation from the mass spectrometer probe into the source area. A high degree of resolution is achieved, since each process responds to a different chemical or physical property of the Polycyclic Aromatic Hydrocarbon (PAH). The resulting analytical scheme, though involving numerous steps, is basically simple and rapid. In all operations, except the final fractionation, only two consecutive fractions are collected. One of these contains the PAH concentrate, the other is rejected.

The final structural interpretation considers the chromatographic mobility, the ultraviolet (UV) and mass spectra, the relative volatility and the appearance in the mass spectrometer of the initial masses of the different and overlapping homologous series. This method is the first one that resolves adequately the complex environmental PAH mixtures, including those containing a contribution from fossil fuels. With PAH concentrates in the microgram-to-milligram range it yields 1-10 kg range. Our analytical sensitivity hinges on that of the mass spectrometer; at nanogram sensitivity, a milligram sample provides a dynamic range of six orders of magnitude. This is adequate to assess the presence of minor series even in a mixture that may well contain tens of thousands of different individual compounds.

$^{b}2$. Porous Layer Open Tubular (PLOT) Gas Chromatograph Columns

Professor Nikelly and I have compared the independent development of PLOT columns in his and our laboratory (referenced in last year's Summary to ONR). Both techniques prepare efficient columns rapidly and our techniques are now used by other investigators at Woods Hole and elsewhere.

$^{b}3$. A Scan and Display Control for Magnetically Scanned Mass Spectrometers

Magnetically scanned sector mass spectrometers yield excellent spectra, covering a wide mass range. The spectral display is most reproducible if the magnet is cycled continuously in order to establish a constant hysteresis history.

We have adapted a single sweep spectrometer to continuous cycling. A simple and flexible control initiates and times the magnetic up- and down-sweep, erases and triggers a storage oscilloscope, advances and arrests the photographic recording chart and actuates an event marker on the recorder of the associated gas chromatograph.

The scan control provides great flexibility and reproducible spectra. It has operated reliably for several years and is most valuable during gas chromatographic and probe operations, when it frees the operator from routine manipulations and permits immediate readjustment of operating conditions as the displayed spectra change in type and intensity. The installation has led to a considerable saving in photographic chart paper.

c. Results

Our initial analyses of the PAH fraction from recent marine sediments immediately demonstrated an unanticipated complexity of the PAH fraction. The principal series from which only unsubstituted hydrocarbons and some alkyl derivatives had been known to occur in environmental samples,

strength over a wide molecular weight range. The minor series, previously unknown from recent sediments, cover an equally wide carbon number range. They are interpreted as the naphthenologs and thienologs of the basic PAH series.

The elucidation of individual structures in such small and complex samples by classical methods is a nearly impossible task. Even for crude oil, where sample size is not limited, few PAH structures have been proven by conventional methods. In spite of this, we believe that our structural assignments stand on a comparable basis with those of other authors on much larger samples of crude oil residues. With their adequately large samples, those authors characterized their fractions further by elemental analysis and nuclear magnetic resonance (nmr) spectrometry. This is precluded in our work because of the limited sample size, but we derive additional important information from the chromatographic mobilities, the UV spectra and the relative sample volatilities.

In order to study the regional variability of the sedimentary PAH fraction and to obtain clues on its origin, we analyzed samples that cover depositional and chemical environments ranging from continental and coastal soils to marsh and subtidal marine sediments, and from high to low redox potentials.

The molecular weight distribution within all homologous PAH series is consistent. In each series, the unsubstituted hydrocarbons predominate and the total concentration of the isomeric homologs decreases nearly twofold for each additional alkyl carbon. The molecular weight distribution appears to be independent of the depositional environment; also, it differs markedly from that of crude oil and ancient sediments.

An evaluation of possible formation processes and considerations of rates and thermodynamic trends leads us to suggest that these hydrocarbons are formed in natural fires, are dispersed and mixed by air transport and eventually deposited into surface sediments.

Our findings have analytical, geochemical and environmental implications. The sedimentary PAH fraction is far more complex than was previously recognized. In fact, a complete resolution into individual components, and their quantitative determination is difficult, if not often impossible. Regardless of the detailed mode of origin, the sedimentary PAH fractions may be accompanied by other organic compound classes, in similar complexity. This would imply that our present insight into the composition of non-biological sedimentary organic compounds may be more limited, and our analytical capabilities more restricted, than generally accepted.

We now demonstrate that the sedimentary PAH fraction contains, in addition to the previously recognized carcinogens (benzo[a]pyrene, benz[a]anthracene) other, not previously recognized carcinogens (dibenzothiophene, methylchrysenes, etc.) and a wealth of other polycyclic compounds that may comprise many biologically active compounds. Therefore, we need to re-examine the environmental toxicology of the sedimentary PAH fraction. Finally, our interpretation would imply, that carcinogenic and mutagenic hydrocarbons occurred on the earth's surface during geologic time spans. This raises the question of whether these compounds might have contributed significantly to the processes of natural selection, mutation and to the evolution of species.

ORIGIN OF HYDROCARBONS IN DEEP SEA CORES

John M. Hunt

The objective of this research is to investigate the origin and distribution of light and heavy hydrocarbons in cores of the outer continental margins and deep sea. This is a part of a long-range program aimed at understanding the origin, migration and accumulation of hydrocarbons in marine sediments. The project involves (1) field observations such as the analysis of Deep Sea Drilling Cores and long piston cores for hydrocarbon distribution and their relationship to organic content, lithology, temperature, age and other environmental factors, (2) laboratory studies such as the low temperature heating of immature marine sediments to yield hydrocarbons during the maturation process. During the past year, the work was mainly concerned with determining the distribution of C_4 - C_7 alkanes and C_{15+} hydrocarbons in deep sea cores.

Gasoline Range, C_4 - C_7 Alkanes

Last year, it was reported that C_4 - C_7 hydrocarbons were identified in several Deep-Sea Drilling Project (DSDP) cores at the parts per billion (nanogms/gm) level. Additional cores have been analyzed during the past year including some from the top ten-meter interval in the Black Sea. Practically all sediments except nanofossil chalks and red beds of the deep sea appeared to contain these light hydrocarbons. To date, a total of 27 normal, iso- and cycloalkanes that occur in petroleum have been found in the deep sea sediments. The total yields correlate with organic carbon (correlation coefficient = +0.75). This indicates that the hydrocarbons are forming *in situ* from early diagenetic reductions of other forms of organic matter. Most samples yielded less than 200 nanograms of alkanes per gram of dry sediment. However, a few very high yields were obtained in the range of 1,000 to 6000 nanogms/gm. These high yields were associated with a basalt intrusive which cooked some of the organic matter thereby generating comparatively larger quantities of hydrocarbons.

The results also indicated that certain hydrocarbons form very early during diagenesis, while others form late. The earliest formed hydrocarbons are generally the butanes, pentanes, 2- and 3-methylpentanes and methylhexanes, n-hexane, n-heptane, and methylcyclohexane. The hydrocarbons that seem to form latest are 2,2-; 2,3-; and 2,4-dimethylpentanes; 1,cis-3-, and 1-trans-2-demethylcyclopentanes, and 3-ethylpentane. About one in twenty samples contain a trace of 2,2,3-trimethylbutane. A few samples contain olefins which are now being examined by mass spectrometry. Large anomalies in individual hydrocarbon yields are scattered erratically through the samples. For example, n-pentane constituted about 40% of two samples and 2-methylhexane made up 31% of another. When it is realized that an individual hydrocarbon represents only 0.0001% of the organic matter, it is understandable that such anomalies can be attributed to a small labile portion of the organic matter. Such anomalies would be expected to disappear when sediments are buried deeply enough to reach the temperatures at which appreciable quantities of hydrocarbons are generated, usually greater than 50°C.

C_{15+} Hydrocarbons

The C_{15+} hydrocarbons and non-hydrocarbons were also determined for several samples which had been analyzed for the C_4 - C_7 hydrocarbons. Yields of C_{15+} saturate and aromatic hydrocarbons ranged up to about 200 ppm with a mean around 50 ppm. The yield of nitrogen, sulfur, oxygen com-

pounds plus asphaltenes was generally four to ten times higher than the yield of hydrocarbons. This large excess of non-hydrocarbons to hydrocarbons is typical of organic matter which has undergone very little alteration. Although the samples ranged in age from Recent to Lower Eocene, none of them were subjected to temperatures higher than about 40°C which is insufficient to cause a large conversion of the organic matter to hydrocarbons.

The ratio of odd numbered paraffin chains to even numbered paraffin chains in the C_{24} - C_{32} range has been around 1.5 for most samples. This indicates a predominance of marine organic matter over terrestrial organic matter. However, a somewhat surprising result has been the high yield of naphthenes (cycloparaffins) compared to normal and isoparaffins. The cycloparaffin fraction of the total saturate hydrocarbons has ranged between about 80 and 90%. Since cycloparaffins are not considered to be a dominant constituent of the saturate hydrocarbons of marine organisms, the source of these compounds must be either from microbial activity or from some types of marine life that have not been analyzed in detail.

INPUT AND LOSS OF PETROLEUM AND CHLORINATED HYDROCARBONS IN THE DEEP NORTH ATLANTIC OCEAN

George R. Harvey

The objectives of this work were to determine if petroleum, the insecticide DDT, and the industrial chlorinated biphenyls (PCB's) have penetrated to the deep sea floor. If so, we wanted to determine the routes and rates of these chemical pollutants to their final destination in the sea.

PCB and DDT have been found in most North Atlantic sediments lying under 3,000 m or more of water. Their rate of deposition on the sea floor has been calculated at about 2×10^{-6} g/m^2/yr. However, their rate of loss from the upper 100 m of the water column is about one thousand times faster. There is sufficient falling particulate matter to adsorb and carry down these quantities of PCB and DDT being deposited in the sediments. However, particulate scavenging is insufficient as an explanation for the PCB and DDT flux from the upper 100 m. The true explanation for the latter flux is the subject of our continuing research.

We have continued to be concerned about the difficult evaluation of hydrocarbons found in sediments. Petroleum and biogenic hydrocarbons are constantly being introduced into the sea. Differentiation of these recently biosynthesized hydrocarbons from their fossil ancestors can be very complicated. However, the sediments of the New York Bight and Hudson Canyon can be safely assessed as containing petroleum. On the abyssal plain, the array of hydrocarbons present do not match the known marine hydrocarbons but more closely resemble those from land plants. The concentration of petroleum *per se*, is barely detectable. The origin of these abyssal hydrocarbons is the subject of our ongoing studies. They may be from land - the PCB and DDT found in those sediments are definitely from terrestrial dispersion - or, they may be from biologically altered petroleum.

In summary, oil polluted sediments appear confined to the continental shelf areas, especially near known dumping sites. At present, there is no clear evidence of oil polluted sediments beyond the shelf, although polluted sediments may be migrating in that direction.

PETROLEUM CONTAMINATION: QUANTIFICATION AND PASSIVE TAGGING IN ORGANISMS AND SEDIMENTS

John W. Farrington

Our goals have been and continue to be the advancement of our knowledge of the precision, accuracy, limitations and suitable applications of methods for detecting low level petroleum contamination in marine organisms and sediments. In addition, by judicious selection of sampling sites and cooperative efforts with Dr. George Harvey's IDOE-NSF Project we have provided information concerning current levels of petroleum contamination in a variety of typical heavily polluted and lightly polluted depositional environments in the northeastern United States Continental Margin and estuarine areas.

Methods of Analysis - Organisms

Hard shell clam (*Mercenaria mercenaria*) samples from a heavily polluted area of Narragansett Bay, Rhode Island, and less polluted area of that bay, and from a relatively clean depositional environment - Waquoit Bay on Cape Cod, Massachusetts - have been analyzed for composition and concentration of hydrocarbons. Three extraction methods have been evaluated and compared, Soxhlet extraction, homogenization, and alkaline digestion in methanol. There was a statistically significant difference between the results of the homogenization vs. Soxhlet extraction and Soxhlet vs. digestion methods. The Soxhlet method was more efficient in each case. However, in practice the difference is small and would be apparent only if large numbers of replicate measurements were made.

Subsamples of clam homogenate spiked with 10 ppm API No.2 fuel oil have been analyzed. Gas chromatographic analysis indicated that the lower molecular weight hydrocarbons of the spike were lost during the analysis. The gas chromatographic passive tagging parameters of the No.2 fuel oil were altered by interference from hydrocarbons already present in the clams prior to spiking. This demonstrates that passive tagging by gas chromatography will be very difficult for low level petroleum contamination in marine organisms.

Sediments

Similar experiments to those conducted for the clams have been used to test analytical procedures for hydrocarbons in sediments. These experiments are in the process of completion.

We have initiated a program of hydrocarbon analysis of sediment cores from continental margin and estuarine areas of the northeastern United States. Early results indicate that there is a record of increasing petroleum contamination in the marine environment preserved in these cores. The results assist us in devising means to quantify man's petroleum contamination of marine sediments and distinguishing contaminant hydrocarbons from hydrocarbons introduced into the marine environment from natural processes other than oil seeps.

Intercalibration

We have continued our efforts for intercalibration of hydrocarbon analysis in marine samples by providing intercalibration subsamples of cod liver oil spiked with petroleum hydrocarbons to all interested laboratories. We have periodically analyzed subsamples and determined that intercalibration samples of this type can be stored for periods of at least two years without significant change in hydrocarbon composition.

BIO-ORGANIC GEOCHEMISTRY OF RECENT SEDIMENTS

John W. Farrington

We have completed hydrocarbon analyses of sediment samples taken in the western North Atlantic Continental Margin and Abyssal Plain areas between the northeastern United States and the area around Bermuda. We have concentrated on the types of biogenic hydrocarbons present and have attempted to trace their origins by comparing their composition to the known composition of hydrocarbons in organisms. Abyssal plain sediments have an n-alkane distribution similar to that reported for land plants and land organisms. This is true even for sediments 400 to 600 miles southeast of Bermuda. There is no clear predominance of hydrocarbons from marine phytoplankton, zooplankton, or fish found in the abyssal plain sediments. If it is assumed that the traces of specific hydrocarbons in the sediments such as n-hexadecane originate solely with marine organisms in the overlying water column then it can be calculated that only 0.5 to 3% of the organic matter produced in the euphotic zone ever reaches the abyssal plain areas.

We have initiated a study of organic matter in several adjacent depositional environments approximately 400 miles east of Bermuda. A cruise in September of 1974 collected an initial suite of samples and a cruise scheduled for February of 1975 will complete the sampling phase of the program. Our objectives are to study the effects of varying deep sea depositional conditions on the distribution of organic matter and the diagenesis of the organic matter after deposition.

Our work on fatty acid and organic nitrogen compound diagenesis in deep sea sediments continues. Extractions of these compounds from the sediment samples is being completed and analysis of the extracts will be undertaken during the next year.

MARINE GEOCHEMISTRY OF STEROIDS

Robert B. Gagosian

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 seawater and the sediments. During the past year we have initiated a program of studying this cycling of steroids by analyzing seawater and sediments in as many marine sedimentary and oceanic environ-

ments 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 seawater was accomplished (Gagosian, 1975).

The sterol concentrations in fourteen surface and nine deep water samples collected from the continental shelf and slope waters of the western North Atlantic and Sargasso Sea ranged from 0.1 to 1.3 µg/l seawater. Isolation and structural elucidation by gas chromatography and combined gas chromatography-mass spectrometry show that cholesterol and β-sitosterol are the major free sterols in both the surface and deep water. Fucosterol, brassicasterol, 22-dehydrocholesterol, campesterol, 22-methylenecholesterol, norcholestadienol, and stigmasterol are found in lower concentrations at the surface and in the deep sea. Cholesterol is the major sterol ester in both the surface and deep water, while very low concentrations of other sterol esters were found. The ratio of total free sterols to total esterified sterols is approximately two in both the surface and deep water.

Marine sources of sterols in seawater include phytoplankton, yeasts, and marine animals such as crustacea and molluscs. Terrestrial plants also contribute to sterols found in seawater. These sterols may enter the marine environment through river runoff and aeolian transport on particulates. Sterol transport to the deep sea may occur by convective overturn and vertical diffusion or from vertical fluxes of large particles from the surface.

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CHEMICAL COMMUNICATION BY MARINE ORGANISMS

Robert B. Gagosian

Our major effort for the past year has been to study the cycling of organic compounds in marine organisms and their oceanic environment in order to better understand chemical communication by marine animals. This work was concerned with the isolation of steroidal organic compounds.

A detailed procedure for the isolation and structure elucidation of molting hormones from the lobster (*Homarus americanus*) was accomplished (Gagosian *et al.*, 1974; Gagosian and Bourbonniere, 1975). The quantity of molting hormone isolated was 6 µg/kilogram wet weight of lobster. This compound, ecdysterone, has the same structure of the molting hormone found in insects.

In addition, the sterol compositions of two continental shelf species of crustacea, the lobster, *Homarus americanus*, and the shrimp, *Pandalus borealis*, were determined (Gagosian, 1975a). Cholesterol was found to be the major sterol in both species with minor amounts of desmosterol, 24-methylcholesterol, 24-ethylcholesterol, 24-methylenecholesterol, and 22-dehydrocholesterol. To our knowledge, this is the first report of 24-methylcholesterol and 24-ethylcholesterol in marine decapod crustacea of the suborder *macrura*. Since most crustacea cannot biosynthesize sterols, their sterol sources must be exogenous. Possible exogenous sources for campesterol and β-sitosterol are marine yeasts, phytoplankton and terrestrial detritus.

Caution should be exercised when comparing sterol distributions among members of the same species sampled from different locations. The sterol content of the marine fauna and flora in the animal's surrounding oceanic environment should also be considered as being an important contribution to the overall sterol content of the animal.

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CHEMICAL COMMUNICATION AND BEHAVIOR OF AQUATIC ANIMALS

Jelle Atema

Our research has been focused on three different aquatic species, the lobster, *Homarus americanus*, the catfish, *Ictalurus nebulosus*, and the mud snail, *Nassarius obsoletus*. In all cases we analyzed behavior such as feeding and social behavior for those aspects that involve chemical signals. The lobster was studied also for its potential in aquaculture. In a nine-month study we observed the behavior of small groups of mature and immature lobsters in a semi-natural environment created in our two 3,000 gallon octagonal aquaria. Our attempt to combine the advantages of a study in nature with those of controlled laboratory studies was successful in many ways, most notably in our observations on pair formation prior to mating. We thus discovered that the female lobster is protected by the (dominant) male during the time of her molting, a period of a few days in which a lobster is particularly vulnerable. We demonstrated again the overriding importance of shelter for these animals, and that egg-bearing females are more secretive than usual, avoiding most social contact. Artificially elevated temperatures up to 28^{o}C in summer seem to not affect lobsters where some other species from the same general ecosystem died.

When we attempted to teach a food odor discrimination task to lobsters, it turned out that they could learn to recognize one odor and show an appropriate response, but were more often than not confused when faced with a two-odor discrimination task. The learning process was extremely slow and memory of the learned task lasted over five weeks.

Catfish studies on chemical senses have been continued in the direction of social behavior and the function of small and related neurological structures. It was necessary to establish predictably stable groups of fish in order to measure lesion effects on social behavior. We developed a method to differentiate externally between sexes, which is difficult for catfish. With this knowledge we were able to form stable groups and analyze their social behavior for which we began to use complex statistical procedures. Effects of bilateral lesions of lateral and of medial olfactory tracts showed similarities to comparable lesions in rodents. Satisfactory quantification

of social behavior is still generally lacking in this field and we are making attempts at improvements.

When these stable social groups are exposed to 5°C temperature rises, distinct changes in behavior take place similar to those observed in more artificially designed experiments. We are about to finish this latter aspect of our research.

The mud snail was the subject of successful field work a year ago and proved again to be a very rewarding animal for chemotaxis studies in the laboratory. We discovered that feeding on mud is necessary to maintain their alarm reaction to a substance released from the body fluids of a damaged conspecific. We found that this alarm substance is species specific and causes only light responses in related species and none in sympatric, nonrelated species. Attempts to isolate the substance for chemical characterization (in collaboration with Dr. Meinwald's laboratory at Cornell University) showed that it is a large molecule which survives boiling; it is extracted with water, not with organic solvents. In nature, it survives 16 hours at ambient temperature, it is adsorbed on to mud, and snails respond to it for long periods (hours, at least) after a one-time exposure. It serves most likely as an anti-predator device, but no predator has been identified as yet.

All research is being continued at Boston University and the Marine Biological Laboratories in Woods Hole.

Seawater Chemistry

DIFFERENCE CHROMATOGRAPHY OF SEAWATER

Paul C. Mangelsdorf, Jr.

The method of Difference Chromatography (D.C.), developed in this laboratory for the analysis of major ions in seawater, is now being used mainly for studying seawater-sediment interactions.

Samples of interstitial water from deep-sea sediments, obtained with the "Harpoon" *in-situ* sampler, are customarily analyzed by D.C. for Ca/Na, Mg/Na, K/Na, and total normality. We are finding that the measurements of both the Mg/Na and the total normality need to be improved if gradients of Mg^{++} and Na^{+} in the deep-sea sediment pore waters are to be observable above our noise levels.

In order to work with these interstitial waters it has been necessary to modify our D.C. to include detection and measurement of NH_4^{+}, which is especially abundant in near-shore reducing sediments, and which created an unanticipated interference in some of our earlier work.

Research on the ion-exchange properties of clays, of fluvial sediments, and of marine sediments has been carried out over a period of years, with D.C. being used to observe the effects on seawater of interaction with ion-exchanging materials. The addition of our NH_4-measurement capability has been especially valuable for work of this kind. When an NH_4-loaded clay is mixed with seawater the NH_4^{+} release is (approximately) a measure of the cation-exchange-capacity of the

clay, while the uptake of the several cations indicates the exchangeable cation complement of the clay when in equilibrium with seawater. A measurement of change of total normality indicates whether or not the process involved is purely ion exchange.

Sediments from the North River salt-marsh estuary have been studied in this fashion revealing that

1. the bulk of the exchange capacity in these sediments is associated with the organic fraction;
2. the monovalent cations bound on the clay-silt fraction greatly outnumber the divalent cations. To a first approximation no Mg^{++} at all appears to be bound on the clay-silt fraction.

Experiments are now underway to determine whether a useful analysis of major anions, especially the SO_4/Cl ratio, can be achieved by using much more dilute operating salinities than has been our custom. The preliminary results are very promising.

Frederick L. Sayles and Wen M. Chang were co-investigators in this research.

SEAWATER PHOTOCHEMISTRY

Oliver C. Zafiriou

We hope to characterize the photochemical reactions initiated in seawater by sunlight and to understand their biological and geochemical significance. Practically nothing is known in this potentially vast field. Consequently, we have concentrated on a few model systems that are significant and/or tractable.

Three different systems are under investigation. The solar photolysis of nitrate and nitrite - conceptually a single system - continues to be the major effort. The solar photolysis of the essential micronutrient thiamine in seawater is a second system of biological interest. The solar photolysis of dissolved organic compounds in seawater is a third major photochemical reaction type, unfortunately rather intractable.

The preliminary nitrate-nitrite results reported last year have been consolidated into a major paper (Zafiriou, 1974) that attempts a comprehensive look at this system, from light absorption rates through photochemical reactions to the geochemical effects of the products. This is the first such study for any system in seawater.

We have completed experimental work on the flash photolysis of seawater and related solutions with Dr. Elie Hayon at the Pioneering Research Laboratory in Natick. Qualitative interpretation of the results of several hundred experiments reveals that radicals produced by flash photolysis (and in nature by sunlight and nitrate/nitrite) interact with several species of the carbonate system to yield new inorganic radicals; our suggestion here last year that the interaction was principally with dissolved organic matter (DOM) is incorrect. Quantitative evaluation of the data by iterative fitting to a kinetic model on the computer is in progress. This work is being done principally by Mary Bannister. The results should yield an exciting variety of "firsts" in our knowledge of the free radical chemistry of seawater; unfortunately, the data workup is quite tedious.

We are measuring the quantum efficiency of the nitrite photolysis so that we can make calculations of *in situ* rates of photolysis based on experiment rather than the estimate of 0.01-1.0 used in Zafiriou (1974). These measurements should enable us to take the next step - designing feasible in-the-sea studies of the photoreaction in favorable locations, such as the eastern Equatorial Pacific, where both high surface nitrite concentrations and bright sun occur. The quantum yield measurement being developed utilizes conventional ferrioxalate dosimetry. The formidable difficulties posed by competitive absorbers and by product recombination to nitrite are overcome by use of a double scavenging technique (NO for O_2 and t-butyl radical; t-butanol in water for OH).

The solar photolysis and thermal decomposition of thiamine was studied on R/V *Knorr* 38-II using thiamine-spiked surface Sargasso seawater. As expected, sterile-filtered samples were appreciably decomposed by sunlight in days; however, the dark decomposition was quite slow. In contrast, our preliminary work reported last year, and that of other investigators, has generally found fast dark decomposition (*ca.* two-day halflife). We find that µg/liter amounts of added copper bring the rate in Sargasso seawater up to the rates observed in coastal waters. We hope to obtain funding to make a concerted study of the light and dark chemistry of thiamine in seawater, in conjunction with simultaneous bioassay studies of the biologically active thiamine content of the waters in which the chemistry is done.

We have now shown that the ultraviolet (UV) component of solar radiation is capable of altering the dissolved organic matter (DOM) in coastal water; it is known that shortwave UV oxidizes DOM semi-quantitatively. Further studies on the efficiency of this process and on oxidation of various fractions of DOM are planned.

Reference

Zafiriou, O. C. 1974 Sources and reactions of OH and daughter radicals in seawater. J.G.R., 79: 4491-4497.

THE GEOCHEMICAL OCEAN SECTION STUDY

Derek W. Spencer

The Pacific Geochemical Ocean Section (GEOSECS) cruise aboard the R/V *Melville*, ended in June, 1974. A total of 266 stations with analyses of salinity, dissolved oxygen, phosphate, nitrate, silicate, alkalinity, total carbon dioxide, argon, nitrogen and both surface and deep radon-222 at about 40 depths per station were completed. Samples for shore-based analyses of both radioactive and stable isotopes, trace elements and particulates were collected and distributed to the participating Institutions. The completed GEOSECS station locations are given in Fig.1.

An atlas of the Atlantic Ocean shipboard data is currently in preparation at the GEOSECS Operations Group and is expected to be available late in 1975.

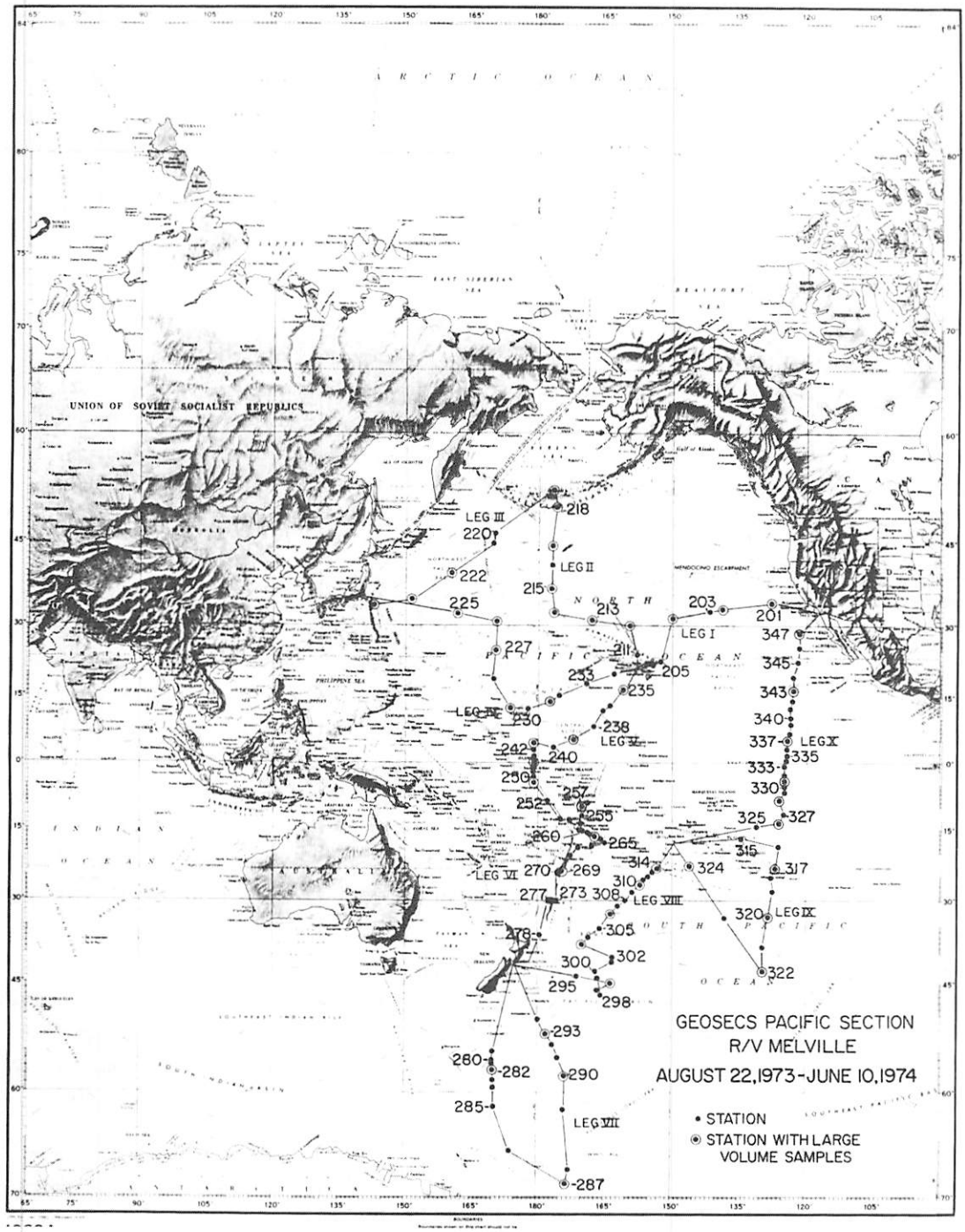


Fig.1 (Spencer)

THE DISTRIBUTION OF PARTICULATE MATTER IN GEOSECS SAMPLES

Peter G. Brewer and Derek W. Spencer

Interpretation of Nephelometer and Total Particulate Profiles

The Geochemical Ocean Section (GEOSECS) program has accumulated data on the distribution of total suspended matter in the Atlantic and Pacific Oceans along meridional sections. These data are being interpreted by means of a one-dimensional model incorporating a viscosity-dependent settling velocity, a variable vertical eddy diffusion coefficient and *in situ* consumption. The basic equation:

$$K \frac{\partial^2 c}{\partial z^2} - Vn \frac{dc}{dz} + J = \frac{\partial c}{\partial t} = 0$$

is used in the finite difference form. It is assumed that the vertical eddy diffusion coefficient is some function of vertical stability. Since viscosity increases markedly with decreasing temperature then, in the absence of consumption, a greater abundance of particles should result in deep water. Such is not the case and rapid biological consumption of particles is observed. The greater proportion of the mass flux to the sediments is provided by these biologically consumed, and excreted, particles. Simple vertical models are not applicable in the presence of strong horizontal gradients, and these are found to exist in the far North and South Atlantic.

Analysis of GEOSECS Particulate Samples

We have determined the concentrations of particulate Ca, Mg, Sr, Ba, V, Al, Cu, Mn, Cr, Hg, Fe, Co, Zn, Sc, La, Sb by means of instrumental neutron activation analysis. The data reveal that approximately 80% of the marine particulate matter is biogenic in nature, except in near-bottom "nepheloid layer" samples where our analyses can account for the bulk of the dry weight of material. The biogenic elements Ca, Sr, Ba show marked surface enrichment: Ca $\sim$ 1 µg/kg, Ba $\sim$ .05 µg/kg, Sr $\sim$ .04 µg/kg with a decrease with depth. The most rapidly depleted element is Sr with mid-water concentrations of $\sim$ 0.005 µg/kg, followed by Ba and Ca. No marked change in particulate calcium distribution can be observed at the level of undersaturation with respect to calcite. Al, Sc, La, Fe and Mn show a distribution attributable to clay material and are enriched in near-bottom waters. The elements Cr, Sb, Hg, Cu show unexpectedly high concentrations, possibly indicative of industrial contamination.

The Salinity/Density Relationship (with Alvin Bradshaw)

We have examined the effect of the increased alkalinity, total CO_2, silica and dissolved gases, found in deep ocean water, on the salinity/conductivity/density relationship. Through an evaluation of existing data on the partial equivalent conductances and partial molal volumes of the various components, we propose that the density anomaly of deep ocean waters can be described by

$$\Delta\sigma\theta = 0.0537\ \Delta\ \text{Alkalinity} - 0.0096\ \Delta\text{total } CO_2 + 0.042\ \Delta Si$$

where the concentration differences are expressed in m. equiv./kg, m. moles/kg and m. moles/kg, respectively. In the Pacific Ocean, salinity as used to calculate density is in error by -0.012‰ and as a truly conservative tracer by +0.008‰. This effect can lead to an adjustment of *ca.* 500 m. in the depth of an isopycnal surface.

Alkalinity and $CaCO_3$ Dissolution (with George Wong and Michael Bacon)

It is commonly reported that the change in alkalinity of deep ocean waters simply reflects the dissolution of calcium carbonate. Our evaluation of recent oceanic calcium data suggests that this is not so. The ocean has an apparent "excess" of calcium; in the Pacific this equals 20-60 μ moles Ca/kg. We suggest that this results from a flux of protons which are, in effect, titrating some of the alkalinity *in situ*. These protons derive from the redox changes associated with photosynthesis and oxidative decomposition. The commonly used Redfield-Ketchum-Richards model plankton reaction scheme makes tacit recognition of this phenomenon:

$$(CH_2O)_{106}\ (NH_3)_{16}\ H_3PO_4 + 138\ O_2 = 106\ CO_2 + 122\ H_2O + 16\ HNO_3 + H_3PO_4$$

From this it is clear that the observed change in alkalinity can only provide an upper limit on the amount of $CaCO_3$ that has dissolved. The corrections applied from consideration of the nitric and phosphoric acid fluxes are only a partial solution, since other redox reactions,e.g. S and I will also contribute. These data suggest a significant reevaluation of the oceanic CO_2 - carbonate system.

MINOR ELEMENTS IN SEAWATER

Peter G. Brewer and Derek W. Spencer

We have developed a precise and sensitive technique for the determination of dissolved and particulate reduced iodine in seawater. Seawater samples (250 ml) are loaded onto an AG-1 x 8 anion exchange column. Chloride, bromide and iodide are eluted successively with 2M $NaNO_3$. Iodide is co-precipitated with Pd metal as PdI_2 which can then be determined by neutron activation analyses. Particulate iodine is also determined by neutron activation analyses of the particles retained by a 0.45μ filter.

Review of Minor Element Oceanography

We have completed a major review of the recent work on minor elements in seawater for the second edition of the textbook "Chemical Oceanography".

CHEMICAL OCEANOGRAPHY OF THE CARIACO TRENCH

Peter G. Brewer

During the early part of the year, we participated in a cruise to the Cariaco Trench. Our data in the past had revealed that the deep water of the trench has warmed at a rate of $0.004^{o}C$ per year over the last 20 years. These data are consistent with the downward diffusion of heat from surface waters with a vertical eddy diffusion coefficient of 0.8 cm^2/sec at the upper boundary. Calculations of the upward flux of βE, the redox buffer capacity of the deep water, yielded a probable chemosynthetic rate of only 30 m. moles $C/m^2/yr$. This is only 2% of the chemosynthetic rate found in the Black Sea, and this low value is substantiated by direct microbial estimates of the dark uptake of $^{14}CO_2$.

METHANE SATURATION ANOMALIES IN SEAWATER

Peter G. Brewer and Mary I. Scranton

Our evaluation of existing data on CH_4 in seawater has revealed that open ocean surface water has a CH_4 concentration predicted from atmospheric equilibrium (*ca.* 50µl STP CH_4/1. seawater). Below the surface at 50-150 m. a methane maximum of up to a factor of 2 increase is frequently found, and below that depth a gradual decrease occurs, such that abyssal waters contain only *ca.* 5% of their atmospheric equilibrium value. These data may be explained either by production of CH_4 *in situ*, or by advection of the methane maxima from shallow waters overlying CH_4 producing sediments. The first would require a chemical and biological novelty, since methane-producing bacteria are obligate anaerobes, the other would give important information on mixing processes. In order to test these theories, we have constructed a gas stripping and trapping system, coupled to a gas chromatograph with dual flame ionization detectors. This is to be used in the Atlantic Ocean during the coming year.

Radiochemistry

THE DISTRIBUTION OF SOME CHEMICAL ELEMENTS BETWEEN DISSOLVED AND PARTICULATE PHASES IN THE OCEAN

Derek W. Spencer and Peter G. Brewer

Lead-210 and Polonium-210 in Dissolved and Particulate States in Seawater (with Michael Bacon)

We have continued our investigation of the oceanic distribution of Pb-210 and Po-210 in soluble and particulate forms in an attempt to further understand processes of trace element scavenging and particle transport in the sea. The bulk of our sampling was performed in the tropical and eastern North Atlantic during Cruise 32 of F/S *Meteor* in November and December of 1973. We are also analyzing samples from the Cariaco Trench (A-II-79) and the Pacific Ocean (GEOSECS). Some GEOSECS samples are being used in an intercalibration with Scripps Institution of Oceanography.

Results from two profiles in the North Atlantic support the conclusion of previous investigations that Pb-210 is rapidly removed from the water column following its production by decay of dissolved Ra-226. Above approximately 500 meters, there is an excess of Pb-210 supported by delivery of this nuclide from the atmosphere. Below this depth, the water column is systematically depleted in Pb-210, a result that probably arises in large part from the scavenging effect of sedimenting particles. Near-bottom features in the profiles, however, suggest an accelerated rate of scavenging associated with the sediment-water interface, and the possibility of topographic controls on the Pb-210 distribution is indicated.

There is evidence for even more rapid turnover in the case of Po-210, both profiles showing depletion throughout the water column. Our profile for the western tropical Atlantic, however, shows two maxima in the Po-210/Pb-210 ratio, both maxima containing measured values greater than unity. One of these maxima is strongly associated with the high salinity water found at a depth

of about 100 m. in this region and the other is found just above the core of low-salinity water of Antarctic origin. These features suggested the presence of strong *in situ* sources for polonium that are yet to be identified.

RADIOACTIVE FALLOUT AND CHEMICAL POLLUTANT STUDIES IN THE ENVIRONMENT

Vaughan T. Bowen

Contracts:

AT(11-1)-3563.00 -- Radioelement Studies in the Oceans.

AT(11-1)-3563.01 -- Fallout Radionuclides in Oceanic Water Columns.

AT(11-1)-2379.04 -- The North Pacific Marine Desert: Radiochemical Analyses of Water and Sediment.

AT(11-1)-3568.00 -- Plutonium Concentration along Freshwater Food Chains of the Great Lakes, U.S.A.

Grant:

25/36 -- Responses by Open-Ocean Microorganisms to Environmental Pollution.

Introduction

The four AEC contracts listed above all have to do, primarily with the distributions, in marine or freshwater environments, of long-lived radioactivity resulting from atmospheric delivery of debris from nuclear explosions. The grant, from the Scaife Foundation, has to do with the effects on oceanic microorganisms of chemical pollutants whose delivery pathways are largely atmospheric. It will be clear, then, that there is a thread holding all the work together. This allows some data from each part of the program to be used, profitably, either in planning or interpreting other parts of the program.

The objectives, on a broad scale, of the various parts may be set out as:

I. By studying the distributions of fallout nuclides in the oceans to increase our understanding of air-sea processes affecting material exchanges between these reservoirs, to contribute to understanding the rates and directions of water movements in the Atlantic, and to establish rates and pathways for open-ocean sedimentation.

II. By studying such distributions in a large, freshwater lake, to understand the pathways for, and rates of removal of transuranic nuclides from the biogenous parts of the system, and the pathways: and rates of entry of transuranics into freshwater food chains.

III. To establish the sensitivities, and nature of responses, to chlorinated hydrocarbons by marine microorganisms, and to assess the damage that open-ocean ecosystems could sustain from foreseeable pollutant concentrations.

Methods Development

In the past year we have collated, reported and submitted for publication our radiochemical procedures for plutonium, americium and curium in environmental samples. In addition we have developed a purely radiochemical method for plutonium 241 and another for americium 242m. We have also completed development of an improved radiochemical method for iron 55 -- an especially difficult problem in sediments because of the high load of stable iron. Two method papers are in press, and two are now undergoing review.

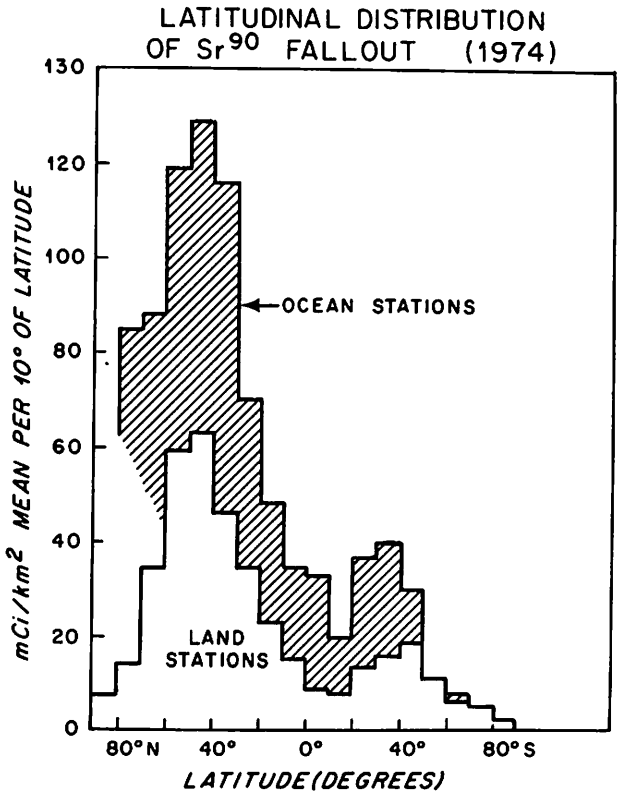
Long-lived Fallout in the Oceans

A. Strontium 90 and Cesium 137: By combining data from GEOSECS and from our own extensive cruising in 1971-72 we have a quite good synoptic view of the changes in contents of these soluble nuclides in Atlantic Ocean water columns. The result is surprising: even after 10 years of water movement trying to homogenize these distributions (note that the peak year of fallout delivery was 1964), the histogram of mean fallout per 10^{o} latitude band, obtained from integrating vertical profiles of concentration in the water columns, parallels exactly that for land stations from 80^{o}N to 50^{o}S latitude -- only south of 50^{o}S is the ocean curve differently shaped. This parallelism is shown in Fig.1, which also shows how consistently over these latitudes, the ocean contains much more of these nuclides than does the land. For the latter observation we have no explanation; the former obviously is trying to tell us that the seas are as solid as is soil -- but we are reluctant to accept the message.

Another interesting use of our data is in connection with tritium data from the University of Miami; ratios of Sr 90 or Cs 137 to tritium change with latitude in surface ocean water, because these nuclides are delivered by different mechanisms: Sr 90 or Cs 137, only in formed precipitation or in "dry fallout", tritium in formed precipitation and by molecular exchange. And these mechanisms show different relationships to latitude. Both in North Atlantic surface waters, and among various North Atlantic water masses we can demonstrate differences in tritium to Sr 90 ratio ranging over a factor of three or so. These ratio consistencies appear to reveal both the latitude position where a water mass was exposed at the ocean surface, and that horizontal mixing processes within water masses operate only very slowly to obliterate the signs of surface labelling.

B. Transuranic Nuclides: Our data indicate that plutonium and americium from fallout associate largely with sinking particles in the open ocean, and consequently show vertical profiles of concentration very different from those of such soluble nuclides as Sr 90 or Cs 137. These two transuranics strongly covary in the water column, and we cannot yet confirm any systematic change in their ratio versus depth in water. Our deep ocean sediments, however, show a significant excess of americium, as though that nuclide associates with particles of slightly faster sinking rate than does plutonium.

It surprises us that most open-ocean sediment cores, from North or South Atlantic, North Pacific or Caribbean, fall on about the same curve relating total plutonium to depth of overlying water. All but one of the exceptions to this relationship could be explained by horizontal transport of sediment after deposition. We find, also, much less correlation than had been expected



between the depth of penetration of plutonium into the sediments, and the predicted density of benthic organisms.

In coastal marine sediments we are now convinced that plutonium is leaving the mud at a measurable rate, and that Cs 137, for example, is not. These coastal cores also contain less americium than expected. Whether this is because of a short circuited delivery mechanism or because Am leaves at a faster rate than Pu, we cannot yet say.

Our new measurements of Pu 241 and of Am 242m promise to help us to explain some details of the peculiar differences between Pu and Am, but data are still very scant.

In organisms of the oceans plutonium levels are very low, and americium appears to be discriminated against even more than is plutonium. Details of the Pu and Am distributions do show that both these transuranics, from fallout or from some nuclear fuel reprocessing wastes, are more available to organisms in the oceans than has been predicted from laboratory studies. Concentration ratios between wet organisms and surrounding water fall in the range 10^2 to 10^5 (except for fish, which range much lower) -- typical of heavy metals.

Long-lived Fallout in Lake Ontario

We have made a series of sediment cores, water stations and biological collections in Lake Ontario every year since 1971. Analyses of these samples for Sr 90, Cs 137, Pu 239 and Am 241 are not completed but have progressed to the point where we can draw some conclusions:

A. Sediment reworking, probably by current scouring or sediment slumping, is very widespread in Lake Ontario -- in strong contrast to Lake Michigan for example. Where normal sedimentation is indicated the sediment column contains most of the Cs 137 or Pu 239, but very little Sr 90; most of the latter is in the water column. In general Pu 239 and Cs 137 show similar profiles of concentration vs. depth in sediments, but detailed comparison shows a good deal of evidence of separation of these nuclides by in-sediment geochemical processes.

Averaged over the lake bottom, the inventory of Cs 137 or Pu 239 represents only 50%, or less, of that expected to have been delivered in fallout; this is in amazing agreement with an estimate of 60%, recently made, for the lake's retention of nitrate or phosphate. In general it does not appear that fallout in the lake sediment can be regarded as irretrievably out of reach of the biota. In the Niagara River sediment fan very high rates of sedimentation are indicated, and fallout nuclides can be thought of as truly having entered a sink -- a large contribution of radioactivity from Lake Erie also is shown there.

B. In the water column Sr 90 shows always an unchanging vertical distribution, and a very slow change with time -- less than half that predicted by recent models of Great Lakes circulation. Cs 137 has shown differences in concentration between surface and deep waters, but without consistency: one year surface may be high, the next the deep water. Plutonium has been higher in bottom water each year so far, and we attribute this to redissolving Pu from the sediments during the period of stable stratification of the lake.

C. Concentration of plutonium or americium by lake organisms is not much different from the marine patterns. We have some indication of a taxonomic relationship for americium preference by rooted algae. As is usual, fish samples are low in transuranics. Bottom-feeding fish are the most likely to show high levels of plutonium, but there are surprising differences in what they do with it: some deposit most in bones, some most in liver, some actually most in muscle, and some divide it pretty evenly. Some predaceous fish show evidence that the effect of a meal of bottom-feeder must last a long time -- Pu must have a very long biological half-life. We have not found any freshwater fish that concentrate plutonium to levels that would make them significant vectors to man. But, as in the oceans, the data show that in Lake Ontario, at least, fallout Pu is more available to organisms than was predicted from laboratory studies.

PCB Effects on Marine Microorganisms

Both plankton algae and bacteria have shown a considerable difference in PCB sensitivity when near-shore populations, or clones, were compared with the open ocean. In the past year our effort has been concentrated on looking for effects that could be quantified, and that occur at PCB concentrations too low to inhibit growth. Quite a number of these have been found, ranging from

morphological responses of cells or of cell organelles, or of colony-form, to pigmentation, or the selective inhibition of individual enzymes.

Evidence that many of these effects occur at even lower PCB concentrations when the cells are stressed by competition, continues to accumulate. We believe this is very important, since most natural populations are so stressed, making it likely that *in vitro*, single-species, tests of sensitivity will have often suggested too high tolerance for PCB -- or other chemical pollutants.

We have still no strong evidence of measurable effects of PCB at present levels in the marine environment.

GEOLOGY and GEOPHYSICS

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

James R. Heirtzler, Department Chairman

THE GULF OF GUINEA

Kenneth O. Emery

One of the major projects of the International Decade of Ocean Exploration (IDOE) is a study of the continental margins off western Africa. Profiles of seismic reflection and refraction, magnetics, and gravity were made during the first halves of 1972 and 1973. The junction between these two cruises was in the Gulf of Guinea, and the manuscript for the geophysical and geological findings in that region was completed during late 1974. Our cruises totalled nearly 31,000 line-km, and traverses from other ships mostly of other organizations added another 50,000 line-km. Enough line density is available to permit a considerable expansion of previous knowledge of the region. The data show that the southern half of the region has a continental margin of divergence, in which South America separated from Africa about 160 m.y. ago, and that the northwestern quarter also has a continental margin of divergence in which North America separated from Africa about 180 m.y. ago. Between these two regions is an equatorial belt of fracture zones that extends from the Mid-Atlantic Ridge to the coastal region between the Niger Delta and Monrovia and in the opposite direction to just off northern Brazil.

The nature of the separation between continents has controlled the history, composition, and structure of these continental margins. The margin in Africa south of the Niger Delta (divergent) originally was narrow and had restricted water circulation (when it was still separated from the North Atlantic Ocean), so that thick evaporites (salt and gypsum) were deposited along the coast during Early Cretaceous time (about 130 to 100 m.y. ago). As the continents separated still more, the evaporites gave way to normal marine sediments whose weight caused the low-density highly-mobile evaporites to flow and produce salt domes that deformed overlying sediments. At the same time the large Niger Delta began to be deposited, and its weight upon underlying sediments produced shale (and perhaps salt) diapirs beneath the delta (see areas landward of dashed lines in Fig.1). Where the deformed strata are now beneath dry land or beneath only shallow water they have been found to be the sites of large quantities of trapped oil and gas (Angola, Gabon, and Nigeria). Far greater expanses of untested but potentially oil-rich strata are beneath the ocean floor beyond the shelves. As shown by Fig.2, the total thickness of sediments in this region is more than eight-seconds reflection time (or about 15 km). In fact, the weight of the sediments has depressed the oceanic crust to more than nine seconds below sea level (Fig.1).

Very different results were produced in the equatorial belt of fracture zones. There the basement topography and the thickness of overlying sediments exhibit long linear more or less east-west trends (Figs.1 and 2). Evidently, the fracture zones that developed during the movement of South America away from Africa controlled the routes of transportation and the depositional sites of sediments from both sides of the developing Atlantic Ocean. The ridges of the fracture zones served as submerged dams and the troughs as places of sediment accumulation. On the continental margin itself the thickest sediments were trapped in basins that formed atop the continental basement during the initial stages of wrenching apart of the protocontinent. Later sediments crossed these filled basins and built prisms on the ocean floor between the fracture zone ridges that partially dammed the flow of sediment-laden water.

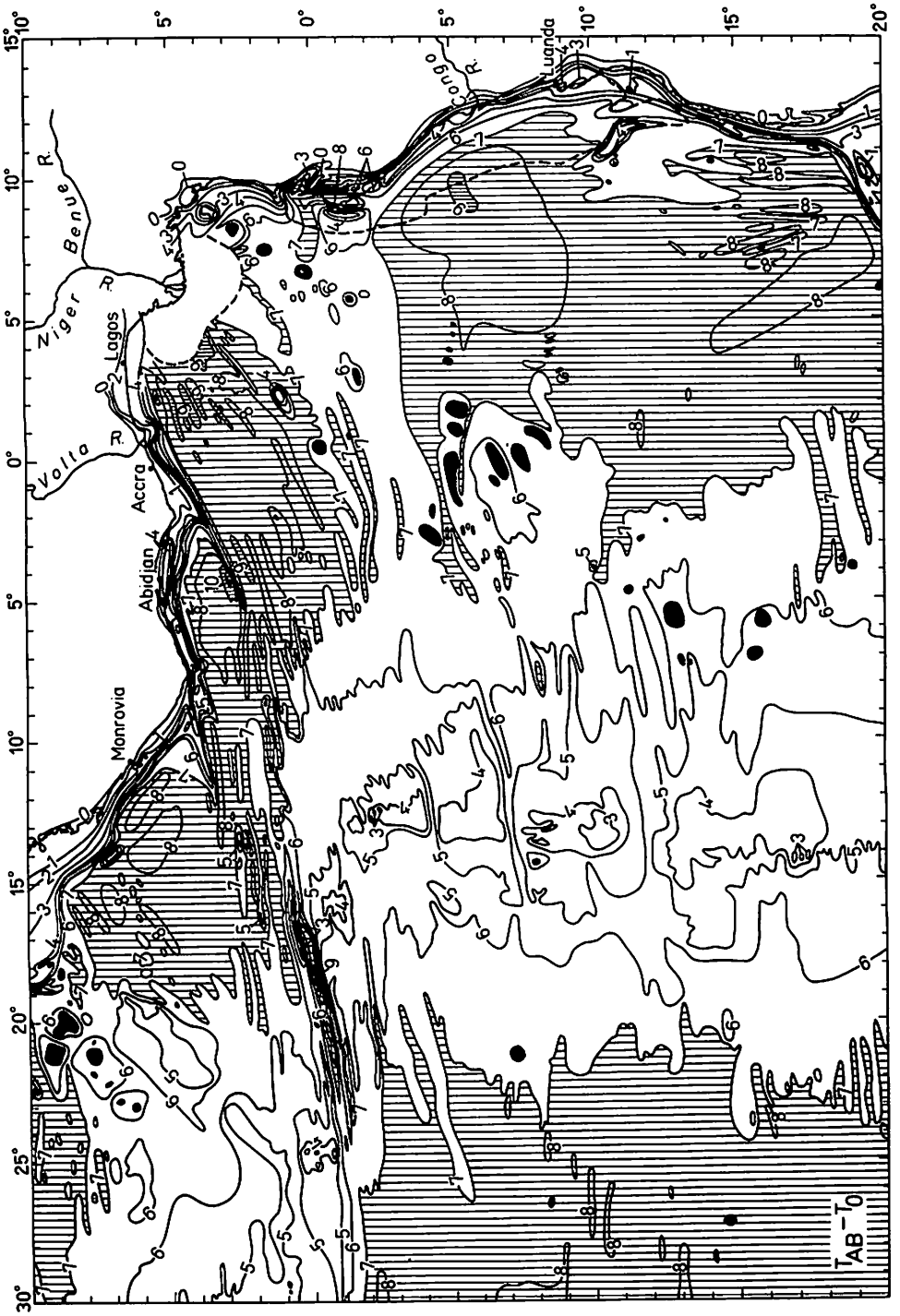


Fig.1 (Emery and Uchupi) Depth to basement in the Gulf of Guinea region with contours expressed in seconds of reflection time

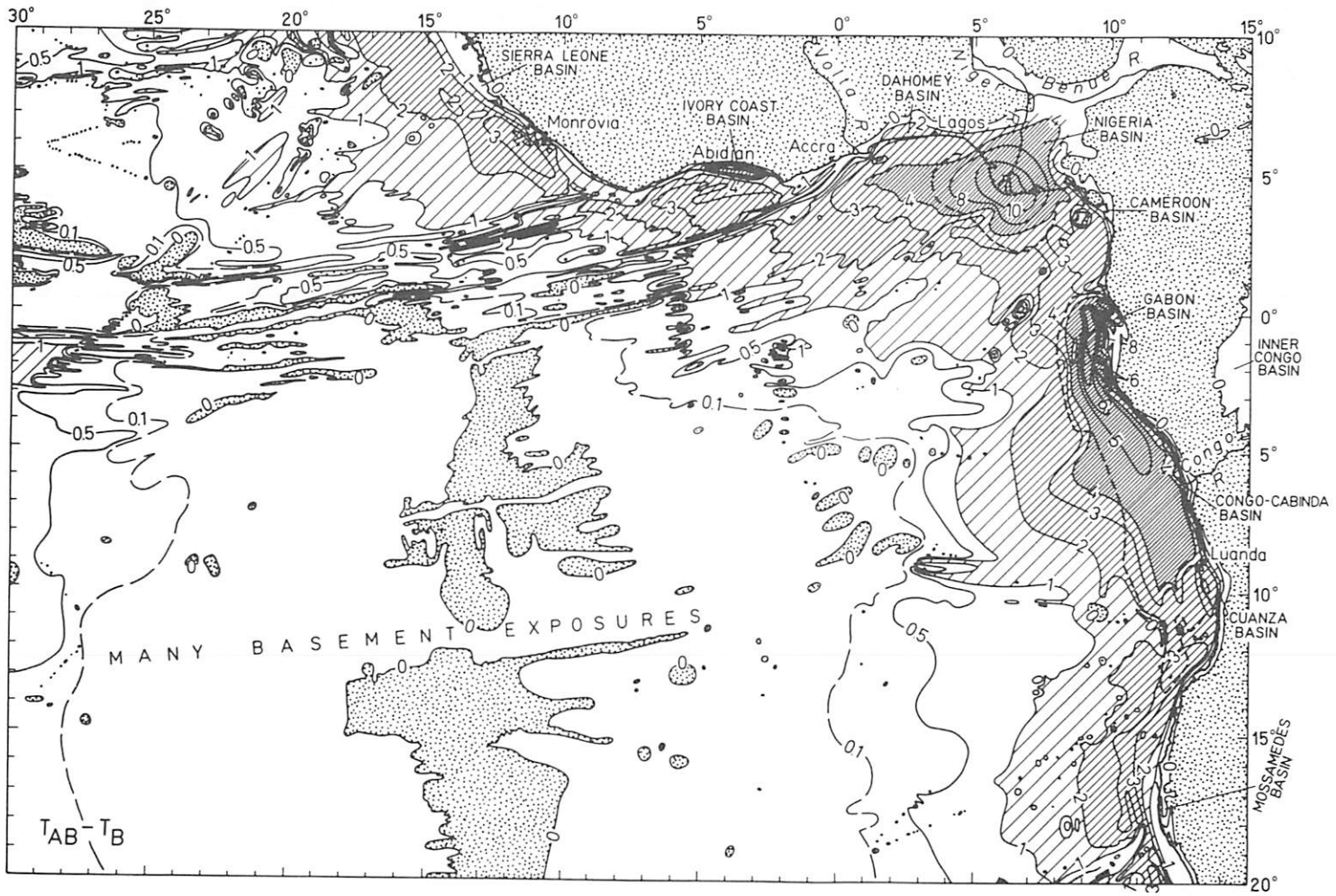


Fig.2 (Emery and Uchupi) Total thickness of sediments atop continental and oceanic basement with thickness contours expressed in seconds of reflection time.

The northernmost region of divergence has relatively thin sediments, probably because both rivers and sediment supply are lacking in that part of Africa. Sediments also are thin far from shore along the Mid-Atlantic Ridge and its bordering regions, partly because South America still occupied that area while sediments were accumulating on the present continental margins of Africa and partly because sediments from shore are not able to reach so far oceanward even yet.

The potential oil resources of the ocean floor in the Gulf of Guinea have value to the west African nations (including those which sent participants aboard R/V *Atlantis II*) as sources of revenue. They also are of interest to the industrialized nations as a potential source of energy needed for their industries.

Dr. Elazar Uchupi was co-investigator on this project.

MARINE GEOLOGY OF THE BRAZILIAN CONTINENTAL MARGIN

John D. Milliman and Colin P. Summerhayes

During the past two years, the writers have been studying the morphology, shallow and deep structure, surficial sediments, oceanography and suspended material of the Brazilian continental margin. During this time more than 40,000 line kilometers of ships' track have been steamed and more than 3000 sediment samples analyzed. The results of these studies have been reported in more than 30 articles and manuscripts, including a monograph on Brazilian continental margin sedimentation (Milliman and Summerhayes, editors).

Activities in 1974 included the conclusion of studies on sediments, oceanography, suspended matter and economic potential of the Brazilian margin, and the continuation of geophysical studies. These latter studies, included the analysis of data collected during cruises off Brazil in 1972-1973 and a cruise on R/V *Chain* 115 in 1974.

Studies conducted aboard the *Chain* cruise involved several distinct investigations. First, was the study of the continental plateaus off northeastern Brazil - Pernambuco Plateau, Rio Grande do Norte Plateau, and Ceara Guyot. All three appear to have thick sedimentary cover over igneous topographic highs; these highs probably are connected to fracture systems and presumably formed during rifting of South America from Africa in post-Jurassic times. Both Pernambuco Plateau and Ceara Guyot contain phosphorite and manganese deposits, which may have economic potential (Milliman and Amaral, 1974).

The major purpose of the *Chain* cruise was a two-ship seismic refraction study of the deep-sea basin off northern Brazil. A total of nine end-to-end profiles were run, and at each, basement with oceanic velocities was reached. Sediment thicknesses range from about four to six kilometers off northeastern Brazil to more than 12 kilometers off the Amazon Cone. Subsequent sonobuoy measurements show that the sediment thins landward of the Amazon Cone, reaching about five kilometers thickness on the inner shelf.

Suspended matter studies on the Amazon shelf indicate that more than 99 percent of the terrigenous matter carried by the Amazon settles from the surface waters shoreward of the 3‰ isohaline surface. Presumably most of this sediment deposits in response to the decrease in vertical turbulence, but also through flocculation of clay minerals. As the light penetration in the Amazon increases, extensive diatom blooms utilize a large amount of the dissolved silica within the river effluent. This is the first instance in which biological uptake of silica within an estuary has been demonstrated.

Reference

Milliman, J.D. and C.A.B.Amaral 1974 Economic potential of Brazilian continental margin sediments. Anais 28th Congresso Bras.Geol.Soc., in press.

SEDIMENTS OF THE RIO GRANDE RISE AND VEMA CHANNEL, SOUTHWEST ATLANTIC OCEAN

David A. Johnson

During Leg 6 of *Chain* Cruise 115 (April-May, 1974), a multi-disciplinary scientific program was carried out within the Vema Channel and on the northern flanks of the Rio Grande Rise (see Fig.1). Geological, geophysical, and physical oceanographic data were obtained in view of the following principal objectives:

A. Correlation of Paleomagnetic and Biostratigraphic Datum Levels

This investigation was directed toward refining the Neogene paleomagnetic time scale in an area of predominantly calcareous sedimentation, the Rio Grande Rise. Reflection profiling surveys have shown that the sediment accumulation pattern on the rise is highly irregular, with deep canyons and channels transecting the pelagic sediment cover. On some flanks of the rise, deeper stratigraphic horizons are apparently outcropping at or near the sea floor. Our objective was to sample a thick stratigraphic sequence within a small geographic area, using closely spaced and precisely located cores.

Thirty-two successful cores were obtained on *Chain* 115, Leg 6. Of these, 23 were within a small area on the north flank of the Rio Grande Rise (see Fig.2).

By examining each core at 150-cm intervals immediately after the core was obtained, we determined the biostratigraphic age and degree of continuity within each core. Our original objective was to obtain cores which were as old as possible by working our way downslope and stratigraphically down-section. However, we found that the Eocene and Oligocene sediments on the lower slopes were sufficiently lithified to cause bending of the core barrels or poor core penetration. Consequently, we attempted most of the cores near the crest and upper slopes of a prominent ridge (see Fig.2) where we were able to consistently obtain full core penetration into Miocene and Pliocene sediments. Ten cores of Miocene/Pliocene age, totalling approximately 70 meters of sediment, were obtained in the area of study. There is an excellent chance of stratigraphic continuity for a substantial portion of the Miocene/Pliocene within these cores.

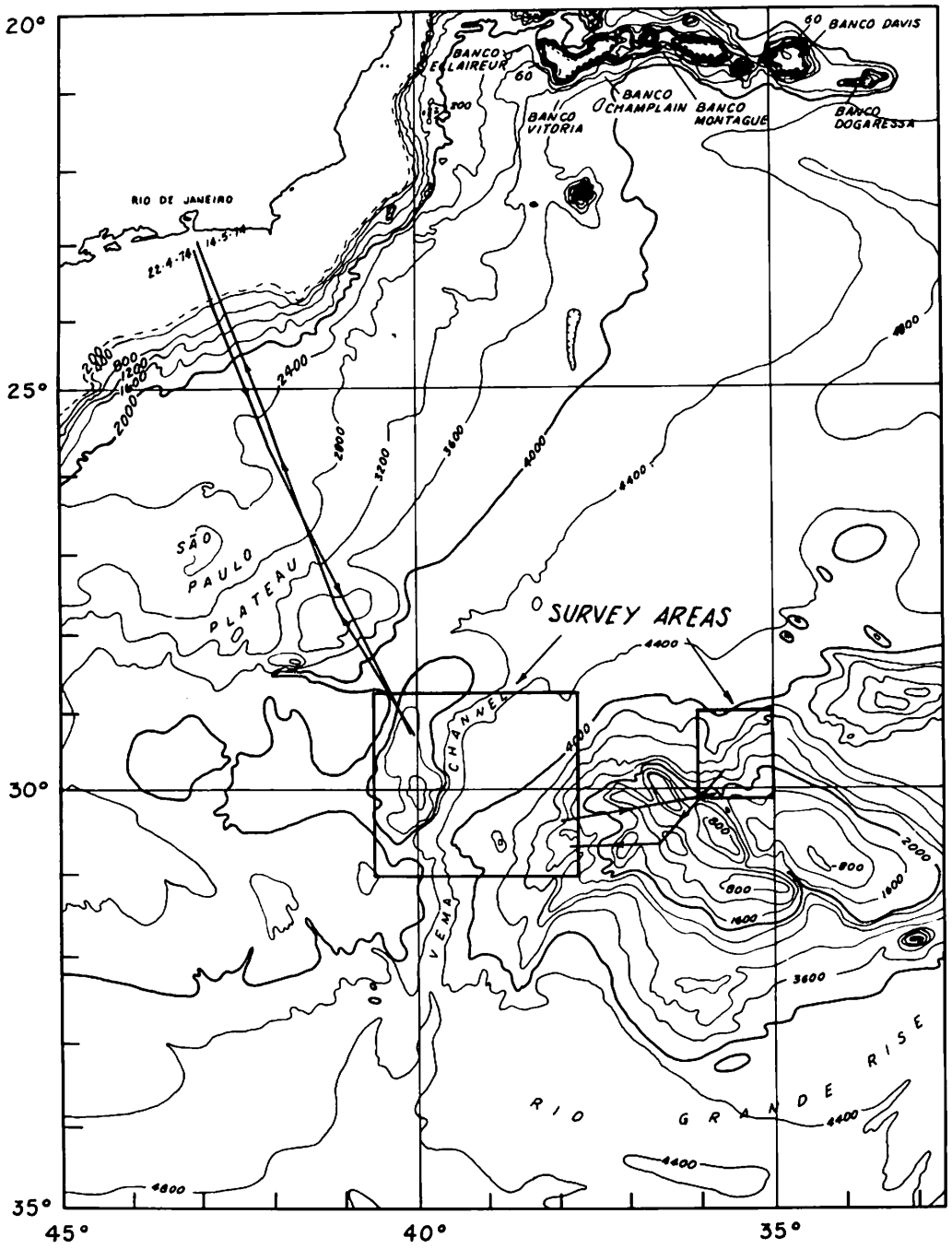


Fig.1. (Johnson) Cruise track of *Chain* 115, Leg 6. Bathymetric contours in corrected meters. Detailed bathymetry of work areas in Vema Channel and on Rio Grande Rise is shown in Fig .2 and 3.

B. Paleo-Oceanography of Vema Channel

The Rio Gra de Rise serves as a major topographic barrier to the northward flow of Antarctic Bottom Water (AABW). The Vema Channel, with a sill depth of approximately 4800 meters, cuts through the Rise near 40°W, and provides a passage for deep and bottom water between the Argentine Basin and Brazil Basin (Fig.1). A sharp abyssal thermocline marks the upper boundary of AABW within the Vema Channel. Cores from above and below this thermocline show strikingly different lithologies, which probably are a result of dissolution effects. Cores taken above the AABW contain assemblages which show strong effects of chemical dissolution.

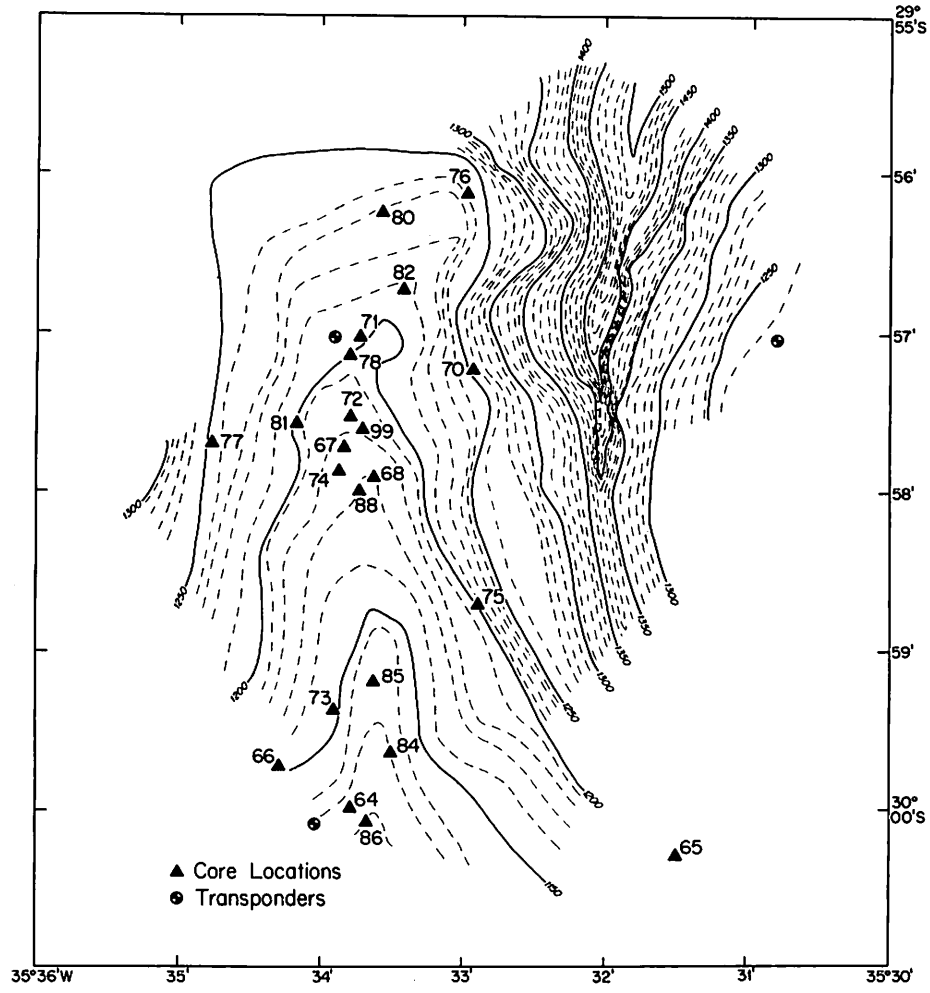


Fig.2. (Johnson) Bathymetry of Vema Channel, after Lonardi and Ewing (1971). Contours are in uncorrected fathoms. Locations of current meters, cores, and profile of hydrographic stations are shown.

The objectives of the investigations in the Vema Channel region were:

1. Establish present flow conditions within the Vema Channel, and determine how these conditions are reflected in the dissolution patterns of microfossil assemblages in core top samples.
2. Obtain a profile of cores up the eastern flank of the channel, and examine dissolution patterns of microfossils at depth in these cores. These dissolution sequences can then be interpreted in terms of vertical fluctuations of the lysocline during the Pleistocene.

Several types of observations were obtained which enable us to determine the present flow pattern of Antarctic Bottom Water within the Vema Channel, and observe its effects on the depositional record. These data include bottom current measurements (5), bottom water temperature profiles (9), hydrographic stations (5), and nephelometer stations (12).

Eight cores were obtained along a profile down the east flank of the channel at approximately 100 meter depth intervals within the range of 3000 to 4000 meters (see Fig.3).

Core analyses and interpretation are being carried out in two stages: First, a set of sedimentological and paleontological criteria will be developed from a detailed study of the core tops in order to characterize, in geological terms, the present upper boundary of the AABW. These criteria will then be applied to down-core studies as a means of determining the position of the top of the AABW through time. The study will include analysis of:

(1) Variations in carbonate content in order to estimate changes in the accumulation rate of calcite;

(2) Variations in the relative abundances of select species of foraminifera, scaled according to their relative resistance to solution;

(3) Variations in the abundance of specific benthic foram taxa.

Age control within the Vema Channel cores is provided by nannofossil biostratigraphy, paleomagnetic stratigraphy, C^{14} dating, and oxygen isotope stratigraphy.

William A. Berggren, Charles R. Denham, Bilal U. Haq and George P. Lohmann were co-investigators on this project.

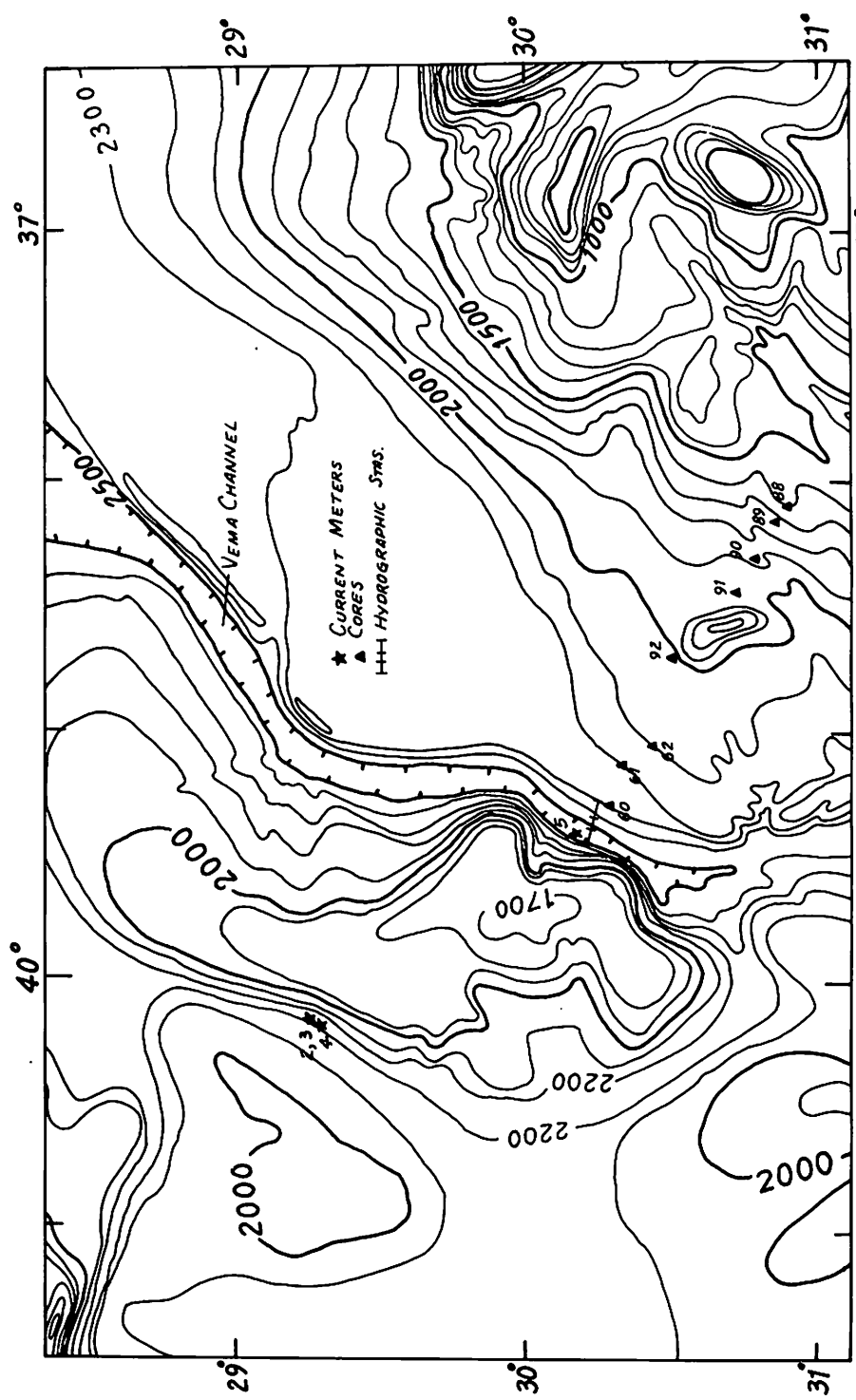


Fig.3. (Johnson) Bathymetry of area of closely-spaced cores on northern flank of Rio Grande Rise. Contours in uncorrected fathoms. Locations of acoustic transponders and cores are shown.

CAPE BASIN, SOUTH ATLANTIC: SEDIMENTATION AND SEA FLOOR PROCESSES

Colin P. Summerhayes

The Cape Basin is the only deep ocean basin of the eastern Atlantic to receive any substantial amount of Antarctic Bottom Water. The northern part of the basin is also unusual in receiving almost entirely organogenic sediments, because of its situation off a desert coast where upwelling brings highly productive water to the surface, in the Benguela Current. We are examining in some detail the sediments, topography, and shallow subbottom structure of the northern Cape Basin in order to determine (i) the effects on the basin sediments of the productivity of the Benguela Current, now and in the late Pleistocene; (ii) the distribution and effects on the sediments of the circulation of Antarctic Bottom Water; and (iii) the nature, extent, and origin of some huge submarine slides which cut into the continental margin of Southwest Africa on the eastern side of the basin.

Our work centers around a single transect of the basin, from Walvis Bay west to the edge of the Walvis Ridge. Along the transect, in January 1974, we collected several piston cores in areas of different sediment type, took bottom photographs to determine the incidence of bottom currents, made hydro casts to examine the distribution of Antarctic Bottom Water, and collected suspended matter from the surface and throughout the water column to determine the modern conditions of sedimentation. The core samples arrived in Woods Hole in June. Since then, most of the sediment analyses, and the analyses of suspended matter have been completed, and work has begun on the interpretation of these data and of the 3.5 kHz records showing bottom and subbottom characteristics.

Our most significant finding is that the irregular topography which is widespread on the continental slope and rise, in water deeper than 2000 meters, has been caused by submarine sliding, rather than by bottom current activity as formerly proposed. These slides appear to be among the biggest ever recorded; they are up to 100 km across, and extend 300 km downslope; the volume of material displaced from the upper part of the slides onto the continental rise appears to be of the order of 10-15 x $10^{10} m^3$. Significantly, many of the features noted on 3.5 kHz records across these features have been noted in other areas, and it may be, therefore, that large-scale sliding is more widespread on the ocean floor than we had previously supposed.

The effects of Antarctic Bottom Water on sedimentation are localized in the western part of the basin, along the foot of the Walvis Ridge, where the youngest sediments of the abyssal plain have been removed in a narrow zone of scour about 25 km across and up to 80 meters deep below the general level of the plain. The scoured sediment has locally been redeposited in the form of structureless drifts up to 80 meters high, 15 km across, and 70-80 km long. Although we had hoped to find that scouring had exposed mid-Tertiary sediments, we found instead that the sediments affected are Pleistocene, interbedded calcareous turbidites (derived from the Walvis Ridge) and pelagic red clays. Either the scour is of recent genesis, or there has been - since the inception of Antarctic Bottom Water activity in the Miocene - a continual scour and fill balance between Bottom Water erosion and turbudite deposition.

Brian D. Bornhold of the Canadian Geological Survey, Ottawa, was co-investigator on this project.

A GEOLOGICAL AND GEOPHYSICAL STUDY OF THE EASTERN MEDITERRANEAN

David A. Ross

This program is a cooperative one involving scientists from the Woods Hole Oceanographic Institution and Egyptian organizations. The Egyptian groups cooperating in the project are, Cairo University, Ain Shams University, the Atomic Energy Commission, University of Alexandria, the Institution of Oceanography and Fisheries and scientists from a UNDP (United Nations Development Project) project who are studying nearshore processes along the Mediterranean.

The program has two main objectives, the first to study the sedimentary regime of the Nile Cone and Nile Delta. To accomplish this a detailed investigation of the composition and mode of transport of the sediment supplied from the Nile into the eastern Mediterranean will be made. The second objective is to ascertain the structural framework of the Nile Cone and eastern Mediterranean. We plan to make echo-sounding traverses (12 kHz and 3.5 kHz), magnetic and sonobuoy measurements, and obtain continuous seismic profiles. Our profiles will tie in with existing and planned DSDP sites. Specific structural problems to be considered can be divided into shallow and deep structural categories. The shallow ones include the origin of a hill and valley structure at the edge of the Nile Cone, establishing when the recent deformation in the area has developed and how it has affected the Nile Cone and Herodotus Abyssal Plain. Deep structural problems include the delineation of ancient trends, an estimate of the size of the delta and cone, nature and extent of seismic reflector M (which has not been mapped yet in this area), and an evaluation of the proposed past connection between the Mediterranean and Red Sea. The answers to these problems will shed considerable light on the evolution of the eastern Mediterranean and the development of the Nile Delta and Cone.

The major results of the first year of this project have been mainly logistical in that several trips have been made to Cairo and Alexandria to discuss detailed aspects of the program. More recently the program took on a more cooperative aspect in that our Egyptian colleagues will plan and coordinate all the nearshore work we plan to do on their continental shelf.

MARINE DESERT

NUCLEAR WASTE REPOSITORY ASSESSMENT OF THE MID-PLATE MID-GYRE REGIONS

Charles D. Hollister

Objective of this research is to fully describe Benthic Boundary Layer phenomena in "tranquil" abyssal ocean regions and to compare these observations with those from dynamic abyssal environments such as those described in "Abyssal Mud Waves".

In this study the boundary region is defined as a few hundred meters above and a few tens of meters below the bottom. New data from this project's test area approximately 600 miles north of Hawaii, show that current velocities within three meters of the bottom are on the order of two to three centimeters per second superimposed on tidal currents of up to 5 cm/sec. Photographs suggest

a tranquil sea floor lightly covered with small manganese nodule and burrow mounds. The area appears to be one of extremely slow rate of sediment accumulation with an unusually high degree of compaction in the top few centimeters.

This study is also designed as a pilot program for the assessment of the sub-sea floor environment for potential disposal of nuclear wastes. Questions being addressed are: 1) What are the rates of processing of diffusion and advection in and near the benthic boundary layer? 2) If nuclear wastes were implanted beneath the sea floor and then allowed to disperse, what are the natural barriers to a release (here defined as when the waste reaches man in any form)? The results of this study were published in December 1974. (Bishop, W.P. and C.D.Hollister, 1974. Seabed Disposal - Where to look. Nuclear Technology, 24: 425-443.)

PROJECT FAMOUS

James R. Heirtzler, Wilfred B. Bryan, Bruce P. Luyendyk and Joseph D. Phillips

Nineteen hundred and seventy-four was a year of major field operations on Project FAMOUS (French American Mid-Ocean Undersea Study). The science divers and pilots made a field trip to Hawaii in January. In February they had a diving program in the Tongue of the Ocean. In April there was a joint United States - France meeting in Woods Hole. During June, July and August *Alvin*, *Lulu* and *Knorr* conducted operations on the Mid-Atlantic Ridge with *ALVIN* making 17 dives. These vessels worked with the two French submersibles and their supporting ships. In December Bryan attended a meeting of petrologists in France to discuss their rock analysis program. Twenty papers and reports were published, in press, or in final stages of preparation in 1974.

Robert D. Ballard, James G. Moore, Tj. van Andel, George H. Keller and Kenneth C. Macdonald were co-investigators on this project.

NEW ENGLAND SEAMOUNTS

James R. Heirtzler and Robert D. Ballard

Returning from the Azores last summer *Alvin* was able to make the first manned submersible dives on seven New England seamounts (Corner Rise, and Gilliss, Nashville, Rehoboth, Manning, Balanus, and Mytilus seamounts). Basaltic rock was collected on most of these while diving to depths of up to 3050 m and observing the seamounts for a distance up to 500 m upslope. The R/V *Knorr* dredged another four seamounts on which it was not possible to dive in the time available. Shallow water carbonates were recovered from Mytilus. The results of these dives will be analyzed during 1975.

Robert Houghton and Patrick T. Taylor were co-investigators on this project.

NEAR-BOTTOM PROCESSES AROUND MYTILUS SEAMOUNT

David A. Johnson

A deeply-towed instrument package was used for conducting near-bottom observations of the benthic boundary layer adjacent to the northeast flank of Mytilus Seamount, and on the surrounding continantal rise. Observational techniques included a narrow-beam echo sounder, 4 kHz seismic profiler, side-scanning sonars, stereo cameras, and thermometer. Principal results of the study can be summarized as follows:

1. Substantial erosion of continental rise sediments has occurred adjacent to the eastern flank of Mytilus Seamount. The presence of converging channels up to several tens of meters in depth has resulted in an irregular pattern of net sediment accumulation above an early Pleistocene acoustic reflector.

2. Concentrations of suspended matter in the near-bottom water vary greatly over small horizontal distances (km or less). Bottom photographs show that visibility is reduced to a few meters or less as a result of high concentrations of particulate material in a region of thick sediment accumulation adjacent to the north flanks of the seamount. Visibility increases at greater distances from the base of the seamount, and at shallower depths approaching the crest of the seamount.

3. The region of highly turbid bottom water corresponds to an isothermal ($\sim$1.7^{o}C) layer which is overlain by a sharp benthic thermocline. The isothermal layer is restricted to the north flank of the seamount, and is indicative of intense vertical mixing within this localized region. At increasing distances from the base of the seamount a more normal benthic temperature gradient (.08^{o}/100 m) is present. The topographic effects of the seamount within the flow of the Western Boundary undercurrent may be responsible for creating vertical instabilities in the near-bottom water on a small scale.

4. The direction of flow of bottom water near Mytilus Seamount was <u>not</u> uniformly parallel to the regional contours throughout the period of our measurements (3½ days). Upslope (northward to northwestward) current flow was recorded for considerable periods of time (one-two days) at each seamount. The direction of flow abruptly and simultaneously shifted to southward at each of the current meter stations. This irregular flow pattern may be a consequence of interactions between the Western Boundary Undercurrent and migrating eddies of the overlying Gulf Stream water. Such an interpretation is consistent with previous observations indicating that the effects of the Gulf Stream appear to extend throughout the water column in several relatively deep areas (>3 km).

Peter F. Lonsdale was co-investigator on this project.

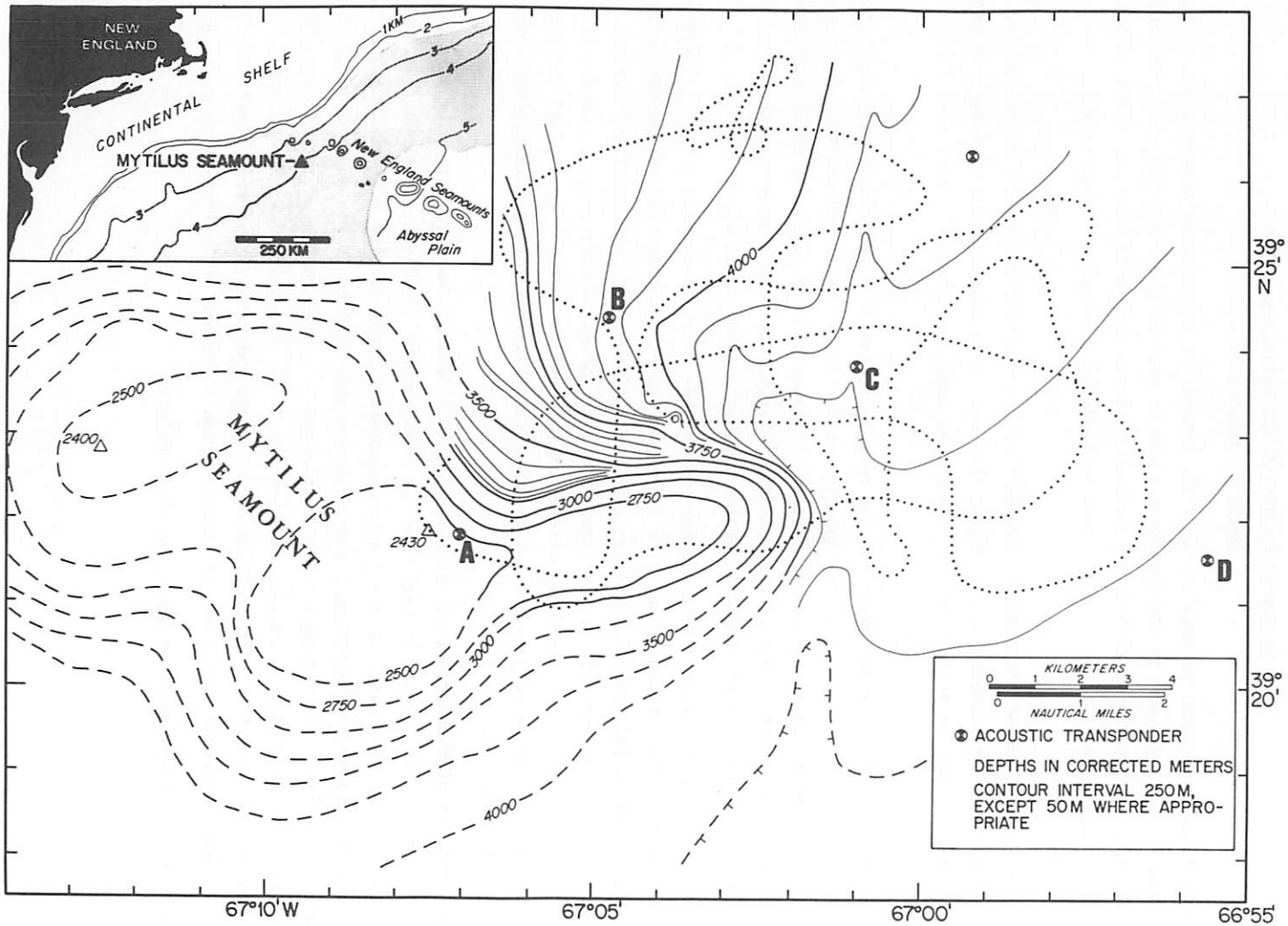


Fig.1 (Johnson and Lonsdale) Near Bottom Processes around Mytilus Seamount.

PETROGRAPHY AND MAJOR ELEMENT CHEMISTRY OF BASALT GLASSES FROM THE FAMOUS AREA, MID-ATLANTIC RIDGE

Wilfred B. Bryan

One of the unique features of young submarine basalt lava pillows is the presence on their surface of a one-to-two centimeters thick layer of pure basalt glass which results from almost instantaneous quenching of the extruded lava when it encounteres cold seawater. These glasses, rare on terrestrial basalt flows, provide a unique opportunity to study features of crystal-melt equilibria in basaltic liquids, because they provide an unambiguous sample of liquid (glass) compositions, while the composition of minerals in equilibrium with that liquid are represented by scattered mineral phases (phenocrysts) suspended in the glass. Thus, each glass is the product of a natural quenching experiment, and as such it is especially easy to relate data from these glasses to experimental silicate systems.

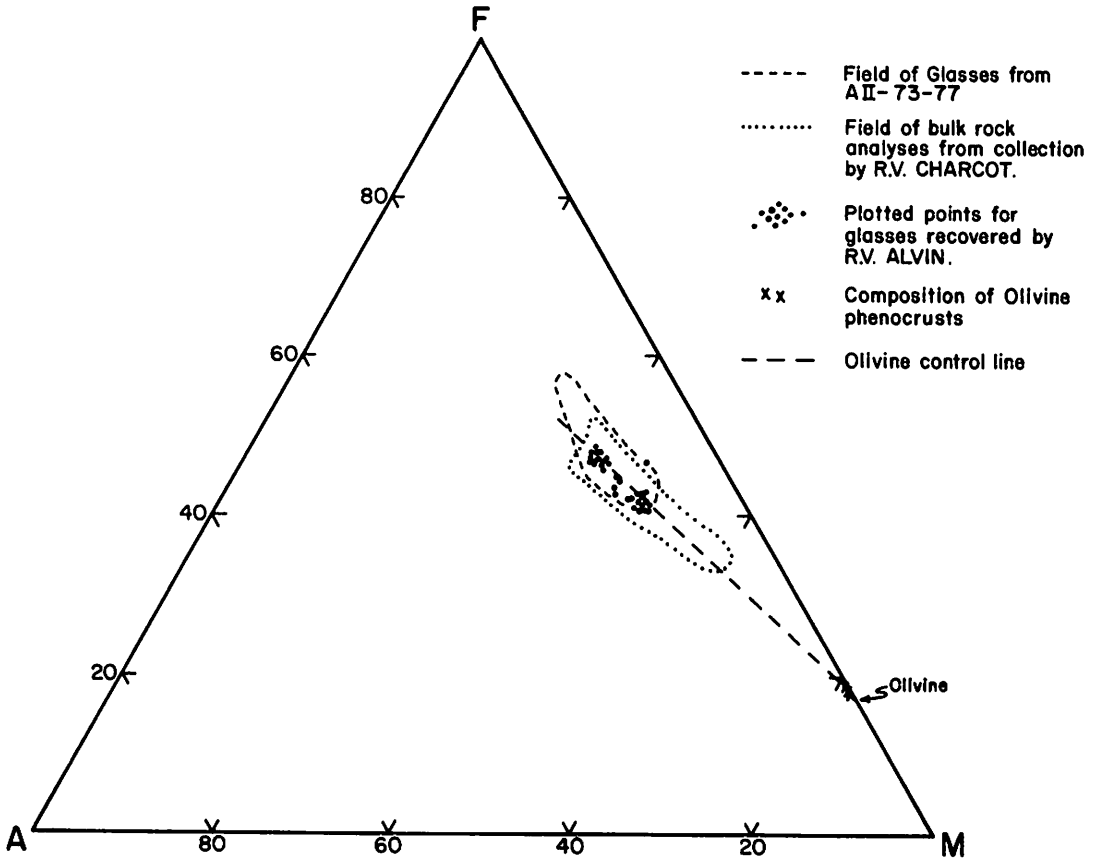


Fig.1 (Bryan)

We now have electron microprobe analyses for some 45 basalt glasses from dredge samples obtained on *Atlantis II* cruises 73 and 77, and *Knorr* cruise 42, and some 43 glasses representing samples from the 15 rift valley dives by R/V *Alvin* during the summer of 1974. Analyses of typical mineral phases (olivine, plagioclase, pyroxene) have also been completed. The data are most readily summarized in an AFM diagram (Fig.1) which also shows the variation in bulk rock data in the R/V *Charcot* collection (R. Hekinian, personal communication). The *Charcot* data are all bulk rock analyses by X-ray fluorescence and represent a mixture of liquids and suspended crystals, and some are notably enriched in olivine. The extension of the *Charcot* data along the olivine control line defined by our olivine analyses confirms the dominant role of olivine crystallization and accumulation in determining the bulk rock composition trends. The few phenocryst-free analyzed glasses in the *Charcot* collection agree closely with our analyses of the more magnesian glasses, as suggested by the figure. There is a curious tendency for the *Alvin* data to fall into one of two tightly-clustered groups, with the more magnesian group representing data from the recently active central volcanic high and the more iron-rich group being typical of the flanks of the Median Valley. These differences are confirmed by petrographic differences, the first group being characterized by phenocrysts of plagioclase, olivine, and spinel, and the second group by plagioclase and pyroxene. Glasses as iron-enriched as those represented by the part of the *Atlantis II* 73-77 field projected toward the F corner were not recovered by *Alvin*. All of these glasses come from dredge hauls along the central volcanic axis of the rift valley south of fracture zone B, which was not sampled by *Alvin*. This supports bathymetric evidence that these two rift valleys may be developing in somehwat different ways, or may be at different stages of development, and indicates the need for caution in interpreting the data.

In most of the glasses plagioclase and olivine crystals are the principal phenocrysts and are in the proportion of 2:1 as they should be if the glasses lie along the cotectic in the analogous experimental system diposide-anorthite-forsterite. More detailed calculations confirm that most of the compositional variation can be accounted for by fractional crystallization, using methods similar to those applied to DSDP (Deep-Sea Drilling Project) basalts (described elsewhere). However, there remain some disturbing discrepancies for components such as TiO_2 and K_2O which suggest that other processes may be operating. Titanium and potassium may be especially sensitive to the influence of the Azores "mantle plume" as indicated by concurrent work of Jean G. Schilling, from the University of Rhode Island. We are continuing to test alternative models for magmatic evolution and expect during the coming year to obtain trace element data which may place appropriate constraints on these hypotheses.

In more detailed studies, we have examined age relations between flank volcanism and volcanism on the central high, using manganese crusts and carbon-14 dating of attached corals. This confirms the essential equivalence in age between some flank lavas and the central high, and suggests an age of about 1000 years for the latest eruptions. Also, crystal sorting in a zoned lava tube has been studied; by analogy with similar features in exposed terrestrial dikes and from theoretical studies, this sorting implies appreciable flow through the tube. This confirms other observations suggesting that some lava tubes serve as major feeders for submarine lava flows.

Joseph D. Phillips and James G. Moore were co-investigators with Wilfred B. Bryan in the preceding research on basalt glasses.

SUBMERSIBLE INVESTIGATIONS

Charles D. Hollister

The objective of this research is to understand dynamic, near-bottom processes presently active on continental margins through direct observation from research submersibles such as DSV4 *Sea Cliff* and the Nuclear Research Submersible *NR1*. Observations were made in Pelekuna Submarine Canyon off the island Molokai, the Mona Canyon off Puerto Rico, the Hudson Submarine Canyon and the Western Blake Plateau and Florida Straits. Preliminary data suggest that the Pelekuna Canyon, now extending to 2000 m below sea level, was formed in a subareal environment. No evidence was observed for extrusive submarine volcanic activity, a marked contrast to the well-developed pillow flows observed around the island of Hawaii. A summary of the results of this project was presented at the GSA (Geological Society of America) annual meeting (November, 1974).

UNITED STATES/JAPAN COOPERATIVE PROGRAM

Carl O. Bowin

A report on the Tokyo Surface Ship Gravity Meter (T.S.S.G.) and its comparison with the LaCoste and Romberg Air Sea Gravity Meter has been prepared in cooperation with Jiro Segawa of the Ocean Research Institute, University of Tokyo. The T.S.S.G. uses the frequency of a single vibrating string to measure vertical acceleration. An important source of error caused by a non-linear relationship between the frequency of vibration and environmental acceleration, has been suspected since T.S.S.G. was first used. A new data processor for the T.S.S.G. has been constructed which is based on a rapid reading of frequency of vibration by means of pulse train logic. Results from the new processor have been compared with the results from the conventional method of data processing, and we have confirmed improved performance of the new processor. The problem of the phase lag of measurement which occurs when an analogue type low pass filter is used, has been solved by use of a deconvolution filter. In order to check the performance of the T.S.S.G. equipped with the processor, we carried out comparison measurements using both the T.S.S.G. meter and the LaCoste & Romberg Air-Sea Gravity Meter S-32 on the same ship. The comparison measurements resulted in a reasonably good coincidence for the results of the two meters, suggesting that the T.S.S.G. meter can be used for accurate measurement of gravity at sea.

As part of this cooperative program 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 and Keith Louden) the data obtained with LaCoste and Romberg sea gravity meter S-32 during cruises KH-72-1 and KH-72-2 of the *Hakuho Maru*. Reports on these data for the Ryukyu island arc and Sulu Sea are in progress. Samples of an intrusive biotite dacite collected on Okinawa during a port stop

of the *Hakuho Maru* have been dated by the Argon 40/39 method by R. H. Reynolds of Dalhousie University. Its age is 13 million years, and together with other information for the region of the Ryukyu arc suggests that the Okinawa Trough on the concave side of the arc may have developed in the last twelve million years.

References

Segawa, J. and C. Bowin 1973 The Tokyo Surface Ship Gravity Meter: Recent Developments for Solving Non-Linear Rectification Error and Phase Lag Problems. WHOI Ref.No.73-89, dtd. Dec.1973.

Segawa, J. and C. Bowin The Tokyo Surface Ship Gravity Meter: Recent Developments and Results of Comparison Measurement. (in press) Geophysics.

ISLAS ORCADAS

James R. Heirtzler

The R/V *Islas Orcadas (*ex *Eltanin)* was transferred from the United States to the Argentine Government for that Government to operate as a research vessel (with United States financial support) *in circum* Antarctic waters.

A meeting of a United States/Argentine steering committee met in early April anticipating joint cruises to start in May or June. Due to technical difficulties the first short cruise did not take place until December, although geology and geophysics personnel were standing by. The first geology and geophysics cruise is now scheduled for the northern fall of 1975.

DATA PROCESSING AND MANAGEMENT

Charles R. Denham and Robert C. Groman

The staff of the Digital Data Library are responsible for the processing and management of marine geophysical measurements and photographs acquired by the Woods Hole Oceanographic Institution. In order to provide chief scientists and other investigators promptly with error-free data in digital and graphical formats, our personnel and computer software perform complete at-sea processing of navigation, bathymetry, gravity, and magnetic measurements. Digital and analog records and photographs are cataloged ashore and made readily available in many different forms. We develop and maintain software for the efficient retrieval and graphical display of data in the master tape library and also aid scientists in gaining access to programs and data within the Woods Hole Oceanographic Institution and from other institutions. Preliminary cruise reports and graphical reference guides to all our digital data are published periodically and given wide distribution. Pursuant to Navy and National Science Foundation policies, our digital data are submitted to the National Geophysical and Solar-Terrestrial Data Center (NGSDC). Since 1970, in cooperation with Carl Bowin's gravity group, we have processed and made available more than 985,000 records of marine geophysical measurements.

During 1974, we made available over 45 additional cruise legs of digital navigation data, 30 of bathymetry, 21 of surface magnetics, and 9 of gravity. In each category, nine legs were acquired

during the Institution's 1973-74 SOUTHLANT (South Atlantic) Expedition. Our photolibrarian and technician developed and cataloged all 1974 deep-sea photographs, as well as about 10% of the Institution's unprocessed backlog.

Beginning with *Chain* 115, preliminary cruise reports are being written containing brief descriptions of the scientific programs undertaken in each leg. The reports are accompanied by computer-generated charts showing navigation, bathymetry, magnetics, and gravity data, as well as composite profiles displaying the underway data with respect to time. Because of their immediate value to ongoing research and to the planning of future cruises, we are attempting to prepare these reports within one month after all the data are processed.

The graphical guide to our digital data (Project MYLAR) has been published (WHOI Tech.Rept. #74-44). These charts of marine geophysical measurements were originally drawn by computer on Mylar master sheets, which will be updated and republished periodically to show new cruises as well as newly processed older cruises.

The Digital Data Library System (WHOI Tech.Rept. #74-68) was completed in 1974. This user-oriented data retrieval system gives researchers easy access to the Institution's entire collection of underway digital data, stored on blocked magnetic tapes. Program MUDDIE was written to retrieve, sort, and display digitized information on the Institution's collection of geological samples. Other software developments were directed at upgrading existing programs to incorporate improved data processing procedures and expanded graphical options. In addition, some new routines were necessary for communicating between the various data formats used by Woods Hole Oceanographic Institution, National Geological and Solar Terrestrial Data Center (NGSDC), and other institutions.

We have begun the task of converting our at-sea data processing package to the new Disc Operating System (DOS-M) now being implemented by the Shipboard Computer Group, which will result in a more sophisticated and flexible processing system. In addition, the DOS-M conversion is an essential step toward marine data processing under the software supervision of the powerful Real-Time Executive (RTE), whose implementation is due in 1976 or 1977.

References

Richards, D., R. Groman, B. P. Luyendyk and C. Denham 1974 Guide to Marine Geophysical Digital Data 1959-1972. W.H.O.I. Ref. No.74-44.

Groman, R. C. 1974 The Digital Data Library System: Library Storage and Retrieval of Digital Geophysical Data. W.H.O.I. Ref. No.74-68.

SEA FLOOR SAMPLES LABORATORY

David A. Johnson

The Woods Hole Oceanographic Institution Geological Collection now contains approximately 1,000 cores, 8,000 sediment samples from the W.H.O.I.-U.S.G.S. (Woods Hole Oceanographic Institution-United States Geological Survey) continental shelf study, 250 dredge samples, and 150 rock samples collected by the deep submersible *Alvin*. This material has been obtained primarily from expeditions within the past 15 years, and has recently been relocated in the new core storage facility (DESC (Data and Earth Sample Center) Building) on the Institution's Quissett Campus.

The following projects have been completed during 1974:

1) Cataloging, photography, and preliminary description of core samples. All of the cataloging and preliminary macroscopic and microscopic analyses of the cores have been completed. Final copies of the lithologic summaries, visual core descriptions, and smear slide descriptions are now being typed and proofread. This descriptive information will be published in the form of a bound W.H.O.I. Technical Repost (Johnson and Driscoll, in preparation). Included in the report will be sample listings and index maps showing sample locations. Core photographs will not be printed and distributed routinely together with the geological descriptions, but prints of individual core pnotographs are available upon request.

2) Digitization of all geological sample data. The digitization of sample data for the entire W.H.O.I. Geological Collection is now completed. It is now possible to quickly produce a full listing of all samples in the collection, using the Xerox Sigma 7 computer at Woods Hole and the Xerox "MANAGE" program. The "MANAGE" program was selected due to its ability to allow data sorting in any one of nine key retrievable categories. The particular categories that can be utilized are: (1) Ship; (2) Cruise; (3) Station Number/Dive Number; (4) Sample Number; (5) Type of Sampling Device; (6) Marsden Square; (7) Depth in Corrected Meters; (8) Physiographic Province; and (9) Rock Type/ Sediment Type. By using these key fields it is now possible to recover data according to the specific needs of individual investigators. A W.H.O.I. Technical Report has been prepared which outlines the format utilized in digitizing the sample data.

3) Formulation of plans for data distribution to other data centers. We have been in contact with the Scripps Institution of Oceanography, the Smithsonian Institution, and Environmental Data Service concerning the availability of our data listings. We plan to provide these and other data centers with a complete station and sampling listing on magnetic tape by early 1975.

Reference

Johnson, D. A. and Alan H. Driscoll 1975 Description of Woods Hole Oceanographic Institution Sediment Cores. W.H.O.I. Technical Report in preparation.

PETROGRAPHY AND COMPOSITIONAL VARIATION IN BASALTS FROM DSDP (Deep Sea Drilling Project)

Wilfred B. Bryan

During the past year work has been completed on rocks from DSDP legs 2 and 3 in the Atlantic Ocean. A paper based on this work was published in Journal of Geophysical Research. Although the holes drilled on these early legs had very shallow basement penetration, the rocks recovered covered a remarkable range of compositions. They included very mafic basalts at sites 14 and 18, which are the most "primitive" or depleted in light rare earth elements and other large-ion trace elements of any sea-floor basalts so far reported. In contrast, at sites 10, 11A, and 15, rare pyroxene-bearing basalts were encountered which show complimentary enrichment in light rare earths and large-ion trace elements. Comparison with experimental silicate systems and calculations using major element and trace element data indicate that most of the compositional variation observed can indeed by explained by a fractional crystallization mechanism. However, a basalt from site 10 which more closely resembles the alkaline basalt typical of oceanic islands and seamounts is more easily explained as derived from a mantle source of different composition compared to that beneath the mid-ocean ridges.

A study of leg 34 basalt from sites 319, 320, and 321 on the NAZCA plate was completed and submitted for publication as part of the preliminary report volume. Again considerable compositional variation was observed, and can be explained by fractional crystallization of typical ocean ridge basalt. However, the NAZCA plate samples did not include the olivine-rich mafic basalts like those which we documented from sites 14 and 18 of leg 3.

A mineralogical study of submarine basalt plagioclase based largely on DSDP samples but also including dredged samples from the Woods Hole collection was published in Earth and Planetary Science Letters. Sector-zoning, apparently unique to submarine basalt plagioclase, was described in some detail. It was also demonstrated that, contrary to traditional assumptions, there is a significant amount of Fe^{2+} and Mg in the plagioclase structure which is largely in tetrahedral coordination. Because this will have a significant influence on the thermodynamic properties of plagioclase, it was suggested that caution must be exercised in calculating submarine basalt crystallization temperatures from plagioclase compositions.

Analytical work was completed on Mesozoic basalt from leg 11, sites 100 and 105 in the western Atlantic. These data, together with that completed for legs 2 and 3, demonstrate that there are no demonstrable compositional variations with time in the Atlantic and that most of the sea-floor basalts seem to have an ocean-ridge origin. Because of the proximity of the leg 11 sites to the continental margin they invite comparison with basalts of the Triassic rift valleys in the eastern United States. In a paper being prepared for publication, we show that there are significant geochemical differences between the Triassic and leg 11 basalts. The nature of the differences are such as to suggest a significant residence time for magmas at the base of the continental crust, allowing crustal contamination before rifting began.

Our investigations have included studies of chemical and textural changes due to submarine weathering. We have demonstrated that concentrations of rare earth elements are affected by extreme weathering and hence are not always a good indicator of the original composition of weathered basalt. We have shown that even delicate quench mineral textures in the original basalt glass may be "fossilized" during weathering, so that some inferences may be made about the mineralogy, and hence bulk composition, of weathered basalt. One promising result of this work has been the recognition by Canadian geologists that ancient Pre-Cambrian basalts, once thought to be extensively altered, retain similar quench textures and hence their original compositions and changes in composition can be deduced for them using the same methods we have applied to submarine basalts. Tentatively, their work suggests that many of these ancient basalts were similar in composition to modern sea-floor basalts, and their similar flow forms (documented in the FAMOUS area and described elsewhere) imply extrusion under water. This leads to the exciting implication that the earth may have had proto-oceans as long as three billion years ago, and that the chemical characteristics of these early oceans might be inferred from the chemical changes preserved in weathered Pre-Cambrian basalts.

Geoffrey Thompson, Department of Chemistry, Woods Hole Oceanographic Institution and Frederick A. Frey, Department of Earth and Planetary Sciences, Massachusetts Institute of Technology were co-investigators in this research.

References

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Thompson, G., W. B. Bryan, F. A. Frey, J.S.Dickey and J. Suen. Petrology and geochemistry of basalts from DSDP leg 34, NAZCA plate. Preliminary reports of the Deep Sea Drilling Program, 34, in press.

DEEP SEA CARBONATE SEDIMENTATION

John D. Milliman

The cementation of calcium carbonate within the marine environment takes place in several distinct manners, which can be differentiated on the basis of stable isotopes, mineralogy, and petrographic properties. Shallow-water and intertidal limestones are in isotopic disequilibrium with ambient waters; this fact, together with other data, suggests that cementation is related to the metabolic activity of blue-green algae and other microorganisms. Deep-sea limestones (200-3000 m water depth) in nondepositional or hypersaline environments are in isotopic equilibrium and display characteristically unique cements, suggesting that cementation occurred by inorganic precipitation. In contrast, deep-sea limestones associated with igneous rocks have compositional characteristics which indicate cementation occurred during alteration of the host rocks or possibly during the volcanic activity.

Despite the fact that some carbonates in the deep sea are lithified, generally calcium carbonate is undersaturated in waters deeper than 500 to 1500 m. The rate of carbonate dissolution, however, is poorly documented. In an attempt to study carbonate dissolution rates, the writer installed dissolution experiments in a number of deep-sea current meter moorings. Preliminary results show that in the central western North Atlantic, aragonite begins rapid dissolution at approximately 3500 m, magnesium calcite at about 5000 m, and calcite at some depth below 5300 m. Comparisons with calcite dissolution experiments from the Pacific suggest that rapid dissolution begins when the ambient waters reach approximately 50 percent saturation with respect to the specific carbonate mineralogy.

ABYSSAL MUD WAVES

Charles D. Hollister

Objective of this grant is to understand the distribution and the origin of Mud Waves and erosional bed forms on the deep sea floor. Principal data was obtained with the Scripps Institution of Oceanography deep-towed instrument package (Deep-Tow). Reduction of the data during early 1974 revealed compelling evidence that the hyperbolic echoes recorded from 3.5 and 12 kHz recorders on surface ships in areas of current-controlled sedimentation are due to interference effects of steep-sided (30-40^{o}), long (2 km) furrows that have been recently eroded by some form of paired longitude vortices moving parallel to the mean current direction as measured in the furrows. The furrows are a few meters to tens of meters across and one meter to approximately five meters high. They were first seen on the side-scan sonar of the deep-towed fish and appeared to have tuning-fork junctions opening up-current. These features have similar morphology to bed forms in terrestrial as well as in the shallow marine environment. This is the first time that such bed-forms have been noted in abyssal depths. The primary results of these findings were published in the summer of 1974 (Hollister *et al.*, Abyssal Furrows and Hyperbolic Echo Tracer on the Bahama Outer Ridge, Geology, Aug., pp.395-400).

In addition oral presentations summarizing these results were presented to the American Geophysical Union in the spring and to the NATO Benthic Boundary Layer Symposium (France) in November 1974. A more complete summary of this effort was published in the fall of 1974 (Flood, R. and C.D. Hollister, 1974. Current-Controlled Topography on the Continental Margin off the Eastern Univer States, In: C.A.Burk and C.L.Drake, (Eds.) The Geology of Continental Margins, Springer-Verlag, N.Y. pp. 197-206).

BOTTOM CIRCULATION IN SUBMARINE CANYONS

Robert D. Ballard

Beginning in January 1974, under Atlantic Foundation sponsorship, a submarine canyon bottom station was established in the Great Bahama Canyon located at the entrance to the Tongue of the Ocean. Two current meter arrays were installed in the axis of that canyon, one at 8,000 ft and another at 10,000 ft, both with the meter less than 30 ft. off the bottom. In March 1974 the two meters were recovered and found to have operated properly providing a continuous series of measurements on the nature of water movement in the canyon over a three-month period. Upon recovering the current meter array at the 8,000 ft site, it was reserviced, the data film replaced, and the array was placed back on the bottom. In June 1974, that cycle was repeated and again in January 1975, resulting in one year of near-continuous operations. It should be pointed out that the last measurement period lasted seven months with the recovered array showing little to no corrosion or marine fouling. The transponder/acoustic release is of A.M.F. design while the current meter is built by Braincon. Analysis of the data collected is currently underway and will be summarized in a later publication.

During the return trip from the Project FAMOUS operations, a second current meter array of identical construction was placed in 7,000 feet of water in the axis of Hydrographer Canyon. That array has been operating since early September 1974 and is scheduled to be recovered in February 1975 after six months of operations.

Donald E. Koelsch and Rodman F. Davies were co-investigators on this research.

SEDIMENT DYNAMICS

Charles D. Hollister

Objectives of this contract are to understand the contemporary dynamics of fine-grain sediment motion and to recognize past deep-water events through the sampling of abyssal sediments. One problem under study now is the mode and rate of clay-floc settling through the logarithmic and viscous sublayer. One achievement under this grant was the design, construction and successful use of a chilled ($3^{o}C$) salt water flume and the successful running of the flume with particle concentrations on the order of 10 parts per million. This is the first time a salt water flume has been controlled to run at these concentrations and temperatures.. Preliminary results suggest that a 50% change in viscosity will decrease the accumulation rate by approximately the same amount. A coulter counter has been leased under this grant in order to allow us to make size analyses of suspended particulate matter.

During 1974 Paleo-circulation patterns have been developed from the Western Equatorial Pacific (Hollister, C.D., D. A. Johnson, P. F. Lonsdale, 1974. Current-controlled abyssal sedimentation: Samoan Passage. J.of Geology, 82: 275-300) and the Atlantic Ocean (Berggren, W.A., and C.D.Hollister, 1974. Paleo-geography, Paleo-biogeography and the History of Circulation in the Atlantic Ocean, In: W.W.Hay (Ed.), Studies in Paleo-oceanography, Soc.Econ.Paleo.and Mineral; Sp. Paper 20: 126-186).

A comparison between the Eastern and Western Margins of the North Atlantic was also completed under the aegis of this grant (Young, R.A. and C.D.Hollister, 1974. Quaternary Sedimentation on the Northwest African Continental Rise. J.Geol., 82: 675-690.)

GEOTHERMAL INVESTIGATIONS IN OCEANIC REGIONS

Richard P. Von Herzen

By measurements of the distribution of geothermal parameters (vertical temperature gradient, thermal conductivity, and bottom water temperature) near and within the sea floor, we are trying to understand the energy fluxes and heat budgets of tectonic processes associated with oceanic regions. Heat flow and bottom water temperatures were extensively measured on Legs 4 and 5 of SOUTHLANT Cruise along profiles crossing the Mid-Atlantic Ridge at latitudes 55°S (the South Atlantic triple junction) and at 32°S. A suite of measurements on the Rio Grande Rise during Leg 6 of the same cruise showed generally normal heat flow values on that feature, and provided vertical profiles of bottom water temperature useful for deducing the character of deep water circulation near the Rise. Measurements from R/V *Knorr* on the Mid-Atlantic Ridge near 36°N latitude in summer 1974 (FAMOUS) complement the measurements obtained in 1973 from *Atlantis II*-77 cruise in the same region. On a cruise to the Gulf of California, in fall 1974, carried out in cooperation with Scripps Institution of Oceanography and the United States Geological Survey, detailed measurements in the Guaymas Basin showed a large heat flow variability over lateral scales of a few kilometers, similar to the pattern on the Galapagos Ridge, attributed to hydrothermal circulation in crustal rocks.

On the JOIDES Deep Sea Drilling Project, instrumentation has been used to obtain heat flow data in deep drill holes on three legs in 1974. Measurements were made in the Bauer Basin (East Pacific at Site 319 during Leg 34 within the sediment column; plans to measure temperatures in hard rock portions at holes on the leg were thwarted by the unexpected difficulty in drilling hard rocks on this leg. However, during Leg 37 on the northern Mid-Atlantic Ridge, measurements in hard rock holes near the ridge crest were apparently successful. The value of heat flow inferred, about 0.7×10^{-6} cal/cm^{2}sec, is rather low so near an active spreading ridge, suggesting that hydrothermal circulation may dominate the local thermal regime and extend at least several hundred meters beneath the sea floor. On Leg 38, measurements were obtained in drill holes at Sites 338 and 341 on the Vøring Plateau, Norwegian Sea; the data have not yet been reduced.

SEA-FLOOR MAGNETIC VARIATIONS - 1974

Richard P. Von Herzen

A three-component vector magnetometer has been developed for use on the sea floor. Thin-film sensors are utilized to digitally measure the earth's magnetic field. Data samples are taken every sixty-four seconds and are recorded on a digital cassette tape. The instrument is housed in an aluminum pressure case which is mounted horizontally in a tetrahedral frame. Power is supplied to the instrument through either an internal or external battery pack. The external battery pack is incorporated into the anchor which is dropped from the frame upon release. The instrument can be recovered either acoustically or by preset timer.

The prototype sea floor magnetometer was tested in shallow water in January 1973 and subsequently deployed three times between March and July 1973, during the MODE project. The instruments were deployed on the Hatteras Abyssal Plain at approximately 28°N, 70°W in 5400 m of water. The first deployment was of short duration (10 days) and served as a deep-water test. The two following deployments were of approximately two months in length and collected 44 days of geomagnetic time variations apiece.

Data analysis is in progress utilizing the method of vertical gradients of the horizontal field variations. Sea surface geomagnetic variations are estimated from geomagnetic variations at Fredericksburg, Virginia and at Bermuda. Latitudinal corrections have been applied to the sea surface estimates. Estimates of field coherence and wave number have been estimated from simultaneous variations recorded at Fredericksburg, San Juan (Puerto Rico), Bermuda and the Bahamas. Future analysis will also utilize electric field data collected simultaneously on the sea floor to make a magnetotelluric sounding.

Preliminary results utilizing the first three diurnal harmonics indicate a one-dimensional structure similar to that found 1200 km off the California coast by Greenhouse, exists on this 150 m.y. old sea floor. The apparent conductivity appears to double from about .09 mho/m at 150 km depth to about .18 mho/m at 350 km depth. The greatest increase in conductivity appears to be concentrated between the depths of 150 km and 200 km. More sophisticated modelling of the entire recorded geomagnetic spectrum is in progress and will add more detail to the above structure especially at shallower depths.

A more extensive field program was mounted in 1974, after modification of the sea-floor instrument package and construction of two additional units. Only two of the sea-floor instruments were recovered, after more than 80 days of simultaneous recording on the sea floor from August to October, together with a magnetometer recording on Bermuda. The sea-floor magnetometers were located south of Bermuda, at 28°01'N, 63°00'W and 27°54'N, 54°58'W. These data will complement and extend the data obtained in 1973, in the MODE-1 area to the southwest of Bermuda.

Kenneth Poehls was a co-investigator on this project.

SEDIMENTARY PALEOMAGNETISM

Charles R. Denham

Studies on the Blake polarity event continued during 1974, exhausting all Woods Hole Oceanographic Institution cores taken near localities where the Blake event had previously been identified by other workers. Despite there now being some twenty sites worldwide which tentatively document the feature, the entire data base still looks very skimpy on close examination. Few cores are known yet where the event spans more than a few specimens, and little consistency exists between cores. The most complete information continues to reside in giant cores *Knorr* 25-3 and 25-4, from north of Puerto Rico. Further sampling was conducted on the latter core, confirming several Late Brunhes reversals below the Blake event. Correlation of these older features between the two cores remains uncertain, as does the exact chronology of the Blake event itself. Oxygen-isotope measurements in *Knorr* 25-4 are now underway by Nicholas Shackelton, Cambridge University, in order to learn the true age and duration of the event. Meanwhile, special demagnetization studies on natural and anhysteritic remanent magnetization (NRM and ARM) in twelve specimens spanning the Blake polarity transitions have failed to show any significant difference between Blake and non-Blake sediment there. Thus, the three-fold reduction of average NRM seen during the event in both giant cores may reflect a decline in geomagnetic field strength at that time. Laboratory experiments on the effects of ambient field strength and state-of-compaction are planned to examine further the reliability of these materials as ancient magnetic recorders.

Coring on the Rio Grande Rise, during *Chain* Cruise 115 Leg 6, initiated a paleomagnetic/biostratigraphic study of the Late Miocene in calcareous sediments. Preliminary measurements in over 500 specimens from seven cores have confirmed the existence of a weak, but stable magnetic polarity record there, which will be examined in detail in 1975.

A small study of natural and viscous magnetization in eleven basalt specimens from Deep Sea Drilling Sites 319A and 321 was completed, concluding that the samples had mixed stabilities, and that their directions of original remanence were probably irrecoverable.

Sampling of land-based outcrops was undertaken for new studies. Some 275 specimens were drilled from two widely-separated localities on Barbados, for a paleomagnetic/biostratigraphic investigation of the Late Eocene. Their magnetization is extremely weak, but apparently stable. Elsewhere, about 100 samples were collected from two stratigraphically-overlapping sites in mammal-bearing Late Oligocene sediments of the South Dakota Badlands. Their purpose will be to help isolate magnetozones which will contribute to a more-positive stratigraphy in these important continental materials. The results are expected to be useful for studies of mid-Tertiary sedimentation and mammalian evolution in that region.

GRAVITY FIELD

Carl O. Bowin

The principal objective of this program is to utilize gravity data in conjunction with other geologic and geophysical information to define and understand the tectonic processes that are responsible for the major structural features of the Earth's surface. An example is the recently completed study of the gravity field and tectonics of the Caribbean region. Gravity anomalies, topography, volcanoes, seismicity, and the terrestrial flow of heat are inferred to be indicators of present tectonic activity and maps illustrating these parameters were prepared. Examination and comparison of these maps indicate that there are large variations in parameter magnitudes along presumed plate boundaries, and that different data sets in many instances suggest different locations as sites of significant tectonic activity.

Variations of the gravity field are interpreted to indicate that the easternmost end of Cuba, Jamaica, portions of Hispaniola, Puerto Rico, the Lesser Antillean Islands, the Santa Marta Mountains, the Eastern, Central, and Western Andes, the Coast Range of Colombia, central Panama, and the Nicoya Peninsula are sites of excess mass and are probably being uplifted. Mass deficiency in the eastern Caribbean is associated with the negative anomaly belt east of the Lesser Antilles, the east-west trending zones along the Puerto Rico Trench north of Puerto Rico and in eastern Venezuela and Trinidad. The deficiency east of the Lesser Antillean Island Arc is due to the underthrusting there of the Atlantic plate beneath the arc. The east-west trending zones lie away from the Caribbean plate on the other side of transform faults. It is inferred that compressive forces across the transform faults may be responsible for the east-west trending negative free-air anomalies. These anomalies may result, north of the Greater Antilles, from depressed lithosphere caused by a former period of underthrusting, and in Trinidad and eastern Venezuela, from a visco-elastic downwarping of the crust. Differential motion between the North and South America plates is inferred to explain the compression across the transform faults bordering the eastern part of the Caribbean plate.

A speculative attempt at defining the present boundaries of the Caribbean plate was made within the concepts of plate tectonics (Fig.1 and 2). The variations in topography, gravity anomalies, seismicity, and heat flow along the borders of the Caribbean plate, as well as the lack of consistency in location of the major variations between the data sets, suggest that some degree of non-rigid deformation is important locally in the development of some plate boundaries. Principal areas of inconsistency are Jamaica, eastern Cuba, western and central Hispaniola, Northeastern Venezuela, the Santa Marta mountains, the Isthmus of Panama, and in the vicinity of Central America. The cause of the local variability in topography, gravity, seismicity, and heat flow is poorly known. The curvature of the Isthmus of Panama and its structures may have formed through non-rigid northward motion of the north end of the Panama block over the Caribbean plate. Such a northward flow may have occurred in part because of subduction beneath Panama of a spreading center that had previously existed south of Panama. The subduction of thin lithosphere may have made this crust easier to deform laterally (northward).

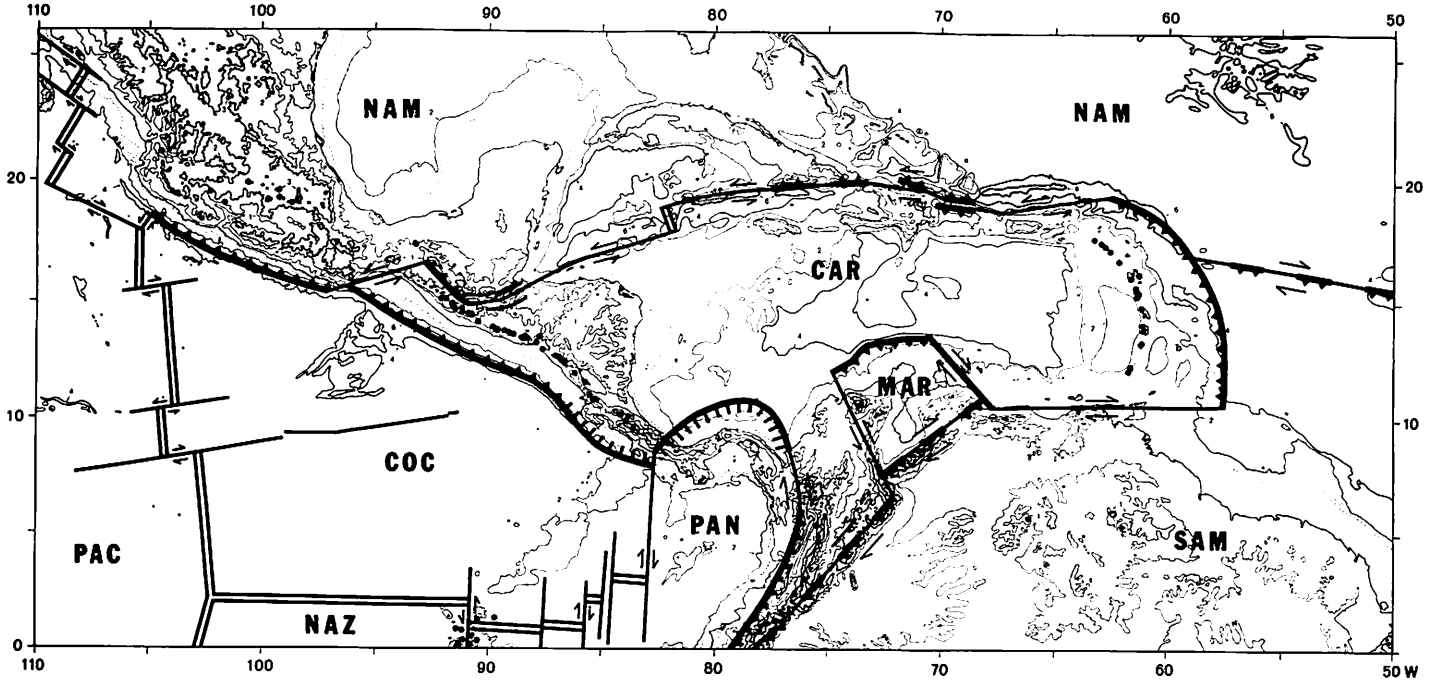

Fig.1 (Bowin) Inferred present plate boundaries. Double lines are extensional and sea-floor spreading sites. Single thin lines are locations of strike-slip (transform) motion. Heavy lines indicate surface trace of thrust faulting at sites of compression. The markings on the heavy lines are on the down dip side; the triangles indicate subduction, and the hatchering is where the hanging plate is inferred to be uplifted above its normal equilibrium level. Non-rigid deformation, particularly at compressive plate boundaries, is presumed locally to be important especially in northern and eastern Panama. Plates are labeled: NAM, North America; SAM, South America; CAR, Caribbean; COC, Cocos; PAC, Pacific; NAZ, Nazca; PAN, Panama Block; and MAR, Maricaibo Block.

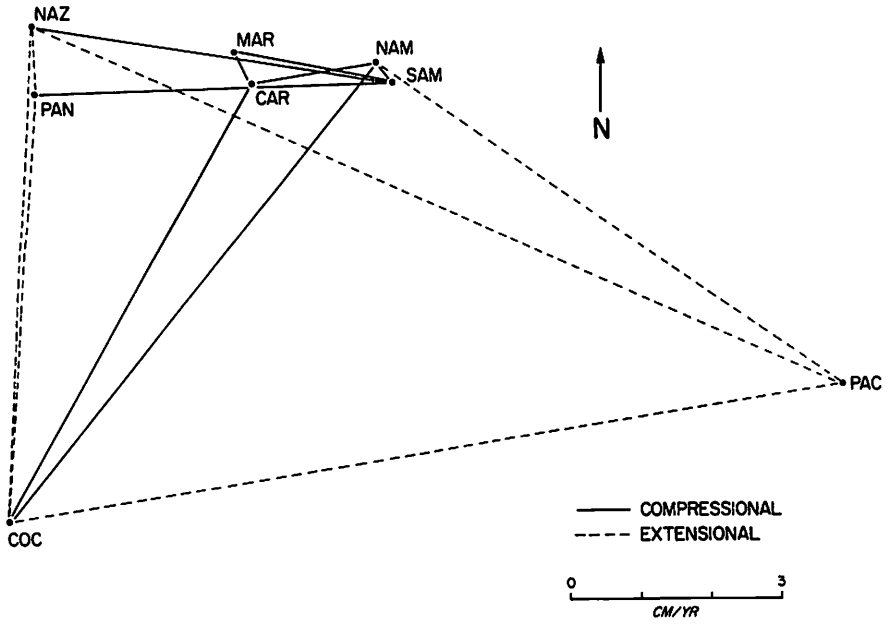

Fig.2 (Bowin) Plate motion vector diagram. This diagram is only schematic because such vectors of motion are not constant over a plate, but vary with distance from poles of rotation. However, in a general way it does indicate the relative motions between the plates indicated in Fig.1, and hence the stability of the boundaries shown in that figure. Plate labels as in Fig.1.

As part of a project acceleration to this contract, gravity measurements aboard the R/V *Thomas Washington* of the Scripps Institution of Oceanography were conducted in the Bay of Bengal, Indian Ocean and in the Pacific between Singapore and Guam, and between Guam and Hawaii. Preliminary examination of the data indicates large negative free-air gravity anomalies (greater than -100 mgal) over the continental margins of India and Burma in the Bay of Bengal. The most negative values appear to occur near the north end of Sri Lanka (Ceylon). Unexpectedly large free-air gravity anomalies (60 mgal peak-to-trough) were found over the western part of the Bengal fan in areas of smooth sea floor topography. This information together with seismic refraction and reflection data should provide details of the basement structure underlying the sediment fan.

MARINE SEISMOLOGY

Elizabeth T. Bunce and Sydney T. Knott

The objectives of our studies are to map the geological structures beneath the oceans and to deduce their composition and the processes that have produced them, in context with the broad spectrum provided by other and concurrently taken geophysical and geological information.

Our tools are the continuous seismic profiler (CSP), high-resolution echo sounder using 3.5 and/or 12 kHz sources, and wide-angle reflection and refraction studies with sonobuoys. A major effort is being made to develop a more complete understanding of the spectral and energetic response of the sea floor and substrate and to classify sediment characteristics by means of these acoustic measurements using digital signal processing techniques (see Fig. S-1). 'Giant Core' - obtained sediments and on-site 3.5 kHz reflection information form the basic materials of this study to date.

Our seagoing efforts were focused on *Chain* Cruise 115, SOUTHLANT (November 1973 to early July 1974), in the equatorial and South Atlantic Ocean (Fig. S-2). The major objective of our bathymetric and seismic work throughout the cruise was to relate observed sea floor formations to the mechanisms which produced them, both surficially as sediment dynamics and deeper as the effects of tectonic processes. To this end, we participated in detailed investigation augmented by hydrographic and heat flow measurements of eight regions in which, among other processes, bottom waters by reason of past or present flow have contributed to the formation of certain features such as gaps and rises respectively. Some of these are described in other parts of the Summary, (cf: Summerhayes, Walvis Ridge; Johnson, Vema Gap and Rio Grande Rise).

In the Kane Gap of the Gambia Basin - Sierra Leone Rise area we found evidence for both present-day bottom current activity and for the presence of Antarctic Bottom Water (AABW) which had passed through the equatorial fracture zone.

In the southern Cape Basin a profile along 34^{o}S is strikingly similar to others shown by Uchupi and Emery (1972, WHOI Ref. 72-95) to the north. All show an oceanic basement surface with subdued relief on which the sediment deposition has apparently been more uniform than in other regions of the Atlantic. That is, the sedimentary sequence ranging from 0.2 to 0.5 sec thick is generally conformable to the mild basement relief. The magnetic profiles are also subdued. The nature of these basement characteristics suggests relatively rapid growth of sea floor in the Basin while the uniformity of the sediments would indicate rapid deposition.

A small area on the northern flank of the Rio Grande Rise examined in some detail revealed a series of erosional gullies high on the flank, trending down slope, and coalescing to form canyons that join at still lower levels to form one major northward trending canyon. Our piston cores from an erosional surface between two gullies, and others by Lamont-Doherty Geological Observatory recovered material from several Tertiary epochs. The hiatuses in time should serve to narrow the time in which major erosional processes in this area occurred.

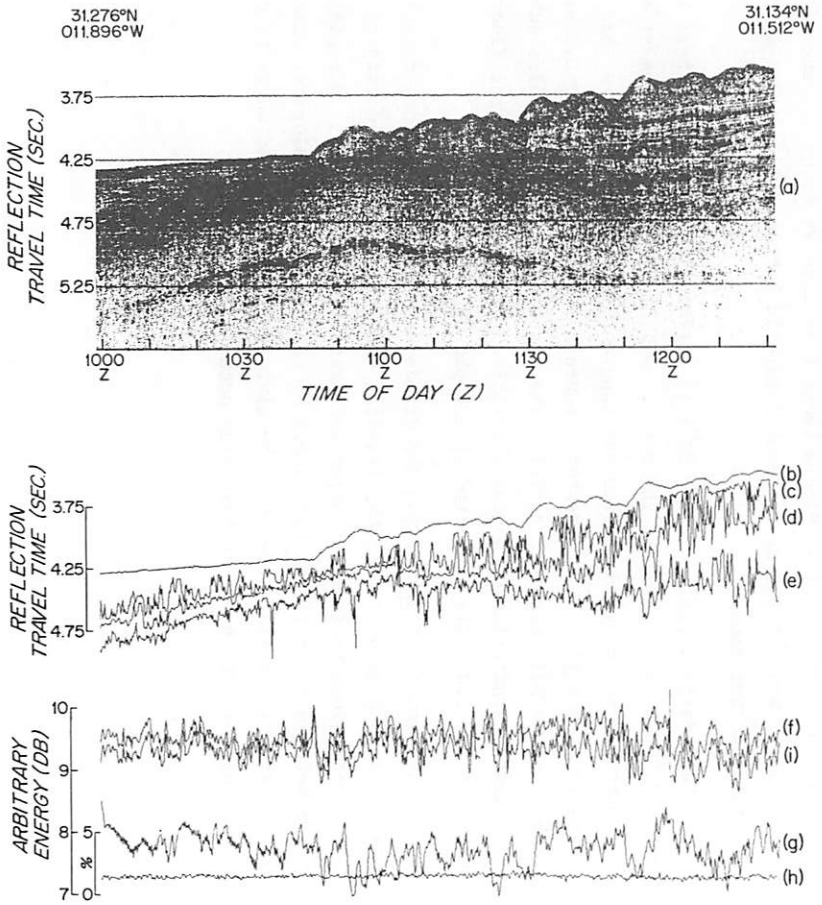

Fig. S-1. Differences in sediment characteristics evidenced by variations in the rate of reception of reflected energy with travel time. a) Bandpass filtered profile of reflection sequences from the continental rise west of Morocco using a profiler system consisting of a 4.9 liter air gun at $1.1 \times 10^7 N/m^2$ pressure and a single 30-m streamer.
Lower display overlays the upper and shows:
b) the sea floor reflection tracked by a level discriminator. c), d), and e) are contours on the cumulative energy curves of succeeding reflection sequences, at 30%, 50% and 80%. The squeezing together of the cumulative energy percentage contours between 1000Z and 1040Z on the profile are indicative of an increasing rate of consolidation in the sea floor with depth as the apron of sediments thins over a basement rise. In contrast, the more open and uniformly spaced contours from 1150Z to 1220Z indicate a 1.0 second thick section with a lesser rate of consolidation. From 1220Z to 1230Z the uniform spacing between the sea floor and the 30% contour suggests a 0.1 second thick interval of sediment underlain by a discrete change in impedance.
The lower four traces are:
f) the total energy returned; g) first arrival energy (43 ms window). Some of the fluctuations in f) and g) in the return are due to changes in source level, and to the scattered part of the sea-floor return.
h) the percentage of data points whose amplitude is greater than three times the average value of an entire reflection sequence. i) the energy in that portion of the return specified in h). Traces h) and i) show that about half of the reflected energy comes in about 2% of the travel time and are an indication of the specularity of the reflection sequence.

In the southeastern Atlantic, the presence of an unexpectedly thick biogenic sediment accumulation in the region to the northeast of the triple junction and at the eastern end of a fracture zone trending N 45°E may be evidence that the fracture zones cutting the African-Antarctic Ridge are passageways for AABW from the Antarctic Basin to the Cape Basin.

Our present work in acoustic stratigraphy has stemmed in part from the many indeterminate correlations of seismic reflectors with lithology and/or physical properties in Deep Sea Drilling cores. Edward P. Laine, a graduate student in the Department, has been working on 'Giant Core' and 3.5 kHz reflection information with us. This is a continuing cooperative effort with the Sediment Dynamics (Hollister) Group by means of which we are correlating our classifications of sea floow and sub-bottom reflectors by remote means with recovered material.

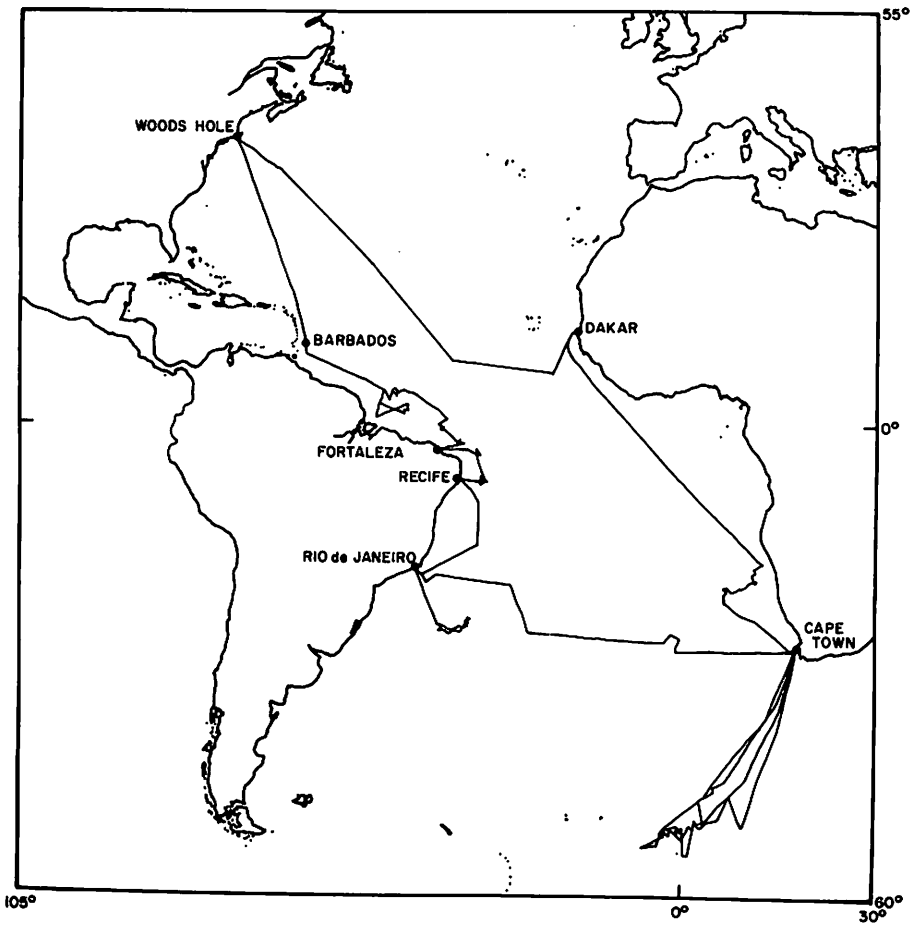

Fig. S-2 (Bunce and Knott) Track of *Chain* Cruise 115, November 1973 - July 1974.

RADIOLARIAN BIOSTRATIGRAPHY AND PALEOCLIMATOLOGY IN THE EQUATORIAL INDIAN AND PACIFIC OCEANS

David A. Johnson

The following results have been obtained during 1974:

1. Paleoclimatology. The radiolarian assemblages have been examined in two cores from the equatorial Pacific (V24-58; RC11-209) which were analyzed previously for carbonate content and paleomagnetics (Hays *et al.*,1969). Several carbonate cycles corresponding to glacial/interglacial climatic fluctuations were identified, and correlated with the paleomagnetic time scale. We examined the radiolarian assemblages at 10-cm intervals in these two cores, and found that a significant correlation exists between the carbonate content and the "paleotemperature" of the radiolarian assemblages, using Nigrini's method of paleotemperature analysis. This correlation suggests that Quaternary radiolaria may be useful in paleoclimatic analyses, and that equatorial assemblages changed substantially during glacial'interglacial climatic cycles.

2. Evolutionary lineages. Two late Neogene evolutionary lineages have been investigated in these same two cores (V24-58; RC11-209) from the east-central Pacific. We have attempted to establish an evolutionary lineage for the stratigraphically important collosphaerid *Buccinosphaera*

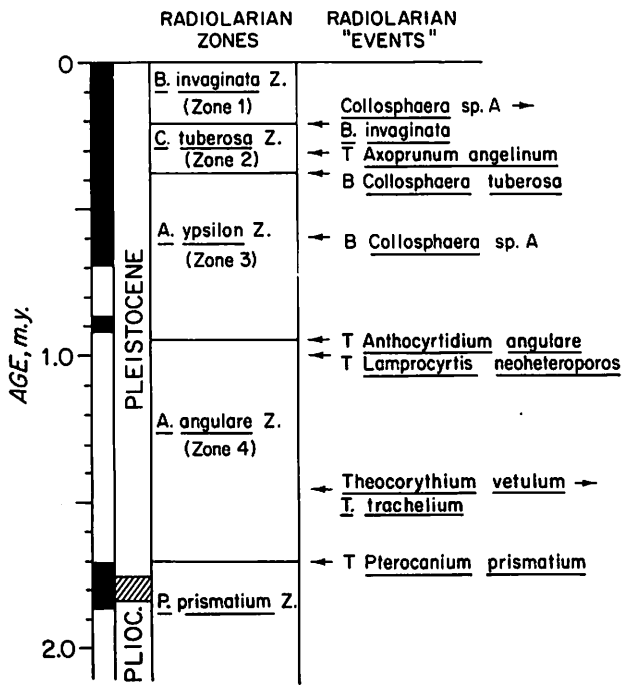

Fig.1 (Johnson)

invaginata Haeckel, whose first appearance defined the base of Nigrini's youngest Quaternary zone. This species apparently evolved from a form which we designated *Collosphaera* sp. A. via a series of morphologic changes ultimately leading to the test invaginations characteristic of the genus *Buccinosphaera*. This datum level has been dated at about 210,000 years B.P. Recognition of this evolutionary lineage has partially solved the stratigraphic problems caused by the scarcity and poor preservation of *B. invaginata*. We are also investigating the *Lamprocyrtis heteroporos→ L. haysi* lineage to determine whether the first and last appearances of the individual morphotypes are well-defined, and to establish absolute ages for those morphologic and/or evolutionary "events" which are readily identifiable.

3. Absolute ages of additional datum levels. We have successfully identified and established absolute ages (in the equatorial Pacific) for several Quaternary radiolarian events many of which have previously been recognized to be stratigraphically useful. These events are summarized in Fig.1.

Reference

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BIOGEOGRAPHY OF EARLY CENOZOIC CALCAREOUS NANNOPLANKTON IN THE ATLANTIC OCEAN: MIGRATION OF FLORAL ASSEMBLAGES IN RESPONSE TO CLIMATIC CHANGE

Bilal U. Haq and William A. Berggren

Geographic distributions of calcareous nannoplankton assemblages have been mapped on paleogeographic reconstructions of the Atlantic Basin for 13 selected time-slices through the Paleogene.

These patterns show that during the early part of the Lower Danian a boreal province (dominated by a single coccolith species, *Prinsius martinii*) developed in the North Sea and Denmark. This cool-water assemblage remained prominent in high-latitudes throughout most of the Paleocene, migrating and disappearing into even higher latitudes during the Early Eocene. At the same time, warm-water assemblages migrated from low to high latitudes until, in the Early Eocene, most of the Atlantic was characterized by a tropical, Discoaster-dominated flora.

Through the Middle and Late Eocene, nannofloral assemblages again migrated to lower latitudes in response to a general cooling trend.

With the return of cool climates in Oligocene, tropical assemblages are confined to lower latitudes and a boreal assemblage once again develops. This assemblage is dominated by the coccolith *Ericsonia hesslandii*, a form morphologically similar to the Paleocene boreal species, *Prinsius martinii*. During the coolest part of the Oligocene (Middle), the boreal assemblage invades the low latitudes, dominating even the typically tropical nannoflora.

George P. Lohmann was a co-investigator in this research.

PALEOCENE CALCAREOUS NANNOPLANKTON BIOGEOGRAPHY OF TETHYAN REGION

Bilal U. Haq

Nannoplankton distributional patterns in five time-slices of the Paleocene of the Tethyan Seaway (Western Indian Ocean, Pakistan, Iran, Jordan, Israel, Caucasus, Tunisia, and France) were mapped to determine: a) the biogeographic differentiation, if any, within the Tethyan region; b) similarities and differences in assemblages of the Indian Ocean on one side and Atlantic Ocean on the other.

In the Danian (NP2 and NP3 Zones) the Tethyan region is dominated by an assemblage composed dominantly of two coccolith species (*Coccolithus cavus* and *Ericsonia subpertusa*), showing similarities to both Indian Ocean and the mid-latitude Atlantic assemblages. During lower Middle Paleocene (NP5 Zone) the dominant assemblage of the Tethyan region and Indian Ocean is still composed of *C. Cavus* and *E. subpertusa* but with the addition of another taxon, namely, *Prinsius bisulcus*. Mid-latitude Atlantic assemblage is similar but is dominated by a circular placolith species, *Toweius craticulus*. In upper Middle Paleocene (NP7 Zone) the Tethyan assemblage shows a marked change due to the evolutionary appearance of discoasters at this time, retaining only one component from the last time-slice (*C. cavus*).

During Upper Paleocene (NP9 Zone) the differentiation between Tethyan, S.W.Indian Ocean and the Atlantic assemblages is complete. The mid-latitudes of the Atlantic are still dominated by *T. craticulus*. A boreal *Prinsius martinii* assemblage persists in the higher latitudes, having dominated this area throughout the Paleocene. Tethys and N.W.Indian Ocean contain a dominant *Discoaster* and *Sphenolithus* assemblage and S.W.Indian Ocean a *Discoaster* assemblage.

During the Paleocene the assemblage distributional patterns of Tethyan and surrounding regions show the effects of gradually warming climates, the earliest containing elements of both warm and cooler waters and the latest, a distinctly warm assemblage with no elements of cooler high latitudes.

Anne Boersma was a co-investigator on this research.

BIOSTRATIGRAPHIC, PALEOBIOGEOGRAPHIC AND PALEOECOLOGIC STUDIES OF CENOZOIC BENTHONIC FORAMINIFERA

William A. Berggren and Rudolph C. Tjalsma

During 1974 we studied Cenozoic benthonic foraminifera with the following objectives: 1) to clarify the taxonomy of various Cenozoic taxa as framework for more refined biostratigraphy; 2) to determine more accurately the stratigraphic ranges of selected benthonic foraminifera in terms of calcareous plankton zonations; 3) to interpret the paleoecology (including paleobathymetry) of various faunal assemblages; 4) to document more adequately the Cenozoic biogeography of selected benthonic forms; 5) to interpret paleocirculation patterns in terms of biogeographic distribution patterns.

The project grew out of a general realization of the fact that although a large descriptive-taxonomic base existed, comparatively little attention had been paid to this group as potential

tools in paleoecologic and bathymetric reconstructions during the past two decades when primary attention was turned to the use of planktonic foraminifera in biostratigraphy and biochronology. In actual fact the two are mutually complementary for with the refined planktonic foraminiferal biostratigraphic framework now available, it is possible to delineate the actual stratigraphic range of various benthic taxa with much greater precision than was heretofore possible.

With exploration activities now being extended into deeper parts of the continental shelf and eventually into slope and perhaps abyssal regions, reliable information on the geologic history of these areas is of paramount importance. Such information can be provided by studies on the biostratigraphy, paleoecology and paleobathymetry of benthonic foraminifera which are the dominant fossil group in these environments.

To widen the data base for this investigation we have the cooperation of Madame Jane Aubert of Société Nationale des Pétroles d'Aquitaine (SNPA). SNPA's immense quantity of data, from the Mediterranean, African, Middle and Far Eastern regions, complements our data and is of great importance in our attempt to determine paleobiogeographic patterns.

Four studies were made during the year and their general conclusions are outlined below:

1. A synthesis of Paleocene circum-Atlantic and Tethyan benthonic foraminiferal faunas based upon our own material, unpublished oil company data, and available literature revealed two distinct depth-controlled assemblages, a predominantly middle-to-outer shelf assemblage ("Midway" type) and a lower continental slope - abyssal plain assemblage ("Velasco" type). Most elements of these assemblages are essentially cosmopolitan, reflecting more equable climatic conditions. The paleogeographic distribution of a selected number of species was determined.

2. Paleocene - Late Eocene benthic assemblages have been studied from nine field sections in Tunisia. Precise biochronologic control was provided by associated planktonic foraminifera. The assemblages were generally of the "Midway" type and characteristic of middle neritic depths. although two other assemblages were recognized; an inner neritic assemblage deposited in a lagoonal environment and an outer neritic-upper bathyal assemblage. A comparison with similar assemblages elsewhere was made.

3. Paleocene benthic faunas from DSDP (Deep Sea Drilling Project) sites from the western Atlantic between 30^{o}N and 30^{o}S latitude were studied. Close similarities were observed between these faunas and the faunas described from the classic land sections of the Velasco Formation (Mexico) and the lower Lizard Springs Formation (Trinidad). Quantitative analysis enabled us to distinguish lower bathyal from abyssal assemblages. A chronological succession of assemblages, at lower bathyal as well as at abyssal depths were recognized through the Paleocene (Tjalsma, 1975).

4. An analysis of the benthonic foraminifera of the late Miocene of southwestern Spain has shown that a relatively rapid fall in sea level ($\sim$50-70 m) occurred about 5.5 my ago following a more gradual, combined tectono-eustatic change in bathymetry of over 200 m between 6.5 and 5.5 my ago. This change in bathymetry is interpreted as being linked with the growth of the Antarctic ice cap

during the late Miocene and the gradual, and eventually total, isolation of the Mediterranean Basin from the world ocean system (Berggren and Haq, 1975).

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BIOGEOGRAPHY AND MICROPALEONTOLOGY OF MODERN COCCOLITHOPHORIDS

Susumu Honjo

If the rate of the calcite dissolution in ocean water measured on calcite crystals and planktonic foraminiferan tests by Peterson and Berger in 1966 were applicable to free-falling coccoliths in deep sea, and if their rate of descent were in the order of a hundred meters per year (our measurement of the sinking rate of a laboratory-cultured coccolith species was 1.2 to 1.6 $\mu m\ sec^{-1}$), they would disappear soon after sinking below the saturation depth. In reality, however, coccolith ooze ranges widely over the ocean floor at depths far exceeding the saturation depth.

In order to understand the transport mechanism of coccoliths and fine-grain carbonate sedimentation in the open sea: 1) we investigated systematically-collected suspended coccoliths in the deep-sea layers of the Central Pacific Ocean, 2) we analyzed particles, particularly fecal pellets, collected by a Wiebe sedimentation trap deployed near the deep-sea floor in the Tongue of the Ocean, near the Bahamas. Integrating our investigations with the results of a combined productivity study and community analysis of the coccolithophores in the overlying photic layer, we have constructed a model of coccolith sedimentation to the deep-sea floor.

The yearly production of coccoliths in a photic column should be equal to the number of suspended coccoliths in the aphotic extension of the same column within a depth equal to the yearly sinking rate of an individual coccolith, if the only source of suspended coccoliths were the disintegration of coccospheres and none were lost within the photic layer. However, at $10^{o}N$, $155^{o}W$, for example, the yearly production of coccoliths in a photic column with a m^2 surface area was estimated to be 2×10^{12}, while only 3×10^{7} of suspended coccoliths were found in the extension of the same column from 0.4 to 0.5 km. This implies that only a few coccoliths in every 10^{4} produced in the photic layer arrive at the 400 m level by individual sinking.

Suspended coccoliths are abundantly distributed throughout a meridional aphotic water profile of the central North Pacific Ocean as deep as 5 km in concentration of 10^{3} to 10^{5} per liter. Their state of preservation varies from unaltered to slightly etched at all depths. This observation clearly contradicts the above-mentioned geochemical expectation. The species composition of coccolithophore assemblages in the overlying productive layer was present throughout the aphotic water column and no significant screening of species was found throughout the water column.

Viewed under the electron microscopes, the abundant fecal pellets collected by a Wiebe sedimentation trap deployed near the sea floor at 2.2 km deep in the Bahamas, appear to be almost exclusively made of well-preserved coccoliths and coccospheres of various species. The dry weight of an average green fecal pellet was approximately 0.8 μg and contained approximately 4×10^4 coccoliths. The sinking rate was measured to be an average of 170 m/day. It was estimated that a minimum of 500 to 1000 fecal pellets reach the sea floor per m^2 per day, or .1 to .3 gm/m^{-2} yr^{-1} calcite.

From these evidences, fecal pellet transport of coccoliths appears to be a fast and efficient channel which provides at least three orders of magnitude more coccoliths to the sea floor than individual sinking. Thus the discrepancy between production and flux of free-fall coccoliths can at least be partly explained by grazing and subsequent fecal transport.

The abundant, well-preserved coccoliths suspended in deeper water column probably have been shed from fast-descending fecal pellets. The laboratory sinking experiment of greenish fecal pellets supports this view. Fresh coccoliths or coccospheres may thus be constantly replenished at all depths, however, they are disintegrated within a short time and do not reach to the bottom where the depth exceeds the saturation depth. If, as our data suggests, coccoliths produced in the photic layer are sealed in fecal pellets and transported to the underlying sea floor within a short time, oceanographic filters such as selective dissolution, lateral transport which may work on slowly-descending coccoliths will have little influence on the distribution of coccolith ooze. In addition, most dissolution probably takes place after the arrival at sediment-water interface. The contribution of coccoliths to alkalinity control in the deep sea must accordingly be mainly attained by upward diffusion following dissolution at the sea floor and the role of dissolving coccoliths suspended throughout the water column appears to be minor.

SUSPENDED PARTICLES IN SEA WATER, QUALITATIVE, QUANTITATIVE STUDY OF ELECTRON MICROSCOPE

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 samples, 180 were selected for detailed examination of the non-combustible fraction using optical and electron microscopy together with computer methods of particle measurement and counting. The results showed that, generally, all major components of the suspended matter 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 average about 2%, skeletal debris plus clay minerals - 23%, and combustible organic matter - 75% of total sample weights, 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 noncombustible fraction and an oceanward increase in median diameter of the mineral grain.

Electron microscopy with the combination of energy-dispersive X-ray probe analysis served as very useful tools for a detailed study of a scope of samples of suspended matter. The results showed the presence in surface waters of detrital minerals, several forms of clay minerals, and of many kinds of skeletal debris. The latter include diatoms, coccolithophorids, silicoflagellates, radiolarians, acantharians, tintinnids, dinoflagellates, and even soft organic matter. Some of these constituents were found to be more diagnostic of the open ocean, whereas others are typical of nearshore areas. They are attributed to discharge of detrital sediments from rivers and growth of plankton from nutrients also brought by the rivers, followed by dispersion by ocean currents and partial settling from suspension.

Suspended particles in the subsurface water of the open sea, 400 m to 5,000 m along the 155° meridian, Central Pacific Ocean, were studied by a similar method to compare the occurrence in the marginal seas. They consisted of fragments of organic hard tissue, amorphous remains and a small number of inorganic particles such as clay minerals. Coccoliths and some coccospheres were well-preserved and abundantly found throughout the deep-sea column. Silicate hard tissue, such as diatoms, radiolarians and silicoflagellates showed significant graded dissolution with depth. On the other hand, highly sensitive solution particles such as acanthalia skeletons were found in relatively deep water suggesting accelerated vertical transport by fecal pellets.

The distribution of coccolithophore was studied in the surface waters of marginal seas in eastern Asia and the Red Sea. The occurrence of coccolithophore in surface water was more aggregated than their occurrence in the open sea. Most of the surface samples contained a small standing crop. An exception was the western half of the South China Sea where consistent and fairly high concentrations were observed. It was interesting that coccolithophore were consistently distributed in subsurface water particularly in the Arafura Sea, Gulf of Carpentaria, and the central Red Sea. The species composition of the coccolithophore community was almost monopolized by *Gephyrocapsa oceanica*. Species diversity was significantly lower than the oceanic environment. Specimens found in the marginal seas suffered skeletal deformations both in degree and kind, regardless of species. Nitrogen-deficiency and other environmental stress seems to be one of the reasons for this deformation and highly aggregated distribution. Neritic environment in marginal seas may not be suitable for the survival of most coccolithophore species found in the open sea of equivalent latitudes except *G. oceanica*.

DINOFLAGELLATE STUDIES

David Wall

1. A study with Professor W. R. Evitt (Stanford University) was completed dealing with the relationship between living *Ceratium* and comparable Cretaceous marine microfossils and the results currently are in press with *Micropaleontology*. We noted that the thecal structure of *Ceratium* has been misinterpreted and hence that its systematic position has been misunderstood despite the fact that *Ceratium* is probably the most abundant and intensively studied modern genus. We described patterns of tabulation and horn structure in selected Cretaceous marine fossils that resemble living *Ceratium* and concluded that the similarity was too great for them to be entirely unrelated, despite the stratigraphic hiatus that separates the last occurrence of these Cretaceous forms in the Maestrichtian and present times. We suggested that in the course of geologic time, only some members of a ceratioid lineage were able to produce sporopollenin cysts and therefore to fossilize, that is, during the Cretaceous, but that some continuity to present-day *Ceratium* through the Tertiary was provided by non-fossilizing species. Living species of freshwater *Ceratium* produce cysts in contrast to the more numerous living marine species but examination of examples from Lake Zurich (a classic location for freshwater cysts by virtue of earlier work) revealed that they have cellulose walls and no archeopyles or tabulation patterns and therefore are unlike Cretaceous cysts excepting for their distinctive external shapes.

2. A set of significant culture experiments was completed with living marine dinoflagellate cysts from Somes Sound, Mount Desert Island, Maine. These cysts included representatives of two fossil genera (*Bitectatodinium* and *Planinosphaeridium*) that have not been found alive before. They were successfully germinated under controlled laboratory conditions and the nature of the motile thecate stage was determined. The results of this work are being prepared for publication.

3. A study is progressing dealing with the distribution of dinoflagellate cysts in modern marine sediments from selected areas including the eastern seaboard of the United States, Bermuda, the Bahamas, areas of the Caribbean Sea, the Mediterranean Sea, the South Atlantic off the Argentine, the eastern Pacific near the Peruvian upwelling system at 15^{o}S and the western coast of South Africa. The main purpose is to identify recurrent patterns in the distribution patterns of benthic cyst populations that have both ecological and paleoecological meaning. Thus far the data have been analyzed using computer programs for diversity, percentage similarity, average proportion of expected number of species shared and factor analysis (orthogonal varimax vector analysis). Several distinctive assemblages and biofacies have been defined and currently attempts are being made to relate the latter to environmental parameters to determine what governs cyst distribution.

5. Two review articles were written in conjunction with talks and meetings attended. These were "Modern Dinoflagellates as a Standard for Paleontologic Inquiry" which was presented to the Annual Meetings of the American Association for Stratigraphic Palynologists in Anaheim, October 1973 and second, "Taxonomy and cysts of Red-tide Dinoflagellates" which was submitted for the Proceedings of the First International Conference on Toxic Dinoflagellates at Boston, November 1974.

INTERNAL WAVES IN THE OCEAN AND SOUND TRANSMISSION

John C. Beckerle

The objective of this contract was to define a simultaneous acoustic environmental experiment based on examination of the literature and a study of both large and small internal waves from different cruises. The literature examination revealed a marked increase in 1973-1974 in the interpretation of acoustic signal fluctuations in terms of oceanographic data. An internal report on this is in the final stages of preparation. Several papers were completed that are related to this study. They are:

E.O.LaCasce Jr. and J.C.Beckerle "A preliminary experiment to measure periodicities of large-scale ocean movements with acoustic signals". In press in *J.Acoust.Soc.Am.*

J.C.Beckerle "Doppler shifted internal waves relative to a towed sensor in a thermal front region". In press in *Deep-Sea Research.*

J.C.Beckerle, H.Broek and E.O.LaCasce,Jr. "A study of acoustical fluctuations and ocean movements over one deep-ocean skip distance" Submitted to *J.Acoust.Soc.Am.*

J.C.Beckerle and J.B.Hersey "Horizontal scales in the main thermocline derived from the topography of a constant sound speed surface between Bermuda and the Antilles. In press in *J.Geophys.Res.*

J.C.Beckerle "Air and sea temperatures during traverse of hurricane Alma 1966". 1974. *J.Phys.Oceanog.* 4(3): 487-492.

GIANT CORER

Charles D. Hollister

The objective of this grant is to design and fabricate a new model of the Woods Hole Giant Corer. The new corer will have increased free-fall velocity by utilizing a ballistic shape and a hydraulic expansion jet in the weight stand. It will be instrumented with acoustic sub-bottom pinger probes of 3.5 and 12 kHz and accelerometer, inclinometer and a core orienting device. The core will be delivered to Woods Hole Oceanographic Institution during the first month of 1975. Core description and summary of previous work was published in the fall of 1974 (Driscoll, A.H. and C.D.Hollister, 1974. W.H.O.I. Giant Piston Core; State of the Art. *Marine Tech.Soc., Proceedings 10th Annual Conference,* pp. 663-676.)

SIX-CHANNEL CONTINUOUS SEISMIC PROFILING (CSP) ACQUISITION AND PROCESSING

Kenneth E. Prada and Arthur B. Baggeroer

Single channel digital seismic data acquisition and processing were extensively carried out during the International Decade of Ocean Exploration (IDOE) African program (1972-1973). The results of this work were reported during this year (1)(2)(3). These results prompted a proposal for a multi-channel digital CSP system and in March work was begun to develop the hardware and data processing software necessary to implement a six-channel system.

The goals of the six-channel approach, to be achieved by exploiting the spatial structure of the reflected signals, are:

a) depth-velocity dependent focusing to improve primary reflections and suppress multiples,

b) velocity/depth spectra estimation,

c) signal-to-noise ratio improvement for detection of deep reflection horizons by means of additional sensor coverage.

Two principal processing methods are to be used: common depth point stacking and velocity spectra analysis. These algorithms will employ methods which are standard in the geophysical literature, as well as some unique methods for velocity estimation and stacking. These unique methods are based upon high resolution procedures which are finding extensive use in a variety of applications. The high resolution velocity method is described in Reference (4).

The bulk of the year has been devoted to acquiring the components for the six-channel system. These include the towed array, a larger acquisition computer and the gain ranging amplifier system.

The towed array is approximately one kilometer long. It is comprised of mixed-length active and passive sections. The sectional construction of the array in conjunction with the different section lengths will enable a variety of geometric configurations. This, in turn, will accommodate the various structural and topographic areas where the array will be used.

The use of a multi-channel system requires increased source energy levels. We propose to use an array of air guns in varying chamber sizes. A series of tests were conducted aboard *Lulu* this year to determine the optimum configuration of an air gun array. Analysis is being carried out on these data and should indicate the chamber sizes, separation and tow depth for best results.

Other equipment, including a high-speed graphics system, is to be purchased shortly. Some items, such as the gain-ranging amplifier package, are being developed in-house. A large tow and storage winch for the hydrophone array is being designed and constructed by an outside contractor.

The development process will culminate in a test cruise during the summer of 1975. The test cruise will be followed by another cruise in the region of Georges Bank to implement the six-channel system in studying specific problems previously not possible using single-channel methods.

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SKYLAB RADAR ALTIMETER DATA

Carl O. Bowin

The accurate delineation of large scale topography of the sea surface is equivalent to surface gravity measurements and hence can be useful for determining mass anomalies in the earth's crust. Satellite altimeter data offers two advantages over normal shipboard gravity meter observations. Firstly, large scale features of several hundred to several thousand kilometer width are transversed quickly by a satellite pass and hence problems of datum levels and instrument drift tend to be minimized. Secondly, orbiting satellites easily cross regions of the earth's surface that are remote and hazardous for surface travel. The southern oceans and the Arctic Ocean are particularly obvious regions in point. Unfortunately, self-contained data recording for later transmission is not provided on the GEOS-C satellite and hence altimeter information from areas of the earth remote from tracking and receiving stations will have to await later missions.

The altimeter information obtained during the SKYLAB mission instrument testing has already provided useful data on the marine geoid. Our preliminary analysis of geoid perturbations to be expected from seamount structures indicates that the sea surface bumps observed near an island of the Cape Verde group and a seamount off Brazil are valid geoid features. The positive and negative free-air gravity anomaly belts along the continental edge of eastern North America (see Fig.27 in Emery *et al.*, Continental Rise off Eastern North America, *The American Association of Petroleum Geologists Bulletin*, 54(1): 44-108, January, 1970) provide a useful way of comparing the SKYLAB altimeter data with surface ship gravity data because the widths of the gravity anomaly belts are nearly constant but the amplitude varies along their length. SKYLAB mission SL-2 pass 9 crossed the continental margin near Wallops Island, Virginia, and shows no evident perturbation of the sea surface over the shelf edge where the surface gravity anomaly relief varies from about +20 mgal to -30 mgal, a peak-to-peak relief of about 50 mgal. However, farther south, pass 4 crossing the Blake escarpment shows a sea surface perturbation of about four meters relief and the gravity anomalies vary from about +10 mgal to -110 mgal, a peak-to-peak relief of about 120 mgal. From this simple comparison as well as from other considerations it is clear that altimeter observations from satellites will not eliminate the need for surface gravity measurements. In combination, however, they offer an extremely important approach for the study of the shape of the earth, the perturbation of the geoid, and the determination of mass anomalies within the earth.

COMPARATIVE STUDY OF DEFORMATION PATTERNS ON EARTH AND MOON

Wilfred B. Bryan

There is an extensive literature covering arguments for and against the existence of old and fundamental structural patterns on both the Moon and the Earth. Growing interest in the geological implications of possible Earth-Moon interactions has renewed interest in the possible existence and nature of these ancient structural patterns, their possible origins in a common event early in the history of the Earth-Moon system, and their influence on present-day deformation on both planetary bodies. Most of the published evidence for the so-called "Lunar Grid" has been derived from low-resolution telescopic photography. During the past year we have examined the frequency distribution of about 1000 linear structures appearing in high-resolution Apollo photographs and in 1/250,000 scale ortho-photo maps prepared from these photographs. Our observations confirm frequency maxima for trends at 325^{o}, 0^{o}, and 45^{o}, in substantial agreement with trends presented in previous literature. Detailed study of structural evolution in and around some of the major Maria basins shows, moreover, that these same trends appear in the oldest highland material, appear to survive major impact events, and become re-established in volcanic mare fill, spanning overall a period of at least one billion years of Moon history. Other evidence suggests that these same structural trends have continued to localize minor lunar deformation events to very recent time.

Review of literature on terrestrial structural patterns reveals substantial agreement that the major trends are essentially the same as those observed on the Moon; this may be a coincidence or indication of a common cause such as fracture induced by tidal stresses. We have considered evidence that at least some major sea-floor fracture zones appear older than the adjacent sea floor, and that some of these appear continuous with continental fracture zones dating back to early Paleozoic or Pre-Cambrian time. This leads to a model for sea-floor spreading in which the trends of both spreading centers and fracture zones are inherited from the trends of ancient fracture zones in the separating continental blocks. We have considered both published and unpublished experimental data on brittle fracture in rocks which indicates that, once an initial structural anisotropy has been established in a rigid plate, it will be very difficult to generate new structural patterns in that plate even with very large changes in the direction of applied stress. These facts lead us to suggest that the driving force for plate motions may be a deep-seated convection cell or "plume" which is partly decoupled from surface movements, thus directions and rates of surface motions reflect the resolution of these deeper forces along established surface fractures and are not necessarily the rates or directions of the underlying cell. Further, we note that experiments in brittle fracture commonly produce not orthogonal fracture, but rather patterns characterized by 30^{o} or 60^{o} angles. We believe that recognition of the control of ancient fracture patterns on newer deformation events such as major impact on the Moon or sea-floor spreading on the Earth may help to clarify many current problems. In particular, the following important consequences may be emphasized:

1. Major sea-floor fracture zones may provide important clues to the location and trend of mineralized fracture zones on land, even where the latter are now buried or obscured by glacial till, ice, or recent sediments.

2. Once a pattern of spreading and fracture zones has been established it will be very difficult to re-orient these directions, and any such re-orientations should show a simple geometric relation to earlier spreading events.

3. Fracture zones need not be orthogonal to spreading rifts, and in fact an angle of about 60^{o} between the two is compatible with complimentary shears produced by brittle fracture.

Peter Jezek and Mary-Linda Adams were co-investigators on this project.

GRAVITY FIELD OF THE MOON

Carl O. Bowin

Almost all of the mass distributions that have been proposed to account for the large positive gravity anomalies associated with lunar mascons have assumed single body sources of a mass excess. In the case of mare fill with a reasonable density contrast (+0.5 gm/cm^3) with crustal material, this requires a fill thickness of about 16 km for Mare Serenitatis to account for the observed gravity values at 100 km height. Such a great thickness would require a 16 km deep hole prior to filling and such a topographic depression is inconsistent with gravity anomalies away from the mare basins where near-isostatic conditions appear to prevail. It also is inconsistent with the depths of the topography of Mare Nectaris and Mare Oriental basins which have but little fill, and with estimates of mare thicknesses based on buried crater dimensions. A two-body mascon solution, however, requires only a 2 km thickness of fill and a 12 km rise of a lunar Moho beneath Mare Serenitatis to account for the observed gravity anomalies. The top of the mantle dome or plug is placed at 60 km depth to match observed seismic velocity structure. This mascon structure has an anomalous gravity field that is in good agreement with anomalies observed at several heights above Mare Serenitatis.

TRAINING AND TECHNICAL ASSISTANCE IN MARINE SCIENCE - A VIABLE TRANSFER PRODUCT

David A. Ross and Leah J. Smith

During the past year we have participated in several sea-grant discussions and prepared a report showing how marine science training can be transferred to countries less developed in scientific capabilities. Our report was incorporated into a larger Sea Grant Project which has been presented to Congress for consideration as a major Sea Grant effort in technology transfer. We indicate in our report that marine science is a viable transfer product for training and technical assistance programs with developing countries. To develop this point we presented the major research interests, techniques and instruments of the various branches of marine science and showed how some could be used in a transfer program. To ascertain past experiences and present interest in cooperative projects with foreign scientists we sent a questionnaire to over 100 United States marine scientists. The United States scientists showed a high level of interest

in cooperative marine science programs. Over two-thirds had participated in some type of international marine science program, many of which involved marine technical assistance. The respondents suggested many problem areas in such programs, particularly inadequate funding, variations in scientific background among participants, cultural and language problems, and government bureaucracy. The experiences and criticisms of some marine scientists from developing countries were also reviewed and compared to the views of United States scientists. The foreign scientists noted as problems insufficient opportunity to participate in the planning of the programs, inadequate length of programs, and difficulties with funding and government support. We suggest several mechanisms to expand and improve the effectiveness of educational and technical assistance programs in the marine sciences with developing countries. Based on our study we felt that there is considerable interest among United States marine scientists in having training and technical assistance marine science programs with foreign countries. Further developments await funding and leadership.

OCEAN ENGINEERING

DEPARTMENT OF OCEAN ENGINEERING

Earl E. Hays, Department Chairman

ACOUSTICS SECTION

Earl E. Hays

ACOUSTIC DATA CAPSULE PROGRAM - ACODAC

Earl E. Hays

The Acoustic Data Capsule (ACODAC) system has been designed to obtain long-term measurements of ambient noise in the deep ocean from a vertical array of six hydrophones and to record signals for transmission loss studies. The ACODAC consists of a 40-inch diameter pressure vessel containing a seven-channel analog tape recorder and the associated timing and amplifying electronics for 10.66 days continuous operation. Since its inception in 1971 Woods Hole has participated in 33 depolyments made in the North Atlantic, Mediterranean, and Caribbean.

In 1974 the project, which is funded by the Long Range Acoustic Propagation Project (LRAPP) of the Office of Naval Research, has as major seagoing operations:

Test Cruise - R/V *Chain*, a test of new Kevlar cable with six triads of conductors to compare faired and unfaired cables to suppress strumming.

Coherence Studies - R/V *Chain* deployments in support of studies by Dr. Robert P. Porter and Dr. Robert C. Spindel measuring temporal and spatial phase fluctuations.

WESTLANT Operations - R/V *Chain*, four deployments to make a specialized acoustic assessment in the area bounded by Bermuda, Mid-Atlantic Ridge and the Antilles.

Eight deployments of ACODAC were made from R/V *Chain* during the period from 15 August to 17 November 1974. Two magnetometer systems of Dr. Richard von Herzen were recovered during the cruise. The new Kevlar type mooring tested was 15,000 ft. in length and the data obtained showed that strumming suppression was achieved and cross talk was negligible. Kevler (Fiber B) is a new material which has the strength of steel for the same diameter with a specific gravity of 1.35 and an elastic elongation of 2% at 70% breaking strength. Prior to the *Chain* cruise various materials and fairings were tested from January to May 1974 from the edge of the Iselin facility dock. The results from the modest tests have been received with a great deal of attention in the moored acoustic community.

Much of the acoustic ambient noise data were processed at sea with the shipboard Hewlett Packard computer system. This was in the form of digitizing the recordings and making unedited plots. Sound velocimeter profiles plots and navigational plots were standard outputs. The final processing of the ambient noise and the statistics are accomplished at Woods Hole. This work supports the acoustic computer system 50%.

The annual meeting of the LRAPP technical review group (65 persons) met at Woods Hole for two days in early June with the project as host.

ALVIN MODULAR ACOUSTIC SYSTEM

Paul T. McElroy

The *Alvin* Modular Acoustic System is a general purpose acoustic system intended to serve a variety of scientific and technical needs. It has been modularized to permit as wide a range of experiments as possible and computerized both to maximize its data rate and to allow modifying experiments during the course of a dive based on intermediate results.

Its utility lies in its scientific applications including spectral and angular measurements of acoustic returns from such things as fish schools or bottom sediments. It can also address a variety of technical questions such as map-making and bottom search.

A thorough discussion of the proposed system can be found in McElroy, Hess (1972) and details of progress made during 1974 can be found in the semi-annual progress reports (McElroy, Hess, 1974a and b, 1975). The work in 1974 has been essentially that of hardware implementation. The display unit has been constructed, tested, and is undergoing final troubleshooting. Work on the transducer mount has continued and is nearly complete; this includes programs and hardware interfacing to permit computerized control of transducer training in azimuth and elevation. The keyboard and Light Emitting Diode (LED) displays used to enter into the computer those parameters necessary for running of the system are constructed and fully interfaced; programs are written and hardware complete. As the system increases in complexity, we find that some of the earlier work requires modification. Thus, following the addition of transducer training capabilities to the system, earlier keyboard programs required updating.

Some units, although constructed, still require testing and troubleshooting; this includes the entire digitization capability. However, we hope for completion of the basic system in early 1975, to be followed by at-sea tests.

Figure 1 shows the rack-mounted units which comprise the inboard components of the submersible system.

Frederick R. Hess was co-investigator on this project.

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McElroy, P.T. and F.R.Hess (1974a, b, 1975). Appearing in Technical Progress Reports on Advanced Marine Technology for the periods 1 August 1973 - 31 January 1974 (WHOI-74-27), 1 February 1974 - 31 July 1974 (to be issued), and 1 August 1974 - 31 January 1975 (to be issued). Woods Hole Oceanographic Institution. (Unpublished manuscripts.)

Fig.1 (McElroy and Hess). Inboard components of the submersible system arranged from top to bottom as follows: Rockland frequency synthesizer; Nova 1210 computer; control unit containing Ross cassette, manual control thumbwheels, and keyboard with echo display; display unit with transducer-pedestal azimuth and elevation readouts; tunable receiver, and the data/logging tape recorder.

HIGH RESOLUTION PULSE-DOPPLER NAVIGATION SYSTEM

Robert C. Spindel

An underwater, acoustic navigation system that combines the major attributes of the existing Advanced Research Projects Agency (ARPA) Pulse Submerged Navigation System and the existing Office of Naval Research (ONR) Continuous Wave (CW) Doppler Navigation System has been developed. The new system operates in a combined pulse and Doppler mode. In its current configuration it yields accuracies within range (about 10 km) of a bottom-moored beacon (CW)-transponder (pulse) net of about ±15 meters. Relative position accuracy within the net is about 0.04 meters.

Specialized hardware for the Doppler portion of the system has been developed to simplify interfacing with a shipboard minicomputer. The most important items in this category are the Doppler receiver and digital cycle counter. Pulse navigation system components such as transponders and receiver have been modified for Doppler compatibility. A software operating system for the Doppler section has been written; software for the pulse portion of the system is essentially identical to the original ARPA system.

An experiment was conducted in September of this year to analyze the accuracy of each portion of the system. In addition, tests were made of a survey procedure designed to exploit the availability of Doppler information. Previous survey procedures have been concerned only with pulse systems. The Doppler survey is optimum in a least squares sense.

William M. Marquet and Robert P. Porter were co-investigators on this project.

ARRAY COHERENCE: EXPERIMENT AND ANALYSIS

Robert P. Porter

Phase and amplitude fluctuations of low frequency acoustic signals received at long ranges in the ocean continue to be the central items of study in these investigations. An experiment was conducted late this year using a unique recoverable acoustic source (designed by Douglas C. Webb) moored near the island of Eleuthera. Fluctuation data was obtained simultaneously at two frequencies approximately an octave apart in order to test frequency scaling relationships. Data with two types of aperture were acquired. First, mixed spatial and temporal apertures were formed by free-drifting hydrophone receivers, either ship-suspended or sonobuoy-deployed. These apertures spanned the range of zero to eight hours, and zero to six kilometers. Second, spatially fixed temporal apertures were formed using moored buoys Acoustic Data Capsule Program (ACODAC). Several days of continuous data of this type were collected.

A data acquisition system was developed that enabled real-time output of phase and amplitude fluctuation information aboard ship. This system includes the processing of hydrophone drift data acquired in real-time by a bottom-moored Doppler tracking system designed expecially for these experiments. The tracking system was integrated with a pulse positioning system which facilitates surveying of the Doppler beacons and improves survey accuracy by approximately an order of magnitude ($\approx$ 20 m).

The spatial coherence of sound radiated by small sea quakes has been estimated using data obtained from sonobuoy arrays located over the Mid-Atlantic Ridge. Spatial coherence has been found to be as high as 0.7 at 14 Hz, to be about 0.5 between 16 and 60 Hz, and to drop sharply to zero above 60 Hz. Significant processing gain is possible using high-resolution spectral analysis; improvements over conventional delay and sum processors of as much as five-to-one have been observed.

A long-range, side-looking echo ranging technique was tested at sea late this year. Large time-bandwidth acoustic signals are injected into the ocean from a ship-towed transducer, and echoes from ranges in excess of 200 km are received on a deep linear array, also towed by the ship. Matched filter data processing exploits the measured stability of the ocean transmission path and yields processing gains of about 20 to 30 dB. Signal processing is entirely automatic, under executive control of a small minicomputer.

Robert C. Spindel was co-investigator on this project.

DEVELOPMENT OF AN ACOUSTIC PROBE FOR OCEAN BOTTOM AND SUB-BOTTOM SURVEYS

Willard Dow

Brief experiments conducted some years ago off Bermuda demonstrated that a high-powered short pulse echo sounder, operated at a high frequency (12 kHz) close to the bottom, can sharply delineate bottom and sub-bottom microstructure in sediments to depths of 40 fathoms beneath the sea floor. The high resolution and detail shown in these records cannot be realized by echo sounding or seismic profiling from the surface in deep water, because of spreading losses, averaging of returns from wide areas, and high attenuation of both transmitted and reflected pulses over the long acoustic paths involved.

However the purpose of the new technique is not to supplant deep profiling from the surface, but to augment such surveys by providing more detailed information concerning small bottom areas of particular interest.

The Bermuda experiments indicate that such micro-surveys are indeed practical. Towing the sounder 200 - 500 ft. above the sea floor produced a detailed bottom profile regardless of water depth. Possible applications include warning of bottom hazards which could damage equipment or deep vehicles, location of sites suitable for bottom-mounted instruments or structures, and outlining of shipwrecks. Operating close to bottom could permit location and delineation of sediment ponds or lineaments, salt domes, gas traps (pagoda structures) and other bottom and sub-bottom features to determine whether further investigation via photography, coring, drilling, etc., is warranted.

The immediate object of the current Sea Grant project is to construct a deep echo sounder or "Acoustic Probe" incorporating the features outlined above. It is then planned to conduct sea trials from R/V *Knorr*, probably in the Gulf of Maine and Bermuda areas early in 1975.

The new probe will be compact (20 cu ft), self-contained, battery operated and easily launched by one man. Output of the deep receiver will be telemetered to the ship's laboratory via single or dual conductor logging cable which also serves to lower the instrument into the sea.

The cost of this preliminary model (not over $11,500) is being minimized by simple design and making use of certain existing structural components. If the sea trials indicate that this instrument proves useful in delineating the varied bottom structures encountered, a more sophisticated unit incorporating any required modifications may then be fabricated.

Such modifications could include acoustic telemetering of the deep receiver output signals to the surface, thus eliminating the need for conducting cable.

The current model is now essentially complete except for the transducer which is under sub-contract.

The writer wishes to thank Dr. Charles Hollister and Edward Laine of the Geophysics Department for offering their substantial assistance in connection with the sea trials of the new instrument.

OCEAN DYNAMICS AND SOUND VELOCITY FIELD

Eli J. Katz

The development of the towfish went into a third phase this year while earlier models were still being used and previous data were still being analyzed.

The first model, a simple lead-weighted fish, was once again towed at constant depth over the propagation range of an acoustic experiment this autumn. In this fashion, the range variability of the sound velocity field was observed *in situ* by Richard Jaffe.

Data from both this early model and a depth-variable model were analyzed by Walter Zenk and Richard Jaffe. The wave number spectra of the temperature (and sound velocity) fluctuations at a constant depth were estimated from tows near the surface (25 m), sub-surface (300 m) and in the main thermocline (700 m). At the deeper two depths the spectra were found to be analogous to one another and spatially homogeneous. In contrast, the near-surface tows yielded highly variable spectra. Both variance levels and spectral slopes reflected large-scale changes in the surface layer.

Further development of the towfish was carried on by Warren Witzell, Jr., and Frederick Hess. The instrument package was expanded to include the beginnings of a method of measuring the water current, while the remote control of the tow depth was improved. (See Figure.) The towfish can now make controlled two hundred meter excursions or be flown at a constant depth to within two meters. Current measuring is effected by a two-axis Doppler-scattering acoustic sensor, with the orientation of the tow body being monitored by a flux-gate compass. Field data obtained during the GATE (GARP* Atlantic Tropical Experiment) experiment this summer were encouraging in that strong and continuous scattering signals were obtained at the deepest depth towed (200 m). Subsequent analysis raised questions about the sensitivity of the current sensor to high-frequency fish motion, and a tow tank study has been initiated.

*Global Atmospheric Research Program.

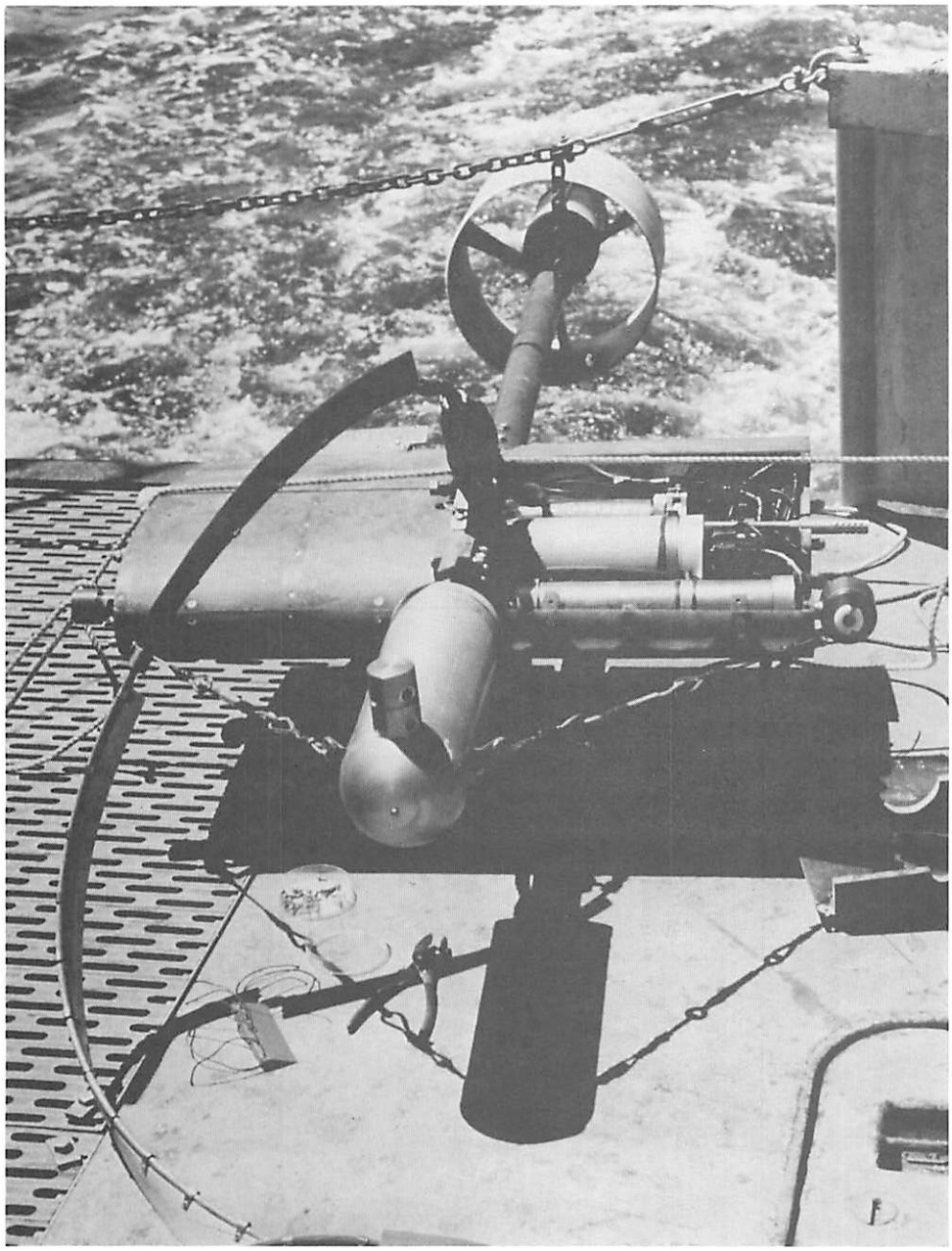

Fig. (Katz) Towed instrument package. New instrument package towed ten meters below depth-controlled tow fish. In the wing (show half shrouded) are temperature, pressure, conductivity and dissolved oxygen sensors. In the nose is a two-axis acoustic current sensor; in the tail a flux gate compass. Signals are sent to the ship, one scan a seond, digitized by an encoder in the wing.

VOLUME REVERBERATION

Paul T. McElroy

Four separate studies in volume reverberation were completed during 1974:

1. Clustering of Volume Reverberation Spectra. Volume reverberation spectra arise from analysis of sound scattered from mesopelagic fishes. Since those fishes group geographically, it is reasonable that spectra of sound scattered from those fish can be clustered on a geographic basis. This point was established in McElroy (1974a) using a simple measure called the cross-standard deviation. Correspondence analysis (Benzecri, 1973) is an alternative method of clustering data which we applied for the first time to spectra, using the volume reverberation spectra as an example. Correspondence analysis has the following advantages: 1, the clustering is quickly displayed in a two-dimensional plot, (Fig.1); 2, eigenvectors computed in the analysis are spectral curves which are characteristic of extremum environments, called volume reverberation environments; 3, those frequencies serving as indicators of a particular cluster of spectra are identified; and 4, spectra can be extrapolated to their appearance in unmeasured conditions. A paper (McElroy, Smith, 1975) summarizes the

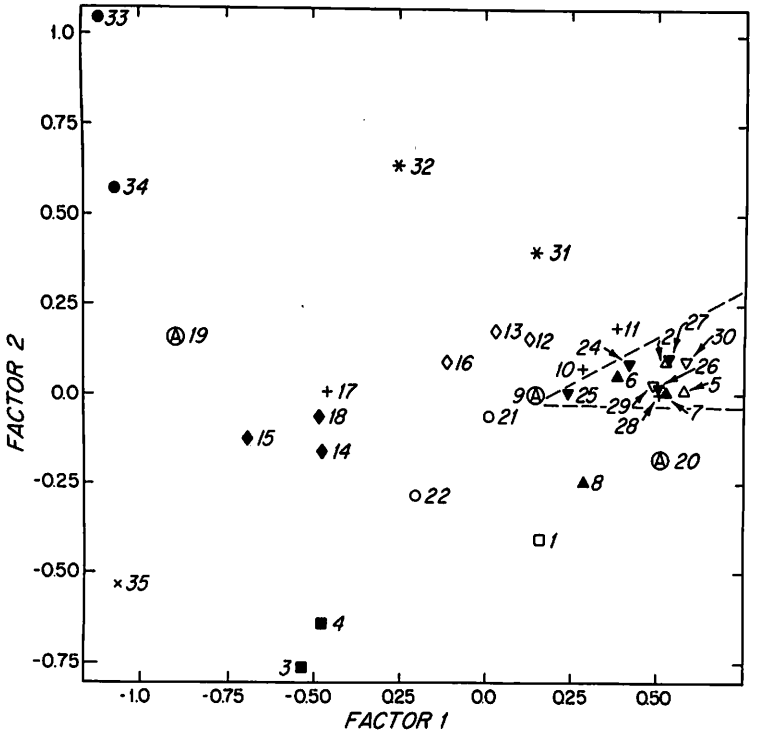

Fig.1 (McElroy) Clustering of the 34 stations of R/V *Chain* Cruise 105, based on factor scores determined from the two most important eigenvectors. The factor scores are computed using correspondence analysis methods (Benzecri, 1973). The symbols refer to different pelagic regions as determined by the cross-standard deviation method (McElroy, 1974a). The dashed lines mark the cluster of Gulf Stream system stations (except for #8).

governing equations of correspondence analysis, gives a geometrical interpretation, and discusses the application to volume reverberation spectra. The paper is written as a basic reference for those wishing to apply the technique to spectra from any discipline.

2. Column Strength Spectra Measured during Three Cruises in the North Atlantic and Mediterranean. A technical report with that title (McElroy, 1974b) was issued based on volume reverberation measurements at 85 stations occurring in *Atlantis II* 49, 59, and *Chain* 105. The measurements cover the range of 1 kHz to 31.5 kHz in one-third octave filter bandwidths. Plots and tables summarize the spectra and related data, which in turn can be subject to the statistical and physical-oceanographic interpretations found in McElroy (1974a) and McElroy, Smith (1975).

3. Nature of Echoes Scattered from Biological Targets. Advanced signal processing techniques are a necessary supplement to energy measurements in characterizing fish and groups of fish. In a review paper (McElroy, 1974c) I have discussed the signal distortions created by single fish targets, the ordered and random ways in which fish congregate, the theoretical development for acoustic returns from fish groups, and their application to specific experiments. These include measurement of fish transfer functions, zero-crossing structure, auto-correlation, and Doppler effects.

4. Level and Zero Crossings. In Spindel, McElroy (1973) we developed a theoretical model to describe the level-crossing structure of superimposed echoes from randomly-distributed fish targets. One rewarding outcome was an ability to measure the density of fish targets and their determination in an experiment. Ehrenberg and Erickson (1975) have challenged the model. We have replied (Spindel, McElroy, 1975), noting both that our empirical model should be valid in the limit of high fish densities and that it is in agreement with the experimental data while theirs is not.

Two additional studies were carried on during 1974, although not brought to fruition:

5. Multipole Resonance Effects. The gas bladders of fish are resonant systems. We have examined volume reverberation returns from explosive charges hoping to see evidence of returns at more than one frequency which could be attributed to dipolar and quadripolar as well as monopolar effects. The data have been inconclusive.

6. Correlation of Net Hauls and Volume Reverberation. We have carried out a detailed comparison of the contents of 34 net hauls from *Atlantis II* 59 and volume scattering strengths determined contemporaneous with the hauls. By employing curve-fitting procedures we sought to 1) determine if the acoustic data were a good predictor for the biological (and vice versa) and 2) evaluate parameters describing net-haul efficiency and gas-bladder behavior. Some of the correlations have been high (.95), but overall the results remain ambiguous pending further study.

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OCEAN STRUCTURES, MOORINGS AND MATERIALS SECTION

Robert G. Walden

ENGINEERING SERVICES FOR PHASE I, CURRENT MEASUREMENT SYSTEM DESIGN SUPPORT

Robert G. Walden

The objective of this study is to provide the necessary designs, specifications and technical guidance for procurement of systems by the Naval Facilities Engineering Command which will reliably measure deep ocean currents in support of ocean engineering and construction projects within the United States Navy. To this end we have developed an environmental model including an estimation of the velocity fields in an open ocean environment from 300 meters below the surface to 6000 meters depth. We have attempted to quantify current magnitudes, directions and temporal variations to obtain value ranges which can be used in a rational design of a suitable mooring. A design and maximum current profile was established from many observations of current measurements made during MODE (Mid-Ocean Dynamics Experiment). (Figure 1)

A survey of Eulerian current sensing and recording instruments was conducted to form a list of candidate instruments for the proposed mooring. Two commercially manufactured current meters were identified as most nearly meeting the requirements of the proposed use; the AMF-Vector Averaging Current Meter and the Aanderaa Model RCM-5.

Through the use of our computer program the range of motions of these sensors in an actual mooring was determined when subjected to the environmental model as shown in Fig.1. In addition we have looked at their dynamic behavior when excited by strumming. We have attempted to quantify the measurement accuracy resulting from these motions.

Various mooring designs were investigated in order to assess the effects of various tradeoffs on total system performance. The final design with certain alternatives will be completed early in 1975.

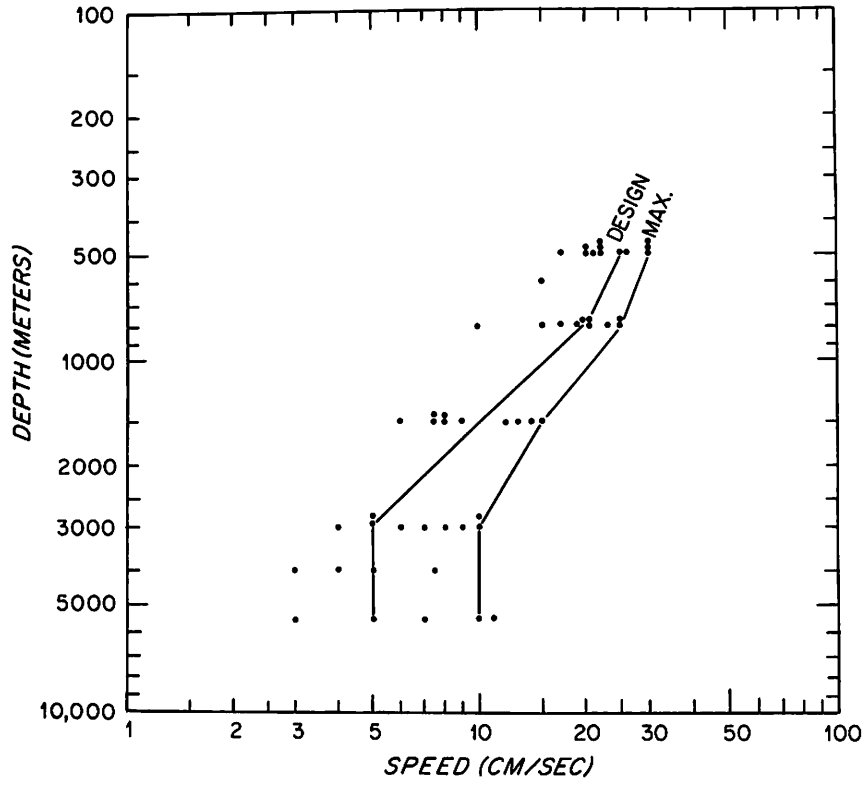


Fig.1 (Walden) MODE area maximum observed values from 11 moorings. Design and worst case profiles are shown.

MICROBIOLOGICAL FOULING AND CORROSION CONTROL

Stephen C. Dexter

Work continued during 1974 on the interdisciplinary problem of investigating the role of the substrate surface energy (critical surface tension for wetting, γ_c) in determining the rate of bacterial slime film formation on various metallic and nonmetallic structural materials and on toxic antifouling paints. The number of marine bacteria attached per unit area to the surfaces of the various substrates is being measured by a lipopolysaccharide test utilizing *Limulus* lysate, and by scanning electron microscopy (SEM).

We have shown by SEM that there is a minimum in the curve of bacteria attached per square centimeter vs. critical surface tension, and that minimum is in the neighborhood of 25 ergs cm^{-2} on the critical surface tension scale (See Fig.1). The lipopolysaccharide test has also shown that the bacterial attachment rate to polyvinylfluoride (γ_c = 28 ergs cm^{-1}) during the first

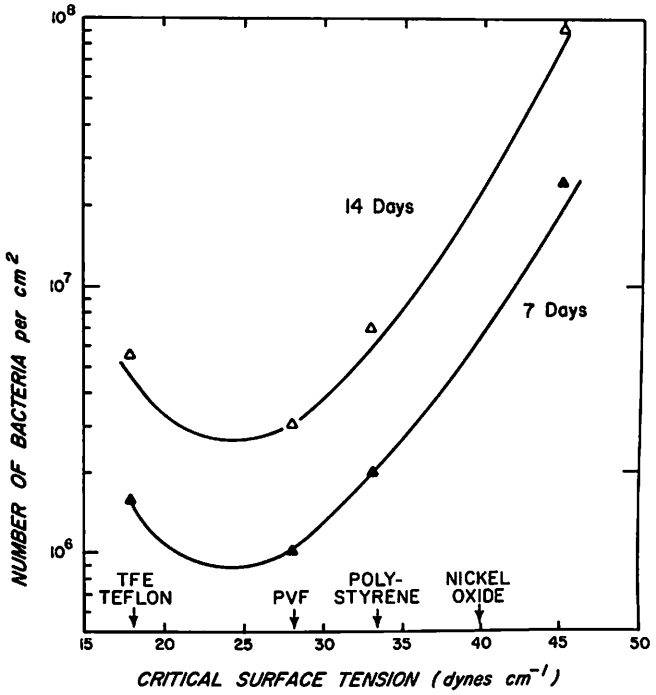


Fig.1 (Dexter) Number of attached bacteria per cm^2 from the SEM data as a function of critical surface tension for wetting.

week of exposure to warm surface seawater is as slow as it is on the highly toxic surface of pure copper.

These results have a direct bearing on attempts to control marine microbiological fouling (slime film formation) without the use of toxic agents, and they may also have an influence on the corrosion of metallic alloys in seawater.

INFORMATION PROCESSING CENTER

Melvin A. Rosenfeld

SHIPBOARD COMPUTER SYSTEMS, PROGRAM AND ANALYSIS, OPERATIONS

Melvin A. Rosenfeld

Shipboard Computer Systems

The main emphasis this year was on developing compatibility between different systems and on improving the performance of peripheral devices. Engineering modifications were made to provide backup operation in case of device failure; device control programs were strengthened.

A new disk storage device (Daconics Floppy Disc) was installed and evaluated. This system provided three new programming languages (FORTRAN IV, SNOBOL, SUPER BASIC), more flexible input/output capabilities, and greater compatibility with other computers within the Institution.

Part of an equipment grant from the National Science Foundation was used to purchase a Calcomp plotter which was installed on the *Atlantis II*, and a high speed paper tape reader as a backup device for the shore-based Hewlett-Packard.

Shipboard activity included support for the Geology and Geophysics digital data library, navigation data processing, buoy deployment and recovery, hydrographic data reduction, biological data analysis, an on-line acoustic navigation system, a towed fish sensor and an ACODAC (Acoustic Data Capsule) cruise.

Programming and Analysis

Applications programming this year included programs to investigate heat in the North Atlantic, weather in the Atlantic and Indian Oceans. A contour mapping program was produced, a series of general-purpose cluster analysis programs, and a series for processing internal wave data. Another package, of three systems, was designed to track a free-fall, multi-sensor device and to process data received from it.

A program was written to run two Calcomp plotters at the same time from one Hewlett-Packard computer. Long plots can now be run on one plotter while the other turns out a number of short ones.

Statistical consulting was provided to Woods Hole Oceanographic Institution graduate students and staff members, including the design and analysis of a sonar beacon survey system for precision navigation, and the investigation of the statistical properties of diversity measures used by ecologists.

The IPC (Information Processing Center) education program evolved to include four kinds of classes, given this year - elementary FORTRAN, advanced FORTRAN, the Sigma 7 operating system, programming practices. The programming consulting service was expanded to provide computer users at the Clark Laboratory with a consultant on the premises.

Operations

Operation of the Sigma 7 and the Calcomp plotters continued on a two-shift basis. Due to refinements in equipment utilization, including a disk catalog system, a program to save the job queue after a system failure, and the connecting of another Calcomp plotter to run simultaneously with the one previously in use, roughly thirty percent more work was processed this year with no increase in scheduled operating hours.

A magnetic tape storage vault was built as an addition to Shiverick House. With this, safety features were obtained, as was floor space in the main computer room, allowing the rearrangement of Sigma 7 components in preparation for the multi-batch/time-sharing system equipment to be installed early in 1975.

Much effort in 1974 was directed toward planning, proposing and preparing for the multi-batch/time-sharing system, its equipment, telephone lines and remote terminals.

Economy measures taken this year included the altering of Sigma 7 procedures to reduce the amount of printer paper used and the elimination of solid color punch cards which were more expensive and made recycling of the cards difficult.

The Sigma 7's chargeable use increased from 2466 hours in 1973 to 3203 hours in 1974, an increase of 30 percent. The Sigma 7 job statistics are:

	1973	1974
Number of jobs processed	58,847	74,855
Total hours used	2,849	3,704
Central processor hours	2,151	2,761
Cards read	9,139,707	10,008,188
Pages printed	1,343,202	1,418,745
Cards punched	754,210	826,914
Tape mounts	44,453	51,900
Average CPU time/job	2.19 mins.	2.21 mins.
Average no. cards read/job	155.31	133.70
Average no. pages/job	22.83	18.95
Average no. cards punched/job	12.82	11.05
Average no. tape mounts/job	.76	.69

Internal Woods Hole Oceanographic Institution chargeable use by department was distributed as follows:

W.H.O.I. Department	Percentage of use
Physical Oceanography	67.2
Geology and Geophysics	16.4
Administration (business)	6.9
Biology	4.1
Ocean Engineering	2.2
Chemistry	2.2
Education	1.0
	100.0

HYDROSTATIC PRESSURE TEST FACILITY
1974 UTILIZATION

William S. Shultz

Total number of Tests: 125

Total number of Cycles: 271

Total hours at Pressure: 410 approximately

Tests:	Pressure (lbs/in^2)	%
34	10,000 or above	27.2
7	9,000 to <10,000	5.6
17	8,000 to <9,000	13.6
6	7,000 to <8,000	4.8
16	6,000 to <7,000	12.8
10	5,000 to <6,000	8.0
21	1,000 to <5,000	16.8
14	Under 1,000	11.2

Including: 9 Certification Tests (implodable items) DSRV *Alvin*.

Use by Departments, percent:

Ocean Engineering	40
Biology	32
Chemistry	12.8
Geology & Geophysics	11.2
Physical Oceanography	.8
Student Program	3.2
	100.0 %

DEEP SUBMERGENCE ENGINEERING AND OPERATIONS SECTION

Lawrence A. Shumaker

William M. Marquet, David S. Hosom and Arnold G. Sharp were co-investigators on the project discussed here.

OPERATIONS SUMMARY

On 1 January 1974, DSRV *Alvin* embarked on R/V *Lulu*, was underway from Ft.Pierce, Florida en route to Nassau, New Providence Island, Bahamas. During the period 1 January through 9 March, 1974, six cruises were made operating out of Nassau and Andros Island. Work accomplished included Current Studies, Biology and Recovery and Inspection Work for the U.S.Navy. In addition, training dives were made for the FAMOUS (French American Mid-Ocean Undersea Study) Program and tests of new penetrator installation configurations were made including a dive to 10,000 feet.

Alvin/Lulu arrived back in Woods Hole on 21 March and preparations were begun for the FAMOUS operation. These preparations included a short cruise off Provincetown for shallow trials in May.

On 6 June with *Alvin* on deck and *Lulu* towing astern, R/V *Knorr* got underway for the Azores and FAMOUS. Upon arrival at Ponta Delgada, Azores, on 18 June, *Alvin* was transferred to *Lulu*. From 19 June until return to Woods Hole on 3 September *Alvin* conducted a total of 27 dives including 17 on the Mid-Atlantic Ridge, one to inspect a defective acoustic array for the Navy, one for the Deep Sea Drilling Project, one for vehicle test and seven for the Office of Naval Research during which each dive was made on a different seamount in the New England Seamount Chain.

In September and October, two short cruises were made, under NOAA (National Oceanic and Atmospheric Administration) sponsorship, to the Hudson Canyon area and the Woods Hole Oceanographic Institution Bottom Station.

On 6 October, with a year's total of 60 dives, *Alvin* began her annual overhaul, scheduled for completion 1 March, 1975.

Details of cruises and dives are shown in Tables I and II.

Although funding continued to be a major problem for most of the year, a Joint Memorandum of Agreement signed by the U.S.Navy, National Science Foundation and National Oceanic and Atmospheric Administration in Movember appears to provide a solid funding base for the next three years.

ALVIN ENGINEERING

Titanium Hull The most pressing technical problem in 1974 was verification of the structural integrity of the new *Alvin* titanium hull for operations to at least 10,000 feet and hopefully to 12,000 feet. The area of greatest doubt was the electrical penetrators. Extensive laboratory work, detailed later in this report, was accomplished and the results were utilized in the installation of electrical penetrators in the Number 2 hull which was pressure cycled 6000 times to the equivalent of 12,000 feet at the Naval Ship Research and Development Center, Carderock, Maryland. Subsequent inspection showed no damage to the penetrators and this method of installation was

Table I

1974 CRUISE SUMMARY

DSRV *ALVIN*/DSRVT *LULU*

Cruise No.	Sponsor	Period From-To	General Location	Chief Scientist	Ops. Director	Purpose
66 Leg 2	WHOI/ NAVO	1-1-74 1-5-74	TOTO	R.Ballard P.Wiebe	V.P.Wilson	Current Studies Sedimentation
66 Leg 3	All	1-6-74	Transit to Andros	None	E.L.Bland	Transit
67 Leg 1	WHOI/ NUSC	1-14-74 1-25-74	TOTO	J.Teal J.Santos	V.P.Wilson	Biology and TOTO Range Work
67 Leg 2	WHOI/ NSF	1-28-74 2-8-74	TOTO	R.Ballard	V.P.Wilson	FAMOUS Trials
67 Leg 3	NSF	2-22-74 2-27-74	TOTO	L.Shumaker	V.P.Wilson	Trials and Training
67 Leg 4	NSF/ ONR	3-4-74 3-9-74	TOTO	P.Wiebe	V.P.Wilson	Biology
68 Leg 1	All	3-10-74 3-11-74	Transit to Florida	None	V.P.Wilson	Transit
68 Leg 2	All	3-12-74	Transit to WHOI	None	V.P.Wilson	Transit
69 Leg 1	ONR	5-24-74 5-28-74	Province-town, Ma.	L.Shumaker	V.P.Wilson	Trials and Training
70 Leg 1	NOAA	6-6-74 6-18-74	Transit to Azores	None	V.P.Wilson	*Knorr* towed Transit
70 Leg 2	NOAA	6-19-74 6-23-74	Ponta DelGarda	W.Bryan	L.A.Shumaker	FAMOUS Geology
70 Leg 3	NOAA	6-24-74 7-8-74	FAMOUS area	W.Bryan	L.A.Shumaker	FAMOUS Geology
70 Leg 4	NOAA	7-9-74 7-27-74	FAMOUS area	W.Bryan	L.A.Shumaker	FAMOUS Geology
70 Leg 5	NUSC	7-28-74	AFAR Range	A.Ellin-thorpe	L.A.Shumaker	Echo Tower Inspection

Table I (continued)

Cruise No.	Sponsor	Period From-To	General Location	Chief Scientist	Ops. Director	Purpose
70 Leg 6	NOAA	7-29-74 8-13-74	FAMOUS area	W.Bryan	V.P.Wilson	FAMOUS Geology
70 Leg 7	NOAA/ ONR/ DSDP	8-14-74 9-3-74	Return to WHOI	J.Heirtzler	V.P.Wilson	Sea Mount Geology
7	NOAA	9-17-74 9-23-74	Hudson Canyon	R.F.Dill	V.P.Wilson	Megabenthic Studies
72	NOAA/ NSF	10-1-74 10-6-74	WHOI Bottom Station	R.S.Dyer	L.A.Shumaker	Benthic Biology
73	ONR	10-15-74 10-20-74	South of WHOI	R.Drever	None: *Alvin* Ashore	Instrument Tests
74	ONR	11-18-74 11-20-74	Vineyard Sound	G.Rowe	None: *Alvin* Ashore	Biology

Table II *ALVIN* 1974 Dive Log

Lulu Cr. No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Dive	Time Surf.	Time Sub.	Depth m/ft.	Remarke
66	1-4-74	487	24-37.11N 77-35.10W	NUSC Array recovery	V.Wilson D.Foster	L.Shumaker	1051	1524	4^h33^m	5840'	Recovered current meters
67	1-15-74	488	24-41.3N 77-36.5W	NUSC Inspection	J.Donnelly D.Foster	J.Santos	1302	1826	5^h24^m	1772^m	AUTEC Array Inspection
67	1-16-74	489	24-41.3N 77-36.5W	NUSC Inspection	V.Wilson D.Foster	J.Santos	0943	1628	6^h45^m	1670^m	AUTEC Array Inspection
"	1-17-74	490	"	"	J.Donnelly D.Foster	J.Santos	1030	1845	8^h15^m	1664^m	" "
"	1-18-74	491	24-53.6N 77-39.8W	W.H.O.I. Biology	J.Donnelly	K.Smith H.Berteaux	1250	1711	4^h21^m	1960^m	Inspected new bottom station

Table II *Alvin* 1974 Dive Log (continued)

Lulu Cr.No.	Date	Dive	Location	Sponsor/ Purpose	PIC/CP	Obs.	Time Dive	Surf.	Sub.	Depth m/ft.	Remarks
67	1-20-74	492	24-53.6N 77-39.8W	W.H.O.I. Biology	V.Wilson	F.Grassle C.Wirsen	1134	1905	7^h31^m	2010^m	
"	1-21-74	493	"	"	J.Donnelly	J.Teal R.Turner	1100	1847	7^h47^m	1902^m	
"	1-22-74	494	24-53.5N 77-40.0W	"	D.Foster V.Wilson	K.Smith	1317	1831	5^h14^m	1914^m	
"	1-23-74	495	"	"	J.Donnelly	J.Teal F.Grassle	1042	1847	8^h05^m	1882^m	
"	1-24-74	496	24-59N 77-44W	"	V.Wilson L.Shumaker	R.Turner	1045	1116	31^m	296^m	Aborted because of ground
"	1-29-74	497	25-00.2N 77-44.4W	8000 ft. Test dive FAMOUS	V.Wilson L.Shumaker	J.van Andel	1012	1644	6^h32^m	2500^m	Successful
"	1-30-74	498	25-57.5N 77-43.7W	FAMOUS Training	J.Donnelly	R.Ballard J.Moore	0950	1756	8^h06^m	2500^m	
"	1-31-74	499	24-58.8N 77-43.3W	FAMOUS Training	V.Wilson	W.Bryan J.Moore	0940	0959	19^m	280^m	Abort due to leak indication
"	1-31-74	500	24-58.8N 77-43.3W	FAMOUS Training	V.Wilson	W.Bryan J.Moore	1255	1910	6^h15^m	2500^m	
"	2-1-74	501	24-58.8N 77-43.4W	FAMOUS Training	J.Donnelly	R.Ballard W.Bryan	0948	1721	7^h43^m	2200^m	
"	2-2-74	502	24-58.5N 77-42.2W	FAMOUS Training	V.Wilson	R.Ballard J.van Andel	1005	1859	8^h54^m	2220^m	
"	2-3-74	503	24-58.9N 77-43.0W	FAMOUS Training	J.Donnelly	J.van Andel J.Moore	1047	1833	7^h46^m	2200^m	
"	2-4-74	504	24-58.5N 77-43.3W	FAMOUS Training	V.Wilson	W.Bryan J.Heirtzler	1004	1707	7^h03^m	2350^m	
"	2-5-74	505	Vicinity Clifton Pier	Training and Quali-fication	D.Foster	R.Graham	1349	1507	1^h18^m	40'	Foster's first solo dive.

Table II *ALVIN* 1974 Dive Log (continued)

Lulu Cr.No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Dive	Time Surf.	Sub.	Depth m/ft.	Remarks
67	2-5-74	506	24-59.0N 77-37.0W	NSF Xponder Recovery	J.Donnelly A.Barrs	None	1138	1646	5^h08^m	1680^m	Successful recovery malfunctioning AMP xponder.
"	2-25-74	507	24-54.0N 77-42.2W	W.H.O.I. Trap Inspection	V.Wilson D.Foster	None	0909	1150	2^h41^m	1360^m	Abort due to penetrator weeping
"	3-5-74	508	25-17.0N 77-37.0W	ONR 10,000 ft. test dive	V.Wilson L.Shumaker	B.Walden	1050	1604	5^h14^m	2960^m	Successful dive
"	3-6-74	509	24-54.0N 77-42.2W	W.H.O.I. Biology recover sediment trap	J.Donnelly	P.Wiebe K.Ulmer	1013	1518	5^h05^m	2100^m	Successful closed doors on sed.trap
"	3-7-74	510	24-53.7N 77-39.4W	W.H.O.I. Biology recover experiments at Bottom Station	V.Wilson D.Foster	P.Polloni	1043	1747	7^h04^m	7500'	Successful relocation of Bottom Station
"	3-8-74	511	24-59.8N 77-44.2W	W.H.O.I. Biology	J.Donnelly	K.Lawson P.Polloni	1017	1624	6^h07^m	2560^m	
"	3-9-74	512	25-10.7N 77-27.2W	W.H.O.I. Biology	J.Donnelly A.Barrs	K.Lawson	0917	1225	3^h08^m	6510'	Last dive in series
69	5-22-74	513	W.H.O.I. Pier	ONR Trim Dive	V.Wilson J.Donnelly	None	1343	1602	2^h19^m	15'	Tethered trim dive
"	5-24-74	514	42-08N 69-36.6W	ONR Trim Dive	V.Wilson J.Donnelly	L.Shumaker	1045	1225	1^h40^m	250^m	Trim dive and check-out
"	5-28-74	515	Woods Hole harbor	ONR Qualification	L.Shumaker	D.Hosom P.Curtis	1547	1629	42^m	60'	Shumaker's first solo
"	6-3-74	516	Woods Hole harbor	ONR Test	V.Wilson J.Donnelly	None	1440	1502	0-22	50'	Check-out
"	6-21-74	517	37-25.0N 25-33.0W	NOAA Test	V.Wilson D.Foster	J.Donnelly	1805	1945	1-40	775^m	Successful dive

Table II *ALVIN* 1974 Dive Log (continued)

Lulu Cr.No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Dive	Time Surf.	Sub.	Depth m/ft.	Remarks
70	6-30-74	518	36-49.0N 33-16.0W	NOAA FAMOUS Program	V.Wilson L.Shumaker	R.Ballard	1008	1703	6-55	2780^{m}	Highly successful - 127# rock, water samples, cores
"	7-1-74	519	36-49N 33-16W	"	J.Donnelly	J.Moore R.Ballard	0952	1752	8-00	2805^{m}	Very successful - no penetrator leaks at all
"	7-2-74	520	36-49N 33-15W	"	L.Shumaker	J.Moore J.van Andel	1008	1710	7-02	2706^{m}	Successful dive
"	7-3-74	521	36-49N 33-15W	"	V.Wilson	J.van Andel R.Ballard	1100	1719	6-19	2671^{m}	Successful dive
"	7-4-74	522	36-49N 33-16W	NOAA FAMOUS Program	D.Foster	W.Bryan J.Moore	1013	1727	7-14	2744^{m}	Successful dive
"	7-5-74	523	36-50N 33-15W	"	J.Donnelly	J.Bryan R.Ballard	0913	1500	5-47	2816^{m}	Successful dive
"	7-15-74	524	36-49N 33-16.5W	"	V.Wilson	J.van Andel J.Moore	0834	1440	6-06	2613^{m}	
"	7-16-74	525	36-48.6N 33-16.2W	"	L.Shumaker	J.van Andel R.Ballard	0934	1619	6-45	2723^{m}	
"	7-17-74	526	36-48.8N 33-15.1W	"	J.Connelly	W.Bryan J.Moore	0950	1917	8-27	2703^{m}	
"	7-18-74	527	36-48.3N 33-15.4W	"	L.Shumaker	J.van Andel W.Bryan	1038	1757	8-09	2800^{m}	126 pounds of rocks
"	7-19-74	528	36-48.5N 33-16.0W		J.Donnelly	J.Moore G.Keller	0920	1620	7-00	2749^{m}	
"	7-20-74	529	36-48/8N 33-16.0W	"	D.Foster	R.Ballard J.Heirtzler	0916	1650	7-34	2749^{m}	
"	7-21-74	530	36-48.1N 33-16.3W	"	V.Wilson	R.Ballard J.Heirtzler	0949	1705	7-16	2634^{m}	
"	7-28-74	531	36-58.9N 25-20.2W	NUSC NLON	L.Shumaker V.Wilson	A.Ellin-thorpe	0950	1415	4-25	592^{m}	

Table II *ALVIN* 1974 Dive Log (continued)

Lulu Cr.No.	Date	Dive No.	Location	Sponsor/ Purpose	PIC/CP	Obs.	Dive	Time Surf.	Sub.	Depth m/ft	Remarks
70	8-3-74	532	36-36.7N 33-28.0W	NOAA FAMOUS Program	J.Donnelly	W.Bryan J.van Andel	0947	1638	6-51	2228m	67# rocks
"	8-4-74	533	36-36.8N 33-28.5W	"	D.Foster	R.Ballard G.Keller	0919	1640	7-21	2288m	56# rocks
"	8-5-74	534	36-47.5N 33-16.1W	"	V.Wilson	W.Bryan J.van Andel	0955	1709	7-14	2735m	97# rocks
"	8-6-74	535	36-49.3N 33-16.5W	"	J.Donnelly	G.Keller R.Ballard	0857	1645	7-48	2752m	Last FAMOUS dive
"	8-16-74	536	36-52.8N 33-38.6W	DSDP	J.Donnelly	R.Ballard J.Heirtzler	1425	2003	5-38	1874m	Unable to locate reentry cove
"	8-21-74	537	35-09.3N 48-10.2W	ONR	D.Foster	R.Ballard J.Heirtzler	0934	1543	6-09	2002m	Calvin Seamount
"	8-24-74	538	34-46.5N 57-07.3W	ONR	J.Donnelly	R.Ballard R.Houghton	1039	1628	5-49	2597m	Nashville Seamount lost stern prop rotation
"	8-25-74	539	35-35.9N 58-38.5W	ONR	D.Foster	R.Ballard P.Taylor	1018	1707	6-49	2665m	Gillis Seamount
"	8-27-74	540	37-26.4N 59-47.1W	ONR	J.Donnelly	J.Heirtzler R.Houghton	1020	1730	7-10	2988m	Rehoboth Seamount
"	8-28-74	541	38-08N 61-00W	ONR	D.Foster	J.Heirtzler P.Taylor	1240	1816	5-36	2169m	Manning Seamount
"	8-30-74	542	39-23.9N 65-27.1W	ONR	J.Donnelly	J.Heirtzler R.Ballard	1141	1808	6-47	2821m	Balanus Seamount
"	9-1-74	543	39-24.4N 67-08.2W	ONR	D.Foster	J.Heirtzler P.Taylor	1035	1708	6-33	3041m	Mytilus Seamount
71	9-18-74	544	39-26.5N	NOAA	J.Donnelly	J.Uzmann R.Theroux	1004	1528	5-24	1240m	
"	9-19-74	545	39-28.3N 72-12.0W	NOAA	D.Foster	J.Uzmann R.Theroux	1129	1135	0-06	35m	Aborted due to ground on 30v.bus.
72	10-5-74	546	39-45.6N 70-39.8W	NOAA	J.Donnelly	B.Robison C.VanRaalt	1218	1827	6-09	1802m	Inspected garbage Bale & recovered Mud Box from WHOI Bottom Sta.#1.

then utilized on *Alvin*. Since this installation, *Alvin* has made 20 dives to over 8000 feet with no degradation of the penetrators. To further validate the overall integrity of the hull assembly, the Number 2 hull was pressurized to the equivalent of 22,500 feet with 72 hour holds at 18,000 feet and 19,100 feet, and 10 hours at 22,500 feet.

Electrical Penetrators. Laboratory tests were continued during 1974 in an effort to ascertain that the tapered penetrator bodies would not tend to be squeezed and forced to move outward due to the quite high hull compressive stresses at the 12,000 ft. depth. While the outward force on the penetrator can be calculated, the results of such calculations depend on the coefficient of friction for the mating surfaces. In most friction-force calculations a handbook value of friction coefficient is accurate enough; however in this case where both mating parts are of titanium, and some form of anti-galling compound must be used, a more exact determination of the frictional behavior was considered necessary.

Wedge-shaped titanium blocks were used to model the hull-squeeze situation (Fig.1). A strain-gauged bolt prevented outward motion of the central block but permitted direct measurement of the outward force as the assembly was loaded in compression. About three dozen separate tests were conducted, some of 24-hours duration. Tests were run with the mating surfaces a) clean and dry, b) having the anti-galling compound Molykote M77 applied according to manufacturer's instructions, and c) containing an excessive amount of the Molykote M77. Tests indicated that with the excess amount of anti-galling compound the surfaces essentially were prevented from coming together and the resulting frictional resistance was very low. However with the compound correctly applied, the coefficient of friction averaged about 0.27, and for the surfaces clean and dry, the coefficient had approximately this same value. Earlier, calculations had indicated that a value of coefficient of friction of 0.13 or greater would be sufficient to prevent any tendency for the tapered penetrators to be forced outward by the squeezing action of the hull.

New Viewing Windows. Under an agreement between this Institution and the Naval Undersea Center in San Diego, California, that laboratory manufactured and tested the new spherical sector acrylic plastic viewports intended for use in the submersible *Alvin*. These windows, designed to fit the existing conical seats in the *Alvin* titanium pressure hull, are said to be optically and structurally superior to the plane-surface conical windows presently in use. Six viewports were fabricated and all were proof-tested at a depth of 13,500 feet. Two units were selected for severe testing, and they will not be used in the submarine (Figs.2 and 3). One of these was subjected to 30 consecutive pressure cycles to a depth of 13,500 feet. The other was pressurized to 45,000 feet (almost four times the operating depth of *Alvin*) and held for 100 hours without failure. During the 1975 operating season at least one of the new viewports will be installed in *Alvin* for evaluation.

New Control Center. During this calendar year, a major change was made in the outboard electrical distribution system on *Alvin*. The original control center was located above the battery boxes in the only space available that was near the batteries. It is not feasible to drop batteries when *Alvin* and *Lulu* are at sea and therefore any problem requiring access to the control center resulted

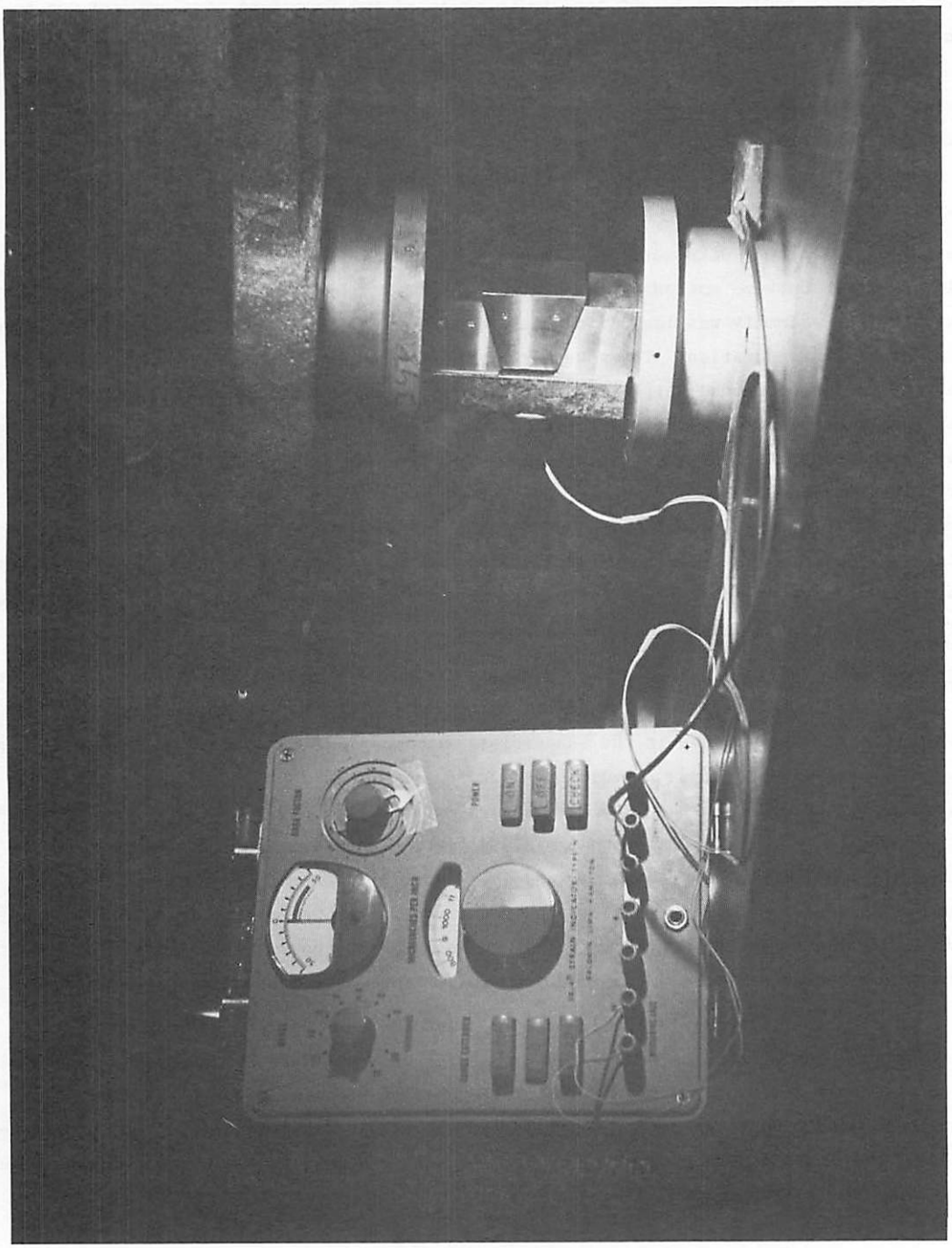


Fig.1 (Shumaker) Friction Tests of Titanium Alloy 6Al-4V.

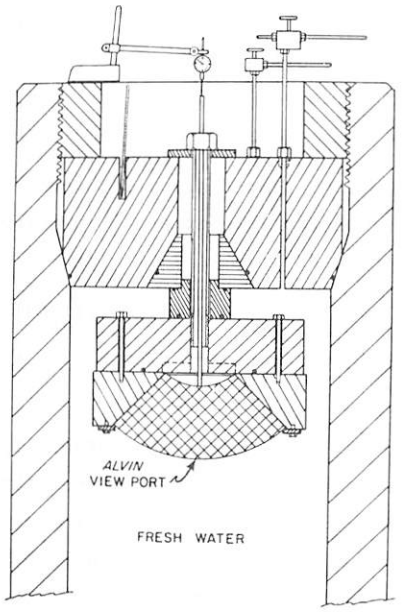


Fig.2 (Shumaker) Arrangement for Testing of *Alvin* Windows in the 18-inch diameter Pressure Vessel at C.E.L.

Fig.3 (Shumaker) Spherical Sector Window showing Strain Gauge Attachments.

in an aborted cruise. When the variable ballast system was changed to a seawater system, the space occupied by the variable ballast (v.b.) oil bladder was cleared. A new control box has been designed to fit the space on the port side of *Alvin* formerly occupied by the v.b. bladder. This box will be capable of being opened at sea by removal of a section of outer skin and a box cover.

The component layout in the control center has also been redesigned to provide more reliable operation and easier maintenance. Considerable external rewiring has been done since most external wires are connected to the control center.

One new penetrator has been installed to provide additional science wire availability.

These changes will provide *Alvin* with greater flexibility for meeting a variety of science requirements in the coming year.

Weight and Stability. As in previous years, weight and stability computations were performed for the submersible *Alvin* using the Woods Hole Oceanographic Institution Sigma-7 computer. Longitudinal and vertical components of the BG distance were determined for the vehicle in its normal submerged condition, for the released forebody, and for a number of emergency conditions. In addition, calculations were done to find pounds-per-inch immersion and moment-to-heel one degree (surface and submerged). A weight and stability report was prepared in the usual form and issued as a W.H.O.I. Technical Memorandum (Ref.1). Only minor weight changes have been made to the submarine since the 1973 weight report was issued. Since the elimination of the mercury-dump valves, the option to jettison trim mercury as an emergency measure no longer exists and this is reflected as a decrease in the number of emergency conditions computed. Certain modifications were made to the frame. Damaged welds were repaired, and a number of diagonal braces were added aft in the vicinity of the battery boxes. Stiffening gussets were placed near the base of each sphere-support pedestal.

The 1974 vehicle total displacement was 32,590 pounds, approximately 70 pounds greater than it was in 1973.

Reference

1. Sharp, Arnold G. 1974 DSRV *Alvin* Weight Report. W.H.O.I. Technical Memorandum No.8-74, December, 1974.

ENGINEERING PROJECTS

Work has continued on several Advanced Marine Technology projects for the Advanced Research Projects Agency under the Office of Naval Research contract N00014-71-C-0284; NR 293-008. This year also saw the start of a new project under ONR contract N00014-74-C-0179; RR042-09, studying operator performance factors on Undersea Manipulators.

ALVIN Navigation System. The final at-sea engineering evaluation trials of a new precision *Alvin* navigation system were conducted during February 1974 in the Tongue-of-the-Ocean (TOTO). The system was used extensively during FAMOUS (French American Mid-Ocean Undersea Study) conducted near the Azores during the summer of 1974.

The navigation system tracks both a submersible (DSRV *Alvin*) and her mother ship (R/V *Lulu*) relative to near-bottom moored transponders deployed as local area position references. The major part of the equipment and the navigator remain on the ship.

During the February trials it was observed that when *Alvin* was working on or very near the bottom that it was not unusual for the direct acoustic path from the submersible to one or both of the reference transponders to be blocked by local topography. It was demonstrated that when this happens it is likely that the signals received will result from a signal from *Alvin* bouncing off the sea surface to interrogate the reference transponder that was topographically blanked. It was shown that this surface bounce signal path could be used to calculate the position of *Alvin* when the normal direct path signals were lost. The programs for the HP9100 calculator used in the ALNAV (*Alvin* Navigation) system were rewritten to automatically look for, identify, and calculate *Alvin* positions using either the direct or surface bounce signal paths.

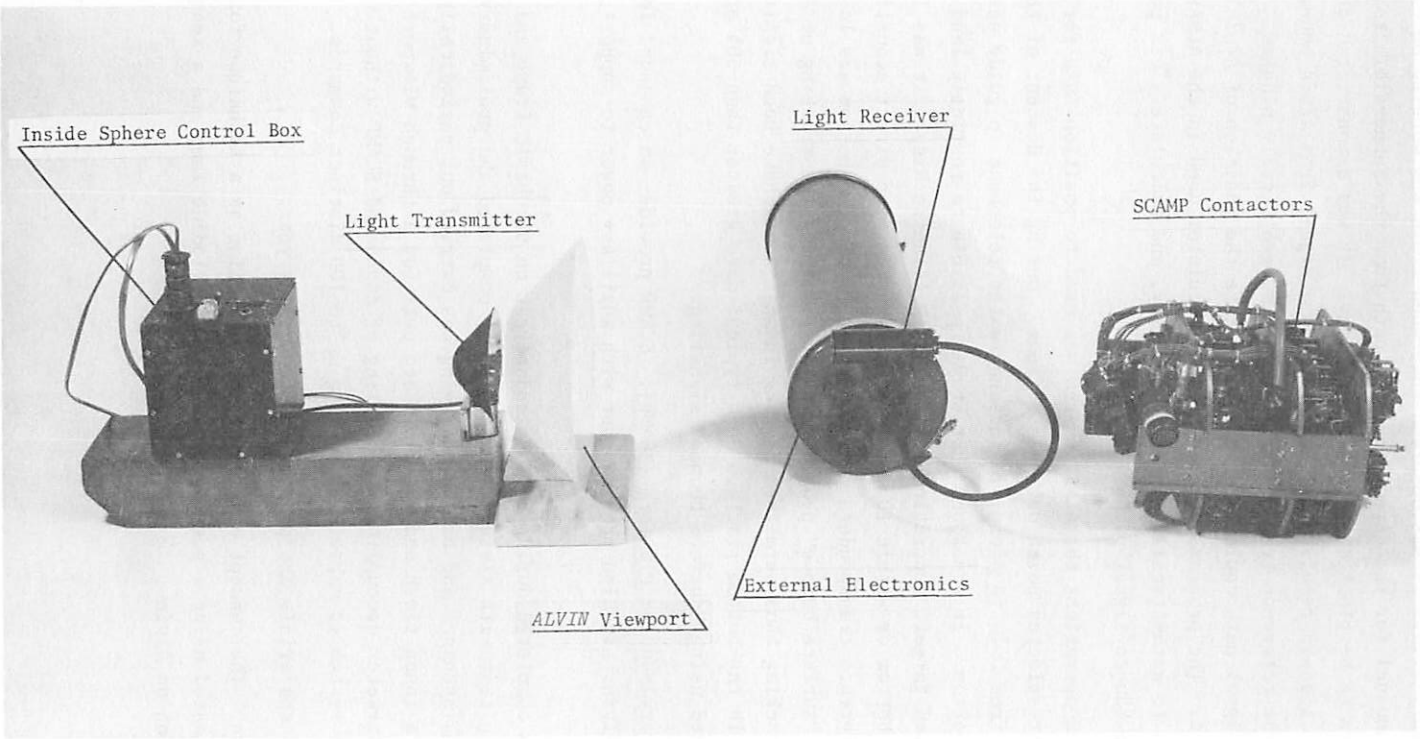
During the FAMOUS operations the ALNAV system was used to position *Lulu* for the launching of *Alvin* over a scientist-selected point on the sea floor. During the descent of the submersible, instructions were sent from *Lulu* to *Alvin* via the underwater telephone to guide her to the preselected target point on the bottom. It was found that it was possible to routinely land *Alvin* within 50 meters of a preselected target. Operating in the Middle Atlantic Ridge, it was found that when *Alvin* was operating on the bottom or within 10 meters of the bottom, the direct acoustic signal path from *Alvin* to the reference transponders moored 100 meters off the bottom was lost. When this happened, the automatic "surface bounce" program usually permitted the tracking of *Alvin* to continue. The surface bounce tracking thus permitted filling in what would have been significant and sometimes gross holidays in the bottom tracks. On a typical dive greater than 50% of the bottom track positions were obtained using "surface bounce" signaling.

Self-contained Ancillary Modular Platform (SCAMP). SCAMP provides an enhanced load-carrying ability for the submersible *Alvin*. It also provides her with auxiliary power to support a variety of scientific apparatus.

Construction was completed during this calendar year on the basic frame and the optical control system. A mating test with *Alvin* was successfully completed and preliminary harbor tests were conducted. Routine maintenance and battery charging was carried out periodically. The optical command system utilizes a xenon flash and silicon photo cell for a through viewport command link. This makes feasible an underwater decoupling and coupling of *Alvin* and SCAMP without use of mating connectors. The command system is capable of sending up to 100 distinct commands.

System tests and sea trials are planned for the coming year.

Wide Area Illumination. The concept of wide area illumination as a technique for better submersible viewing is being evaluated using a power package, a quartz iodide lamp and a xenon gas arc lamp designed for installation on *Alvin*.



SCAMP - Light Command System. A coded command is sent from the control box, via the light transmitter through the viewport to the light receiver and external electronics. The external electronics control the SCAMP contactors.

A 30-volt D.C. lead acid auxiliary battery pack has been designed and built for addition to the submersible. The pack uses standard *Alvin* batteries with a 150 amp hour capacity. A fiberglass and aluminum oil-filled box has been manufactured and the frame has been fitted to *Alvin*. Control of the pack is from within the ship.

Two quartz iodide 30V 750 watt lights have been purchased and a syntactic float was made. The syntatic float will also be used for the xenon gas arc lamp.

A "streamlite - 1 Million" xenon arc light has been purchased and repackaged in an underwater configuration. Some adjustments were required to obtain better heat dispersion without using the fan from the original package. Special consideration was also required in high voltage isolation particularly with regard to underwater connectors.

Undersea Manipulators. This was the first calendar year for the undersea manipulator operator performance program. The program is a continuation of work initiated some time ago at an industrial firm. The purpose of the study is to establish design guidelines and engineering criteria based on operator performance with various control modes. Future design efforts can be guided by specifications that are based on an understanding of performance as a function of engineering complexity. The psychophysical test program is being conducted by Eclectech Associates as a subcontract to Woods Hole Oceanographic Institution while the applied tasks are based on *Alvin* associated undersea manipulator experience.

A research manipulator was constructed under the previous contract that is capable of being configured in different control modes. Operator tests were then conducted using this manipulator in the rate, position and preliminary force feedback modes. The manipulator was installed at the Woods Hole Oceanographic Institution and after a familiarization period used to conduct further tests. Of interest at the present time is a bilateral force feedback configuration and both operator tests and engineering tests were conducted during this year.

WASTEWATER RESEARCH FACILITY

Peter E. Kallio

Design, construction, and operational supervision of a Wastewater Research Facility located at Otis Air Force Base continued through 1974. The project, which is under the direction of Dr. B. H. Ketchum, Associate Director, and Dr. W. B. Kerfoot of the Department of Biology, (see separate summary), was started in 1973. Construction commenced on 19 December, 1973, the plant was put on-line in May, and full operational status was achieved on July 17 with initiation of a regular four-day schedule of irrigation with chlorinated effluent.

The major engineering system uses a portion of the secondary treated effluent from the existing Otis Sewage Treatment Plant; stores it for a period of about two weeks (except during winter schedules); draws it into a pumping station where it is chlorinated to disinfect; and discharges the effluent through a force main to several fields for irrigation of animal feed crops. The

purpose is to recharge potable water to the water supply, while simultaneously providing nutrients and water to a marketable crop. Detail components of this system include a pumping and control station, holding basin, force main and associated manholes, three 1/3 acre fields irrigated by fixed impact nozzles, and a 3½ acre field irrigated by a 150 foot rotary irrigator.

The pumping and control station consists of a 10 x 20 foot metal building containing a 20 hp electric main pump with 180 gpm capacity and up to 100 psi discharge pressure. It also contains the gas chlorinator, electromagnetic flow recorders, and the several controls and safety interlocks. A system of two hydraulically self-powered valves prevent starting or stopping surges in the pipeline even in the event of power failure shutdown. The building is constructed over an eight-foot-deep pit which contains valves permitting draining of the pipeline or holding basin, and cross-connecting for backflushing. Electric service at 240 vac three was brought in from the Otis Treatment Plant, about 900 feet distant.

The holding basin was constructed in an existing sand filter bed by the erection of an earth dike and excavating an additional two feet to form a 100 ft. square area to hold approximately 300,000 gallons of effluent. The sides are sloped two-to-one, the bottom is pitched to the corner at the pumping station, and the whole sealed with a continuous 20 mil thick PVC liner. A structure was erected in the low corner, connected to shore by a foot bridge, to house the intake and drain and to permit service of these as well as provide a convenient sampling point. Effluent is admitted weekly, using an existing gravity main of the Otis Treatment Plant.

The force main which carries the chlorinated effluent to the agricultural fields is 2400 feet of 4" dia. PVC of bell and spigot type, with four manholes which contain the control valves to select the appropriate fields for daily irrigation, and the air and vacuum valves. It is pitched the entire length to permit complete draining through the pumping station, though it is normally kept filled. The force main system was hydrostatically tested to 150 psi and showed a leakage rate of less than three quarts in one hour, about 0.05% of the total volume.

Irrigation of the three 1/3 acre fields utilizes conventional quick-connect aluminum tubing and standard impact nozzles on one-foot risers. The nozzles are operated at 50 psi and deliver about seven gpm each. The fields are planted to Reed Canary Grass, a hay crop, and are given the equivalent of one, two, and three inches of rainfall, respectively, each week to determine the most effective rate of application.

Irrigation of the three 1/2 acre rectangular field is by means of a center pivot rotary irrigation machine. It consists of a 150 foot long truss supported about 10 feet above ground by a fixed swivel tower at one end and wheel-driven legs at the other. A one hp electric motor turns the wheels which causes the machine to rotate about the fixed swivel tower at the center of the field. This machine delivers 120 gpm at eight psi and is operated 13 hrs. 20 min. per week to apply the equivalent of two inches of rainfall. The field is planted to four crops, all animal feed, being Reed Canary Grass, Alfalfa, Timothy, and Smooth Brome.

A total of 42 bales of feed was harvested from these fields in late September.

Only minor alterations were required during initial tests, and the plant has been operating with complete reliability, with the exception of continuing nuisance with the flowmeter, since May.

A 12-foot by 60-foot trailer has been placed for use as a field laboratory and office. Electric service and drinking-water well have been provided, sanitary facilities are being planned.

Local communication telephone between trailer and pumping station, separated by over 1200 feet, utilizes a 40-conductor signal cable buried in the trench with the force main. This cable also provides remote alarm to the trailer and will be used for future instrumentation and remote monitors.

An adjacent abandoned Air Force Building has been partially renovated for use as housing for the farm tractor, agricultural implements, and future machinery requirements. A 10-foot by 30-foot earth ramp was constructed to allow vehicle entry. This building also provides temporary storage of harvested crops. Approximately 1000 feet of way have been cleared through woodland to permit vehicle access to wellheads.

Fifty-five lysimeters, which extract soil moisture in the plant root zone, have been installed to allow chemical analysis of water as it passes through the soil. These have been installed in irrigated and non-irrigated fields as well as in the sand filter beds.

A total of 14, 2" dia. PVC monitoring wells have been installed to permit evaluation of water quality in the ground water in either natural water, water which has been returned through the irrigation areas, and water effected by the existing Otis filter beds at the treatment plant.

Recently, an 8" dia. developed well was completed near one of the sand filter beds for the purpose of experimenting with underground storage, and later recovery of percolated effluent for irrigation or recreational purposes. A diesel driven pump with a 350 GPM capacity has been procured for this well, with installation scheduled for early 1975. Planning for additional fields, pipelines, and holding basin in conjunction with this well has been initiated for 1975 construction.

INSTRUMENT SECTION

Douglas C. Webb

JOINT PROGRAM FOR THE OBSERVATION OF COLD RINGS

Douglas C. Webb

The purpose of this program was to observe for the first time the motion of cold rings using long range, neutrally buoyant floats. It is a joint program between NAVOCEANO (Naval Oceanographic Office), University of Rhode Island, and Woods Hole Oceanographic Institution.

The fraction of the programs summarized here was concerned with the fabrication and deployment of the submerged instruments and the design and construction of the receiving station equipment.

Ten floats of a modified MODE I (Mid-Ocean Dynamics Experiment) design were prepared during the summer of 1974. All carried relocation and recovery equipment as well as internal recorders for the measurement of temperature and pressure. The float design differed only in detail from the design used during MODE I, the most important change being the use of one rather than two transducer tubes, the single transducer being mounted asymmetrically on one side of the pressure housing.

Three self-contained receiving sets were designed and built for installation in Navy stations. These were all two-channel receivers with a graphic recorder and self-contained timing equipment.

All floats were deployed from R/V *Lynch* during October 1974 and both the floats and receiving equipment have been functioning satisfactorily.

This experiment is still in progress and it is expected that at least some of the floats will be tracked through 1975.

SOFAR FLOAT DEVELOPMENT FOR POLYMODE

Douglas C. Webb

The work is a continuous and comprehensive program of the study of Mid-Ocean Dynamical Processing using neutrally buoyant floats. Emphasized are preparations and development for the POLYMODE experiment to be carried out in 1976 and 1977.

During 1974 the field work consisted of preparing four floats as follows:

(1) measurement of acoustic signalling performance at different depths. A float was prepared which changed its depth steadily from 650 meters to approximately 2,000 meters over a period of several months. Launched in March 1974.

(2) trial of new signalling system proposed for POLYMODE. A single float able to signal on both the MODE I signalling schedule and the new proposed POLYMODE signalling schedule was prepared and launched in September 1974.

(3) trial of depth stabilizing system proposed for POLYMODE. Two floats were prepared with prototype pressure measurement and control equipment and are to be launched from *Atlantis II* in January 1975.

Laboratory work has been primarily in the area of design of the new signalling system, and the associated equipment i.e. float equipment, receiving station equipment, and analysis routines. As well, the transducer and its mounting have been redesigned and improved and the internal battery simplified.

This work will continue into 1975 with a target of being able to place a purchase order for commercially fabricated floats and receiving station equipment for use in the POLYMODE experiment by July 1975.

Included in this program is a redesign of the inverted echo sounders used in MODE I.

This work, which has been carried on under the direction of David Bitterman, has progressed well. Radical changes in the design will hopefully permit a much-improved performance of this instrument. Trials of the new design will be carried out in February 1975 and if successful, it is planned to build 40 instruments for use in POLYMODE.

SALT FINGERS AND MICROSTRUCTURE

Albert J. Williams 3rd

Ocean mixing occurs by molecular diffusion. There is no other process which can produce water of intermediate temperature and salinity from two masses of water with different properties. Molecular diffusion is only appreciable, however, over scale lengths smaller than a meter. Thus, mixing must be preceded by stirring which intimately intermingles different water types.

Salt fingers have long been proposed as a microstructure in which vertical mixing might occur where warm, salty water overlies cool, fresh water. These centimeter scale convective cells were observed in the Mediterranean Outflow in July, 1973. They occurred at the horizontal interfaces separating 12-meter thick mixed layers. We think they are responsible for both the thick layers and the thin interfaces because a sequence was observed in which an isolated fingering interface, bracketed by thin mixed layers, was followed by a short staircase of thick layers and thin interfaces which was then succeeded by a long staircase. Possibly this staircase development is triggered by advection of extra warm and salty water into an area. The efficiency of the fingering staircase process at mixing heat and salt downward, depletes the excess in a day or two after which the staircase disappears.

Other microstructures are probably generated by velocity shear instability or by breaking internal waves. Microstructure similar to mechanical stirring was observed more than half the time in the upper 300 meters of the Caribbean near Puerto Rico in September, 1972. Turbulence generation by such mechanical instability should be transient and should decay in a fraction of an hour. Apparently the events are quite frequent near the coast and near the surface where our measurements were made which lends support to those who favor the boundaries of the ocean over the interior as a mixing region.

Very thick layers were observed in the Tyrrhenian Sea in May, 1973, which, though similar to those of the Mediterranean Outflow staircase, are probably of different origin. The Tyrrhenian layers were 10 times as thick and the interfaces 30 times as thick as in the Outflow. Further, they are permanent and widespread, the bulk of the water from 600 meters to 1500 meters belonging to only 12 values of potential temperature and salinity. Perhaps these mini water masses are formed every few years. Once formed, they are maintained and slowly altered by a much smaller scale finger-staircase process occurring within the thick interface between the very thick layers. We observed such a finger-staircase structure there.

MARINE TERMINAL CURRENT MEASUREMENT SYSTEM

James W. Mavor, Jr.

Various methods for measuring and telemetering ocean currents which may cause significant or dangerous ship set at offshore docking terminals have been investigated. Anticipated sea and current conditions, sensor types, sensor to shore telemetry and system reliability, maintenance and cost requirements were considered. The maneuverability of large tankers at slow speed in shallow water was taken into consideration in defining the required accuracy of the system.

Of existing point measurement sensors, the electromagnetic current meter was considered most nearly suitable, but a new system was considered worthy of a feasibility study, which has been performed, resulting in a recommendation favoring a modular class of rugged inclining telemetry spar buoys which measure directly the vertically averaged square of the velocity, which is a direct measure of the force acting to cause ship set.

PHYSICAL OCEANOGRAPHY

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

L. Valentine Worthington, Department Chairman

STUDIES OF OCEANIC PROCESSES

OCEANIC VARIABILITY AND DYNAMICS

Thomas B. Sanford

The scientific objective of this project is to understand the structure and dynamics of ocean currents and waves. Particular emphasis is placed on studies of the vertical structure of the velocity and density fields which provide new insights into the dynamic processes at work shaping the structure in time and space. The program also seeks to relate new observations to previous work, especially in the areas of eddy motion, microstructure generation, and internal wave and acoustic propagation.

Much of the effort in 1974 was devoted to an evaluation of our velocity profilers and analysis of the MODE-I (Mid-Ocean Dynamics Experiment) velocity profiles. Studies were undertaken into the structure and propagation of internal waves, the interaction of the MODE-I eddy with bottom topography, the refraction of sound within strong shear zones and the intercomparison of profile data from several methods.

During the past year, a comprehensive report (W.H.O.I. Ref.No. 74-46) has been completed which reviews the principles of operation, describes the construction and analyzes the performance of the electromagnetic velocity profilers (EMVP) developed over the past several years. Particular attention was given to identifying the sources and influences of method errors. Comparisons were made between two EMVP's and also between other profile data. The evidence supports estimated velocity uncertainties of about $\pm$.5 cm/s over small vertical scales (<500 dbar). On larger vertical scales, up to the water depth, the uncertainties increase to about $\pm$1 cm/s.

A set of velocity profiles at one location over an inertial period clearly reveals the essential structure of both the low- and high-frequency contributions. The low-frequency structure of the MODE-I eddy consists basically of only the first baroclinic mode. In contrast, the higher frequency profile is composed of many inertial and tidal waves occurring intermittently in the vertical.

In order to separate the contributions of the low-frequency (or steady component over a short series) from that of the inertial and higher frequency motions, we have fitted five profiles taken about every six-to-seven hours to a mean profile plus a rotary component. That is, at every depth level the velocity values from each profile are fitted in a least square sense to time means and circularly polarized, clockwise rotating with time components. Figure 1 shows the result of this analysis in the form of east and north profiles of the steady current, the inertial component, and the differences or remainders when fitted profiles are subtracted from the original data. Since the inertial component is rotary, Fig.1 represents the east and north components at 0000 24 May, 1973. Thus at 0600-0700 (1/4 vertical period) the east component changes sign and becomes the north while the north rotates to become the east component. The steady profile is remarkably smooth when compared with the other profiles. The degree of smoothness demonstrates that the time variable structure is quite coherent in depth and time over one day.

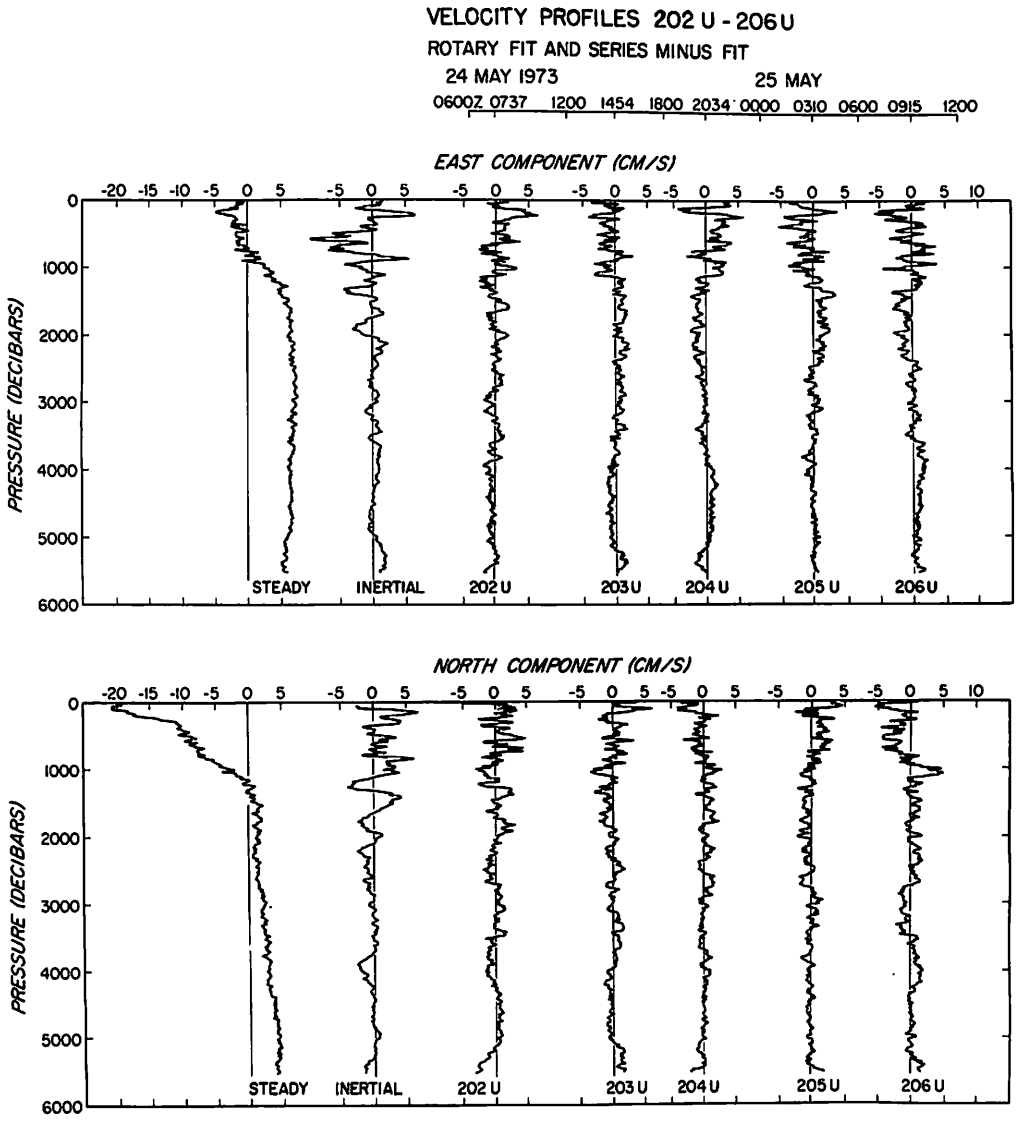


Fig.1 (Sanford)

Further analysis of the velocity profiles, using a technique of vector spectral analysis, has detected vertical propagation of near inertial-period waves. This method, previously applied to vector series in time, has been used to study the vertical spatial structure of velocity profiles. Prior to the use of spectral analysis, however, it was necessary to minimize the influence of vertical variations of the Brunt-Väisälä frequency. These variations result in a modulation

of the amplitudes and vertical wavelengths of internal waves, as can be seen in Fig.1. The procedure was to normalize the current amplitudes and stretch the vertical coordinate according to a WKB scheme. The vector spectral analysis, applied to the normalized and stretched profiles, yielded wave polarization estimates which were related to the sign of the vertical group velocity of internal waves. The analysis of a set of velocity profiles indicates that the net energy flux of the waves near the inertial frequency is downward.

Strong shear zones, so evident in profile data, influence the propagation of sound. In MODE-I, velocity and sound speed profiles revealed strong shears of large horizontal extent and of inertial frequency in regions of low sound-speed gradient. These observations indicate that shear refraction is most likely when the ratio of the vertical gradient of sound speed and the Brunt-Väisälä frequency is of order one. To demonstrate the influence of shear on ray paths, a simple current and sound speed model was studied. The model consisted of a layer of low sound speed gradient containing an isolated lens of inertial current. Nearly horizontal sound rays from a source in this layer experienced strong downward refraction in traveling one direction, in contrast to those rays moving in the opposite direction which tended to be focused.

Rays propagating for long ranges may be subjected to shear-induced refraction in several shear layers. Further, rays from a wide range of source depths may become horizontal, or nearly so, within or near the isospeed, shear-current layer. In this manner, variations in long-range propagation may be expected to be induced by the vertical shear as well as by the inertial wave modifications to the sound speed structure.

AN ABSOLUTE VELOCITY PROFILER BASED ON ELECTROMAGNETIC (EM) AND DOPPLER PRINCIPLES

Thomas B. Sanford

The goal of this work is to develop an absolute velocity profiling device. The present Electromagnetic Velocity Profilers (EMVP's) which have been developed at this Institution measure relative velocity. The present work involves the design and construction of a separate device to measure the absolute velocity profile near the sea floor by a method based on the Doppler effect. When used with the present EMVP's, the Doppler unit will provide the true profile near the bottom which will then provide the unknown constant not observed by the EMVP. The ultimate goal of the work is to combine into one instrument both the Doppler and EM systems.

The project began in June and most of the effort has been devoted to circuit and acoustical transducer design and fabrication. As initially built, the acoustical transducers had larger side-lobe transmission than expected. Acoustical signals produced by these side lobes and reflected by the bottom contribute larger interference than desired. So, much of the effort later in the year was spent trying to understand and correct this problem. The problem cannot be eliminated but it can be reduced by improved transmitter and receiver beam characteristics and signal processing.

The next stage in the development is to conduct tests in a shallow tank or flume early in 1975. These tests will determine the level of the desired signal compared with the noise or undesired signals. The relative signal level achieved will then determine the signal processing method to be used and its expected performance.

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-period 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 396 Nansen bottle stations have been made. Only seven stations were made in 1974. The first five were so poor in quality that operations were suspended in April until someone from the Woods Hole Oceanographic Institution could visit Bermuda in July and check out the equipment and procedures used. After that two more stations of better quality were made. Plans are underway to provide several trips a year to Bermuda for Woods Hole Oceanographic Institution personnel in order to maintain a closer check on the equipment.

An extensive analysis of eighteen years of *Panulirus* data, January 1955 through December 1972, stations #9 through #374, has been completed and the text is in preparation. This study will illustrate the changes in temperature, salinity and oxygen which have taken place during the years of this program. The long-range cooling and freshening of the entire water column is accompanied by a related increase in oxygen content.

A study of the steric level at the station site in relation to sea level for the second eight-year period of the series, June 1962 through May 1970, has been completed and the text is in preparation.

It is planned to complete both of these studies during the next year.

ACQUISITION AND USE OF TEMPERATURE-SALINITY DATA

Elizabeth H. Schroeder

This section of the Physical Oceanography Department processes and maintains temperature and salinity data collected by research vessels from the Woods Hole Oceanographic Institution and other institutions. These data in the form of bathythermograms, XBT traces and Nansen bottle casts are maintained to provide convenient access to permanent records in several forms for easy use in research.

Through December 31, 1974, this section has processed 416 mechanical bathythermograph slides, 2,780 expendable BT records and 14,168 BT prints received from outside sources. A total of

16,607 BT and Nansen bottle station cards were averaged by month at standard depths and added to our data collection; 2,323 of these were stations copied from various sources. There is a large backlog of data to be averaged.

In addition to reading and checking these data to ensure proper quality control, twenty mounted BT reading grids were issued to various people for use on cruises.

HORIZONTAL WAVENUMBER SPECTRA AND VERTICAL COHERENCE OF INTERNAL WAVE FIELDS

Eli J. Katz

A cruise is being planned for the fall of 1975 with the objective of measuring the coherence of the internal wave field over a range of vertical separations from five to one hundred meters at depths from 200 to 800 meters in a general region to the east of Bermuda. The resulting coherence spectra is expected to define the horizontal wavenumber at which coherence is lost at a specific separation. The results of a limited observation of this type are described in the summary of "Mid-Ocean Dynamics Experiment: Observations of an Isopycnal Surface" elsewhere in this report.

PREDICTING THE CHARACTERISTICS OF THE WELL-MIXED LAYER

Rory Thompson

Several one-layer models were implemented on a computer and forced with observed meteorological data for Ocean Weather Station "N". The model outputs are found to compare rather well with the oceanographic outputs, both in mixed-layer depths and sea-surface temperatures. One implementation of the Pollard-Rhines-Thompson model (*Geophys.Fluid Dyn.*, 4: 381-404, 1973) in a one-year forecast had maximum error of ½°C. This implementation is fast enough to use in climatological models. It was shown that sea-surface temperature anomalies could be created in the models by changes in turbidity (biota), and could be "masked" in summer, to re-appear in the fall.

VERTICAL MOTION STUDIES

Arthur D. Voorhis

1. Vertical convection in a Red Sea brine pool.

A paper was submitted for publication which discussed vertical convection in the Atlantis II hot brine pool. This pool is the largest in area (≈ 60 km^2) of three pools found in small deeps midway along the rift portion of the Red Sea. All of them are characterized by a remarkable thermal haline structure in which very hot saline water occurs in one or more horizontally uniform, well-mixed layers separated by very sharp vertical gradients of temperature and salt. Two brine layers occur in the Atlantis II pool; a deep layer extending from about 2040 m to the bottom (which has a maximum depth of about 2170 m) and an overlying lighter, cooler, and fresher intermediate layer about 30 m thick.

Measurements made since 1965 indicate that the volume, temperature, and brine content of the Atlantis II are gradually changing. This activity plus the persistence of the mixed layers within a confined deep suggests that they are maintained by thermal convection. Our paper discusses an effort made during a cruise of R/V *Chain* in February 1971 to detect this convection by measuring directly vertical currents in the intermediate brine layer of the Atlantis II deep, using one of the vertical current meters developed at Woods Hole Oceanographic Institution. The results suggested that at least two types of thermal convection were active: a primary small-scale convection responsible for the warming of the layer in recent years, and a secondary large-scale cellular convection driven by non-uniform horizontal heating which maintains vertical mixing in the layer.

2. Current and density structure along the shelf edge south of New England.

We are preparing for publication the results from a field investigation conducted in June 1971 in which horizontal and vertical currents have been measured south of New England along the east-west transition zone separating coastal shelf water from offshore slope water. In this zone, which runs along the shelf edge, light shelf water overlies heavier slope water in a frontal boundary which intersects the bottom at a depth of about 100 m and slopes upward offshore to the sea surface. Currents were measured by tracking three neutrally-buoyant vertical current meters in both shelf and slope water for periods of two to five days. Numerous vertical profiles of temperature and salinity were also measured over the drifting meters using a CTD (Conductivity, Temperature and Depth).

The mean along-slope component of the horizontal current appeared highly baroclinic with most of the flow confined to the overlying shelf water as a westward jet with speeds at the surface in excess of 20 cm/sec. The westward transport of shelf water along the boundary is estimated to be about 0.7 Sverdrups. The mean cross-slope component of the horizontal current was small, less than 2 cm/sec, in both shelf and slope water. In the latter the motion appeared as a slow up- and downslope motion with a period greater than two to three days which was probably due to adjustments of the frontal boundary.

Vertical currents measured in the overlying shelf water were due to high frequency internal waves with amplitudes of 10 m and periods as short as a few minutes, which were propagating along the frontal surface. In the underlying slope water large vertical motions of as much as 50 meters were observed near the bottom. The data suggests that they are caused by breaking internal waves of the diurnal tide. These large motions are also correlated with the appearance of mixed layers at the bottom and may be the primary mechanism for their formation.

The relationship between temperature and salinity along the shelf edge is very complicated. It appears that the transition zone between shelf and slope water is not a simple one between two water masses but is, instead, a layered complex of a number of slightly different water masses which have been advected at different rates along the shelf edge.

Reference

Voorhis, A.D. and D.L.Dorson. Thermal convection in the Atlantis II hot brine pool. *Deep-Sea Research* (in press).

INTERNAL WAVE INTERACTIONS

William F. Simmons

Platinum point conductivity probes used widely for measurements of vertical displacement in salt-stratified liquids, and used at Woods Hole in weakly nonlinear internal wave experiments, have been discovered to possess two major shortcomings. The most severe one is that the response of a probe (in a linearly stratified liquid) to sinusoidal motions is not purely sinusoidal, and nonlinearities of 10 - 20% are typical. Thus accurate measurements of energy flow with respect to frequency are not possible. Second, the dynamic response characteristics (transfer function) of the probes are unknown. Phase lags are usually so large that reliable identification of vertical mode numbers is impossible.

These faults have been overcome by two independent methods. One was the construction of a tiny forced-flow conductivity cell, with an outside diameter of $\sim$ 1 mm. The other was the fabrication of apparatus which oscillates the sensor tip of an L-shaped probe about the vertical axis, so that the sensor moves rapidly back and forth in a small horizontal arc, frequency and amplitude being adjusted to minimize mixing. Apparatus, data-handling facilities, and methods were developed to test the probes for linearity of dynamic response and to obtain an estimate of their transfer function. Test results indicate that both methods are successful.

Debugging of the twenty-segment internal wave paddle was initiated in November.

Early in the year, Barry Ruddick was able to overcome a difficulty in formulation of a Rossby wave-inertial wave interaction problem. The rate of energy transfer to the Rossby wave was found to approach zero with the Rossby frequency, and was at no time significant. Thus resonant interactions are not likely to be an efficient mechanism to transfer energy from inertial to very low frequencies.

LABORATORY MODELS OF OCEANIC PROCESSES

John A. Whitehead

This year we have been completing work on two topics. The first has been a refinement and extension of previous theoretical and laboratory work involving inviscid flow of fluid with a free upper surface through constrictions in a rotating frame. This is an extension of "classical" weir flow hydraulics to a rotating frame.

A primary objective has been to obtain a clearer understanding of flow through straits and over sills in the ocean. Flow over a wide weir has been formulated and laboratory tests are underway. The effect of time-dependence has also been incorporated into a number of models and tested experimentally. An interesting field example of stationary flow through a long, narrow opening occurring in Spencer's Gulf, South Australia, has been modeled and seen to compare reasonably well with our first theory, developed two years ago.

Considerable activity has gone into a second topic this year, convection of fluid heated from below. It is becoming clear that the mantle of the earth is overturning due to convective motions, and that this motion is linked to the production of new oceanic floor, and hence to the existence of oceans themselves. The location of the heat source is presently unknown, it may be mostly in the upper mantle, in the entire mantle, or in the core of the earth. Basic experimental studies of the structure of moving fluids heated below and within are badly needed for comparison with observations of the structural features of the earth. In conjunction with Frank Richter and Barry Parsons of the Massachusetts Institute of Technology, we have been observing convection of a very viscous layer of silicon oil 7 cm deep whose temperature difference from above to below is scaled to match (in a fluid dynamical sense) the temperature difference which is believed to exist from the top to the base of the convecting mantle. The resulting convection possesses much structure, whose properties and stability we have been systematically studying.

MID-OCEAN DYNAMICS EXPERIMENT

DYNAMICS OF UNSTEADY CURRENTS

Peter B. Rhines

Interpretation of neutrally-buoyant Sound Fixing and Ranging (SOFAR)-float trajectories, from Rossby's Sargasso Sea Experiment, is proceeding (with Dr. Howard Freeland). As well as giving a 'moving picture' of particle-motion in 200-km eddies at the 1500-m level (two such movies, in fact, have now been made), the long-term statistics establish (i) that over the Hatteras abyssal plain there is westward phase propagation characteristic of planetary waves; (ii) that the kinetic energy is very variable in space, even after 18 months averaging, showing an increase in energy to the west and south of 28^{o}N, 70^{o}W, and a decrease to the east; (iii) that the currents show polarization apparently in sympathy with the shape of the Blake outer bank, and the Antilles, which act as the dynamical western boundary; (iv) that ordinary notions of eddy diffusion plus a broad-scale, weak mean flow are inadequate in this region, due to the severe spatial variation of even long-term statistics.

The theory of mean flows generated by eddies and waves has been considered, for a homogeneous fluid. On an unbounded β-plane, potential vorticity conservation implies that a zonal Eulerian circulation, $\bar{u} = -\frac{1}{2}\beta\,\overline{\eta^2}$, is generated by eddies with north-south particle displacement η, in source-free regions. This westward flow is balanced by eastward jets in the near field of sources.

Computer experiments on this and other topics in geostrophic turbulence continue at the National Center for Atmospheric Research.

The theory is being pursued by Mr. Kuh Kim, of instability of oceanic flows that are themselves neither uniform nor steady. This is analytically more troublesome than in the meteorological case of a basically steady zonal jet, but both baroclinic and barotropic instability have been found and examined in detail. It is of interest that intermediate-scale circulations, between that

of the basin and of the 200 km eddies are particularly susceptible to this instability, and the ensuing turbulent cascade of energy.

Projects with students included a theory of intermittent interactions between internal waves and a descriptive model of deep-ocean temperature fronts.

MID-OCEAN DYNAMICS EXPERIMENT: OBSERVATIONS OF AN ISOPYCNAL SURFACE

Eli J. Katz

On four occasions during the 1973 Mid-Ocean Dynamics Experiment (MODE) field experiment, a density surface in the main thermocline was mapped by continuous towing. During the present year the observed vertical displacement field was analyzed both in the large and in the small: from contour maps of the low-pass filtered field and by estimates of horizontal wavenumber spectra.

The vertical displacement fields showed snapshot images of the large anticyclonic eddy which was identifiable in all the MODE field observations. As the only spatially continuous observation, the measurement of isopycnal slopes associated with this eddy from the tows are particularly unambiguous. A slope of 7×10^{-4} (7 meters per 10 kms) was repeatedly observed over 50 km radius regions to each side of the eddy center, while, directly at the center, a single track measured a downward vertical displacement of 35 m in 11.5 km. Assuming the eddy to be in geostrophic balance, the isopycnal slopes compared reasonably well with the shear across the thermocline as measured by the current meter moorings at the same time periods. Over two months, an average westward advection of the eddy was estimated to be at a speed of 2 cm/sec. Contour charts and the geostrophic comparison were presented at the 55th Annual Meeting of the American Geophysical Union (Washington, D.C., April 1974) and are reported in the MODE Synoptic Atlas and the Dynamic Report, respectively.

Estimates of the horizontal wavenumber spectra of vertical displacement agreed with our earlier studies in a similar area, confirming the stationarity of this estimate of the potential energy in the internal wave field. The displacements due to the internal wave field are an order of magnitude smaller than the eddy depression; the standard deviation of the former being less than eight meters. The wavenumber spectrum is in good agreement with a much-discussed model of internal waves formulated by Christopher Garrett and Walter Munk.

New and first-time-ever estimates were made of the coherence spectra between two sensors towed nominally at 10 and 20 meters vertical separations. The coherency between two temperature signals so obtained decays rapidly at horizontal scales of three and one kilometer wavelengths, respectively, presumably due to energetic vertical wavelengths of the same length or smaller than the separation distance. These spectral results are described in the following papers: "Tow Spectra from MODE", by E.J.Katz, *J.Geophys.Res.* (in press); and "On the Stationarity of Temperature Spectra at High Horizontal Wavenumbers", by W.Zenk and E.J.Katz, (submitted to *J.Geophys.Res.*).

MODE HOT-LINE NEWS

Ferris Webster

The *MODE Hot-Line News*, a regularly-issued newsletter, was begun in March, 1972 to disseminate information about the scientific progress of the Mid-Ocean Dynamics Experiment (MODE). During 1974, MODE-I formally ended and the results of the experiment began to appear in the regular scientific literature. This resulted in a reduced need for the *MODE Hot-Line News* and the frequency of appearance was reduced. As the tempo of activities for the POLYMODE experiment increases, it is expected that the newsletter will play an important role as a means for informal scientific communication.

THE SOFAR FLOAT EXPERIMENT

Arthur D. Voorhis and Douglas C. Webb

The author with Douglas C. Webb of the Department of Ocean Engineering proposed, constructed, and deployed twenty Sound Fixing and Ranging (SOFAR) floats of a new design for the Mid-Ocean Dynamics Experiment (MODE) field program, which was conducted in the spring of 1973 to obtain a synoptic description of the current and density fields over a period of four months in a limited oceanic area, 300 km square, centered at $28^{o}00'N$, $69^{o}40'W$. Each float was an independent Lagrangian drifter ballasted to be neutrally buoyant at a nominal depth of 1500 m and designed to be tracked acoustically from distant shore stations over distances of approximately 1000 km.

The primary purpose of the floats was to provide from their drift tracks a real time description of the horizontal currents at 1500 m during and after the field program. The secondary purpose of the floats was to use them as drifting plot forms to measure the vertical advection of momentum and potential energy. This was accomplished by instrumenting ten of the floats to sense and record internally vertical water velocity, water pressure (float depth), and water temperature. Approximately 300 float days of this recorded data were recovered at the end of the MODE field program.

The author has spent a considerable fraction of his time since the end of MODE in processing the raw data from the instrumented floats and in presenting it in a form (Voorhis and Benoit, 1974) useful to other participants in the field program. Most of this work was completed in the first half of this year. The analysis of this data, not yet complete, shows the following:

a) Over 95% of the total vertical kinetic energy at 1500 m was due to up-and-down motions having periods between the local inertial period (approximately 25.5 hours) and the Väisälä period appropriate to the density stratification at 1500 m (approximate mean of 1.6 hours). This is the permissible range of periods for free internal waves. The day-to-day variation of this energy was remarkably small over the MODE area during the entire four months of the experiment, typical variations being no more than 30%. The daily r.m.s. internal wave vertical velocity and amplitude were 0.45 cm/sec and 10.0 m respectively. Frequency spectra show that the vertical kinetic energy is distributed rather uniformly over the entire range of periods with a broad peak at the Väisälä period, a sharp peak at the M_2 semidiurnal internal tide (12.42 hours), and a broad peak centered around 22 hours. No reliable peak at the inertial period could be detected.

b) Vertical motions with periods shorter than the Vaisala period were very small and their nature is not yet clearly understood.

c) Of particular interest to MODE were long, slow vertical motions having periods greater than the inertial period which, although not very energetic, were indicative of slow geostrophic adjustments in the ocean. Unfortunately, our measurements were not really precise enough to accurately resolve the motions. Nevertheless, it was possible, by filtering our records, to find long-term upward and downward water displacements of 50 to 100 m over periods of 30 to 40 days.

Reference

Voorhis, A.D. and R.R.Benoit 1974 MODE SOFAR float *in-situ* data summary. *W.H.O.I. Ref.*No.74-37 (unpublished manuscript).

MOORED ARRAY EXPERIMENTS

MOORED ARRAY PROGRAM

Nicholas P. Fofonoff, William J. Schmitz, Jr.

A total of 29 moorings was set in 1974 in several scientific experiments, devoted in large part to two major experiments. An array of 15 moorings (32 current meters, 2 temperature depth recorders) was set from April to December between Site D and the Gulf Stream.

A pilot experiment of nine moorings (32 current meters and 23 temperature/pressure recorders), POLYMODE-0, was set extending east along 28°N from the MODE region (centered at 28°N, 69°40'W) to 55°W, and north from 28°N to 36°N, along 60°W. These are scheduled to be recovered in April, 1975.

In addition, a total of 118 CTD (conductivity, temperature, depth) stations were taken in support of the various scientific activities of the Moored Array Program. The Moored Array Program was supported by the following agencies: Office of Naval Research, National Science Foundation (IDOE and DES) and the Applied Physics Laboratory of The Johns Hopkins University. Details of the scientific activities supported by these agencies follow in individual summaries. Engineering experiments are described separately in the summaries for the Department of Ocean Engineering.

James R. Luyten and Melbourne G. Briscoe were co-investigators in the above research.

a. LOW FREQUENCY FLUCTUATIONS IN THE NORTH ATLANTIC SUBTROPICAL GYRE

Our efforts to explore the existence and isolate the mechanisms of the low-frequency variability in the western North Atlantic have focused, in 1974, on current and hydrographic observations along 70°W. These observations are consistent with a recirculation in the deep subtropical gyre, as proposed by Worthington (1975). The amplitude of these fluctuations is strongly latitude dependent indicating that there exist dynamically significant Reynolds stress gradients in the deep ocean and a variety of spatial scales (Fig.1).

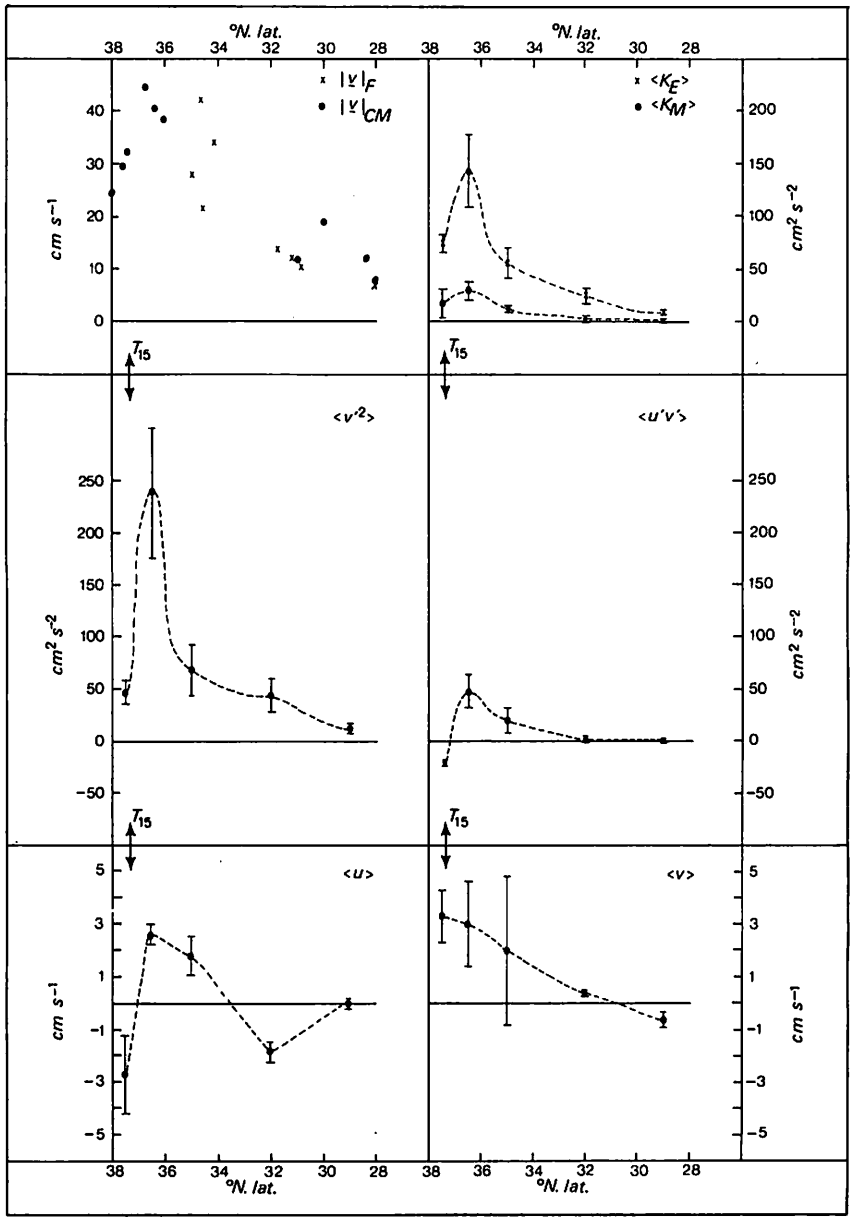


Fig.1 (Fofonoff, *et al.*) Latitudinal distribution of maximum speeds ($|\underline{v}|_F$ for neutrally-buoyant float data, $|\underline{v}|_{CM}$ for current meter data), fluctuation and mean kinetic energy per unit mass ($\langle K_E \rangle$, $\langle K_M \rangle$), Reynolds stresses ($\langle v'^2 \rangle$, $\langle u'v' \rangle$) and (east, north) velocity components ($\langle u \rangle$, $\langle v \rangle$), for a nominal depth of 4000 m and primarily along 70°W longitude, except for the float data in the vicinity of 34°N latitude. The brackets < > denote composite time and latitudinal averages.

Long-term moorings in the MODE region (nominal center 28°N, 70°W) were continued throughout 1974. These data indicate that a significant variability in the statistics of the flow in the MODE region exists on eddy scales.

In August 1974, nine moorings were set as a pilot array (POLYMODE-0) for the next generation eddy experiment. This array is scheduled to be recovered in April 1975. These efforts have been sponsored jointly by Office of Naval Research and National Science Foundation/International Decade of Ocean Exploration (NSF/IDOE), and involved the participation of the following scientists: W. J. Schmitz, Jr., N. P. Fofonoff, J. R. Luyten, and P. B. Rhines.

Reference

Worthington, L. V., 1975 On the North Atlantic Circulation. *The Johns Hopkins Oceanographic Studies*, in press.

b. MOORING OPERATIONS

A total of 29 moorings was set in calendar 1974, under the supervision of Robert H. Heinmiller, Jr. All but one were of the intermediate type and most were in large arrays. The routine deployment of moorings for nine to ten months has enabled us to reduce our cruise schedule but keep more instruments at sea than in previous years.

On the April cruise a three-mooring array was set at Site D, a twelve-mooring array set between Site D and the Gulf Stream and two new MODE-site maintenance moorings were deployed. An intermediate mooring with a section of jacketed Dacron as fishbite armor was set near the Gulf Stream. A surface mooring was deployed in April as a surface mooring dynamics experiment. Shortly after deployment a factory-made wire termination pulled out. The experiment was aborted, and the gear was recovered using the back-up recovery capability.

On the July/August cruise, a nine-mooring array was set in an area south and west of Bermuda, and the POLYMODE-0 array. The MODE maintenance moorings and the fishbite test were recovered.

The December cruise consisted mostly of recoveries. The Gulf-Stream array was recovered, together with the Site-D array (all set in April) and the one-year intermediate test (set in December, 1973). A test mooring was set near Site J to test VACM modifications, a new fishbite armor and a new wire-rope construction.

The current meter shop continued to design and test improvements to the 850 current meter. A new set of COSMOS circuitry has been tested to replace the standard manufacturer's circuit boards.

Efforts to bring our documentation and cruise reports up to date are nearing completion. Complete documentation of mooring operations should be available by summer of 1975 including current-meter and release maintenance, mooring design, and field operations.

Moorings in 1974

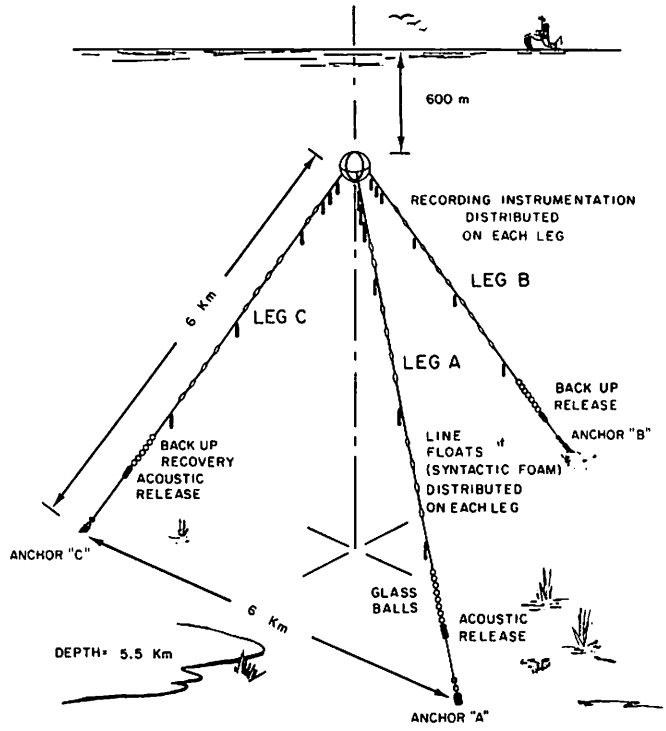
Number	Month Set	Location	Type	Duration	Recovery		Notes
517	Dec. '74	Site D	Interm.	363	Complete		One-year engineering test
523	April	"	"	241	"	)	
524	"	"	"	240	"	)	Thompson array
525	"	"	"	240	"	)	
526	"	Gulf Stream	"	239	"	)	
527	"	" "	"	239	"	)	
528	"	" "	"	240	"	)	
529	"	" "	"	239	"	)	
530	"	" "	"	245	"	)	
531	"	" "	"	244	"	)	
532	"	" "	"	245	"	)	Luyten Gulf-Stream experiment
533	"	" "	"	245	"	)	
534	"	" "	"	246	"	)	
535	"	" "	"	244	"	)	
536	"	" "	"	244	"	)	
537	"	" "	"	244	"	)	
538	"	MODE	"	101	"		MODE Site maintenance
539	"	"	Surface	---	"		Dynamics experiment - aborted
540	"	"	Interm.	101	"		
541	April	Gulf Stream	"	90	"		Fishbite test
542	July	Polymode	"	At Sea	--		
543	"	"	"	" "	--		
544	"	"	"	" "	--		
545	"	"	"	" "	--		
546	"	"	"	" "	--		
547	"	"	"	" "	--		
548	"	"	"	" "	--		
549	"	"	"	" "	--		
550	"	"	"	" "	--		
551	Dec.	Site J	"	" "	--		VACM engineering test

c. INTERNAL WAVE STUDIES

During 1974 the work on internal waves has been supported principally by the Applied Physics Laboratory of The Johns Hopkins University and by the Office of Naval Research. The focus of the work has been the Internal Wave Experiment (IWEX), and has involved a large number of investigators: K. Hasselmann*, N. Fofonoff, F. Schott*, M. Briscoe, C. Frankignoul*, T. Joyce, P. Muller*, D. Olbers*, W. Zenk*, Y. Desaubies, and S. Hayes. (*Visitors).

APL/JHU initiated IWEX in April 1972, and has provided substantial funding through 30 June 1975. Starting in July 1974 ONR has shared some of the costs.

The original goal of IWEX was the determination of the four-dimensional (frequency and three spatial wavenumbers) energy spectrum (the kinematics) of the internal wave field in the main thermocline in the open ocean. The experiment, a deep-sea tri-moored array of 29 current meters and pressure-temperature recorders (Fig.2), was deployed in late October 1973 and recovered successfully in mid-December 1973. During 1974 our work has consisted solely of data processing and preliminary analysis.



TRIMOORED INTERNAL WAVE
EXPERIMENT (IWEX)

Fig.2 (Fofonoff *et al.*)

The principal data processing has been the calculation of cross-spectra between all pairs of variables, for each of 25 pieces of the total time series; this yields 45,750 cross-spectra, each composed of 600 frequency points.

The preliminary analysis has mainly been the assessment of various subsets of the spectra. A workshop held at Woods Hole Oceanographic Institution, 23-27 September 1974, discussed the preliminary results and mapped out the flow of work for the main analysis, much of which will take place during 1975 in Hamburg, Germany.

The "inverse modeling" analysis to take place during 1975 is a direct attempt to reach that original goal. First results are expected in the spring of 1975 and a workshop is scheduled in Hamburg for March-April to discuss those results. A report of the modeling attempts and of the 4-D energy spectrum is expected by the end of 1975.

A collection of papers on oceanic internal waves edited by Briscoe, supported by the Office of Naval Research, will begin publication in the Oceans and Atmospheres section of the *Journal of Geophysical Research* in January 1975 and will continue for several months. In addition, an IUGG (1971-1974) Quadrennial Report by M. Briscoe on oceanic internal waves, will appear in *Reviews of Geophysics* in June 1975.

d. LOW-FREQUENCY VARIABILITY ALONG THE CONTINENTAL RISE

The energetic meandering of the Gulf Stream is suspected as the source of much of the low-frequency variability in the western North Atlantic. The radiation of energy away from the Stream via topographic Rossby waves may play an important role in the dynamics of the Gulf Stream. We have undertaken a variety of observations to examine the nature of the current variability along the continental rise between $36^{\circ}30'$ and $39^{\circ}30'$N in the vicinity of 70°W and its relation to the meandering of the Stream. An array of 16 moorings and 32 current meters was set in this region in April 1974 and recovered in December 1974. The current meter records are being processed. On the cruise to the region in May, we determined the positions of the Stream (T_{15}) and obtained 37 time series of vertical profiles of the horizontal current, temperature, conductivity, and pressure in four locations within the array. During the months of June and July, eight airborne surveys were made of the surface temperature in this region to determine the position of the surface expression of the Gulf Stream. This work, supported jointly by NSF/DES and ONR, involved J. R. Luyten, P. M. Saunders, F. C. Fuglister, and J. C. Swallow.

The three-year, three-mooring array (supported by ONR) around Site D ($39^{\circ}10'$N, $70^{\circ}00'$W) terminated in December. Preliminary analyses of this data set look encouraging for the view that the low-frequency motions below the thermocline can be described as topographic Rossby waves, with energy source in the Gulf Stream (R.O.R.Y. Thompson).

e. INSTRUMENT AND MOORING RELIABILITY

The principal result of the increased emphasis upon instrument quality control has been the substantial increase in data return during 1974, reaching over 90% data recovery in December from the eight-and-a-half-month Gulf Stream-Continental Rise Experiment (J. P. Dean, S. C. Dexter). The rotor problem has been corrected, and a redesign of the vane bearings, coupled with detailed electrochemical corrosion protection, appears to have eliminated the vane striction problems. The increased corrosion protection for the acoustic releases and current meters greatly reduced the corrosion on the components of the one-year intermediate mooring recovered in December 1974.

The mooring reliability efforts have focused on the instrument depth stability (R. H. Heinmiller, R. Walden). The source of the static departures from design depths was identified as the synthetic line used in the compound moorings. The length of the synthetic line under tension depends upon the tension history of the line. We have eliminated the synthetic components of the intermediate moorings in favor of an all-wire mooring. The dynamic depth stability has been greatly improved by optimizing the quantity and distribution of the glass spheres used as buoyancy elements.

f. SPATIAL AND TEMPORAL VARIATIONS IN NORTH ATLANTIC FINE STRUCTURE IN 1974

The CTD (conductivity, temperature, depth) program has supported the moored array project within the past year with a data base for hydrographic measurements at each mooring site whose distribution, in space and time, permits a statistical study of the geographical distribution of oceanic fine structure. The acquisition and analysis of these data involved T. M. Joyce, S. P. Hayes, R. C. Millard, Jr., D. E. Moore, and G. H. Volkmann.

In the MODE area the vertical variability of temperature and salinity throughout the water column on scales as small as ten meters is consistent with internal wave straining. A 12-hour yo-yo time series in the main thermocline was analyzed for the study of the vertical wave number, frequency spectrum of internal waves. On scales smaller than ten meters characteristic signatures of sheets and layers begin to appear. This transition scale and, hence, the intensity of vertical mixing, is a function of geographical position; microstructure activity increases as the Gulf Stream is approached from the Sargasso Sea, suggesting the Gulf Stream region as a source for production of microstructure (as well as eddies).

A study of Mediterranean water in the MODE region indicates that salinity anomalies advect along isopycnals; little evidence exists showing that double diffusion plays a dominant role in the stability of these structures.

CTD profiles to the bottom show a 90% occurrence of a well-mixed layer in potential temperature and salinity with a thickness up to 140 decibars, variable in both space and time, which is <u>not</u> the result of local vertical mixing. The latter is supported by the fact that a correlation of thick-cold, thin-warm has been observed.

g. INSTRUMENT CALIBRATION

The newly-formed calibration facility continued to be used during 1974, primarily to make precision temperature calibrations on thermistors (A. L. Bradshaw and K. E. Schleicher). There were 267 calibrations made for the Mid-Ocean Dynamics Experiment (MODE) project and 81 for other projects. Numerous temperature and pressure calibrations were performed on CTD's.

The two Leeds and Northrup bridges used to measure the thermistor resistances were recalibrated with the Guildline transformer ratio bridge. This intercalibration now allows us to refer the accuracy of all the thermistor resistance measurements to that of a single resistor. In addition a 100-gallon seawater, constant temperature bath has been introduced.

h. MOORED ARRAY DATA PROCESSING

Data from 91 current meters were processed during 1974 (R. E. Payne). This was one more than in 1973 in spite of not having any experiments of MODE magnitude. Two data reports were published: *W.H.O.I. Ref.No.* 74-4 (1967 data) and *W.H.O.I. Ref.No.* 74-52 (1968 data). Requests for current meter data from 27 non-Woods Hole Oceanographic Institution scientists were filled, the majority of which were for MODE data. All the MODE current meter records which are of sufficiently high quality have been transmitted to the archives of the National Oceanographic Data Center.

A new program was written for objective contouring of array data and a large number of improvements and up-datings were made in the standard data processing programs (J. A. Maltais).

OCEAN AND ATMOSPHERE

AIR-SEA EXCHANGE

Peter M. Saunders

In the past year we have been concerned with the analysis of data from JASIN (Joint Air-Sea Interaction) experiment which took place at Ocean Weather Ship J in September 1972.

Our principal effort has been to relate current meter observations made on surface and near-surface moorings and the evolution of the surface temperature field as observed by repeated mapping with an airborne infrared radiometer. Striking inconsistencies were revealed by these techniques (e.g. the temperature field was advected much more slowly than the measured currents indicated) which let us to abandon efforts to verify our isotherm tracking technique and instead examine the quality of the current measurements.

Intercomparison between a vector-averaging current meter (VACM) at a depth of 10 m beneath a surface toroid and drifting buoys drogued with 4m x 1.5m x 1.5m canvas crosses at the same depth gave remarkably good agreement (see the accompanying table). Although conditions were far from rough with winds of 5 - 15 kts only, nevertheless for the following reasons, I believe these are as taxing circumstances as are encountered in strong winds! The performance of Savonius

MEAN CURRENT

Drogue No.	Period	Start End	Duration	Drogue (12 m)	VACM 1261 (10 m)	Current speed ÷ rotor speed (average)	Wind	Swell
4	4Z 16Z	14 Sep 14 Sep	12	11.0 cm/s 013°	12.1 cm/s 016°	0.1-0.35 (0.25)	10-15 kts NE to E	2-3 ft. 7-8s N, S
5	19Z 07A	15 Sep 16 Sep	12	21.6 cm/s 024°	19.2 cm/s 018°	0.3-0.5 (0.35)	10-15 kts SW	2-3 ft. 7s Con .
6	19Z 07Z	16 Sep 17 Sep	12	27.1 cm/s 042°	25,5 cn.s 039°	0.4-0.55 (0.5)	10-15 kts SW	2 ft. 7s Conf.
8	10Z 22Z	26 Sep 26 Sep	12	(7.9 cm/s 013°)	(4.5*cm/s 023°)	0.15-0.22 (0.2)	6-10 kts WSW	5 ft, 8s NE, W

*VACM 1256 at 5 m

JASIN '72 INTERCOMPARISONS (Saunders)

rotor/vane-type current meters in the wave influenced zone is, I suggest, dependent on three parameters: (1) wave period, (2) wave amplitude and (3) 'angle of attack' of flow. Both rotor and vane performance improve with increasing wave period, deteriorate with increasing wave amplitude (for a fixed mean current), and also deteriorate with increasing angle of attack. Little is known of this last effect except that vertical velocities 10 - 30x horizontal introduce large errors (x2 to x4) into the horizontal currents: our drogue/VACM intercomparison measurements show that when vertical and horizontal velocities are equal, the effects are very much smaller (not greater than 10%). Furthermore, we have found that a convenient measure of the effects of wave amplitude is the ratio of the current speed (magnitude of vector average) to the rotor speed. In data from the JASIN experiment this number varies between .05 and 0.9, the former corresponding to very weak currents/high wave noise and the latter to strong currents/weak wave noise. Latter values are comparable to those encountered on subsurface moorings (known from the MODE experiment to give accurate current measurements) and former values are rarely exceeded in near-surface measurements even in strong winds. Finally we have demonstrated the effects of wave period by intercomparing a VACM at 10 m with an Aanderaa current meter directly below it at 12 m (both below a surface toroid). In the same wave field, current speeds from the Aanderaa were found to exceed those from the VACM over a 12-day period by a factor of 2.5, yet the rotor speeds differed by only 2%! The cause, we established, was the slow response of the 1-m Aanderaa vane to the fluctuating field so that it failed to register wave-induced reversals of the flow: hence vector averages were too large. This has led us (1) to conclude that Aanderaa instruments cannot be employed near the surface and (2) to emphasize the critical nature of direction data in measuring surface currents.

ENERGY PRODUCTION FROM NATURAL PROCESSES

William S. von Arx

This investigation concerns a study of the power in natural cycles and identification of points where man's intervention may be both practical and ecologically safe over an indefinite span of time.

A study is made of the energy involved in geophysical processes (including gravitation), biological and botanical processes (including those induced by man); ranking of these processes by order of their total power; and studying those points in each cycle where man may intervene to extract power, and the probable disturbance(s) produced by his so-doing. A further object is to establish the power level at which man may survive indefinitely within the limits imposed by the natural energetic regimen of the earth and sun.

An experiment has been planned in which solar energy may be converted into technically useful forms. Methods have been found for the production of large volumes of hot brine under solar radiation (Tabor effect). This resource can be used directly for heating purposes. At the same time gaseous fuels (hydrogen and methane - for raising steam or operating internal combustion engines) can be produced through the Oswald-Golueke method of anaerobic bioconversion of aquatic plants (fresh water or marine) grown in culture. Both the hot water and gases can be stored, thus smoothing

out the day-night effect. Moreover the algae can be stored for later bioconversion into gas thus smoothing out the variations of production and power demand from season to season and place to place.

The proposed experiment will conserve all mass; only the incoming flux of solar energy and the output of heat and mechanical power will be exchanged with the environment. The small amounts of electric power required to conduct the experiment are to be supplied by a wind-driven generator and ballasting battery.

Calculations indicate that a compound system for solar energy conversion yielding both hot water and high energy fuel can be operated in middle latitudes to supply domestic and institutional needs. The "tuning" of both physical and biological elements to optimize production on a pilot scale is an object of this inquiry.

BOUNDARY LAYER AND FRONTAL ZONE STRUCTURE OVER THE EAST CHINA SEA

Andrew F. Bunker

The objective of the research is to determine the structure of the atmospheric boundary layer as air flows over the East China Sea. The work includes observational and analytical studies of continental, maritime and frontal zone air. The research is being carried out in cooperation with Japanese meteorologists as part of the Air Mass Transportation Experiment (AMTEX). The Japanese stationed weather ships in a ring around Okinawa during the month of February 1974 to obtain surface observations and upper air soundings.

The principal investigator joined the personnel from the National Center for Atmospheric Research (NCAR) to fly with the NCAR Lockheed Electra instrumented aircraft to Okinawa to participate in the AMTEX observing program. Unfortunately, shortly after leaving San Francisco for Okinawa the aircraft experienced failures of the cabin pressure and the propeller control systems. The propeller control system could not be repaired in time to fly to Okinawa to join the AMTEX program.

In March 1974 the Electra was flown to Wallops Island, Virginia, to carry out similar observations over the Gulf Stream and to make observations for other projects. Three successful flights were made over the cool coastal waters and warm Gulf Stream waters. Turbulence was measured in the boundary layer and in a frontal zone and recorded on magnetic tape. The reduction of the data will lead to the computation of fluxes of momentum, water vapor and heat through the air and to a description of the boundary layer. The data on the tape has not yet been converted to meteorological parameters, due to the pressures of the Global Atmospheric Research Program's Atlantic Tropical Experiment (GATE) project. Hence they have not been analysed.

In view of the cancellation of the Okinawa flight and the unavailability of the Gulf Stream data only a small amount of time has been spent on the project since March. In anticipation of a successful flight to Okinawa for AMTEX '75 in February, a computer program has been partially written to analyse sircraft data obtained while flying 200-km legs through a cold front at six levels. The

program is designed to give averages over 2-km distances relative to the moving front of all meteorological parameters measured by the aircraft instruments; to determine their gradients and to compute divergences and frontogenetical terms. The tapes as processed by the NCAR computer systems will give one-second averages of the turbulence and standard meteorological parameters, the positions from the inertia navigation system, the altitude and the winds. Depending upon the ground speed of the aircraft, about 20 one-second averages will be available for each 2-km average. From studies of the sparse data available in the literature about frontal zones it appears that an average over 2 km will give the needed resolution and significant averages that can reveal the structure of the zone and the boundary layers in cold and warm air masses.

Surface and upper air observations for AMTEX '74 have been received recently from the Management Committee in Tokyo. This material is being studied to aid in preparations for the AMTEX '75 flight.

GENERAL OCEAN CIRCULATION

LARGE-SCALE CIRCULATION

Bruce A. Warren

During the past year, I have devoted all my effort to attempts to account for the structure of deep western boundary currents, particularly their great width. These are an order of magnitude wider than currents like the Gulf Stream and Kuroshio, and their width cannot be rationalized by the traditional inertial or frictional boundary-layer thicknesses. The "slope-broadening" theory of Stommel and Arons seems plausible for the deep flow in the South Atlantic (for which it was devised), but it certainly fails for the deep current of the South Pacific, which extends far to the eastward of any continental slope, and probably for the deep boundary current in the western Indian Ocean as well. It has seemed worthwhile to me to expend so much effort on this problem because the large width and low speed of these currents suggest that they must be strictly geostrophic (in the sense that $\beta v = f\partial w/\partial z$), and this in turn implies a "double" current structure, with poleward flow above the equatorward-flowing current nearer the bottom. This circumstance would impose strong constraints on the proper interpretation of hydrographic station data ("level of no motion", volume transports, etc.)

After exploring several possibilities, a simple model has been worked out of deep flow which is geostrophic, with a density field governed by vertical advection and horizontal (zonal) mixing, and with the vertical density distribution at the western boundary specified (from observation). For plausible values of the mixing coefficient ($\sim 10^7 cm^2 sec^{-1}$), and with density data appropriate to the South Pacific, the model yields a northward-flowing boundary current $\sim$ 1000 km wide, in conformity with observation. It also yields a southward-flowing current of the same scale above the deep flow. This is an attractive feature, since it offers a rationalization (through southward advection) for the oxygen minimum and silicate maximum layers at depths of 2 - 3 km in the western South Pacific, whose property-depth curves here, unlike those in the central South

Pacific, cannot be well-modeled by a balance between vertical advection and vertical diffusion. This model does not purport to "explain" deep boundary currents, since it takes the density distribution at the western edge as given; but it links the horizontal scale and velocity structure (through determining the surface of zero meridional velocity) to a given density-depth curve, and thus appears useful to the interpretation of traditional scalar observations.

ZONAL STUDY OF THE ATLANTIC EQUATORIAL UNDERCURRENT

Eli J. Katz

During the Global Atmospheric Research Program's Atlantic Tropical Experiment (GATE) this past summer, the R/V *Atlantis II* was engaged on a two-month study of the equatorial undercurrent and its environs from 10°W to 33°W. Five extensive hydrographic (including dissolved oxygen, silicate, phosphate and iodate determinations) and current meter sections, and twelve additional STD-type sections were made across the undercurrent with the collaboration of John Bruce. The primary field objective was to map the zonal changes in the meridional position and properties of the undercurrent. The longer range objective is to combine these data with an extensive set of time series data obtained by seven other ships (from the United States and four other countries) which made comparable observations at various longitudes, and to interpret these data in the context of extensive meteorological observations and additional hydrographic observations made by the 39 GATE ships.

Observations of the undercurrent tracked from the *Atlantis II* showed reasonable agreement with historical data. A maximum easterly component of the undercurrent which varied between 90 to 130 cm sec^{-1} (Fig.1), just below a strong westerly surface current, was measured. A gradual and basically monotonic zonal decrease (from west to east) in core salinity (36.4 to 36.2 ‰) was traced between the two longitudes. The zonal pressure gradient at the sea surface, initially accelerating, eventually slightly decelerating when going from west to east, appears to be of the same magnitude as that of the 1964 R/V *Crawford* equatorial section. No evidence of either bifurcation or surfacing of the undercurrent has been found. However, the density of the observations has uncovered an unexpected ambiguity in definition: while there have been previous reports suggesting that the layer of maximum velocity and maximum core salinity may not be congruent in depth, the present observations suggest the additional possibility that these two traditional indicators of the undercurrent across the Atlantic may be as much as 40 nm apart meridionally.

Continuous profiles of temperature, salinity and dissolved oxygen often show the presence of a well-mixed layer up to 100 m thick beneath the equatorial undercurrent. Brian Petrie is examining the changes of the properties in this thermostad (previously studied in the Pacific but generally ignored in the Atlantic) along and across the equator. The data suggest that there is strong vertical mixing beneath the undercurrent with the kinetic energy of the shear flow being reduced, supporting the increasing potential energy of the thermostad.

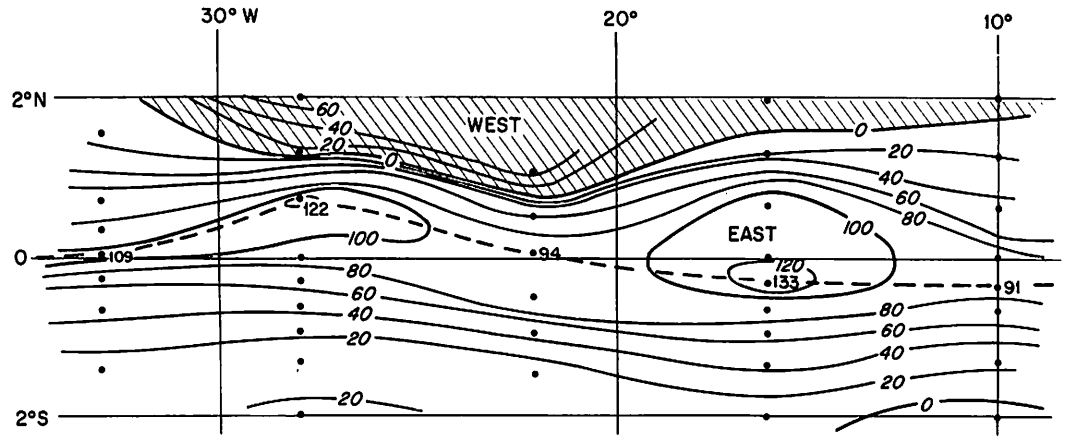


Fig.1 (Katz) East-west component of Atlantic Equatorial Undercurrent in cm/sec at depth of maximum eastward current (45 to 90 m) relative to 300 m depth during June and July 1974, *Atlantis II* Cruise #83, as measured by current meters suspended from the ship. Dots show current station positions and dashed contour gives location of maximum current. Depth of maximum current decreased from west to east as follows: at 33°W, 90m; 28°W, 85m; 22°W, 80m; 16°W, 60m; and 10°W, 45m.

Towed STD measurements yield sections of the undercurrent with 2 nm meridional spacing. They indicate a meridionally well-defined salinity core, with a narrow transition zone from fresh to saline and a broad core of about 40 nm in the one section fully analyzed. A Doppler-scattering acoustic current meter, deployed on the tow body for the first time, offers the possibility of detailing the meridional profile of current velocity in similar detail on several sections. The problem of adequately resolving the current from the forward motion of the tow body is being worked on by Douglas Luther.

DEEP VARIABILITY OF THE MEDITERRANEAN SEA

Arthur R. Miller

With the exception of the surface layers, Western Mediterranean Water can be defined as a simple mixture with only two sources, namely, Levantine Intermediate Water (13.200°θ, 38.500‰) and Mediterranean Occidentale (MEDOC) Winter Water (12.672°θ, 38.397‰). These maximum values represent resident quality in the mean water column. The high salinity of both sources comes about through the concentration of surface waters by way of evaporative and moisture fluxes in the air-sea exchange process. For salt balance, the annual salt accretion passes over the Gibraltar sill into the Atlantic Ocean. At sill depth the value of outpouring Mediterranean water represents roughly the product of mixing 50% of Levantine Intermediate Water, originating in the Western Mediterranean, with 50% of MEDOC Winter Water from the Western Mediterranean. In the Western Med-

iterranean Basin this 50% mixture varies seasonally in depth from 600 meters to 800 meters to rise ultimately to sill level of 320 meters in the Alboran Sea east of Gibraltar. Below these levels Winter Water is predominant, varying seasonally in percentage concentration.

The results of these investigations have been presented at the 24th Congress of the International Commission for the Scientific Exploration of the Mediterranean Sea held in Monaco in December, 1974. A second paper was given entitled "The Significance of the Mediterranean Sea to Global Climatology". This paper was intended to call attention to the possibility of the Mediterranean Sea having important climatological influence. It is difficult to exclude this possibility if one considers that the drainage area affecting the Mediterranean extends from the Equator to about 60° North. As a processing area for salt concentration the consequent moisture flux from the Mediterranean Sea to the atmosphere should be climatologically significant. The balance of temperature and precipitation determines the success or failure of crop harvests. Thus, the chain of climatological processes may involve the Mediterranean Sea as one of its important links.

COOPERATIVE INVESTIGATIONS IN SPANISH COASTAL WATERS

Arthur R. Miller

The estuaries of northwestern Spain consist of the Rias Altas along the northern coast and the Rias Bajas along the western coast (see Fig.1). Among the latter, the Ria de Arosa stands out as an area of high productivity and is foremost in intensive shellfish farming and aquaculture. To the south, the neighboring Rias of Pontevedra and Vigo have become highly industrialized and are unimportant for marketable species. With the Ria de Arosa relatively free from the effects of industrial pollution, an explanation for its high productivity has been found in the natural circulation processes by means of combined interdisciplinary investigations aimed at defining the food chains, the nutrient conditions, the circulation patterns, and the meteorological characteristics. It has been found that a three-phase system can provide the environmental support for intensive aquaculture. This system consists of a transport mechanism in which coastal flow promotes (1) the rise of deep nutrient-rich water to shelf level where (2) offshore wind conditions induce shelf water to enter the estuary to be distributed to shallower areas (3) through the combined action of directing land forms and local winds.

The program of investigation is by no means finished. It appears that the Ria de Arosa is an oceanic estuary providing an excellent opportunity for carrying estuarine studies into deep water and for determining renewal processes in coastal water. Seasonal studies, now coming to full cycle, show that basic nutrient conditions are tied closely to the environmental sequences in which deep water is brought into the estuary. The biological consequences and food-chain characteristics show that cultivation by knowledgeable means enhances the natural productivity for maximum food production. Seminars have been given at various establishments in response to developing interest in this relatively little-known estuary. Dr. Kenneth Tenore has been conducting these seminars on invitation from various groups. Two papers have been presented describing

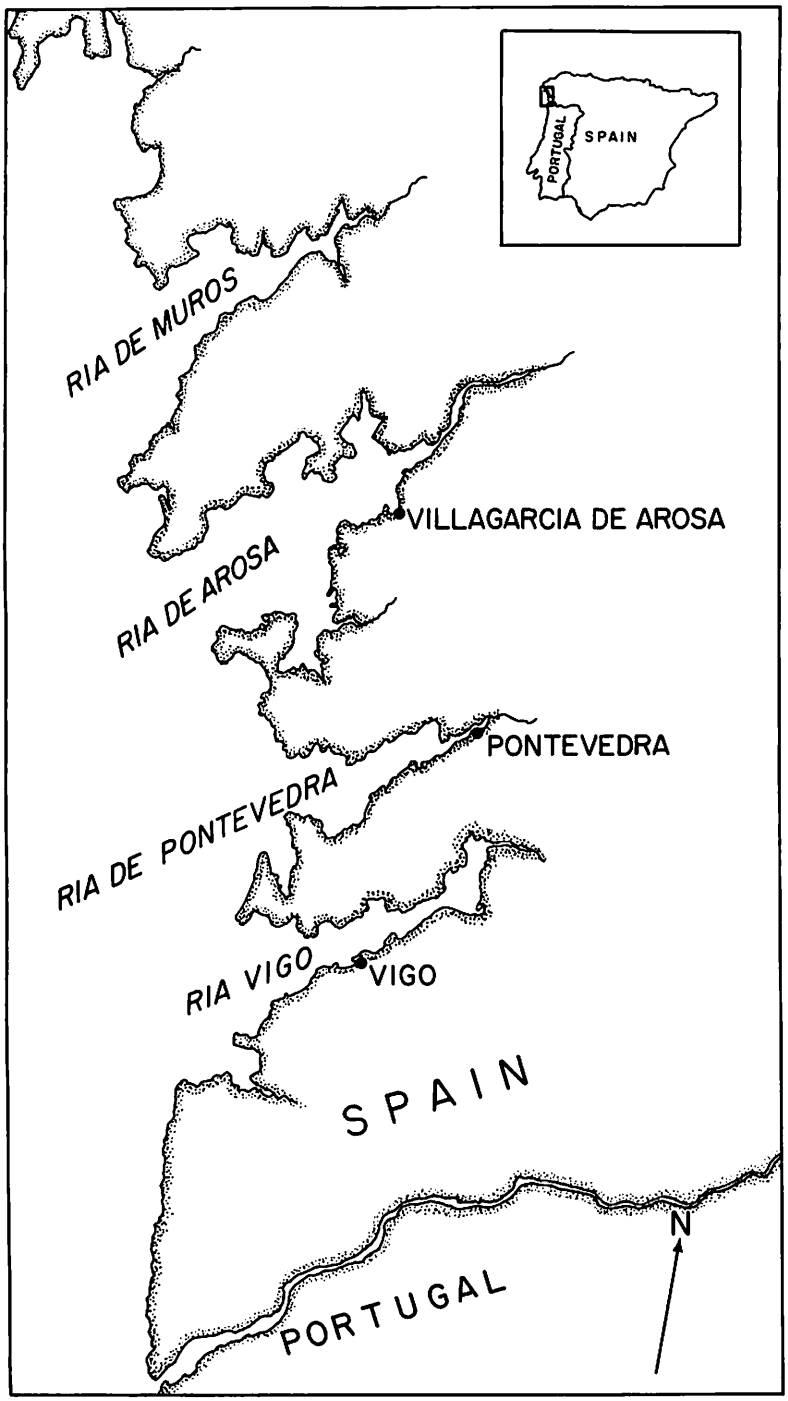

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Fig.1 (Miller)

the progress of these investigations. The paper, "Possible Dependency of Intensive Culture of Galician Mussels on the Mediterranean Outfall" by A. R. Miller, J. G. Gallego, K. R. Tenore, and G. Parrilla Barrera was presented at Bordeaux and is published in Volume 2 of the 2nd Colloque Inter-International sur l'Exploitation des Oceans (BX 108, 9 pages). It is also being published in Spain under the title, "Posible Dependencia de la Salida de Agua Mediterranea sobre el Intenso Cultivo del Mejillon Gallego". "Wind-driven Circulation in a Spanish Estuary" by Joseph Chase was presented at a Coastal Circulation seminar sponsored by the American Geophysical Union in Mystic, Connecticut, and at the International Council for the Exploration of the Sea in Copenhagen, Denmark. It is to be published in the journal *Estuarine and Coastal Marine Science*.

WATER MASS FORMATION AND WORLD WATER MASS CENSUS

L. Valentine Worthington

The major work during 1974 has been a study of the formation of 18^{o} Water. This water mass is formed in late winter in a region of net negative (ocean to atmosphere) annual heat flux in the northern Sargasso Sea. A similar water mass, Subtropical Mode Water, is formed south of the Kuroshio where a similar region of negative heat flux exists. Both regions are subject to winter outbreaks of polar continental air. It is believed that both the negative heat flux and the water mass formation are brought about by these outbreaks.

In October-November a cruise was made to the formation region and 79 oceanographic stations and 423 expendable bathythermograph lowerings were made. This has established the amount of 18^{o} Water present before the onset of winter. A second cruise, planned for March-April 1975 will make possible an accurate estimate of how much 18^{o} Water, if any, has been formed. The 18^{o} Water in the October-November cruise was only 80% saturated with oxygen - newly-formed 18^{o}Water should be 100% saturated.

A further effort during 1974 has been the calculation of the heat exchanges between the ocean and the atmosphere in the western North Atlantic upon which water mass formation, if any, must depend.

We have purchased 47 tapes from the National Climatic Center at Asheville, North Carolina. A program has been written to determine the four components of heat exchange at the sea surface (absorbed solar radiation, infrared back radiation, sensible heat flux and evaporative heat flux). The net annual heat flux in kcal $cm^{-2}yr^{-1}$ in the area of study is shown in Fig.1; this is the mean for the period 1941 to 1972. The basic division is the Marsden square, but each Marsden square is divided into 10 subareas. These smaller divisions enable us to separate the water masses of the western North Atlantic precisely, so that, for example, the heat flux over the Gulf Stream is not averaged in with that over Slope and Shelf water.

The main features of this chart are two regions of negative heat flux, the greater one south of New England and the lesser one east of Newfoundland. The greatest difference between our results and those shown in Budyko's (1963) classic atlas of heat exchange is that in ours the

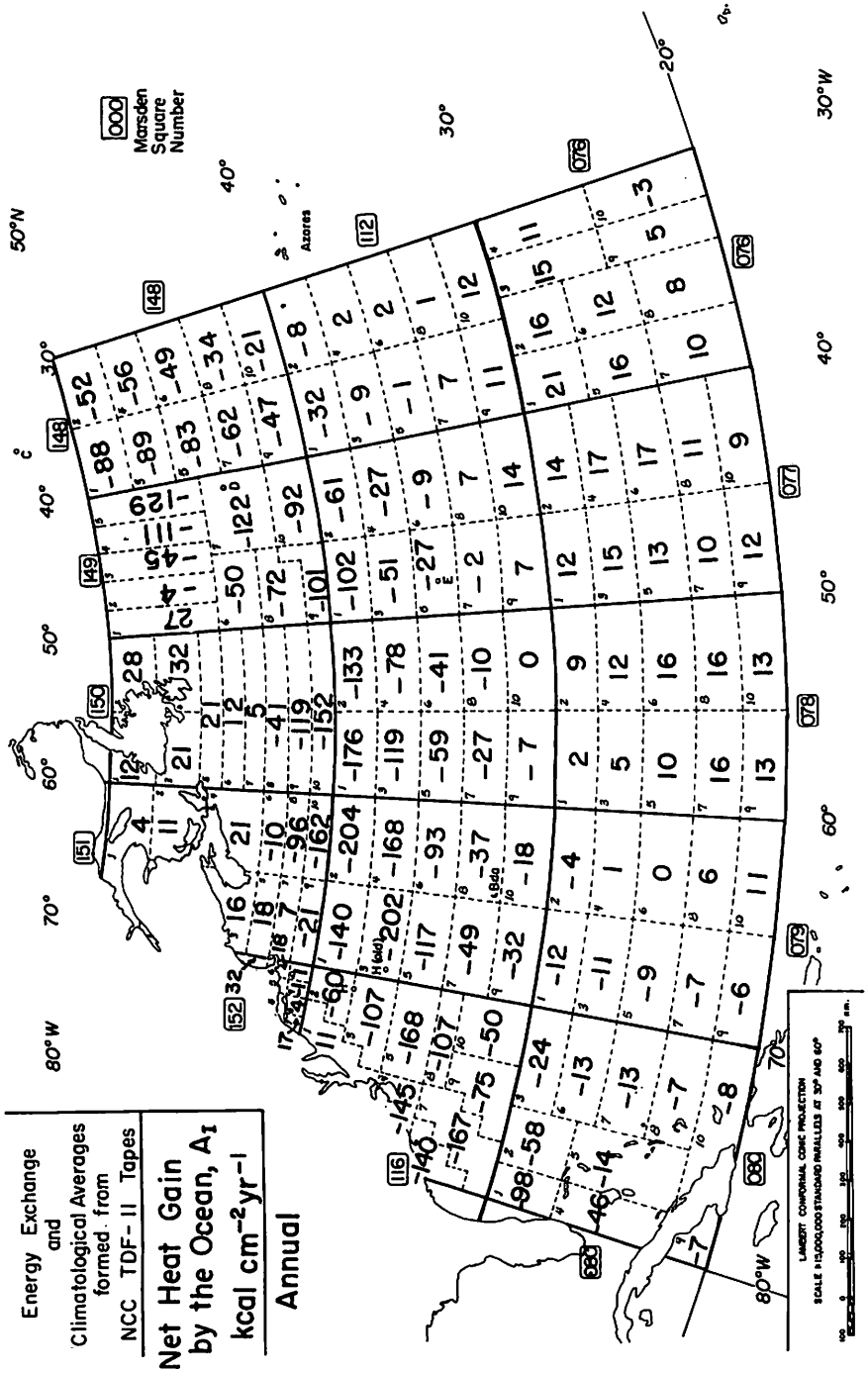

Fig.1 (Worthington)

greatest net negative heat flux takes place over the warm waters of the Gulf Stream and the Sargasso Sea. Budyko averaged over much larger areas which contained both warm and cold water. This caused odd features; for example, his greatest heat flux takes place on the continental shelf and Delaware Bay. Our results (Fig.1) show that these coastal waters are actually gaining heat slightly. This makes better sense oceanographically since these coastal waters originated as Labrador Current water with temperatures generally below -1°C and are warmed to about 7° (in winter) by the time the last remnants of this current reach Cape Hatteras. The computed results have arrived too recently to have been fully analyzed, but certain long term climatic trends have already appeared. In the northern half of the trade wind belt (20° - 30°N) there is a steady decrease in heat input to the ocean between 1941 and 1969 due to increasing winds and cloud cover. This trend appears to have been reversed around 1970.

Work on the fine-scale water mass census for the Indian Ocean has been completed as far as existing data allow. Since the stations must be of the highest quality for a study of this kind, many shallow and poorly-made stations cannot be used. This is illustrated by Fig.2 in which the areas where no acceptable stations are available are shown in black. The basic bookkeeping unit for this census is the 5° square and no such square which did not contain at least one high-quality deep station was counted. As new data arrive these black areas will gradually diminish.

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GULF STREAM STUDIES

Frederick C. Fuglister

The data from three Gulf Stream cruises in which this investigator took part, are being analyzed. These cruises are: *Chain* 114, September 20 to October 20, 1973; *Knorr* 40, April 29 to May 23, 1974 and *Knorr* 44, December 4 - 19, 1974.

The first cruise concentrated on the slope water current and the Gulf Stream in the area between 47° and 55° West longitude; the second and third cruises dealt with the slope water area and the Gulf Stream between 67° and 71°W.

Observations included regular and expendable bathythermographs, Nansen bottle and CTE (conductivity-temperature-density) stations; acoustic dropsondes and drogued buoys. On the last cruise an array of moored current meters that had been set out in slope water and Gulf Stream in April, 1974, were all successfully recovered.

Although there is some evidence of ring formation in these data and in the six, north-south sections made by Worthington between 56° and 68°W in October-November 1974, none of it is clear-cut and unambiguous. There is an abundance of evidence for spatial and time variations in the current patterns.

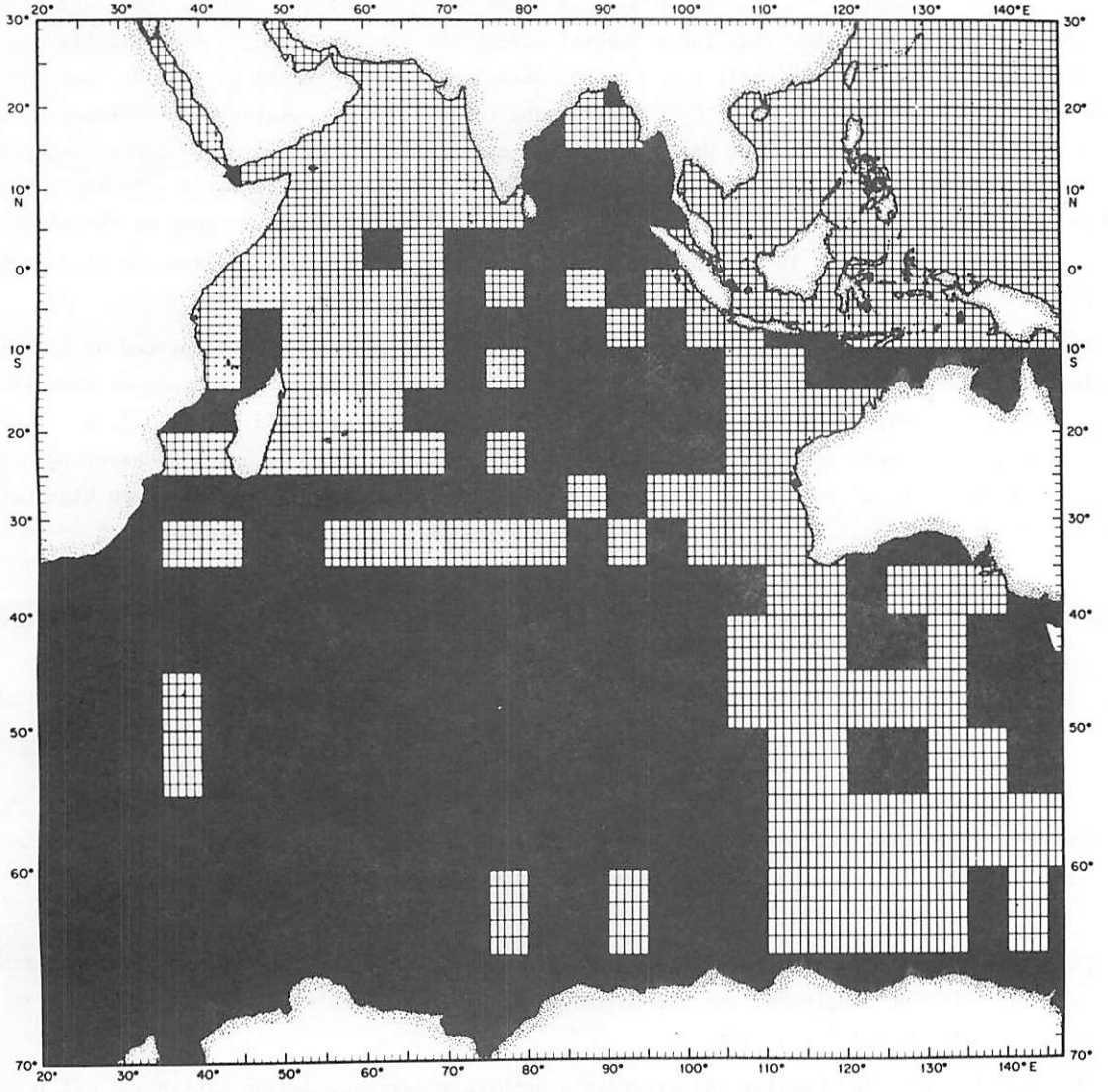

Fig.2 (Worthington) Oceanographic Station Coverage Chart of the Indian Ocean. Black areas indicate where no acceptable deep stations are available at present.

Even though this investigator has not as yet completed any of his analysis of these data, there is no question but that a large quantity of first-class information on the Gulf Stream and its environs has been obtained during this period.

A STUDY OF THE NORTHERN APPROACHES TO THE CARIBBEAN

William G. Metcalf

In February 1974, the continuing study of the flow through the passages connecting the Atlantic Ocean and the Caribbean Sea was carried to Mona and Windward Passages. Four current meters had been moored close to the Windward Passage sill in November 1973 and retrieved in early March 1974 on R/V *Knorr* Cruise 37. During this cruise, hydrographic station sections were occupied across both the Atlantic and Caribbean ends of Mona and Windward Passages to monitor the water types present. Another section went from the Atlantic Ocean, across the Windward Passage sill and into the Cayman Basin, and others went across the Cayman Basin from Cuba to Haiti, from Haiti to Jamaica and from Puerto Rico to Venezuela.

The Windward Passage current meter and temperature recorder records showed marked tidal oscillation and a small net inflow. A Woods Hole Oceanographic Institution "Blue Cover" report listing the hydrographic station data and giving profiles of the temperature, salinity, oxity and silicate in the various sections, is nearly ready for distribution. Analysis of the data from the current meters and the hydrographic stations is continuing.

Also continuing is the analysis of the hydrographic station data from the 1970 and 1972 cruises which dealt with the passages through the chain of the Lesser Antilles between puerto Rico and Venezuela. In this work, the water types found at opposite ends of the passages are being compared to obtain clues as to the water movements in those passages.

A brief paper of drift bottle observations in the Eastern Caribbean which was accepted for publication in 1973 has finally appeared in print. A paper on the deep flow in the Anegada-Jungfern Passage has been submitted for publication.

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CURRENTS AT THE EDGE OF THE CONTINENTAL SHELF SOUTH OF CAPE COD

W. Redwood Wright

In September 1974 the temperature and salinity structure at the edge of the shelf was examined during a three-week, three-leg cruise on R/V *Eastward* from Beaufort, North Carolina, to Woods Hole and back. The first and last legs, of five days each, were zig-zag crossings of the shelf edge from Cape Hatteras to Cape Cod. The second leg, of 12 days, was devoted to the region between 70°15' and 71°45'W. The shape of the shelf/slope water boundary was determined by expendable bathythermograph, and eight parachute drogues were tracked at different depths from periods of a week to 10 days. In all, 516 XBT's and 63 Nansen bottle stations were made. A shallow thermistor chain with 11 sensors spaced over 100 meters depth was tested and used briefly to track the boundary, but most of the sensors were lost when it was towed across a submerged trawl line.

Preliminary analysis of the cruise results indicates:

1. The shelf water/slope water boundary is intricately convoluted, with long tongues of shelf water extending out into the slope water similar to the surface phenomena seen in satellite photographs. The size and spacing of major features are both of the order of five to ten miles but the shape and position of the features themselves are constantly changing.

2. Temperature sections across the shelf showed a familiar pattern, with a tongue of cold shelf water at about 50 m overlying warmer slope water which extended up the shelf as far as the 100-m curve. The salinity observations showed, however, that the narrow tongue is a temperature phenomenon only and that fresh coastal water actually reaches the sea surface. The density sections showed nearly horizontal structure, with little evidence of the strong temperature and salinity gradients. The absence of horizontal shear was a marked contrast to the sections made in 1971 when the density field could support a half-knot shear between shelf and slope water.

3. Drogues were placed in the shelf water minimum layer, in the slope water maximum both underneath the minimum and seaward of it, and in the seasonal thermocline. The most striking result was that all the drogues, regardless of which water mass they marked, moved generally WSW parallel to the bottom contours, at about five to six miles per day. There was some tendency for a shoreward component of motion in the deeper drogues, and other nonuniformities were observed. This general movement is similar to that observed earlier over the interior of the shelf and also agrees with the motions deduced from bottom drifters.

4. Perhaps a third of the XBT's showed a homogeneous bottom layer up to 20 m thick. This bottom layer was found in depths from 70 to 250 m and occurred on both sides of the shelf water/slope water boundary; it was thickest about four miles north and south of the boundary and became very thin or nonexistent in the region of the boundary.

A paper on the initial phase of this program will be submitted for publication early in 1975. It describes the seasonal fluctuations in the shape of the shelf water/slope water boundary south of Cape Cod on the basis of 32 years of bathythermograph and Nansen bottle observations.

A volumetric temperature-salinity census of the waters of the Middle Atlantic Bight will also be completed early in 1975. The stations to be used in the census have been selected and the temperature and salinity traces have been drawn. The next steps will be tabulation and summation by appropriate T/S intervals.

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 now being analyzed and evaluated. The purposes of this large cooperative experiment were mainly to understand large-scale, lakewide dynamical phenomena. In the nearshore zone, the manifestation of lakewide wind-driven flow is the "coastal jet", a concentrated band of relatively high speed current. Much of the Woods Hole work is concerned with the dynamics of coastal jets.

Coastal zone data were collected during three "alert" periods of IFYGL, in spring, mid-summer, and early fall. A detailed analysis of the spring regime was completed early in 1974 and published in the July *Journal of Physical Oceanography*. The analysis of the summer alert period has also been completed and was published in the October issue of that journal. Further work was carried out on the observed asymmetry of coastal jets: the experimental data indicated that winds blowing along a lake produce much stronger coastal jets on their right-hand shore than on the left. The net result of many different wind impulses is then a cyclonic mean circulation. Another study in preparation concerns some further aspects of observed coastal currents and their behavior during the fall alert period of IFYGL.

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COASTAL BOUNDARY LAYER TRANSECT (COBOLT)

Gabriel T. Csanady

The direct goals of the COBOLT project are the exploration and understanding of nearshore flow induced by winds and tides along a straight, uncomplicated coastline south of Long Island. The physical boundary provided by the coast is likely to influence motions in its vicinity to a considerable degree, tending to establish some sort of coastal boundary layer there. An important aspect of the sea-coast interaction is that the coast is in fact a gently sloping beach, very different from a vertical wall sometimes assumed in simple coastal zone models. Other important

physical factors are the presence of a free surface below which another boundary layer is present, the surface mixed layer, and the frequent presence of density gradients, due to horizontal and vertical nonuniformity of temperature and salinity.

At least some of the important influences acting upon the coastal boundary layer are nonlocal and depend on the shelf-wide pattern of wind-driven circulation and of tidal motion. These larger scale patterns are not very well known or understood. A particularly large source of uncertainty is the interaction between the continental shelf and the deep ocean. The details of the various exchange processes at the shelf's open edge (mass, momentum and energy fluxes) are completely obscure.

In the perspective of the above remarks, the total COBOLT program may be thought of as consisting of a "core" program aimed directly at the description of the flow structure in the coastal boundary layer, and of ancillary efforts aimed at understanding specific aspects of the more important physical factors which play a role in coastal boundary layer dynamics.

During 1974 a sophisticated data collection facility was designed and orders for instrumentation were placed. Currents will be measured using electromagnetic current meters, and these data, as well as temperature and salinity sensor outputs, telemetered to shore from several special shallow water moorings. A pilot study of coastal boundary layer structure was carried out during summer and fall 1974 using a small launch and instruments lowered overboard.

Several aspects of the problem were also attacked theoretically. One completed study aimed at the shelf-wide circulation pattern.

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